Einstein vs. Bergson

Transcodification: Arts, Languages and Media

Edited by
Simone Gozzano

Volume 3

Einstein vs. Bergson

An Enduring Quarrel on Time

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DE GRUYTER

ISBN 978-3-11-075350-9
e-ISBN [PDF] 978-3-11-075370-7
e-ISBN [EPUB] 978-3-11-075372-1
ISSN 2702-7732
DOI https.//doi.org/10.515/ 9783110753707

Library of Congress Control Number: 2021941695

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at http://dnb.dnb.de.

The book is published open access at www.degruyter.com.
Printing and binding: CPI books GmbH, Leck

www.degruyter.com

Carlo Rovelli

Preface: The Times Are Many

I have had the misfortune, but also the fortune, of not being able to participate in the conference that has prompted the publication of this book. It was a misfortune because I missed the livelihood of the presentations and especially the personal discussions, debates, and quarrels that are the true life of conferences. But it was also a fortune, because I received this entire book, and could read it all, calmly, and meditate it, before writing this Preface. So, this Preface is really a *a-posteriori* reflection on the content of the book.

I believe that the debate on the nature of time is based on a substantial mistake. The mistake is to assume that there is a single something, which is *Time,* whose nature we somehow have to grasp. This, I think, is the origin of all the confusion. Time is a very concrete reality we experience directly (we are late, we enjoy time, we die). It is essential in our life. But it is not a single notion; it is a stratified notion, generated by a variety of different phenomena, and we are confused when we fail to disentangle them.

When Bergson talks about Time, he knows what he is talking about. It is the time we experience. The experience of the passing of time is a real and concrete experience. I find that to call this passing of time *illusory* is misleading: there is nothing illusory in the passing of time: on the contrary, it is one of the most solid and objective realities we face.

But to identify this experience with the physics of the ticking of a clock and the motion of a pendulum is a mistake. The two phenomena (our experience and the ticking of the clock) are related, but they are not the same phenomenon. To say that they are the same is like saying that a novel written on the numbered pages of a book is the same thing as the sequence of the numbers of the pages. Our experience of time is a rich experience that is powerfully coloured by things like the memory we have of past events (and not of future events, I'll come back on that), the constant anticipation of the future that our brain is concerned with, and the intrinsic motivations of our activities that are constantly driven by motives and that therefore orient us towards the future (Husserl has described this phenomenology with great insight). Our experiential time is made of all this. Clocks do not have memories, do not anticipate the future, do not calculate what they have to do next and do not have objectives. Hence clocks do not have the experience of time that we have. The time of the clock (is related to but) is not the same thing as the time of our experience. The time of elementary mechanics is (roughly) the time of the clock. It misses entirely the time of our experience.

 https://doi.org/10.1515/9783110753707-001

Does this mean that the time of our experience necessarily escapes scientific inquiry? No, why should it? Simply, it requires us to study a more complicated system than a pendulum or an elementary clock. Concretely it requires us to make two distinct steps, both important.

The first step is to distinguish the complete description of natural systems that is assumed in mechanics from the strongly coarse-grained description of natural systems that is studied by thermodynamics and statistical mechanics. In particular situations (such as in our universe, or at least the portion of the universe where we happen to inhabit), the variation in (clock) time of certain coarse-grained variables (such as those through which we interact with the world around us) is strongly oriented: it satisfies the second law of thermodynamics. One can show that in such situations the macroscopic variables rather generically present traces of the past but not of the future (Rovelli 2020a), and the macroscopic evolution can branch towards the future but not towards the past (Rovelli 2020c). Therefore, in a precise sense the past is fixed and the future is open: meaning that the macroscopic present state has large information about the macroscopic state of the past and much less about the future. These are facts of the natural world.

These observations explain why the physical phenomenology we observe is so strongly oriented in time, but they are not sufficient to account for the time of our experience: the time of thermodynamics is closer to the time of our experience than the time of mechanics, but it is not yet it. To account for the time of our experience we have to take into account the specific functioning of our brain: its peculiar way of dealing with memories, anticipations, and aims. The science that deals with that is neuroscience, not physics.

Does this mean that the time of our experience is somehow in contradiction with physics? Of course not! That would be like saying that an airplane is in contradiction with physics, because we study it in specific aero-space books and not in elementary books of mechanics, or a computer is in contradiction with physics because informatics is not physics. There is no contradiction between the behaviour of complex systems studied by branches of sciences and elementary physics. There may be articulations that we do not control well, phenomena that we have not understood yet, but we haven't any evidence of contradictions.

Now comes the key point. The mistake is to take the complex experience of time that we have and to assume that all aspects of it are general, and must underpin nature in general. This is a serious mistake, and is the first mistake that Bergson makes. This is a very common mistake. Let's look at it more in detail, because it is the central source of confusion in the debate about time.

Let me make a simple example that I find illuminating. Consider the notion of *up* and *down*. This is a very useful notion. It is obviously not illusory. It is real.

It is very intuitive for us. It is even a bit hard to avoid it in thinking about space. Does this imply that everywhere in the universe there must be a *up* and a *down* well defined as they are around us here? Of course not. *Up* and *down* are notions that make sense in the vicinity of the surface of a big mass (the Earth for us), not in an arbitrary point of interstellar space, where all directions are the same. So: *up* and *down* are useful notions to organise natural phenomena in our immediate environment, but we make a mistake if we illegitimately extrapolate their relevance. They do not have global relevance. The example shows that some notions that we consider intuitive are good but are not applicable to domains larger than those in which our experience developed.

Let's use this observation in relation to the notion of time. As we have seen, some aspects of our experience of time depend on our specific functioning (our brain). Others of course do not. For instance, all temporal characteristics of a clock as they are described in Newtonian mechanics do not depend on our brain. The aspects of time that differentiate the time our experience from the time of elementary physics, namely precisely those on which Bergson focused, depends specifically on our brain.

The fact that some macroscopic phenomena depend also on us should not be a surprise. Think at the sunrise, sunset, and the entire rotation of the sky. It is not a phenomenon concerning the Sun and the sky alone: it is a phenomenon that involves both the position of the celestial bodies and our own position on a spinning planet. There are many aspects of the phenomenology that we observe that have this double nature (colour is another typical example). The time ticketed by a clock has nothing to do with the functioning of our brain, but the time we experience does. Projecting the features of experiential time outside ourselves is like pretending to understand why colour space is three dimensional without taking into account that our eyes have receptors sensitive to three difference frequencies: a silly objective. This is Bergson's mistake. Time is not a single notion: we must disentangle its features to understand it.

But this is only half of the story, because the Bergson-Einstein debate was prompted by Special Relativity. The point made above, in fact, becomes much stronger with modern physics. Let's see how.

What Einstein realised first is that the common idea that the duration between two events is a fixed quantity is only a first approximation due to our limited experience. Two clocks that are separated and moved back together in general have measured different time intervals. Two persons separated and then brought back together in general have aged differently. This is a hard fact, pace Bergson, who denied its possibility. A fact that today is supported by innumerable concrete experiences and is virtually out of doubt.

This hard fact implies that our intuition of a common global time does not represent nature correctly. Is not that our intuition is wrong. It is right, but it refers to the domain of experience that is familiar to us with the precision in evaluating time durations that is familiar to us. What is wrong is not the idea that we all age together (here on Earth, and as far as we usually see, we do): what is wrong is to extrapolate this idea to situations of which we do not have much experience.

There is never a contradiction between the *manifest* image of the world, and the scientific one, if we are careful in not extrapolating. The *manifest* image is how things correctly appear, within our approximations and precisions. The difference between the *manifest* image of the world and the scientific one is the same difference as the image of a forest on a mountain seen from afar as a uniform green velvet, and the image of the same forest as a complicated mess of trees, as seen from nearby. There is no contradiction between the two images: they are just how something looks from two perspectives.

The Newtonian idea of a universal common time, thus, is simply wrong. Contrary to what some time stated, by the way, cosmology does not rescue it: the *cosmological time* is only an average, good only in the homogeneous approximations. The *proper time since the Big Bang* measured on Earth is different from the time form the Big Bang measured on Andromeda (or even on Jupiter for that matter), because proper time runs at different speeds depending on the masses nearby (a hard fact). When Andromeda and the Milk will meet (they are going to), what will be the age of the universe? That measured in Andromeda or that measured in the Milky way? The answer is that the 'age of the universe' is an approximate notion only. It breaks down in the details.

It follows that the notion of a common present all over the universe makes no sense, given what we know about the world. Hence Presentism – in the sense of the doctrine that reality is just what exists in the present all over the universe – is in flagrant contradiction with what we actually know about Nature.

Contrary to what often claimed, however, this does not force us towards the absurd metaphor of a static four-dimensional 'block' universe, where nothing moves (Rovelli 2020b). The fact that temporality is organised differently from what we thought does not imply that there is no change, no happening, in the universe. (To be static is not to change in time: in which time would the block universe be 'static'?) If anything, the opposite is true: the 4-dimensional spacetime of General Relativity is not static in any sense, and is not 'block' in any sense: it is the description of happenings. It is the description of stories, events, changes. These just do not happen to be organised along a single temporal sequence: given two of them, sometimes there is no meaning in asking which happened first. They are organised in a complicated 4-dimensional geometry that

Einstein's theory describes. What Einstein's theory describes is not a static reality: it is the real agitated universe we see moving around us, the way different happenings influence or do not influence one another.

Of course, it takes an effort of imagination to understand clearly a four-dimensional ensemble of events (happening) that does not flow in a single sequence. But this is the same kind of effort of imagination that at first makes it hard to believe that the Earth is round and people elsewhere live upside down with respect to us; or that we are standing on a fast-spinning rock. It always takes an effort of imagination to realise that Nature is not everywhere organised according to some conceptual prejudice we developed in the limited domain we habit. But we humans have a good adaptable brain: we learn, and we are capable of coming out from prejudices. A relativist who works with General Relativity gets used to it and then considers it so natural that she has difficulty remembering why for most of us it is natural that all clocks tick at the same speed.

To adapt our intuition to our discoveries, however, we must avoid a common methodological mistake: to confuse introspection with investigation of general aspects of nature. This is the mistake of some philosophy (certainly not all philosophy). Understanding with precision and investigating our own concepts and our own intuitions is great, but only if we are open to the fact that these same concepts and intuitions may *not* be appropriate to describe the world at large. This is again Bergson's mistake: confusing the phenomenology of human experience of time with necessary aspects of nature.

You see that Bergson's mistake is therefore double. First, he misunderstands the relation between experiential time and Newtonian time, and attributes the (real) discrepancy between the two to a presumed incompleteness of the scientific description of the world. Instead, it is just the result of the fact that the human brain is complicated. This is the same mistake as saying that fundamental physics is necessarily intrinsically incomplete because in the world there are bicycles and elementary physics books to not contemplate bicycles.

The second mistake is to resist Einstein's discovery on the basis of the fact that they contradict his intuition. Of course, they do: so does the fact that the Earth is round and spins. Our intuitions must adapt to new knowledge, not vice-versa.

So far, I have only talked about physics that is well established. Let me close by talking about the problem of time in Quantum Gravity, because this is the domain in which I work, and there are numerous discussions about Quantum Gravity in this book.

I think, again, that most discussions about the problem of time in Quantum Gravity are mistaken and misleading. In fact, I do not see any problem of time in Quantum Gravity. The problem appears only if we pretend to project onto the physics of quantum gravitational phenomena a notion of time that does not pertain to it, that is not appropriate to describe it.

Quantum Gravity is a theory of events, of happenings. In this sense it is 'temporal'. But these events are not organised in a single sequence labelled by a single preferred time parameter, nor organised in a 4-dimensional continuum theory as in Einstein's geometries. They are related to one another probabilistically and the theory provides the probability relations of some events given others (Rovelli and Vidotto 2014). All this can be done without any need of a specific 'time' variable. The world is described by variables, and by the probability amplitudes describing the relations between them. Relativistic physics is not the description of how physical variables change in time: it is the description of how physical variables change with respect to one another (Rovelli 2004). This is coherent, and the question 'where is the time variable' is a meaningless question (Rovelli 2011), like the question 'where is the centre of the universe?' As far as we know a universe has no centre. To search for a time variable for Quantum Gravity is like searching for the centre of the universe: it is to project a notion that pertains to a limited domain onto a physics where this notion does not fit.

The variables that describe the gravitational field are among the variables in the theory. They have a property: in the classical approximation in which we disregard quantum phenomena they happen to admit an interpretation as a 4d space-time Einstein geometry (Rovelli 2020d).

In the further approximation when the gravitational field is weak, this geometry is approximated by Special Relativity. In the further approximation where things move at small relative speed, there is one special variable of the gravitation field that is precisely the Newtonian time variable, and our clocks track it.

In the further approximation in which we limit ourselves to macroscopic variables, our universe is time oriented, has traces of the past and is open towards the future. If we then consider also the specific functioning of the human brain, which is immersed in the time oriented macroscopic thermodynamic world, and we fold in its memories, its anticipation of the future and the motivations and aims that are intrinsic to its functioning, we get the full phenomenology of experiential time.

So, the solution to the problem of the nature of time is to break the problem apart into pieces. To understand all aspects of time we have to use all these different scientific theories. There is no single 'true' time: there are the events of Quantum Gravity, there is the space-time of General Relativity with its notions of multiple proper times along different paths, there are the different Lorentz times of Special Relativity, there is Newtonian time, there is the oriented time of thermodynamics, and there is the experiential time experienced by us, which are our brains and bodies. None of these 'times' (plural) is the 'true' time. They are all related, but all different, because they are distinct by different properties (Rovelli 2018).

Quantum gravitational events, *general relativistic proper time*, *Lorentz times*, *Newtonian time*, the *oriented time of the second law of thermodynamics*, *experiential time* (or, better, *the different times of our experience*), these are all related but distinct times, and the confusion comes from confusing them or pretending that the feature of the more complex notions must apply to more general domains than what is proper to them.

So, in a sense, it seems to me that many of the articles in this book are right, but they talk about different things, pretending to be all talking about the same thing. The mistake is only if they pretend to capture a *true general nature* of time. If they do so, they sound to me like the blind men describing the elephant after having touched different parts of his body: 'it is a column!', 'no, it is a tube!' …

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Introduction

As scientists and philosophers working in the universities and research laboratories of the city of L'Aquila, we asked ourselves how we could commemorate the tenth anniversary of the earthquake that struck the city on 6 April 2009. A striking coincidence of dates came to our aid. Striking because the clash between the 'greatest physicist of the 20th century' and the 'philosopher of France' also took place on 6 April 1922, nearly a century ago in Paris. In the aftermath of these traumatic events, the chasm between two dimensions of time – the subjective and the objective – became palpable. For the inhabitants of L'Aquila, the private and qualitative time of memories and pain in the post-earthquake years did not coincide with the public and quantitative time of reconstruction, in the same way that, for the most brilliant intellectuals and scientists of the early 20th century, the spatialized time of Einstein's Relativity seemed incompatible with the lived time at the core of Bergson's investigation.

6 April is therefore the date for the event of a double, but unitary, fracture. In an attempt to mend it, the University of L'Aquila, together with the Gran Sasso Science Institute, organised an international conference entitled *What is time? Einstein-Bergson 100 years later*, which was held in L'Aquila on 4–6 April 2019. Scientists and philosophers coming from diverse theoretical backgrounds took part in the conference, and each, within the boundaries imposed by their own discipline of reference, revisited the meaning of the question that drove the rift between Einstein and Bergson: is the time that the scientist measures the same as that on which the philosopher reflects? The outcome, as this volume of proceedings testifies, was both fruitful and unexpected: fruitful because the nature of time was virtuously refracted by different areas of knowledge; unexpected because this refraction did not give rise to any fragmentation. Over the days of the conference, the question raised in Paris almost a century ago, acted like a magnet pulling together, without blurring, contributions from physics (E. Coccia) to cosmology (M. Bersanelli), from philosophy, both analytical (C. Calosi, M. Morganti, D. Donati/S. Gozzano) and continental (P.-A. Miquel, P. Montebello, A. Campo/R. Ronchi, L. Vanzago) to neuroscience (M. Wittmann/C. Montemayor), from logic (J.-C. Dumoncel) to biology (G. Longo). These *successive* presentations reflected a deeper *simultaneity:* that of a commonality that does not sacrifice but enhances difference (exemplary, in this sense, are the essays by É. Klein, Y. Dolev, M. Dorato, E. During, C. Wüthrich, M. Weber, and M. D. Segall).

Bergson defended the rights of this qualitatively heterogeneous continuity from the beginning to the end of his life. He did not desist even on the day he

https://doi.org/10.1515/9783110753707-002

met Einstein: for Bergson Relativity did not undermine the philosophical intuition that different durations coexist but, instead, confirmed it. In Paris, however, the conflict between science and philosophy was inevitable. At the time, Bergson was one of the most influential intellectuals on the European scene. His stance on Relativity led the Nobel committee to award Einstein the Nobel Prize for his discovery of the laws governing photoelectric activity rather than for his theory of Relativity. In his earlier work, Bergson had indirectly challenged the assumptions underpinning the latter, despite his admiration for Einstein's intuition. The German physicist, therefore, came to Paris motivated by the desire to defend the validity of his new theory and, to this end, presented a paper on Relativity rather than on the photoelectric effect, as many might have expected given this was the discovery for which the prize was awarded: it was not the validity of this discovery that was in question. The invocation of Bergson's name by the chairman of the Nobel committee, and thus the invocation of the name of the man who had devoted all of his life to showing that time should not be understood exclusively through the lens of science, had publicly disavowed Einstein's work. For the ambitious physicist, this was intolerable.

So, although planned as a cordial and academic event, the Parisian meeting turned into something quite different. Bergson took part, wanting only to listen, and spoke reluctantly for half an hour. The thesis he put forward was simple but scandalous: the relativistic point of view implies the philosophical one. Einstein dismissed it in a minute with fiery words: 'there is no such thing as philosophers' time; there is only a psychological time that is different from that of the physicist'. None of the participants in the *séance* remained neutral, and what happened in just over three hours subsequently polarised any discussion on the nature of temporality. Bergson has been perceived as the one who did not understand the scope of the new theory and, for this reason, Einstein's victory has gone down in history as a victory of science over philosophy, of rationality over mysticism, of calculation over intuition. The contrast between the *time of the universe* and the *time of consciousness* continued to be drawn in the following years, and since neither the scientist nor the philosopher budged from their respective positions, no attempt was made to bridge the rift. Bergson and Einstein have become emblems of the difficult, if not impossible, relationship between science and philosophy, and although not all scientists agree with Stephen Hawking in decreeing the death of the latter, the majority of them believe, nonetheless, that it is moribund.

Overall, the debate between Bergson and Einstein on 6 April 1922 deserves to be counted in the annals of missed opportunities. Rather than a real confrontation, what took place in Paris was a singular monologue in two voices. The frustration it aroused in the audience was only proportional to the expectation surrounding an event advertised in the press at the time as ’exceptional’. Bergson, probably discouraged by the outcome of the previous evening’s exchange between Einstein and the mathematician Painlevé, did not raise what he saw as the major problem with the theory of Relativity: the existence of a plurality of heterogeneous times. Instead, he chose to read a passage from the book he was working on and which would soon be published, *Duration and Simultaneity*. But, in so doing, he guaranteed his own defeat. Isolated from its context, this passage suggested he had misunderstood the heart of Einstein’s theory: the relativity of simultaneity. Bergson distinguishes between an intuitive and natural simultaneity, the ‘simultaneity of flows’, and a scientific and artificial simultaneity, the ‘simultaneity of instants’. However, by stating that the former is absolute and that the latter originates from it, he gave the impression of wanting to restore the old, Newtonian, concept of a universal time, deriving it, moreover, from perception rather than calculation. Einstein reminded the philosopher that the intuitive notion of simultaneity is no different from the naïve notion of simultaneity. Science had replaced it with the idea of a simultaneity ‘of events themselves’ independent of a perceiving subject; it was this new, more precise, notion that could be relied upon.

Yet, Bergson judged this substitution to be incomplete: the simultaneity that binds two events together cannot be separated from the subject that perceives them, and hence from absolute simultaneity. Furthermore, this kind of simultaneity must also be distinguished from that obtained by comparing the times displayed by clocks. According to Bergson, in fact, there are three orders of simultaneity that must be taken into account: simultaneity resulting from the exchange of optical signals from synchronised clocks; simultaneity as the connection between more or less distant events with which those clocks are associated; and, finally, simultaneity between these events and the consciousness in which they appear simultaneous to the extent that they are one or two events indifferently, depending only on whether consciousness takes place as an undivided act of attention or as a divided act that does not, however, ever split up. For Bergson, only the latter is simultaneity in the current sense of the word. And although there is no doubt that it can be observed above all between close events, he explains, there is nothing in principle that prevents it from being extended to distant events: a superman with an extraordinary capacity for vision would perceive very distant events as simultaneous, in the same way that ‘intelligent’ microbes would verify an interval even between two clocks positioned in the same place. But there is more: Bergson is convinced that, if this kind of simultaneity did not exist, clocks would be useless and would not be manufactured, because knowing what time it is does not mean ascertaining a correspondence between the times shown on clocks, but rather points to the correspondence between these indications and the moment in which one finds himself.

For a physicist, measuring time means counting simultaneities, but if there were no contemporaneity of the stream of consciousness with the movement of the clock by which single moments are recorded, he could not measure time. A physicist, says Bergson, does not measure time thanks to space but *thanks to time*, and that is why, ultimately, every physicist insists on calling 'time' the space he counts: his consciousness is still there and can, if necessary, infuse living duration into a time dried up as space. In short, any instantaneity as a measure of time always implies two things: a continuity of duration and a spatialized time, because if it is true that time is measured through the mediation of movement, this depends above all on the fact that we ourselves are capable of moving. Every movement, then, is a mixture of duration and space, and Bergson devoted all of his works to the articulation of the relationship between these heterogeneities, including the 'bastard' text of 1922.

Released in the autumn of that year, *Duration and Simultaneity* offers the key to understanding the failure of the *séance*. The critics were harsh. Bergson was accused of having made mathematical errors, of having persisted in considering paradoxical phenomena for which Relativity offered a coherent explanation, of having wanted to bend Relativity to his own philosophy and, finally, of having taken the opportunity to reintroduce Newton's time, which Einstein had thrown out of the window, back through the door. Many, and not only his opponents, considered this work an obscure text, perhaps the worst that Bergson had written. Bergson himself modified it several times, adding appendices and two different introductions. He even went so far as to forbid its publication in 1931. Ignored above all by philosophers, probably because of their ignorance of the mathematical language involved, Bergson's 'cursed' text earned him a personal curse: Alan Sokal and Jean Bricmont called the 'philosopher of France' an inattentive and conservative imposter, a man who wickedly challenged the new science by contrasting the accuracy of its calculations and forecasts with the vagueness of intuition and the immediate data of consciousness.

Yet Bergson was certainly not reckless. Skilled in mathematics and in constant dialogue with the sciences of his time – to which, contrary to what has been claimed, he was in no way hostile – Bergson only wrote his books after taking the time to assimilate all the available literature on the subject and, more importantly, only if necessary. If one really wants to understand the reasons that led Bergson to write more than two hundred pages on the theory of Relativity in spite of the criticism that he had previously addressed to the spatialized time of science, it is from these last two considerations that one must start. For Bergson, it is true, Einstein had merely invented a new way of spatializing time. But he nevertheless decided to study the matter in detail, because, in his eyes, the theory of Relativity was not just a physical theory, but 'a new way of thinking'. New, and yet in accordance with old common sense. Bergson's great thesis is, in fact, that Einstein's Relativity succeeds in affirming the 'unity of real Time' better than Newtonian mechanics. And it is this 'real Time' that is the very subject of his essay of 1922: a time that should not be hastily identified with the time-frame of classical physics, nor be considered as Bergson's final stratagem to claim the rights of the subjective time of consciousness: unlike subjective time, real Time is measurable. Better: real Time is that time one can *actually* measure.

Besides, if Bergson had limited himself to finding, in Einstein's theory, an *a fortiori* confirmation of the validity of his initial intuition, why would he have devoted such a stringent analysis of such daunting density to further explicating his thesis, running the risk of losing even his most faithful readers? Bergson started studying Relativity for personal interest but, once his dossier was published, it was still necessary to apply the principle he applied to all his books: 'J'ai fait chacun d'eux en oubliant tous les autres; je pars de la "durée" et je cherche à éclairer ce problème, soit par contraste, soit par similitude avec elle'. His books, however, are not all consistent with each other. The time of *The Creative Evolution*, for example, does not coincide with that of the *Essay on the Immediate Data of Consciousness*, nor can the time of *Duration and Simultaneity* be superimposed on the time of *Matter and Memory.* In his work of 1896, Bergson thematises a plurality of durations, each differently rhythmed, and it is for this reason that, in 1922, he does not speak of 'Duration' in the singular, writing it with a capital letter. Only real 'Time' is singular and written with a big 'T', although this does not mean that there is only *one* time. Its unity does not coincide with a uniform totality or block of duration, because the idea of a superhuman consciousness co-extensive with the whole universe with which Bergson introduces this unique time, has only a regulative value. That is, Bergson never doubts that variously rhythmed durations occur in the same time. But rather than an all-encompassing overflight, 'unique real Time' is, for him, a medium of coexistence between independent durations that are in a state of *mutual* and *regional* surveillance.

The universe as such, as we read in the beginning of *Creative Evolution*, 'endures'. And the problem of *Duration and Simultaneity* – Bergson's only book in which time is the explicit theme – is to understand *dans quelle mésure*, that is, to understand what kind of multiplicity real Time exhibits as a *non-transcendental* unity of durations. As we can see, this is a cosmological problem (see, infra, Bersanelli): *everything* in the universe is duration according to Bergson, but duration is not a *whole*. The fact that it is everywhere in nature does not mean that there is a global duration of nature in which the discrepancy between individual flows is recomposed in the sense of annulled. For Bergson, the material universe that lasts is the *extensive* expression of the *intensive* unity of simultaneous durations (see, *infra*, Montebello), and this unity is a multiplicity of interpenetration in which a qualitative rather than numerical, a synthetic rather than analytical identity is expressed. When it is *open* rather than *closed*, the totalization of durations is neither spatial nor categorical, but temporal, because Bergson never renounces either the idea of a difference in nature between actual flows, or the idea of differences in relaxation and contraction within a virtuality that encompasses them and is actualised by them. Bergson thinks that these two certainties do not exclude, and indeed imply, a unique time, and he is convinced that Relativity allows for its most rigorous definition. But in what sense? And how can he succeed in making the new theory say the opposite of what it professes to say?

Bergson repeatedly states that the temporal plurality envisaged by Einstein's theory does not correspond to any real plurality. The German physicist's mistake, in his opinion, was precisely to confer reality on something that lacks it. Consequently, there is nothing to change in the formulas and calculations of Relativity. All the philosopher has to do, says Bergson, is to interpret the theory of Relativity (see, *infra*, Dolev), by clarifying what the terms in which it is stated correspond to. More specifically, a philosopher has to establish what is real and what is conventional in the theory. Multiple times, for example, are fictitious: neither perceived nor perceivable, neither experienced nor available to experience. Nevertheless, Bergson's demonstration of their abstract character is obscure, provisional, depending as it does on that 'barely conscious reasoning' through which, by analogy with what every consciousness intuits by turning its attention to the inner flow of duration that pervades it, Bergson comes to attribute this same flow to other consciousnesses and then extends it to the entire material universe. The twins' experiment proves this. For Bergson, the twins live, perceive, and measure the same time because the temporal differences attributed to them by Relativity are only variations between abstract measures of time. According to Bergson, the disparity between the twins is metric and, what interests him most, is that, *exactly as a disparity*, it is recorded within *the same interval* of time (see, *infra*, Campo/Ronchi). Such is the nature of 'unique real Time'. And Bergson suggests that, as soon as one divests oneself of the physicist's point of view by renouncing the choice of a single reference system, one intuits that the twins are interchangeable.

Yet, the arguments used by Bergson to defend the identity between durations – that each has a different relationship with the universe – betrays more obstinacy than rational conviction. Thus, most of his opponents have had good reasons to conclude that Bergson did not understand the essence of the new theory. 'Relativity of simultaneity', they claim, does not so much mean arbitrariness in the choice of a reference system, but rather relativity of space-time to the intensities of motion with which the measuring instrument travels through it (see, *infra*, Coccia). Therefore, relativity of simultaneity to speed and relativity of the latter, in its infinite variation, to the speed that does not vary: the speed of light. Bergson, in their view, is guilty of having crushed the new Relativity into the old one, Galilean relativity, understanding the first only in terms of the second, i. e., as the reciprocity of displacement between systems that move with uniform rectilinear motion and are interchangeable in the sense of symmetrical. However, while it is correct to say that Bergson disregards the difference between inertial and accelerated systems, it is not correct to conclude from this that he also misunderstands the *new* meaning of the *old* word 'relativity'. All Bergson does is to deprive it of special importance, convinced as he is that the relativisation of simultaneity to speed makes it something indifferent to the nature of events and, more significantly for him, indifferent to the perception that a consciousness has, or can have, of it.

Similarly, if Bergson disregards the difference between uniform and accelerated motion, it is because, from the point of view of real Time, it makes no sense. Bergson, that is, does not mean to detract from the importance of acceleration, and if he restricts his book to the topic of special Relativity, it is less because he believes that general Relativity can be entirely reduced to it, than because he judges the space of the latter, as opposed to the time of the former, to be a space in which physicists can find themselves and whose properties are not only conceived but also perceived, or at least perceivable, by those physicists who occupy it. This is why, almost a century after his discussion with Einstein, profoundly questioning his enduring intuition is perhaps more productive than revisiting his mistakes (see, *infra*, Dorato). What does it mean, in fact, that it is from the point of view of real Time that there is no difference between the two types of motion? And in what sense is real Time measurable if Bergson also presents it as 'lived' time? Is it perhaps the case that between duration and space, quality and quantity, the opposition one would like to see doesn't really exist? Could it be that nature, as Alfred N. Whitehead has shown, is not bifurcated into two incommensurable realms?

As we said at the beginning, 6 April is the date of an event of a double but unitary fracture. What we can now add, before giving the floor to the various voices that have attempted to mend it, is that it is a *double but unitary fracture* that has a *double and unitary solution*. Real Time, in its function as a hinge between those heterogeneous elements that are the lived and the measured, the concrete and the abstract, is a mixture (see, *infra*, Dumoncel): a common genre within which what is different varies as does *one* species *from* another. The case of twins is again illuminating: Bergson devotes himself to this case because, although different, the twins are, after all, *different together*. And it matters little, from this point of view, whether the distinction that separates them concerns durations or the measures that are taken. For Bergson, in any case, this difference remains relative, even in the sense of marginal, with respect to the common fringe of the present within which it is recorded. Bergson wants to keep the reader's attention on this shared, extended, present, which makes the twins indiscernible more than it divides them, by preferring the language of perspective to that of time-substance and its accidental mutations. His thesis is that the dilation of time, the dislocation of simultaneity, and the contraction of lengths are optical effects. First because they concern only abstract measures of time rather than real Time, thus affect space – and perspective guards the secrets of space. Second, because they occur within and are ultimately subordinate to an identical amount of time: twins are interchangeable in the very sense that they are contemporaneous.

In brief, regardless of whether space-time is real or not, the simultaneity of Peter and Paul is safe: the twins are simultaneous, and they are one or two only depending on whether attention is divided between them without splitting or remains united. So, in the end, Einstein and Bergson not only share the language of contractions and dilations, but also a problem (see, *infra*, Donati/Gozzano): the search for a unity of multiplicity. Although the plurality of proper times, each calibrated to the intrinsic qualities of the concrete motion from which it was extracted, is irreducible to global time as a common measure defined through procedures of coordination at a distance, Einstein too recognises a unity behind the disharmonic multiplicity of local times: the constancy of the speed of light. Yet it is a parametric, conventional unity, whereas Bergson, with his concept of 'intuitive simultaneity', forces us to revise our ideas about temporal coexistence (see, *infra*, During) and to visualise a real – this means 'non-transcendental' – unity of experience in the form of a supra-luminal connection between durations. In order to think about this, however, we need to break both with the principle of locality and the logical consequence we derive from it: the principle of causality. Both locality and causality, for Bergson, apply to the phenomenal realm, the 'objective' or 'luminous' realm of the simultaneity of *events themselves*. And both, for this reason, govern the structurally delayed *time of knowledge* instead of generating an authentic *knowledge of time*.

In *The New Alliance*, Stengers and Prigogine argue that Einstein ruled out the other simultaneity, the 'intuitive' or 'absolute' one, on the basis of the unobservability of the transmission of a signal at a speed greater than the speed of light. The theory of Relativity, they say, is built around an unobservable that is different from the one around which Thermodynamics was built: perpetual motion. The latter is defined as absent from nature; whereas Relativity defines an observation, and therefore a type of communication between nature and the person describing it, as impossible. Nevertheless, in the history of science, demonstrations of impossibility have usually occasioned paradigm shifts. In the study of Relativity, Quantum Mechanics and Dynamics, e.g., they have taught us that nature cannot be described from the outside, as if we were mere spectators. Every description is a communication, and this communication is subject to general restrictions that often reflect our perceptual limitations. However, on 6 April 1922, Einstein gave voice, for the last time, to the great dream of classical science: to emancipate itself from the imprecision that the presence of a live observer introduces into descriptions of nature. And that it is a dream, is exactly what Bergson pointed out in his reply to Pièron, who took the floor immediately after Einstein brusquely dismissed him…

Although there is no doubt that the psychological ascertainment of simultaneity is imprecise, says Bergson, one must nevertheless resort to psychological ascertainments of simultaneity, which are still imprecise, even to demonstrate this point in laboratories. In fact, there is always a journey of our body, and it is at the height of this 'withness of the body', to borrow Whitehead's expression, that the intuitive experience of simultaneity is placed. It mediates between duration and its measure, between flows and instants calculated along the lines of the universe drawn by the *durées* with the same spontaneity with which a shooting star, passing through the sky at a very fast speed, draws a streak of fire. From here, *ex post*, it is possible to reconstruct something of the indivisible mobility that underlies its passage because, when the star has disappeared, the time of its movement will appear as the unwinding of a thread. For Bergson, however, what, from that moment onwards, will be divisible into points will never be the event of the star, never its unfolding (see, *infra*, Klein). Divisible is always and only the fact, the after-effect, the unfolded, and this is so, even though the example of the star suggests that the externalisation of duration in space is not a process that may or may not occur, but an automatic, necessary act.

Perhaps, then, we should also interpret the local extraction of time starting from the movement to which it is relative. As a mixture, real Time is something akin to the *space of movement* (see, *infra*, Calosi), but of a movement that only secondarily coincides with the trajectory of space-time traversed by material clocks associated with reference systems (see, *infra*, Morganti). It is, first and foremost, the rhythm of a duration, the beat of a consciousness: a living clock (see, *infra*, Longo and Wittmann/Montemayor). Whitehead intuited this. Although he does not speak explicitly about 'proper' or 'local' times, this extraordinary mathematician lent to philosophy turned the notion of 'extension' into the driving force of his reflection, stating that our concepts of space and time, and therefore space-time *tout court*, are derived from it by abstraction (see, *infra*, Vanzago). Space and time, for Whitehead, are *abstract* measures, in the sense of *extracted* from a more fundamental concreteness: that which imposes itself on perception as a brute, *stubborn* fact. 'Extension' is the name of this immediate fact constituted by the reciprocal succession and superimposition of events or durations. And to exclude extension, according to Whitehead, is to exclude a substantial part of our experience, perpetuating both our fallacious belief in a double or bifurcated nature and a material universe composed of points-instants that sketch lines across space-time (see, *infra*, Segall).

'Extraction' and 'extension' are terms for the fact that there is a measure of duration not *in spite* of but *thanks* to its being experienced, that is, not *in spite* of but *thanks* to the solidarity between an event and the diagrams capable of depicting it. Thus, real time is a very strange time: a *proper* time from which *another* time emerges (see, *infra*, Wüthrich). That 'other' time is counted in instantaneousness and it is a time that does not differ from space. Whitehead, then, is right: the motto and starting point for our knowledge of the world around us should be 'meditate on your viscera' (see, *infra*, Weber). For when projected outwards, the viscera describe a trajectory and attribute a space to themselves; but when they touch us from within as sensations emanating from the whole organism, they are part of our actual conscious life and endure. That they are not directly observable, in the light of the latest achievements of science, does not provide an excuse for excluding them from a new, unified theory; at least not if, in the event of a new alliance between science and philosophy (see, *infra*, Miquel), this new theory aspires to leave a trail of fire in the sky like a book on the most famous quarrel about the nature of time: the quarrel between Einstein and Bergson.

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Part Three: The Nature of Time, the Time of Nature

Part Four: Metaphysics, Logic, Neuroscience, Biology and Cosmology of Time

Part One **Some Preliminary Questions**

Étienne Klein
Who Is Entitled to Talk about Time? Philosophers or Physicists?

Abstract

Speeches, theses, theories, systems claiming to have captured the nature of time proliferate. They sometimes complement each other, other times compete or contradict each other. Therefore, to whom should we give any credit? And according to what criteria? We are trying here to put philosophical systems and physical theories against each other.

1 Introduction

We have to be honest: we reflect on time without really knowing what it is we are thinking about: is time a substance? Is it a fluid? Is it an illusion? Or a social construct? There are many common sayings that suggest it is a physical being, while others imply the opposite, for example that it is a product of our consciousness, or a simple word that we use to say this or that aspect of natural processes. Who can actually say, with any certainty at all, whether time accommodates events or is in fact created by them? And who can say that they know enough, with enough certainty, to explain what clocks are really telling us when we say they are telling the time? We all feel entitled to answer these questions, but we generally end up with a muddle: each of us knows at least one person saying that time stops when everything stops changing, another person saying that time still passes when nothing happens, and yet another saying that it only passes in our consciousness, whereas another one says that nowadays time truly accelerates, or even does not exist. The least we can say is that there is no harmony of viewpoints on time: telling it is never the same thing as talking about it, and still less as understanding it. So, fundamentally, what is time really like? Is it how we think we perceive or experience it? How it is represented by physicists? How it is thought of by philosophers?

A priori, it is to philosophers that we need to turn, since the question of time has been and continues to be one of their main preoccupations. Haven't many of them come up with clever, coherent systems for thinking about it more clearly? Indeed, they have (Aristotle, Saint Augustine, Leibniz, Kant, Husserl, Bergson, Heidegger, to name but a few). But nevertheless, anyone whose only resort on

 https://doi.org/10.1515/9783110753707-003

Fig. 1: *Le Théâtre de Chronos*, Marie-Christine Rabier (image published with permission from the author).

the subject of time his philosophy will come up against two problems. The first is a common problem due to the very essence of philosophy: it is the fact that not all philosophers agree with one another; in their discourse, time is sometimes the principle of change, sometimes it is a static arena filled with what has already happened waiting for what is going to happen; sometimes it is seen as a purely physical being or, alternatively, as an invention of the imagination or a product of certain cultures, or even as an illusion. So there are choices to be made. But on the basis of what criteria? The elegance of the proposed system? Its appeal? Its rigour? Its plausibility? Who came up with this system? The second difficulty, which is related to the first one, is the fact that philosophy itself is divided on the question of time, in the sense that it places the different doctrines in two very distinct categories.

In one category (Aristotle, Leibniz, Russell, Carnap etc.), time has to be thought of as a simple order of anteriority or posteriority, with no reference to the present moment or to the consciousness of any observer, or even to the mere presence of an observer: the only thing that exists, in this category, is temporal relationships between events; time therefore appears to be an order of succession in which sequences of events are objective, definitive and independent of us. For instance, if one says ‘Newton was born before Einstein’, this sentence is true now and will remain to be true at any other moment. What I mean is that its truth does not depend on the moment when it is said. In the other category (Augustine, Kant, Bergson, Husserl, Heidegger), time is a passage: the passage of a particular moment, the transit of the present to the past and the future to the present. Because this movement can only be described if there is a subject present to perceive it, time appears to be not just a chronological order, but an endless dynamic motion, the driver of which is linked to subjectivity. In this case, the truth of a sentence will depend on the moment where it is said. For instance, if one says ‘the weather is beautiful’, it is true now but can become false tomorrow. Now, the question is: towards which of these two schools of thought should rational thought lean?

It’s difficult to say, because each one leads to conceptual difficulties. If we argue that time does not exist in itself without a subject to perceive it, then we are confronted with well documented fact, which poses a serious difficulty for this idea: in the 20th century, scientists established that the universe is at least 13.7 billion years old and that humans only appeared a mere 3 million years ago. What do these figures tell us? That during much of the what the universe has experienced or undergone, humanity, a very young species, has not been present. That most of the universe’s time has clearly been spent without us. Consequently, if we argue that time is dependent on there being a subject and could not exist without one, a quasi-logical problem arises: how did time pass before we came on the scene? Many authors[1] have pointed out this paradox that is called the *paradox of ancestrality:* saying that time exists only *within the subject* or that time only has subjective reality surely makes it difficult to explain the appearance of the subject *within time*. If, on the contrary, we take the view that time exists and passes autonomously, independent of us, then we still need to identify and characterise what *drives* time, i. e., the imperceptible mechanism that makes one present moment appear and another present moment appear immediately after it, pushing it out and taking its place, before yet another present moment pushes that one into the past, taking its place in the present, and so on.

Theoretical physicists are striving to find the source of this hidden dynamic, especially at the frontiers of Quantum physics (which describes nuclear and electromagnetic forces) and the theory of General Relativity (which describes gravi-

1 Especially the philosopher Quentin Meillassoux in Meillassoux 2012.

tation), but they have not yet properly identified it[2]. Thus, to conclude this first part, we can say that *if we decide that time depends on a subject, we face a peculiar problem, and if we decide that it does not, we face a knotty problem…*

2 Questions Raised by Representing Time by a Line

These impasses refer back to a question raised by Henri Bergson in *Duration and Simultaneity:* How can something which is successive, he wondered, be engendered by points that are present altogether, that are juxtaposed? By what mechanism do points on a straight line through space manage dynamically to become temporal? The physicist Lee Smolin recently drew attention to this puzzle, which he sees as a major conceptual difficulty blocking the progress of theoretical physics:

> A motion through space […] becomes a curve on the graph […]. In this way, time is represented as if it were another dimension of space. Motion is frozen, […]. We have to find a way to unfreeze time – to represent time without turning it into space (Smolin 2008, 257).

He is right: without even realizing it, by representing time as a line of points resembling those in space, we change, we transpose its very nature (or perhaps even, we contradict it?): 'From the moment when you attribute the least homogeneity to duration – commented Henri Bergson – you surreptitiously introduce space' (Bergson 1910, 104). Hence, drawing the time axis as a line with an arrow becomes an almost monstrous act: by doing this we make successive moments, which by definition cannot all be present at the same time, coexist spatially, i.e., *exist together in the same present moment*. Essentially, we represent moments in time in the same way as if they were points in space, which changes or indeed goes against their specific nature. In his *Critique of Pure Reason*, Immanuel Kant had already identified this incongruity:

> We represent the succession of time by a line progressing to infinity, in which the manifold constitutes a series of only one dimension; and from the properties of this line we infer all the properties of time, with this one exception, that while the parts of the line are simultaneous, those of time are always successive (Kant 2007, 69).

2 To find out more, see Klein 2011.

The habit we have of drawing time in this way masks a massive problem: when a moment is present, where are the other moments, for example those in the future? Have they existed elsewhere since the dawn of time, merely waiting to become the present for a moment, at the moment when time moves on to them? Or are they still part of nothingness, outside of reality, and they only become fleetingly real at the moment when they are present?

3 Time and Language

Stopped in our tracks by these genuinely terrifying questions, we could take some intellectual comfort from reflecting on the fact that time is only a word, a name, the meaning of which could be found by some accurate analysis. Hence, it would be possible to conduct quasi-scientific research into what it actually means: the meaning of this word is essentially nothing more than the ways in which we use it. Therefore, we just have to ask what our sentences are attempting, somehow or other, to convey. But if we advance this hypothesis, we quickly become aware of the existence of another serious paradox: as soon as it is isolated from the words surrounding it, removed from the verbal flow in which we placed it, the word ‘time’ becomes an unfathomable mystery: is time a particular substance? Does it exist by itself? Does it depend on events? After all, it seems that when we talk about time, ‘we understand each other, and ourselves, only thanks to our rapid passage over words’ (Valéry 1954, 214). ‘Time’ may be one of our most commonly used words, but in no sense does it shed light on the reality it purports to name. Telling time, verbalising it, does not mean referring to it *as itself*, however clever our turns of phrase may be.

The way we think about time is also heavily dependent upon the way our existence relates to it. The temporal phenomena that we are subject to or witnesses to make us believe time looks like them or sums them up. We assign to time as many different descriptors as there are different experiences of time: so we talk about time being ‘empty’ on the basis that nothing is happening or we are bored; time ‘speeding up’ on the basis that the pace of our lives keeps getting faster; time being *cyclical* when similar events repeat themselves; we speak of *psychological* time, meaning that there is a sort of second, independent time that passes without reference to the time shown by the clock; but also *biological*, *geological* and *cosmological* time. It’s as if time, its essence, becomes confused with the different uses made of it or its different circumstances or guises. But if time has so many guises, can it really have the slightest consistency of its own? Is it still conceivable? Doesn’t the act of projecting too many disparate ideas on time kill the very idea of time? The final difficulty, linked to the previous one, is that time is the victim of an abuse of language. In his *Confessions*, Saint Augustine said that we have few accurate expressions for talking about time, and plenty of inaccurate ones.

Indeed, the multiple senses of the word ‘time’ have been used so much over time that its avatars take up a large amount of space in dictionaries: it is now used to refer to succession, simultaneity, change, the future, duration, urgency, waiting, speed, wear, ageing, and even death. This is obviously too much for a five-letter word to bear. *Cleaning up the verbal situation* (to use Paul Valéry’s words) is therefore what is needed. How do we do this? And on what basis? What can we use as the foundation? Physics, which has been so effective since it grasped time mathematically, making it a key parameter of its equations, is certainly one good way of performing a semantic clean up. To do this, we need to try to decipher and translate into ordinary language what the most fundamental physics equations would say about time if they could talk. It’s a tricky and uncertain task, because equations cannot speak for themselves, but if it is done properly, it can identify messages that, as we will see, can be profound, powerful, and at times incisive. But if we go down this path, one doubt always arises about the words used to express the Newtonian revolution, which marked the birth of modern physics.

4 Does the Parameter *t* Represent the True Time?

We all know that Sir Isaac Newton, in his *Philosophiae naturalis principia mathematica*, introduced into physics the variable *t* in his equations for dynamics, and that he chose to call it ’time’. We have become so used to this representation that it seems completely natural, to the point that it no longer occurs to us to ask this simple question: on the basis of what prior conception of time and what line of reasoning did Newton choose this name? And on the basis of what prior knowledge did he *recognise* time in the shape of a mathematical variable? In his writings, Newton was not really clear on the subject. Logically, he should have given the parameter *t* a different name, because the physical time that he invented shares none of the properties that we ordinarily attribute to the idea of time: intangible, abstract, this time *t* has no rate of flow because giving it one would assume that the rate of passing of time varies in relation to the rate of passing of time. Nor does it share any of the characteristics of the temporal phenomena that take place within it, even though we talk about time as if it were the same thing as them. It is homogeneous, in the sense that all instants of time have the same ontological status, which means that it does not change over time its way of being time, i.e., it does not depend on itself. Finally, it is imperturbable, indifferent, impassive, in the sense that nothing can disrupt its course. Is that real time or just a poor caricature of it? Doesn't the parameter *t* just refer to an incomplete version of time, or does it refer to something altogether different?

These questions lead on to another, counterfactual, question: what would have happened to the way we think about time if Newton has decided to call the variable *t* by a different name, such as *trick?* If this had happened, physicists would not have talked about time in the same terms and it would never have occurred to us to ask them about it. They would have been content to organise closed symposia about this trick that appeared in their equations in the 17th century; for their part, philosophers, historians, sociologists and other biologists would have carried out talking about time without having to worry about the discoveries of physicists… In short, if Newton had not made this rather arbitrary decision, our lexical world, and therefore our intellectual situation, would have been quite different today. Yet, nowadays Newtonian time is physically dead: it has even been wiped out metaphysically – it gave up its soul in 1905, following the publication of Einstein's theory of Special Relativity – but this did nothing to resolve these semantic questions. In fact, far from being arguments just for the sake of argument, they are debated today with even greater seriousness. To describe gravitation and the other three fundamental interactions within the same formal system, theoreticians come up with all sorts of hypotheses about space-time, and their calculations are turning both its structure and its properties: space-time could have more than four dimensions, be deducible from an underworld that is more fundamental than it, or be discontinuous[3].

The question that arises for them is therefore this: what are the characteristic properties of time, the ones that should be given to it *a priori*, by which it can then be recognised in the form of this or that variable or mathematical construct? To *re*cognise time in a set of equations, or to detect its absence, surely it is first necessary to know what it is? But how do we find out what it is *at the outset*, i.e., before having a physical theory identifying its nature and properties? It suddenly looks like we are at the start of a vicious circle. It is particularly vicious in that some theoretical physicists argue that we could do without the idea of time altogether, on the grounds that it does not seem to appear in the most fundamental equations, or that it is only an *emergent* property, i.e., deducible, from a certain

3 To find out more, see Klein 2011, Part One.

spatial scale, from a hidden world where it does not exist[4]. After all, why not? We would still need to check that, even though new equations seem to have made it disappear, it has not fled elsewhere, not put on a mask, not dressed itself in some other garb, such as that of the *dynamic variable*, *causality* or *relationship of order between events*. To be able to certify that time has indeed dissolved into thin air, we first need to say exactly what the thing we call time is and that we are assured has evaded reality, and also explain how our minds came to create such a fiction, to believe in such a ghost.

5 Asymmetry of the Container Is not Asymmetry of its Content

If we choose to ignore all these difficulties, i.e., if we decide to accept that physicists' time is perhaps not real time but at least a more genuine time than others, a time that is more in contact with the reality of the world, then the formal systems of physics could become a theoretical basis from which we can undertake a critique or indeed challenge some of our ways of talking about time and thinking it. One example of this is that physics equations do not agree with the quasi-systematic link we make between time and becoming, or at least, its formal systems make a clear distinction between the *course of time* and the *arrow of time*[5]. The course of time is what establishes a difference, a distance, between moments in the past and moments in the future: in time, tomorrow is not in the same place as yesterday; they are separated from one another by a certain duration. The arrow of time, on the other hand, is the manifestation of the becoming, the way it is recorded in the apparent dynamics of phenomena. It expresses the fact that some physical systems change in an irreversible way: they will never, in the future, return to the states they were in in the past. The course of time and the becoming are not only seen as different from one another in physics, but also almost as opposites. For the course of time can be considered, to a certain extent, to be separate from all forms of change since, because all moments of time are uniform, they all have exactly the same physical status.

When all is said and done, time seems to be able to exist without change. Supposing, for example, a sort of thermal death of the universe were to occur, in which nothing moved and nothing changed, this would not cause time not

4 See Rovelli 2014.
5 See Price 1996.

to exist[6]: we could still ask *for how long* nothing has changed. Where it is present, the arrow of time happens *in addition*, dressing up the course of time, which is irreversible in its essence, with phenomena that are also irreversible. This irreversibility of phenomena has for a long time appeared to contradict the fundamental equations of physics, because these are all reversible, i. e., their form does not change when you reverse on paper the direction of the flow of time, so instead of going from past to future, it runs from future to past[7]. But, while staying within the framework of these equations, physicists have ended up identifying possible explanations for the arrow of time[8]: they all assume the prior existence of an established course of time, within which temporally directional phenomena, i. e., phenomena that cannot occur in both directions, take place[9]. The operational efficiency of physics, its experimental successes and its ability to predict have become so impressive that we are entitled to think that this distinction it makes between time and becoming is almost a philosophical discovery: it affects philosophy itself, and should ultimately affect the meaning of the expressions we use to talk about our experience of time.

6 Course of Time vs. Arrow of Time: Roman Opalka's Paintings

This distinction in physics between the course of time and the arrow of time might appear quite abstract, but it can be illustrated more concretely thanks to the work of Roman Opalka, the extraordinary beginnings of which are worth recounting. One afternoon in 1965 Halszka, the artist's partner, arrived very late to meet him at a café in Warsaw. His lengthy wait caused him to reflect with anguish on the passing of time, and completely changed his creative work: between that defining day and his death in 2011, Roman Opalka painted the sequence of whole numbers on black canvases using titanium white paint, day

6 See Shoemaker 1969.

7 The fundamental equations of physics are reversible in the sense that the flow of time for them is arbitrary: everything they can do they can also undo. Taken literally, they do not embody the idea of 'the arrow of time'.

8 Of the main ones, we could mention: 1. *The second law of thermodynamics*, i. e., the increase in entropy over time, for isolated systems, 2. *Measurement in quantum physics*, which is generally interpreted as a temporally asymmetrical process; 3. *The expansion of the universe*, which would make it impossible for any system to go back to a previous state because the universe itself has evolved.

9 For more details see: Sachs (1987); Zeh (1989); Savitt (1995).

after day for forty-six years. Whenever a canvas was completely filled with numbers, he took a black and white photograph of himself.

The succession of numbers he painted is a material expression of the irreversible course of time, which does not change as it passes: each number written has obviously never been written before (just like every present moment is utterly new), but it is always achieved in the same way, using the same simple protocol, by adding one to the previous number. As for the photographs that Roman Opalka regularly took of himself in exactly the same conditions, they express the slow sequence of changes affecting his body, that is the irreversibility of his own aging. This shows two completely different realities: *on the one hand*, the course of time represented by the succession of numbers and the growing number of canvases; *and on the other*, the becoming illustrated by the sequence of portraits of the same human being undergoing the process of change. This dual representation (the first that *counts*, the second that *recounts*) is all that we need to demonstrate that both sorts of irreversibility, which we constantly see combining in everyday life, to the point where they seem indiscernible, can actually be separated out, as physics suggests or in fact demands.

So, is it the end of the story? No, for at least one reason: because, in the mathematical description of physical time, the nature of each instant is equivalent to that of all the others, we still need to comprehend the singularity for each of us of the particular present moment that we are living: within the line of time, the present appears unique to us, radically different from all the other instants, because it is the one in which we are… present. In any case, a moment is only described as ‘present’ with reference to us: the only thing that distinguishes it from the other moments is that it hosts *our* presence. However, on the line representing physical time, it is a perfectly ordinary moment: nothing seems to distinguish it from the moments that come before it or those that come after, apart from the fact that we are present in it. At first sight, the mathematical description of time therefore seems to trivialise the present by removing from it everything that makes it special in relation to other moments: by definition, every moment of time is, has been or will be present. One question therefore arises: what makes the present moment, in physical terms so ordinary, become so singular for us? Does its specialness come from us or is it intrinsic? In other words, does *a present of the world* exist, which would be a very dazzling proposition, or does what we call the present only mark *our presence in the world?*

Conclusion

At the end of his life, Einstein said he was very troubled by this problem of the ‘status of the present’. His theory of Relativity stipulates first that what is present for us at a particular moment no longer exists or does not yet exist for an observer travelling in relation to us: it therefore becomes impossible to define a *present moment* in which all the phenomena occurring at the same moment in the whole universe would appear. It then struggles to justify the *presence of the present*, nor does it explain what could be special about the present moment compared to all the other moments in time. In his *Intellectual Autobiography* the philosopher Rudolf Carnap recounted an enlightening anecdote:

> Once Einstein said that the problem of the Now worried him seriously. He explained that the experience of the Now means something special for man, something essentially different from the past and the future, but that this important difference does not and cannot occur within physics. That this experience cannot be grasped by science seemed to him a matter of painful but inevitable resignation. I remarked that all that occurs objectively can be described in science; on the one hand the temporal sequence of events is described in physics; and, on the other hand, the peculiarities of man’s experiences with respect to time, including his different attitude towards past, present, and future, can be described and (in principle) explained in psychology. But Einstein thought that there is something essential about the Now which is just outside of the realm of science (Carnap 1963, 75).

Can physics alone get to the bottom of this problem? Will it in future resolve the question of the present posed by its past? If so, this means that something is still missing, that it is therefore incomplete because it is not yet able to describe, in purely physical terms, the entirety of our experience of time. But if the course of time is dependent on our subjectivity, if in some way our awareness of it genuinely plays a role in its motion, then that is a property that lies outside the realm of physics. Which other disciplines should we look to in order to explore this further? The cognitive sciences? The neurosciences? Philosophy? Or something else altogether?

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Yuval Dolev

Einstein vs. Bergson, Scientism vs. Humanism

Abstract

This paper argues that interpretations of scientific theories should be as attentive and faithful as possible to everyday language and experience. Scientific theories do not choose their own interpretation, they do not favor, or give credence, to one interpretation over its rivals. Rather, the strength and viability of an interpretation are determined by the degree to which it is attuned to irremovable aspects of everyday language and experience. This is true in particular of Special Relativity. Thus, nothing in Special Relativity vindicates the claim that passage is an illusion, or supports eternalism. The suggestion that Relativity does establish the truth of eternalism derives from metaphysical, rather than scientific grounds, grounds that are not suggested or supported by the theory itself. This is illustrated in Putnam's famous 1967 paper, the conclusions of which imply a frontal collision between physics and experienced time. It is this concern that prompted Stein to object to Putnam. I claim, however, that Stein's alternative ends up collapsing to a picture very similar to Putnam's. Following this analysis, the paper turns to discuss the distinction between Humanism and Scientism. Put crudely, while scientism identifies what can be known with what can be known scientifically, Humanism allows the field of empirical research to include, in addition to the testimony of the senses, our emotive stance vis-à-vis what we see, our sentimental reaction to what we experience, and to take into account the salient and constitutional normative aspects of many of our dealings and interactions with our environment. The result is an empiricism that offers a richer, fuller, profounder understanding of reality than that which is limited only to science. I argue that the choice between Humanism and Scientism is strictly philosophical, and not scientific. Finally, it is stated that Humanism is more faithful to the science, its methods and empirical spirit, and that scientism, in contrast, serves disturbing, and currently quite vocal, anti-scientific sentiments.

1 Dilation vs. Passage, Interpretation vs. Theory

It is uncontroversial that time is frame dependent —time dilation is a fact. But in conjunction with time-dilation it is often contended that time's passage is merely

 https://doi.org/10.1515/9783110753707-004

psychological. And this latter claim *is* controversial. Why the difference? It is widely held that both are results of Special Relativity (hitherto SR). Nevertheless, dilation is not a subject for philosophical inquiry and debate while passage very much is. One dissimilarity that immediately strikes the eye is this: dilation is empirically testable, measurable; the unreality of passage is not. Whether time's passage is an illusion or a feature of objective reality is not a question regarding which any observation or experiment could be relevant. Which is not to say that debates regarding passage are not about facts, or about the fundamental structure of reality, they very much are, just that the opposing claims figuring in the dispute are not testable in the manner that dilation is. How then are they evaluated? The reason why no experiment or observation can advance the issue of passage is that any outcome of an experiment and any observation will be *interpreted* by the disputants in accordance with their view. Indeed, the teachings of SR regarding passage come out of interpretations of the theory. So, the question is how to assess the strength of an interpretation.

I will argue (unpopularly, I'm afraid), that an interpretation's worthiness is determined, not only but importantly also by the *sensitivity of the interpretation to everyday language and experience*. However, everyday language and experience have fallen to disrepute over the last decades. This, I maintain, is lamentable. First, contrary to a myth that has gained momentum in the course of the 20th century, everyday language and experience are not in conflict with science (more on this below). Second, in truth, no interpretation of a scientific theory can ignore them, and I hope to show that those interpreters that turn to everyday language and experience deliberately and unabashedly have an advantage over those that were caught in the tide of hostility to everyday language and experience that swept large areas of the philosophical scene in the second half of the 20th century and continues to dominate much of philosophy today.

But let us start with a preliminary question: why is an interpretation of SR needed in the first place? Aren't scientific theories self-explanatory? In the most obvious and straightforward sense an interpretation is needed because the mathematical symbols used in a theory can denote various entities and so their meanings must be fixed for the theory to be a theory of so-and-so. Somewhat schematically we can envision one and the same mathematical framework that, under one interpretation of its symbols, describes the dynamics of a certain economy and under a different interpretation describes the migration patterns of birds.[1] But ascribing a reference to the mathematical symbols of a theory is just

1 That the theory is not identical to its mathematics is also made evident by the math-free renthe first level of interpretation. The philosophically more challenging stage pertains, not to which concepts the mathematical symbols represent, but to how to understand these concepts. That's where the heated interpretative controversies regarding Relativity (and no less so Quantum Mechanics) take place. Disputants can accept the formal framework, e. g., the Lorentz transformations and the mathematical reasoning leading to their formulation, and yet sharply disagree about what the transformations say, or about their implications, e. g., as to whether they do or do not entail the illusoriness of passage.

It is important to stress that also on this more advanced level of interpretation, theories do not provide their own interpretation and do not point to a correct one. Where there is more than one possible interpretation of a theory, the mathematical framework together with the basic understanding of the meaning of the mathematical symbols do not establish which interpretation is true, and not even which is superior —were that the case the dispute would have been over before it began and the theory itself would in fact be telling us all there is to learn from it. An interpretation of a theory must go beyond what the theory itself says and to stick its neck out without enjoying the backing or confirmation of the theory. I emphasize this because I will be claiming that those who present their stance regarding passage as a logical consequence of SR or as corroborated by the theory are misguided on this point and misleading their readers.

2 NPO vs. GPR

It is somewhat telling that it took more than 50 years from the publication of SR until papers offering rigorous Relativity-based 'proofs'[2] that time's passage is not part of physical reality were published. If the unreality of passage was a straightforward consequence of Relativity either such arguments would not be necessary at all or they would appear more or less at the same time as the theory itself. But what Relativity says about time is far from straightforward, and it took decades for the conceptual complexity of the issues to become appreciated. The first articulations of systematic arguments were Rietdijk's (1966) and Putnam's (1967). We shall focus on Putnam's argument, and specifically, on the key component of his argument, the *There Are No Privileged Observers* premise —henceforth NPO. Here it is:

ditions of it, as in Einstein's *Relativity, the Special and General Theory* and Feynmann's *QED*, to mention two examples.

2 In contrast with mere declarations, such as Einstein's, that passage is merely an illusion or that the time of the philosophers does not exist.

> If it is the case that all and only the things that stand in a certain relation *R* to me-now are real, and you-now are also real, then it is also the case that all and only the things that stand in the relation *R* to you-now are real (Putnam 1967, 241).

A few comments are in order regarding this premise.

(1) The title *There Are No Privileged Observers* (NPO) echoes one of the two fundamental premises underpinning Relativity theory (and indeed all of physics), namely, the Galilean Principle of Relativity (GPR). According to this principle the laws of nature are independent of the location or motion of the scientist investigating them. In the language of Relativity this means the invariance of the laws of nature under change of frame of reference (of inertial motion in SR and also of acceleration for GR). Or, to put it differently, the principle states that there are no privileged observers —there is no special location or state of motion which affords unique access to the correct form of the laws of nature.[3] This last formulation underscores the supposed affinity between the two principles. The NPO could actually be read as an obvious corollary of the GPR, an addition which should be embraced just as readily as the highly valuable original. The two, however, are categorically different (as is elaborated below). The one is a crucial methodological principle which was instrumental in physics' most fundamental discoveries,[4] the other is a metaphysically contentious position. NPO is a paradigmatic example of a metaphysical opinion, used in interpreting a scientific theory that, as I will claim, with no good reason comes to be viewed as emerging from the theory it interprets, or at least as enjoying the support of that theory. Put differently, while GPR is part and parcel of the physics that generates the Lorentz transformations, NPO is not in any way underpinned or even suggested by Relativity theory or by scientific methodology, and surely makes no contribution whatsoever to the science of Relativity.

(2) There's a stark difference in the language with which the two principles are articulated. GPR is surprisingly non-technical, uncomplicated, and stated with no recourse to special jargon, unfamiliar terms or odd uses of familiar

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3 An illuminating and detailed discussion of GPR and its centrality for physics is found in Di Salle 2008.

4 One of the most explicit examples of the cruciality of GPR is Special Relativity. Thus, in Einstein's famous train experiment (see Einstein 1920, 30) it is the GPR that tells us that both observers, the one on the platform and the one in the train, are experiencing things *as they actually are*, even though one sees the two lightnings striking simultaneously and the other sees the same events as not-simultaneous. The GPR-based supposition that despite experiencing the situation differently, both observers can trust their senses is key for deriving the Lorentz transformations.

terms.[5] NPO is the exact opposite. The use of "real" in its formulation is worse than odd, it is meaningless. As Austin stressed 80 years ago, no meaning can be attached to reality claims that are just made in the void, such as *X is real* (or *X exists*). Reality claims have meaning only in certain contexts, specifically, contexts which give a clear sense in which X could be not real. "We can perfectly well say of something that it is pink without knowing, without any reference to, what it is. But not so with real" (Austin 1962, 69). Imagine that you are told of an object inside a sealed box that it is *real*. You'd be guessing in the dark what sense to make of this proclamation (in contrast with being told that it is pink). You may think to yourself that it is a real diamond (Austin's example, again), but that would be making sense of the statement by making explicit the relevant contrast—fake diamonds.[6] Now, the central claim figuring in the formulation of the NPO principle is that things standing in a certain relation to me are "real". But what are we to make of this use of "real"? How is it better than saying that the object in the sealed box is real? The key ingredient in the premises of Putnam's argument from Relativity is, so it appears, not one we can attach a definite sense to.

(3) Let us assume for the sake of discussion that we do understand the NPO principle.[7] Then the problem is that the argument premised on it blatantly begs the question. Here's Putnam again:

> *R* must be restricted to physical relations that are supposed to be independent of the choice of a coordinate system (as simultaneity was in classical physics) and to be definable in a "tenseless" way in terms of the fundamental notions of physics (Putnam 1967, 241).

For Putnam's argument to work, a tenseless language has to be assumed, and *R* must be defined tenselessly. That, in turns, is tantamount to defining "now" in a tenseless way: *R* is the relation things have to me-*now* and to you-*now*. However, rendering "now" tenseless already grants the truth of the tenseless view of time,

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5 In his *Dialogue Concerning the Two Chief World Systems* Galilei presents the ship thought experiment, which, demonstrates the GPR. The description of the situation in the ship and the experiment's results do not pose a challenge to any intelligent reader.

6 This goes back to Kant's objection to thinking of existence as a property —the paradoxality of such a thought is obvious: Vulcan, it turns out, is something that has many properties, among them being a planet, being of such and such a mass, but lacking the property of existing (for more see, for example, Donollan 1974).

7 Why so many readers never suspected its intelligibility is a question meriting a discussion. I conjecture that the reasons have to do with certain cultural trends that prevailed in the second part of the 20th century, but, other than the brief remarks towards the end of the paper, this topic will not be broached here.

or of eternalism[8] —few eternalists deny that some things are happening now while others happened before now and other will happen later, such statements are perfectly fine as far as eternalism is concerned, as long as *x is happening now* is understood to mean *x happens at the moment t in which x is located in tenseless time*, that is, as long as "now" is understood tenselessly. But if rendering "now" tenseless already establishes the truth of eternalism, then the appeal to Relativity theory is utterly superfluous. Worse, it turns out that the premises in the argument from Relativity to eternalism already assume eternalism, namely, that the argument is question begging.[9]

(4) In remark 2 above it has been observed that "real" can be used only when the context makes explicit a clear contrast with a manner of being not real. We now stress that being *past* is not a way of being *not real*. Pastness, as I've argued previously,[10] is not an ontological category. There are real and many differences between the past, present and future. But these are not captured by reality claims, claims to the effect that present events are real in a manner that past and future events are not. I have long been insisting that our grip on tense consists, not in any imagined ontological distinctions, but in how tense is given in actual experience. Pastness, specifically, is anchored to the many emotive and epistemic manners in which pastness is experienced, and in the variety of sentiments, attitudes and beliefs, which are what they are in virtue of being occasioned by an event that is now past, or more accurately, occasioned by its being past. There are forms of knowledge (e. g., that it rained earlier in the day), feelings (satisfaction at how the meeting went or regret for not having joined the trip), dispositions (to retrospectively dismiss as a trifle the root-canal we were terrified by beforehand), which are typical exclusively of our experience of events that are now past and which are never met with in connection with events that are not past.[11] What we never encounter as a constitutive ele-

8 The differences that distinguish "the tenseless view" from eternalism, if there are any, are irrelevant to this paper.

9 In what may be an expression of an unconscious worry that he is committing this error Putnam writes —"It is unfair to assume a form of language which presupposes that Aristotle was wrong [here Aristotle is identified with an open-future conception of time —YD] and then to use the assumed correctness of this linguistic formalism as an argument against Aristotle" (Putnam 1967, 244).

10 See my (2007), as well as subsequent publications, especially my (2016b).

11 The claim is not that all knowledge is restricted only to what already happened. We have knowledge of present states of affairs, and perhaps also of future ones, but it is different in kind, has different groundings, and, most importantly, is experienced differently than knowledge of the past. Likewise, we can experience satisfaction as we anticipate something we are ment of how we experience an event's pastness is its being "not-real", or it's being "ontologically absent", "ontologically inferior", or whatever locution is attempted here (the converse, the eternalist's thesis that past events are 'equally real' is just as much off the mark, of course).

Thinking of tense as an ontological issue, as having to do with whether events are real or not, exist or not, depending on where in time they are located, is probably the deepest and most widespread mistake in contemporary philosophy of time. Once tense is thought of in these terms one is forced to choose: either all and only what is present exists (the position of Putnam's "man on the street") or else all events are real even if they are not present —the conclusion Putnam derives from SR. However, this is an utterly bogus dilemma, both horns of which violate basic rules guiding the use of "real", which, moreover, is blind to the manner in which pastness, and tense in general, is attached to experience.[12] To sum up, underneath Putnam's NPO principle lurk many and serious issues. It so happens, however, that these problems have not been noticed. To the contrary, I believe NPO was regarded as an apparent offshoot of GPR, and the conviction that Relativity theory establishes the correctness of the tenseless view of time, or of eternalism, or of the block universe picture, has become widespread. Many take Putnam's argument to constitute a tight, rigorous derivation of eternalism from SR, a formal rendition of what Einstein himself expressed repeatedly as a scientifically based revelation regarding time, namely, that passage is an illusion.

3 Putnam vs. Stein

Still, Putnam's argument was not endorsed universally, and shortly after its publication voices of dissent were heard, most famously Stein's (1968). Stein was adamant that Putnam's reading of SR was mistaken, and he offered a rival interpretation for SR, one which keeps the present as a fact of objective reality, but collapses it to a point in spacetime. However, as I've argued elsewhere (Dolev 2018), in fact, far from negating Putnam, Stein actually reinforces him because Stein's present, captured by his notion of *becoming*, also boils down to things happening when and where they do, a characterization which, again (point 3

looking forward to, but again, the satisfaction is, sensuously, of a different kind than the satisfaction felt regarding something that has already transpired.

12 To be clear, the experience-based conception of time I offer as an alternative to the ontological analysis is a form of *realism* regarding time, and pertains to objective rather than to merely psychological time, see my 2007; 2014.

above), is perfectly consistent with eternalism. In fact, since most eternalists are happy to concede that events occur, become, even "are present", at the positions in space and tenseless times in which they are located, Stein's local present may actually be an absolutely effective manner of relaying the gist of eternalism.

But before examining this weakness in Stein's objections to Putnam, it is important to consider the motivations behind them. As far as I can tell, Stein's qualms regarding Putnam's *block universe* are fuelled by his conviction that, as much as possible, physics ought not to collide with the world as we know it from experience. And a salient feature of reality as we know it from experience, language and thought is the becoming of future events present and of present events past, that is, the passing of time. The error Stein wants to remove consists in the conclusion that Relativity theory is incompatible with this notion of *becoming*. Thus, Stein's objection to Putnam's argument is prompted, so I conjecture, by an urgent need to defuse the momentous conflict with experience that tenseless interpretations of SR run into.[13]

However, Stein's proposal falls precisely into the pit it tries to escape, for it too ends up clashing, no less violently than Putnam's interpretation, with experience. Stein resurrects tense —the spacetime manifold is divided to a past, a present or a future (though only partially —given point a point in spacetime it does not apply to regions that are space-like separated from it). But the price is intolerable —spatially limiting the present so that anything that is not here cannot be present runs against one of the most basic features of the world as we know it from experience, namely, that some events are present even though they are not *here:* a car is passing down in the street, an airplane is passing above in the sky, there are fish swimming in the ocean now, and at present the Bruins are ahead in the game against Vancouver, as can be seen on the TV screen in Boston. But if the present is spatially restricted, none of these things are actually happening now. In fact, they are not past or future either, because they are space-like separated from me-now.[14] Even the clock is "there" on the wall, and not "here", and so cannot be held as showing that it is now 12 PM. Stein's becoming is restricted to a geometric, volumeless point, and so, absurdly, one cannot attribute presentness even to what is happening at the tip of one's

13 It is worth recalling in this connection that Einstein himself was gravely troubled by the supposed clash between SR and experience (Carnap 1963, 37–38).

14 With the added uncomfortable corollary, pointed out by Putnam, that they were future and will be past but are never present.

nose.[15] All this is, of course, in stark contrast with how we experience, speak and think.[16]

In short, many of the present events we experience are distant, sometimes we actually need instruments, such as TVs, to experience them, and distant places are the location of events that are happening now. As Whitehead (1977) already pointed out, the nature of experience commits us

> (1) to the immediate presentation through the senses of an extended universe beyond ourselves and *simultaneous* with ourselves, (2) to the intellectual apprehension of a meaning to the question which asks what is *now immediately happening* in regions beyond the cognisance of our senses (Whitehead 1977, 127).

Thus, if Stein was motivated by a desire to harmonize SR with experience, the result was just the opposite. Stein's notion of becoming, which turned out to be music to the ears of eternalists, is just as foreign to experienced temporality as is the block universe.

The question of the spatial extent of the present is still being debated, but in the context of the present paper the moral I wish to derive from Stein's response to Putnam pertains rather to the significance of attention to experience —if I'm correct, Stein's initial conviction that Putnam was wrong in his interpretation of SR was motivated by Stein's belief that physics must align with experience and that, therefore, a frontal collision between physics and irremovable aspects of how we experience the world is indicative of a serious problem in our understanding of the physics in question. In this Stein was correct. As is argued below, for an interpretation of a scientific theory to be viable the tension between what the interpretation says of reality and what our experience says of it should be minimal.

15 Later elaborations of Stein's theses, e. g., in Hogarth and Norton 1995, suggested that the present, though spatially restricted, is voluminous and comprises a substantial chunk of space. The so-called "Alexandrov present" (discussed by Savitt in his 2010) belongs to this family of conjectures. However, these proposals bring no relief, as I discuss in 2016a; 2018.

16 There are also issues arising from the prevalent view that the Now is temporally volumeless, a point in time. Hence, it is claimed that because signals take time to travel, strictly speaking, we always experience the past. I hold the view in question, namely, that the present is point-like, to be an unfounded dogma. However, this topic cannot be discussed within the scope of this paper.

4 Experience vs. Theoretical Imposition

This moral ought to be stressed because it has become common practice to denounce ordinary experience as grossly inaccurate and utterly irrelevant insofar as understanding the fundamental structure of reality is concerned. But in truth, there's no escaping natural language when doing science. As I argue elsewhere, fundamental features of reality, for example, time having a direction, are not captured by the mathematics of physics or its laws, but rather enter physics as part of the ordinary language and experience which constitute the background for the development and operation of physics. Take for instance the notion of an "event". It is as prevalent in science as outside of it—trains moving along a platform, iron rods sliding through coils—these are the types of events Einstein reflected on as he was developing the ideas that led to SR. Without recourse to events in experience and thought there is no science. And events have salient, even constitutive properties and features which we only know from everyday experience, such as:

1. Events are not objects.
2. Events have duration, their temporal extent is not a volumeless point.
3. They are either past or present or future, regardless of spatial location.
4. There are contexts in which they constitute indivisible units. Here's Bergson: "We must return to the direct perception of change and mobility. Here is an immediate result of this effort. We shall think of all change, all movement, as being absolutely indivisible" (Bergson 2010, 167).

Each of these claims has been contested and negated. From Aristotle onwards[17] it is assumed that events can be broken down *ad infinitum* and shown to be comprised of point-like temporal atoms. This is in conflict with 2 and 4. As for 1, a debate has been going on in the philosophical literature regarding the relationship between events and objects, with some writers, from Russell (1927) through Quine (1950) and nowadays Sider (2001), to name but a few, defending the claim that events just are objects of a certain kind. And as just discussed, 3 is supposedly overthrown by SR. The point is that these challenges are not to how we *experience* events but to how they are *conceptualized*. The way we experience events remains the same, and continues to include the above features, regardless of these challenges. You see the second hand of a clock skip from one line on the dial to the adjacent one. The event you are experiencing (as well as the event

17 More accurately, from Parmenides and Zeno onwards.

which is your experience) is a present event which spans a voluminous second, involves objects but is not one itself, and is experienced as an indivisible unity, even though it can, in thought, be broken down into successive parts.

The same holds for very distant events. A space-walk 45 light minutes away from Earth (say on one of Jupiter's moons) will be past by the time the video-stream from it can be seen on the monitors of the control center, but it will still be experienced like any other event —consisting of objects without itself being an object, spanning time, being past (rather than present or future) and constituting a unified whole. Even before images of it arrive, people at the control center will speak of it, and visually imagine it as all these things. No one in the control center would think it strange if a colleague commented —"if they are on schedule, the crew is five minutes away from completing their mission, let's hope all is going well". To the contrary, nothing could be more straightforward, and more straightforwardly comprehensible, than such an utterance. Moreover, nothing could be more straightforward than apprehending the distant event as taking place *now*, as *present*, even if it will take another 45 minutes for live images of it to arrive.

It is impossible to *peel off* tense from how events are experienced, or thought of, no matter what kind of metaphysical doctrine one is committed to. Likewise, with the event's cohesiveness and duration. It is not possible in experience to deconstruct the space-walk and then re-experience it as consisting of a continuous series of infinitely many Zeno-like static, extension-less states. What is possible is to *argue* that the repair is *in fact* not one event but a series of point-like static states, that is, that in reality events are very much unlike what we experience them to be. Again, such arguments do not alter how events are experienced, only how they are conceptually analysed. But, if we wish to remain faithful to experience then, unless we are presented with irresistible reasons not to do so, we must accept events as we know them from experience. Whenever possible, the conclusions of arguments undermining what we know from experience should be rejected. When it comes to science, we are all the more committed to do so, for empirical science entirely relies and feeds on experience, even when it narrows its attention down to *experiment and observation.*

At the end of the day *experiment and observation* must themselves be experienced, namely, must themselves be experienced in the way that the moving of the second hand of the clock or the car in the street are experienced —*ordinarily.* Take away ordinary experience and you've lost science. Of course, if there are decisive conceptual arguments that force us to revise our experience-based beliefs about the nature and structure of events then we will be compelled to do so. To the best of my judgement, none of the arguments in the philosophical literature are conclusive in this manner. Science too can force, and indeed often does forces us to re-evaluate and modify, sometimes quite radically, beliefs we hold about the objects and events we experience. Time dilation is a rather dramatic example. But none of these re-evaluations can lead to self-defeating conclusions, that is, to conclusions which, were they true, would undermine the possibility of doing the science that leads to them. Denying that events, or any of their properties, including those gleaned from ordinary language and experience, are part of reality, would be such a conclusion. Events, with their tensed properties (namely, their being past, or present, or future), are part of the world of science no less than they are ubiquitous in ordinary experience. Especially in the context of science, we should accept that events are what we experience them to be.

But I know that asserting science to be reliant on ordinary experience and language is contentious, and I will not push this thesis any further here. I do want to emphasize one claim that is central to the present discussion, which is, that the disagreements on this matter are not scientific but purely philosophical. The challenges briefly mentioned above to events being unified, cohesive wholes with temporal volume that are tensely located, were all conceptual, not one of them came from or was based on a scientific theory. To the contrary, again, science regularly works with the ordinary notion of event. If there is a dispute about the nature of events, or regrading science's reliance on the ordinary notion of events, the source of the dispute is always some *metaphysical* doctrine, as opposed to a physical, or scientific theory. Of course, this fact is masked by the fact that often it is physicists that voice the metaphysical doctrine in question. Take the often-cited case of Eddington's two tables, the *ordinary* one and the *scientific* one. The ordinary one is *substantial*, but not so the *scientific* one, which "is mostly emptiness. Sparsely scattered in that emptiness are numerous electric charges rushing about with great speed; but their combined bulk amounts to less than a billionth of the bulk of the table itself". Of our notion of the first, ordinary table Eddington says that it belongs to

> conceptions which convey no authentic information of the back-ground and obtrude irrelevances into the scheme of knowledge...I need not tell you that modern physics has by delicate test and remorseless logic assured me that my second scientific table is the only one which is really there–wherever 'there' may be (Eddington 2010, x).

These are the words of an eminent physicist. However, according to a criterion given by another eminent scientist, C.S. Pierce, who was also a ground-breaking philosopher, every table is indeed substantial, and nothing could be more *really* *there* than substantial, hard, solid tables (Peirce 1878).[18] True, Pierce wrote before Eddington, but it's not due to lack of acquaintance with the science of Eddington's times that he offered his analysis of solidity. It is absolutely safe to assert that Pierce would have stood behind his analysis also after mastering the physics of Eddington's time, or, indeed, of current day physics. The clash between Eddington and Pierce regarding what's *really there* is not about scientific fact, and so cannot be settled by appeal to more science. One does not have to accept Pierce's pragmatic criterion, but one cannot reject it by citing science. The fact that on one side of the disagreement regarding the solidity of the table is found a highly respected physicist creates the false impression that those who reject the notion that the ordinary table is *really there* are clashing with physics, whereas in truth their clash is with other thinkers who defend an alternative metaphysics, one that is only paraded as science. The same is true regarding time and passage. Putnam in 1967 presents an argument in support of the so-called "block universe" and the claim that all events, regardless of their spatial location, are *equally real*. And he states that this picture is mandated by physics. Stein offers, on the basis of the same physics, what is (supposedly) an alternative picture.

However, neither has physics on his side. Physics is mute on this question, because, just like the question of the table's substantiality, it is not a scientific one. Rather it has to do with interpretation, and interpretations diverge not on scientific fact but on philosophical preferences. It is not science, but certain metaphysical stances that take themselves to be supported by science, that are hostile to the reality of ordinary tables or of time's passage, or, more generally, to everyday experience and language. Outside of these metaphysical prejudices, there is no reason to resist the claim that science routinely, indispensably, and irremovably employs notions taken from everyday experience. Moreover, and, in light of this, there's all the reason to adopt as a methodological principle the policy to strive, when interpreting a scientific theory, to do the least violence to ordinary language, and to seek and prefer an interpretation which harmonizes maximally the findings of science with pre-scientific knowledge of the world. A scientific theory that runs counter to deeply entrenched everyday concepts and beliefs presents us with a very grave predicament.

As noted above, guided by a scientific theory we can modify and alter, sometimes in radical ways, our beliefs about the world. But there's an important distinction to be made here, which was already introduced at the opening of the

18 Pierce speaks of hardness, but it is clear from the texts that Pierce and Eddington are thinking of the same property.

paper, between scientific ideas confirmed by measurement, and ideas derived from interpretations of scientific theories. *Time dilation* and Quantum *non-locality* are paradigmatic examples of the former. In both cases, however, there is no clash with everyday experience. Both phenomena belong to scales that are not directly experienced, and are witnessed with the aid of instruments, which are themselves experienced ordinarily, and which do not manifest these unique behaviors.[19] In contrast, changes derived from interpretations of theories pertain to everyday experience. And because they are not grounded in measurement, they can be rejected without clashing with the theory, only with an undesirable interpretation of it. Our topic is a case in point. Thus, nothing about SR forces us to accept that, contrary to everything we can glean from reflection on experience, time's passage is merely an illusion, or that events are not tensely located, e. g., that our births are not really in the past, which would be the case if nothing was really past or present or future. Given that passage is not eliminable from experience, including from the very experiences that underpin the development of SR, dubbing it an illusion is almost self-refuting. If there's a way to reject this conclusion, and there is a way, we must opt for it.

Because science is there to explain, explore, predict the world we inhabit, which is the world we know from ordinary experience, there's no advantage to an interpretation of a theory that does violence to basic, irremovable features of experience. If someone chooses to silence the testimony of sensory experience and adopt a conception of the world structured around a narration inspired by scientific theory, no one can prevent him from that. But it is important when confronted with such cases to highlight the fact that the choice is one of philosophical preference, not one condoned by scientific theory or its interpretation. That's exactly what Bergson did when he remarked to Einstein that the latter's rejection of passing time as merely *psychological* is a philosophical, metaphysical stance and that as such it is "a metaphysics grafted upon science, it is not science" (Bergson 1999, 47). To accept the testimony of experience and continue to think and speak (and experience) the table as substantial and events as tensed, or to go with an alternative conception which rejects these assertions as merely reflecting one's psychology —this is not a dilemma between science and everyday experience, or between science and philosophy. It is a dilemma between two philosophical approaches to the world and to experience, neither of which is more grounded in science than the other.

19 Much technology utilized Quantum Mechanics (lasers, random number generators) and Relativity (GPS). But experiences of the instruments that employ such technologies never includes direct experience of non-locality or of time-dilation.

Sellars (1962) famously pitched the scientific and the manifest images against each other, giving fundamental primacy, at the end of analysis, to the scientific image. Towards the end of his life, decades after *Time and Physical Geometry*, and from a very different philosophical position than the one he held in the 1960s, Putnam rejected Sellars dichotomy and argued that the scientific and manifest images do not actually clash, that neither is superior with respect to the other and that, rather, "a realist needs to recognize that the world has many levels of form, and theoretical physics is not the measure of all things" (Putnam 2016, 119). Bergson too was a conceptual pluralist, which, as for Putnam, meant being a realist also about aspects and facts of reality that are not captured by, and are not reduceable to, scientific language or theory. The same goes for James and Wittgenstein. None of these thinkers harbored any anti-scientific sentiments. To the contrary, they had immense appreciation for science and its achievements, but their conception of reality, grounded as it was in the infinite richness and diversity of human experience, included more than what science tells us about it, as invaluable and ingenious as the teachings of scientists are.

5 Bergson vs. Einstein, Humanism vs. Scientism

Science is currently under attack —deniers of global warming are spearheading the assault, opposers of vaccination join them, flat-earthers, of which, amazingly, there are thousands, add a colorful touch to this cacophony. Then there are cult leaders who create their own pseudo-science, such as Marshall Applewhite, the founder of Heaven's Gates, who's "science" promised his followers that the 1997 the Hale Bopp Comet was there to carry them to TELAH, *The Evolutionary Level Above Human*, all they needed to do in order to board the vehicle was commit suicide.[20] I mention these anti-scientific, dangerous, attitudes so as to draw a clear and sharp distinction between them and a criticism I find valid and urgent, not of science, but of what is sometimes called *scientism*. Scientism is a philosophical stance which, to put it crudely, gives science absolute authority as the sole source of genuine knowledge and understanding, while decrying everyday experience and language for being vague, inaccurate, unreliable, prone to error, etc.

When presented with the many questions and phenomena about which science is, for the moment, at least, mute, scientismists, if they can be called this

20 At the time this paper is being written Covid19 is breading a new brand of anti-scientific sentiment.

way, have a ready rejoinder —future science has answers. This rebuttal is invoked even in relation to topics that cannot so much as be framed in scientific terms, such as those pertaining to meaning, normativity, freedom.[21] I've been arguing that the reality of time's passage is another question which cannot be settled scientifically because it cannot even be posed as a scientific question. *Future science*, used in this manner, as a blanket and content-wise hollow promise, is nothing other than a form of Messianism. That proponents of scientism tend to present their arguments as scientific, or as grounded in science, which, of course, they are not, does not change this.

In opposition to scientism there's the view—for the purposes of the present discussion let us, following James, call it Humanism—which is premised on the basic principle that the world *just is* the world as it is given to us in experience, and that, moreover, in studying this world no kind of experience can be ruled out on *a-priori* grounds as irrelevant to the study. Specifically, humanism rejects the supposition that we must repress (in what would be an utterly unscientific manner) the data and evidence emerging from reflection on and the exploration of everyday experience and language. These, according to humanists, are vital if we are to get a clear understanding of the many phenomena that make up our environment and of our place in it. Humanism insists that the world studied by science is the very same world as the one we live in and are acquainted with from everyday experience, and that to decree, in advance, that only science, and not everyday experience, is pertinent to our exploration of this world is nothing but dogma.

It is of course worth mentioning that some proponents of Humanism were themselves scientists or philosophers well versed in the science of their day, such as James and Wittgenstein, and later Putnam. There's absolutely nothing anti-scientific about Humanism. To the contrary, Humanism celebrates science. But it does not forget that science is an activity conducted by human beings, who are irremovably embedded in everyday language and experience. Moreover, it focuses on how everyday language and experience figure as essential and irreplaceable scaffoldings sustaining science, its methods, its specialized languages,

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21 Of course, it is possible to perform an MRI on the brain of a subject who is in the process of exercising her freedom of choice with regard to some task. But to identify freedom of choice with brain processes requires much more than MRI images, it requires a philosophical argument. Similarly, for basing a denial of freedom of choice on empirical evidence. In general, the contention that scientific findings settle philosophical issues is usually supported by arguments that are blatantly circular, that is, that first identify some phenomenon with physical processes and then present the scientific theory of that process as science's contribution to, not to say "resolution", of the philosophical inquiry.

and so on. You can remove scientific terms, notions, and concepts from everyday language, you cannot remove everyday language from science. What motivates both schools? Scientism is driven, at least in part, by the praiseworthy ambition that fuelled logical positivism at the time, namely, the desire to establish our conception of reality on nothing other than hard fact and rational reasoning. Positivists such as Ayer were uncompromising —it's either *scientific* or *nonsense*.

It is however important to remember that for the Vienna Circle, the forum which formulated many of the principles of logical positivism, the insistence on this *science or nonsense* dichotomy was prompted to no marginal degree by the pressing political circumstances under which, and, to an extent, due to which, they met, namely, those of post WWI and pre-WWII Europe. The dismissal of all that is not scientific did not arise logically out of a philosophical analysis, but from the worry that it is non-scientific sources of knowledge, understanding and opinion, specifically religion, metaphysics and ideology, that are responsible for the disaster of WWI. As is made abundantly clear in Neurath's manifesto,[22] no less than in philosophy, the Vienna Circle was interested in the political reshaping of society, thinking that it is the only way to thwart another world war. It is thus no coincidence that the push towards "the elimination of metaphysics", to use Ayer's term, erupted between the wars. In the context of these historical circumstances scientism is seen less as a programmatic philosophical framework and more as a negation of cultural currents that are perceived as highly dangerous.

However, outside the political/historical context, scientism itself becomes an ideology, a philosophical framework serving the idea that scientific theory *alone* offers reliable knowledge and understanding of reality. The attack on everyday language and experience is a by-product of this ideology, which at present cannot be justified by appeal to external, political conditions. And it is a harmful attack, philosophically speaking, for, as indicated throughout this paper, everyday language and experience are the platform sustaining science and its interpretation. Done in the name of science, the repudiation of everyday language and experience, is self-defeating. Almost ironically, Humanism turns out to be more faithful to the scientific spirit, understood broadly, for, as already pointed out, it is driven by interest in and curiosity with respect to all experience-based evidence, including that of everyday experience. James' pragmatism, like that of Pierce's before him, is very much inspired by science, and by the conviction that the only route to knowledge and understanding is observation and study of what we experience. However, for him the realm of experience includes our inner

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22 Chapter 9 of his *Empiricism and Sociology* (1973).

lives — sentiments, dispositions, attitudes, emotions, as well as whatever can be gleaned from attentiveness to everyday language.

This is true of Wittgenstein as well. Needless to say, when the field of our empirical research is allowed to go beyond sensory perception and to include, for example, our emotive stance vis-à-vis what we see, our sentimental reaction to what we experience, when the salient and constitutional normative aspects of many of our dealings and interactions with our environment are also accepted as part of the empirical data on which we structure our knowledge and understanding, we get a richer, fuller, profounder understanding of reality. At the same time, the many pitfalls logical positivists justifiably worried about reopen before us. Many disagreements arise that cannot be settled in the lab or by calculation and logical analysis. Interests, tastes, opinions, biases, goals re-enter the picture. What Humanists knew all along, however, is that scientism too is not invulnerable to these pitfalls. They are a fact of existence, even in science itself. As Duhem has long ago and so persuasively demonstrated, even in the course of doing science, crucial disagreements are resolved, ultimately, not by further observation and analysis, but by scientists' appeal to their good sense (much of Kuhn's work is a detailing of this very assertion). Not only does scientism not constitute a defense against the pitfalls threatening any attempt to investigate reality, it is in fact the result of falling into one, namely, tampering with evidence by falsely discrediting some of it. It is a dogmatic doctrine which turns its back on crucial input —the one found in the painstaking phenomenological analysis of everyday language and experience.

Moreover, scientism actually plays into the hands of the very enemies it faces, namely, the adversaries of scientific advancement mentioned in the opening of this section. It fuels anti-scientific sentiments by portraying science as, to quote Putnam (paraphrasing Protagoras) again, "the measure of all things", which it is not, and making in the name of science false promises, e. g., to resolve philosophical issues. Science has not established that passage is an illusion, or that tables are not hard, or that free will is a myth. To propound these claims in the name of science is to alienate science from human life and to saddle it with the kind of indefensible folly it should never be associated with, none of which helps its popular reputation. Einstein himself was not an advocate of scientism. To the contrary, his strong verificationism, placed human observation at the heart of the scientific enterprise. But, as the last hundred years have taught us, when philosophy is highly attentive to science it can evolve into scientism. The remedy is not to stop being attentive to science, but to be cautious not to lapse into scientism.

It is an unfortunate twist in the history of 20th century philosophy that a philosophical movement, which breathed unprecedently fresh life into verificationism, thereby giving immense weight to what humans can confirm by means of their own experience, ended up serving a philosophical agenda in which human experience is marginalized to the point of losing significance. I read Bergson's comments on Relativity as an attempt to warn against this development. At the time his voice was silenced. It appears as though it is beginning to be heard again.

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Matteo Morganti
Is Time Unreal?

Abstract

This paper discusses the view according to which time is not an objective feature of reality, independent of the knowing subject. Rather than attempting to provide an exhaustive historical reconstruction of the debate concerning the (un)reality of time, we will proceed by looking at two paradigmatic and rather different arguments to the effect that time is an illusion: a well-known, purely philosophical argument due to McTaggart, and an argument (or, maybe better, a family of considerations) coming from contemporary research in physics, in particular quantum gravity. Interesting common aspects will be emphasized and, in closing, a few more general considerations will be made.[1]

1 Introduction

One of the key features of our commonsense perception of the world is no doubt its being temporal. It seems simply obvious to anyone that time passes, and that everything is affected by this.[2] Similarly, philosophers and scientists alike often take for granted the existence of time, at least as long as they inquire into other aspects of the world. However, upon reflection, it turns out that it is not at all obvious that time is an objective feature of reality, independent of the knowing subject. Indeed, arguments have been provided by both philosophers and physicists in favor of *antirealism* about time, i.e., the thesis that time is an illusion, a mere by-product of our experience of a timeless reality. While there are several such arguments in the literature, here we will discuss in some detail two of them: one due to the British idealist philosopher John McTaggart, the other based on very recent research in physics, and formulated in a particularly perspicuous way by physicist Julian Barbour. The rationale behind this is twofold. On the one hand, proceeding in this way makes it possible to see that antirealism

1 The author gratefully acknowledges the financial support received by the MIUR, Italian Ministry of Education, University and Research, through the PRIN 2017 project "The Manifest Image and the Scientific Image" —grant number 2017ZNWW7F.
2 It also appears undisputable that there is an objective, global distinction between what is present and what is future or past, but this is not the issue that interests us here.

 https://doi.org/10.1515/9783110753707-005

(about time and more generally) is not just a philosophical fancy, but something that we may have to accept for a wide variety of reasons, based on both conceptual analysis and empirical science. On the other hand, it will be interesting to notice that the worldviews that are suggested by McTaggart and by at least one important group of physicists who recently argued in favor of the unreality of time have some remarkable features in common. While presenting the two arguments against the reality of time just mentioned (Sections 1 and 2), we will also point out an important consequence of their acceptance: the need for an *error-theoretic account of our temporal experience* —that is, an account that explains why the world seems objectively temporal to us when it is not. In closing (Section 3), we will additionally make some brief methodological considerations, considering possible reactions to arguments for temporal anti-realism.

2 McTaggart

John McTaggart Ellis McTaggart (1866 – 1925) was a British idealist philosopher who worked in Cambridge. His main interest was in Hegel, whom McTaggart studied carefully as well as critically. On the basis of his knowledge of Hegel's views and the idealistic tradition, McTaggart devoted the rest of his philosophical life to the attempt to capture through a priori reflection the basic structure of reality, which he obviously identified with the Absolute. A key step in this process was constituted by the publication of *The Unreality of Time* (McTaggart 1908). In this paper, which was later revised and included as chapter XXIII of his major work, *The Nature of Existence* (McTaggart 1927), McTaggart provided a purely conceptual analysis of time and change, and concluded that time is not an objective feature of an external reality. Rather, time is just an appearance, and reality is to be understood in terms of a timeless, unchanging Being.

McTaggart's argument is based on a fundamental distinction, which has later become commonplace among analytic philosophers. When we speak or think about time, says McTaggart, both the *past/present/future* and the *before/simultaneous with/after* distinctions and corresponding categories are necessary. Indeed, time manifests itself in two ways, one *dynamic*, whereby things[3] are (and become!) past, present or future; and one *static*, such that things are in cer-

3 "Thing" here is to be intended in a generic sense, not restricted to material objects. As a matter of fact, a distinction should be drawn between objects—such as my computer—on the one hand and events—such as my computer being warm at time *t*—on the other. In extant discussions concerning time it is mostly events that play a central role. For present purposes, however, we won't need to be too rigorous about this.

tain relations with each other in a sequence which does not become, and is instead fixed. For instance, the death of Shakespeare was future at the time of his birth, then became present, and is now past. As such, it exhibits dynamic temporal features. At the same time, however, the death of Shakespeare simply *is* after that of Julius Cesar, (more or less) simultaneous with that of the Peruvian writer Garcilaso De La Vega, and before that of Goya. The former type of facts constitutes what McTaggart calls "A-series", with its corresponding A-theoretic vocabulary. The latter type of facts belongs instead to the "B-series", which, analogously, has a matching B-theoretic vocabulary.

According to McTaggart, both series are essential for a complete characterization of time. Yet, the A-series is the truly fundamental of the two. This is because, according to McTaggart, time is essentially connected to change, but *change can only occur within the A-series*. In more detail, the very idea of time seems to be required to make sense of the experiential fact that things change and, in particular, come to have contradictory properties – as when an apple is green and sour at time t_1 and red and ripe at time t_2. As a consequence, schematically, time is necessary for change: C→T. But time is also sufficient for change. This is because, says McTaggart, a universe without change would be a universe without time (¬C→¬T, which is of course equivalent to T→C). Therefore, we can conclude that there is time if and only if there is change: T↔C. However, if time is essentially connected to change in this way, it must be primarily analysed in dynamic terms, hence, in terms of the A-series. For, how could one express the change of, say, the abovementioned apple merely in terms of the static B-series, that is, by simply pointing to the fact that the green apple *is* before the red apple?

Starting from these assumptions, McTaggart construes his argument for the unreality of time. In particular, he argues that any realistic analysis of change in A-theoretic terms leads to *inconsistency*, and consequently time cannot be real. In more detail, McTaggart's argument can be summarised as follows:

1. *Real time presupposes change* (assumption)
2. *Change involves A-properties* (assumption)
3. *The possession of A-properties entails either infinite regress or circularity* (or both)
4. *Change cannot be defined without inconsistency* (from 2 and 3)
5. *Real time entails inconsistency* (from 1 and 4)

3 Time Is Not Real

Obviously enough, premise 3 is the key step in the argument. McTaggart lends support to it by reasoning as follows. First of all, if time passes, there is some entity *x* going through different states (premise 1). This entails that *x* changes its A-properties: *past-ness, present-ness, future-ness* (premise 2). More precisely, this must be intended in the sense that *each particular state*, or stage, of the same entity possesses different A-properties. In our example, that there is an apple which is first green and then red means that, say, the red apple[4] is future (when the apple is unripe), present (when the apple is ripe) and past (when the apple becomes rotten). Equivalently, the red apple has the A-property of being future, but also that of being present and that of being past. However, past-ness, present-ness and future-ness are clearly incompatible with each other: if something exemplifies one of these A-properties, it cannot possibly exemplify either of the other two. Thus, it must be acknowledged that, if we assume that time is real, we are forced to attribute incompatible properties to things.

Obviously, one could reply that the contradictory properties are not exemplified at the same time, so that what is *now* future *will* become present, what is *now* present *will* become past, and what is *now* past will become even more remote. Or, slightly differently, that the same thing is future with respect to the past, present with respect to the present, and past with respect to the future. Indeed, that this is the case transpired already in the scenario considered a moment ago: the apple is not red and green at the same time! Specifying "respects" of A-property-exemplification in this way, however, doesn't help – at least according to McTaggart. For, he argues, upon scrutiny introducing this further qualification turns out to lead to *circularity/infinite regress.*

On the one hand, while dynamic, change-related time was meant to be analysed in A-theoretic terms, now we are circularly *presupposing* it to make sense of our property attributions ("the apple is green, *then* it becomes red…", "the red apple is *first* future *then* present…"). Moreover, on the other hand, to the extent that we invoke an external temporal dimension along which to make sense of the dynamics of change and of our use of A-predicates, then we are inevitably required to account for the dynamic features of that dimension itself. Unless we do so, we still fall short of providing a satisfactory analysis: we have, e.g., a red apple that simply *is* future-in-the-past, present-in-the-present and past-in-the-future, *without any becoming whatsoever.* Unfortunately for the supporters

4 Or, which is the same for our present purposes, the *event* of the apple turning red, or being red at time *t*.

of the reality of time, as soon as we undertake an analysis of the supposed dynamic nature of time, this simply reiterates the initial problem at a higher level, and a vicious regress seems in the offing.

Summing up, McTaggart argues that, as soon as we suppose that change is real and objective and try to provide an ontological analysis of it, contradictions arise in our attribution of properties to things; and that, in order to avoid such contradictions, we are forced to either a) presuppose the very dynamic features of reality that we were attempting to analyse; or b) keep on analysing change at one level in terms of the dynamic features of a supposed higher-level of (temporal) reality, *ad infinitum*. With the foregoing, premise 3 seems to be established. If one is convinced by this, then—obviously enough—one has to either accept McTaggart's conclusion, or challenge the premises. In particular, since steps 4 and 5 in the argument above are merely a matter of deduction, and we just agreed that McTaggart is right that 1 and 2 entail 3, one has to either agree with McTaggart or, alternatively, challenge premise 1 and/or premise 2. Rejecting premise 1 involves accepting the possibility of time without change—defended, for instance, by Sidney Shoemaker in a famous paper[5]—while rejecting premise 2 requires endorsing a purely B-theoretic account of change, according to which change is indeed nothing over and above the exemplification of different properties at different times by the same thing (or, more precisely, the exemplification of different properties by different temporal parts of the same thing). Such a view was defended for instance by Russell, and has many supporters nowadays.[6] Arguably, it is the natural approach to take given the indications coming from relativistic physics.[7]

There is an intense ongoing debate concerning both options, as well as on the overall strength of McTaggart's argument. We will briefly get back to this towards the end. Here, however, we will not attempt a critical assessment, and will instead assume that the argument is successful. Under such an assumption, it is interesting to look at McTaggart's own proposal—which he introduces to satisfy the legitimate request for an explanation of why our experience seems to be essentially temporal given that time, as he argued, is not real. In order to provide what in the introduction I called an "error-theoretic" account of temporal experience, McTaggart postulates the existence of a C-series. The C-series is an ordered *a-temporal* sequence, with an internal structure but no directedness. It corresponds to objective metaphysical facts, whereby events are mutually

5 See Shoemaker (1969).
6 See, e. g., Oaklander (1984).
7 See Savitt (2017).

interrelated. How does time come out of this? According to McTaggart, this happens because the A-series is in our minds, and we project it onto the C-series, so giving rise to the B-series. Time, then, is an ideal component, which we actively add—in a rather Kantian fashion—to the raw material that constitutes reality.[8] The picture that emerges is that of a Parmenidean unchanging universe, much in line with the sort of idealism that, as mentioned earlier, was popular in the United Kingdom at the time of McTaggart, and that McTaggart himself endorsed and peculiarly merged with mystic elements.[9]

Indeed, much in the same way as Zeno—who notoriously devised a number of paradoxes to show that motion, becoming and plurality are mere illusions, and therefore his teacher Parmenides was right—McTaggart uses a priori conceptual analysis to conclude in favor of his own conception of the Absolute as a unitary, forever unchanging One.

4 Quantum Gravity

Let us now move on to the second line of argument against the reality of time, in this case coming from contemporary physics.

As an introduction, let us note that our intuitive conception of time appears to agree with what is known as *Presentism* —roughly, the view that all existents are located on an ever-changing three-dimensional surface, and only (what exists at) the present instant is real in an unrestricted sense.[10] Special Relativity

8 Interestingly enough, this sort of Kantian viewpoint is also in the background of yet another argument for the unreality of time: that is, Gödel's (1949) argument according to which, given that universes in which there is no universally shared becoming are physically possible, time cannot be an objective feature of physical reality. Gödel's argument is complex and has been widely discussed. Here, we can only recommend the interested reader to look at the original paper and some of the available recent analyses of it (see, e. g., Yourgrau 2005).

9 In a bit more detail, more or less in the period of the publication of *The Unreality of Time* McTaggart explored the notion of eternity and claimed that our perception of things as in time is an illusion, as everything is ultimately contained in an a-temporal reality (McTaggart 1909a); and presented his own conception of mysticism, which he explicitly characterized in terms of a deep unity of all the parts of the universe, whose realization is either an inevitable ultimate state of things or, more relevantly for us, eternally present insofar as reality is not really temporal (McTaggart 1909b).

10 I only say "appears to agree" because intuitions may vary. For instance, one may find it more natural to think of the universe as a "growing block" such that the flow of time continuously "adds material" to what exists —hence the truly significant distinction is that between past+present on the one hand, and future on the other. One may even have pre-philosophical reasons for puts this into question: as is well-known, if the theory is interpreted realistically, it follows that simultaneity is not absolute, hence no privileged *foliation* exists.[11] That is, there is nothing physical that corresponds to the globally extended "Now", shared by absolutely every physical thing, that is postulated by presentists. This has led many philosophers to opt for *eternalism*, the view that reality is a four-dimensional spatio-temporal block in which every event has the same ontological standing, and the distinction between past, present and future is always relative to specific space-time locations.[12]

For our present purposes, what is worth pointing out is that, if one agrees that eternalism should be favored on the basis of philosophical analysis and physics-based considerations, in a sense one already moves towards temporal antirealism. For, in a four-dimensional block time does not objectively flow. Nor is there space for a strong notion of change intended in the sense of "coming into/out of existence".[13] However, much more can, and should, be said concerning time and contemporary physics.

The crucial fact here is that, there is a rapidly growing consensus that a careful discussion of the metaphysical nature of time cannot be based only on Relativity. The main reason for this is that Einstein's theories are in conflict with the other fundamental pillar contemporary physics, namely, Quantum Mechanics; and, because of this, physicists are currently seeking a unified theoretical account —so-called "Quantum Gravity". Indeed, only a working theory of Quantum Gravity would make it possible to preserve the explanatory power of the two separate theories while avoiding their clash. If this is so, it is only Quantum Gravity that could be regarded as a fundamental theory of physical reality, and consequently be used by philosophers as a basis for claims concerning the ultimate nature of things, time included.

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not considering the present in any sense special, or for believing that it is, but there need not be a universally shared "Now".

11 "Foliation" is a technical term which refers to the decomposition of certain mathematical entities known as "manifolds" according to specific criteria. In the context of General Relativity, it is basically a "slicing" of space-time into three-dimensional surfaces.

12 Some authors have argued that General Relativity re-establishes presentism, as time can be conceived of as the global dimension along which the entire cosmos evolves. However, this is very much open to debate, and depends on specific assumptions which are far from innocent. We do not need to get into the details of this in the present context.

13 It is important to be clear, however, that eternalism is not a form of temporal antirealism *per se*. The point here is that, *if* one is a realist about time, agrees (with McTaggart and others) that real time implies objective change and essential dynamicity, and takes this to imply genuine *coming into being*, then s/he will definitely not regard eternalism as a satisfactory account.

Putting it slightly differently, and in a bit more detail, it looks as though, as long as philosophers want to ground their metaphysics on our best current science, the latter must be interpreted realistically. But, clearly, this raises a problem if two putatively fundamental scientific theories contradict each other: for, to be sure, one cannot be a realist about an inconsistent overall picture of reality! That there is indeed a clash between Quantum Mechanics and Relativity is particularly evident as far as time is concerned. For, Quantum Mechanics presupposes an absolute time, evolving in a certain direction and determining the evolution of physical states with respect to a privileged frame of reference, naturally identified with the global present. And this is in straight contradiction with the abovementioned fact that Relativity seems to describe a four-dimensional space-time with no objective simultaneity, hence no objective, frame-independent, universal distinction between past, present and future. From this, the need follows for a theory of Quantum Gravity—and with it the need for a naturalistically-inclined metaphysics of time to keep up-to-date with developments in physics and re-evaluate, and possibly re-shape, our philosophy of time in light of Quantum Gravity.

Now, as mentioned a moment ago, Quantum Gravity is currently only a desideratum and an ensemble of research programmes, not a well-defined theory. What could a theory of Quantum Gravity look like? And what would follow from it with respect to time? Very roughly, there are two options available. On the one hand, one can start from Quantum Mechanics, giving absolute time center stage, and then attempting to include space-time in the quantum-mechanical description. String-theory, based on the idea that reality is fundamentally constituted of vibrating unidimensional quantum entities, is at the moment the best attempt in this direction. Although it is a well-developed theory and many researchers work on it, however, string theory has a great drawback: it seems to systematically escape empirical testing, which is of course a fundamental requirement for physicists. This is why many look more favorably at a very different approach, whereby one starts from General Relativity and then *quantizes*. So-called "Loop Quantum Gravity"[14] is perhaps the paradigmatic form of this perspective on Quantum Gravity, but there are others. For our purposes, it is interesting to look at this second approach in more detail, and in particular at the way in which it has been implemented by Julian Barbour.

To get straight to the point, the basis for contemporary work on Loop Quantum Gravity and similar theoretical frameworks is so-called "Canonical Quantum Gravity". Canonical Quantum Gravity emerged in the 1950s and 1960s as an at-

14 See, e. g., Rovelli and Vidotto (2015).

tempt to employ in the case of gravity the same techniques that had been used to obtain a quantum formulation of electromagnetism. As soon as the theory was made sufficiently effective, it became clear that employing it inevitably leads one into the *problem of time* (Callender 2010). In a nutshell, the problem is that once gravity is quantized time turns out to disappear altogether. More specifically, in order to make General Relativity "quantum-friendly" one has to provide a dynamical (*Hamiltonian*[15]) interpretation of the entities it describes, so that only quantities that are conserved through motion are physical; and then perform a "translation" in quantum-mechanical terms. Once this is done, it turns out that an exhaustive description of physical systems is provided purely in terms of physical magnitudes distributed in space and their mutual interrelations, without the need (nor the possibility) to represent them as evolving along a temporal dimension.

In other words, once Quantum Mechanics enters the picture, the Hamiltonian constraints have the consequence that the only acceptable physical quantities are constant, i. e., lack temporal evolution. Moreover, since we are now providing a unified description of matter and space-time, reintroducing time as an external parameter is not an option. Thus, one moves from a time-dependent equation describing the behaviour of physical systems (the Schrödinger equation which is fundamental in Quantum Mechanics) to a time-independent equation that describes the entire universe as "frozen".[16] While there are other theoretical options (we will briefly get back to them in the final part of the paper), the natural way of understanding this is in terms of a truly *timeless* universe.

Against this background, let us now look more specifically at Barbour's work. In studies carried out in the last three decades or so,[17] Barbour translated Ernst Mach's idea of grounding the whole of physics in relations between observable quantities into the view that the only things that exist are *configurations* of physical systems—that is, ensembles of interrelated objects and properties—and reference to absolute space and time can, and in fact should, be systematically

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15 Roughly, Hamiltonian mechanics emerged as a reformulation of Newtonian mechanics focusing on energies rather than positions, masses and forces. It made it possible to provide descriptions of physical systems independently of their specific coordinates.

16 This is the well-known Wheeler-DeWitt equation. While the Schrödinger equation says that $i\hbar(d/dt)\psi=\hat{H}\psi$ (notice the temporal variable in the left-hand side), the Wheeler-DeWitt equation has it that $\hat{H}(x)|\psi>=0$, that is, basically, the total energy of the system—in this case, the universe —is constant.

17 The most significant results of which are presented in a well-known book (see Barbour 2000).

avoided and re-interpreted in terms of relationships between different configurations.

To support this view, Barbour started from classical physics. He noticed, first of all, that although knowledge of just the properties and relative distances of a bunch of particles obeying Newton's laws is not enough for reconstructing the evolution of physical systems,[18] only a little more is needed. In particular, once a generalised principle of least action[19] is added to the picture, it becomes possible to *uniquely* pick out future configurations of physical systems starting from purely relational information about their present state, that is, without the need to posit an absolute spatio-temporal background.[20]

Barbour then applied the same idea to Relativity. He showed that, once General Relativity is formulated as the dynamical theory of the geometrical features of space coupled with that of matter fields (in the spirit of so-called "geometrodynamics"[21]), it turns out to have a purely Machian nature. That is, by applying some technical machinery, the relativistic framework too can be taken, without loss of information, to describe nothing over and above relationships between three-dimensional configurations. As a matter of fact, as Barbour emphasized, General Relativity seems to contain right from the start exactly the sort of action principle that one has, as it were, to actively "plug into" classical mechanics.

Obviously enough, the last step consists in the extension of the same theoretical apparatus to Quantum Mechanics, so that the generally relativistic description of the universe is quantized as required. It is at this stage that Barbour's

18 This is because such knowledge does not suffice for specifying the total kinetic energy and the "orientation" of a given physical system, hence for predicting its evolution according to Newtonian mechanics. Indeed, the fact that this can instead be done by having recourse to absolute space and time (that is, to unobservable posits) was exactly the reason why Mach's original project of constructing a fully relational physics was regarded as a failure.

19 Very roughly, the principle of least action is a rule (introduced in the XVIII century by Euler, but also hinted at earlier by Fermat and Leibniz) that identifies the equations of motions for physical systems by picking out those that minimize the physical magnitude called "action"—which is a mapping from trajectories to real numbers—in a sense giving preference to descriptions based on the "shortest paths".

20 In this context, the configurations that follow each other in the relevant sequences of (descriptions of) physical systems are determined by what Barbour calls "best matching". Basically, a generalisation of Pythagoras' theorem applies, and the overall differences among distinct configurations with respect to all the quantities appearing in them turn out to be systematically minimised.

21 Geometrodynamics is essentially the attempt to interpret space-time entirely in terms of geometry. It became popular in the 1960s thanks to the work of John Wheeler and others, and then fell into decline. Recently, however, it has regained relevance, exactly in connection to ongoing research in Quantum Gravity.

universe freezes. For, it turns out that, in order to obtain a fully Machian physics, including Quantum Mechanics, an assumption concerning the angular momentum of the universe is needed. Indeed, there is a subset of the solutions to any Newtonian theory that indicates that, provided that the total angular momentum of the physical system under consideration (measured with respect to its center-of-mass inertial frame) is *zero*, then relative quantities are sufficient for a complete physical theory. And this corresponds to the abovementioned fact that the right way of describing the total state of the universe on this approach to Quantum Gravity is via the Wheeler-DeWitt equation (see footnote 16), which is naturally interpreted as conveying the information that the energy of the universe is constant, i.e., nothing ever happens, there is no physical change, hence no time.

Summing up, it looks as though once one attempts to construct a theory of Quantum Gravity by "adding" Quantum Mechanics to General Relativity—in particular, once one does this along Machian lines, describing everything in terms of relative configurations, as Barbour does—one ends up with a *frozen formalism* that mirrors the fact that the universe does not change. This, not in the relatively uninteresting sense that the universe is a four-dimensional "block" (an eternalist view that, as mentioned earlier, is already suggested by Special Relativity alone), but rather in the stronger sense that *time is not part of the picture at all*. Thus, all (physically) possible states of the universe are *ontologically on a par*, and what seems to be a sequence of states in time is in fact a complex, static collection of all nomologically admissible configurations, i.e., of all the "ways the universe could be".[22] This is, then, the particular form that the problem of time besetting Quantum Gravity acquires in the context of Barbour's relational approach.

Faced with this, Barbour endorsed a *many instants* interpretation of the universe described by Quantum Gravity, which can be explained roughly as follows. Starting from some necessary preliminaries, in Quantum Mechanics physical systems are described in *probabilistic* terms: rather than exemplifying definite properties at all times, they have probabilities of possessing certain properties, and different magnitudes and values are typically attributed with non-zero probability. Indeed, this is one of the striking features of Quantum Mechanics, and demands an explanation. What could it possibly mean that a particle has, say, probability 0.6 of being located in region *r* and also probability 0.4 of being located in region *s*, and that these probabilities are objective, in the sense that they do not simply express our ignorance about the actual location of the particle?

22 Obviously enough, this last expression must be handled with care: it is intended to refer to the universe as we normally think of it, not to universe as it is described by Barbour.

Directly related to this, there is another issue, widely regarded as the key conceptual conundrum that arises in Quantum Mechanics: the *measurement problem*. Very roughly, the problem is that, while quantum systems are typically in states of *superposition* (as in the case of the particle described a moment ago, which has no determinate location but is in some sense both in region *r* and in region *s*), we never observe superpositions: we will certainly find the particle either in *r* or in *s*. But how can this be? Given that measuring apparatuses are themselves physical systems, hence should be described based on Quantum Mechanics, why don't we find *them* in superposition states?

One possible answer to this question is provided by the many-worlds line of thought, originated by seminal work by Hugh Everett (1957). According to it, whenever a system comes to have non-zero probability for more than one experimental outcome (i. e., for the detection of a particular property with a specific value for that system), there is a *splitting* of the universe in as many *branches* as the possible outcomes.[23] On this construal, probabilities correspond to the *weight* of the various branches with respect to a given experimental question, and superpositions to the existence of more than one definite state, i. e., branch, for each physical system.[24] Allegedly, this has the advantage of neutralizing the measurement problem and explaining the nature of quantum properties and quantum states in an essentially classical context.

Whatever the merits and limits of this interpretation of Quantum Mechanics, what is relevant for our discussion is that Barbour turns it into a view whereby all the states of these many "worlds"—he calls them "Nows"—exist together timelessly.[25] Since there is no time, the idea is, the many admissible histories of the universe, each one of them constituted by possible configurations, simply coexist, without having any sort of dynamic development. That is, they are all equally real in a timeless and changeless "Platonic" realm of eternal and unchanging entities—not surprisingly, Barbour explicitly calls this all-encompassing universe "Platonia".

As readers have probably noticed already, one striking consequence of the view just described is that, this time based on scientific considerations, once again one arrives at the conclusion—as in the case of McTaggart, and Zeno be-

23 Again, modal notions must be used carefully here. The Everettian approach to Quantum Mechanics does not entail that new branches are created all the time, as the merely possible becomes actual; nor that the future part of a branch is a mere possibility.

24 Doubts may remain concerning the microscopic/macroscopic divide. Arguably, many-world theorists should deny that there are observation events that literally determine the splitting of worlds/branches —otherwise the measurement problem would not be not solved.

25 From which the name "Many Instants Interpretation", mentioned above.

fore him—that time is an illusion, and reality is a sort of unitary, invariable and static Parmenidean One. According to Zeno, assuming that the cosmos is temporal implies the reality of motion; but motion implies contradiction, hence cannot be real; hence, reality is an atemporal One. For McTaggart, the reality of time implies the reality of change; but change cannot be coherently described and leads to either circularity or infinite regress; hence, reality is an atemporal One; lastly, Barbour argues that a coherent and complete description of the physical world entails that time is not a real physical magnitude; hence, reality is an atemporal One.

As in the McTaggartian perspective, in this case too an error-theoretic account of temporal experience becomes necessary. Not surprisingly, Barbour realized this early in the development of his theory, and put himself out to establish what he calls a "psycho-physical parallelism": i.e., a systematic account of the physical grounds for our seemingly temporal perceptual experience. Barbour's explanation of temporal experience is based on the idea that physical reality contains "time capsules" and "records", that is, physical systems with a complex internal structure conveying information that our brains interpret as dynamic even though it is not —much like in the case in which we perceive motion when we see a fast sequence of still frames. In support of this idea, Barbour uses a number of controversial and not-fully-developed considerations concerning the evolution of quantum systems and quantum probabilities. For our present purposes, however, the above sketch of Barbour's error-theory is sufficient.

5 Assessment

Summarising our discussion so far, then, in spite of our commonsense intuition it looks as though there are good a priori and a posteriori reasons for *denying the reality of time*. Some of these reasons are expressed in a very clear and uncompromising way in McTaggart's well-known argument, and on the basis of certain developments in contemporary physics, respectively. Taking also into account Zeno's arguments against the reality of motion, the picture represented in Fig. 1 emerges.

As already noted, and as can be easily seen from this schematic representation, the different perspectives have interesting shared features. Two of these features, in particular, seem paradigmatic of antirealism about time. First, the idea of a timeless universe may arise and be motivated in different ways, but it is often accompanied by the idea of reality as a changeless "One" – shared by McTaggart mysticism-inspired, idealistic monism and by Barbour's Platonia, and clearly analogous to the Parmenidean conception of Being. A second com-

Zeno	McTaggart	Barbour
Motion (as it appears to us) is impossible	Change is inherently contradictory	The physical world must be timeless
hence		⇩
Reality is an unchanging One – Being just is		
	Reality is structured, but not temporally	
	Kantian approach: temporal element added by the subject (see also Gödel)	Physics and biology: time capsules + quantum probabilities + structure of our brains ⇒ perception of time

Fig. 1: McTaggart, Barbour and Zeno: are appearances misleading?

mon trait is that, once time is regarded as an illusion, providing an error-theoretic account of temporal experience—be it provided along Kantian lines[26] or in more scientifically-oriented terms—becomes necessary. Faced with this, it is of course natural to ask how seriously one should take these arguments. This leads to a number of important methodological questions concerning philosophy, science and their mutual interplay which, it goes without saying, it is impossible to even just start addressing satisfactorily here. Nonetheless, it is useful to offer at least a brief general assessment before closing. Is it truly necessary to start conceiving of time in antirealistic terms in light of arguments like those we

26 It is barely worth pointing out that Kant would reject talk of error theory, since for him time is objectively a part of the —phenomenal, rather than noumenal—object of knowledge.

have discussed in this paper? If not, what considerations could be used to counter the sort of reasons provided by McTaggart and by physicists for thinking that we live in a timeless universe?

A first option, and indeed the most natural in philosophy, is 1) to try to refute the arguments that appear to represent a threat to established beliefs. As mentioned earlier, one may for instance claim that McTaggart's argument is valid but also unsound, as a different conception of change or of time should be endorsed, allowing one to reject premise 1) or 2) (or both) above. Obviously enough, this in turn raises a number of further questions: Does time require (the possibility of) change? Can we truly account for change in a static, B-theoretic universe? Or is the resulting metaphysical picture changeless and timeless anyway? A second possibility, relevant in the case of the arguments based on current research in Quantum Gravity, is 2a) to try to change (the interpretation of) the relevant scientific theory or theories. One may, for instance, prefer different theoretical frameworks, such as the abovementioned string theory, or causal set models,[27] which seem to leave room for a robust notion of time and becoming. In this case, though, it appears legitimate to require that such preference be not *exclusively* motivated by the desire to steer clear of unwanted metaphysical consequences; or at least that principled reasons be provided for letting philosophical preferences dictate the scientific agenda.

Alternatively, one might 2b) interpret the "disappearance" of time in a non-eliminativist way. For instance, by regarding time as an *emergent* feature of the universe: that is, as a physical magnitude that, albeit real, is not fundamental as we thought it was, but rather derivative on other, truly fundamental, physical magnitudes —much like temperature is a macroscopic property which is entirely reducible to facts about the motion of microscopic particles. Indeed, Rovelli overtly talks about *thermal* time in connection to his views of Quantum Gravity and the problem of time (see Connes and Rovelli 1994). Although careful work is required to disentangle the many concepts involved and the different theoretical options available here, the idea of an *emergent* time might turn out to be instrumental to the definition of a coherent, reductionist/relationist yet not eliminativist, view of time.[28] In connection to this, one might 2c) contend that it is wrong to assume that there must be one objective time for every corner of the universe,

27 Causal set theory is an approach to Quantum Gravity which regards space-time as discrete and constituted by points/events which are mutually related by partial order (i.e., reflexive, antisymmetric and transitive) relations corresponding to causal links (see, e.g., Dowker 2013).
28 It seems fair to stress that the notions of reduction, elimination, emergence and cognate ones may well have definite meanings for philosophers but are not always used unambiguously, especially by non-philosophers.

and endorse a weaker form of temporal realism. To this purpose, in particular, one may exploit the fact that even in a frozen universe *local*, *internal* clocks can be reconstructed on the basis of specific physical sub-systems and their properties.

A more ambitious attempt would be 2d) to reconstruct a global time variable by further developing the existing theoretical apparatus of Quantum Gravity. Remarkably, this is what Barbour himself has done in recent years, suggesting that a particular theoretical formalism (so-called "Shape Dynamics") may indeed allow one to identify a universal, cosmic time (see, for instance, Barbour, Koslowski and Mercati 2014). One last option, in a sense more extreme but at the same time less demanding, is 3) to simply bite the bullet and continue to conceive the things that we experience and study daily as temporal. Perhaps time is not objectively out there, and is rather part of the phenomenal objects of knowledge in the Kantian sense. Or maybe it is just an appearance that we have to gradually recognize as such via rational reflection and mystic intuition, as McTaggart would have it. But it is certainly also the case that the contents of our perceptual experience are not negotiable, and that whatever we do in our daily lives—be it as laymen, scientists or philosophers—can be done in exactly the same way by acting *as if* time were real.[29]

Conclusions

Both the purely a priori analysis of McTaggart and the empirical-data-based models of (certain versions of) Quantum Gravity lead us to the surprising conclusion that time is unreal. If this is so, then interesting consequences follow—on the one hand, the need for an underlying metaphysics; on the other, the need for an error-theoretic account of temporal experience. As for the former, we have seen that, like Zeno, both McTaggart and Barbour seem sympathetic to-

29 A radical version of this reaction is the "common sense first" approach—forms of which can be found in the philosophy of Thomas Reid and G.E. Moore—according to which commonsense appearances are so strong that they systematically trump the results of conceptual reflection, no matter how sophisticated. In this case, it would not just be a matter of not taking the issue seriously and live *as if* time was real, but rather of insisting that we in fact have good reasons for taking time to be real based on our experience of reality. In relation to science, this approach is clearly in contrast with realism about scientific theories and/or the naturalistic methodology according to which science should be taken seriously when doing metaphysics. On the other hand, perhaps some sort of middle ground can be found, and some degree of pluralism (in this case, about time and the meaningful descriptions of it) is possible, or even necessary.

wards forms of Parmenidean monism. As for the latter, the underlying trait seems to be that time is in our minds—either in the Kantian sense that we actively project it onto reality, or in the sense that it is a by-product of the interaction of physical reality with our brains. Even if the arguments against the reality of time are not accepted, on the other hand, there are important take-home lessons. First, one has to carefully identify alternative theoretical options, and reasons for and against those that are taken seriously; secondly, and more generally, a precise methodology should be defined before comparatively assessing the various alternatives, especially when they encompass philosophical and scientific considerations. Indeed, the case of time is paradigmatic of the potential clash between the commonsense image of the world, which we all share at the level of everyday experience, and the sophisticated image of reality that we obtain through conceptual analysis and scientific research. Whether one reacts to such a clash by sticking to commonsense and to the undisputable contents of one's own perception of things, or one decides instead to learn from it and consequently shift to a novel conception of reality—along the lines of Parmenides, Kant or Barbour's Platonia, or maybe along those suggested by current theoretical research on emergent space-time and local clocks—, time certainly remains a mysterious entity that scientists and philosophers alike will have a lot to think about in the future.

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Part Two **Bergsonian Issues**

Donatella Donati, Simone Gozzano

The Eternal Quarrel on Time

Abstract

In this paper we consider the dispute over the nature of time that divided Einstein and Bergson one century ago. In particular, we will focus on the role to assign to consciousness with respect to a physical quantity, time. We shall claim that there is a position that both Einstein and Bergson were not opposed to but rather were compatible with, and this is a form of eternalism. However, when interpreted by Bergson's perspective on consciousness, such a view comes with a very high price, that of panpsychism.

1 Introduction

Bergson, the philosopher, and Einstein, the physicist, clashed on the nature of time. On April 6th 1922, at the Société Française de Philosophie (French Philosophical Society) the most important philosopher of the time and the physicist that set a revolutionary theory that changed our most rooted conception of time and space, met in a public debate.[1] The story goes that the two thinkers ended up by leaving on the terrain an irreconcilable fracture between time as considered by science and time as considered by philosophy, or at least by a number of philosophers of phenomenological faith and continental methodology. It seems natural then, almost one century after, to take stock on whether that disagreement was really irreconcilable. Bergson held an articulated view of time, one in which a personal, or psychological conception of time, was the most important one and it was to be, at most, flanked with the purely physical view of it.

The personal view was dominating over the purely physical one, deemed to be insufficient to characterize the deep, and essentially human nature of time. Einstein, famously, argued that there was no "time of philosophy", advocating a view of time as what is measured by clocks, thus dismissing the idea that there is a time beyond the physical nature of time, the one that could be measured. In this paper, we try to show that there is a common metaphysical terrain for Bergson and Einstein, so as to reduce the import of their disagreement. Such common terrain can be found in a version of eternalism, one to which we will get

1 See Canales (2015).

https://doi.org/10.1515/9783110753707-006

by considering two other options, that seems to fit more naturally to Bergson's view: the Growing Block and the so-called Moving Spotlight.

In this brief paper we shall proceed as follows. We will first consider Bergson's view of time. We will then summarize Einstein's view. The third task will be to provide an outline of the main metaphysical views on time considered in this paper. We will finally argue that there is a specific position that both Einstein and Bergson were not opposed to but rather were compatible with, but this comes with a very high price, that of a form of panpsychism. In the next pages, however, we do not aim to be philological, that is, we are not ascribing the hypothesis we are going to advance directly to the two authors. Rather, what we want to do is to argue that, given the positions they held, it is possible to devise a metaphysical common ground that can be traced back to their positions.

2 Bergson and Einstein on Time

To begin with, let us consider in brief Bergson's view on time. Bergson's conception of time is inextricably intertwined with his concept of duration, which he considers to be pivotal to understand our conscious experience. Bergson thinks that in our conscious experience we are continuously facing novelties, unforeseeable experiences that characterize our mental life. "The more we study the nature of time, the more we shall comprehend that duration means invention, the creation of forms, the continual elaboration of the absolutely new" (Bergson 1911, 11).

So, time is approached through our conscious experience. Such experience is a matter of change, and change entails time. Ultimately, then, our conscious experience is, in its most fundamental nature, the experience of time, because it is the experience of change. This crucial feature of time as duration is clearly expressed in some other passages as when Bergson asks to dive into our own internal conscious life to discover that we find ourselves in "a duration in which the past, always moving on, is swelling unceasingly with a present that is absolutely new" (Bergson 1911, 199–200).

Bergson held such a view wholeheartedly in *Time and Free Will* and then slightly moved broadening it up, in particular in *Matter and Memory*, by taking duration to be a feature of the universe. Finally, in *Creative Evolution*, he took consciousness, as we call it now, to be into the picture as well. In the passages quoted above, two different theses are converging: the first is the thesis that change entails time; the second is the thesis that change entails that one cannot foresee how the elements of the present will group in the future. That is, the future is intrinsically unpredictable because of the novelty it brings in. The first thesis is a vexed and challenging point, on which philosophers have always been thinking about. The second thesis needs some discussion.

On the one hand, it can be dismissed right away, for the following reason. Any regularly cyclic phenomenon can be conceived as one in which change occurs and in need of time to unfold. If an idealized pendulum goes from A to B and then back to A, there is a change in the position of the pendulum and so time is needed for such a change to occur. At the same time, the pendulum's next position is foreseeable with a good degree of approximation. Surely, there can be many ways to interfere with the pendulum going back and forth, but there can also be subatomic regular oscillations, as those present in zapphire atoms, that are extremely reliable, and are a sort of change in need of time to unfold.

Actually, atomic clocks are built on such regularities, showing that more than measuring time, these phenomena are time itself. So, it is not the case that change entails unpredictability, and we cannot hold the entailment from change to unpredictability. On the other hand, this thesis goes right at the heart of Bergson's view on time: things are not given until they are completely given: their being is their becoming. So, predictability is a false issue, because it amounts to the unfolding of things in the universe, and for Bergson such unfolding was the core of duration. After all, if something can be predicted, there is a sense in which it is not new; if it is truly new, then it cannot be predicted. So, even if this second thread cannot be dismissed right away, it is questionable, because it amounts to a very strong form of emergence, an issue we will not consider in this paper.

Why was Bergson holding true the unpredictability? The fact is that Bergson was connecting to this second thesis a more wide-ranging view on the concepts of duration and human experience. That was the view that duration was intrinsically heterogeneous, an idea set in order to contrast the rising of a deterministic view of science that was thought to be dismissive of human autonomy and freedom, a problem that was pretty clear already at the time of Bergson. This was a common interpretation of Bergson at that time. Consider the following passage:

> Doubtless, my present state is explained by what is in me and by what was acting on me a moment ago. In analysing it I should find no other elements. But even a superhuman intelligence would not have been able to foresee the simple indivisible form which gives to these purely abstract elements their concrete organization. For to foresee consists of projecting into the future what has been perceived in the past, or of imagining for a later time a new grouping, in a new order, of elements already perceived. But that which has never been perceived, and which is at the same time simple, is necessarily unforeseeable (Cunningham 1914, 527).

Novelty was the crucial element to block any deterministic view, here personified by a Laplacean demon. At the same time, Bergson was underlying the relation between duration and consciousness, as it has been recently stressed,[2] rather than providing an ontological framework for time. So, duration, the way in which Bergson understood time, is a continuous opening of possibilities and options, the unfolding of contingency, and time was requested for it and, in a way, was resolved in it. Such unfolding of contingencies is the unfolding of novelties, which cannot be foreseen. Consequently, there was no specific reason to think that clocks and clocks only could measure time, or simultaneous events, because time is intimately related to the conscious life and not to the ordering of synchronous events.

According to Einstein, time was given a spatial interpretation, one according to which space and time are a unitary entity permeating the universe. As such, spacetime could be measured, and is dependent on the speed of the reference frame, that is, on the speed at which the clocks measuring the interval between any two events travel. And, as we already said, time is the regular going on of the clocks, which are necessarily to be considered as frame references. Time, then, has no more a special or privileged status, it is on a par with space, and it is the speed of light that becomes the constant from which spacetime depends. Our experience of time and change, in this theory, is definitely put aside.

Since Bergson's reflections on time, many things have changed. Nowadays, a number of metaphysical positions have established themselves in the literature, and it is interesting to consider whether and to what extent we may consider Bergson to belong to one or more of these views. It seems to us that among the current views on time, the one that best fits into Bergson's own view is a particular version of eternalism: a mixture of the Growing Block and the Moving Spotlight theories which were, by the way, already present at Bergson's time. On the one side, inasmuch duration allows for the opening up of new possibilities, the future has to be considered as open and not predetermined by past events and laws of nature, as for the Growing Block. On the other side, since it is only through consciousness that we experience time itself, the Moving Spotlight seems the more adequate. Let's explore this point.

2 See, e. g., Guerlac (2020).

3 A Look at the Analytic Philosophy of Time

Within the philosophy of time one of the main differences among the theories mentioned above is given by a different conception about what is to be past, present or future. Here we will focus on three theories that are different for one crucial aspect: two hold that an "objective present" does not exist, the other defends the idea that an "objective present" exists and it is an ontologically privileged moment in time. The theories we are interested in are the Growing Block view, the Moving Spotlight view and Eternalism. Let's have a look at each in turn.

The Growing Block Theory (henceforth GBT) is the view that only past and present entities exist, while future entities do not, and the present is the slice of time at the edge of a fourdimensional block that grows bigger and bigger as new slices come into existence. This view, originally devised by Charles Broad (1923), is the one that better fits with the idea of an open future, one that is still to be settled as the reality unfolds by piling up slices of new moments, moving from the past to the present. In Broad's own words: "The passage of time, then, should be conceived as one in which fresh slices of existence have been added to the total history of the world [...] the sum total of existence is always increasing" (Broad 1923, 66–67).

The idea that time is intrinsically linked to human experience can be tied to the Moving Spotlight view. According to such a view, imagined by Broad himself, time is a moving epistemic grasp of events already unfolded. Broad expressed this view in terms of a policeman with a spotlight (his "bullseye") pointing to the houses while he is cruising with his car down a road: things are there but not for us unless we enlighten them. The houses that have already been illuminated are the past events; those that have not been illuminated yet are the future ones, those that are illuminated are the present, and they have a privileged ontological status. On this account, then, it is the present that moves: it moves across the array of events.

Since things are already there, though, the future seems to be closed, in opposition to the GBT; because in the Moving Spotlight view things appear only when enlightened, so at the present moment. Hence, we should conceive of the present moment as the one in which things appear to our conscious experience. Is there a sense in which these two views can be merged or made somehow compatible? Our answer is positive: Bergson seems to hold a particular view that is a merging of the two views, but we need to elaborate and justify this sentence in some details.

The most reasonable way to interpret the merging could be the following: the Moving Spotlight and the piling up of the slices of the Growing Block coincide. The spotlight enlightens the piling up of the slices of the present. However, the Moving Spotlight view posited that future events are always there, beyond our grasp. If the future has to be considered as open, this tenet should be dropped by the Moving Spotlight view, and this can be done by stressing that the ontology and the epistemology of the events coincide: to be is to be presently known (enlighted). There are no future events just set but not enlightened. So, to sum up, the Moving Spotlight view defends the intuitive idea according to which the present is ontologically privileged, that all the entities in the four-dimensional manifold exist in it, and that the present is illuminated by a light that moves forward.

So, according to the Moving Spotlight, what is past, present or future is not relative to the entities that occupy a given spatiotemporal location, rather it is an ontological matter. We think the combination of these two views (the epistemology of the Moving Spotlight and part of the ontology of the GBT) capture well what Bergson had in mind when he characterized, as we saw above, a duration in which the past is always moving and is continuously producing and setting forth a present that is new and unforeseeable. It should be acknowledged, though, that in Bergson the spotlight view assumes a different twist because he thinks that duration is consciousness, and so there is no question of ontological disappearance once consciousness turns away from a given object or state of affairs.

Both these views, however, are at odds with Einstein's conception of time, which is much closer to another theory: Eternalism. Eternalism is the view that all entities, past, present and future are equally real and ontologically on a par. What exists is located at different spatiotemporal points within a four-dimensional manifold, but the fact that different entities are located at different points does not mean that one is more real than another. For example, as well as Rome is closer to us than London does not make Rome more real than London, Napoleon's horse is not less real than my dog only because it is located in the XIX century. According to eternalists, the present is not an ontologically privileged moment in time, what is present, past and future is relative to the entities that occupy a certain location within the manifold. This view clearly fits into Einstein's Relativity theory and, in a sense, can be considered as a natural consequence of Einstein's Relativity theory. Let's have a look at an argument that shows why eternalism is the only theory of time implied by Relativity.[3]

3 See Ney (2014).

1. If either Presentism[4], the Moving Spotlight and the Growing Block theories are true, then which entities are real depends on which are present, past or future.
2. Which entities are present, past or future depends on facts about which entities are simultaneous with the here and now.
3. If Relativity is true, then which entities are simultaneous with the here and now is a matter of one's perspective (as a consequence of Relativity).
4. Relativity is true.
5. Which entities are simultaneous with the here and now is a matter of one's perspective (3, 4 and MP)
6. So which entities are present, past or future is a matter of one's perspective (2, 5).
7. So if Presentism, the Moving Spotlight, the Growing Block theories are true, then which entities are present, past or future is a matter of one's perspective (1, 6).
8. But what is real is not a matter of perspective (assumption: what is real is an objective matter).
9. Therefore, neither Presentism nor the Moving Spotlight nor the Growing Block theories are true.

As Ney claims:

> Eternalism is the only ontology of time that avoids making existence subjective, since it makes no distinction in reality between past, present and future events and objects. And so eternalism is the ontology thought to be implied by the special relativity theory (Ney 2014, 144).

4 A Quarrel

In Einstein's view there is no ontologically privileged present. What is present as such is relative to a reference frame and since there could be a frame reference for each spatiotemporal point, every spatiotemporal point is on a par with every other else. Because everything could be present from a reference frame, since there can be an endless number of frames, each determining a present, there can be endless presents from any moment. Therefore, everything is eternally there.

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4 Presentism is the view that only what is present exists.

On Bergson's view, since duration is the fundamental element of time, you cannot have a reference frame, needed to measure time events, without consciousness. Each reference frame, then, presupposes consciousness, and each reference frame has a spatiotemporal location. Thus, all these consciousnesses, each corresponding to a reference frame, determine "the present" which is clearly not ontologically privileged. In this sense, Bergson is not a Moving Spotlight defender but, in our view, a "conditional eternalist": if consciousness is present and is sufficiently distributed over the universe, then eternalism is guaranteed. If there is no consciousness, then there is no time. This is because, at least in our interpretation, Bergson's present is crucially relative to a conscious being, the one that determines and has a grasp on it at the same time.

Since conscious beings may occupy different spatiotemporal locations, they can determine different time flows, that is, series of temporal events. Under this interpretation, though, it is not possible to say that the future is not foreseeable, as Bergson did, because of the multiple locations of these conscious beings which determine that it is possible for one to be in the relative future of another one. The thesis that the future is not foreseeable must be dropped. Now this point may be considered from two perspectives: on the epistemological side, it says that we simply do not know what will happen next, but it is in line of principle possible that the future is determined nevertheless. So, being unforeseeable simply means not known yet.

From a metaphysical point of view, it could disclose a deeper thesis: the idea of a closed future presupposes a deep dispositional realism[5]. This would be the view that even if not all the frames of reference are actually occupied by a conscious being, and so there would be some regions of the space-time that are not under the light cone of a knower, the universe still has a closed future because if there were a conscious being in every reference frame–so, if potentially every reference frame hosts a conscious being —then that being would know what can be known from that point of view.

This view should be interpreted in this way: the future being closed means that every time- interval is the truth maker of a sentence that fixes a time order between two events, such as "a happens earlier than b" and such a sentence has a tenseless truth-value. Sentences such as "a happens earlier than b" are possible only if they fall within the light cone of a system of reference. So, for each point in the space time, there has to be a system of reference. Hence, there are infinitely many frame references. Now, in Bergson's terms, each frame refer-

5 Dispositional realism is the view according to which dispositions (or causal powers) are real properties.

ence must have a conscious being for, without consciousness, there would be no time. However, since it is unreasonable to hold that a conscious being is present at each single space-time point, it follows that each point has a form of consciousness, infimum but present.

Basically, the dilemma is as follows: either there are infinite conscious beings, one for each frame reference, or everything has a degree of consciousness, as for panpsychism, the view that mental properties are massively and uniformly distributed across the universe. Since the first option is difficult to accept, the second one holds. This doctrine is panpsychism, the idea that matter and mind are not categorically nor qualitatively distinct, and there is now some convergence on the idea that Bergson was actually defending a form of panpsychism. It should be stressed that this dilemma arises independently on assuming determinism or the Laplacean demon: it is the very nature of panpsychism that makes the dilemma. This is not the proper paper to say which form of panpsychism but, as Hirai (forthcoming) has made clear, Bergson was holding a form of panpsychism in which the present retains memory of the past. An interesting quote is the following:

> Only one hypothesis, then, remains possible; namely, that concrete movement, capable, like consciousness, of prolonging its past into its present, capable by repeating, itself, of engendering sensible qualities, already possesses something of consciousness, something of sensation (Bergson 1991, 246 – 247).

In this case, Bergson could be seen as the conditional eternalist we were imagining. Could be such a view maintained *per se?* What is the price to be paid? For instance, we now know that the value of certain quantum phenomena can be determined by an observer measuring the phenomena. But natural interactions determine the collapse of the wave function as well. Therefore, if a quantum phenomenon is left in a state of superposition, we would have an aspect of reality not closed yet, because it has not been measured yet. This could be irrelevant from a general point of view, of course. What is relevant, though, is that in order to affirm that the future is closed form a general point of view we must assume that every possible frame of reference is conscious, and panpsychism is true. That would be a converging position for both Bergson and Einstein.

Clearly, it seems that having the closeness of the universe depending from a conscious observer is at least unmotivated from an Einstenian perspective, if not outright false. The philosopher of Einstenian faith can well abandon the idea that consciousness is necessary to give an empirical content to the thesis that the future is closed. The future is closed in line of principle, she may suggest. As per Ney above, if one adheres to eternalism, the idea of having the order of events depending on a conscious being is making existence subjective again, thus losing the advantage eternalism gives. In this case, the physicist and the philosopher will part company again.

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Mauro Dorato

Some Contemporary Reflections on Bergson's *Time and Free Will*

Abstract

By relying on a quotation by F.L. Pogson[1] to be found in the introduction to his translation of Bergson's *Time and Free Will* essay, in this paper I discuss Bergson's theory of the relation between time and free will by analysing three key notion of his philosophy, namely that of creative power of nature, of memory and of duration. In particular, I discuss a possible reinterpretation of his metaphysics by using the growing block model of reality, and his anti-associationist philosophy of mind—by him identified with determinism—which seems to require a finite duration of the present experience. Finally, I propose a reinterpretation of his conception of free action by using Kane's contemporary approach to the problem.[2]

1 Some Methodological Considerations

There is little doubt that Bergson's philosophical work has always focused on the nature of time, in particular on the difference between the time of our direct experience and the time of physics.[3] Consequently, Bergson's critique of physical time—regarded by him as a mere spatializing abstraction from the real duration—was not only caused by the philosophical and scientific challenge emerging from Einstein's two theories of Relativity, but predated their famous meeting on April 6, 1922.[4] Some contemporary reflections on *Time and Free Will* will show

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1 In this paper I will follow Pogson's 1913 translation of the original text, as it has been checked by Bergson himself (Bergson 2001).

2 I thank two anonymous refereed for their important suggestions and Alessandra Campo for her decisive and patient editing help. This paper has benefitted of the grant progetti di ricerca di rilevante interesse nazionale financed by the Italian Ministry of Public Education—Bando 2017 Prot. 2017ZNWW7F.

3 An informative and accessible survey of different views on the nature of time in the 20th century is in Fano and Tassani (2002).

4 Of course, Canales to whom we owe the complete and fascinating reconstruction of their meeting is well aware of this fact. See Canales (2015).

 https://doi.org/10.1515/9783110753707-007

in what sense Bergson's earlier criticism of physical time affected his later confrontation with Relativity. 'Contemporary' as it is used here implies a conceptual evaluation of Bergson's arguments that is independent of a philological attention to the literature in psychology and neurophysiology that Bergson had read before the completion of his work in 1899. In the following, I will therefore first briefly expose his conception of the creative power of nature and of duration, and then compare his notion of the relationship between time and free will with some relevant contemporary scientific and philosophical theories.

2 Various Approaches to the Problem of Free Will and Bergson's Position

Schematizing, in the history of western philosophy we find *three* different ways of articulating the inextricable conceptual link between time and free will:

(1). Aristotle's *logical* discussion in the ninth book of *De Interpretatione* of the so-called "future contingents" (non-necessary future-tense statements) —was based on the thesis that if we attribute a definite truth value to such statements and at the same time accept bivalence, we are not free. If it is now true that tomorrow there will a sea battle, the captain is not free to decide whether he wants to attack or not, since he cannot but attack. The same conclusion holds if it is now false that tomorrow there will a sea battle. And since in virtue of bivalence, a statement is either true or false, in both cases we are not free.

(2). The well-known *theological* problem of a omniscient or prescient God who, knowing in advance what each of us will do, necessarily deprives us of the power to choose freely.

(3). The more serious *scientific* threat to our free will, coming from determinist laws conjoined to initial conditions

These *logical*, *theological* and *scientific* arguments threaten in a similar way our free will, which typically requires as a necessary condition the possibility to choose between a set of different, real alternatives.

Bergson's approach to the problem and his defense of free will is targeted against the third conception of determinism and is based on the idea that, thanks to our direct intuition of the continuous flow of our inner experience, we are immediately aware of our freedom. Despite my 'reconstructive' approach, in order to summarize Bergson's philosophical attitude toward the issue of free will, it is necessary to put it in the context of his general philosophical outlook.

In order to go some way toward the achievement of this very ambitious aim in the very small space of a paper, I have decided to rely on a quotation from F.L.

Pogson[5] extracted from his introduction to Bergson's *Time and Free Will* essay, that he translated 1910. "If a man were to inquire of *Nature* the reason of her *creative activity* and if she were willing to give ear and answer, she would say – 'Ask me not, but understand in *silence*, even as I am silent and am not want to speak" (Pogson VIII, in: Bergson 2001, my emphasis). My choice is plausibly justified by the fact that Bergson himself agreed with the translator to use it as a motto summarizing his own philosophy up to 1910, a motto that is an epigraph taken from Plotinus.

My attempt at this point is to try to expand on the key words appearing in the succinct quotation above by discussing them in some more details.

2.1 Nature

First of all, according to Bergson, Nature (with a capital N) is *active:* as such, it is not to be conceived as a Cartesian clockwork composed by corpuscles impacting one another, or as Newtonian particles attracted by forces. Bergson's conception of nature is more similar to Leibniz's, even if the philosophical system constructed by the German philosopher is rather different.[6]

Despite his anti-cartesian conception of nature, Bergson inherited from Descartes a radical dualism between matter and mind, mirrored by his epistemic dualism between the two faculties of *intellect* and *intuition*. The *intellect* is a faculty that is essential for the effectiveness of our action in the material world because it is capable to separate and distinguish the objects in space and to fix in time the continuous, unified and temporal flux *intuited* by our consciousness (see also Russell 1914, 6). It must be kept in mind that, according to Bergson, it is this experienced continuity (of which we are immediately certain) that prevents an application of the concept of causality to our mental states.

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5 In this paper I will follow Pogson's 1913 translation of the original text, as it has been checked by Bergson himself (Bergson 2001).

6 According to Leibniz, reality is composed of unextended, active centers of energy (monads), only part of which are conscious. Bergson's spiritualism has been much more influenced by the 19th century advances in psychology and the neurocognitive sciences, but a deep analogy between the two philosophers is given by the fact that also *our* experience of duration, like any Leibnizian monad, only reflects part of realty, that according to Bergson consists of absolute duration.

2.2 Creativity and Novelty

The other buzz word, *creativity*, cannot be discussed without making reference to the notion of *élan vital* as it is defined in the *Creative Evolution*, something that here, of course, cannot be done in full. In our context, suffice it to say that the *creative*, active power of Nature stands for the power to generate something *new* that did not exist before and that is unpredictable from the past. In his opinion, this kind of novelty is incompatible both with Darwin's "chance and necessity approach" and with a teleological account of living beings. In fact, Bergson's creative power does not just concern living beings, but penetrates the whole of Nature and therefore pervades also inorganic matter.

With respect to this view, it is indispensable to recall the proximity of Bergson's notion of *duration* to Whitehead's concept of *process*, whose main philosophical outlook was greatly appreciated by the French philosopher,[7] given that the former extended such a concept to all matter, animated and inanimate. A process for Whitehead is something that cannot be crystallized as a change of things in time but is the basis of the identification of the being of the world with its becoming. The moment of becoming is indeterminate, since it is only after the process has taken place that can we regard it as a fact and therefore as subject to causation. Clearly, the perception of an event that is happening in the present can be fully described only after the event has taken place, but according to Bergson it can be made sense of only when the whole constellation of memories that is related to it emerges to our mind, or only *post factum* so to speak.

Three main remarks must be pointed out at this stage, in particular *vis à vis* the role of the past in Bergon's notion of creativity.

(1) The first point involves the psychic experience of a growing past and its ontological correlate. Given his idea that each present experience *P* occurring at a time t_1 is pregnant with a growing past, *P* is different from any other experience, past or future. The reason is that *P* also contains the immediate, continuously flowing memory of all past experiences: our past experiences affect the way we live the present ones. In addition, remembering the past, as Primo Levi also had it (1969), is not a *passive* but a *creative* act, given that the *content* of the present, unique recollection *R* of a past event *E* is constantly influenced by whatever has been experienced *after* the direct experience of E and before *R*.[8]

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7 For a comparison of Bergson's metaphysics with Whitehead's philosophy, I am greatly indebted to one of the two referees, whose suggestions have been extensively used in the following lines.

8 A contemporary explanation in scientific terms of this essential phenomenon is given in Edelman (1980).

The same destiny occurs to *R* after its occurrence, so that our memory of *E* is always different. The key difference between spatial and temporal experience is well expressed by the following passage:

> Our experience of duration is unlike the quantitative homogeneity presupposed by the concept of space: things in space can be counted because they are external one to the other in a homogenous medium. On the contrary, our immediate experience of time (duration) is heterogeneous because each immediately given data is always different and yet is unified by an act of 'unification of disparate content': 'several conscious states are organized into a whole, permeate one another, [and] gradually gain a richer content' (Bergson 2001, 122).

This constantly changing interpenetration of different temporal experience makes time wholly different from the multiplicity of objects in space and is what Bergson calls *duration*; the richer content of our experience of time is due to the above-mentioned role of memory, extending more or less in the past (immediate, closer or more remote). Counting objects on the contrary, presupposes time (as in Kant) but the activity of counting is possible only because each counted object is *external* to any other.

On the contrary, we cannot "count" the different temporal experiences in succession: Bergson's "organization in the whole of several conscious states" points to the well-known fact that *a succession of experience is not an experience of succession*. The latter is a synthetic act. In order to gain a deeper understanding of what Bergson calls "unification of disparate content" one can refer to contemporary phenomenological discussions about the extendedness of the experienced present, the so-called "Specious Present", a term coined by Clay (1882) and then further articulated by the American psychologist and philosopher William James (1890) and many others after him. Our experience of music is often used to illustrate conceptions that are similar to Bergson's holistic approach to temporal experience (see for example Husserl 1990): when we hear a succession of a few notes forming a melody, we unify in a single, simultaneous experience what is temporally successive (the single notes). Contemporary discussions[9] about the psychology of our temporal experience are therefore highly indebted to Bergson's seminal intuitions.

Even though Bergson does not go so far as to imply that the psychic novelty of the contents of our mental acts depends on what we would call today a "Growing Block Model Of Reality", I daresay that he would not be, at least *prima facie*, wholly unsympathetic with such a metaphysical underpinning of our subjective

9 For a review of the empirical literature on the nature of our present experience, see, among others, Dorato and Wittmann (2019).

experience of accumulations of memories. The so-called "Growing Block View of Reality", originally formulated by Broad (1923), claims that there is literally nothing after the present moment (the future so to speak is "empty"), while the present is the moment in which new elements of reality that did not previously exist become actual. What has become present remains forever part of reality, since it must be presupposed to explain the incessant creative power of Nature.[10]

There is an obvious reason to associate the Growing Block metaphysics to Bergson's view of time. In fact, it would explain our experience of an always richer temporal experience, given by the *accumulation* of memories with the constant change of future events becoming real in the present. The constant increase of our memories corresponds to, and can explained by, a continuous "accumulation" of real facts or events in the world. It is interesting to note that a metaphysical model according to which, as is typical our understanding of our life, each passing day is closer to the moment of our death, and more and more remote to the moment of our birth, would contradict Bergson's view, since in this "erosionist" model, the past would become less and less real.[11]

In his *Introduction to metaphysics*, these intuitions are expressed by Bergson with the metaphor of the two spools "with a tape running between them, one spool unwinding the tape, the other winding it up" (see Lawlor and Moulard 2020).

(2) The second remark anticipated at p. 68 is the fact that Bergson rejected any Darwinian explanation of the origin of *new* species: as such, his natural philosophy runs counter to what today (and to a lesser extent also at his times) is a *very well-confirmed scientific theory*. To the extent that a naturalistic metaphysics requires that metaphysical hypotheses should at least be logically consistent with the results of our best scientific theories, Bergson's metaphysical view should be rejected, based as it is on an anthropomorphic view of life, according to which "life, from its origin, it is the continuation of one and the same impetus, divided into divergent lines of evolution" (Bergson 1911, 61).
Interestingly, his major objection against Darwin's idea of natural selection is frequently voiced also today by contemporary creationists: it is impossible to explain the complexity and the teleological features of living beings by introducing what he calls a "mechanistic hypothesis". The mechanistic hypothesis that he is referring to corresponds to Darwin's natural selection acting on variations due to contingency and chance: "What likelihood is there that, by two entirely different

10 I owe the idea to explain Bergson's thesis of novelty with this metaphysical view to Simone Gozzano, with whom I discussed it at some length.
11 See Casati and Torrengo (2011); Norton (2015).

series of accidents being added together, two entirely different evolutions will arrive at *similar results?*" (Bergson, 1911, 63–64, my emphasis). As in *Duration and Simultaneity—vis à vis* the twin paradox and the special theory of Relativity—also in this case his criticism to Darwinism is based on a serious misunderstanding, according to which "two divergent branches of evolution converge to the same point" (Bergson, 1911, 63–64).

This is not what happens in the evolution of species as it was described by Darwin and as we know it today: the divergence of traits does not imply convergence as Bergson has it, but rather more divergence. Supposing that Bergson had read Darwin's main book (he quotes from it), in his understanding of Darwinism he neglects completely the fact that natural selection, acting differentially on the constantly changing DNA of the various species, favor those that are capable of reproduction by giving birth to more descendants. In Bergson's instead, the creative evolution of life works against inert matter by promoting complexity.

In a word, according to Bergson, Darwin's mechanistic explanation is not sufficient to explain the origin of novelty in nature, which depends on a vital impetus (*élan vital*) that overcomes the resistance of inert matter, a hypothesis which to a contemporary reader remains completely unexplained.

However, according to Bergson, neither Darwinian mechanicism *nor* a mere teleological approach to evolution would ensure the kind of novelty that he is after, since also within the latter approach the whole (the *telos*) would already be given at the beginning, as in a foetus.

The doctrine of teleology, in its extreme form, as we find it in Leibniz for example, implies that things and beings merely realize a previously arranged program. *However, according to Bergson, "if there is nothing unforeseen, no invention or creation in the universe, time is useless again.* As in the mechanistic hypothesis, here again it is supposed that all is in advance. Finalism, thus understood is only inverted mechanism" (Bergson 1911, 45, my emphasis).

From this passage, it is clear that Bergson identified the "creative power" of nature producing novelties with the *unforeseen* or the *contingent*, which takes us to our third remark.

(3) The third way of understanding the notion of creativity comes from the opposition between determinism and indeterminism. In this third sense, which is the most important for the purpose of this paper, according to Bergson *novelty requires the failure of determinism* (see the sentence italicized above). Parentetically, Bergson had received an excellent mathematical education, and he was certainly aware of the locus classical of the definition of determinism given by Laplace in his 1820's *Treatise on Probability:*

> We ought to regard the present state of the universe as the effect of its antecedent state and as the cause of the state that is to follow. An intelligence knowing all the forces acting in nature at a given instant, as well as the momentary positions of all things in the universe, would be able to comprehend in one single formula the motions of the largest bodies as well as the lightest atoms in the world, provided that its intellect were sufficiently powerful to subject all data to analysis; to it nothing would be uncertain, the future as well as the past would be present to its eyes (quoted in Nagel 1961, 282–283).[12]

It is often but incorrectly alleged that determinism is incompatible with true novelty in the universe: in this case, we are told with a misleading metaphor that the whole temporal evolution of the world would be "contained" in the initial conditions.[13] But note that this would be true only if determinism amounted to the *epistemic* notion of predictability as in Laplace's passage above endorsed also by Bergson (see note 12). But this is not the case, as deterministic chaos abundantly shows. Within chaotic phenomena, the evolution of a system is dictated by a *deterministic* equation, but its evolution soon becomes unpredictable, where the "soon" in question depends on the system one is considering.[14] It is only if predictability implied a complete information about the initial state of the universe (an impossible ideal) that could we claim with some reason that (1) in deterministic models of the universe the present and the future are all (epistemically/informationally) "contained" in the past so that (2) no creative power or novelty can be attributed to nature.

In other words, unpredictability is not sufficient to defend free will, since also within the Growing Block—in which future events don't exist unrestrictedly[15]—we have both complete novelty and at the same time a deterministic though thoroughly unpredictable evolution of physical systems. On the other hand, the block view of the universe, which is closed to *novelties* regarded as coming into being, *is compatible with indeterminism.* Since my third interpretation of Bergson's view of the creative power of Nature is grounded in the text, we must conclude that one cannot defend the view that novelty is guaranteed by unpredictability. And yet, many followers of Bergson, after the quantum revolutions,

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12 Here is Bergson's very similar reinstatement of Laplace's passage: "A superhuman intellect could calculate, for any moment of time, the position of any point of the system in space. And as there is nothing more in the form of the whole than the arrangement of its parts, the future forms of the system are theoretically visible in its present configuration" (Bergson 1911, 11).

13 As we have seen, *mutatis mutandis* for Bergson the same claim holds for a teleological account of life.

14 See Ruelle (1991).

15 See Mozersky (2011) for the meaning of unrestricted quantification; for instance, the current pandemic, in year 2018 was not existing and yet the universe could be in principle deterministic.

argued incorrectly that the new Quantum Mechanics, allegedly introducing indeterminism in nature[16], was a confirmation of Bergson's philosophy of nature.

One of the founding fathers of the theory, Louis De Broglie argued that "if Bergson could have studied quantum theory in detail … he could doubtless have repeated, as in *The Creative Mind*, that 'time is this very Hesitation or it is nothing'" (De Broglie 1941, quoted in Canales 2015, 235). De Broglie clearly identifies the *hesitation* of the quantum system before measurement with the unreducible chance that the experimental apparatus reveals when the state of the system is not in a eigenstate of the observable. Keeping in mind that causal knowledge corresponds in the language of the first two decades of the last century to *Kausalgesetz* or determinism, Canales tells us that the (alleged) attacks on causal knowledge due to Quantum Mechanics was regarded as consonant to Bergsonism by authoritative journals of philosophy. There is even a conversation that has been reported according to which Bergson would have said "that which is funniest [*drôle*], is that physicists have come back to find liberty!" (Mondor 1957, 69).

The illegitimate and superficial identification of Heisenberg's principle of indeterminacy relations with a failure of causation (determinism) depends on the fact that the formulation of determinism needs at the same time a definite and simultaneous specification of position and momentum of a particle, a fact that in Quantum Mechanics cannot be achieved since position and momentum are conjugate variables and cannot be measured by the same apparatus at the same time. But this principle does not entail that the theory is indeterministic; in fact, widely discussed and exact deterministic formulations of Quantum Mechanics (like that offered by Bohmian mechanics) assume that the quantum probabilities are epistemic.[17] Furthermore, from a more rigorous philosophical perspective, indeterminism, if regarded as imposing a branching structure to time—in which a unique past diverges into many possible futures, all compatible with the same past—cannot be regarded as a sufficient condition for a free choice in as in libertarian philosophical frameworks. Consequently, the role of chance in any human deliberation must be discussed less superficially: deciding what we ought to do by throwing a "quantum coin" cannot the paradigm of a rational choice. And for the compatibilists, indeterminism is not a solution to the problem of the freedom of the will: one needs additional arguments to reject

16 Caution is needed because alternative formulations of quantum theory, like Bohmian mechanics, are fully deterministic. See Goldstein (2017).
17 See Goldstein (2017).

the compatibilist view, according to which our will is free when it is unconstrained, even if determined by previous desires.

In a word, if (a) the creating power of nature in Bergson's sense consists in the fact that its temporal evolution produces unpredictable elements and if (b) freedom consists in this unpredictability, this third sense of novelty is as implausible as the second, which engages a desperate fight against Darwin's explanation of the evolution of species. For this reason, a plausible interpretation of the creative power of nature is given, rather, by a metaphysics of a Growing Block, which *might* explain why Bergson identified novelty and freedom: each act of our consciousness is free because, even on determinism, it is different from the previous ones despite the similarity of the circumstances of choice, and reality can be regarded at least in part as brought about by our intentions and actions. I will now try to connect this conception of freedom to some key passages in the *Essai sur les données immédiates de la conscience*.

3 Freedom in Time and Free Will

In the third chapter of the book *Time and Free Will* Bergson analyses very carefully the problem of determinism, regarded both from the physical and the psychological perspective. In the physical realm, the principle of conservation of energy, acting on corpuscles subjects to the law of attraction and repulsion is assumed for the sake of the argument (Bergson 2001, 145). But Bergson decidedly questions its appropriateness for a psychological kind of determinism, since this thesis depends on the possibility of considering our psychical states as invariably correlated to physiological states.

Before discussing the positive side of his conception of free will, we must stress his opposition to the claim that the principle of the conservation of energy—which became central in physiochemical phenomena after the rapid development of thermal physics[18]—also applies to living beings. There might be a special kind of energy in the latter entities, due to the fact that, unlike what happens in inert matter, *there cannot be a return to an initial state (except in intervals ot time exceeding the age of the universe, see also below)*. The inapplicability to living beings of the conservation of energy and therefore, on Bergson's view, to determinism as he sees it,[19] depends on the irreversibility of the development of

18 Suffice to remind the reader of the two famous principles of thermodynamics stated by the German physicist Rudolf Klausius "The energy of the world remains constant. The entropy of the world tends to a maximum." (Klausius 1867, 400).

19 To a contemporary reader, this identification is dubious to say the least.

living beings and in particular of *conscious* beings. Therefore, it depends on the different role played by *time* in inert matter and in our consciousness: "inert matter does not seem to perdure or to take any trace of past time" (Bergson 2011, 153). There is no real change in inertial matter, which seems to remain "in an eternal present" (Bergson 2011, 153), but in the case of conscious beings the duration or the extension of a past sensation in the present one implies a certain kind of *gain:* the past is always real for any state of consciousness, because any present sensation is affected by all of our past experience in the way sketched above.

The connection of free will with time should now be clear. In a nutshell, Bergson equates determinism with the principle of conservation of energy, and this principle in its turn with the (controversial)[20] idea that physical time is fundamentally reversible (Albert 2010). Since there can never be a conscious state that repeats itself (each is pregnant with a different past), the principle of conservation of energy, and therefore determinism, according to Bergson, *does not apply to conscious states*. Before proceeding, it should be pointed out that Bergson's argument is rather weak. He is certainly on target when he considers the principle of conservation of energy to be one of the strongest arguments in favor of psychophysical parallelism or even (though he does not consider this possibility) of an identity theory of mind and brain. However, also in physics macroscopic time *is* irreversible, and the ubiquity of the growth of entropy must be explained in terms of time symmetric mechanical laws and initial conditions (presumably of the universe), in such a way that the entropy of a closed system never decreases. The return to the initial state, guaranteed by Poincaré's recurrence theorem (Sklar 1993), requires a time that is longer than the age of the universe! *Practically, there is no difference between physical and psychological time as far as irreversibility is concerned*.

Furthermore, there are some physical processes, called non-Markovian, that do "keep trace" of the past, unlike Markovian process, which have no memory of the past since their probability depends only on the previous states. Bergson is right on target when he stresses that in living beings the past is much more important in determining their present and future states, but also the Earth, unlike an electron, keeps traces of its remote past, and the difference between conscious states and 'inert matter' in this respect could be regarded as one of *degree*.

Bergson continues his defense of free will by pointing out that there are *two* kinds of time —a theme that will return later in his debate with Einstein in *Duration and simultaneity* (1965). One is the abstract time presupposed by mathe-

20 Some processes regarding muons in radioactive decay show a failure of temporal invariance (Horwich 1987).

matics and physics, the other is the internal time of consciousness, which is pure duration (*durée*).[21] One of the lasting contributions of Bergson's philosophy lies in his deep reflections on the conflict between these two notions of time: this question is still at the center of the contemporary philosophical debates on the nature of time. Bergson argues that, since many philosophers too often intermingle and confuse these two kinds of time, they come to think that also conscious states are subject to physical time. This is the main reason why they don't regard our actions as free: abstract time is presupposed by the study of inert matter, where determinism reigns with no limitations.

The fundamental argument that Bergson puts forth to defend our free will is his justified attack on associationist philosophy of mind, where the self is regarded (on the wake of Hume and Mill) as a mere collection of ideas and emotions, each of which is separated and external one to the other in a homogenous medium. In our internal life, on the contrary, Bergson correctly points out that conscious states "penetrate and melt one another, each tinged with the colouring of all the others" (Bergson 2001, 165). This implies that each of us loves and hates in *different* ways (Bergson 2001, 165), according to our different character, since each of us has had a different set of experiences, each of which reflects holistically all the others we had in the past like a monad reflects the universe. According to Bergson, the fact that our selves are singular and unrepeatable is another argument in favor of the fact that we possess a free will since, not only is the development of the self *unpredictable* and *novel*, but it is also characterized by *duration*, i.e., the permanence and fusion of all the relevant, remembered conscious states constituting a temporal experience. And once more, the link between time and free will emerges: abstract time goes together with associationism, which in its turn implies psychological determinism, while duration implies a duration in the present of all *past* conscious states of a person. In Bergson's view, a radically holistic conception of selfhood guarantees our free will since someone's personality is not given by the sum of her conscious state "but is present in each of them. And the outward manifestation of this inner state is what we call a free action, since the self alone will be the author of it, and since it expresses the whole of the self" (Bergson 2001, 165–66).

A reconstruction of this argument might go like this. If one acts upon a single detached desire or reason, the corresponding act will not express the *whole* personality of the doer, since on deterministic associationism, the self is frag-

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21 It is ironic, even if not significant from a conceptual viewpoint to remark that in the *Scholium* to the *Principia Mathematica* Newton referred to absolute time, flowing equably, as *duratio* (duration)!

mented into a detached series of conscious states, each of which is the deterministic *cause* of the next, and the personality results from the sum of causes and effects, each of which detached from the other. A deterministic action, in Bergson's view, would not express 'the whole of the self''s past—and therefore one's entire personality—but, at any present moment of her life, only the content of the present experience, caused by immediately previous ones.

In contemporary terms, and stretching somewhat my hermeneutic/reconstructive approach, some such actions might even be regarded as the deeds of an addictive person, a wanton—who is incapable of postponing the satisfaction of her current desire (Frankfurt 1982)—and therefore as the actions of a person who discounts the future and does not act in virtue of an intention that integrates her whole life. The free actions are those in which the present state of mind takes into account *the imagined future and the remembered past of the self*, in such a way that an attitude that has been appropriately called *temporal neutrality is not violated.*[22] For this reason, Bergson claims, if each conscious state is, thanks to its duration, inextricably entangled with all the others, the action will express the *personality* of the doer, her global, holistic self, and will therefore, in a very plausible sense, be *free*. In a word, according to Bergson *freedom is self-expression, and therefore basically autonomy:* the unconscious determination of our will should be compared to hypnosis, a phenomenon that later interested also Freud.

Actions done under hypnosis are paradigmatic examples of heteronomous determinations of our will, which, in Bergson's unfair rendering of determinism, exemplify a will guided by external forces. The rendering is unfair because also in compatibilist conceptions of free will, determinism is compatible with the claim that our will is free because we can do what we want, where the "we" refers to our will when it is not determined by external factors like hypnotic states, threats, and impediments of this kind. One could claim that also on compatibilism, determined motives of our actions are the expression of our personality, a claim that, *pace* Bergson, could be jeopardized only by the introduction of some form of *chance* or indeterminism separating the past from the future.

It is extremely important to stress the fact that Bergson correctly rejects the implausible idea that we enjoy an *absolute* form of freedom. In almost all actions of our life, we are guided by a sort of memory that today we would call *procedural*, the kind of automatic memory that is involved when we ride a bike or wash our hands. In these actions, there is no expression of the self and an association-

22 See Brink (2011).

ist/deterministic description of the relevant action is appropriate: Bergson correctly likens them to "reflex acts" (Bergson 2001, 168).

In these actions, language plays a social role that, however, crystallizes our deepest self. In most of our waking hours, the means-to-end actions, in which what he calls the intellect plays a very important, indispensable practical role, the self does not emerge but remains at the surface. If I can interpret rather freely Bergson's point (but possibly not too unfaithfully to his explicit intentions) the rare but free actions are, instead, those in which "we form ourselves", to put it with Kane (2005, 130), who refers to these as *self-forming actions*. Similarly, Balaguer (2010) refers to "torn decisions" as those in which our free is particularly manifest. Since these actions fully reflect our past selves in a holistic way, they also shape the type of person that we will become in the future. In Bergson's language, a really free action expresses the whole enduring self, its past, its present and its future, in a word, its *duration*. It is appropriate to summarize what I just wrote with the following quotation, resembling Kane's conception of a free action. "It is at the great and solemn crisis, decisive of our reputation with others, and yet more with ourselves, that we choose in defiance of what is conventionally called a motive, and this absence of any tangible reason is the more striking the deeper our freedom goes" (Kane 2005, 130).

My brief synopsis of Bergson's understanding of the relation between time and free will would not be complete if I omitted to mention that the essential difference between time and space that he defends also serves to explain his criticism to the principle of alternative possibility (Van Inwagen 1986), on which almost every contemporary discussion on free will is based. Notably, in Bergson's opinion the branching time structure (one of the possible interpretations of his idea of novelty, see above) is inappropriate to defend or attack indeterminism or determinism. A branching, non-linear structure of time is a geometrical representation of a decision process that for Bergson essentially involves time and not space, because it is based on the becoming of the self and of the totality of reality.

Fig. 1: At the bifurcation point, the free decision "brings" the history of the self to the "right".

The defender of libertarian conceptions argues that we *could have done otherwise* given the same past because *the path* (symbolizing the course of action we are about to take as in Fig. 1) "is not already taken, therefore it may take any direction whatever" (Bergson 2001, 182)[23] but then he continues "it is not possible to speak of a path till the action is performed. But then it will have been traced out" (Bergson 2001, 182). In fact, he continues, "before the path was traced out there was no direction either possible or impossible, for the very simple reason that it could not have been a question of a path" (Bergson 2001, 182). This reasoning is grounded on the presupposition that the principle of alternative possibility is based on a spatialization of time: in this case, the attempt to represent it with a fork (a path, see Fig. 1 above, where the bolded, thicker path is the one actually taken by the world, and the other path remains a possibility). But freedom is pure duration, becoming, so it cannot be crystallized by representing it with a spatial, symbolic graph. The idea here is that any symbolic representation involving space, the metaphor of the fork, is static, and then incapable of rendering the change in our conscious states in which becoming consists. Even "the moving now conception of time" (Skow 2015) would render only metaphorically the idea of the seamless change of the enduring self. On the contrary, the metaphysics of the Growing Block explains the accumulation of our memories and therefore, given Bergson's view of temporal experience the fact that to bring into being a previously non existing path and therefore a non existing reality.

One can accept his conception of selfhood and at the same time point out that his reasoning in the quoted passage is wrong. The evaluation of the future contingent certainly lies at the point of bifurcation, but even *after* a certain path has been taken, it makes sense to claim, counterfactually, that if the evolution of the world had been governed by indeterministic laws, the future could have been different without presupposing any change in the past state of the universe. In deterministic models, on the contrary, we could have done differently if the past had been different, so that the difference between deterministic/linear models and indeterministic/branching models remains even if the future is "empty".

4 Bergson's Criticism of Language as an Instrument to Grasp Becoming

In various passage of time and free will, Bergson points out that language, with its cataloguing function typical of juxtaposition in space of different *things*, has an extremely important practical role but is incapable of grasping the property that each enduring conscious state has to reflect throughout time the whole personality of a human being. We refer to love and hatred as if two different human

23 Here Bergson reproduces almost exactly the libertarian conception of free will.

beings had the same feelings, which lead us to suppose that they are in the same mental state. Language must generalize via *universals* that, however, are not apt to grasp the *uniqueness* of an individual, which is a necessary and sufficient condition for her autonomy.

Pure duration escapes the limitation of language. This is the main reason why, in the opening quotation of the paper (Pogson's), silence is recommended as the best way to understand the creative power of nature, which manifests itself at the highest degree in our consciousness. *It is intuition, our direct awareness of our inner states that leads us to decide one course of action rather than another.* The intellect's only function is to calculate the consequences of our choice. However, this produces another drawback of Bergson's conception of a free choice. He says that looking back at an important decision, we have the impression that *we acted without a reason* (Bergson 2001, 170). He is led (if not forced) to defend this claim because he wants to leave room to our intuition and not just to the *calculating*, *spatializing* intellect. And, paradoxically, he claims that the more an action is without a reason, the more is free:

> we wish to know why we have made up our mind, and we find that we have decided without any reason, and perhaps against every reason. But in certain cases this is best of reasons. For the action which has been performed does not then express some superficial idea, almost external to ourselves, distinct and easy to account for, but agrees with our most intimated feeling, thoughts and aspirations, with that conception of life which is equivalent to all our past experience (Bergson 2001, 170).

The obvious objection is why a conception of life that reflect all our past experiences should not be a conscious reason motivating us to choose one path rather than another. If the process that leads us to decide one *path* rather than another is hidden from us, it cannot be based on feelings, because typically we are aware of the feelings or emotions that move us to self-forming actions expressing our past. Furthermore, the opposition between feelings and reason is not supported by the contemporary neurophysiological research:[24] without emotions or feelings no decision could be reached.

However, in order to be more charitable to Bergson's view, which should not be saddled with anachronistic considerations coming from contemporary discoveries but only with his own conceptual unclarities—this was after all the methodological assumption of this paper (see the introduction)—and in order to go some way toward justifying his position on the role of reasons in self-forming decisions of our life, we should consider that he intended *reason* in a very limited

24 See Damasio (1994) among others.

sense, as a *momentary* cause of our action, which is called into play by the practical needs of our daily life. With this caveat in mind, we can agree with Bergson's claim that the really important decisions in our life are not due to momentary inclinations, but are expression of our whole selves regarded as enduring "entities". No duration of the selves, no self-forming decisions. However, it remains to be shown why this sort of decisions are free, in the sense that they are *not* an expression of some form of causal determinism encompassing a complex series of previous experiences. The fact that a temporally holistic conception of the self allows us to claim that the decision is a deep expression of the values of the individual person is not sufficient to claim that the motivation to follow one path rather than another is not fixed by previous events.

A final word on Pogson's reference to "our silence and Nature's *silence*" contained in the quotation above. Silence is necessary for the liberation of the self from the practical needs of our daily life based on our intellect that classifies objects on which we must act. Behind language there is *space*, the outer world, and therefore the crystallizing, abstract time of physics. But the true nature of the self is not expressible in words, because if this were possible, we would fragment our conscious states, thereby eliminating their duration in each of our actions. The elimination of this duration entails, as we have seen, a denial of our freedom. The cost to gain freedom is high: Bergson argues in favor of freedom with more or less plausible arguments that are however formulated in linguistic form: language is something we must get rid of in order to perceive the unity of the self with the creative, free power of Nature. So, in a way, this claim reminds us of the early Wittgenstein's approach to philosophy: in the case of Bergson, one must use language in order to show that language is necessary but not sufficient for a free action.

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Paul-Antoine Miquel

Duration and Becoming in Bergson's Metaphysics

Abstract

In this paper, we will insist on four points. First, Bergson's philosophy is a metaphysics of duration, based on a lived experience that is called "intuition". Intuition is a direct experience of the reality as such, because, as duration, the real is not separated from us. Second, intuition is the very "method" of philosophy and Bergson draws a clear distinction between philosophy and science. However, science has also an experience of reality. Bergson's metaphysics follows *a dual* approach of reality based on two perspectives: philosophy and science. Thirdly, metaphysics is the experience of time, but through this experience we are not locked into the world of our subjective consciousness. Four, duration is certainly not simply lived by our consciousness, as a correlate of our subjective intentionality. Such a statement would be a complete misunderstanding of Bergson's philosophy, since duration is also present *as becoming*, into the material universe. To be more explicit, duration is not simply a psychological human property, it is also a cosmic one.*

Introduction

In this paper, we will insist on four points. First, Bergson's philosophy is a metaphysics of duration, based on a lived experience that is called "intuition" (Bergson 1946, 32–33). Metaphysics cannot be pure speculation. It means that, contrary to Kant's philosophy, we can have a direct experience of the reality as such (*Ding an sich*), because we are considered as an *active* part of it, and not simply hierarchically *included* in it. The world is also our world, the real is also our lived participation to the reality. As duration, the real is not separated from us, as some kind of first unmoved engine, or some kind of absent divinity.

Second, intuition is the very "method" of philosophy (Bergson 1946, 32; Deleuze 1968), and Bergson draws a clear distinction between philosophy and science. However, science has also an experience of reality. When science is not

Note: Special thanks to Elie During, who revised the manuscript.

https://doi.org/10.1515/9783110753707-008

speculating, it moves in the "absolute" of matter (Bergson 1946, 33, 41; Bergson 1922, 201). Bergson's metaphysics (Bergson 1922, 193) follows *a dual* approach of reality based on two perspectives, coming from philosophy *and* from science. Unlike all classical metaphysics from Plato to Heidegger, there is no hierarchical privilege attributed to metaphysics on science.[1]

Thirdly, metaphysics is the experience of time, but through this experience we are not locked into the world of our subjective consciousness. We are also element of the material universe in which our body is included. This experience of inclusion is also an ontological one, meaning that our mind is open to *another world* than the world of consciousness. But this experience of the material world is coming from science, because science is "life looking outward, putting itself outside itself" (Bergson 1922, 170). It cannot be directly described by philosophy.

Four, duration is certainly not simply lived by our consciousness, as some kind of correlate of our subjective intentionality. Such a statement would be a complete misunderstanding of Bergson's philosophy,[2] since duration is also present *as becoming,* into the material universe. To be more explicit, duration is not simply a psychological human property, it is also a cosmic one. "Nevertheless, it is along this thread that is transmitted down to the smallest particle of the world in which we live the duration immanent to the whole of the universe" (Bergson 1922, 11).

Therefore, in order to sympathize with it, intuition must "use ideas as conveyance" (Bergson 1946, 48). Intuition is not able to provide *alone* a metaphysical experience of cosmic duration as becoming. It needs intelligence to do it. Reciprocally, intelligence is not able to read alone by its explanations and theories the intimate nature of the material universe, which will not *only* consist into a Being, because the Being of the universe is nothing but *also* the result of a Becoming.

1 Duration and Space

In *Time and Free Will*, Bergson proposes "to isolate consciousness, from the external world" by a "vigorous effort of abstraction" (Bergson 1910, 90). In order to do this, we must recognize the difference between duration and space. Homogeneous space is already an experience by which consciousness fits with the ma-

1 "In doing this we make a clear distinction between metaphysics and science. But at the same time, we attribute an equal value to both" (Bergson, 1946, 42).
2 See Deleuze (1968); Worms (2006); Miquel (2007); Ansell-Pearson (2018).

terial world. The more consciousness goes outside itself, and the more it will be able to capture external material entities in homogeneous space. However, duration is not space. Adding the present moment to the previous one, as if they were simultaneous entities, is not dealing with these moments, "but with the lasting traces which they seem to have left in space" (Bergson 1910, 79). Thus, any spatial representation of time, can deal with numbers and prediction, but not with the very concept of *succession*. Events are not collections of units, and they cannot be represented in space.

As a second deeper argument, a series of sensations has nothing to do with a series of physical qualities, like position or velocity in mechanics (Bergson 1910, 32–74). Qualities can be distinguished and put in order, so that if the series is reversed, we will get some reverse order of qualities. However, sensations cannot be distinguished and measured, as we distinguish and measure qualities, since they can precisely not be simultaneously compared, as qualities do. Such a comparison requires space.[3] One would counter-argue[4] that it would be possible to put sensations in order by ordinal measurement, even if we do not compare them. But this order will not be characterized as a functional relation external to its relata understood as variables; like for instance the relation: "A is bigger than B" (Russell 1914) or "C is later than D" (McTaggart 1908). A and B sensations would be *interpenetrated* and *organic* entities. As a sensation, the previous sound of a melody is *always here in my consciousness*. *It doesn't disappear* in the present, even if it was also in the past. Thus, if we come back to our "deeper self" (Bergson 1910, 125), if we find duration in succession with *interpenetration* of conscious states, it would be by overcoming in our mind the superficial one, that "retain something of the mutual externality which belongs to their objective causes" (Bergson 1910, 125).

2 Matter and Memory

In Bergson's second book, the analysis of the lived duration must be deepened, by completing the scheme of succession with the image of the cone of memory, a first decisive philosophical invention. The lived memory that in fact inhabits our consciousness also shelters a past that is *co-extensive* (Bergson 1947, 195) with our present, in the sense that precisely it does not *coexist* with it, like two com-

3 See Deppe (2016).
4 See Berthelot (1911).

mensurable segments of the same line.[5] Essentially *virtual*, memory is then that movement by which the past "expands into a present image, thus emerging from obscurity into the light of day" (Bergson 1947, 173). As coextensive, the past is lived in an internal experience, that cannot be reduced to a material one.

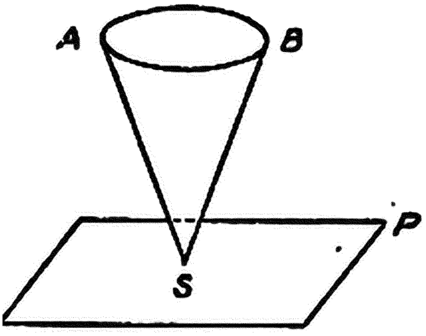

Fig. 1: Bergson's cone of perception in *Matter and Memory*.

However, the difference between actual and virtual, between the present and the past, is not a difference of substance. First of all, there is a difference of degrees between the present and the past, as habit. Second, there is a *difference of nature* between the present and the past as souvenir, meaning that the past is not simply an ancient present. The past grows up in the present, as some coextensive internal dimension of it. Finally, the virtual, as a past, can only be characterized *recursively* from the relationship between the virtual and the actual. The process of consciousness is some kind of creative and virtuous circle.[6] The virtual is a pure difference;[7] it is more than the present, but it doesn't exist without the present, as it is clearly mentioned by the image of the cone SAB, which has simultaneously an actual top S in the plane of images P, and a virtual base AB.

As there is no darkness without light, there is no virtual without actuality. The world of our lived consciousness is closed on itself, by placing its double unconscious otherness *in it: the past, and the present*. The consciousness is closed on the lived co-extensiveness of several layers of the past that are present in the memory as a kind of psychic potential, because it is at the same time open on the present. The opposite of the virtual, the actual is thus also in some way its

5 To be more explicit, the *coexistence* of two commensurable segments is a property of spatialized time, and the *coextension* of the past in the present is a property of internal duration. It means of course, that these two words are not synonymous.

6 See Hwang (2019); Hui (2019).

7 See Deleuze (1968).

contradictory, but it is also its *complementary* through which the virtual differs unceasingly from itself.[8] And this is how it finds its consistency. There is therefore no plane of coextension, without the coexistence of contemporary events/images with *my body* in the plane P. "At S the image of the body is concentrated; and since it belongs to the plane P, this image does but restore and receive actions emanating from all the images of which this plane is composed" (Bergson 1947, 196).

To sum up, in consciousness duration and memory cannot be lived as our own spiritual world, without to be open to the present, as a pure discrepant dimension of duration. This discrepancy (Miquel 2007) is what characterizes the otherness of the virtual, as a fundamental dimension of the temporality of the human mind. Finally, human consciousness appears as a spiritual entity that "*draws from itself more than it has*" (Bergson 1946, 38), because of this internal "difference of nature" (Bergson 1947, 71) between the coextensivity of souvenirs and the coexistence of contemporary images in the present.

3 The Experience of the Universe

The second important consequence is that, in *Matter and Memory*, actuality becomes the characteristic of a present, as a dimension of time.[9] In order to understand this paradoxical point, Bergson introduces three new philosophical statements.

1. Starting from duration, could we ontologically understand what duration is not? The answer is: the negation of consciousness is nothing but matter, as *another dimension of duration*, the dimension of the present. As *my present* connected with *my body*, it means firstly that the present is also a dimension of the human mind. That is why my mind is also material, and not simply spiritual.[10]

2. However, it means also, that *my* present is not only in my mind. As a material dimension of reality, my present is also *included into the* material universe.

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8 See Miquel (2007).

9 To be more explicit and for people that ignore it, in his first book the French philosopher was dualist. He stated that "within our ego, there is succession without externality; outside the ego, in pure space, mutual externality without succession" (Bergson 1910, 109). On the contrary, in *Matter and Memory*, externality, as *concrete extension* is a dimension of duration, the dimension of the present. And reciprocally in *Creative Evolution*, duration is also present *outside of us*, as *élan vital*.

10 To be more explicit, and for people that ignore Bergson's books, it means that in *Matter and Memory*, the French philosopher rejects explicitly classical dualism.

And the *expanded experience* of the presence of my mind, and of my brain into the material universe, is nothing but *pure* perception. By pure perception, consciousness is open to the pure coexistence of images, which cannot fit with the coextensivity of memory. Objects perceived are not only images. For me, they are not only representations, because I believe immediately, that they exist independently of the way I am thinking of them. I see the table here, and I know by some kind of common sense intuition, that this table exists. Why is it so? Because *in my perception*, the table, the tree, and finally the garden, *are images related to themselves*.

As far as the ego is concerned, it does not exist, as such, in my perception. When I perceive, I also perceive my body. And thus, my body is an image in this world of images. But to mean that perception comes from my body and my sense awareness is nothing other than accepting that I perceive material images in the world of images. Through this experience, I do not see the images as correlated with my subjective consciousness. I see, on the contrary, *my perception as an image included in another world*, to which my consciousness is also open. This is an experience of contemporaneity, through which through which *I am going out* the immanent world of the duration lived by my consciousness. More precisely, this new experience means that I see the table, the tree and the garden as being linked to the same objective world of images, and that I see these images as also linked to my body, as a subjective center of action and decision. The ideal perception is nothing more than the pure limit between these two perspectives: the world of images in relation to themselves, and the world of images in biological relation to my body and my consciousness.

Finally, to understand the contemporaneity of the material world, I must let both perspectives emerge in my mind. I cannot remain a prisoner of a subjective point of view, since by my perception I see things "in themselves" (Bergson 1947, 59). Such an assertion comes from the fact that contemporaneity, as the coexistence of material images, is another dimension of duration, *already present in my mind:* the dimension of the present. There is no duration without actuality, and therefore I have no experience of duration lived by my consciousness without at the same time experiencing what is outside my consciousness and uncorrelated with it,[11] namely the experience of my body, and then that of the relationship between my body and the other bodies of the universe. This *enlarged* experience shows the locality of our temporal consciousness in the whole universe.

3. The third crucial statement is that prolongation of pure perception is nothing but science, as already explained by Bergson in *Matter and Memory:*

11 See also During 2018, 422.

> Now no philosophical doctrine denies that the same images can enter at the same time into two distinct systems, one belonging to science, wherein each image, related only to itself, possesses an absolute value; and the other, the world of consciousness, wherein all the images depend on a central image, our body, the variations of which they follow. The question raised between realism and idealism then becomes quite clear: what are the relations which these two systems of images maintain with each other? And it is easy to see that subjective idealism consists in deriving the first system from the second, materialistic realism in deriving the second from the first (Bergson 1947, 13–14).

Science gives a true and more developed experience of contemporaneity, because *a point of view* of the universe as a system of images emerges in scientific explanation, by experiences, measurement and laws. There is no scientific explanation without that our mind would refer to something external to it, without that it could be open to another perspective than the perspective of our mind. In this system of images, every change is correlated with another material change. It is not immediately correlated with a subjective change from the point of view of my consciousness. On the contrary, from the point of view of science, my consciousness appears in its solidarity with my brain, with my nervous system that are parts of the material universe (Bergson 1947, 9; 31; 52). Thus, the coexistence of images has a metaphysical meaning. *It is not nothing*. The coexistence of material images is not the suppression of reality, it is not a deficient cause. The coexistence of images is *the substitution* of a dimension of reality by another.

In this new experience of reality, what changes depends on invariant principles, as in any classical physical theory, and truth comes from intelligence, geometric proof, experimental tools. Truth comes from the crystallization of the present in mathematical space. According to Bergson, an experience of contemporaneity of this kind emerges in every scientific theory. Such an experience is not simply a subjective representation of the material universe. Rather, it comes from the intuition that we are included in the material universe as a set of images that exists as such. Consequently, the fact that every scientific theory *refers to something* takes the form of an ontological commitment by which consciousness is able to go beyond itself. This is why science is thinking and touching the reality, unlike in Heidegger's phenomenological ontology (Heidegger 2001). Science has an absolute view of matter, it has an experience of what it is *as such*, and not simply of its manifestations (Bergson 1946, 45; Bergson 1922, 191). Science is also able *to stay in touch* with the materiality of our perceptions, and with the relations between our perceptions and the central nervous system in our brain.

4 Duration in the Universe

1. However, while scientific explanation does focus on the contemporaneity of the material universe, it cannot be reduced to space, symmetries and invariant structures. The way Bergson understands the difference between *space* and *concrete extension*, in *Matter and Memory*, could be compared with the difference between the concept of "Presentational Immediacy" understood as a "continuum" (Whitehead 1929, 69 – 82) in Whitehead's metaphysics, and the concept of "common world" (Whitehead 1929, 148).

A continuum is a potential, "whereas actuality is incurably atomic" (Whitehead 1929, 61). Therefore, like space is not matter in Bergson's philosophy, Presentational Immediacy is not contemporaneity, in Whitehead's philosophy. Contemporaneity deals with causal independence of actual entities (Whitehead 1929, 61), which means that they cannot coexist simultaneously in the common world, even if every actual entity is also an element in the constitution of other actual entities (Whitehead 1929, 48), thanks to the principle of relativity (Whitehead 1929, 148). They cannot coexist simultaneously, because each actual entity *prehends* the other ones as a *datum*, from its own local perspective, that is why there is no global objective *prehension* of *every* actual entity, and that is why the universe is nothing but a process, in which God itself is included, as an actual entity (Whitehead 1929, 88). As Whitehead says, "every actual entity, in virtue of its novelty, transcends its universe, God included" (Whitehead 1929, 94).

According to Bergson, space is only the homogeneous crystallization of this contemporaneity by intelligence. Contemporaneity is actuality. But actuality is not pure nothingness, and it is not timeless. If virtuality is otherness, if virtuality is the lived, recursive and creative return of the past into the present, through which the process of consciousness loops upon itself, contemporaneity must be understood as *what is other than otherness*. This statement has a very important consequence: it is not possible to reduce contemporaneity to identity and invariance. Identity and invariance are the vision of contemporaneity that emerges from classical scientific theories.[12] But *true contemporaneity is coexistence and repetition*, because in Bergson's metaphysics, *becoming is not a variety of being.* Being is much more a variety of becoming. Would it be possible to show *by a philosophical analysis of scientific explanation*, that true contemporaneity, as coexistence and repetition, is a variety of becoming, and not simply a variety of being?

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12 More particularly in classical physical theories, like mechanics; and of course, not in biology of evolution or in paleontology.

In coexistence first, *actuality* and invariance deal with *continuity*, and second continuity gets a physical cosmic dimension that cannot be fully reduced to a formal and a geometrical one. This way of thinking is already based on the analysis of motion in classical mechanics. Every motion is divisible into earlier and earlier sections, but *the act of moving* cannot be the result of a division. It can be approximated by infinite calculus, but a geometrical line is not able to make any move! This is the true lesson of Zeno paradox. In electromagnetism, there is continuity, without any objects, entity or atom. It is a continuity which is not obeying to the principle of impenetrability of matter, because of the *principle of superposition* used in wave mechanics. That is why Bergson insists on Faraday and Maxwell, and that is why he substitutes the concept of "concrete extension" (Bergson 1947, 244) to the concept of "extension" (*étendue*).

Let's insist to a provisional conclusion, before to go further. Materialism and physicalism are not precise, when these philosophical doctrines try to understand matter, as if it could be *independent* of duration. Focusing on one famous controversy, this is exactly why no possible debate could occur between Einstein and Bergson. Relativity theory is based on strong structural invariants, like every classical physical theory. But in Relativity theory the notion of contemporaneity is much more complex that it seems to be, at first glance[13] because the remote action is denied. Every action is a local one, thanks to the choice of the speed of light as an invariant principle. Furthermore, as remarkably emphasized by Einstein itself,[14] the vision of contemporaneity in Relativity theory is certainly not compatible with the vision of contemporaneity in Quantum Mechanics. In Quantum Mechanics, continuity and coexistence are managed by the complex relation between *superposition* and *measurement* that introduces the collapse of the wave function.

Finally, the relation between coexistence and continuity stays a very serious problem in science, which is differently declined in each scientific theory. It certainly explains why unlike Einstein, de Broglie (1941) sympathized with Bergson's views.

2. Second, the intimate structure of the present is not simply contemporaneity. It is also repetition, which deals not only with differential calculus, but also

13 See During (2014); During (2018). "Si l'on renonce à la physique des actions à distance pour s'en tenir aux actions locales (par contact), et si la propagation des effets de proche en proche ne peut avoir lieu qu'à vitesse finie, il est clair en effet que toute connexion prend du temps : le principe de localité se prolonge en principe d'action retardée. Mais cela signifie aussi que tout ne peut être connecté à tout. Cette intuition simple débouche sur une transformation sans précédent de la forme du nexus causal" (During 2018, 422).

14 See Einstein, Podolsky and Rosen (1935).

with statistic and probabilities. Repetition is identity as the coming back of the same, identity *as a result of a becoming,* and not as the characterization of a being: "to be in the present and in a present which is always beginning again, —this is the fundamental law of matter: herein consists necessity" (Bergson 1947, 279). Repetition is conceived by Bergson as *interrupted tension*. The more the past is similar to the present, the more this similarity will return, as in some kind of passive and sleeping memory (Bergson 1896, 247). Thus, repetition introduces a tendency into matter. The same future is coming *recursively* in the present, like when we throw a coin again and again on the table. The more we throw it, and the best the same distribution of probability is checked, *up to a maximum*. In *Creative Evolution*, this hypothesis permitted to define entropy as a fundamental law of matter. It also explained why Bergson quoted Boltzmann in his third chapter (Bergson 1922, 258). Following Boltzmann's H theorem, provided that a law of partition could be defined, the expansion of a monoatomic gas in a closed container would be planned, and the maximization of entropy would be nothing but the *attractor* of the dynamics of this closed system.

This vision of the same future that keeps coming back introduces a break in temporal symmetry: the future will not be as the present was, and we cannot statistically come back from the future to the present, as we went from the present to the future. Following Boltzmann, such a come-back is possible, in conformity with the so-called "ergodic assumption", but it is statistically improbable. Since the law of evolution of a gas relaxation is based on statistics, and not on determined trajectories, it means that the entropic transformation *is* not reversible. There is an arrow of time in physics, even in the context of statistical mechanics.

3. However, repetition is not creation. Would it be possible to find some creative duration in the material universe? That's precisely the question asked by Bergson in *Creative Evolution*. Science insists on the contemporaneity as a crucial dimension characterizing the material universe. Science explains contemporaneity with the help of symmetries and invariant structures. But would it be able to explain life on the basis of an ontology that insists preferentially on the dimension of contemporaneity and repetition?

Following Bergson, life is characterized by the concept-image of *élan vital*. First of all, life concerns all living organisms in the biosphere. It is not limited to one. It concerns all the organisms as an immanent and creative duration present into them, and into their relations. That is why Bergson says that it looks like a consciousness (Bergson 1922, 24; 28[15]). Secondly, life is not just a memory,

15 See also Worms (2006); Miquel (2007).

it is a force of anticipation, *un élan*. Life influences the future, as a force capable of surpassing itself. What exactly does this mean? The first property that characterizes life is that its future is always *the result of its activity*. It cannot be planned from the present. Thus, creative evolution is a transformation that cannot be characterized by an invariant structure, because of this *vis a tergo* by which the gate of the future is not closed (Bergson 1922, 108–110). Life is an *élan* and not an attractor, because the dynamic of life crucially depends on *how* the living agents live. Its meaning can be analyzed retrospectively, but certainly not prospectively.[16]

As a first consequence, evolution is not predictable, because the causes here, "unique in their kind, are part of the effect, have to come into existence with it, and are determined by it, as much as they determine it" (Bergson 1922, 172–173). As a second consequence, evolution produces novelties. Novelties are not simply inventions. They are *inventions of possibilities*, because the set of possibilities characterizing the activity of life can never be fully described *before* living agents act: "Evolution is a creation unceasingly renewed, it creates as it goes on, not only forms of life, but the ideas that will enable the intellect to understand it, the terms which will serve to express it" (Bergson 1922, 108). The third consequence is that living organisms are some kind of local vital forces, they cannot be reduced to mechanical structures, meaning that they future is already depending on the way they act. They are organized and adaptive agents and not simply mechanical devices. What they are doing depend on their individual memory and history.

Would such a vision of life be directed against science? On the contrary, it should be noted that such a philosophical image is not far removed from Darwin's hypotheses and proposals in *the Origin of species by means of natural selection* (Darwin 1859). Unlike neo-Darwinian population geneticists such as Ronald Fisher (Fisher 1930), Darwin did not focus his entire theory on the hypothesis of natural selection, even though he characterized it as "a paramount power".[17] The explanation of the origin of new species reposes instead on three principles: "descent with modifications", "natural selection" and "divergence of characters". In accordance with the third one, evolution is represented by a diagram (Darwin 1859, Ch. 4) meaning that the more time is passing, the more different species will appear in a cascade of successive pathways. By the way, *this diagram is not a tree*, since various independent origins are drawn on it. As a direct consequence, the logic of species classification becomes a chronological

16 See Montévil (2019).
17 See Gayon (1992).

logic, whereby the genus is no longer an abstract category, but simply a common ancestor.

However, and in accordance with the first principle, the space of possible states characterizing the heredity of a biological system is continuously renewed by the principle of variation at each stage of evolution, so that new species may appear again and again. Finally, natural selection is not simply a power of elimination. It is represented as a creative and plastic power of *divergence*. It should be noted that this point will be at the center of a very famous scientific controversy between Fisher and Wright during the 20th century.

4. As a second crucial point, the *élan vital* is nothing but a thermodynamic differential force, producing effects "in which it expands and transcends its own being" (Bergson 1922, 52), because it carries within it an entropic power of waste and dissipation, which again means that there is no life without matter (Di Frisco 2016). Life is like "a container" with "cracks" on the side, through which "steam escapes in a jet", like "a reality that 'is making itself', in a reality that 'unmakes itself''" (Bergson 1922, 261). In *La nouvelle alliance* (1979), Prigogine and Stengers, implicitly refer to this image as a kind of anticipation of the physical and chemical concept of "dissipative structure". In deciphering the philosophical meaning of this image, one understands that life draws more from itself than it has, because what is not life is also a dimension of life. There is no life without entropy, for the organic nature of life comes from entropy.

However, contrary to a simple dissipative structure, *life is represented as a creative tendency inventing material systems that expend more and more entropy over time, enabling more and more new vital functions*. Contrary to the vegetal, the animal is expending motion, so that a new vital function could emerge: instinct. Unlike the animal, the human being is able to spend thoughts without acting, so that a new vital function could emerge: intelligence. Finally, life is a polarized intensive activity, and as such, it changes permanently, because what is not life is also an internal dimension of life. There is no intensity without entropy, no biological rhythm without habits, no creation without repetition. Life is the overcoming of the organic, through the inorganic understood as an immanent force, and not simply as an external obstacle or accident.

Conclusion

1. To sum up, metaphysics alone has no experience of the material universe. The ontological experience of the material universe, is nothing other than an ontological commitment coming from perception and from science. Science is intelligence looking outward, it is the expanded experience in our mind of the mate-

rial universe, as an entity that also exists as such, that has its own perspective, which is not the subjective perspective of consciousness. This is why, to understand the relation between our consciousness and the material world, metaphysics has to "ride" (Bergson 1946, 48) intelligence. However, when riding intelligence, intuition finds in the physical world, that matter is more than space. Matter has a sleepy memory, and matter has also its own tendency; which is extension. Intuition also proposes that the evolution of life cannot be reduced to an entropic thermodynamic transformation, because of this continuous recursive activity of the organic through and by the inorganic. Such a proposition is not a scientific assumption, *but it can be helpful, as some kind of heuristic consideration.*

In this way of thinking, metaphysics is not an activity against science. It is only focused on the fact that it would never be possible to give *a complete theory of the physical world* by science. Any scientific theory, even a purely formal one, would always be incomplete, because it *refers* to another world than the world of consciousness. Scientific explanation would always be based on the use of concepts like *continuity* and *discontinuity*, or on the use on principles and methods that cannot be directly justified by science, because of its external ontological commitment. Philosophical investigation would be based on *analogies* between the immanent world of consciousness, and the immanent duration present in the universe thanks to the help of new scientific theories and hypothesis. Reciprocally, it means also that there is always some kind of negative control of philosophical concepts and philosophical visions by scientific activity. If they cannot be nor directly neither indirectly connected with science, they are simply *sterile* and *speculative*.

2. Second, metaphysics is adding to science a very different ontology, compatible but paradoxically also antagonist with science. Following Bergson, science gives us a plan for the coexistence of material images, in the form of a scientific theory. This experience of *objectification* is therefore not, as such, symbolic and artificial. On the contrary, it gives a vision of the material dimension of reality. Science *refers to something*, and at such, it involves some kind of ontological commitment (Bergson 1946, 42). A scientific theory has to be in touch with the physical world, by some kind of expanded intuition. However, *objectification* deals with measurement, with predictions, with falsifiable assumptions, and finally with the search of symmetries and invariants. That is why the ontology of scientific theories will always introduce a bias in explanation: *it will always try to explain what is changing, by what does not change.*

On the contrary, metaphysics has to privilege a *logic of substitution* to a *logic of exclusion*. In *Creative Evolution*, Bergson develops what he calls "the two orders theory" (Bergson 1922, Ch. 3–4). The negation of spirituality is not nothing.

It is matter. How would it be possible to think matter as another order, and not as a pure disorder? In the Platonic, and in the Aristotelian logic, *the same* has a prevalence on *the other*. Identity has a privilege on difference, and necessity has a privilege on contingency. More particularly, the relation between necessity and contingency is a hierarchical one, since in Aristotle logic, necessity is defined by exclusion of contingency, as what cannot not to be. There is no possible "included middle",[18] in such a way of thinking. Conversely, in a logic of substitution:

> If A, not A is not nothing.

The other has a prevalence on the same, because the same can be thought as *what is other than the other*. In this way of thinking, identity must be understood as a variety of otherness.[19] This heterodox logic of substitution is obviously at stake in Bergson's definition of life, since its organic nature is recursively coming back continuously from the inorganic entropy of matter, drawing a philosophical picture, that could be directly connected today with the concept of "anti-entropy" proposed by Longo and Montévil (2014).

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18 The principle of excluded middle states at the epistemic level, that for any proposition, either that proposition is true or its negation is true, in other words: $\neg\neg$ p=> p, and at the ontological level that, if there is A, then not A cannot be.
19 It should be noticed, that such a way of thinking is not proper to Bergson. It comes from French spiritualist tradition : "Il est inintelligible que la permanence absolue suscite le changement. C'est donc le changement qui est le principe ; la permanence n'est qu'un résultat" (Boutroux 1905, 27).

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Elie During

Time as Form: Lessons from the Bergson-Einstein Dispute

Abstract

The confusion surrounding the early philosophical reception of Relativity theory can be traced back to a misconception regarding the status of "time" in philosophical—and possibly scientific—discourse. For all its empirical grounding in actual perception and measurement, time is neither an empirical object, nor a category in the ordinary sense. As Aristotle first acknowledged, time is not some abstract or idealized motion; as such, it cannot be reduced to a generic representation of becoming. Kant underscored that time itself is immune to change, suggesting that it is best characterized as a *form* whose function for understanding is to coordinate a cluster of ideas and problems pertaining to persistence and change, as well as coexistence, in accordance with the most general principles of experience. The vindication of the unity and universality of time by philosophers as far apart as Russell and Bergson stems from the conviction that such basic temporal ideas cannot easily be taken apart. The fact that time comprises a subjective or psychological element is, in that respect, a peripheral issue. Thus, Bergson's "quarrel" with Einstein revolves around the possibility of apprehending simultaneity at a distance as a sheaf or envelope of durations unfolding in *real time*. Neither *proper time* (invariant, local) nor *coordinate time* (frame-dependent, global) can properly reflect the intuition of that thick present. While Bergson strives to incorporate it back into the relativistic framework based on the experience of lived simultaneity, Whitehead formalizes it in terms of *contemporaneous* extended events. Yet both seek a *regional* understanding of the matter, in line with some contemporary philosophers of spacetime. The (in)famous twin paradox is examined in this light, along with certain critical concepts in Bergson's philosophy of time. The challenge is to unpack the meaning of coexistence beyond the immediate phenomenological features of proximal co-presence.

1 A Cautionary Tale

> [T]he principle of relativity has given prominence to the conception of 'local time', and has somewhat diminished men's confidence in the one even-flowing stream of time. Without dogmatising as to the ultimate outcome of the principle of relativity, however, we may safe-

 https://doi.org/10.1515/9783110753707-009

> ly say, I think, that it does not destroy the possibility of correlating different local times and does not therefore have such far-reaching philosophical consequences as is sometimes supposed. In fact, in spite of difficulties as to measurement, the one all-embracing time still, I think, underlies all that physics has to say about motion (Russell 1914, 103–104)

The author of these lines is not Henri Bergson, but none other than Bertrand Russell, one of his most vocal and sarcastic philosophical opponents. In his 1914 Lowell lectures, published as *Our Knowledge of the External World*, the Cambridge philosopher deemed it "safe" to assume that philosophy—if not physics itself—would not need to relinquish the idea of a unique, "all-embracing" time as long as local time measurements could be dealt with in a unified and consistent manner. This somewhat controversial claim can still be found unchanged in the 1922 reprint edition of his book. It is only a few years later, in the revised edition of 1926, that Russell chose to suppress the entire paragraph, no doubt prompted in doing so by the harsh polemic that followed the publication of Bergson's essay on Relativity theory, *Durée et Simultanéité*.[1] In the meanwhile, *The ABC of Relativity* had put things straight, emphasizing, in what appears as a radical doctrinal U-turn, "the collapse of the notion of one all-embracing time" (Russell 1925, 225).[2] Russell's ideas were now in line with the orthodox view that Relativity theory in fact destroys the possibility of singling out a uniquely defined cosmic "now", and more generally of achieving a total temporal ordering of point-events in space-time.

One is left wondering why Russell did not realize this clearly before the early twenties, or why he chose to knowingly downplay one of the most far-reaching philosophical implications of Relativity theory and emphasize instead what may seem, under the most charitable interpretation, a rather trivial point: assuming we neglect gravity, the basic kinematic features of motion can always be referred to a unified system of time coordinates *within* any arbitrarily chosen inertial reference frame. According to this deflationary account of the situation, the point Russell was trying to make in 1914 and 1922 was basically repeating Kant's argument in the *Metaphysical Foundations of Natural Science*, namely that the relativity of kinematic perspectives does not really challenge the rational ideal of an

1 Bergson's book was released during the summer of 1922. It was republished the year after, augmented with several appendices (see Bergson 1999 and Bergson 2009 for the English translation).

2 See also Russell 1925, 56: the promotion of proper time suggests that we "abandon the old belief in one universal time". The same argument is repeated in a piece for the *Encyclopaedia Britannica*, "Philosophical Consequences of Relativity" (Russell 1926), where Russell explains that time, being private to each body, does not constitute a single cosmic order.

all-embracing time serving as the backdrop of all determination of motion. In that sense, absolute time, just as absolute space, can be retained as a regulative Idea stripped of any cosmic substance. How this should impact actual physics is, naturally, another matter. It may be argued that Einstein's accomplishment resided in showing that, when it comes to elucidating the spatio-temporal underpinnings of the dynamics of moving bodies, the regulative Idea of absolute time is useless at best—as useless, that is, as the aether concept. As many of his colleagues, he believed that common sense and philosophical understanding alike had to reform themselves to embrace the new outlook—otherwise, they would be mere impediments to scientific progress.

If one is reluctant to dismiss Russell's original appraisal of Relativity theory as one more expression of some deep-seated philosophical prejudice in favor of absolutes, then a few hypotheses suggest themselves. Was Russell on to something more substantial, in the spirit of his early rebuttal of relational conceptions of time and space, leading to the epistemological vindication of absolute motion?[3] Was he echoing, rather, Whitehead's view that time, considered as the form of actual process, extends in some sense "beyond the spatio-temporal continuum of nature" (Whitehead 1925, 181)? Or was he merely applying a basic principle of philosophical prudence regarding such fundamental concepts as time, space or causality?

Whatever the answer may be, the example of Russell's Lowell lectures should encourage us to adopt, in turn, a principle of hermeneutic relativity (or symmetry) when it comes to reassessing certain episodes in the early philosophical reception of Relativity theory. Bergson's engagement with Einstein is a case in point. More generally, Russell's cautionary tale should prompt us to think carefully about the reasons that can bring well-informed philosophers to advocate an ideal of temporal unity that is *prima facie* at odds with the mainstream interpretation of physical theory offered by people in the trade.

2 On the Formal Character of "Time"

My contention in what follows is that the difficulty can be traced back to the formal nature of the time concept, or to be more accurate, the fact that time is best characterized in terms of *form*. The implications of this claim need to be clarified before undertaking any serious research on topics related to the "philosophy of

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3 See Russell (1901), echoing his discussion with Poincaré regarding the relativity of space. See also Russell 1903, 489–493.

time". The underlying intuition, negatively formulated, is that what we call "time" can neither be a thing-concept in the usual sense, nor a proxy for an abstract, relational structure holding between pre-existing things. *Time* does not stand for an object or an empirical state of affairs, even one endowed with a remarkably high degree of generality. In this regard, it is very much like *information*, *energy* or *matter*—which, as Lenin reminds us, is not a concept but a category. Along similar lines, Wittgenstein argues that names such as *thing*, *object*, *event*, *existence*, or indeed *concept* really stand for what the *Tractatus*, 4.126 ff, introduces as "formal concepts" (Wittgenstein 1974, 33–34). That there are objects and events is not a fact, it is a constitutive part of our form of representation. Time too cannot be treated as any other element of fact. And yet its formal character does not prevent it from having genuine content,[4] conferring in effect rational coherence on a plurality of contrasting dimensions and aspects of becoming. Accordingly, if time indeed does something for us, it cannot be reduced to a mere intellectual device superimposed upon the varieties of temporal experience (for instance, an ordering scheme for events happening "in" time according to relations of succession and simultaneity); nor can it be assimilated to an empty framework for the manipulation of metric variables.

The most perceptive among philosophers have acknowledged this special status of time in some way, even when their instinct led them to discard the usual conception of form as overly abstract. Whether any of this should concern the physicist is of course debatable. Bergson and Russell had different views on this particular issue, but they did not stand very far apart regarding the special philosophical status for the concept of time. At any rate they both believed that once everything has been said about the physicist's handling of time measurements and the psychologist's elucidation of temporal experience, there is still room for a philosophical inquiry about the meaning of "time".

Now what are the indications that time indeed assumes the status of a form, for lack of a better word? The truth is that this theme runs throughout the entire history of philosophy. In the *Physics*, Aristotle emphasized the fact that time is not itself a variety of motion, that it is everywhere the same and cannot possibly flow at a faster or slower rate. In the section of his first *Critique* devoted to the *Analogies of Experience*, Kant famously insisted that time itself does not change and cannot be perceived as such. Wittgenstein, in a section of the *Tractatus* devoted to the formal nature of so-called "laws" in logic and physics (6.3611), claimed that there is "no such thing" as "the passage of time" (Wittgenstein

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4 See Gilles-Gaston Granger's characterization of "formal content" in his 1982 postface to *Formal Thought and the Sciences of Man* (Granger 1983).

1974, 83), which of course isn't the same as saying that time does not pass—whatever *that* could mean. Heidegger, who confessed to being interested in time and temporal experience only in so far as they could contribute to an elucidation of the question of being, also insisted in *Sein und Zeit* that from an ontic point of view, the most conspicuous aspect of an ontological approach to time was its formality (*Formalität*), a formality verging on "emptiness" (Heidegger 1996, 230). Arthur Prior argued on metaphysical ground that the *present* cannot be relativized without compromising the very meaning of existence, thus drawing our attention to a point of conceptual grammar: existence and coexistence are related in a way that is independent from frame-relative ascriptions of simultaneity (Prior 1970). Russell, as we have just seen, did not recoil from maintaining an "all-embracing" time form even though the new physics held the one even-flowing stream of time as the "relic of a bygone age", to paraphrase his famous statement about causal laws. Bergson in turn, while conferring special status on lived, concrete duration, identified its generic form as a multiplicity "resembling no other": a *sui generis* qualitative multiplicity, at once continuous and heterogeneous, incorporating a double principle of conservation and differentiation.[5] One wonders what is to be gained from characterizing such a concept as *psychological* time.

The list could go on. Each of these examples deserves to be carefully spelled out: such a task is beyond the scope of this contribution. For our purpose it is enough to observe that, taken together, all of the above claims exhibit a common thread. They converge in the sense that time is not an object, nor a sortal concept applying to whatever particular instance we take to exhibit *temporal* features. For lack of a better word, time is a form.

Given the prevalence of this formal theme, it was only natural for philosophers to approach Relativity theory with some circumspection. The shared feeling was that the significance of Einstein's new insights into the nature of time could not merely consist in proclaiming the relativity and plurality of times, as if some unfortunate accident had struck the temporal aether and disrupted its

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5 This conservation principle should not be confused with the principle of permanence formulated in Kant's *First Analogy of Experience* under the category of substance. If duration is deemed *substantial* by Bergson, it is in virtue of the dynamic continuation of the past into the present, a process which clearly involves more than either endurance or perdurance, while remaining fundamentally neutral with respect to A-time and B-time interpretations of time's "passage". As for the principle of differentiation, it is merely another aspect of continuation: the continuous weight exerted by the past upon the present implies that no moment of time can be repeated identically. Thus, Bergson suggests a temporal counterpart of the Leibnizian principle of indiscernibles that circumvents the concepts of substance and essence.

inherent unity, leaving us with a multiplicity of dispersed temporal shreds. Here we may take our cue from Gaston Bachelard: “when Einstein’s Relativity came along”, he writes, “it deformed primordial concepts that we thought were fixed forever. From then on, reason multiplied its objections, dissociating fundamental ideas and then making new connections between them, trying out the boldest of abstractions” (Bachelard 2002, 19). The implication, as far as time is concerned, is that the philosophical transformation brought about by the new physics did not primarily concern an enigmatic temporal substance that erring philosophers had previously defined in absolute, metaphysical terms. Dissociating fundamental ideas, trying new connections: the amount of conceptualization and problematization required to fit “time” into the relativistic framework suggests that something more is at stake than the overthrowing of a dubious theoretical entity of the aether kind. For the same reason, the fact that relativistic time can be given straightforward operational meaning under certain usage, lending itself to consistent measurement, is not enough to turn “time” itself into an empirical concept. The first step towards acknowledging the formal character of time consists in realizing that the dimensions of experience that “time” is intended to capture are not necessarily of the kind one may measure (like a flow rate), much less count and sort out (like apples in a basket). As will become apparent, this has little to do with the fact that time comprises a subjective or psychological element.

How is time not an empirical concept, given that we measure it? Here again, we can only offer cursory remarks. The following will suffice. Granted, we do measure durations in relation with particular processes. But the problem of time, properly speaking, only arises when it comes to coordinating such durations with a view to the totality of durations within the universe. At that level, “time” must be treated as a form effecting, in Russell’s words, the correlation of local times. As we shall argue, it is inseparable from an extended sense of coexistence. And yet physicists readily speak as if there were as many distinct “times” as there are reference systems in relative motion, or ways to causally connect time-like separated events, thereby suggesting that something more substantial is at stake than the sheer multiplicity of temporal measurements, as if the object previously known as “time” had been somehow pulverized. Such formulations are ambiguous at best. The only way to make sense of them is to include them in a comprehensive account of time form in which measurement is but one dimension among others.

The same logic of object-oriented discourse brings us to view relativistic time as a time *stripped out* of some of its classical features: unity, uniformity, distant simultaneity or a constitutive reference to the present moment. Thus, we customize the concept of time as if these were optional elements in the package, elements that one could assemble and re-assemble without compromising the integrity of temporal form. The bifurcation of temporal concepts into objective (physical) and subjective (psychological) sub-genres obeys a similar pattern: it reinforces the impression that time constitutes a particular field of study that one may choose to approach from different perspectives, laying emphasis on this or that particular set of aspects exhibited by temporal phenomena, pitting time consciousness against so-called "clock time", and so on.

According to the boldest among physicists, time may turn out not to exist at all, as if time was again a thing, the existence or non-existence of which could be in question. No amount of relationist medicine will rid us from such category mistakes. Defining time as a relational structure does not make it any less *real*, unless one endorses strong metaphysical views regarding the nature of emergence and the ontology of relations. Admittedly, more often than not the alleged "disappearance of time" is merely a roundabout way of saying that, at the fundamental level, the world is best described in terms of an atemporal theory, or perhaps that the physical world as described by our best scientific theories does not exhibit a fixed temporal backdrop, a universal arena of change. This point has been made in different ways, and on different grounds, by such authors as Lee Smolin, Carlo Rovelli, Julian Barbour. One may for example underscore the fact that the Wheeler-De Witt equation, sometimes described as *the wave-function of the universe*—under the disputable assumption that the universe as a whole behaves as a Hamiltonian system—, does not include any reference to an external time.

There is much philosophical confusion behind the idea of *atemporal* dynamics, but the theme strikes a sympathetic chord with the formally minded philosopher of time because the fact that dynamics can be expressed without time is consistent with the sense that time itself does not change, and accordingly does not exhibit dynamic features. When pressed further, however, the natural philosopher that lays dormant in every physicist is tempted to utter something like this: "I have looked for 'time' everywhere, both at the microscopic and cosmological levels, and I have found nothing…". This is baffling, for what on Earth did one expect to find? There is something vaguely reminiscent here of Yuri Gagarin's famous pronouncement on returning from his orbital trip aboard Vostok 1: "I see no God up here!". If the inexistence of time is a provocative way of saying that the universe is not bathing in a temporal aether of sorts, the claim is perfectly acceptable, albeit misleading. It only confirms the fact that time is not itself an object or process, not even a highly theory-laden one, such as the expansion of the universe described by current cosmology.

Once we relinquish the notion of time as a container of change, we may still want to ask what it means for things to be *in time* in the first place. Aristotle's

Physics raised the question only to warn us about the limits of any analogy with the fact of occupying a place. Yet in the same book, time is sometimes likened to an *envelope* of motion, an image which, to be properly understood, would require rising to a higher degree of abstraction. Curiously enough, problems of this nature are almost never addressed in current debates over the substantival or relational nature of time and space-time, whose main focus is on knowing whether a particular object or structure, defined in geometrical terms, exists in its own right, whether it can be grounded in more primitive elements, and the like.

To be fair, the tendency to reify time and treat it as a thing-concept is largely counterbalanced by the operationalist proclivity to frame all temporal issues in terms of what we can actually bring the concept of time to *do* for us: for example, correlating measurements of durations. From this perspective, we may want to define time as the quintessence of all time-keeping devices. At this level of generality, time appears as an ingenious labelling procedure devised by the human mind in the course of its evolution. Scientists inherit from this device; they have only managed to give it a level of mathematical sophistication that enables them to sort the variable configurations that constitute the history of the universe and build everything from there. Yet, at the end of the day, such deflationary accounts of time leave everything untouched; they raise the same issues as the bolder metaphysical views about the "disappearance of time". Oftentimes, the more empirically minded philosophers will offer sweeping ontological pronouncements to the effect that time, once again, doesn't exist, not in virtue of some substantial theory about mathematical constructs, but simply because a universal time-keeping device evolved by higher organisms to make sense of their environment is fundamentally no different from any other human artifact. It is easy to see how an agreement can be found at this basic level with philosophers attached to the idea of time as a subjective form of experience: a pragmatic, historicized reformulation of the a priori will do the trick. But it is only a small step from this to the claim that time is nothing *out there*, or that its very passage is but an elaborate cognitive illusion. And more often than not, such considerations secretly trade on a hypostasized representation of time as some fundamental process underlying all processes. Is this process occurring in the mind only, or does it have genuine objective, physical grounding? If one is not in the mood for metaphysics, an easy way of fudging the problem is to refer to John Archibald Wheeler's memorable dictum that time is the easiest way nature has found to keep everything from happening at once. We can do better than that.

3 A Functional Approach to Form

These scattered and sketchy remarks all point to the same direction: to assess the philosophical relevance of the physicist's pronouncements about time, it is well-advised to approach them in what Carnap described as the formal mode of speech, not only because temporal concepts do not necessarily have direct intuitive, empirical or material content, but more fundamentally because they generally operate at higher level of abstraction than any classifying concept or category. Their function, I surmise, is to provide a coherent framework for a cluster of related issues pertaining to being and event, identity and change, structure and process, purpose and causality, etc. It is to address such concerns that Kant came up with a doctrine of the "order of time" in his *Analogies of Experience*, bringing together the categories of substance, cause and community, to achieve a consistent and unified account of permanence, succession and simultaneity.

From this standpoint, it is clear that 'time' cannot be a mere placeholder for whatever physical theory deems relevant to the mathematical analysis of becoming. A philosophical account of time must somehow resonate with the entire cluster of problems mentioned above, including those stemming from the implicit reference of temporal predication to a present moment ("now", "then"), which may or may not be construed as the mark of an irreducibly *subjective* standpoint. By reminding us of this simple fact, the philosopher is not claiming privileged access to a special object that would lie outside the reach of scientific understanding. He is making a point about the kind of expectations that come with the concept of time. Such expectations and anticipations, as Bergson often emphasized, imply that we do not assume from the outset an unbridgeable gap between the experiential aspects of time disclosed in lived duration and the rules governing our use of the parameter *t* in physical theory. Otherwise, why continue to use the same word ("time") for both? From that standpoint, equating time with a mathematical object effecting the correlation of time measurements doesn't do it more justice than holding it as the immutable and irreducibly subjective form of inner sense. Our framing of time concepts needs to be checked against the complete theoretical background that motivates our reflection on the nature of time in the first place. That is why neither the mathematical nor the transcendental understanding of form can exhaust the meaning of time form. In fact, elucidating the formal character of time may well require a thorough examination of the entire spectrum of temporal experience. In the process, time may turn out to be a very peculiar kind of form indeed, a form of the non-Aristotelian and non-Kantian variety—a form *resembling no other*, to paraphrase Bergson, a form that is in some way adherent to its content.

The crucial question, in any case, is the following: what does it mean to work on a concept, rather than put it to service? Georges Canguilhem nicely puts it in a text about Bachelard:

> To work on a concept is to vary its extension and comprehension, to generalize it through the incorporation of exceptional traits, to export it beyond its region of origin, to take it as a model or inversely, to search for a model for it—in short, to progressively confer upon it, through regulated transformations, the function of a form.[6]

For our purpose, assuming such a functional stance, making use of *form* as a regulative idea, appears more productive than attempting to flesh out its meaning and content from the outset in a definition. Admittedly, philosophers have generally shown more interest in "varying [time's] extension and comprehension", than in "generalizing it through incorporation of exceptional traits". Physicists on the other hand, more particularly those involved in the development of Relativity theory, have achieved an unprecedented level of generalization of temporal concepts by showing that as a general rule—a rule which only becomes conspicuous in certain special conditions or limiting cases (when dealing with velocities close to the speed of light, for instance)—, temporal and spatial aspects must be handled together as part of one single mathematical form in which they appear tightly woven, rather than merely juxtaposed. The elucidation of the structure of relativistic space-time certainly constitutes an important landmark in that respect. On one level, it offers a paradigm of the formal approach to temporal issues. It is also quite helpful in dispelling certain misconceptions such as the alleged "slowing down" or "dilation" of time.[7] Yet it remains to be seen in what sense time itself assumes *the function of a form* once it has been merged in this overarching structure.

Remarkably enough, the generalization achieved by the space-time approach may in fact amount to a *specification* of time form, and arguably to a reduction of its original scope, as indicated by the narrowing down of absolute simultaneity to sheer facts of coincidence and the subsequent promotion of local time, i. e., a quantity measured along spatio-temporal worldlines. Deprived from the independence it enjoyed in the classical setting, where four-dimensional

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6 Canguilhem, "Dialectique et philosophie du non chez Bachelard" (1963), quoted in Hallward and Peden 2012, 13. This quote is featured as an epigraph of each of the volumes of the "Cahiers pour l'analyse" published between 1966 and 1969.

7 A more compelling image is that of space-time itself (its metrical features) acting as some sort of lattice or filtering device, forcing the flow of time to fork out and take spatio-temporal detours that turn out to be temporal *shortcuts* (i. e., routes of lesser elapsed duration).

space-time was merely the Cartesian product of temporal and spatial dimensions with no unified metrics, “time” has clearly not disappeared. It survives in different guises, deprived of some of its familiar privileges. But is it *real time?* Rather than brushing the question aside as an expression of philosophical conservatism, I suggest we rephrase it in formal mode so that the search for *real time* serves as a catalyst for the elucidation of time form, instead of mirroring some pre-existing standard—be it intuitive or conceptual—of what should count as the primordial meaning of “time”.

The same circumspection is in order when dealing with what Bergson holds as the main property attached to *real time* in physics: its unity or universality. Evidently, acknowledging a plurality of time forms would defeat the very purpose of adopting a formal stance in the first place. If we are serious about form, there can only be one time form. The challenge is to explain how such a form can accommodate a plurality of time measurements.

4 *Real* Time is *Measured* Time!

In that respect, Bergson comes across as somewhat more prudent than many of his colleagues, including the early Russell. For one thing, while advocating a single universal time, he left the question open as to the appropriate theoretical format that could instantiate this metaphysical claim at a physical level. In particular, he never entertained the notion that it would be philosophically sound to redeem Newton’s absolute time, or to maintain it in relativized form, in the manner of Poincaré or Lorentz, by granting privileged status to conventionally chosen reference frames bearing *true time*. This would have run against the general orientation of his discussion of the “cinematographic mechanism of thought”. Absolute, uniform time, like all concepts of time modelled after the mathematical time-dimension manipulated by classical mechanics, whether in parameter or coordinate format, implies precisely the kind of overall framing and schematizing of real change that is exposed and criticized in *Creative Evolution*.

In every case, the reconstruction of actual experience effected by cinematographic intelligence implies referring particular processes to the abstraction of a “single representation of becoming *in general* […], a becoming always and everywhere the same, invariably colourless” (Bergson 1998, 304). Bergson was naturally suspicious of the metaphor of universal time flow, which in effect treats time as an all-embracing medium of change underlying every particular duration. It is worth noting that it matters little at this point whether time is one or several, whether absolute time is meant in the original sense intended by Newton, or in the relativized sense underlying the use of a unified system of temporal coordinates within each particular reference frame. The latter solution merely multiplies and aggravates the problem by conjuring up the monstruous image of a "hyper-cinematograph" of sorts, projecting as many global renderings of actual becoming as there are ways of framing it according to particular kinematic perspectives.[8] While it may still be appropriate for physical purpose, Bergson for one did not see any philosophical benefit in salvaging such a conception, let alone giving it genuine ontological status.

Besides, the knee-jerk reaction of dismay triggered by any mention of universal time in relation to Relativity theory should not overshadow this obvious fact: if the philosopher's hidden agenda was to vindicate the conceptual framework provided by Newtonian time (the so-called universal time symbolized by the Greenwich meridian clock), he would have chosen a rather curious route to achieve this —first establishing the inherent limitations of all aether-based versions of Relativity (chapter I of *Duration and Simultaneity*), then systematically contrasting *real time* with the relative and ultimately fictitious nature of all frame-dependent determination of time. Likewise, if all he had in mind was to rescue absolute time, the paradoxical claim to the effect that Relativity theory brings out the "unity of real time" even more clearly than classical mechanics would remain utterly incomprehensible.

In view of all this, the notion that Bergson is clinging to an obsolete conception of absolute time for purely philosophical reasons is simply preposterous. The heart of the matter lies in what the critique of the cinematographic illusion brought to the fore, namely the *framing* function attributed to time in both relativistic and non-relativistic setting. Prima facie, the search for *real time* finds its motivation in a reaction against framed time. But to elucidate its concept on its own terms, we need to contrast it with what Bergson describes as *fictitious times*, i.e., the mathematical expression of the anamorphic transformations affecting temporal measurement as we shift from one reference frame to another. Granted, relativistic effects such as length contraction and time dilation are commonly observed. Such effects, however, do not make these times less fictious, for they can always be construed as perspectival artefacts resulting from the use of arbitrary frames in the account of elapsed durations at a distance. The concept of *real time*, on the other hand, is meant to reflect certain aspects of time that are independent from any such framing, yet no less measurable for that.

The point deserves emphasis: the critical distinction between real and fictitious time operates within the very domain of *measured time*. Contrary to what is generally believed, *real time* is not another name for pure duration. *Duration and*

8 See During (2012); (2015).

Simultaneity unequivocally introduces it as a variety of *physical* time. It is the time actually measured (or potentially measurable) by a real clock attached to a portion of matter. Accordingly, when Bergson insists that *real time* is not the kind of thing that can be torn apart and dismantled by the mere effect of relative speed, he is really making a point about the grammar of *physical* time, which he argues cannot be handled as freely as a mathematical variable. This is a far cry from merely playing subjective or lived time against physical or measured time, even if all determinations of *real time* ultimately lead back to the conditions in which real observers perform actual measurements.

To repeat, *real time* is essentially measured time. It is the time of matter, to the extent that matter lends itself to measurement. For this reason, when it comes to appreciating the motivations behind Bergson's engagement with Einstein, it is entirely misleading to portray him as an advocate of the primacy of lived or psychological duration. If the philosopher and the scientist were confronting each other from the two opposite sides of the subjective/objective divide, they would be speaking at cross-purpose and their quarrel would appear pointless, turning around a homonymous use of "time". Accordingly, Einstein would be justified in proclaiming that there is in fact no third time—no "philosopher's time" besides the time of physicists and the time of psychologists.[9] For once we have accounted for the metric properties of time and for the qualitative features attached to felt time, it seems there is indeed nothing left to study.[10] That, however, is not really the issue. The formal understanding of "time" is the key here: if there is no such thing as the "philosopher's time", no third object requiring special scrutiny, it is only owing to the fact that time is not an object in the first place. So, we may say that Einstein was right after all, although not in the sense he himself intended.

5 The Prospect of Universal Time

In a nutshell, Bergson's claim is not that *real time* is lived, but that it is lived and counted, lived and measured. It is lived even more so as it is counted and meas-

9 This blunt statement can be found in the transcripts of the brief exchange that followed Bergson's lecture during Einstein's 1922 visit at the Collège de France in Paris (Bergson 1999, 158). See During 2020, 44–45.

10 It should be noted that Einstein himself readily acknowledges that a psychological or intuitive apprehension of time is necessarily presupposed by the actual use of measuring instruments (i.e., the reading of clocks). This entails no conflict or contradiction, as long as we agree on a correspondence scheme linking perceptual observations and theoretical constructs.

ured. More importantly, however, it is unique. Therein lies its most conspicuous characteristic.

The underlying metaphysical view can in turn be expressed in both material and formal mode. In material mode, Bergson is defending the view that the universe *as a whole* endures: as such, it is fundamentally analogous to lived, conscious duration. The deeper motivations behind such a view need not concern us at this point. Suffice it to say that the idea of a cosmic temporal wave sweeping across the entire universe is strongly suggested by common sense, not exactly through analogical reasoning, but by virtue of a principle of similarity allowing for gradual extensions from local to global. In any case, for Bergson universal time ultimately remains a conjecture or hypothesis that must be appraised on its own philosophical merits rather than as a blueprint for an alternative physical theory of Relativity along Lorentzian or Poincarean lines.[11]

In formal mode, the reaffirmation of the "unity of real time" stems from a profound discomfort with the ontological slackness resulting from the metaphorical spatialization and reification of time. It is one thing to say, for example, that there are as many time-systems as there are reference frames in relative motion, or as many elapsed durations between two time-like separated events as there are ways of connecting them causally; it is quite another to take the multiplicity of temporal measurements associated with particular movements or processes as evidence for an actual multiplicity of a-synchronous durations unfolding in space, as if these were themselves processes of some kind. At a fundamental level, the search for *real time* is an attempt to rectify the misconceptions fostered by the overused metaphor of time's flow.

The remedy, once again, is to reaffirm the essential unity of time form as a matter of principle. However, this cannot be achieved entirely *a priori*. In keeping with the general orientation of Bergson's empiricist method, the only way to effectively recover that sense of unity is to examine the actual operations carried out by the physicist, rather than dismissing measured time indiscriminately or simply positing genuine duration and the ideal of subjective unity as a transcendental pre-condition for all temporal determination. But this raises in turn a crit-

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11 Édouard Guillaume, an early translator of Einstein in French and editor of Poincaré's scientific writings, entertained just such a prospect. His theories are mentioned in *Duration and Simultaneity* with some reservations (see Bergson 2009, 133; 302–302). Another case in point is Herbert Dingle. An obstinate opponent of Relativity theory, he also authored a long introduction to the first English translation of *Durée et Simultanéité*, claiming that Bergson, objecting to the idea of asymmetric aging in the standard exposition of Langevin's twin paradox, had thereby advanced "a perfectly relevant argument even from the physical point of view" (Bergson 1965, xvii). Fortunately, this introduction was not included in further editions (Bergson 1999).

ical question. If *real time* lends itself to measurement, if the structure of physical theory implies a way of coordinating the results of time measurements, to what particular aspect of physical time does *real time* correspond?

The difficulty with Einstein's Relativity is that "time" appears to be all over the place, refracted at different levels within the entire theory. On one level, space-time itself can be said to assume some of the traditional functions of time form. As we have seen, the phantasmal image of frozen becoming that is conjured whenever space-time is considered as a geometric object (or *block*) literally laid out in four dimensions, conceals a sophisticated machinery that in fact operates like a hyper-cinematograph, offering infinitely many projections of becoming—as many as there are reference frames. All these projections are virtually embedded in space-time and directly recoverable from its metrical form. The Lorentz equations express in algebraic terms the way these projections can be coordinated through appropriate transformations. To the extent that space-time thus achieves a formal totalization of becoming, it suggests itself as a substitute for absolute time, but it can only do so at a level of generality that does not even begin to address Bergson's concerns. The immutable unity of spatio-temporal form symbolized by the Lorentzian metric signature turns out to be too large to convey the temporal unity of interlocking durations within the actual universe. The space-time of Special Relativity has only tangential relevance to the variably curved space-time of General Relativity: it is, in the end, an ideal mathematical object. As such, Bergson believes it does not have any straightforward lesson to deliver regarding the nature of time—a form adherent to real becoming. That is the main thread running through the last chapter of *Duration and Simultaneity* devoted to four-dimensional space-time.

At another level, we find coordinate times attached to particular reference frames (or equivalence classes of coordinate systems), as well as proper times measured along individual worldlines. Obviously, these two determinations of time do not merely coexist alongside each other; they are closely entwined in the metric of space-time. Yet, despite this deep mathematical connection, it seems as if "time" had been split apart and projected upon different planes of expression as a result of its entanglement with space. In actual use, the relativistic framework displays a constant interference of parameter-time with coordinate-time, but the way this oscillation between local and global time is reflected on a discursive level reinforces the feeling that we are dealing with heterogeneous aspects of temporal form. Meanwhile, clocks are moved around, synchronized (either locally, or at a distance, by exchanging light signals) and desynchronized (owing to relative motion, and more importantly, dynamic factors). They time events and measure durations while mutually surveying each other in some sense, notwithstanding the disruptions. And if it is true that time *itself* is never directly measured, if it is better defined, following Carlo Rovelli's suggestion, as an "exchange rate" between other magnitudes endowed with more immediate physical content, then the perfect clock is ultimately nothing but the universe as a whole (or alternately, the most comprehensive theory of that universe). This is yet another confirmation that the form of time cannot easily be pinned down, leaving open the question of where to locate its unity and universality beyond the form of space-time itself.

6 The Lure of Local Time

As far as the basic principles of physical theory, Bergson views himself as a thorough relativist. He has given up absolute space and its material counterpart, the aether. Relying on a privileged frame is not an option, especially if this involves redeeming absolute time in the classic form of frame-time. Clearly, the "unity of real time" must lie elsewhere. Can it be found in *proper time*, the local time introduced by Einstein in his analysis of the logic of measurement, based on rods and clocks? Here is a time marked out by the actual strokes of a clock, a time registered on the spot, so to speak, where the action takes place.[12] It seems time could hardly be any more "real" than that. Yet, given Bergson's criticism of the philosophical abuse of mathematical, homogeneous time, local time could only appear to him as a further development, rather than an overthrow, of the abstract representation of time epitomized by Newtonian absolute time. This deep-seated conviction certainly contributed to downplaying the real novelty behind the Einsteinian use of local time. For the most important lesson to be taken from Relativity, a lesson which many philosophers and physicists alike did not always fully appreciate, is not so much the fact that time is relative to the observer—that is, to the choice of an arbitrary frame of reference—, but more profoundly that time is relative to the varying intensities of motion affecting the observer in the general case where, being accelerated, it cannot be assigned a single inertial frame. Thus, proper time is typically referred to a worldline followed in space-time by a portion of matter (a clock, a human observer) undergoing various degrees of dynamic acceleration. It is, strictly speaking, a length measured along such a worldline, a length whose mathematical expression happens to be

12 The definitions of proper time vary from one textbook to another, depending on the emphasis one wishes to lay on the intrinsic (frame-invariant) aspects of the situation. Some refer to the time measured by clocks sharing the same motion as the observer (i.e., clocks at rest in the reference frame of the observer), while others mention the time registered by a clock "carried" from one event to another.

independent of any particular framing. Taken as the paradigm of local time, it encapsulates the following basic idea: relativistic time is essentially a *path-dependent*—rather than *frame-dependent*—magnitude; it is relative to the observer to the extent that the observer is dynamically related to the universe as a whole.

Now, owing to the metric of relativistic space-time, the *shortest* (i. e., geodesic) path in space-time happens to be the *longest* in time. Langevin's famous paradox of the twins offers a direct illustration of this general point; hence its paradigmatic function.[13] In Bergson's eyes, however, proper time is philosophically useless: the drawbacks of its path-dependency far outweigh the philosophical benefits of its frame-invariance. Its pivotal role in Relativity theory appears to him as a further step in the direction indicated by Descartes: that of a thorough geometrization of matter and motion. More importantly, the suspicion is that proper times measured along stretches of space-time do not have anything distinctly *temporal* about them besides the fact that, being predicated upon continuous motion in space, they suggest a natural temporal ordering of events along "time-like" paths—a proto-temporal schema that Piaget would describe as mere "spatial succession" (Piaget 1969, 26). In other words, what proper time has to offer is at best a local expression of causal order. But as a monotonously increasing parameter defined along space-time curves, it is really a 4D spatial magnitude in temporal clothing. To the extent that it captures something of the flow of causality propagating from place to place, it contributes to the spatio-temporal representation of becoming, but the only way it can infuse a genuine sense of temporal unfolding is by relying on a pre-existing intuition of duration, the prototype of which, Bergson argues, ultimately brings back consciousness in the form of lived duration (i. e., a succession of events without any clear-cut distinction between past and present states, conjoined with the perceived simultaneity of multiple flows distributed across space).

Thus, when some philosophers followed Langevin's suggestion that Bergsonian *real time* could be identified with the physicist's proper time, and thereby restore some sense of invariance and unity beneath the relative projections of frame-time,[14] they could not be farther from Bergson's original intent. For strictly

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13 The twin paradox epitomizes what Taylor and Wheeler describe as a chronogeometrical principle of "maximal aging". In unformal mode: "The worldline of a free stone has maximum wristwatch time between adjacent events" (Taylor, Wheeler and Bertschinger 2006, section 1.6). "Wristwatch time" is another name for proper time; "free stone" stands for any system in uniform motion. According to the authors, the principle of maximal aging in relativistic spacetime is structurally analogous to Newton's first law of motion in classical spacetime.

14 "The philosopher adopts the perspective of *proper time*, the time particular to each [observer]. The physicist adopts the perspective of a common time: the questions he raises bring him to speaking, proper time, though non-perspectival and invariant, is nothing but a local magnitude measured along spatio-temporal paths. When such paths are combined with moving clocks, it seems we have somehow captured time and fixed it along its course, so to speak. Indeed, each clock can be said to give an accurate measure of its own proper time as it moves around in space. But it is important to realize how unfamiliar this variety of "clock time" really is. For one thing, proper time does not come equipped with any sense of simultaneity besides trivial facts of local coincidence (i.e., intersections of space-time paths). Registering the time of the action only where it takes place, proper time entirely lacks the kind of "thickness" or perspectival depth attached to the idea of real, extensive becoming, to the point that one can doubt whether it has any immediate temporal meaning.[15] The fact is that locality without perspective is not enough. To give proper time its full temporal scope, we need to associate it from the outset with some form of global time, or at least a synchronizing procedure allowing relations of simultaneity to occur at some level. Otherwise, it is at best a fibre-time of sorts: more elastic in some respects, yet in the end no less homogeneous and abstract than the more familiar frame-time underlying the use of time coordinates. Only when temporal fibres align and co-moving local observers can be said to share a reference frame, do we recover a sense of global time, albeit a relativized one. When all is said and done, Langevin's universal use of proper time does no more than offer a mathematical substitute for the classic figure of time within a new chronogeometrical framework. The question of the roots of time's unity remains open. For Bergson, it cannot be properly addressed on strictly local grounds.

7 Coexistence in Time: the Real Issue

The inherent limitation of purely local definitions of time is indicative of the extent to which our expectations regarding time form are dependent upon the more basic intuition of *coexistence* in time. From Plato's *Timaeus* through Aristotle's *Physics*, down to the "all-embracing" universal time of modern mechanics and Kant's *Third Analogy of Experience*, philosophers have entertained the idea that time is an envelope or sheaf of becoming, and hence a medium of coexistence, even before it can be defined as a measure (or "number") of local or cos-

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compare the *proper times* of different observers" (Langevin, "Le temps, l'espace et la causalité dans la physique moderne", a lecture at the Société Française de Philosophie, October 19, 1911, quoted in Bergson 2009, 382).

15 Cord Friebe makes a similar point. See Friebe (2012).

mic motion.[16] Generalizing from this idea, we reach the conclusion that time's primary function is one of *co-ordination*—a conclusion corroborated by Piaget's research regarding the development of temporal frameworks in children. More precisely, time form is what enables us to make sense of a plurality of durations unfolding together, not only spatially, by virtue of being part of the same universe, but temporally, by virtue of being together in time. Time is what brings together durations conceived as contemporaneous, if not simultaneous in the strict sense.

Bergson inherits from this rich tradition. Like others before him, he advocates the formal unity of time as a dimension of both change and coexistence. But the concept of duration changes the deal by severing the form of time from the extensive scheme of number typified in the parametrical use of proper time. Accordingly, just as proper time takes on genuine temporal meaning when it is grounded in lived duration—otherwise, why interpret it as a length of "time"?—, the operational definition of simultaneity at a distance by way of light signals, and the subsequent foliation of space-time into frame-dependent planes of simultaneity, must ultimately be referred to what the third chapter of *Duration and Simultaneity* describes as the lived *simultaneity of flows*, rather than instantaneous events. Taken in this broad sense, simultaneity escapes the narrow definition of instantaneous simultaneity at a distance which Einstein famously showed to be relative to the choice of a particular system of reference. Bergson's emphasis on the "unity of real time", together with his endorsement of "the one and universal time", takes its full meaning in this perspective. What is at stake behind the issue of simultaneity is no less than the possibility of recovering a measure of connectedness and unity—a meaningful sense of community—in a universe that the relativistic overhaul of the concepts of simultaneity and duration have seemingly "disfigured" (Bergson 1946, 301–303). The intuition is that the consistent reappraisal of simultaneity as an inherent feature of time form must deliver an insight into the cohesion of the temporal fabric at a cosmic level.

If that was indeed Bergson's intent, it is fair to say that he was not very successful in driving the point home. His famous Paris meeting with Einstein (Bergson 1999, 154–159) was hosted by the Société Française de Philosophie on April 6, 1922 in the margins of a series of lectures given by the physicist at the Collège

16 In his 1770 *Dissertation* (section III, §14), Kant had already introduced simultaneity as the most important consequence of time, insisting on the necessity to acknowledge simultaneity as a relation in its own right, rather than as a shorthand for the non-successive. Thus, simultaneity is the expression of the actual coexistence of things joined in the same moment of interaction: as such, it manifests the ubiquity of time.

de France. The exchange between two of the most brilliant minds of the time has often been described as the intellectual equivalent of the ultimate fight in a heavyweight wrestling championship. The press naturally gave it substantial coverage at the time. Several chronicles and historical works have since provided informative and somewhat entertaining accounts of the circumstances surrounding it.[17] But the editorial dramatization of this altogether disappointing episode has had several unwelcome consequences. It has led some critics and commentators—bolstered by Einstein himself, as it appears—to overemphasize certain peripheral issues at the expense of more fundamental ones.

A case in point is the status of "absolute simultaneity", defined as simultaneity at-a-place (i.e., local coincidence). During the Paris meeting, in order to trigger a discussion with Einstein, Bergson had seen fit to present a section of his upcoming book on Relativity theory, in which a rather convoluted argument is made for an extended use of the concept of simultaneity beyond point-like occurrences. This somehow encouraged the false impression that he was questioning the physicist's reliance on facts of local coincidence (i.e., two events occurring simultaneously at a given point in space), when his aim was merely to question the implicit assumptions underlying any idea of simultaneity. He attempted to do so by showing the hold that certain geometrical representations (such as the idealized point-like events) have on our conception of what counts as absolute, wittily referring to the fictional viewpoint of relativistic *microbes* (see During 2020, 40–42), but the fact is that the more substantial underlying issues were barely addressed in the pages he had chosen to read from. So much so that we are today in the difficult position of having to provide a rational reconstruction for an argument that the two thinkers could not actually have. For the commentator, this implies performing some sort of ventriloquism in Bergson's name.

Let us give it a try, to the risk of anachronism. The observation that simultaneity at a distance, being frame-relative, loses all objective meaning in relativistic setting, is generally believed to have far-reaching and devastating implications for the philosophical understanding of time. Some argue that it inevitably leads to its fragmentation into a kaleidoscopic multiplicity of temporal projections, each reference frame bearing, so to speak, its own time. But is it truly the case? To make temporal sense of such relativization in the first place, isn't it necessary to set it against the background provided by some notion of spatio-temporal coexistence? Bergson, for one, believes that the primitive meaning of simultaneity is founded upon the actual dynamics of interlocking "flows" of matter as apprehended by some perceptual event. He therefore as-

17 See Paty (1979); Biezunski (1987) and (1991); Canales (2015).

sumes the notion to be richer and more concrete—if less global—than the one suggested by "all-encompassing" *planes of simultaneity* cutting across the entire universe.

Others consider the relativization of simultaneity and the ensuing disruption of time as evidence of the need to account for temporal becoming in strictly local terms—i. e., in terms of proper time in the sense defined above. But as suggested, this only seems to aggravate the problem. As Mauro Dorato nicely puts it, once we have given up the notion of a world-wide advance of nature, of a 'now' moving like a front-wave on the ocean of becoming, if we nevertheless want to retain a sense of the overall temporal unity of the cosmic process, "the water provided by an uncorrelated, non-denumerable set of narrow creeks, each of which, representing the *proper time* of a worldline, 'flowing' at a different rate, may also prove insufficient" (Dorato 1995, 184). While the multiple perspectival projections of framed time at least obeyed uniform transformation rules (the symmetries of the Lorentz group), the intrinsic (i. e., frame-invariant) approach to temporal becoming seems to leave us with an utterly pulverized time: a multiplicity of loosely connected threads of proper time with no coordinating principle besides the metric structure of space-time itself and its underlying topology. General Relativity pushes things one step further, forcing us to acknowledge that a global temporal framing is unavailable as a matter of principle. In variably curved space-time, where Minkowski space-time only holds locally, there is no straightforward way of defining planes of simultaneity: the twin paradox becomes the general rule (see below, section 8).

At this point, it would seem as if we ought not be concerned with figurative models of time flow and resign ourselves instead to stripping the concept of time from any global scope. But if coexistence is assumed as a constitutive dimension of *real time*, that would be tantamount to denying the existence of time altogether. The very possibility of conceiving of beings and events as enduring *together* hangs on the coordinating function of time, beyond the trivial mode of coexistence suggested by the generic form of space-time itself (or its phantasmal counterpart, the 4D "block universe"). As mentioned before, the kind of unity achieved by space-time, whether we picture it as a solid made of agglomerated fibres, or as a porous and fluid medium, remains essentially abstract. As a result, the coexistence it exhibits is trivial at best and has nothing specifically temporal about it. Things coexist in the sense that they are part of the same spatio-temporal form. But what Bergson argues about absolute time is true of space-time too: whether we form the image of "an immense solid sheet" (Bergson 1946, 220) or of "an infinity of crystallized needles" (Bergson 1946, 219), in both cases we are committing a category mistake because the space of coexistence itself is in fact treated as *a thing* laid out in space. If the representation of threads of becoming congealed in a "block universe" serves any purpose, it is that of emphasizing the need to come up with a non-trivial and more robust conception of temporal coexistence. The challenge is to achieve this without collapsing coexistence on the usual figures of global simultaneity.

But, to reiterate, there is no reason why philosophical reflection should confine the meaning of distant simultaneity to the physicist's concept of world-wide instants (planes of simultaneity). Fixing simultaneity relations between space-like separated events by means of appropriate reference frames (i.e., systems of coordinates), implementing this through electromagnetic signalling procedures, is but one way to construe distant simultaneity. And the global temporal perspective obtained from the use of coordinate systems by no means exhausts the meaning of coexistence. As a matter of fact, the space-time framework already exhibits patterns of simultaneity that are neither global nor strictly local. We may refer to them as instances of *regional* simultaneity. Interestingly enough, they display intrinsic (i.e., frame-independent) characters, in the sense that they can be directly read off from the invariant topological structure of space-time underlying the causal order.

8 The Twins I: Regional Simultaneity

The twins' story of separation and reunion, as introduced in 1911 by Langevin,[18] is a touchstone in this respect, because it provides a straightforward, almost graphic staging of the oddly disjointed coexistence of two distant flows of duration unfolding and dephasing in parallel—or *in real time*, as it is. Despite the disruptions and discrepancies affecting any attempt at a continuous assessment of standard simultaneity relations between the stay-at-home and the traveller, their mutual history irresistibly conjures the image of a sheaf or envelope of shared time. One cannot simply ignore this on account of the irrecoverable character of absolute simultaneity, as commonly understood by the physicist. My conten-

18 Paul Langevin's 1911 exposition does not mention "twins" but a travelling observer who, on getting back to Earth after a space cruise in space, turns out to have aged less than everyone at home. The difference in the overall elapsed durations can be derived from the basic equations of Special Relativity theory: it depends on the way the travelling observer is accelerated, as well as on the speed at which he is propelled across space during his round-trip. Generalizing the lesson, two accelerated clocks measure different proper times along their respective journeys, even if the interval under consideration is bounded by the same pair of events (separation, reunion). For a complete genealogy of "Langevin's paradox" from Einstein to Bergson (through von Laue, Weyl, and Painlevé), see During (2014).

tion is that the genuine issue behind the Bergson-Einstein dispute crystallizes in this simple question: *in what sense are the twins contemporaneous?* For surely, they are contemporaneous in some sense. There may be no such thing as "the" duration of their separation, but why should we view them as temporally insulated from each other, each locked in his own proper duration, so to speak? Which in turn raises the following question: if we resist this form of temporal solipsism, if we acknowledge a sense of contemporaneity allowing the twins to be temporally related beyond the familiar figures of global instantaneity and local coincidence, how does this reflect on the coexistence of each of them with the rest of the universe? For in the absence of an overall physical connecting medium (aether or otherwise), it seems as if we were left once again with the formal aether of space-time as the sole factor of unity. Should we say that the temporal sense of cosmic unity can only be achieved from place to place, rather than in one stroke? But then how is it possible to overcome the limitations inherent to proper time? How can we recover a sense of temporal depth and perspective without once again framing time?

The truth is that philosophical reflection finds itself in a difficult position: standing halfway between locality and totality, with no clear sense of what could constitute its proper frame of reference, it is confronted with a web of interlocking durations somehow *surveying* each other temporally by the mere fact of belonging to the same universe. The exact nature of this reciprocal survey is what is at stake here, and it need not be formulated from the outset in metrical terms. For the twins separate only to meet again, and surely it makes sense to say that *while* the traveller was away, cruising in space, his brother on Earth got divorced and remarried, whatever the durations elapsed on either side. The twins may turn out to have aged differently, but this does not prevent them from being contemporaries all along, throughout their separation. This much is certain, at least in retrospect. It remains to be seen what is involved in this tenseless statement: the twins *coexist* as they go about their business along separate spatio-temporal routes. How can we confer genuine temporal sense to such a claim? Bergson's appeal to *real time* takes on its full meaning in this context:

> Not only do the multiple times of the Relativity theory do not destroy the unity of real time, but they even imply and uphold it. […] Without this unique and experienced duration, without this time common to all mathematical times, what would it mean to say that they are contemporary, that they are contained in the same interval? What else could such an affirmation mean? (Bergson 1999, 118)

Thus the "unity of real time" is confirmed by the "the simultaneity of flows"—which Bergson contrasts with the "simultaneity of instants"—, and more cogently than any consideration regarding the metrical equality of proper times. Considered in this light, Langevin's space-age scenario presents us with a theoretical toy-model for addressing a more general issue that is cosmological at its core. In fact, it can be argued that the twins' story cannot even be meaningfully told if it is not played out from the outset against a cosmic backdrop, rather than having them hang in abstract space-time as if nothing else existed. The traveller twin, as Whitehead and others have rightly pointed out in Machian fashion, ages less because his personal involvement with the universe as a whole is different from that of his stay-at-home brother (Whitehead 1923, 35).[19] This shows in the fact that he is subjected to inertial forces in the acceleration phases of his journey, while the other is not. Admittedly, Bergson's repeated claim that the twins must nevertheless find themselves, once reunited, having aged the same, did not do much to clarify the matter. But the stubbornness with which he attempted to refute the very premise of the paradox was instrumental in bringing out certain aspects of the situation that are too easily overlooked. Chief among them is the question of the exact range of the twins' perspectives on the "wave" of becoming that carries their respective flows of duration. If these flows are commensurable (which they are, at least in the sense that their respective proper times can be compared), to what extent can they be synchronized? (For they can, at least in the limited sense where unilateral and relative simultaneity relations can be defined on each side). If there is no way of achieving consistent and continuous overall synchrony, in what sense do the twins share a common history? Are figures such as *waves* and *sheafs* suitable to describe the process in which they participate, knowing that the perspectival view taken by accelerated observers induces constant disruptions and shears in the account of elapsed durations? What is the exact locus of the relational present that the twins seem to share despite their diverging proper times? Finally, is the philosopher in a better position than the physicist for assessing the situation?[20]

There is probably no univocal answer to such questions, because coexistence itself comes in a plurality of modes or regimes which appear to be embedded and somewhat superimposed within space-time itself. But it is difficult to ignore them altogether. Simply put, they stem from the sense that the twins

19 See French 1968, 156: "Would such effects as the twin paradox exist if the framework of fixed stars and distant galaxies were not there?"

20 Bergson believes that this is the case, because the philosopher, who does not care much for actual measurement, is free to do without reference frames—leaving them to their mutual, reciprocal motion, overviewing the scene from nowhere, so to speak. It is as if a privilege of extraterritoriality allowed him to describe mirroring perspectives without having himself to choose any viewpoint in particular.

are indeed contemporaneous, although they account for this fact in different ways. In the quotation given above ("they are contained in the same interval"), Bergson likens the "time" elapsed between the moments of separation and reunion—a time which Langevin shows to be measured differently by each—to a thick interval of extended present that they both share within what may be called an interval or *region* of contemporaneity.

This can be given precise topological meaning in the space-time framework (Čapek 1971, 248 ff), provided that we do not forget that the disjoint space-time paths of the twins remain generally incommensurable as far as standard simultaneity is concerned. For introducing an inertial frame somewhere in the picture can yield no more than a relative and arbitrary perspective on the overall simultaneity of their unfolding durations: it is frame-time once again. There is no point denying the relativity of simultaneity defined in such a narrow sense, i.e., as a "simultaneity of instants". Bergson consistently downplays its philosophical relevance because he is convinced that instants are unreal—ideal constructs, just as the frames themselves. No wonder that simultaneity relations between mere mathematical fictions should prove to be relative… The best one can say is that a continuous one-to-one correspondence between simultaneous events on both paths is available in *some* frames. This is already something, because as it happens the very fact that frame-time and global simultaneity relations are available in some frames is itself an absolute (frame-invariant) fact about the situation—a fact that may turn out to be more significant, as far as the "unity of real time" is concerned, than the discrepancy between elapsed proper times.

Thus, the Earth twin, occupying a single frame, can "sweep along" the traveller's path, plotting his distant proper time against his own from one instant to another. The resulting account of the traveller's elapsed time is necessarily relative to the choice of the Earth-bound reference frame: there is nothing absolute, nothing *real* in the kind of simultaneity achieved from such frame-time. A symmetrical attempt from the accelerated twin would necessarily result in gaps, blind-spots and temporal jump cuts, exacerbating the sense of disjunction and separation that is most likely inherent in any relation of simultaneity at a distance.[21] However, this mutual framing of the shared zone of contemporaneity between the twins can be complemented by a continuous exchange of electromagnetic signals between the twins (factoring in Doppler effects), allowing each to form a concrete and continuous—though delayed and distorted—image of his co-

21 For a diagrammatic account of this oddity stemming from the metrical structure of relativistic space-time, see Whitehead (1923).

existence with the other. Langevin's original scenario introduces this additional twist. By opening a live stream of information between the twins, a measure of connectedness and continuity is restored within relativistic simultaneity.

9 The Twins II: Contemporaneity and the Active Present

The temporal perspective introduced by such real-time communication is essentially different from the one classically associated with reference frames, where simultaneity relations apply to distant events that are by definition causally insulated (space-like separated) from each other. It helps us realize, by contrast, what is really involved in the relativization of simultaneity defined in terms of instantaneous planes of simultaneity. Whitehead was perceptive enough to generalize the situation based on purely topological considerations. Drawing from the light-cone structure of relativistic space-time, he devised an elegant definition of "contemporary events": certain pair of events are indeterminate as to their time order simply because their mutual locations in space-time prevent them from influencing each other. In other words, an exchange of signals between them would have to be faster than the speed of light. Such events are said to stand in a relation of mutual causal independence.

This simple definition is also found in Reichenbach's contributions to the philosophy of space-time. One of its advantages is its universal scope: for any given event with its associated light-cone, the set of its "contemporaries" coincides with the set of events laying in the wedge-shaped region outside the cone. The form of the causal nexus thus appears hollowed out through and through: it is as if each event brought with it a negative nexus, the shadow cast by all that is concealed from it. This outer zone of contemporaneity, which Eddington called the "Absolute Elsewhere", is sometimes referred to as the "topological present" in the current literature on space-time coexistence (see, e.g., Balashov 2010, 68). It illustrates two essential facts about simultaneity: a) relations of simultaneity are based on facts of causal disconnection, and b) they extend to thick regions of space-time, rather than being confined to infinitely thin layers of instantaneous coexistence.[22] Bergson already recognized that the simultaneity of instants finds its condition in the simultaneity of flows. Whitehead goes further, showing that for any two contemporary events,

22 In Eddington's terms: "the absolute past and future are not separated by an infinitely narrow present" (Eddington 1929, 48).

there will be some reference frame in which they are simultaneous in the usual, Einsteinian sense (Whitehead 1925, 77). Hence, the relativity of simultaneity can be reformulated in terms of the degrees of freedom we enjoy in slicing at different angles across the zone of contemporaneity attached to a given event. The resulting planes of simultaneity are so many perspectives taken on a more comprehensive region of contemporaneity. Hence their inherent relativity takes on objective meaning: it is an expression of the temporal underdetermination of disconnected events, as much as of the arbitrary choice of reference frames.

Compelling as it is, the interpretation of coexistence as contemporaneousness has some limits: it is restricted to certain classes of events (those that are space-like separated), and more importantly, from a practical standpoint it is ultimately relative to the point-like perspective opened by particular point-events in space-time, rather than space-time paths or stretches of duration. As a result, it is not easily applied to real enduring observers and more generally, extended processes. Nevertheless, the negative definition of coexistence in terms of disconnection or separation manages to capture a basic phenomenological feature of our extended present that is best illustrated by the experience of somewhat helplessly waiting for the answer to a message.[23] It is as if a siphon were draining the time elapsing emission and reception, creating a sense of absence and void.[24] This sheds light on the twins' scenario. For the twins too are separated while contemporaneous. In their case, the element of disconnection (in space) is dialectically intertwined with that of connection (in time). Absence is incorporated within an overall sense of distended co-presence. Following Whitehead, we may say that the situation typically "expresses how contemporary events are relevant to each other, and yet preserve a mutual independence. This relevance amid independence is the peculiar character contemporaneousness" (Whitehead 1958, 16). The point, however, is that the twins' separation is not absolute: the twins qua living observers *endure*; besides pairs of contemporary events on their re-

23 This point is nicely illustrated by Eddington: "Suppose that you are in love with a lady on Neptune and that she returns the sentiment. It will be some consolation for the melancholy separation if you can say to yourself at some—possibly prearranged—moment, 'She is thinking of me now'. Unfortunately, a difficulty has arisen because we have had to abolish Now. There is no absolute Now, but only the various relative Nows differing according to the reckoning of different observers and covering the whole neutral wedge which at the distance of Neptune is about eight hours thick. She will have to think of you continuously for eight hours on end in order to circumvent the ambiguity of 'Now'" (Eddington 1927, 49). The "neutral wedge" refers to the wedge-shaped neutral zone between two light cones: the intersection of their respective outer zones of contemporaneity.

24 Sartre has provided compelling phenomenological elucidations of this experience of separation (see During 2018, 423–425).

spective paths, there are innumerable events which can in fact be causally connected, as illustrated by Langevin's hypothesis of communicating observers. Thus, the various schemas of coexistence appear subtly entangled. As they continuously exchange electromagnetic signals, the twins coexist in the sense Bergson spoke of a simultaneity of flows, but in other respects they are contemporaneous with each other in the sense Whitehead spoke of the mutual relevance of independent events.

Other models of non-standard simultaneity suggest themselves to make sense of the distended coexistence of the twins. Taking one further step in the direction of co-presence, we may consider the active (or interactive) present based on the so-called "Alexandrov interval", defined by the intersection of the future light cone of an event A with the past light cone of an event B causally related to A.[25] Within this diamond-shaped region of space-time, all events can be causally related to both A and B. Thus, if A and B are two events punctuating the worldline of an observer, the interval defines a zone of active present comprising all the entities, objects, processes with which this observer can interact during a short but finite interval of proper time such as the one corresponding to the specious present. This seems rather intuitive, for the objects with which we can interact within the bounds of our specious present certainly contribute to our perception of a field of co-presence in which we participate with other beings. Each of the twins carries with it such an interval of active present. But to properly apprehend their coexistence requires that we pay attention to the patterns of intersection between their respective presents. For observers coexist in a relevant sense when their active presents substantially overlap, outlining a specific zone of co-presence that expresses the particular nature of their relation. (Incidentally, in the case of asymmetrical relations, coexistence may take a unilateral form, distinguishing itself from the common understanding of simultaneity relations as reflexive, symmetric and transitive.) What was introduced earlier as a region of simultaneity—a topological envelope defined by two doubly intersecting worldlines—can now be redescribed as a field of relational coexistence, provided that observers involved in that field interact in a symmetric way during the entire time of their separation. It is thus possible to account for the twins' story in a way that is both frame-independent and conjunctive, offering a unified picture of their shared history, notwithstanding the amount of temporal distortion and disruption induced by the underlying dynamics.

Kant's doctrine of simultaneity in the *Third Analogy of Experience* followed a similar pattern: the relational theme was given by the category of community or

25 On this and other issues of spatio-temporal coexistence, see Balashov 2010, 143 ff.

reciprocal action. Yet, despite the claim that simultaneity is a *sui generis* temporal relation that cannot be reduced to the non-successive, the positive meaning of that relation remained somewhat obscure. To give substance to simultaneity, the best Kant could do was to refer it to the sheer density of the links of mutual causal dependence between enduring objects. In true Leibnizian fashion, coexistence came in the form of a seamless *plenum* of interactions. By contrast, embracing the philosophical consequence Einstein's principle of locality—the idea that in the absence of instantaneous action at a distance, *every connection takes time* —, Whitehead's approach acknowledges the primordial function of causal separation, bringing to light the negative nexus embedded within relativistic space-time. In that respect, contemporaneity is the obverse of simultaneity. Taken together, they form a dual image of coexistence, giving it its full scope.

10 The Twins III: Zeno's Shadow

This survey of some varieties of coexistence served one main purpose, namely to drive home, once again, a rather simple message: we are not dealing with time, properly speaking, unless we make room for all its relevant dimensions, including simultaneity in the generalized sense just considered. The value of the twin paradox resides in the simplicity and generality of the situation from which it arises: it forces us to re-examine our ideas about coexistence. Reflecting these ideas against space-time, interpreting them in the light of a categorial scheme that physics itself does not provide, reveals an intricate and multi-layered dialectics of local and global, invariance and perspective, connection and separation.

The truth, however, is that Bergson argued his case quite differently. He made it seem as if he was trying to preserve at all costs, in an uncommonly *a priori* manner and for essentially conservative purposes, the sheer *equality* of the twins' elapsed durations. This assumption of metrical uniformity directly contradicted one of the tenets of Relativity theory, since the synchronicity of proper times is *not* preserved in the general case involving accelerated observers. More serious still, it obscured the underlying issue of coexistence by virtually aligning the entire situation on the trivial case of two co-moving inertial observers.

A few hypotheses may be ventured as to the reasons behind Bergson's misguided tenacity. The first thing to consider is simply the immediate benefit of refusing to acknowledge the difference in overall aging. Bergson realized that it was the most straightforward way of preserving a sense of temporal unity and shared human experience, while remaining faithful to the metaphysical views set forth in his earlier works (Bergson 1991, 209 – 211). The metrical uniformity of time measurement was immediately compatible with the idea of an essential rhythmic uniformity of both matter (the most relaxed degree of duration) and human consciousness (characterized by its own specific degree of tension). Since the metaphysical grounds of this temporal uniformity were not directly discussed by Bergson in the context of Relativity, it was difficult to resist the impression that the philosopher was merely clinging to some intuitive and ultimately subjective concept of absolute time.

Why did Bergson lay so much stress on *metric* equality, when all he needed to establish was the somewhat looser connection between real time and the generic uniformity of lived duration acting as a connecting thread between dispersed flows of duration exhibiting various degrees of tension? To clarify his motives, it is important to bear in mind the basic insight behind the battery of arguments devised to expose the unreality of the temporal *perspective effects* underlying Langevin's paradox. These arguments can be traced back to another paradox. The "Stadium", also known as the paradox of the "Moving Rows", is arguably the least famous among Zeno's paradoxes of motion. Yet Bergson deems it the most instructive (Bergson 1991, 192). The classic version involves bodies (rows) of equal length moving along parallel tracks within a stadium, at different speeds and in opposite directions. If Aristotle's account in *Physics* VI, 9 is to be trusted, Zeno fallaciously argued that, given the appropriate speed ratio, the elapsed duration attached to a particular moving body would appear to be *double of itself* when measured by the trace left along another body moving at a different speed. It is easy to see that we are dealing here with reference frames in relative motion. In this regard, the pages devoted to "light figures" in *Duration and Simultaneity*, chap. V, while containing no direct mention of the "moving rows", offer a striking parallel with Zeno's paradox. Bergson substitutes for the moving rows a ray of light moving back and forth between two plates—a situation that should be familiar to anyone who has been introduced to Relativity theory by means of considerations regarding the behaviour of "light clocks". Viewed from different reference frames moving at various speeds, the light figure traced by the ray of light will appear variously slanted or distorted, it will exhibit shapes of different lengths—all equally valid spatial projections of one single time lapse.

Based on this example, Bergson interprets relativistic effects such as length contraction and time dilation as mathematical artefacts stemming from the conditions of measurement, more particularly from the correlation of all elapsed durations with trajectories in space. Since the spatial expressions of duration undergo deformations through the prism of speed, durations themselves admit as many values as there are degrees of speed—in fact infinitely many since reference frames can be arbitrarily chosen in order to track light. Relativity, in that sense, offers a coherent theory of the changing kinematic perspectives one may take on real motion and duration: the Lorentz transformations account for the resulting perspective effects while giving mathematical expression to what remains invariant under the virtually infinite multiplication of dilated times. Bergson rightly emphasizes the invariance of proper times beneath the kaleidoscopic deformations of improper times; but as far as duration itself ("true duration"), the measuring operation only touches its surface. The internal change affecting matter remains indifferent to its spatial projections under perspective views. The "unity of real time" is thereby preserved, although mathematically this may seem to boil down to the invariance of local time which, as we have seen before, cannot be the last word on the matter. At this point, Bergson's strategy seems to break down. But his diagnosis, delivered as a distant answer to Zeno's arguments, remains valid as long as we are dealing with uniform motions and inertial frames.

The more pressing problem is to understand how this reflects upon the discussion of Langevin's paradox, which involves accelerated observers. Quite simply, fascinated as he was with the relativistic transposition of the Stadium, Bergson was led to systematically overstate matters of symmetry, perspective and relativity in the more general case illustrated by the twin paradox. As Zeno's shadow was cast over the twins, he was led to believe that the paradox could be diffused as yet another instance of purely perspectival effects. That is why he insisted that a rigorous formulation of Langevin's scenario should maintain a complete symmetry between the twins' space-time trajectories, each being entitled to take himself to be at rest, while the other is in motion.

What about the obvious geometrical objection? In order for the twins to eventually meet again, one of them must make a U-turn at midcourse. Regardless of *who* is actually travelling, a dissymmetry is bound to occur somewhere, at some point, resulting in an overall difference in elapsed durations. As previously stated, the longest route through space-time happens to be the shortest through time:[26] Bergson did not realize the full implications of this basic mathematical feature of Minkowski space-time, because he systematically downplayed the importance of space-time constructions, which he viewed at best as mathematical devices with no real ontological grounding. He generally believed

26 In the idealized "3-clocks version" of the twin paradox where the round-trip involves only uniform motions, this metrical oddity is clearly exhibited by the relativistic counterpart of the more familiar Euclidean "triangle inequality". The sum of the lengths (i.e., elapsed proper times) of the opposite sides of a triangle drawn in Minkowskian space-time is *shorter*, not longer. Hence the idea that crooked paths in space-time constitute temporal "shortcuts". See During 2007, 99–100.

he could play the physicist at his own game by dealing with the paradox in a strictly relational manner, *de facto* abstracting from all the relevant physical features of the situation. By neglecting the dynamic aspects of the situation in favor of the kinematic reciprocity of the observers' perspectives upon their respective trajectories and timelines, he reduced the paradox to a mere thought experiment, an argument to be dealt with on purely conceptual grounds. He made it seem, in short, as if the task of plotting the twins' relative motions in space-time was essentially underdetermined, allowing for multiple equivalent spatio-temporal embeddings. Once the twins were construed as interchangeable, their respective durations could only end up coinciding.[27]

In Bergson's defense, it is based on similar premises that Paul Painlevé, a first-class mathematician and member of the French government, had boldly challenged Langevin (in 1921), and later Einstein himself in 1922. The latter episode took place on April 5, one day before Bergson's meeting with Einstein (Bergson 2009, 402–409). It provides us with another test-case for the principle of hermeneutic symmetry. To make his point, Painlevé had devised an even simpler model than the original: Langevin's Jules-Vernesque rocket and its space journey had been replaced by a train leaving its station to make a round trip. More importantly, the story involved only constant velocities, suggesting a perfect symmetry or reciprocity between observers in relative, uniform motion. From there, Painlevé argued that time dilations being reciprocal, their effects should simply cancel out.

Einstein easily overturned the objection by reminding his eminent colleague that the situation he was describing did not in fact involve two frames of reference in relative motion, but *three*. By the mere fact of making a U-turn to come back to its starting point, the train observer was forced to "hop" on a new reference frame at midcourse. Therein lies the reason for the overall discrepancy in elapsed times. Painlevé immediately conceded Einstein's point and the matter was thus settled to the satisfaction of all parties. Understandably, Bergson did not see fit to take up the matter again the next day, when his turn came. Instead, he chose to deliver a lecture on simultaneity. Painlevé's 5-minutes argument with Einstein nevertheless left a durable trace on him, as attested by the fact that it is literally reproduced (and duly credited) in *Duration and Simultaneity*, and dis-

27 The strategy is reminiscent of the way Berkeley, Mach or Poincaré criticized Newton's absolute space by using the symmetries of a physical situation to establish the actual indiscernibility of two states of affairs. Thus, if the universe were reduced to two particles in relative motion, there would be no way of telling which particle is *really* accelerated, or directly affected by time dilation. The two would be literally substitutable, so that anything said about the one could just as easily be said about the other.

cussed again at length in the appendices. Clearly, it must have had some philosophical merit in his eyes, despite the fact that it had been refuted. But there is little to be gained in defending the indefensible. With the benefit of hindsight, it cannot be denied that the more relevant issues regarding contemporaneity were obscured by Bergson's stubborn insistence on interpreting the twins' paradox through the lens of time-dilation, in terms of referential and reciprocal effects. Relativity, in the broad sense Poincaré gave to this term when speaking of the relativity or homogeneity of space (i.e., the symmetries accounting for the similarity of figures), certainly functioned as an *epistemological obstacle* in that respect. So did the projective metaphor of perspective underlying the criticism of so-called "fictitious times".

Conclusion

These elements of context may help us better appreciate, by contrast, the ongoing relevance of Bergson's otherwise frustrating debate with Einstein. Like several scientists and philosophers of his time, he certainly failed to appreciate the structural relevance of the twin paradox for Relativity theory. This blindspot in his assessment of relativistic time is palpable in the resistance he opposed to the idea of unsyncable durations, and more generally to the notion of local time. But the different circumstantial reasons reviewed in this paper should not overshadow the more fundamental ones, chief among which is a deep attachment to the idea of time as form, despite the emphasis on heterogeneous durations and rhythms. On the upside, from the commentator's perspective, Bergson's quasi-intentional "blunder" and the discussions it triggered provide an opportunity to clear the ground and allow vital questions to emerge in plain sight. The sublimated version of the twin paradox, unfolding in abstract homogeneous space, plainly distorts Langevin's original intent, but by doing so it also directs our attention to the fact that the lines of flow of extended matter, refracted and dispersed as they are throughout the universe, going out of sync at every moment, still do so *together* in a genuine temporal sense. These flows are contemporaneous, and in more than one way. Simultaneity does not reduce to absolute facts of spatio-temporal coincidence or to the conventional framing of world-wide instants: there are such things as sheaves of simultaneity. The twins illustrate this basic truth in their own inchoate manner. Realizing it opens up new perspectives on the problematic temporal unity of material process. This process may well turn out to be fundamentally open at the cosmological level because the universe itself endures and is subject to change, but this should not prevent us from trying to make sense of the unity of material durations. The same naturally holds true of the living in general. The challenge, in every case, is to approach this unity in temporal terms, *sub specie durationis*. What distinguishes Bergson's version of time form in that regard is that none of its concrete models can be achieved in one stroke: they are themselves in the making.

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Alessandra Campo, Rocco Ronchi

Peter and Paul: a Ghost Story?

Let us in a word become accustomed
to see everything *sub specie durationis:*
immediately, in our galvanised perception,
what is taut becomes relaxed,
what is dormant awakens,
what is dead comes to life again.

Bergson, *La Pensée et le Mouvant*

Abstract

For Bergson, Special Relativity affirms the unity of real Time more rigorously than either Newtonian mechanics or common sense. Yet, *time* and *unity* describe different realities in the metaphysics of Einstein's theory and the metaphysics of Bergson's creative duration. The time Einstein adopts as the fourth dimension of space is only a 'mobile image of eternity', and the unity it preaches is an abstract unity, synonymous with mathematical invariance. This is why, according to Bergson, Einstein's Relativity is not completely *relative*. It admits a *unique* real Time in the sense that it admits only *one:* that of the physicist engaged in measuring the world. The so-called twins' paradox is exemplary in this respect.

I Ghost-Relativity

1 The Ghost-Book

Why a ghost story? Because *Duration and Simultaneity* (henceforth *DS*) is, above all, a ghost-book. It appeared as a book by Bergson but then, after its 6th edition (1931), disappeared at the author's request. It returned later, it is true, but only as a ghost, such that nobody knew where to place it. It finally found a place in the *Mélanges* (1972), not in the *Oeuvres*. But, on the occasion of its 7th edition (1968), Jean Wahl, Henri Gouhier, Jean Guitton, and Vladimir Jankélévitch still felt the need to issue a statement to justify its (re)appearance in French bookshops. In a way, then, no one can establish with confidence if *DS* is really Bergson's book or, rather, something more like a symptom: a missing act, for example. If it is spectral, this is also because the term 'ghost', together with all its syno-

https://doi.org/10.1515/9783110753707-010

nyms, obsessively haunts the book. 'Phantom' is one of the words that Bergson uses most often to comment on Einstein's Special Relativity (henceforth SR) and, even if in *DS* it is not always a matter of ghosts – at least not always literally – one finds marionettes and empty puppets.

For Bergson, SR[1] involves virtual or fictitious beings: mirages that seem to have life but really do not. In his opinion, this is exactly what emerges from the famous paradox[2] devised by Paul Langevin in 1911[3] and adopted later, in the strict form of a *twin* paradox, by Hermann Weyl in 1919.[4] Here, the twins Peter and Paul[5] take turns as the ghost: if one acts as a reference system, then the other suddenly disappears becoming a phantom. There is, in short, a dizzying game of mirrors which, for Bergson, reveals the very essence of SR: if Peter lends his eyes to Paul, then Peter can no longer see. He is only seen but does not see. '*Peter* – in Bergson's own words – *would no longer see himself as anything but a vision of Paul*' (Bergson 1965, 72) because, as soon as he is seen by Paul, he becomes a puppet (Bergson 1965, 78): an entity whose ontological stuff consists solely in being watched *from afar*.

According to Bergson, Einstein's SR is like a baroque theatre: a theatre of deforming mirrors which is, at once, comic and uncanny. Comic because, as Bergson argues in his essay on laughter (1900), a comic effect results when an observer suddenly grasps the inanimate, phantasmatic, and virtual nature of somebody's real and actual movement, i. e., a fall or, as in our case, a journey on a cannonball.[6] Uncanny because, as Freud pointed out in his essay on the uncanny (1919), when the most familiar experience suddenly turns into the most unfamiliar, this disturbs us greatly. Now, Bergson assumes that Paul is the homo-

1 Not General Relativity. See Bergson 1965, 157–160.

2 As is well known, this is only a paradox as long as one assumes the symmetry of the uniform motions relative to each other (see, e. g., During 2007, 80–82). The point is that for Bergson there is no difference between a system moving in accelerated or uniform motion. Therefore, from the analysis of SR alone Bergson draws conclusions that are valid for Relativity *tout court*. Also note that, for Bergson, this paradox only has value as a mental experiment. For an analysis of these thesis and their consequences, see During (2020).

3 Von Laue first employed the term 'paradox' in 1912, attributing it to Langevin. See von Laue 1912, 118–120 and von Laue 1913 43; 57–58. But Paul Painlevé was certainly the first to formulate it clearly as such on the occasion of Einstein's visit to the Collège de France on April 5 1922. See Nordmann 1922, 143–152.

4 In *Raum, Zeit, Materie*, Weyl speaks about two twins: 'zwei Zwillingsbrüdern' (Weyl 1919, 158). Max Born, in turn, mentioned twins in his 1920 work on the theory of Relativity. See Born 1922, 194. See also During (2014).

5 Bergson is the first to name the twins.

6 As is well known, depending on the formulation of the paradox, the means of transport changes.

zygotic twin of Peter – a crucial supposition as we will see – such that no one is more familiar to Peter than Paul. Yet, who precisely is said to be returning younger, and thus also changed, from the journey?

Nevertheless, Bergson argues that Paul's movement can produce a comic and uncanny effect, only and precisely to the extent that neither the travel nor the traveller Paul are real in the proper sense. For Bergson, *to be launched into space on a cannonball* means *to be projected onto a screen*, *to be painted on a canvas*. In short: to be represented.[7] 'The Paul who gets out of the projectile on returning from his journey and then again becomes part of Peter's system, is something like a flesh-and-blood person stepping out of the canvas upon which he had been painted' (Bergson 1965, 169). Paul is only the name of Peter's imaginary doppelganger: the virtual projection of *what would happen to Paul*, *from Peter's point of view*, if Paul was travelling on a cannonball around the Earth.

For Bergson Peter's reasoning and calculations while Paul is travelling only apply to a painting, because *what is real* is only the Paul who comes back, as soon as he comes back. Yet, if his movement is only apparent, it is not even correct to express oneself in this way. According to Bergson, we should rather say that Paul is always there and always present: the spectral, i.e., modal, character of plural times proves that Paul is, in reality, contemporary to Peter,[8] even if this does not mean they are identical. As twinning shows, Peter and Paul *are and are not the same person* because twinning, especially of the homozygotic kind, is a strange kind of one which is two and a not-less-strange kind of two which is one.

2 The Ghost Theory

For Bergson, the two twins *are not really two although they are more than one* and that is why the hypothesis of twinning is so essential for him but not for Einstein, who only spoke about clocks. Twinning undermines the Leibnizian principle of indiscernibles, forcing thought to equip itself with blurred vision. Peter and Paul are not really two, as the letter of SR demands, but neither are they one, as its spirit suggests. Then, it is only as an argumentative strategy that Bergson says

7 For Bergson, criticizing SR means criticizing the cinematographic mechanism of thought that underlies it (Bergson 1965, 142). See his *Creative Evolution* for the definition of this mechanism. But see also Poincaré's influence on Bergson, which explains the credit that the latter gave to a reading of Einstein's SR focused on the primacy of perspective and symmetry.

8 The unique time proven by the fictitious character of SR's multiple times is a non-spatial coexistence that Bergson calls 'intuitive simultaneity' and which he thinks of as a non-standard simultaneity for which twinship offers a powerful image.

that Paul could replace the painting becoming a 'referrer' from the 'referred' he was, as soon as he suddenly passes from motion to immobility.[9] That Paul can become a referrer *again* – by assuming himself as a reference system in place of Peter – proves that, in reality, he has *always* been one, although the Peter who takes the measurements on Earth can, for a while – the very time that he is measuring – pretend that this is not the case, that is pretend to be *the one and only* reference system.

Indeed, as soon as Peter starts measuring, Paul becomes nothing but Peter's vision: that very same Peter but, so to speak, doubled as a virtual image. In *DS*, in fact, Bergson employs the term 'virtual' in a classical sense: virtual, he writes, is each phenomenon that is subject to 'a mental torsion' (Bergson 1965, 107), i.e., to a projection. So, if Paul can be said to be 'virtual' with respect to Peter, this is because he is depicted 'at a distance' by Peter and because 'at a distance', for Bergson, means 'according to those rules of linear perspective which are Lorentz's formulas'[10] (Bergson 1965, 77; 108).[11] These rules 'quite clearly express what the measurements attributed to S' must be in order that the physicist in S may see the physicist *imagined* by him in S', finding the same speed for light as he does' (Bergson 1965, 171). Whenever SR supposes only one of the two systems at rest, it is understood that

> only the physicist in system S exists as a physicist, the one in system S' is merely imagined. Imagined by whom? Necessarily by the physicist in system S. The moment we make our system of reference, it is from there, and from there only, wat a scientific world view is thenceforth possible (Bergson 1965, 87).

Bergson's thesis is clear: when a physicist adopts a reference system, thereby immobilizing it, everything that occurs in the other reference systems will be expressed prospectively according to the more or less considerable distance that, on a scale of varying magnitudes, exists between the speed of the referred-to systems and the supposedly null speed of the referrer one. The physicist, in other words, acts like a painter who has to represent the greater or lesser distance of his model: he will modify its dimensions at will. As soon as he immobilises

9 The relationship between Peter and Paul is the same relationship that language's theories establish between the 'referrer' and the 'referred' (Bergson 1965, 76–77; 109; 169–171; 184), that is between the subject of enunciation and the subject of enunciated.

10 Virtual, then, means perspectival and perspectival, for its part, means possible thanks to a calculation.

11 And it is for this reason, after all, that they are perfectly symbolised by that formal ether which is Minkowski's space-time and that they also find a good translation in SR's hypothesis of multiple times (Bergson 1965, 156).

his reference system, Peter makes the others mobile, but mobile in a different way. Yet, in the mathematical representation that he elaborates on the differences between his system and the others, providing data that quantifies the greater or lesser slowdown of the other times, he measures only the greater or lesser distance of their speed with respect to his own which, by contrast, is null by convention.

For Bergson, the slowing of the moving clock is a means, for SR, to record displacement in the same way as the shrinking of the objects that move away is a means, for the eye, to record their moving away. So, if the slowdown of time is real, it is real in the same way that objects shrink due to distance, which actually only translates into 'the impossibility of touching' (Bergson 1965, 74), that is, the impossibility of being physically in more than one place at the same time. Paul's slowed-down time is only an 'attributed time' (Bergson 1965, 77): a simple mathematical expression destined to indicate that it is the system of Peter, and not that of Paul, which is considered as a reference system. Therefore, what is presented as rejuvenation is only shrinkage: a size variation to which no real temporal variation corresponds. The interval that SR estimates between two or more systems is empty. Reduced to mere spacing, 'it is only the nothing of the original time, producing some kind of optical effect in the mirror of motion' (Bergson 1965, 154). Paul's motion is this optical illusion: nothing but a projection of Peter dictated by a theoretical need. Bergson reliably compares it to the one we would obtain by trying to move a piece of furniture in the living room by acting on its reflection in the mirror: if we were able to move over to the distant object and catch it in its true size, we would see the object we have just moved away from gradually shrinking.

Peter and Paul, in sum, are only two people of normal size who see each other reduced by distance (Bergson 1965, 163–164): each of them is a midget in the representation of the other but, neither of them can conclude from this fact that the other is also in reality a midget. The midget remains a ghost, while it is the man of normal size who is real. Vice versa,

> If we reasoned about someone far away, whom distance has reduced to the size of a midget, as about a genuine midget, that is, as about someone who was a midget and acts like a midget, we would end in paradoxes or contradictions; as a midget, he is "phantasmal" the shortening figure being only an indication of his distance from me (Bergson 1965, 163).

3 The Ghost Reciprocity

For Bergson, the Paul considered in space-time is a double of Peter which, spatially, has contracted in the direction of its motion, and, temporally, has expanded each of its seconds; and which, finally, has broken up into succession in time every simultaneity between two events whose distance apart has narrowed in space (Bergson 1965, 21). But these changes, which can be summed up as variations in the length of successive intervals (Bergson 1965, 33), escape the moving observer: 'only the stationary observer is aware of them' (Bergson 1965, 21). Indeed, when Peter attributes slowed-down time to Paul's system, he is no longer thinking of Paul as a physicist, nor even as a conscious being: 'Peter is emptying Paul's visual image of its inner, living consciousness, retaining of the person only its outer envelope (it alone, in fact, is of interest to physics)' (Bergson 1965, 72).

Nevertheless, as soon as Peter represents Paul consciously, i.e., a Paul who lives within his own duration of time and measures it, Peter 'would by that very act see Paul take his own system as system of reference and therefore take his place within this single time, inside each system' (Bergson 1965, 72). Hence, Peter would temporarily do without his reference system, his existence as a physicist and, finally, also without his conscience: he would see himself as 'a vision of Paul's' (Bergson 1965, 72). Peter, says Bergson, takes the figures by which Paul would have designated the time intervals of his own system, were he conscious, and multiplies them by numbers so as to make these figures fit into a mathematical representation of the universe conceived from his own point of view and no longer from Paul's (Bergson 1965, 72). But, Bergson insists, if Paul came alive, it would be Peter who – from the SR's point of view – would find himself deprived of his ability to see, becoming the one observed by an observer he once was.

A real Paul who actually measures real Time, would be an existing Paul who assumes his cannonball as a reference system making it immobile, because, if one of the phantom observers suddenly came to life, he would install himself 'in the real duration of the former real observer, who would become phantasmal in his turn' (Bergson 1965, 149) and then live within the time of an immobilised system, i.e., within the same time that Peter would have lived. 'Would have', Bergson clarifies, because Peter no longer lives it since Paul, until that moment represented, now becomes *living and conscious*.

> Yet, this leaving-and-entering of consciousness, it might be added, obviously does not begin until we turn our attention to physics, because it is then clearly necessary to choose a system of reference. Outside of that, *the men remain as they are*, one group like the other. There is no longer any reason for their not living the same duration and evolving in the

> same time. The plurality of times looms up at the precise moment when there is no more than one man or group to live time. Only that time then becomes real (Bergson 1965, 80, our italics).

If Peter lived, felt, and existed as Paul, he would find that his twin is of the same age (Bergson 1965, 64) and of the same size (Bergson 1965, 64), i. e., that his twin's time has passed and has been measured in the same way as his own. However, as long as he chooses to transport himself to Paul only in his imagination, he will remain a victim of the deceptions of perspective formalised in Lorentz's equations. But Peter is a physicist and, given the impossibility, in physics, of tracing back events in the universe to two different systems of axes at the same time, he can only assume one real Time at a time. Unlike the philosopher, his attention 'is not able to be divided without being split up' (Bergson 1965, 52) because, although he implicitly assumes that reciprocity is the cause of the invariance drawn from Lorentz's formulas, and therefore that Paul, if necessary, can become the physicist in place of Peter, he will always record only the optical effect of the reciprocity of movement (Bergson 1965, 76).

For Bergson, however, this is an error that cannot be corrected in terms of physics: complete Relativity is open only to philosophy. The physicist, on the contrary, has to give the universe a stable configuration (such is his ethical responsibility) and is forced to transpose the hypothesis of reciprocity onto that of non-reciprocity, 'because to express mathematically the freedom of choosing between two systems of axes is actually to choose one of them' (Bergson 1965, 77). This is why, by following the prospective laws of SR, the physicist will always attribute more or less slowed-down times to the systems that he will have gradually abandoned and that he will have set in motion at more or less considerable speeds. Which, translated into Bergson's language, means that

> the physicist, feeling free of the theory of reciprocity once he has done it homage by freely choosing his system of reference, surrenders it to the philosopher and hence forward expresses himself in the language of the privileged system. Paul will enter the projectile, believing in this physics. He will come to realise on the way that philosophy was right (Bergson 1965, 78).

II The False Name of 'Relativity'

1 A Masked Absolutism

The great thesis of *DS*, it cannot be stressed enough, is that SR succeeds in affirming the unity of real Time better than Newtonian mechanics. This can be surprising, says Bergson, but it is the simple truth: 'the idea of a real Time common to two systems, identical for S and S', asserts itself with greater force in the hypothesis of the plurality of mathematical times than it asserts itself in the commonly accepted hypothesis of a unique and universal mathematical time' (Bergson 1965, 80), because, as long as S and S' are taken into consideration, SR invites us to consider them as 'strictly interchangeable' (Bergson 1965, 80). Newton's mechanics, instead, suggested we treat them as different systems in relation to an absolutely privileged system. And, as a consequence of this, although each one was attributed the same mathematical time, it was impossible to demonstrate that the observers placed respectively in the different systems lived the same inner durations and had the same real Time. Only SR is allowed to do so, even though, for Bergson, Einstein failed in his own intuition leaving his theory of Relativity half finished.

What should distinguish SR from Newton's physics is the suppression of any privileged reference system. But, in Einstein's theory, this suppression is not fully achieved. In spite of the fact that SR provides for complete reciprocity or interchangeability between reference systems, it always introduces a dissymmetry. Thus, although Bergson believes that only Einstein had definitively demonstrated the modern idea *par excellence*, that is, the Cartesian idea of the reciprocity of motion (Bergson 1965, 35–38), he argues that there is a difference between the philosopher and the physicist: a difference which consists exactly in the greater allegiance of the former to the hypothesis of a universe in which the privileged reference system has, so to speak, lost all of its privileges. A complete Relativity, in fact, is a Relativity that takes on the full reciprocity of all observers without privileging any of them. Bergson presents this as a radical thought about 'whatever' in which, as the Copernican Giordano Bruno intuited before him, *nothing is centre, everything is centre:* the idea of a complete reciprocity asks to us

> going unceasingly from Peter to Paul and from Paul to Peter, considering them interchangeable, immobilizing them by turns [...] for only an instant, thanks to a rapid oscillation of the attention that does not wish to give up anything of the thesis of relativity (Bergson 1965, 75).

Hence, if SR is partial, it is to the extent that, while admitting *de jure* the reciprocity of all observers, it privileges *de facto* only one of them, thus attesting to itself as a false thought about whatever: a non-Copernican thought in which only a single reference system is at the centre, albeit temporarily. Indeed, once the ether has vanished with the privileged system and the fixed points, all that remains, says Bergson, are the relative motions of the objects in relation to each other. But, since one cannot move with respect to oneself, immobile will be 'that system which we enter mentally. A *living*, *conscious* physicist then exists in it by hypothesis' (Bergson 1965, 168) because when we assume that every motion is relative, immobility 'is of our decreeing' (Bergson 1965, 168).

> It will be the state of the system of reference, the system in which the physicist *imagines* himself located, inside which *he is seen* taking measurements and to which he relates every point in the universe [...] the physicist-builder of Science, is motionless by definition, once the theory of Relativity is accepted. It unquestionably occurs to the relativist physicist, as to any other physicist, to set in motion the system of reference in which he had at first installed himself; but then [...] he adopts another one [...] which thus becomes motionless [...]; and it is then no more than an *image* of himself that he mentally perceives what was just now, in what will in a moment again become, his system of reference (Bergson 1965, 167, our italics)

However, in this way, the difference between Einstein's SR and Newton's classical mechanics ends up having, at most, the breadth of an adverb: whereas the Newtonian physicist could count on a reference system that was *absolutely* and *definitively* privileged, inasmuch as the universe had, in itself, a concrete configuration independent from the physicist's point of view, the physicist of SR can, on the contrary, only choose from time to time a reference system that, consequently, is only *relatively* and *temporarily* privileged. Yet, for the philosopher this variation does not translate into a real difference because, although there is nothing that forbids one from supposing – as SR regularly does – that, at any given moment, one's own reference system is also in motion, as soon as the physicist advances this supposition he immediately chooses another reference system, which then inevitably loses its mobility and become motionless. And, even if this second system may, in turn, be thought of as being in motion, in this very thought, a third reference system is chosen and immediately immobilised, and so on and so forth, indefinitely.

Einstein's universe, therefore, is a universe as real, as independent from our mind and exists in the same absolute sense as Newton's universe. The difference is that if, for Newton, this universe is a set of things, for Einstein, on the other hand, it is a set of relations: those invariant elements 'held constitutive of the reality' (Bergson 1946, 304). The method of SR consists in seeking a mathematical representation of things that is independent from the observer's point of view, but such a representation is a representation that constitutes 'a whole of *absolute* relations' (Bergson 1946, 300). Nothing more contrary, Bergson says, 'to relativity as philosophers understand it when they treat as relative our knowledge of the external world' (Bergson 1946, 300). The essence of SR

> precisely guarantees that the mathematical expression of the world which emerges from this arbitrarily chosen point of view will be identical, if we conform with each other in the rules that are laid down, with that which we will find when we situate ourselves at any other point of view. Hold on only to this mathematical expression, and there is no more time than there is anything else. If you restore the time, you restore things (Bergson 1999, 189–190).

According to Bergson, SR is *restricted* because it expresses a single point of view: that of the privileged reference system and of the physicist attached to it. If it is restricted, then, it is only to the extent that it is partial and unilateral, i. e., to the extent that it is a masked absolutism. While abandoning the old absolute, bearing the good name of 'Relativity', Einstein's theory adopts a new absolute: space-time as a formal substitute for the ether.[12] Such that, says Bergson, if SR qualifies as 'relative' the simultaneity is only because it has made an absolute of the relative[13] by swapping the part (space-time) for the whole (duration), the effect (invariance) for the cause (reciprocity) or, again, the datum (the measure) for the process (the thing) that generated it.

2 The Fallacy of the Physicist

For Bergson, measuring is the opposite of intuiting and it is only by intuiting that it is possible to see everything simultaneously observing. In physics, by contrast, this contemporaneity is inadmissible: measuring means choosing and choosing in the sense of determining. Then, everything which is measured is a logical

12 'In brief, absolute rest, expelled by the understanding, is reinstated by the imagination' (Bergson 1965, 31).

13 'All is relative and only that is absolute' (Nordmann 1924, 195). Lévy-Leblond argues, 'c'est d'ailleurs pour cette raison que la terminologie de "relativité" est d'une certaine façon fort mal venue, parce que le but de la théorie de la relativité [...] c'est précisément de s'occuper de ce qui n'est pas relatif, c'est d'arriver à accéder à ce qui est absolu, à ce qui est invariant, à ce qui ne dépend pas du point de vue; ce qui est relatif, ce ne sont finalement que les apparences, qui nous permettent d'accéder à ce qui est plus profond, plus essentiel, plus intrinsèque – les grandeurs invariantes, les absolus' (Alegria, Noël and Minot 1983, 64).

thing compatible with the principle of non-contradiction, because, by anticipating some of the insights of Quantum Mechanics,[14] Bergson looks at this choice as a division of the indivisible, a localization of the non-localisable. In brief: as a division of what is by nature overlapping. Yet, the choice implied by SR is not, in Bergson's eyes, a free choice but rather an obligation masquerading as freedom. In fact, one must necessarily choose a privileged configuration if one wants to measure, since absolute space and time are no longer at play. In the SR, moreover, the possibility of choosing any reference system in the absence of a fixed framework is based on the fact that the same laws apply in any reference system, i.e., on something that is reliable, inasmuch as it is objective and impartial: the invariance of principles. Thus, although there is consubstantial risk in arbitrarily considering oneself the centre of the world while trying to build a universally valid science,

> the physicist can rest easy from now on; he knows that the laws he formulates will be confirmed, no matter from what vantage point we view nature. For the phantasmal image of his experiment, an image which shows him how this experiment would look, if the experimental device were in motion, to a motionless observer provided with a new system of reference, is no doubt a temporal and spatial distortion of the first image, but a distortion that leaves the relations among the parts of the framework intact, keeps its connections just as they are, and lets the experiment go on confirming the same law, these connections and relations being precisely what we call the laws of nature (Bergson 1965, 112).

The equivalence postulated by SR – thanks to the introduction of invariant elements and the constitution of a formal system that can be used to 'express every event as geometry does for space' (Bergson 1946, 302) – is not the privileged expression of a modal monism, such as the Bergsonian metaphysics of creative duration in which a single real Time is rhythmed in different ways (Bergson 1965, 47), but bears the mark of a substantial dualism: one whose foundation Bergson attributes to the Greek spirit that also permeates modern scientific thinking. In SR, time is opposed to eternity as its lack, because here equivalence is marked by false relativity: an absolutism that is disguised as modern relativism. In SR there is a fictitious plurality of interpretations with respect to the universal and eternal metric of space-time assumed apodictically as a given totality: a fully completed science which is *quelque part* (*quelque part = somewhere = transcendence*). For Bergson, this proves that complete Relativity and incomplete Relativity conceive the ground in a very different way: for the former, it is a living and concrete unity which asserts itself through single differences; for the latter, it

14 Among those who have provided different arguments for the proximity of Bergsonian theses to QM see, e.g., De Broglie (1941); Costa de Beauregard (1947); Gunter (1969).

is a ready-made unity that only awaits discovery: a unity which is given at a stroke in eternity as an abstract identity.

The equivalence postulated by SR and, more generally, by science, both ancient and modern, has the value of an analytical identity (Bergson 1946, 304) between all that temporally exists and the only essence which, transcending it, governs it as a remote rather than immanent cause: the laws of nature as an absolute *fact* of which every single reference system will be, from time to time, an *interpretation.* Einstein's SR, in fact, obtains a homogeneous symbolic expression only by neglecting the difference between the time of a reference system, the one which is real and ascertainable, and the time of all the others, i. e., by an undue *reductio ad unum* whose result is given a priori although, in reality, it comes out *ex post* (invariance is the effect of reciprocity) and that is considered primary although, in reality, it is secondary (invariance is the reciprocity represented). In other words, it is only on the basis of that fallacy, which Bergson calls the 'retrograde movement of the true', that we can choose any reference system by arbitrarily modifying the dimensions of all things. Whether it is a fallacy, then, does not only depend on the fact that all reference systems have been already equalised, because the mathematics has already reduced the dimensions of all things to those relations which will be then preserved during the ghostly becoming of things. For Bergson, the physicist deceives himself also because the relations that he supposes to be eternal are temporary, even though the natural infirmity of our intelligence leads us to believe that they have always been there, and therefore, that they are *given* more than *found*.[15]

While it is thought to be invariance, equivalence is a freeze frame, rather than a continuity of creation. It translates the fact that two or more representations are representations of a one and same thing, that is, of a universe which is independent of our representation. Indeed, if Peter is forced to attribute observations to Paul, it is because he seeks a representation of the world which is independent of any reference system and 'independent', here, means 'a priori identical for all'. For Bergson the only way to satisfy the physicist's desire to be *everywhere and nowhere* is to make all the other reference systems equal to

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15 Our discursive intelligence perceives time timelessly interpreting what is *happening* starting from what has *happened*. It looks at the whole as something that is done or given and not as something that is in-the-making because, due to the retrograde motion of the true, the essence of the so-called "cinematographic mechanism of thought", what comes later seems to be eternally present. That is why physics always swaps the concrete for the abstract, the fact or datum for the event or process that generated it. But, for Bergson, the physicist's mistake is a natural one: our intelligence usually takes the dead past (the '*ed*-form') for the living present (the '*ing*-form') thanks to a retrospective look mistaken for a flyover gaze.

his own and equal on the basis of the only 'difference': that invariance which, although it is derived from a single case, is nevertheless extended to all cases. The research method and the recording procedures of SR, he explains, 'guarantee to the physicist an equivalence between all the representations of the universe assumed from all points of view' (Bergson 1965, 78). And thus, the profession of modernity made by its physicist sounds inauthentic. The physicist of SR certainly has an 'absolute right' (Bergson 1965, 67; 79) to stick to his own point of view, relating everything to his reference system – a right which the old physicist did not fully enjoy. But then he cannot forget that this point of view is his own. Moreover, according to Bergson, he also cannot inflate his chest reflecting on the courage with which he made his decision: by arbitrarily choosing a reference system, the physicist did not run any risk. And, what is more, he has not even chosen: all configurations are equivalent and what they are equivalent to has already been decided once and for all.

3 The Golden Proportion

Invariance is the new form of the old absolute stillness: a relative stillness not so much in the sense of provisional, but rather in the sense of *relative to relations*. It is the latter that are supposed to be eternal by modern science, and the equally supposed eternity of their validity is the reason why, in Bergson's eyes, one never finds a real alternative but, as we have said, always and only a fatal consequence: the decrease of time to a spectral 'moving image of eternity' (Plato, *Timaeus* 37 c-d). After all, that the secret face of relative motion is stillness, that the condition of variation is invariance and, last but not least, that *the true name of relativity is absoluteness*, means that, in SR, time is only thought *sub specie aeternitatis* – but as an eternity 'of death' (Bergson 1946, 220) instead 'of life' (Bergson 1946, 185): an eternity with respect to which the real living duration is only the seal affixed to the creature's deficiency.

For Bergson the incompleteness of Einstein's Relativity depends on the removal of duration, because only its inclusion would prevent the physicist from privileging one reference system over the others, that is from assuming one configuration as the centre for the others. *Sub specie durationis*, reciprocity is granted, because every duration, as an eternity of life, is the connection of all things as living and conscious: of all as reference systems. This avoids the spectral plot of a 'world suspended in the air' (Bergson 1946, 52), which Bergson, with a beautiful image, compares to 'an infinity of crystallised needles' (Bergson 1946, 219): as a continuity of heterogeneity, duration is pure *unitas multiplex* and, consequently, tuning into one's own real Time means tuning immediately into that of all the others. According to Bergson, all durations, despite their different rhythms, coexist in the sense that they co-act or co-evolve together. Each one differs from the other in being more or less compressed, but all together they compose that non-spatial coexistence which is the unique real Time: Bergson's name for contemporaneity as the uninterrupted togetherness of independent durations.

On this basis, we think, one can better understand why it is only by relinquishing his concrete status as a living being, who shares his time with others, that the physicist objectifies and privatises time. The moment he chooses a reference system, he gives up his own concreteness and interiority (becoming oblivious to his own real Time), the concreteness and interiority of others (becoming oblivious to their real Time), and his bond with them (becoming oblivious to the unique real Time). Yet, explains Bergson, there is no physicist who does not promptly heal the loss that this removal entails by recovering in effigy what he has so sacrificed. Neglected *in se*, duration is promptly recovered *in alio:* an image which, by inaugurating an 'artificial diplopia' (Bergson 1965, 111), protects the physicist against the danger of idealism (Carr 1920), which he believes he will incur if he absolutises his own point of view.

However, to recover in effigy, and therefore as a ghost, what the real Time of a real observer must be, is not the same as to move oneself there 'in order to compute it in actuality' (Bergson 1965, 180). 'To measure Paul's time as it is measured by Paul it would be necessary to be in his place' (Bergson 1965, 215). and then, for Bergson, despite believing the opposite, the physicist never comes out of himself.[16] He does, it is true, try to remedy the impossibility of being the other while remaining himself, that is, the impossibility of moving even with respect to himself, thanks to the representation of another self, which is other, mind you, because essentially in motion whereas he, on the contrary, remains motionless. But, since Peter tries to address the impossibility of being Paul while remaining Peter by representing Paul only because of the impossibility of translating their differences in mathematics, Bergson argues that such a trick proves, once again, the partial character of SR.

The physicist, in sum, is not at all out of danger: we can well understand the phantasmatic character even of that vision that he treats as real by the fact that 'there is no way mathematically to express the difference between the two' (Bergson 1965, 127). If Peter did not abstract from himself being a man to become a

16 'The conception of the relativist physicist is an egocentric conception […] He multiplies the successive egocentric views rather than bringing about the philosophical coexistence of the times of the different observers. By the bias of equations, he attains a multifaceted solipsism' (Merleau-Ponty 2003, 109).

physicist, he could not even paint Paul instead of tuning into him. Paul, in fact, is similar to Peter ('as a species to a genus' – Bergson 1965, 135) to the extent that both have been made identical a priori, as a species, according to their true common genus: the laws of nature. And it is no coincidence, therefore, that in *DS* Peter is presented as a painter who has to portray 'two subjects' (Bergson 1965, 73): himself as a physicist and Paul as an observer. The true proportion that regulates this projection is not the one between Peter as a painter and Paul as painted.

Peter must have already become a ghost himself in order to have made Paul in imago. Peter must first represent himself as a reference system by abstracting from his real Time. But to the extent that Peter as a painter or physicist is a ghost compared to Peter as a living being or as a man, in the Baroque theatre of SR one finds that, in the end, all observers are ghosts: the painted Paul is a ghost compared to the painter Peter because the living Peter is a ghost compared to the painter Peter. But the living Peter, in turn, is a ghost compared to the painter Peter because his concrete time is a ghost compared to the abstract eternity of the laws with which he decides to measure it, i.e., to paint it. So that, finally, all plural times supposed by SR are ghosts compared to the reality of the laws by which they are generated; all reference systems – concludes Bergson – assume the same value in relation 'to an entity comparable to the Platonic Idea' (Bergson 1965, 183).

III Complete Relativity

1 Spooky Universality

Intelligence comes after, being indeed itself an *after* compared to the strange *before* of contemporaneity in which intuition places us and of which twinship offers such a powerful image. And when it comes, it does so as a rarefaction of that state of primitive commonality that Bergson calls 'simultaneity of flow' – one of *DS*'s great conceptual inventions – and Whitehead, roughly in the same years, calls 'causal efficacy'. For both the basis of experience is sympathy – that 'feeling the feeling *in* another and feeling conformally *with* another' (Whitehead 1978, 162). Thus, what Einstein isolated as *the privilege of the present reference system* and Santayana, albeit in another context, as *the solipsism of the present moment* (Santayana 1923), is only an illusion connected to another way of perceiving: Bergson's 'simultaneity of the instant' or, to again use Whitehead's terms, 'presentational immediacy'. For both Whitehead and Bergson, the latter corresponds to ordinary sensory perception and consists in the discrimination of forms that express external natural facts in relation to our body. Not, therefore, to an experience *of* the body and *with* the body. This kind of perception overturns all the characteristics of that embodied perception from which derives (presentational immediacy is a development, in the sense of a thinning, of the complex and dense datum procured by causal efficacy in the same way in which the simultaneity of the instant is a development, in the sense of a spatialization, of the complex and dense datum produced by the simultaneity of flow). Its objects are the forms, or qualities, which are clear, distinct, and indifferent, i. e., sensory data, but so to speak abstract from the senses and in solidarity with each other only 'because of their participation in the impartial system of spatial extension' (Whitehead 1927, 23).

Thus, although more sophisticated, presentational immediacy is more fallacious and, although it is more precise, Whitehead claims that it is more sterile: it is always 'confined to the illustration of the geometrical perspective relatedness, of a certain contemporary spatial *region*, to the percipient' (Whitehead 1978, 121). Yet, for the physicist intent on representing 'the whole universe schematically on a sheet of paper' (Bergson 1965, 56) according to the mathematical laws of perspective, presentational immediacy will always be more advantageous. The physicist, in fact, must calculate, where 'to calculate' means 'to count instants by squeezing the intervals at the extremities' (Bergson 1965, 57–58). Working on measurements, then, science records only simultaneities and nevertheless, if we can count simultaneities by synchronizing clocks, i. e., by projecting duration onto space, it is only to the extent that there is a simultaneity which is prior to all of these instantaneities. Bergson qualifies it as 'natural' (Bergson 1965, 89), 'intuitive' (Bergson 1965, 82), 'lived' (Bergson 1965, 82), clarifying that

> simultaneity of the instant and simultaneity of flow are therefore distinct but complementary things. Without simultaneity of flow [...] Real duration and spatialized time would not then be equivalent, and consequently time in general would no longer exist for us (Bergson 1965, 54).

For Bergson if we measure real Time thanks to the simultaneity of the instant, each of these measurements is a measurement of real Time (Bergson 1965, 54–57) thanks to the simultaneity of flow: the transcendental condition for the possibility of each measurement. Only this simultaneity of flow allows us to transpose duration onto a linear time and then, without its continuous unfolding, there would only be 'a space that, no longer subtending a duration, would no longer represent time' (Bergson 1965, 51). To put it differently, if there were not a contemporaneity of the stream of consciousness with the movement of the clock with which the single moments are recorded, 'we would have no particular measurement, we would end up with a figure not representing anything at all' (Bergson 1965, 54), but we would not have measured time. A physicist, for Bergson, does not measure time thanks to space but thanks to time (Bergson 1965, 70), and that is why, ultimately, every physicist insists on calling 'time' the space he quantifies: 'his consciousness is there' (Bergson 1965, 60) and can, if necessary, 'infuse living duration into a time dried up as space' (Bergson 1965, 60).

This, for Bergson, proves that the immediate datum of experience is 'a continual flow from which we simultaneously derive both terms and relations and which is, over and above all that, fluidity' (Bergson 1965, 63, our italics). The physicist, however, 'accepts the testimony of the senses, that is, of consciousness, in order to obtain terms among which to establish relations, then retains only the relations and regards the terms as non-existent' (Bergson 1965, 63). And, unaware of the difference in nature that separates them, he nevertheless will agree that, by extracting the former, he has measured the latter too. In this he is deceived: the physicist, Bergson says, only believes in what he measures. Yet, it is precisely for this reason, that he can never know *what* he measures *while* he measures it: forgetting that every measurement of time takes time (Bergson 1965, 19; 71), the physicist also denies himself the chance of finding time behind space, with the result that, to his eyes, what comes first will also be prior. Indeed, when they are disengaged from dimensions, spatial relations become absolute, and then previous not only in the temporal sense.

For a physicist the primacy of relations is also axiological, because their greater dignity, Bergson suggests, is of a moral order. Thanks to the objectivity and the necessity of relations – all that everyone can know, and know in the same way – intelligence can successfully plan action in the world, because relations, using Husserl's language, are what allow us to feel as if we are on earth even if we are on the moon: even on the moon, after all, we *land* (Husserl 1940). Yet, given that in the perfectly determined whole they describe, the happening of things is reduced to a formality that 'has no longer significance' (Eddington 1920, 51), Bergson puts forward the suspicion that their axiomatic universality is no less spectral than the one codified by Kant, in the form of an empty 'consciousness in general', for his beloved Newtonian mechanics. But then, maybe the task assigned by Bergson to the philosopher – a task, as we shall see, which is very different from the one faced by the physicist – matched a need that was maturing with the rising 'physics of young people',[17] i.e., Quan-

17 Heisenberg defined Quantum Mechanics in this way.

tum Mechanics, to prove that events really happen – and really happen to us instead of, as is the case with the classical framework of SR, thinking that 'they are just there and we come across them' (Eddington 1920, 51) within the limits of the speed of light?

2 The Task of the Philosopher

For Bergson, SR affirms the unity of real Time more rigorously than either Newtonian mechanics or common sense. And yet, as we have seen, both *time* and *unity* are terms that describe different realities in the metaphysics of Einstein's SR and the metaphysics of Bergson's philosophy of creative duration. The time SR adopts as the fourth dimension of space is, in fact, only a mobile image of eternity; the unity it preaches is, consequently, an abstract unity, synonymous with mathematical invariance, which sacrifices dimensions to relations. This is why Bergson dismisses the attempt to base oneself on a common formal expression in order to put all systems on the same level and declare that their times are equivalent as a *petitio principii*. That equivalence, he says, is assumed dogmatically because the unity of time validated by Einstein's SR is an immediate fact of science instead of being a *donné immediate de la conscience*. That is, a datum of Kantian 'consciousness in general' by virtue of which, science can maintain firm confidence in itself because

> the more it deepens the nature of things, [...], the more it will find a perfectly mathematical order. This is for the very simple reason that it is the intellect that deepens nature, and the intellect cannot deepen nature without illuminating it with its natural light [...]. In this sense science is absolutely sure to find, to the extent that it will extend, the ever more complete confirmation of the a priori principles that constitute it. Only that this science is entirely relative to our intelligence, relative to our faculty of perceiving and thinking (Bergson 2017, 320 – our English translation).

As long as by 'nature' we mean the laws that provide the scaffolding for phenomena, science and nature can only be 'the same thing'. If so, the possibility of transporting oneself in thought to every place on this luminous canvas, will make transporting oneself along with one's body a vain, if not useless, project (presentational immediacy, for Whitehead, is the way of perceiving without the 'withness of the body' – Whitehead 1978, 118). However, to mentally transport oneself to Paul is not in itself sufficient for measuring Paul's time as Paul measures it. It is also necessary to 'be in his place' (Bergson 1965, 215), i.e., to be, in some way, in the same body as well as the same mind: only in this way will the same time Peter will find there be real rather than abstract. A journey of our body, after all, 'is always there, and could have been for us the unfolding of time' (Bergson 1965, 51).[18] But how can somebody be in the place of the other while remaining himself? How is it possible to be in two different places at the same time? How, to take up the language of *DS*, can attention be divided without splitting? And in what sense can such *double single movement* be worth measuring if 'there is nothing to change in the mathematical expression of the theory of Relativity' (Bergson 1965, 185)? Can, finally, sympathy be a candidate for the role of *organum scientiae?*

For Bergson, it is true, there is nothing to change in SR, but this does not mean that the philosopher can do nothing in the face of such an admirable and innovative theory. As far as SR is concerned, the philosopher must instead establish what is real and what is not, what is spooky and what is not, distinguishing between what is or could be a lived time and what, on the other hand, is a time that is simply represented by thought: 'a time which would vanish at the very instant that a flesh-and-blood observer would betake himself to the spot in order to compute it in actuality' (Bergson 1965, 180). There are in fact two times, according to Bergson, the philosophical and the scientific, and only the former is real. The time of science, vice versa, is spectral, and spectral in an eminent sense: its reality is purely mathematical. Then, 'one could not raise it to a metaphysical reality, or simply to "reality" without assigning to this last word a new meaning' (Bergson 1946, 300). Indeed, if what is real is only what is given in an experience, i.e., what is ascertained or ascertainable, how can we conclude that the space-time of SR is real since even Kant, in the first *Critique* (*KrV*, B 207), has recognised that space and time are neither perceived nor perceptible, but rather the pure and a priori forms of all perception?

In his work, nonetheless, Bergson has devoted considerable energy to denouncing the imposture of the a priori: the science that is constructed on it, SR included, is no longer a physics but a metaphysics which 'raises into reality – into things perceived or perceivable and existing before and after the calculation – a fusion of Space and Time which exists only in the calculation and which, outside it, renounces its essence the very moment existence is claimed for it' (Bergson 1946, 301). Metaphysics always 'takes the concept for the percept' (Bergson 1946, 155), forgetting the distinction between what is real, i.e., actually perceived, and what is only represented, i.e., virtually conceived. Yet, after having transformed the difference in kind between them into a simpler difference of degree, in this way it inevitably ends up explaining the real only as a 'case of the

18 According to Bergson we cannot be displaced in relation to our self because it is as conscious bodies that we ground an 'absolute'. See Merleau-Ponty 2003, 111.

virtual' (Bergson 1965, 152). The essence of metaphysics is precisely to 'rank the real vision with the virtual visions. [...] Mathematician and physicist certainly have the right to express themselves in this way. But the philosopher, who must distinguish between the real and the symbolic, will speak differently' (Bergson 1965, 152–153).

A philosopher who philosophises *with* science and not *against* it, will ask himself what is real, i.e., what is actually observed and observed (Bergson 1965, 94), inquiring, in the case of SR, whether

> it would be necessary to begin by seeing clearly why it is impossible to attach at the same time to several different systems "living and conscious" observers, why one single system-that which is effectively adopted as system of reference contains real physicists, and why the distinction between real physicists and physicists presumed real takes on a capital importance in the philosophic interpretation of this theory, when up to now philosophy had not had to concern itself with this theory in the interpretation of physics (Bergson 1946, 301).

3 The Precision of the Nuance

To provide an adequate interpretation of SR means, for Bergson, to be 'more Einsteinian than Einstein' (Bergson 1965, 56). And yet, if philosophy has not achieved this *surplus of precision*, it is because it has not made intuition its own method. Philosophy has not taken advantage of the fact that, thanks to intuition, it can place itself, at the same time, on the platform and on the train of another famous Einsteinian experiment – since its freedom is a freedom *from* measurement and not *of* measurement. Therefore, Bergson says, what it has lacked most is precision (Bergson 1946, 7), because precision cannot be obtained by any other method than intuition. In other words, while it is true that intuition is the opposite of measuring, it must be added that intuition is the opposite only of *a certain way* of measuring. Intuition too, in fact, offers us an exact measure of the thing. It does so, says Bergson, by comparing 'the real exclusively with the real and the imagined exclusively with the imagined' (Bergson 1965, 181), i.e., by shaping concepts that fit the thing of which they are concepts (Bergson 1946, 5).

For Bergson, intuition sees 'a perfect reciprocity' (Bergson 1965, 180) whereas SR sees a dissymmetry which is at the origin of its paradoxes. These last are merely effects of perspective that derive precisely from the exchange of the perceived with the conceived, of the real with the virtual, of time with space, of the cause with the effect. They are caused by the metaphysical fallacy which, according to Bergson, characterises science. It consists in the inclusion of a thing in a genre or a concept that is too vast in the sense of 'pre-existing' (Bergson 1946, 30) and only intuition, in Bergson's opinion, is able to avoid this inclusion by discarding the ready-made concepts in favour of 'a direct vision of reality' (Bergson 1946, 30). Intuition cuts the concepts 'to the exact measure of the object' (Bergson 1946, 31) and, by doing so, also re-establishes the rights of nuance. This is the very nuance which metaphysics as presupposed by both ancient and modern science has sworn to deny since its very first steps, that is, since the Greeks invented that other kind of precision which has sacrificed everything that is movement on the altar of the *logos*.

According to Bergson, modern scientific thought is the continuation, by new means, of the Greek ontology. Relations are these *new* means, although they are only used to communicate an *old* message: knowledge is relative to the absolute and eternal truth of ideas given once and for all. The case of our twins is, in this respect, exemplary. Their twinship, as we were saying, puts us in front of a strange 1 that is 2 and a not less strange 2 that is 1, that is in front of a kind of *imprecision* or *nuance* of nature such as that of a couple of people who are *not really two* although they are more than one. To this vagueness, however, SR relates in accordance with the principle of non-contradiction, i.e., by introducing order into what affects our thought, forcing it to go in two directions at the same time without splitting. For Bergson, vice versa, the hypothesis of twinning is precious precisely because, already at an immediately intuitive level (the uncanniness produced by twins), it forces thought to stand between two opposite drives and to equip itself with a vision that is blurred only to the extent that it is diplopic. A vision that is radically different from the orthogonal vision of science.

Science is constituted precisely by restoring monocular vision: a sort of *orthodoxy of vision* that introduces a distinction into what is undivided. It promptly replaces the natural reciprocity between Peter and Paul that, for Bergson, constitutes the immediate datum – 'given as a real datum there is only a reciprocity of displacement' (Bergson 1965, 33) – with an abstract identity and, in this way, hopes to bring back what appears to be an intolerable exception to the norm. Then, if we want to take up the formulas used at the beginning of the essay, we could say that, for Bergson, there is science every time the comic is made serious and the uncanny is made harmless, that is, every time the anomaly of twinning is corrected through a work of disambiguation by which, *arbitrarily*, that umbilical cord which *necessarily* ties the known and the unknown together, Peter and Paul, is severed. So, even if it is to some extent true that science exorcises ghosts, it must be recognised that it does not do so in the same way that philosophy does. Science, for Bergson, fights *ghosts with ghosts* and *illusions* *with illusions* because calculating, after all, means reassuring oneself thanks to a precision which, in reality, is the source of a more serious imprecision.

Philosophy, on the other hand, exorcises ghosts with something that is not a ghost: it exorcises the spectral metaphysics which haunts the dwelling of the physicist by aiming at the *more than human precision of the nuance*. In a certain sense, hence, philosophy exorcises what is spectral with what is real, welcoming *as real* what the scientist usually exorcises *as a ghost:* duration. Indeed, if duration is ousted from a science that is based on something inessential – 'precision is an historical accident' – and that, moreover, 'gives us the promise of well-being, or at most, of pleasure' (Bergson 1946, 151) but not joy, there is no reason not to try to grasp the duration in itself in spite of the difficulties that its expression involves (During 2018). How, in fact, would the duration appear to a consciousness which desired only to see it without measuring it, which would then grasp it without stopping it, which in short would take itself as object, and which, spectator and actor alike, at once spontaneous and reflective, would bring ever closer together – to the point where they would coincide – the attention which is fixed, and time which passes? (Bergson 1946, 8).

Probably, as it appears from that 'barely conscious reasoning' (Bergson 1965, 81) from which intuition is inspired by and according to which

> We perceive the physical world and this perception appears, rightly or wrongly, to be inside and outside us at one and the same time; in one way, it is a state of consciousness; in another, a surface film of matter in which perceiver and perceived *coincide*. To each moment of our inner life there thus corresponds a moment of our body and of all environing matter that is "simultaneous" with it; this matter then seems to participate in our conscious duration. Gradually, we extend this duration to the whole physical world […]. Thus, is born the idea of a duration of the universe (Bergson 1965, 45 – our italic)

Conclusion: What is Real?

In *DS* there is a handover, with regard to SR's main hypothesis – the reciprocity of motion – from the physicist to the philosopher. The physicist, to the extent that he has to refer his measurements to a privileged system, refuses the idea of absolute reciprocity although, as we saw, for Bergson he has an 'absolute right' to do so (Bergson 1965, 67; 79).[19] The philosopher, on the other hand, is

19 The physicist, for Bergson, 'forgets that he is a man before he is a physicist' (Bergson 1965, 79), that is, he forgets the moment in which he finds himself. Yet, it is only in this way that he can *be everywhere* and build a *universal physics*. Then the physicist is not wrong when he transcends himself. His fault is 'only' to forget he has transcended himself.

a philosopher exactly because he does not have to mathematically translate the universe on a piece of paper following the laws of linear perspective. The philosopher does not have to choose. By refusing 'to simply turn into a physicist' (Bergson 1965, 96), he instead only has to intuit, that is grasp real Time both in its nature as well as its difference in kind from virtual time. And yet, as a philosopher, he should never forget that the train and the track are in a state of reciprocal motion. Moreover: 'he will place a conscious observer in both and will seek out the lived time of each. [...] What he will discover is that, what is simultaneity in relation to the track is, simultaneity in relation to the train, that is, that Peter and Paul share the same time' (Bergson 1965, 94).

For Bergson, as we have seen, SR invites us to consider S and S' as 'strictly interchangeable', with the consequence that our thought can make the two people in S and S' coincide together, as if they were two equal figures that overlap and that they coincide, mind you, 'not only with respect to the different modes of quantity but even in respect to quality [...] for their inner lives have become indistinguishable quite like their measurable features' (Bergson 1965, 80 – 81). In fact, the comings and goings of consciousnesses only begin with the assumption of a reference system. By not assuming it, the philosopher can move, 'thanks to a rapid oscillation of the attention' (Bergson 1965, 75), uninterruptedly from Peter to Paul and from Paul to Peter – both alive. When we do not deal with physics, men remain what they are, conscious of one another and equally conscious of the other, real to one another and equally real to the other, because the real, in itself, is not asymmetrical: there is not a single man who only lives time (Bergson 1965, 79) and many ghosts that stir in eternity, but a unique real Time lived by many men.

In this unique real Time, a philosophy that stands for both points of view, stands in its entirety because here one no longer has to choose. When the idea of the reciprocity of motion is fully assumed, there is only the live interaction between Peter and Paul both living, i. e., the non-stop *intuiting* of Peter by Paul and the non-stop *intuiting* of Paul by Peter. Not, then, a mere exchange in which Peter is alive *and* Paul is dead, nor one in which Paul is alive *instead of* Peter being dead. The act at the core of *DS* is not a painting with two subjects, but a double, unique, act: the non-stop *feeling* of Paul by Peter and, reciprocally, the not-stop *feeling* of Peter by Paul, in which both are alive. For Bergson their communication is real because what exists as an immediate datum is only the reciprocity between Peter and Paul and between Paul and Peter. Proof of this is the fact that not even intuition differs from this datum. If to intuit means 'to be completely in the real' (Bergson 1965, 97), then there is no distinction between what *intuition is* and the real that *intuition intuits:* both the real and the intuition that grasps it are communication, because intuition too is an act or birth that has no other existence than in its products or births, which, in turn, do not exist as products or births, that is, as extremities, if not abstractly. What exists, and exists in a primary way, is, rather, their relationship, that is that uninterrupted reciprocal detection of which twinning is perhaps one of the best images.

As a 'sounding' (Bergson 1946, 227) into the real, intuition is intuition of this reciprocal sensing and, at the same time, this same reciprocal sensing in action, because the fact that the real is only the live interaction between Peter and Paul, who are both living, means that real is only that 'third' which, as an instantaneous *koinonia*, making them more than one without ever making them two, also makes them indistinguishable, mitigating their respective identities (a fact that explains the anxiety that many cultures feel when faced with homozygotes). Peter and Paul are *neither* two *nor* one but two in function of a third who is their immanent one.[20] It is impossible, then, to divide them, but it is equally impossible to identify them. *Twinning means contemporaneity* and therefore, as soon as Peter reintroduces duration in his calculations, he discovers he coincides with Paul not only with regard to the different ways of quantity. Peter, says Bergson, finds that his twin has the same age and is of his own size, meaning that what Peter finds is that twins' concepts are cut to the measure of twins' things. Yet, if their inner lives can become indiscernible, just like what is measurable of them, it only is because for Bergson 'contemporaries' are, properly speaking,

> two flows when they are equally one or two for my consciousness: the latter perceiving them together as a single flowing if it sees fit to engage in an undivided act of attention, and, on the other hand, separating them throughout if it prefers to divide its attention between them, even doing both at one and the same time if it decides to divide its attention and yet not cut it in two (Bergson 1965, 52)

Intuition is that kind of attention which is, at the same time, one and many: the privilege of our consciousness. Thanks to this quality, the richness of the nuance is enhanced rather than dissipated because here, unlike what happens with intelligence, the vagueness or indeterminacy of sensory data guarantees their full concreteness instead of their inessentiality. Unlike Rovelli's blurring – the one that determines time[21] – intuition grants an enhanced and not a degraded

20 Rovelli, not by chance, presents entanglement as a triangular and not dual phenomenon. See Rovelli 2020, 106–109.

21 'A macroscopic state (which ignores the details) chooses a particular variable that has some of the characteristics of time. In other words, a time becomes determined simply as an effect of blurring […] But something further is also true: the blurring itself determines a particular varivision: a vision which is very similar to that gained by painters who can turn a visual defect into a resource (see, for example, El Greco's exaptation of his astigmatism). Thanks to the blur we see more rather than less because, to intuit, for Bergson, means to expand perception by extending it to what normally, i. e. pragmatically, escapes it: the 'interval' (Bergson 1965, 57) between those extremities on which our perception is usually fixed.

For Bergson the interval is the unique real Time. But real Time either does something or is nothing. So, what does real Time do? Real Time makes the contours of all things indeterminate by making their essences vague, because if 'time is the stuff of every being' (Bergson 1965, 62), it is so only to the extent that the implication between consciousness and duration is reciprocal (Bergson 1965, 49). 'We place – Bergson says – consciousness at the heart of things for the very reason that we credit them with a time that endures' (Bergson 1965, 49). Yet, to credit things with a time that endures means to grant them a certain, constitutive nuance or interval. It is clear, once again, in our ghost story: that if what is real is the interval[22] between Peter and Paul, this means that real is the *more than one-less than two*. What is real is the nuance and, since 'nuance' is also a name for real Time, even the nuance either does something or is nothing. Now, what does the nuance do if not nuancing? And then, what is ultimately real if not the same process of nuancing as that movement of mutual fading between Peter and Paul?

For Bergson intuition is real inasmuch as it is this movement: nothing but the interval, as imprecision or nuance at work; nothing but the interval as absolute, i. e., more real than the polarities in which, in the form of two reference systems or two twins, our intelligence tends to reify it. According to Bergson the interval is the contemporaneity of what cannot be together by virtue of being

able – time […] it is not the evolution of time that determines the state, it is the state – the blurring – that determines a time' (Rovelli 2019, 84–85).

22 This interval can be looked at as 'une poche de present' (Čapek 1980), which expresses the qualitative identity 'within' which metric disparities arise. Bergson, as we have seen, considers these disparities to be merely perspectival effects. Yet, even when one admits the asymmetry between the times of the twins, i. e., one stops taking into account only uniform relative motion and introduces acceleration, one must acknowledge that this asymmetry occurs within the 'same amount of time' (During 2007, 81). Indeed, twins may age differently, but they age differently *together* (During 2009, 242). According to During, therefore, these different processes of ageing correspond to a different measure of the same time-interval rather than to an actual slowing down of time. '"Slowing down" is a shorthand for "measuring shorter intervals of proper time". Clocks sometimes run late; they do not run slow' (During 2007, 97).

distant[23] and which, nevertheless, communicates as originally undivided. A strange 'distance', therefore, since it looms exactly in the place where Peter and Paul meet. Yet it is a distance as real as their proximity because, as soon as the interval is grasped in its absoluteness, indiscernibility appears as an extended present that keeps every surgical attempt at Whiteheadian 'simple location' in check. In fact, where can we say that Paul begins and Peter ends? At what point, Bergson asks himself, does the *real* upheaval caused by the *experience* of the twins' unity stop and the *fictitious* certainty produced by the *hypothesis* of their division begin? A new physics, in Bergson's opinion, should answer these questions by really thinking about what happens in the interval. And 'really', for Bergson, means without relativizing its motion to something at rest, i. e., to the extremities.

A new physics, then, should be a *physics that does not choose:* a physics that, so to speak, calculates at a speed greater than the speed of light. Indeed, if the idea of the reciprocity of motion becomes a philosophical one (Bergson 1965, 96) as soon as it becomes a token of its extreme consequences, it is precisely to the extent that it shows us a world in which motion, i. e., interchanging, is no longer relative to something else but absolute. And yet, is it possible, for physics, to be physics, i. e., to be the act of measuring, without subordinating itself in this act, to that absolute constraint which is the value of c? The question is extremely complex and remains an open one. However, there is a branch of physics that has taken charge of the interval. In our opinion, Quantum Mechanics – the very Stone Guest of DS[24] – could in fact claim to be that *science of twinning* which, as soon as we stop considering only two reference systems, becomes *ipso facto* the science of the togetherness of all things and their supra-luminal communications or influences.[25] Whether it is quantum rather than classical depends on the fact that, in the classical framework of SR, the so-called 'actio in distans' has no place. Einstein rejected it as 'spooky', as is well known, in order

23 Whitehead interprets this distance as causal independence (see, e. g., Whitehead 1978, 123). For him, contemporaneous events are not causally linked. In this sense, contemporaneity implies disconnection or separation. 'It is as if a certain measure of disconnection (in space?) was dialectically intertwined with connection (in time?), as if absence was dialectically incorporated within the overall sense of copresence shared by the two observers' (During 2016, 18–19). On the goodness of this thesis for the interpretation of the twin paradox see also During 2008, 274–275.

24 Of course, from a chronological perspective, QM was not even constituted as such in 1922. Yet, we believe the time is ripe to attempt a comparison between some Bergsonian insights and some experimental results of QM.

25 Rovelli presents the world of Quantum Mechanics as a world of mutual influences. See, again, Rovelli 2020, 84–86.

not to reject the relativistic version of the principle of non-contradiction: the principle of locality. But this means that he rejected it, above all, because he believed it was something logically contradictory.

Yet, by doing so, in the sign of that new absolute which is the constancy of the speed of light,[26] Einstein also deprived his Relativity of the opportunity to encounter any form of temporal coexistence which, by definition, would have violated its absoluteness. And, what is maybe worse, by excluding such 'spooky' action, Einstein has excluded what, by making the relative a reciprocal, would have also made SR a complete theory rather than a partial one, that is, a real theory rather than a spooky one. Indeed, if in order to measure Paul's time as it is measured by Paul, it is necessary to be in Paul's place, the phantomatic *actio in distans* is paradoxically credited as the only real way to measure. Bergson intuited this when, with his own intuition, he transported himself into a radically relativistic universe (a very Baroque one) where observer and observed are strongly co-implicated; that is when, even before Quantum Mechanics named it 'entanglement', although it is action 'at a distance', he christened the reciprocal surveillance between different durations 'sympathy' (Bergson 1946, 72; 189; 304). No doubt this interplay can perturb, since it is an action at a distance which, in reality, denies any distance. Yet, given that it is said to be 'at a distance' only as long as something like 'a distance' – that is the 'impossibility of touching' – exists and is elevated to the norm, a physicist need only to renounce the privileges of this privileged reference system to discover that, in the end, only sympathy affords 'the joy' (Bergson 1946, 151) of seeing Peter and Paul, together with all that exists, entangled in an indecomposable embrace that cannot be simply located in space-time because of the space-time is, rather, the real *locating*.

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26 'Light is for Einstein the new and only absolute in a world where all else is relative' (Montague 1924, 146).

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Pierre Montebello

The Test of Time: Human and Cosmic Time

Abstract

The ultimate project of Bergsonism is to find a 'living unity' that welcomes life, consciousness, and the material universe. But it proves difficult for this philosophy, which starts from the experience of conscious life and takes the immediate data of consciousness as its guiding principle, to connect our subjective and private psycho-vital experience to the 'objective' and common reality of the universe. In fact, the very concept of the material universe is heavily saturated with intellectual representations that leave no room for a 'living unit'. It is precisely at this level that the debate between Einstein and Bergson gains importance. From Bergson's point of view, there is no way to grasp the real nature of time but by living it; we can only start from the intuition we have of our own conscious, lived experience. In this paper we want to show how Bergson constructs a 'plane' of nature – that is a plane of light – that connects the duration of the universe to the duration of the self. A plane in which nature is understood as the univocal *feuilletage* of durations that we experience: nothing more nor less than the unity of spirit, life, and matter

1 Science and Philosophy: Two Different Methods

For Bergson, the relationship between science and philosophy is essential. Science is not second or secondary. It has its own method, different from that of metaphysics, and its own kind of precision. In *The Creative Mind,* Bergson says that science touches the absolute and then, the real. But this was not a new thesis. Bergson had already expressed it in *Creative Evolution:*

> Positive science, indeed, may pride itself on the uniform value attributed to its affirmations in the whole field of experience. But, if they are all placed on the same footing, they are all tainted with the same relativity. It is not so, if we begin by making the distinction which, in our view, is forced upon us. The understanding is at home in the domain of unorganised matter. On this matter human action is naturally exercised; and action, as we said above, cannot be set in motion in the unreal. Thus, of physics, – so long as we are considering only its general form and not the particular cutting out of matter in which it is manifested – we may say that it touches the absolute. On the contrary, it is by accident – chance

https://doi.org/10.1515/9783110753707-011

> or convention, as you please – that science obtains a hold on the living analogous to the hold it has on matter. Here the use of conceptual frames is no longer natural. I do not wish to say that it is not legitimate, in the scientific meaning of the term. If science is to extend our action on things, and if we can act only with inert matter for instrument, science can and must continue to treat the living as it has treated the inert… But, in doing so, it must be understood that the further it penetrates the depths of life, the more symbolic, the more relative to the contingencies of action, the knowledge. On this new ground philosophy ought then to follow science, in order to superpose one scientific truth a knowledge of another kind which may be called metaphysical [Thus combined, all our knowledge both scientific and metaphysical, is heightened]. In the absolute we live and move and have our being. The knowledge we possess of it is incomplete, no doubt, but not external or relative. It is reality itself, in the profoundest meaning of the word, that we reach by the combined and progressive development of science and of philosophy (Bergson 1922, 209–210).

Let us take up Bergson's arguments again: what is interesting about science is not its uniform approach to both physical matter and other kinds of objects (life, living beings, consciousness, and spirit). What is usually seen as an advantage (science's generality) becomes, for Bergson, a defect. Science does not really grasp life or spirit starting from matter and therefore its knowledge is merely relative. Science treats objects as unreal phenomena. Yet it succeeds in one area: that of *action on matter*. At this level, science even touches reality, grappling with it even if through mathematical and geometrical formulas. In fact, intelligence – science's organum/instrument – cannot be unreal since, for Bergson, it is, properly speaking, action on the real. So, in its general form, science 'touches the absolute', although in its detailed form it forgets time – real time, which is duration – considering only space. Intelligence, then, is not only symbolic or artificial: it has access to the real. Intelligence only become symbolic when it leaves the sphere of action on matter and tries to understand life, living beings, consciousness and spirit, all of which it considers to be inert.

Symbolic, for Bergson, means conventional and relative. But if intelligence is symbolic it is because it is weighed down by the need to act. Intelligence has to organise our action in the world and, therefore, it cannot take change and duration into account. One can act only by leaning on what is fixed, motionless, and not on what is continuously becoming. Nevertheless, Bergson does not consider science and philosophy to be in opposition; instead, he assigns philosophy the task of grasping that absolute which science can only touch symbolically. Philosophy, in fact, can touch the absoluteness of non-material objects (life, consciousness, God), building true metaphysical knowledge. And this is why Bergson makes Saint Paul's famous assertion from the Act of the Apostles, 'In God we live and move and have our being' the key concept of his philosophy – on condition, of course, that 'we replace "God" with the "Absolute"' (Bergson 1911, 210). Indeed, from the point of view of the Absolute wherever we are, we are in Being and not, as Kant argued, at a distance from it, that is, we are within the unknowable 'thing in itself'. For Bergson, matter, life, consciousness and supra-consciousness are all forms of being, absolutely speaking.

In order to respond to those who accused him of having devalued the role of science in *Creative Evolution* – for example, Julien Brenda and Bertrand Russell, who were perhaps his most virulent critics – Bergson restated his theses in the second part of the introduction to *The Creative Mind*, repeating once again that science can also touch an absolute. In a way, then, his 1922 book only clarifies the position he first took in *Creative Evolution* in 1907. In 1922, Bergson says that the sciences are no less precise than philosophy and this is why it is not even necessary to reject physics in its 'general form' as *Creative Evolution* did. Instead, it is necessary to outline the precise contours of intelligence because this also touches on the very structure of matter, a fact that modern trends in science continue to confirm:

> when we bring the intellect back to its precise contours and when we delve deeply enough into our sense impressions so that matter begins to surrender to us its inner structure, we find that the articulations of the intellect apply exactly to those of matter. I therefore do not see why the science of matter should not reach an absolute (Bergson 1946, 44).

That science and metaphysics both touch the real absolutely, although by applying two different kinds of precision, is one of the essential points of Bergson's philosophy. But what does it mean to say that science touches the absolute? To maintain that science touches the absolute means that science is no longer the set of laws governing the phenomenal world as Kant thought, but instead coincides with a level of reality, namely the reality that extends itself in and as space. Intelligence is directly concerned with this extended reality (in *Creative Evolution*, Bergson had already stated: 'Matter or mind, reality has appeared to us as a perpetual becoming' – Bergson 1922, 287).

Yet, by affirming this, Bergson is not according scientific knowledge superior value, nor is he putting science and philosophy on the same plane. While being critical of the sciences, Bergson constantly includes scientific approaches in his analyses. Nonetheless, he always distinguishes between the methods of science and philosophy as two different ways of approaching the same reality. Not because one is real and true, while the other is fictious and artificial. In order to remove any ambiguity from his discourse, and to avoid being accused of irrationalism, Bergson often insists that intelligence is not a pure abstraction: it apprehends a part of reality itself, because both science and metaphysics deal with the real absolute. Science, in sum, does not distort its object, it is not pure constructivism.

Yet, if science touches a material absolute, namely an absolute that is extended in space, metaphysics touches an absolute which lasts and takes time. Thus, it is clear that Bergson challenges Kant in two ways. First, he reinstates the possibility of metaphysics; second, he denies science's dependence on the relativity of knowledge: 'I reject the arguments advanced by philosophers, and accepted by scholars, on the relativity of knowledge and the impossibility of attaining the absolute' (Bergson 1946, 41). This leads to a double benefit: metaphysics becomes possible and science is not phenomenal. Both of them return to reality itself and can be absolute.

Let us now examine the scientific method of precision, starting from Bergson's distinction between two types of reality: evolutionary and material.

> Radical indeed is the difference between an evolution whose continuous phases penetrate one another by a kind of internal growth, and an unfurling whose distinct parts are placed in juxtaposition to one another [...] It is true that alongside the states of consciousness which live this unshrinkable and inextensible duration, there are material systems which time merely glides over. Of the phenomena which follow from them one can really say that they are the unfurling of a fan, or better still, the unrolling of a cinematographic film. Calculable ahead of time, they existed prior to their realization in the form of possible (Bergson 1946, 19)

In some cases, nothing can be accelerated without changing the very nature of reality; in others, acceleration changes nothing – a film, for example, where the speed of its unwinding has no consequences for the content. One might think that Bergson here considers all material systems to be timeless: 'Does the material universe in its entirety form a system of this kind?' (Bergson 1946, 19). But this is not the case; the question is only a methodological artifice: 'When our science assumes this, it simply means by so doing to discard everything in the universe which is not calculable' (Bergson 1946, 19). Science measures space, it does not take time into account; it eliminates time to better take space into account. Science always moves towards the spatial and material dimension of things. But the philosopher

> who does not want to discard anything is really obliged to ascertain that the states of our material world are contemporaneous with the history of our consciousness. As the latter endures the former must be bound in some way to real duration (Bergson 1946, 19).

Thus, the method of philosophy is not at all the same as that of science: it takes into account the whole of experience, leaving nothing aside (metaphysics is an integral experience). More specifically, philosophy connects external things to lived durations, the material universe to consciousness. It seeks duration in those realities that are different from consciousness and finds that they also endure, taking part in duration. Consciousness, in fact, is not isolated. Yet, if it lasts, the other realities, life and the universe, which act upon consciousness, must also last. In this regard the example of the glass of sweet water used in *Creative Evolution* and taken up in *The Creative Mind*, is very important.

Let's take up the argument from *Creative Evolution.* Bergson starts by commenting on the dream that inspires modern science: to get as close as possible to the state of an intelligence that could embrace in a single mathematical formula the totality of the forces that make up nature and the variety of the situations of the beings that populate it. Bergson sums up this project for us: 'The essence of mechanical explanation, in fact, is to regard the future and the past as calculable functions of the present, and thus to claim that *all is given*' (Bergson 1922, 39 – 40). This idea, 'all is given', does not involve time. Bergson has already shown many times that between two times, t and t', science does not deal with the interval but only with its extremities. This interval, in fact, could slow down infinitely or conversely take on an infinite speed, but nothing would change in the scientist's formulas and results.

Science doesn't really take duration into account: it only takes the relations, the juxtaposition of the parts into consideration, firmly believing that 'time doesn't bite'. Scientific time is mathematical and excludes duration, considering only the simultaneous definition of each position of a system's parts. But then, how can we understand succession in the physical world? And, besides, is there even succession in the physical world? Or in the universe? Unquestionably, answers Bergson: 'Succession is an undeniable fact, even in the material world' (Bergson 1922, 10). Yet, succession or history in the universe cannot be explained starting from isolated systems carved out by intelligence: 'this history, in point of fact, unfolds gradually, as if it occupied a duration like our own' (Bergson 1922, 10). For Bergson any succession proves that something is happening, that something new is being produced.

> [I]f the future is bound to succeed the present instead of being given alongside of it, it is because the future is not altogether determined at the present moment, and that if the time taken up by this succession is something other than a number, if it has for the consciousness that is installed in it absolute value and reality, it is because there is unceasingly being created in it not indeed in any such artificially isolated system as a glass of sugared water, but in the concrete whole of which every such system forms part, something unforeseeable and new (Bergson 1922, 358 – 359)

The famous example of the sugar in the water glass now becomes clearer. It is an experiment that links two types of reality: 'If I want to mix a glass of sugar and water, I must, willy-nilly, wait until the sugar melts' (Bergson 1922, 10). This means that a time that is different from mathematical time immediately erupts:

it is the time of my waiting, of my impatience. It is no longer a thought or a conceptual time; no longer a set of relationships. Sugar's time is lived because, although sugar dissolving in water seems to be a physical event independent of me, this event has an absolute meaning for me. Waiting translates into 'a certain portion of my own duration, which I cannot protract or contract as I like' (Bergson 1922, 10) – once again the problem of acceleration!) and for Bergson this 'other' time immediately manifests itself: sugar dissolves in water through a chemical process, but this event, as simple as it is banal, highlights a creation upon which my consciousness inevitably stumbles. Something is happening: an unpredictable event, a duration that is also unique in the universe. Sugar therefore does not only dissolve chemically: it has a duration that must be linked to the duration of the Whole because, for Bergson, as soon as we integrate a physical system into the Whole, its own duration becomes evident. Why precisely at that moment? Why does Bergson allow himself to attribute duration to each physical system, that is to say a form of existence analogous to ours, as soon as it becomes part of the Whole?

Bergson says: 'There is no reason, therefore, why a duration, and so a form of existence like our own, should not be attributed to the systems that science isolates, provided such systems are reintegrated into the Whole' (Bergson 1922, 12). This is the case because melting sugar is not an isolated phenomenon. It is true that science tends to understand matter geometrically and to artificially represent isolated systems in order to better capture the characteristics of extended matter. But even the smallest system is nested within, is linked to, external influences, such that we can go back through these threads to the entire universe, 'in which we live the duration immanent to the whole of the universe' (Bergson 1922, 11). Every part of the universe links us to the Whole. And it is this Whole that is at work in every single system, right down to the glass of water, and that makes itself felt in the very duration of my expectations of what is going to happen. Thus, for Bergson the duration of each physical system is no longer a mystery: it coincides with the creative movement of the Whole through each of its parts, that is with the pulsation of the Whole in each of its systems, which are only conceptualised as isolated units by science. Each duration, in fact, is the emanation of the duration of the Whole and Bergson, therefore, can conclude that 'the universe endures' (Bergson 1922, 11).

After having discovered duration at the core of psychological life, Bergson makes it the stuff of the entire universe. The latter creates forms and continuously elaborates something absolutely new: 'The duration of the universe must therefore be one with the latitude of creation – which can find place in it'(Bergson 1922, 359). This is why, in Bergson's opinion, the methods of science and philosophy should not be fully separated. In the physical universe studied by sciences, it is true that no duration or creation can be detected, because science freezes time to focus on space, that is, in order to act. The work of science consists in isolating parts of the Whole as closed material systems, so as to better decompose them in space. But the work of the philosopher consists, on the contrary, in returning these to the Whole, starting from our experience of 'it'. Philosophy, in short, reintegrates a fragmented physical system into the Whole and grasps its relation to duration. But it can do this only by connecting the universe as a whole to our duration. Our perception, in fact, isolates closed systems as does our science. But, apart from science and its need to plan action, these closed systems are not isolated. They are isolated for science only. In reality, they are connected with a living body capable of 'marking out upon matter the design of its eventual actions even before they are actual' (Bergson 1922, 12).

For Bergson natural perception and science tend to delimit and close, fragment and geometrise because they are based on preparation for action. But, when they are 'repositioned' in the universe of interactions, these closed systems reveal their own durations:

> What else can this mean than that the glass of water, the sugar, and the process of the sugar's melting in the water are abstractions, and that the Whole within which they have been cut out by my senses and understanding progresses, it may be in the manner of a consciousness? (Bergson 1922, 10)

The Creative Mind closely follows the relationship between the closed systems of science and the whole of the universe. Now, science has to build 'material systems in which time only slides' – astronomy, chemistry, physics are cited (Bergson 1946, 19) – by extending the role of natural perception (facilitating action by producing static images). But the experiment with the glass of sugar water shows that 'if one can cut out from the universe the systems for which time is only an abstraction, a relation, a number, the universe itself becomes something different' (Bergson 1946, 20). Thus, 'if we could grasp it in its entirety, inorganic but interwoven with organic beings, we should see it ceaselessly taking on forms as new, as original, as unforeseeable as our states of consciousness' (Bergson 1946, 20). We can see the significance of this statement: the universe also creates forms, has an unpredictable history, namely a form of duration. Yet, it is above all the method that is important: in order to reveal the action that duration has on the other durations (life, universe, even the *naturans* principle of all nature), we must always start from it, and from our experience of it.

2 The Whole Is of the Same Nature of the Self

In sum, Bergson contends that we must not confuse the work of science with that of philosophy. The latter has to return to the real, moving, time which is at the heart of things, life, and consciousness. Starting from his own conscious experience, a philosopher finds duration in all things, because for Bergson each consciousness, as far as it is duration, takes part in a universe that lasts (*Matter and Memory*) and in our lived lives, life being a vital impulse – *élan* – which is another name for duration (*Creative Evolution*). Yet, this method involves a difficulty related to the very nature of direct and psychological experience: to understand how the material universe is also a form of duration. For a philosophy which starts from the experience of conscious life and takes what our experience immediately attests to as merely a guideline, it becomes in fact very tricky to connect psycho-vital experience to the material universe. And please note that this difficulty does not only face Bergsonism. It raised questions for all the 19th-20th century philosophies of nature (Nietzsche, Whitehead, Tarde), which tried to deal with the question of cosmological unity and the nature of matter.

In the western philosophical tradition, the concept of matter has been saturated with intellectual representations that prevent its insertion into the 'living unity' of the cosmos. Thus, it is not surprising that Bergson considered one of the most important issues in *Creative Evolution* to be the fact that the material universe has the same nature as the self: duration. Speaking at the French Philosophical Society in 1908, he explained that one of the objects of *Creative Evolution* is to show that '*le Tout est* [...] *de même nature que le moi*, et qu'on le saisit par un *approfondissement de plus en plus complet de soi-même*' (Bergson 1972, 774). The last part of the sentence is important because it reveals the meaning of Bergson's philosophical method: from the self to the whole, from inner conscious experience to what is involved in this experience (other durations).

The renovation of the concept of matter began in *Matter and Memory*, a book focusing on our relationship to the universe. Here, Bergson claimed that the brain, if isolated, does not produce anything, neither interiority nor thought. Only the relationship between the living body and the world can explain the mechanism of perception together with its connection to pure perception, which encompasses the whole flow of the universe. For Bergson our perception does not create things nor images: it merely produces the static images needed for bodily actions, images selected from the flow of the universe. Perception, then, is linked to the universe, and *Creative Evolution* continued this meditation. At any rate, this is what Bergson said to the Philosophical Society on August 8, 1908, comparing his reflections to those in *Matter and Memory*

> Dans le premier de ces deux livres, on montre que *l'objectivité de la chose matérielle est immanente à la perception que nous en avons*, pourvu qu'on prenne cette perception à l'état brut et sous sa forme immédiate. Dans le second, on établit que *l'intuition immédiate saisit l'essence de la vie aussi bien que celle de la matière* (Bergson 1972, 774)

Philosophy challenges science exactly because it studies the essence of matter. In philosophy, 'l'acte de connaissance coïncide avec l'acte générateur de la réalité' (Bergson 1972, 774) – and to grasp the essence of matter means to grasp it exactly by means of the generating act that produces it. Nevertheless, from the point of view of method, philosophy can only exploit the intuition we have of our experience of conscious life.

In *Matter and Memory*, our intuitive participation in the universe becomes evident. But *Creative Evolution* does not require us to change method: we can move from 'immanent to the whole of the universe' (Bergson 1922, 11) only by starting with ourselves, from our existence.

3 The Tendency of Modern Science to Dematerialise Matter

If science understands matter with the help of mathematical laws, should we think that matter is reduced to these laws, and can only be composed of immobile stable elements? Bergson, always on the lookout for new horizons in science, sees another path at the very heart of physical theories. *Matter and Memory* was inspired by electromagnetism and draws lessons from Thomson and Faraday: 'psychological analysis has already revealed to us that this discontinuity is relative to our needs: every philosophy of nature ends by finding it incompatible with the general properties of matter' (Bergson 1947, 266). Science itself thus encourages us to see matter only as 'modifications, perturbations, changes of tension or of energy, and nothing else'(Bergson 1947, 266).

In *Matter and Memory*, Bergson does not forget to quote Maxwell, who as early as 1864 showed that light is an electromagnetic waveform (see Davies 1988, 32). Even though we had to wait until 1924 before particles of matter such as electrons were considered to have wavelike properties and to listen to scientists talking about waves in matter, the fact remains: ever since, atomic matter has been dissolved in immaterial fields of force. Electromagnetic science is still present in *Creative Evolution*, as can be seen from the references to Faraday's use of X-rays to penetrate the atom, the discovery that every atom 'fills the world' and, more generally, the idea of force fields (see Davies 1988, 67; Nottale 1997, 34). Again, Bergson tells us that science, as well as consciousness, makes us understand that a material point is 'a mere view of the mind' (Bergson 1965, 41). Electromagnetic physics, in fact, confirms that solid bodies are not primary, that matter is first waves and light, indivisible energy, and continuous flow. Consequently, there is no gap between what consciousness reveals to us and what science tends to show: 'Science and consciousness are agreed at the bottom' (Bergson 1947, 260).

In *Creative Evolution,* Bergson stated that 'the more physics advances, the more it effaces the individuality of bodies and even of the particles into which the scientific imagination began by decomposing them: bodies and corpuscles tend to dissolve into a universal interaction' (Bergson 1922, 168). Yet, he would later say this again, in the second introductory essay of *The Creative Mind*, where he shows that, although science has served as a vector for this movement, it did not follow it to its logical end, because of its own conventions: 'When I began to write, physics had not yet made the decisive advances which were to bring a change in its ideas on the structure of matter' (Bergson 1946, 83). He went on to add:

> Sooner or later, I thought, the idea of support would have to be abandoned [...] Sooner or later, I thought, physics will be brought around to the point of seeing in the fixity of the element a form of mobility. When that time came, it is true, science would probably give up looking for an imaged representation of it, the image of a movement being that of a moving point (that is to say, always of a minute solid) (Bergson 1946, 83–84).

The fusion between the wave and the corpuscle is again evoked: a fact that could make us think that a piece of iron is a melodic continuity more than a thing. By necessity, 'the great theoretical discoveries of recent years have led physicists to suppose a kind of fusion between the wave and the corpuscle, between substance and movement, as I should express it' (Bergson 1946, 84). Yet, this text from the second introduction of *The Creative Mind* also refers in a note to the essay *The Perception of Change*, which makes the point even clearer. Here, in fact, Bergson asked himself: doesn't science dissolve matter and each moving thing by making us sense a physical movement? To which he answered:

> A suggestion of this vision of material things already comes to us from physical science. The more it progresses the more it resolves matter into actions moving through space, into movements dashing back and forth in a constant vibration so that mobility becomes reality itself. No doubt science begins by assigning a support to this mobility. But as it advances, the support recedes; masses are pulverised into molecules, molecules into atoms, atoms into electrons or corpuscles: finally, the support assigned to movement appears merely as a convenient schema, a simple concession on the part of the scholar to the habits of our visual imagination (Bergson 1946, 174).

Finally, there are no more things in movement: their supposed movement has become a 'movement of movements' (Bergson 1946, 83). By stressing the triumph of the wave over the corpuscle, in these passages, Bergson is basically saying that *matter radiates*. And what is the meaning of a universe of light, if not that of being a universe that lasts and expands, a universe of energy to which we are necessarily connected? And why is this so important for a theory of nature? Because this matter is also a form of duration and movement, as we have just seen: the example of the glass of sugar water showed us that the material universe does not change without us perceiving it changing, and without us perceiving ourselves being transformed. The durations of the universe and ourselves are therefore intertwined.

To recap, we can say that Bergson followed science's developments and discoveries because modern science tends to dematerialise matter. It is true that science still uses spatializing images, the necessary work of intelligence being to spatialize, but it is clear that even in science, the tendency is to do without such images as much as possible. In any case, the philosopher who understands what duration is for, by having explored it in his psychic life, can only be interested in this kind of science. It proves that matter cannot be reduced to pure stability although it cannot demonstrate this fact by itself. Science, in fact, is not philosophy and *Creative Evolution* has shown that the limits on science following this movement so as take the dematerialisation of matter to its extreme consequences are due to the natural infirmity of its proper organum: intelligence. The latter always cuts matter, always divides it, because it is not made to go back in time, but rather to act on matter.

Therefore, the constitution of closed systems is the essence of the work of physics. By holding that matter is 'decomposable into isolated systems', writes Bergson, 'in attributing to it quite distinct elements which change in relation to each other without changing in themselves (which are *displaced* shall we say, *without being altered*), in short, in conferring on matter the properties of pure space' (Bergson 1922, 214–215), science accentuates the spatiality of matter and thus sets limits on its own work of dematerialisation. Philosophy, on the contrary, seeks to go to the end of this dematerialisation by wresting matter back from spatializing intelligence. For philosophy, in fact, matter is a form of duration. But how can we explain why intellectuality and materiality are nevertheless so well adapted to each other?

In *Creative Evolution*, Bergson reflects on the vital genesis of our psychological frameworks for knowledge, concluding that there is no philosophical reason to set intellectuality and materiality in opposition as has been the case in most philosophies. Why, in fact, does the world obey our mathematical principles? Why is the world knowable? Knowledge would be a miracle if we had had to address a kind of matter that was totally foreign to our intelligence or address it with an intelligence that was totally foreign to matter. The intellect and materiality have to communicate because 'this matter, in all that it has that is intelligible, is our own work!' (Bergson 1922, 216). For Bergson, in particular, spatialized matter is the product of the work of intelligence and intelligence is the product of the work of life. Life produces intelligence to master matter, and this reciprocal genesis of materiality and intellectuality makes us understand why matter is spatialized and why it is always immobilised in our intellectual and scientific representation. Matter, says Bergson, inevitably accentuates 'its materiality, when viewed by the mind' (Bergson 1922, 213).

Yet, to say that materiality derives from intellectuality is to confirm the Kantian thesis of the ideality of space. Our intelligence is certainly a spatial shaping of the world, but it is so for vital reasons that Kant did not grasp. His mistake, according to Bergson, is to have assumed that 'space is given as a ready-made form of our perceptive faculty, a veritable *Deus ex machina*, of which we see neither how it arises, nor why it is what it is rather than anything else' (Bergson 1922, 216). On the other side, to operate the vital genesis of intelligence is to assign it a function by refusing it as an absolute: spatialization serves action. This is why, in the end, science works in the direction of materiality and not in the direction of duration. Indeed,

> [i]t is impossible to consider the mechanism of our intellect and the progress of our science without arriving at the conclusion that between intellect and matter there is, in fact, symmetry, concord and agreement. On one hand, matter resolves itself more and more, in the eyes of the scholar, into mathematical relations, and on the other hand, the essential faculties of our intellect function with an absolute precision only when they are applied to geometry (Bergson 1946, 43)

But this spatialization of matter prevents us from grasping the duration that remains within it. Fully intellectualised, matter becomes spatialized and geometrised, without action, movement, or energy. It is an extended and unfolded kind of matter. All of its parts are therefore divisible and separable ad infinitum. Nothing is transformed within it: this kind of matter has only relative movements (as in Cartesian and Galilean mechanics). We may add that such intellectualised matter is continuous, but only in the sense of mathematical continuity: the abstract possibility of infinite division. But, in reality, this abstract continuity does not allow for continuity of movement to the extent that it exactly underpins the discontinuity necessary for action. In fact, we always find ways to redefine discontinuity, because of these needs, and therefore we always postulate – and thus find – atoms, points, grains, lumps, bodies, and other things with spatial extension. Hence Bergson's well-known thesis: intelligence only represents discontinuity on a background of ideal and mathematical continuity (Bergson 1946, 221–222).

For Bergson there is no point in considering atomism and geometrism as opposites, given that the two work together: the ideal division of space provides fixed points for action. This means that matter is never as completely spread out in space as our intelligence and senses represent it: although it spreads out in the direction of space, matter is not space. This double-line explanation recalls the one describing sugar in a glass of water: just a little 'attention' to this matter, which at first seems spatial to us, suffices to make us feel the 'action of the Whole' (Bergson 1922, 219) within it. Thus, science itself puts us on the path to a matter that cannot be reduced to pure space. Yet, it is the task of philosophy to broaden this trend of science by grasping it within a wider experience that includes our own duration. Within it, in fact, we can understand that there is also movement without mobility in matter and a movement of the universe, which has its own history.

4 Energy Degradation

A second important way in which Bergson refers to physics in *Creative Evolution* concerns the second principle of thermodynamics. Bergson wants to show the slope of the universe towards space. Just as electromagnetism shows us the reality of physical motion, just as a glass of sugar water connects us to the duration of the universe, thermodynamics shows us the reality of that movement which is the extension of the universe. The second principle of thermodynamics affirms that an isolated system progressively and irreversibly converts its potential energy into an equipotential structure. Thus, according to Bergson, it confirms the tendency of the material universe towards spatialization. To spatialize now means to pass from a difference in potential to a homogeneous structure. And the universe, if it is assumed to be closed, energetically evolves by tending towards entropy. This is why the second law of thermodynamics appears to Bergson as 'the most metaphysical of the laws of physics' (Bergson 1922, 256). Moreover, it indicates the direction in which the universe is moving, namely the uniform distribution of energy: 'is seen to be ever exhausting something of the mutability it contains' (Bergson 1922, 257).

Therefore, we find that once again physics allows us to escape from the relativity of movement. But how can we account for this trend? For Bergson, the lesson of thermodynamics remains meaningless if we don't relate it back to our own experience. In fact, even with respect to entropy, the attestation of our conscious life experience is crucial. The scientist who sticks to matter does not aim to explain how consciousness, life, and the universe communicate and relate to each other. What philosophy brings, on the contrary, is the intuition that the essential mutability of the world cannot have its source within matter itself. If matter has a tendency towards spatialization, how could it be the creator of energy? For Bergson, we can only interpret this entropic fall by confronting it with our psycho-vital experience, that is by connecting it to our existence, to our experience of duration. If we can understand it, in other words, it is because we can see that the universe does not last in the same way that our life and our consciousness do.

Yet, the scientist cannot understand it, having cut himself off from part of the experience. So, according to him, the direction of the initial mutability towards stability is physically explainable, although the eruption of energy that conditions this mutability will never be so: he may suppose an infinite universe at the beginning, but he will never bring forth energy from this infinite universe. According to his definition of matter, in fact, such a universe would be precisely a universe spread out with material elements that are absolutely external to each other: a universe without tension, relation, and potential. 'In reality, the problem remains insoluble as long as we keep on the ground of physics' (Bergson 1922, 258) says Bergson. In other words, when he wants to explain the presence of energy, the physicist will not look for any kind of *extra-spatial* energy of which he has no concept. But the philosopher sees it at work in every moment of life and, above all, in his living conscious experience.

The physicist does not believe that any sort of extra-material energy can exist. Thus, he will stick to the definition of matter he has just given, namely matter as a slope towards uniformity and stability. The philosopher will instead point out that there is a distinction between extra-material creation and material conservation, between open and closed, between philosophy and science. But how can we establish this distinction if we abstract from our experience of being a duration intersecting with other durations? Let us insist on this point of method: the fact that the universe radiates and falls towards entropy cannot be understood other than by starting from our duration and the way it implies the duration of the universe (the glass of sugar water). Thermodynamics, in fact, leads us to think that the universe has a direction or an extra-spatial primordial energy that only later will fall back into space.

5 The Intricacy of Durations

Bergson does not posit the universe as an objective, all-encompassing framework that precedes us. The universe is neither fixed nor unchanging. The universe is deduced from our perception, from what is transformed and sensed in our conscious life experience. We don't change without things changing, the world doesn't change without our knowledge of this change, because life, matter, and consciousness are durations, and there is communication between all of these durations. Our perception – here synonymous with intuition – is in itself only a relation between durations. We perceive the material world, as one reads in *Duration and Simultaneity*,

> and this perception appears, rightly or wrongly, to be inside and outside us at one and the same time; in one way, it is a state of consciousness; in another, a surface film of matter in which perceiver and perceived coincide. To each moment of our inner life there thus corresponds a moment of our body and of all environing matter that is "simultaneous" with it; this matter then seems to participate in our conscious duration (Bergson 1965, 45)

Duration and simultaneity even goes so far as to say that we live a cosmic life as much and more than an individual life (Bergson 1965, 51). Then, it is not by chance that, in *The Creative Mind* Bergson uses the example of colours being wavelengths to get the point across. Here Bergson proposes an experiment that consists in imagining ourselves as a colour and wondering whether we might not be immediately connected to the durations of other colours.

> But just as a consciousness of colour, which would harmonise inwardly with orange instead of perceiving it outwardly, would feel itself caught between red and yellow, would perhaps even have, beneath the latter colour, a presentiment of a whole spectrum in which is naturally prolonged the continuity which goes from red to yellow, so the intuition of our duration, far from leaving us suspended in the void as pure analysis would do, puts us in contact with a whole continuity of durations which we should try to follow either downwardly or upwardly: in both cases we can dilate ourselves indefinitely by a more and more vigorous effort, in both cases transcend ourselves. In the first case, we advance toward a duration more and more scattered, whose palpitations, more rapid than ours, dividing our simple sensation, dilute its quality into quantity: at the limit would be the pure homogeneous, the pure *repetition* by which we shall define materiality. In advancing in the other direction, we go toward a duration which stretches, tightens, and becomes more and more intensified: at the limit would be eternity (Bergson 1946, 220).

The Creative Mind clearly defends the thesis of the co-implication of durations each one involving the other. Our experience of conscious life, in fact, implies a relationship to the duration of the universe, that is to another experience of conscious life. Moreover, it also bears witness to a more contracted or more intense duration, which would, at the limit, be the 'eternity of life' (Bergson 1946, 220): a pure and free creativity where our own duration, Bergson says eloquently in the same text on colours and durations, 'would find itself like vibrations in light' (Bergson 1946, 220). Light even brighter than the visible universe, because it is the light of a true source. In relation to science, the philosopher's work is therefore to *think about how things communicate*, and for Bergson they can only communicate inasmuch as they are durations: movements that act mutually. In this regard, he writes in *Creative Evolution:*

> The philosopher must go further than the scientist. Making a clean sweep of everything that is only an imaginative symbol, he will see the material world melt back into a simple flux, a continuity of flowing, a becoming. And he will thus be prepared to discover real duration there where it is still more useful to find it, in the realm of life and of consciousness. [...] So understood, philosophy is not only the turning of the mind homeward, the coincidence of human consciousness with the living principle whence it emanates, a contact with the creative effort: it is the study of becoming in general, it is true evolutionism (Bergson 1922, 390 – 391).

6 Sympathy

But how can we move in the direction of the duration of non-human things, that is in the direction of other durations? The notion of sympathy plays a prominent role here. Several times Bergson defines intuition as sympathy and his use of the term sympathy to describe the intuition of another reality is very significant. Intuition, considered as sympathy, becomes a movement of fusion towards otherness: 'For one does not obtain from reality an intuition, that is to say, a spiritual harmony with its innermost quality if one has not gained its confidence by a long comradeship with its superficial manifestations' (Bergson 1946, 235).

It is thus necessary to become familiar with the object, to acquire enough facts to 'melt' them into a unity that comes close to what the envisaged reality is. Only then can there be an intuitive leap from multiplicity to unity, from static to dynamic, from space to time. Sympathy is the means by which I begin to espouse the movement of the other reality I apprehend. And, by doing so, I can open myself to durations other than my own. This point is crucial. We do not only have an intuition of ourselves: we can also intuit a thought that is external to us and sympathise with it. Yet, for Bergson we can only do so starting from what has been inserted in language and concepts. In order to know another philosophy, for example, we are forced to start from the philosophical system that expresses it, from its sources, its similarities with others, its cultural environment. And it is only once this kind of *impregnation*, *contact* or *effort* has begun that we can grasp the essence of that philosophy by penetrating the system's real and simple intention. Thanks to intuition, in short, we no longer seek to 'go around' the system. We grasp its intuition intensively and no longer extensively.

Bergson presents sympathy as a relationship between my duration and others. Sympathy is an effort to place myself in other durations, by placing myself in their movements. As we said, this is a crucial point because without this effort we would not be able to capture other durations. In other words, it is as if sympathy makes cosmology – the capture of durations in matter, life, and other spiritual realities – possible. It is, in fact, 'intuition of ourselves' (Bergson 1946, 35). Yet,

> Between our consciousness and other consciousnesses the separation is less clear-cut than between our body and other bodies, for it is space which makes these divisions sharp. Unreflecting sympathy and antipathy, which so often have that power of divination, give evidence of a possible interpenetration of human consciousnesses. It would appear then that phenomena of psychological endosmosis exist. It may be that intuition opens the way for us into consciousness in general. But is it only with consciousnesses that we are in sympathy? If every living being is born, develops and dies, if life is an evolution and if duration is in this case a reality, is there not also an intuition of the vital, and consequently a metaphysics of life, which might in a case prolong the science of the living? […] Let us go still further. Above and beyond the organizing process, unorganised matter appears as though decomposable into systems over which time slips without penetrating, systems which belong to the realm of science and to which the understanding can be applied. But the material universe in its entirety *keeps* our consciousness *waiting*; it waits itself. Either it endures, or it is bound up in our own duration. Whether it is connected with the mind by its origins or by its function, in either case it has to do with intuition through all the real change and movement that it contains […] In short, pure change, real duration, is a thing spiritual or impregnated with spirituality. Intuition is what attains the spirit, duration, pure change. Its real domain being the spirit, it would seek to grasp in things, even material things, their participation in spirituality, I should say in divinity were I not aware of all the human element still in our consciousness, however purified and spiritualised (Bergson 1946, 35–36).

As we can see, the movement of sympathy leads us to an intuition that takes us out of ourselves, and beyond our humanity. It is an intuition of the vital, the material, and even the divine nature of the world. Each time we have an intuition, Bergson says, we grasp a real movement: a change which is an indivisible duration. All that lasts is a matter of intuition. And therefore, thanks to intuition we also understand the difference between matter and spirit, space and time. Now, science studies systems without time, proceeding to an increasingly fine analysis of their elements. But it always must be relayed by an intuition of what makes their movement and their capacity to change real, that is, by an intuition of what makes their vital impulse real: the duration of the universe. And please note that it is in this sense that Bergson speaks of a metaphysics of life: it is 'of' life because it takes the spiritual dimension of life into account. And, in the same way, he speaks of a metaphysics 'of' the material universe which captures the irreducible movement of the whole's duration.[1]

Let us note in passing Bergson's general interest in inter-psychological phenomena: *interpenetration of consciences*, *psychological endosmosis*. In 1900, Bergson took part in the foundation of the International Psychical Institute, and in 1909 he became a foreign correspondent for the Society for Psychical Research. Its aim was to study psychic phenomena such as telepathy, divinatory dreaming (telepathy and dreaming), spiritualist or mediumistic phenomena, the unconscious, and so on. When he became president of the Society for Psychical Research, he gave his lecture on *Ghosts of the living*. But the text of *The Creative Mind* on endosmosis is an excerpt from his lecture of 28 May 1913. Sympathy, in fact, is said to be similar to an endosmosis in which different durations mutually intermingle

> Let us not forget, moreover, that it is space which creates the sharp divisions. Our bodies are external to one another in space; and our minds, in so far as they are attached to those bodies, are separated by intervals. But if the mind is attached to the body only by a part of itself, we may conjecture that for the other part of the mind there is a reciprocal encroachment. Between different minds there may be continually taking place changes analogous to the phenomena of endosmosis (Bergson 1920, 86–87).

The essential thesis is that *consciousness overflows the organism*, so that what is to be explained are not these phenomena of communication between consciousnesses that go beyond bodies and their spatial situatedness. What remains to be explained is rather why they do not happen more often.

Conclusion

For Bergson, our intuitions or sympathy, open us to other durations and so we have to pay close attention to his notion of spiritualism. Spiritualism is not the entrenchment of duration in subjectivity, nor does it stand in contrast to science; on the contrary, it wins over nature, it invades nature, it concerns all beings. And it does so with the help of science. To intuit, in fact, means to reach the

1 At the end of the text, Bergson seems to regret that this intuition is not quite capable of carrying itself to the point in which the participation of things in divinity happens. Mystical experience, in fact, plays a key role in *The Two Sources of Morality and Religion*. For Bergson the mystics lead us in embracing natura *naturans* and it is for this reason that intuition, the mystic's organum, opens us up to a cosmology that is grasped not only purely in an interior and psychological sense.

spiritual dimension of all beings. And so *spiritualism is not synonymous with acosmism*. Who emphasises the spirit does not move away from things or from the universe. Thanks to intuition one finds them again, touching them as truly as science does, but by another means, another vision, another method.

Spiritualism, for Bergson, means that a spirit or psyche is present in all realities of the actual world. Science and metaphysics, in fact, do not split the real, as if there were two distinct realities. They are two different points of view taken on the same real: space and time, but the real time, i.e., duration. This is why Bergson says that metaphysics is not 'the superior of positive science' (Bergson 1946, 48). Both embrace the same reality, and both do so absolutely; 'both touch the bottom of reality' (Bergson 1946, 41). In the same way, the realm of metaphysics is not purer, more complex, more delicate than that of science. Metaphysics grasps the same reality as science, but in a different way. Thus, spiritualism does not intend to flee from reality: it rather dwells within things. While science examines the material nature of things, metaphysics makes us understand that things also have another, spiritual dimension: duration.

Life, in short, is not only matter, it is duration too; the universe is not only mechanical, it also lasts. And it is within this framework that we must appreciate the debate between Einstein and Bergson and the meaning of *Duration and Simultaneity*. It is easy to understand that Bergson's aim was not to correct Einstein on a physical level nor to oppose a lived time to a physical time. For him, it was rather a question of finding, in physical time but beyond its measures, its immanent duration and, moreover, to find in this duration all the durations of the universe. For Bergson there is no single physical absolute time but a multiplicity of durations that are constantly weaving together and opening up to a new cosmology. And it is because the universe is duration that other durations can be grasped by contrast with it. Philosophy has to unfurl this implication in order to reveal a new cosmos.

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Part Three **The Nature of Time, the Time of Nature**

Eugenio Coccia

The Time of Physics

Abstract

Space and time are fundamental concepts of the natural sciences. To simplify, we can say that until 1905 they were considered essentially as containers that house substances and bodies whose mutual interactions and movements constituted the real object of study. Einstein's Relativity changed everything. It freed space and time from prejudices that had gone unnoticed over the centuries. He brought them down from the Olympus of the *a priori* and led them to be protagonists of a new physical theory accessible to observation. We report here on the time of physics, and on the path taken by Einstein to arrive to the formulations of Special and General Relativity, which is also the starting point for modern physics theories trying to reconcile General Relativity with Quantum Mechanics.

1 Preamble

April 6, 1922, Paris, Société Française de philosophie. A dispute on the concept of time is underway between two heavyweights: Henri Bergson, philosopher and Albert Einstein, physicist. Bergsonian time speaks of a "human" duration to things. These constitute a "vitalist" time in the sense that they mark subjective durations to life. Einstein point of view is that all we can do with the tools we have—those of science and rational thought—is to mathematically express the mechanics of time, ridding ourselves once and for all of "vitalist" superstitions and contagious metaphysical moods.

2 Galilei

If the role of time as a fundamental variable parameter of natural phenomena was already understood in the late Middle Ages, it is only with Galilei that time becomes a measurable physical quantity. Galilei is the first to give a role to the scientific notion of time—which is included in his *Saggiatore* among the "primary or objective qualities"—and to give it an accurate artificial measure. His observations on the motion of bodies lead him to formulate the principle of inertia: all the bodies to which a force is not impressed remain at rest or, in

 https://doi.org/10.1515/9783110753707-012

case they have an initial speed, continue to move in a uniform rectilinear motion. Galilei gets there by mentally purifying the movement of bodies from the resistance effect of the medium in which they move. The bullets, once set in motion, tend to keep their motion because (this is the important point) the state of motion is a natural state like the state of rest. We can say that before the principle of inertia was formulated there was an asymmetry between movement and stillness: the first had to be motivated and the second not. With Galilei the motion at constant speed becomes natural and equivalent from the physical point of view to the state of rest: the two states even become indistinguishable. This is the deep meaning of the Galileian principle of relativity. Let Galilei speak:

> Shut yourself up with some friend in the main cabin below decks on some large ship, and have with you there some flies, butterflies, and other small flying animals. Have a large bowl of water with some fish in it; hang up a bottle that empties drop by drop into a wide vessel beneath it. With the ship standing still, observe carefully how the little animals fly with equal speed to all sides of the cabin. The fish swim indifferently in all directions; the drops fall into the vessel beneath and, in throwing something to your friend, you need throw it no more strongly in one direction than another, the distances being equal; jumping with your feet together, you pass equal spaces in every direction. When you have observed all these things carefully (though there is no doubt that when the ship is standing still everything must happen in this way), have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating this way and that. You will discover not the least change in all the effects named, nor could you tell from any of them whether the ship was moving or standing still. In jumping, you will pass on the floor the same spaces as before, nor will you make larger jumps toward the stern than toward the prow even though the ship is moving quite rapidly, despite the fact that during the time that you are in the air tibe floor under you will be going in a direction opposite to your jump. In throwing something to your companion, you will need no more force to get it to him whether he is in the direction of the bow or the stern, with yourself situated opposite. The droplets will fall as before into the vessel beneath without dropping toward the stern, although while the drops are in the air the ship runs many spans. The fish in their water will swim toward the front of their bowl with no more effort than toward the back, and will go with equal ease to bait placed an5rwhere around the edges of the bowl. Finally, the butterflies and flies will continue their flights indifferently toward every side (Galilei 1967, 186 – 187)

Galilei really made the bucket which "drop by drop into a wide vessel beneath it" (Galilei 1967, 186) and did not just serve to show the impossibility of establishing "whether the ship was moving or standing still" (Galilei 1967, 187). It was also the working principle of a chronometer capable of measuring time intervals with the precision of a tenth of a second, which he used to study the motion of falling bodies. It is Galilei himself who describes it: "as for the measurement of time, a large bucket full of water was held, attached at the top, which poured a thin stream of water through a thin tube, welded to the bottom" (Galilei 1967, 190).

Assuming a constant flow, time was measured by weighing the water collected in a small glass with the most exact balance.

Galilei will use this system to measure the rolling times of spheres along an inclined plane, a brilliant idea to lengthen the falling times (compared to making bodies fall vertically) and be able to measure them precisely. He was thus able to establish the law of motion of bodies due to gravity, measuring the spaces traveled being between them as the squares of times. He also understood that the pendulum would make a great clock. He arrived there by observing the oscillations of a chandelier fixed to the ceiling of the Cathedral of Pisa. He noticed that the pendulum has a period that depends only on its length, not on the amplitude of the oscillation (at least for small oscillations) nor on the value of the mass hanging from its end. This last experimental fact, due to the equivalence between inertial mass and gravitational mass, will be the basis of Einstein's theory of General Relativity.

3 Newton

Isaac Newton was born in 1642, the year Galilei died. In what framework of space and time does Newton's mechanics operate? This is his thought, reported in *Principia Mathematica* (1687):

> 1. Absolute, true, and mathematical time, in and of itself and of its own nature, without reference to anything external, flows uniformly and by another name is called duration. Relative, apparent, and common time is any sensible and external measure (precise or imprecise)3 of duration by means of motion; such a measure—for example, an hour, a day, a month, a year—is commonly used instead of true time. 2. Absolute space, of its own nature without reference to anything external, always remains homogeneous and immovable. Relative space is any movable measure or dimension of this absolute space; such a measure or dimension is determined by our senses from the situation of the space with respect to bodies and is popularly used for immovable space, as in the case of space under the earth or in the air or in the heavens, where the dimension is determined from the situation of the space with respect to the earth. Absolute and relative space are the same in species and in magnitude, but they do not always remain the same numerically. For example, if the earth moves, the space of our air, which in a relative sense and with respect to the earth always remains the same, will now be one part of the absolute space into which the air passes, now another part of it, and thus will be changing continually in an absolute sense (Newton 1999, 408–409).

Newton thus expresses his conviction of an absolute space and time "without reference to anything external". It is a conception that seems to correspond to our elementary intuition. This was not the view implicitly accepted in previous centuries, which was instead that of Aristotle. According to Aristotle, where there is nothing, and nothing moves to indicate the passage of time, space and time simply do not exist. For Newton, on the other hand, space also exists even where there is nothing to indicate a reference and time exists even if there is nothing that moves showing its unfolding. According to Newton, in space, bodies could remain *absolutely* in one of the following states: at rest, in straight and uniform motion, in accelerated motion. This last condition was clearly recognized with the appearance of fictitious forces, such as centrifugal forces, and evident effects, such as the crushing of the Earth at the poles or the rotation of the pendulum's swing plane. Leibniz's critique (which Ernst Mach took up centuries later in a deeper way and stimulating Einstein's mind on this problematic) was based on the fact that in this way absolute space assumed the role of cause of physical phenomena, regardless of the effect of other bodies. However, as far as Newtonian time is concerned, no one could complain, it was so natural that time would flow imperturbably at the same pace for everyone and everywhere.

4 Maxwell

Newtonian physics worked and the scientists' attention shifted to other fields. Thermodynamics allowed us to understand the relationships between energy, heat and mechanical work, making the first industrial revolution possible in the 18th century. Then came the century of electricity and magnetism, and new extraordinary things happened. Someone was needed to translate the amazing fact that electricity, magnetism and light were manifestations of the same reality into mathematical equations: electromagnetism. This was James Clerk Maxwell, and his four equations are among the most famous in the history of modern physics. In a sense, Maxwell represents for electromagnetism what Newton was for mechanics. There was in fact something in Maxwell's equations, a detail, which will prove to be fundamental for modern physics: the speed of propagation in vacuum of the electromagnetic signals that appears in his equations is a constant, therefore independent of the characteristics (such as position and velocity) that it is found to have who emits the signal or who receives it. This constant is indicated by all with the letter c, from the Latin *celeritas*, and is equal with a good approximation to 300 thousand km/s. But we know from Galilei that the concept of speed has relative meaning, its measurement depends on the state of motion of the observer. There is therefore no absolute speed, identical for everyone. Now one came out instead! How was it possible that the speed of light was constant regardless of the observer's motion, and therefore did not add to or subtract from other speeds?

It is at this point in the story that an unknown employee of the Bern Patent Office intervenes. It will find the solution and change our concepts of space and time. In Einstein's Relativity, the spatial and temporal intervals will not be rigid and will depend on the observer, but with one impassable limit: in the phenomena of nature, the cause always precedes the effect. The principle of causality imposes a temporal order on events, and this order cannot change with the observer. To guarantee this order there is the non-overcoming of the speed of light in vacuum.

5 Einstein

Einstein faces the dilemma between Galilei's relativity and Maxwell's electromagnetism. Could they both be correct? That is, could on the one hand the stillness and uniform motion be indistinguishable and on the other hand there be a constant speed in all reference systems? Einstein's answer was: yes, they could. But there was a price to pay: two fundamental physical quantities, linked to elementary mental categories, space and time, had to be completely rethought. Let's see how, by performing a thought experiment, a *Gedankenexperiment*.

We postulate that both—Galilei with his relativity and Maxwell with his constant speed of light—are right. Let's try to imagine time and space measurements performed in reference systems moving relative to each other. For this we mentally build a clock able to show in a simple way the effects of relative motion between reference systems. The measurement of time has always been based on the counting of periodic phenomena. The first examples were the rotation of the Earth until finding the Sun in the same position (the day) or a complete revolution of the Earth around the Sun (year) and their appropriate subdivisions in equal intervals. Then came the pendulums and mechanical oscillations, finally in modern times the atomic oscillations to give ever better precision to the time measurements. Let's build a clock using the light: we count the oscillations of light reflected back and forth between two mirrors facing a fixed distance L. The speed of light, by definition is c, so the time it takes to go from one mirror to another is $T = L/c$. A complete oscillation back and forth will take double time, equal to $2\,L/c$. It is a watch like any other, has a constant period and is able to measure the passage of time.

We deliver it to a friend who takes a train, equipped with glass walls for observation convenience, which travels with constant speed compared to us who stay still at the station. For our friend on the train, the clock will continue to *tick* with the same rhythm it had when it was at rest in the station –do you remember Galilei? Any measurement has the same result in rest as in uniform rectilinear motion. Suppose that the train passes in front of us proceeding in a straight and uniform motion with speed v. Looking through the glass wall of the wagon we then see the clock, held by our friend in a vertical position, working while it is in motion with respect to us. We observe that for us the light to go from one mirror to another takes a longer, oblique path D than the vertical path L that our friend sees, since for us the two faces of the mirror move horizontally with the speed of the train during the light oscillation. And since light always travels at speed c (as Maxwell tells us), the longer travel distance we see will result in a longer time taken by light to travel from one mirror to the other on the clock, compared to that measured by our friend. See Fig. 1.

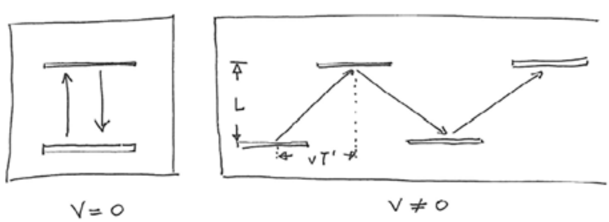

Fig. 1: Left: a simple clock which counts the oscillations, the ticks, of light reflected back and forth between two mirrors facing a fixed distance L. Right: the same clock as seen by an observer respect to which the clocks moves in a straight and uniform motion with speed v. For the observer the light takes a longer, oblique path to go from one mirror to another since for him the two faces of the mirror move horizontally with speed v during the light oscillation. And since light always travels at speed c, the longer travel distance will result in a longer time taken by tick, as measured by the observer.

The time measurements performed in the two reference systems in motion with respect to each other are not the same. For us, the time marked by the clock on the train is dilated with respect to the time our friend measures. It is a logical and astonishing consequence of the constancy of the speed of light in any frame of reference and of Galilei's principle of relativity. If the clock were mechanical, instead of using light, would we have the same result? Yes, of course! In fact, if our friend had also brought a mechanical clock with him, it could only have been always in synchrony with the one made with light, otherwise he would distinguish the state of motion from that of rest and would violate Galilean relativity. So from the station I could only see the same time dilation on both clocks.

Let's calculate how much time dilates. Let's say that the elementary interval that light takes us to go from one mirror to the other passes from the value T = L/c measured by our friend on the train to the value T' = D/c measured by us at the station. To know what T' is, just apply the Pythagorean theorem. The path to go from one mirror to another is L = cT for my friend who sees the mirrors facing each other, while for us it is the hypotenuse D = cT' of the right triangle whose sides are L and vT' –which is horizontal displacement of one of the two mirrors during the time T' (v is the speed of the train). Try to do the math to believe, the time measured for us will be:

$$T^{'} = T \; \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} = T \; \gamma$$

The factor, which is usually indicated with the Greek letter γ, is a number greater than 1, because the speed of the train v is certainly less than that of light. From here follows the higher value of T' compared to T. The clock in motion goes γ times slower, in short.

For any reasonable value of train speed v, the γ factor is so close to 1 that it is practically impossible to measure the difference between T and T' with the clocks we deal with in our daily practice. The factor γ becomes significantly greater than 1 only at very high speeds and would become infinite if the train went at the speed of light (an impossible event). It goes without saying that accurate measurements actually made in the years following the formulation of Einstein's theory, from those with aircraft equipped with atomic clocks to those made with satellites and in elementary particle physics laboratories, will fully confirm these calculations and this vision of reality. Of course for our friend on the train, we are moving at speed v relative to him. So, if we also had a watch identical to his, in a completely symmetrical way it would be our time interval to be measured by him as longer than his. There is no contradiction. To meet and compare our clocks, one or both of us must stop being an inertial system. Our friend would have to stop and go back for example, this would break the symmetry of the situation.

The surprises don't end here. Let's try to measure a space interval. We mark two points at distance L along the station platform. When the train passes at speed v, we measure the time it takes to sight the two points, that is to travel along the stretch L. The resulting time T will naturally be equal to L/v.

The same measurement is performed by our friend on the train. Keep in mind that the station is now in motion with respect to him with speed v and that his clock is slower than ours by a factor γ. We conclude that the time he measures to pass the stretch that he will call L' will be T' = L'/v. But since we know that T'= Tγ = (L/v) γ, it follows that the distance L' measured by our friend will be reduced with respect to L by a factor γ:

$$L' = \frac{1}{\gamma} L$$

For the observer on the train space has contracted. Also in this case, the effect is extremely small if we do not involve very high speeds.

In summary, we have two observers in rectilinear and uniform motion that perform different measurements for the same intervals of time and space.

These differences are in a certain sense the price to pay so that the laws of physics are the same in all reference systems in relative rectilinear and uniform motion and therefore so that observers cannot distinguish the state of rest from that of uniform motion.

The first experiment that spectacularly demonstrated time dilation was done by studying cosmic rays. These consist primarily of high-energy particles from space (especially protons) that bombard the earth's atmosphere, generating other particles because of the impact and often real showers of particles that reach the ground. Among these secondary particles there are muons, similar to electrons but 200 times heavier and, above all, unstable: they tend to decay into other particles in a few millionths of a second. They are mostly generated in the upper atmosphere, and given their short lifetime, they would not have the time to reach the ground. Instead they get there! Since they travel at speeds close to those of light, their lifetime as measured by us here on Earth is considerably dilated, so actually they live longer and have the time to arrive to the ground.

As Bruno Rossi, protagonist of these measurements but above all one of the protagonists of Italian physics, said: nature has made available to us watches that travel at speeds that we cannot make ours reach.

However, Special Relativity, and indeed Galilean relativity itself, requires the process to be symmetrical. If we traveled astride the muon, there would be no time dilation, so how would we get to the ground? The answer is simple: in this case we would see the Earth with its atmosphere layer coming towards us at very high speed, there would be an evident contraction of the lengths and the atmospheric layer would appear thinner to us. So our muon actually arrives to ground. The relativity of time intervals has among its consequences that of making the concept of simultaneity also relative. To explain it, let's go back for a moment to the example of the train passing through the station, while we stand still on the platform. Our friend on the train stands in the middle of the wagon with his arms outstretched towards the two opposite end walls of the wagon with a laser pointer in each hand and simultaneously sends two pulses of light to the two ends of the wagon, where two flashes are ready to signal its arrival. The two ends of the train are equidistant to him and since the light goes at speed c in both directions, it is obvious that he will see the two flashes simultaneously. Standing still at the station instead we see the two pulses of the laser traveling, always at speed c, towards moving walls. One wall meets the impulse, shortening its path, the other moves away from the impulse, lengthening its path. Therefore, we will see the impulse that goes against the first wall arriving before the one on the second wall. Two simultaneous events for one observer are not simultaneous for another in uniform relative motion with respect to the first.

If we imagine that we can reach speeds close to those of light, we encounter so-called "paradoxes", which in reality are not such, even if they seem so. The most famous is that of the twins. Two twins in their twenties decide to separate, one stays on Earth and the other embarks on a "high-speed" spaceship for a long round trip during which his vehicle will reach speeds close to c. After 10 years, the traveling twin returns home to celebrate their thirtieth birthday with his brother but finds his 80-year-old brother who in the meantime has h ad children and grandchildren. It is a situation in perfect agreement with the theory of Relativity.

The paradox lies in the fact that from the point of view of the traveling brother (from his reference system) it is the brother who remained on Earth who moved away with the whole planet at sidereal speed and then rejoined the spaceship. It should then be the brother on Earth who remains younger! How is the paradox resolved?

The solution lies in the lack of symmetry of the situations experienced by the twins. Only the one who took the spaceship accelerated to reach the very high speed, then decelerated to go back, accelerated again to reach high speed in the opposite direction and then finally must decelerate to land back on Earth. When all the calculations are made, taking into account also the theory of General Relativity that we will explain shortly, we see that these differences are decisive.

From all these considerations, the principle of Special Relativity emerges in its simplicity and elegance: All the laws of nature, formulated in a specific reference system, remain valid in completely identical form, when referring to another reference system which is moving of rectilinear and uniform motion with respect to the first.

The term "Special Relativity" refers to the scope of validity of the theory, limited only to cases of rectilinear and uniform motions.

6 Spacetime

Space and time in Einstein's Relativity are no longer independent entities; they change with the same factor of proportionality in passing from one inertial reference system to another. One expands and the other contracts. It is as if they were partial aspects of a more general reality. Separately they do not give us an adequate representation of physical phenomena, we must consider them part of a more general physical property in which they are indissolubly united. What is this property?

A great mathematician, Hermann Minkowski, who had been Einstein's professor at the Zurich Polytechnic, understood that time must be considered a fourth dimension of the same quality as the three spatial dimensions, with the difference that must be regarded mathematically as an imaginary dimension, and can therefore be represented geometrically with a coordinate similar to the other three spatial coordinates.

From then on, the description of events will be associated with a new representation of reality: four-dimensional spacetime. The transformation from one reference system to another will correspond to a rotation in four dimensions in which all four coordinates can change. The distance between two events in spacetime will remain invariant, just as rotations in two or three dimensions keep the distance between two points in space unchanged.

Einstein's Theory of Relativity is ultimately the geometric theory of spacetime and can be seen as the last stage in the evolution of human thought on space and time. Aristotle considered three-dimensional space a hierarchical and differentiated entity, with absolutely privileged places. Galilei and Newton made space and time homogeneous and undifferentiated but they have kept their independent and absolute character. Einstein also drops these latter privileges: space does not have the same magnitude for everyone, time does not flow in the same way for everyone.

7 General Relativity

In the spacetime of Special Relativity free bodies and light rays move in a straight line. Euclidean geometry applies. Spacetime is therefore limited to being the theater where gravity acts as an additional and indispensable element to the explanation of phenomena, without however interacting and modifying the theater itself. According to General Relativity, instead, space, time and gravity are not three distinct entities, but something inextricably linked. Gravity is nothing more than the effect of the curvature of space-time due to the presence of matter and energy.

Before delving into more in-depth explanations, and understanding the path that led Einstein to what has been called the most beautiful theory ever formulated, let's get to the heart of General Relativity in a few lines. Let's imagine two two-dimensional beings who think they live on one plane, a universe with only two dimensions, completely flat. The two protagonists of this story propose to carry out an experiment with an outcome that they consider obvious: to stand at a certain distance and move, at the same speed, along parallel lines, then occasionally remeasuring the distance that separates them they expect to always find the same distance. Therefore, both leave, being careful to go at the same speed, and proceed along the direction perpendicular to the one that unites them, thus believing that they move according to the dictates of Euclidean geometry along two lines that will never meet. After a while they stop and measure the distance between them. They discover with surprise that they have approached.

At first they believe they were wrong, they repeat the experiment several times, but they always get the same result. Eventually they give up and come to the following conclusion: "When we move in that direction, there is a force that attracts us". They do not discuss the premise of living on a plane and decide to introduce a force to explain what they observe. They reason *à la Newton.* What Einstein would conclude instead is that perhaps the two characters are not on a plane, but on a spherical surface: if the geometry is changed, their approach will no longer be explained by the addition of a further ingredient to flat spacetime—that is the force of gravity—but simply with the fact that starting from the equator and actually going in a direction perpendicular to that which unites them, the two travel along two meridians. Their approach is therefore completely natural: it is a consequence of the curved geometry in which they live. There is no need to introduce any force.

The moral is: in the universe there is no force of gravity, all bodies move free but in a curved spacetime. This very simple example is perhaps able to grasp the meaning of the revolution introduced by Einstein, adding that is the presence of matter (and energy) to generate the curvature. We are facing a completely different conception of the universe from that of Newton. We do not live in a Euclidean space: in the region near matter, around the Sun for example, we can think that there is a kind of *depression*, as if the Sun were a heavy lead sphere placed on an elastic carpet. According to Einstein, a planet revolves around the Sun like a ball thrown around the lead sphere, forced by the curvature of the carpet. It's not just a different way of explaining the same predicted effects of Newton's law. From Einstein's vision arise equations capable of explaining new phenomena, with revolutionary consequences for the Universe, its origin and its destiny.

8 The Einsteinian Path

After the formulation of Special Relativity, the problem remained of understanding how to ensure that the laws of physics did not remain valid only in inertial frames of reference but in any frame of reference however in motion. That is, how to formulate a general theory of relativity. In this sense, Special Relativity had made no progress with respect to Galilean relativity. These are the words of Einstein:

> All the previous considerations [on space and time in pre-relativistic physics and on the theory of Special Relativity] are based on the hypothesis that inertial systems are equivalent […] but that they are privileged, with regard to the formulation of natural laws, over reference spaces in different states of motion. The attribution of such a privilege to particular states of motion is not justified […] either by particular properties of bodies, or by the concept of motion; this privilege must therefore be considered as an independent property of the space-time continuum. The principle of inertia, in particular, seems to lead us to attribute physically objective properties to the space-time continuum. Just as from the Newtonian point of view it was necessary to make the two hypotheses: *tempus est absolutum, spatium est absolutum*, so from the point of view of the special theory of Relativity we must say: *continuum spatii et temporis est absolutum*. In the latter hypothesis, *absolutum* means not only 'physically real', but also 'independent in its physical properties, having a physical effect, but not in turn influenced by physical conditions' (Einstein 1923, 59).

Einstein will succeed in the intent to free physics from absolute space and time, but after many years of effort. The starting situation of General Relativity was much more complicated than that of Special Relativity. The latter had behind its "claim" a series of experimental facts established over many years of research on electromagnetism and the compelling agonizing problem to be solved of a constant speed in all reference systems. The general theory, on the other hand, had behind it only a subtle observation to explain and some epistemological dissatisfactions. The observation was the anomaly of the precession of the perihelion of Mercury, the planet closest to the Sun. The point of Mercury's elliptical orbit closest to the Sun (the perihelion) moved year after year by a very small but still too large amount to be explained with Newton's theory. So much so as to hypothesize the disturbing presence of another small planet, baptized Vulcan—because being close to the Sun it should have been very hot—, which instead was not found.

A first dissatisfaction was due to the fact that Newton's theory did not predict a propagation speed of gravity, or rather this speed was implicitly infinite. Conversely, it was evident from Maxwell's equations of electromagnetism, that the influence of an electric charge on another distant one does not occur instantaneously, that is, with infinite speed, but at the speed of light. So, if an electric charge is moved from its position, the information reaches the second after a certain time. On the other hand, in Newton's theory if a mass is moved, all the others, however far away, "know" it immediately. Information in Newtonian gravity travels at infinite speed. Gravity was incompatible with Special Relativity, and Einstein thought of getting his hands on it. Then there was another cloud in the sky of Einstein's mind, and it was a disturbing experimental fact already highlighted by Galilei and Newton: the inexplicable coincidence of inertial mass with gravitational mass. This explains why all bodies reach the ground together if dropped from the same height, and why the period of the pendulum does not depend on the mass hanging at its end. (We are naturally neglecting light objects that can be affected by friction with the air).

All this was well known but it gave Einstein a lot to think about. In fact, the role that mass has in the equation $F = ma$ is to express the reluctance to change the body state of motion, that is, it is a measure of the body's inertia, let's call it the inertial mass. The role that mass plays in the Newtonian law of gravitation is instead another. Here the masses appear in the role of attracting and being attracted to other masses. The similarity of Newton's law to Coulomb's law of electric force, where electric charges play the same role, suggests that the masses here appear as gravitational "charges", sources of an attractive field. The mass m of the same body in Newton's equation therefore deserves a different name, that of gravitational mass. These two masses, which play different roles for the same body, turns out to be equivalent, or the acceleration of gravity on Earth to have the same value for all bodies would not be justified (it is experimentally verified with great precision). The equivalence of inertial mass and gravitational mass, according to Einstein, was not accidental and it had a profound meaning, which until then had eluded natural philosophers.

There were two factors that made Einstein's journey difficult. While the mathematical language of Special Relativity was already well developed, the development of General Relativity will require a new effort in understanding the relationship between physics, non-Euclidean geometries and absolute differential calculus. As Einstein said, compared to this problem, the original theory of Relativity is child's play. Moreover, while Special Relativity was soon understood by his colleagues and he had immediately found authoritative supporters, such as Max Planck, for the development of General Relativity Einstein found himself alone. Planck himself, having listened to Einstein's state of the art of his efforts while working on his new theory, paternally advised him to let it go: he would not be successful and in any case no one would take him seriously. But Einstein certainly couldn't let go, he had the happiest thought of his life:

> When, in 1907, I was working on a review article on Special Relativity for the Jahrbuch der Radioaktivität und Elektronik, I also had to try to modify the Newtonian theory of gravitation in order to make its laws compatible with Special Relativity. [...] It was then that I had the happiest thought of my life, in the following form. The gravitational field has only a relative existence, analogous to the electric field generated by magnetoelectric induction. In fact, for an observer who falls freely from the roof of a house, there is no gravitational field —at least in the immediate vicinity. In fact, if the observer drops bodies, they remain in a state of rest or uniform motion with respect to him, regardless of their particular chemical or physical nature (obviously neglecting the air resistance). Consequently, the observer has the right to interpret his state as a 'state of rest'. Thanks to this idea, that very unique experimental law according to which, in a gravitational field, all bodies fall with the same acceleration, suddenly acquired a profound physical meaning. [...] The independence of the acceleration of falling from the nature of bodies, well known experimentally, is therefore a solid argument in favor of the extension of the postulate of Relativity to coordinate systems in non-uniform motion with respect to one other (Einstein 2002, 135 – 136)

In this writing there is enlightenment. The magical moment equivalent to what Newton must have felt when he thought the Moon was falling to Earth. Einstein realizes that the principle of equivalence of inertial mass and gravitational mass is a fundamental empirical fact and he erects it as the foundation of its construction.

The starting point, as we read in Einstein's passage from 1907, is another *gedankenexperiment*, whose protagonist is a man who throws himself off the roof. Years later it will be described by him as "the Elevator Experiment" (in 1907 there were obviously few elevators). This experience illustrates Einstein's happiest idea and reveals the extraordinary equivalence between inertia and gravity. A stationary system in a gravitational field is equivalent to an accelerated system. A free-falling system in a gravitational field is equivalent to an inertial system. This is the new formulation of the equivalence principle, which Einstein transformed into a fundamental principle of physics.

9 Gravitation and Geometry

To understand how it is possible to use Einstein's principle of equivalence to arrive at General Relativity, let's proceed to a new *Gedankenexperiment*.

Imagine we are observing a glass-walled elevator free-falling in a gravitational field. Inside the elevator there is a friend of ours who experiences the freedom of being in an inertial reference system, it is as if he were stationary and far from any gravitational field. He has a laser pointer in his hand and shoots the light beam horizontally, towards a side wall as shown in Figure 2. Naturally he will see the light go straight towards the wall, any other behavior of the light beam would indicate the non-inertiality of his system. But how do we, standing still on the ground, see the same scene?

For us, the elevator and the laser are falling and accelerating. We see the beam of light actually "follow" the cabin and fall with it. The trajectory of light will therefore be the combination of a horizontal motion at the constant speed of light (proportional space and times) and an accelerated vertical motion (spaces proportional to the square of times). The result is a curved motion for the light beam, precisely a parabolic motion, like that of projectiles in a gravitational field. The conclusion is astounding: in a gravitational field the trajectory of light is not a straight line.

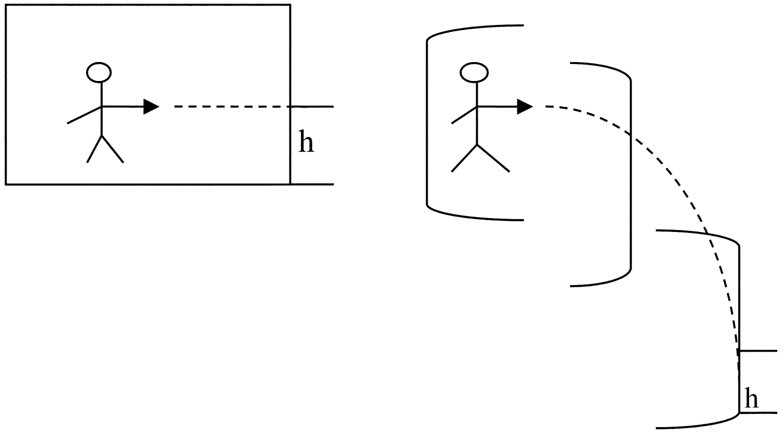

Fig. 2: The different trajectories of a light beam as seen by a person inside an inertial reference system constituted by a glass-walled cabin (left), and by an observer who sees the same cabin free falling in a gravitational field (right). In a gravitational field the trajectory of light is not a straight line.

Einstein knew well that in Euclidean space, where the Pythagorean theorem holds, the shortest line connecting two points (called the geodesic line) is a straight line. In inertial systems, for example, Euclidean geometry applies and the geodesic line is a straight line.

The thought experiment described above suggested to Einstein that in the presence of a gravitational field, space-time is no longer Euclidean and geodesic lines are no longer straight lines. Einstein's thoughts can be expressed like this: if everything that happens in space-time senses the presence of gravity, it means that gravity modifies space-time. What if what we call gravity is nothing more than the visible manifestation of the curvature of spacetime? In other words, what if curved spacetime was gravity? This is how the fundamental message of the new theory is outlined: the presence of mass and energy modifies the geometry of space-time, curving it. The curved space-time in turn tells bodies and light how to move: following its geodesic lines, which will no longer be straight lines.

To find the equation that could mathematically translate these concepts, Einstein had to labor for ten years. We will get there with the approach followed by Tullio Regge. Let's start with Euclid and the axioms of his geometry. The famous fifth postulate asserts the existence of only one parallel to a given straight line passing through a point outside this. From this postulate it follows that the sum of the internal angles of a triangle is 180 degrees. If we draw a triangle on a sphere, however, this is no longer true, just think of a triangle consisting of two meridian arcs and an equator arc. The two base angles by definition are both 90 degrees, their sum is already 180 degrees. The sum of the three internal angles will therefore certainly be greater than 180 degrees. It is shown that if we draw any triangle on the surface of a sphere of radius R, using great circle arcs, which are the geodesic lines on the sphere, the relation holds:

$$\alpha + \beta + \gamma - \pi = \frac{A}{R^2}$$

Where A is the area of the triangle. We can then define a coefficient K as follows:

$$K = \frac{1}{R^2} = \frac{\alpha + \beta + \gamma - \pi}{A}$$

A triangle drawn on a flat sheet, which can be seen as a portion of a sphere of infinite radius, will naturally have K = 0. On a spherical surface, wherever the triangle is drawn using geodetic lines, however angles are chosen, and for any area, the value of K will not change, as this coefficient is directly related to the radius of the sphere. For any curved surface, even if not spherical, we can think of drawing very small triangles, calculating the value of the angles and of the very small enclosed area and having K values that change point by point on the surface. In other words, we will have a quantity K (x) which will be a function of the point x on the surface. This quantity is known as Gaussian curvature and has universal significance, depending only on the intrinsic curvature of the surface at that point. Let's take an example of what we mean by "intrinsic". For the surface of a cone or cylinder, K is zero, just like for a plane. In fact, I can make those surfaces by appropriately rolling flat sheets. Instead, let's try to wrap a flat sheet to make a sphere, or a horse saddle surface. Impossible, precisely because there is an intrinsic curvature in the sphere and in the horse saddle.

For a number of dimensions greater than two things get complicated (also due to our inability to mentally visualize objects in more than 3 dimensions). For each point of the surface, we can no longer limit ourselves to a single value of the curvature, as for a two-dimensional surface, and the curvature K will depend on the orientation in multidimensional space of the geodetic lines used to define it. The list of all possible curvatures in a point is called the "Riemann Tensor" from the name of the great German mathematician who first defined it. For a 4-dimensional space, the Riemann tensor has twenty components. Both the Gaussian curvature K and the components of the Riemann tensor are expressed as the inverse of an area. The value of this area is also important because it tells us that if we are considering an area much smaller than that we can neglect the curvature and use Euclidean geometry.

Einstein was looking for the mathematical equation that quantified how the geometry of spacetime was affected by the distribution of matter. He found himself having to learn the language of absolute differential calculus, developed by two great Italian mathematicians, Gregorio Ricci Curbastro and Tullio Levi-Civita. With the latter Einstein had an intense and fruitful correspondence. Einstein said that Levi Civita rode that subject on the horse of true mathematics, while he was forced to go on foot. The equations, in their complete form, represent the conclusion of a splendid climb to what is considered one of the highest peaks reached by human thought. Geometry and matter are represented by quantities that have indices, which take the values from 1 to 4 to signify their possible components in four-dimensional space-time. We must write them:

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

$G_{\mu\nu}$ contains the components of the Riemann tensor and expresses all the possible curvatures of space-time while $T_{\mu\nu}$ contains the possible distributions of matter and energy. If $T_{\mu\nu}$ is equal to zero, $G_{\mu\nu}$ describes a flat, i. e. Euclidean, spacetime. If we do not consider the indices, the equation can be written in a conceptually simpler way while retaining its essence:

$$K \approx \frac{G}{c^4} \varrho$$

where K is the Gaussian curvature and r is the density of matter and energy.

Of all the symbols of the first equation, the most important is the sign of equality: the curvature of space-time is determined by the mass and energy present in that region. The equations of General Relativity are the analogue, for gravitation, of Maxwell's equations for electromagnetism, while Newton's gravitation appears as the analogue of electrostatics: it is valid for slow motions and low gravitational fields. These are the conditions experienced by bodies on Earth and in the solar system, which is why Newtonian mechanics has not been questioned for centuries.

There are some fundamental differences between electromagnetism and gravitation. One is that electric charges are of two opposite signs, electrons and protons therefore tend to attract each other to form neutral atoms and bodies. The electromagnetic interactions then lose their effectiveness. The gravitational charge, on the other hand, has only one sign and is always attractive. The larger the body that forms, the greater its ability to attract and be attracted. The celestial bodies and structures present in the cosmos are therefore shaped by gravitation. Another difference: photons, quanta of the electromagnetic field, are neutral and are not sources of other electromagnetic fields. Instead, the quanta of the gravitational field, the gravitons, in turn generate gravitational fields. This makes Einstein's equations non-linear and very difficult to solve.

General Relativity teaches us that, unlike what happened in classical physics, space and time are not simple containers of nature but are themselves part of it, intervening in the development of phenomena and being modified by them. They do not constitute an empty theater where reality is staged, they are instead reality themselves, a flexible and deformable continuum, a sort of cosmic jelly that dictates to any form of energy how to travel.

10 The Time of General Relativity

Einstein tested his equations with the problem of the anomaly of the precession of the orbit of Mercury, and was comforted: the right value was coming! He immediately suggested another fundamental test to highlight the difference between Newton's theory and General Relativity. During total eclipses, from the Earth we should see that the stars that are behind and around the Sun occupy a different position than usual, that they "move away" from each other, because the light they emit deviates due to the curvature around the Sun, giving us an apparent different location on the celestial vault. It was the photos taken in 1919 during a total solar eclipse on the Atlantic island of Principe that gave Einstein a planetary notoriety, thanks to the resonance that the news had in the press around the world. The leader of that ocean-going expedition was another original scientist, the Englishman Arthur Eddington. Later, in 1936, Einstein showed that a body of large mass, such as a galaxy, could act as a gravitational lens if it came between a light source and the observer. The image of the source can be seen by the observer multiplied or deformed depending on the arrangement in space of the source, the lens and the observer. If the three are perfectly aligned, the source can appear as a ring of light, the so-called "Einstein Ring". These predictions were then promptly verified and the spectacular gravitational lensing technique is now also used to estimate the presence of the mysterious dark matter in galaxies and clusters.

In the above observations we have highlighted the deformations induced by matter on space. But time is also distorted. In the universe, contrary to what was implicitly believed for centuries and what was posed as an assumption by Newton, there is no single time valid for everyone. Time flows differently for every observer, at every point in space-time. In particular it flows more slowly where gravity is strongest. We can make a new example to highlight how this is a necessary consequence of the equivalence principle. Imagine again that we are observing the glass-walled elevator in free fall in a gravitational field. Our friend with a laser pointer is still inside the elevator, ready to do another experiment. The lift is equipped with a sensor on the roof that measures the frequency of the incident light, and is calibrated to emit a powerful flash of light outside if the measured frequency is exactly that emitted by the laser pointer. The frequency of a wave is inversely proportional to the wave period, that is, the time interval between successive peaks. As the elevator falls, our friend shoots the laser light up towards the sensor. Since it is located in an inertial reference, by definition the sensor can only measure the light at the same frequency as that emitted by the laser, and the flash in fact signals the completed experiment.

The same result must also happen for us who see the elevator fall into a gravitational field. But for us the sensor is moving towards the light, because it is in accelerated fall. In these conditions the sensor should measure a higher frequency as a consequence of the Doppler effect. (Given a wave that propagates in space—light, sound, of any kind—if you move towards the wave front, the distance between the peaks is shortened and therefore a higher frequency is perceived. If instead we move away from the wave front, the distance between the peaks increases and the frequency decreases. This is the Doppler effect, and explains for example why the frequency of the sound of an ambulance siren becomes increases as it approaches us and decreases when moving away.) Necessarily, also for us the sensor must register the same frequency as the laser, in fact we have seen the flash. So, there must be an equivalent and opposite effect that cancels the Doppler frequency increase. There is no alternative: the electromagnetic wave rising vertically from a height where gravity is stronger to another where it is weaker must decrease the value of its frequency, or what is the same, increase its period.

This effect is measured and is called gravitational red-shift. The historical reason for the name "red shift" is that red light is at the lowest frequencies in the visible spectrum. The key experiment to demonstrate this was conducted in 1960 by

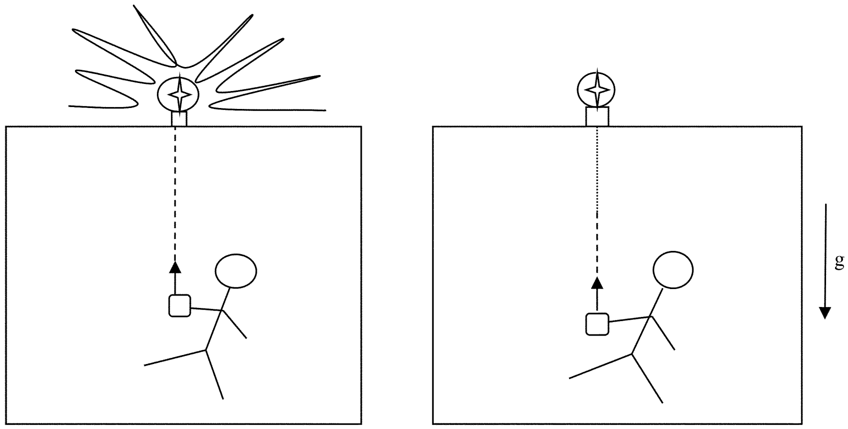

Fig. 3: Left: in an inertial system the frequency of a beam emitted by a laser pointer does not change in its travel towards the roof, as would be shown by a flash emitted by an appropriate detector tuned at the same frequency. Right: The same phenomena must be seen by an observer in a gravitational field looking the system free falling. But for this to be true, the Doppler effect due to the accelerating roof, which would increase the detected frequency as depicted and would prevent the flash emission, must be perfectly balanced by an opposite effect decreasing the frequency. This is the gravitational red-shift.

physicists Pound and Rebka, using not the light of a laser but the gamma radiation (high frequency electromagnetic waves) of a radioactive source and exploiting the difference in height (22.6 meters) between the basement and the top floor of a Harvard University building. The electromagnetic oscillations going upwards actually decreased their frequency.

This effect has extraordinary implications for the speed at which time passes. A regular sequence of peaks, like any other periodic phenomenon, can be taken as a measure of time, the peaks of the wave being nothing more than the ticking of the clock.

We can therefore conclude that time does not flow in the same way in regions of space placed at different values of the gravitational field. Our biological time is marked by biochemical phenomena that involve—all—electromagnetic signals. It is not only the artificial clocks, the ones we build, that keep time slower or faster, *we ourselves are clocks* and we will age faster by being where gravity is weakest, while we will live longer staying where the gravitational field is most strong. It is evident that these effects are not like those of Special Relativity. In that case the effects were reciprocal: in the station we see the clock on the train go slower as well as the observer on the train sees ours go slower than his. In General Relativity there is no this symmetry. We on the ground floor will see those on the top floor age faster than us, and on the top floor they would see us younger.

The knowledge of the relativistic effects on time finds a spectacular application in GPS, the Global Positioning System, used by the navigators of our cars and by smartphones. The system depends on about twenty satellites, equipped with atomic clocks, which orbit the Earth at about 20 km in height.

The system works by converting the travel times of radio signals exchanged between satellites and a terrestrial receiver, for example our car, into distances, thus allowing us to precisely locate its position. But it is necessary that the clocks of the satellites and of our car are synchronized, and this can only happen if we take into account the effects of Special Relativity and General Relativity. Due to Special Relativity, since satellites are moving relative to our car, their clocks are delayed by 7 millionths of a second compared to ours every day. However, since they are in a region where the gravitational field is weaker, they move forward by 46 millionths of a second every day. The net effect is that satellite clocks go 39 millionths of a second faster every day than ours on the ground. If this difference were not corrected, the daily error on the location of our car would be more than 10 km.

We make use of Einstein's Relativity every day. Einstein's equation turns out to be a gold mine. Over time, other precious nuggets have been extracted from this mine such as black holes, singularities, gravitational waves, the expanding universe.

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Christian Wüthrich

One Time, Two Times, or No Time?

I dedicate this paper to the people of L'Aquila,
who had to suffer through the catastrophic earthquake
that hit their beautiful town in the early hours of 6 April 2009.

May The Eagle rise again.

Abstract

Contemporary research programs in fundamental physics appear to suggest that there could be two (physical) times—or none at all. This essay articulates these possibilities in the context of quantum gravity, and in particular of cosmological models developed in an approach called "Loop Quantum Gravity", and explains how they could nevertheless underwrite our manifestly temporal world. A proper interpretation of these models requires a negotiation of an atemporal and a temporal sense of the emergence of (space)time.

1 Einstein, Bergson, and Quantum Gravity

The date of 6 April is of course noted for another event connected to this conference: the 1922 Einstein-Bergson debate on the occasion of Einstein's visit to the *Société française de Philosophie* in Paris. In his brief reply to Bergson, Einstein famously asserted that there was no "philosopher's time", which he took to unduly reify aspects of our experienced time, i.e., of the "psychologist's time". The trouble with the philosopher's time was, for Einstein, that it contradicted the "physicist's time": the philosopher's time hypostatises the apparent simultaneity of distant events, while the physicist's time, following the insights of Special Relativity, denies that these events are connected by an objective and absolute relation of simultaneity. At least as expressed in these brief remarks, Einstein ac-

Note: This work was supported financially by the John Templeton Foundation (the views expressed are those of the authors not necessarily those of the sponsors). Thanks to the audience at the conference "What is Time? Einstein-Bergson 100 years later", held at the University of L'Aquila on 4–6 April 2019. I warmly thank the organisers of this conference, Eugenio Coccia, Simone Gozzano, Rocco Ronchi, and last but not least Alessandra Campo, for their kind invitation.

https://doi.org/10.1515/9783110753707-013

cepts the existence of (only) two times: that of the physicist and that of the psychologist.

The reconciliation of what Wilfrid Sellars (1962) called the "scientific image", which would include Einstein's physicist's time, with the "manifest image" and its psychologist's time constitutes one of philosophy's noblest—and most urgent—tasks. Einstein's point—as I read him—is that such a reconciliation does not require a *tertium quid* in the form of an extraneous structure to be added to those required by the physics and the cognitive science involved in the phenomenology of temporality. Any such addition would be explanatorily idle at best and incoherent at worst. I tend to agree.

The debate between Einstein and Bergson turns on the then recently discovered relativity of simultaneity, a core element of Einstein's theory of Special Relativity of 1905. With Special Relativity, physics had provided deep insights into the elusive nature of time, as it did on numerous other occasions. Our best current understanding of spacetime, and hence of (the physicist's) time, derives from General Relativity, a very successful theory of gravity and spacetime formulated by Einstein in 1915. Since General Relativity presupposes that the matter which interacts with spacetime is correctly described by pre-quantum physics, however, it will eventually have to be corrected and replaced by a quantum theory of gravity. As quantum gravity remains beyond our empirical reach, physicists have developed diverging attempts to formulate such a theory. Despite their significant differences, many approaches suggest that space and time will not be part of the fundamental furniture of the world, adumbrating the most radical revolution in our understanding of time yet. Instead of being fundamental, space and time are emergent properties of the fundamentally non-spatiotemporal structures postulated by quantum gravity, very much like the solidity of a glass and the liquidity of the water it contains. Just as not any fusion whatever of silicon dioxide combines to form glass or not any hydrogen dioxide forms liquid water, the fundamental degrees of freedom may fail to coalesce into a spatiotemporal form, and thus will not give rise to anything like the space and time we know and love. Only a serendipitous collective action of the fundamental degrees of freedom will form drops—or indeed an ocean—of spacetime and thus deliver a world remotely like ours.

If borne out, this leads to three scenarios. First, it may or, second, may not be that time emerges from the fundamental structure. The third—tantalizing, but perhaps rather common—possibility is that a world contains both domains with and without emergent spacetime, rendering spacetime a "regional" option. In fact, our universe seems to be just like that: apart from the well-behaved spatiotemporal "phase" we inhabit, it contains a very early "epoch", which should not be expected to be spatiotemporal —the Big Bang. Quantum gravity suggests that *at* or *near* the Big Bang, we find a non-spatiotemporal "phase". If this is right, then it would suggest another way in which time might emerge: as a "transition" from an *earlier* non-spatiotemporal to a *later* spatiotemporal states of the universe. How should we categorize the emergence of spacetime—or failure thereof—in these contexts? How can we conceive of a transition from timelessness to the regular temporal evolution of our world? Answering these questions will be necessary for an appreciation of the viability of the emergence of spacetime and thus of a quantum theory of gravity, particularly in a cosmological setting. And it constitutes a central piece of a reconciliation of the scientific with the manifest image. The aim of this essay is to stake out some first steps towards this goal.[1]

This paper offers an accessible presentation and elaboration of some central theses and arguments articulated in Huggett and Wüthrich (2018). It presupposes no familiarity with either quantum gravity or the method of contemporary philosophy of physics. It starts in § 2 by explicating a remarkable apparent consequence of attempts to bring together quantum physics with General Relativity already mentioned above: the disappearance of spacetime from the ontology of these putative fundamental theories. Given that our world is manifestly temporal, time, or something very much like it, must arise from these non-spatiotemporal structures in order for these theories to be empirically coherent and empirically adequate. Time, or, more precisely, spacetime, emerges from the fundamental structures. Models in quantum cosmology in particular suggest that this emergence must itself have temporal aspects. I will exemplify this using cosmological models of Loop Quantum Gravity (LQG). Thus, it appears as if there are two kinds of time present in the objective structure of the physical world. § 3 articulates these two senses and clarifies their relation. Understanding both senses of time and their relation enables us to arrive at a coherent interpretation of these cosmological models of LQG, suggesting that these may describe either a contracting and re-expanding universe or, more likely, the twin birth of two parallel universes connected at the Big Bang. These interpretations are considered in § 4. Brief conclusions and an outlook follow in § 5.

1 I apologise for the many scare quotes, but these are intended to serve as reminders that spatial and temporal locutions are not well-defined in this context.

2 No Time? The Disappearance of Spacetime in Quantum Gravity

Space and time have long been used as convenient expedients to set apart material, physical existence from other forms of existence such as abstract, mental, or divine. According to this venerable standard of partitioning existence, all and only occupants of space and time enjoy *physical* existence. As Larry Sklar exclaimed, a non-temporal, non-spatial world seems "devoid of real being altogether." (Sklar 1983, 45) This is natural enough, as our physical world is manifestly spatiotemporal, endowed with a time —with *one* time.

It is precisely this commonplace which gets challenges in contemporary fundamental physics. General Relativity (GR) is one of the most successful theories in the history of physics, apparently correctly predicting phenomena such as the deflection of light near massive stars, gravitational time dilation, and the existence of black holes and gravitational waves, to name just a few highlights. It furnishes the basis of our vastly improved understanding of our cosmos and its origin and enables technology such as the global positioning system. GR interprets gravitation not as a force as did Newton's theory, but instead as encoded in the geometry of spacetime—a "geometrization"—, the fusion of space and time necessitated already by Special Relativity. More particularly, the strength of the gravitational field is given by the amount of curvature in the spacetime continuum, bending the worldlines of objects from stars and planets to humans and zebras to elementary particles in outer space as if the objects attracted one another. To date, no experiment or observation which directly contradicts GR is known.

Despite its impressive palmarès, GR cannot stand as the last word on gravitation and thus on the structure of spacetime. The reason is as simple as it is damning: GR assumes that matter is classical, i.e., as described by classical physics. But if the physics of the twentieth century has taught us anything, then it is that matter cannot be so described: it is irreducibly quantum. In this sense, there is a plethora of experimental evidence invalidating GR, from simple double-slit experiments to the Large Hadron Collider. Just as the location services in every smartphone rely on the insights from GR, its technology is built on the recognition of the deeply non-classical properties of its matter.

In light of this, GR will have to be replaced by a quantum theory of gravity, by which I designate any theory that can combine the quantum effects of matter with the presence of (strong) gravitational fields. Such a theory is yet to be fully articulated, let alone empirically confirmed. Currently many approaches compete for attention, young talent, and funding. Among them, string theory is most prominent and presently the frontrunner in all three categories, but there is also Loop Quantum Gravity (LQG), non-commutative geometry, causal dynamical triangulation, causal set theory, asymptotic freedom, and many more. The foundational physical principles, the structures or ontologies, even the methods and ambitions differ widely across the field.

Notwithstanding these differences between research programs, there is a recurring theme in the field: many approaches to quantum gravity either presuppose or entail that fundamentally, there is no space or no time or neither of the two. This denial of space and time takes different forms in different programs, and certainly comes in different degrees. Regardless of these variations, the constancy with which the theme recurs is remarkable. This is the sense in which there may be no time.

Before we study a concrete instance of the disappearance of spacetime, let me remark on two generic philosophical challenges a physical theory without space and time in its ontology faces. First, an epistemological point. It may appear as if a non-spatiotemporal theory in this sense is empirically incoherent.[2] A theory of physics is *empirically incoherent* just in case its truth undermines the empirical justification for believing it to be true. A physical theory could thus turn out to be empirically incoherent because it denies a necessary condition of empirical confirmation. A theory *sans* spacetime would thus be empirically incoherent since there could not be, it seems, "local beables" which manifest themselves in localized observables in space and time. Space and time and thus the possibility for material objects to occupy, or be located in, space and time appears to be a precondition for making and reporting observations. With space and time inexistent, and thus this possibility denied, it appears impossible to make the observations needed to confirm the theory at stake and thus for justifying belief in it. Empirical incoherence is not logical inconsistency: an empirically incoherent theory is certainly a logical possibility and potentially even a nomological one. There is of course no guarantee that nature is so kind to us as to yield to scientific investigation; but empirical coherence is undoubtedly a presupposition of scientific enquiry and its failure would be devastating to our attempts to discern nature's deep structure. So, a physical theory better either be consistent with the fundamental existence of spacetime or else identify the error of this argument.

Second, a more metaphysical concern. By moving to a more fundamental theory, we may have grown to expect that we thereby advance to the next

2 Huggett and Wüthrich (2013) applied the concept of empirical incoherence to quantum gravity. See Yates (forthcoming) for a clear recent presentation.

level—at higher energies, or smaller spatial scales—of unveiling the constitution of (part of) our world. Thus, when we supplant GR with a more fundamental theory of spacetime, we would think that we will learn something about the constitution of spacetime —and perhaps of matter, if the theory is unified enough to also be more fundamental than the standard model of particle physics. But constitution, or indeed mereology, appears to be inherently and ineliminably spatial, or perhaps spatiotemporal.[3] How then could a theory denying the fundamental existence of space or spacetime deliver a more fundamental theory of the *constitution* of anything? Clearly, such a theory better either be consistent with the fundamental existence of spacetime or else deliver an account of constitution and mereology which is not implicitly spatial.

We will return to these two challenges in the next section. For the remainder of this section, let us look at Loop Quantum Gravity (LQG) to discover one way in which space and time may be absent in a theory of quantum gravity.[4] LQG starts out from GR as our most successful current theory of gravity (and of spacetime), and attempts to transform it into a theory of quantum gravity by applying a "quantization", i.e., an almost algorithmic procedure which turns a classical theory into a quantum one. There are several such quantization recipes available, and just as with cookbook recipes, none of them guarantees success. LQG uses the so-called "canonical quantization", a procedure which has successfully been applied in other instances, such as the quantization of electrodynamics. Omitting the technical details, what matters for present purposes is that this recipe requires, as a first step, that GR be recast in a particular form, the so-called 'Hamiltonian' form. In this form, the physics at stake is captured in terms of a spatially extended physical system which evolves over time according to dynamical equations. This is perfectly adequate, indeed apt, for many phenomena we may be interested in.

However, it appears inept for relativistic physics in which space and time have been fused into one, disregarding GR's central lesson that there is no absolute *time* external to spacetime itself in which *space* might evolve. This disregard shows in two ways. First, relativistic spacetimes with an unusual topology which does not permit a consistent (however non-unique) split of spacetime into space and time are simply declared unphysical and thus omitted. Second, the dynamical equation of GR, Einstein's field equation, is not formally equivalent to the

3 See Le Bihan (2018) for a discussion of this point.

4 This material draws on Huggett and Wüthrich (forthcoming), as well as on Huggett et al. (2013, §2) for the problem of time and on Wüthrich (2017) for the various aspects of the disappearance of spacetime in LQG. These sources go into significantly more technical details, which I try to avoid presently.

dynamical equation of the Hamiltonian form. In order to establish this equivalence, additional equations called "constraint equations" must be imposed on the Hamiltonian formulation. Such equations always 'constrain' some function to be zero, hence their name. One of the constraint equations deserves our attention: the Hamiltonian constraint equation. This equation is remarkable in that the function constrained to vanish is the so-called "Hamiltonian function", which in Hamiltonian mechanics serves to generate the system's dynamics.[5]

Since the classical Hamiltonian function is thus constrained to vanish, or the quantum Hamiltonian operator annihilates the physical states of the system, it appears as if there cannot be any non-trivial dynamics. Furthermore, in the equations we find no quantity which seems to correspond to a physical time, no "*t*". In Hamiltonian GR, and any canonical quantization built on it, all physical quantities are constrained to remain constant over a time that does not appear to exist. This is the "problem of time".[6] Naturally, this is considered a problem since our world is manifestly imbued with *blooming, buzzing confusion*, thoroughly awash in constant change which occurs over physically real, measurable—indeed experienced—time. That the resulting quantum theory of gravity appears to deny the fundamental existence of either time or change thus stands in crass tension with our manifest picture of the world. Consequently, even some of the founding fathers of LQG have paid considerable attention to resolving this issue either by sketching how to recover time from the fundamentally non-temporal structure or by rejecting the above rough argument to its unwelcome conclusion.[7]

LQG remains a work in progress. The canonical quantization program turns out to lead to hopeless technical challenges. The partial glance at the fundamental structures it permits despite its unfinished status unveils the following. The (provisional) "Hilbert space" of the system—roughly, the space of its possible quantum states—admits a basis of states with a natural geometric interpretation. In other words, the theory as it is known to date states that the fundamental structure (the gravitational field) is generically in a *superposition*—roughly, a state of *simultaneous combination*—of these geometrically interpretable base

5 Via "Hamilton's equations" in the classical theory. In the quantum theory, the Hamiltonian operator results in zero when acting on quantum states. Apologies to the reader for all these homonyms, but at least it should not be too difficult to guess the name of the Irish mathematician who developed the formalism.
6 See, again, Huggett et al. (2013), § 2 and references therein.
7 See, e. g., Rovelli (2020), Smolin (2013).

states. These base states are dubbed "spin network states" and can be represented by abstract labelled graphs.[8]

Spin network states afford a straightforward geometric interpretation —as they are eigenstates of geometrically interpretable operators defined on this Hilbert space. This natural interpretation sees them as discrete, combinatorial structures consisting of grains of space or spacetime connected by adjacency relations. Let us unpack this a bit. First, the structure is often interpreted in the literature[9] to be spatial (rather than spatiotemporal) in the sense that it is the structure which one expects to give rise to space (rather than spacetime), connected to the fact that the Hilbert space is not the definite one just yet. The correctness of this interpretation, however, is far from obvious, and depends on one's perspective on the role and fate of time and, relatedly, on how to complete the research program of LQG. I will return to this point below.

Second, the structure is discrete or "chunky", giving us a sense that space(time) consists in inscissible atoms of space or spacetime, rather than in an ever more finely divisible continuum. This granularity of spatial, or spatiotemporal, geometry is a direct consequence of the discreteness of the spectra of the geometric operators. The connections between the atoms of space(time) indicate a form of contiguity or adjacency between those that are so connected. Hence, we find a network of atoms of space(time) joined by a neighbouring relation.

The third point to note is that the generic state of the fundamental structure is a *quantum superposition* of these spin network states. Thus, the structure cannot generically be interpreted to have a particular, determinate geometry in the sense of a determinate number of atoms of determinate sizes with determinate facts of the matter which ones among them are adjacent. Generically, the structures are in some state of *combination* of networks with different determinate geometries. The sense in which the generic states does not have a determinate geometry is thus analogous to the sense in which a generic electron does not have a determinate spin in a given direction, or, perhaps more accurately, a generic quantum electromagnetic field does not contain a determinate number of photons with a determinate direction of polarization.

Finally, to repeat, LQG has not so far delivered a final and complete theory — it remains a research program under construction. The *pièce de résistance* turns out to be the Hamiltonian constraint equation. Although known in formal outline, the construction of a concrete Hamiltonian operator, let alone the full solution of the resulting equation prove to present formidable technical and con-

8 See, e.g., Fig. 1 in Wüthrich (2017).

9 See, e.g., Rovelli (2004), §1.2.2, §6.

ceptual challenges that have resisted convincing and widely accepted resolution to date. These obstacles have not halted the program; instead, physicists have developed two promising work-arounds, to be discussed in the next section.

3 Two Times? The Emergence of Spacetime

The first strategy to circumvent the stumbling block of the Hamiltonian constraint equation is to switch half way through from the canonical quantization recipe to the so-called "covariant" one, which seeks a path integral formulation of the theory. This move is based on the insight that at least for simple quantum systems, the two recipes deliver equivalent quantum theories. It is hoped—though of course not proved—that this will be the case here too. This covariant version of LQG takes spin network states as *initial* and *final* states and seeks to express the dynamical content of the theory in terms of transition amplitudes (and hence probabilities) for such pairs of states. Despite the importance of this approach in LQG, we will not further discuss it here.[10]

The second strategy simplifies considerably the systems studied to render the technical difficulties manageable, hoping that the lessons learned from such reduced systems transpose into the more generic context. Loop Quantum Cosmology (LQC) does just this: prior to quantization, it reduces the space of admissible models by imposing an additional condition.[11] This condition demands that the model be precisely spatially isotropic and homogeneous, thus reducing the number of degrees of freedom required to account for the system.

Requiring complete spatial isotropy and homogeneity is precisely what is done in modern cosmology, and hence LQC is thought to capture the *cosmological* sector of LQG, i. e., those models which may in fact describe the large-scale structure of the universe over the course of its history. The so-called "Cosmological Principle" requires that both the spacetime structure and the matter distribution are spatially isotropic around us, i. e., exhibiting the same properties in all directions around us. This principle is reasonably well confirmed by the distribution of the cosmic microwave background radiation and the large-scale distribution of luminous matter in galaxies. However, isotropy around us does not imply either isotropy around any other point in space or full spatial homogeneity, i. e., the sameness of properties everywhere in space. For this, cosmology invokes a much more speculative (though plausible) principle, the "Copernican

10 See Rovelli and Vidotto (2015) for an excellent introduction.
11 See Bojowald (2008); (2010), ch. 4 for a popular introduction.

Principle", according to which we are not privileged or in any way physically special observers. In other words, if the universe is the same around us, it should be the same around every point in space, and so all observers see a spatially isotropic universe. This, in turn, implies that the universe is spatially homogeneous. It can be shown that the so-called "Friedmann-Lemaître-Robertson-Walker (FLRW) spacetimes" are the only spatially isotropic and homogeneous spacetimes in GR.

LQC thus assumes spatial isotropy and homogeneity. Since it also assumes but a single scalar field (clearly an assumption that will have to be revisited), *space* at a *time* can be described by one single degree of freedom describing the relative size of space in dynamical evolution, with the scalar field serving as clock variable. In relativistic cosmology, this quantity is the "scale factor" $a(t)$, which is a function of time t (and so presupposes a 'cosmic time' t, which is, however, available in FLRW spacetimes). Imposing this symmetry (of isotropy and homogeneity) thus leads to a significant simplification of the system studied and makes the attendant mathematical difficulties more manageable. This simplification occurs at the classical level, i. e., before quantization is attempted.[12] In the full theory, the spin networks are generally large, complicated, and irregular, without recurrence or pattern. In contrast to this, the symmetry-reduced quantum configurations of LQC turn out to be highly regular. Consequently, they can be represented by lattice graphs with straight edges of the same length resulting in surfaces of an area of the square of this base length.

Again, these surfaces are interpreted to represent the universe spatially, with the scale factor giving its "size". In the quantum theory, there is an operator corresponding to this scale factor. When applied to the spin network states, one can determine the value the scale factor takes for these states, finding that it can be zero or assume one of a (quasi-)discrete set of values.[13] Classically, the FLRW models are *singular*, i. e., all worldlines of physical objects are past-finite. This is naturally interpreted as the universe having a finite age. One might think that there is thus a time before which there was no time. However, the past-finiteness of the universe does not imply that there was a first (instantaneous) moment; rather, one should think of the cosmic time t as assuming positive values strictly larger than 0. Just as there is no smallest positive real number, there was no first moment in time in those models. The moment $t = 0$ is not part of these models, and so corresponds to no physically existing time. The past-finiteness of

12 Although the order of symmetry reduction and quantization should in principle not matter.
13 The precise sense of "discreteness" in play here is subtle. For more on this, see Wüthrich (2006, 123).

all worldlines is a sign that the FLRW spacetimes are singular "there",[14] i.e., they are not mathematically well-defined. This non-place, or the behaviour of the universe in its infancy right 'after it', is called "the Big Bang".

Another sign of singular behaviour at the origin is the diverging (scalar) curvature 'there'. Tracking the relative size of the universe backward in cosmic time it becomes smaller and smaller. As the curvature scales inversely with the scale factor, it grows beyond any bounds as we approach $t = 0$. This divergence at the Big Bang is often seen as a failure of GR itself, as are similar singularities in relativistic models (such as those found in black holes). Peter Bergmann articulated what I take to be a rather common view among physicists:

> [Singularities] are intolerable from the point of view of classical field theory because a singular region represents a breakdown of the postulated laws of nature. I think one can turn this argument around and say that a theory that involves singularities and involves them unavoidably, moreover, carries within itself the seeds of its own destruction (Bergmann 1980, 156).

Consequently, it is a natural expectation that a more fundamental theory of quantum gravity replacing GR ought to eliminate these singularities. This expectation is borne out in LQC, at least to a significant degree:[15] the quantum operator corresponding to the scalar curvature is well-defined at what would classically be the Big Bang. More specifically, the curvature in the model of LQC increases as we trace it back through smaller and smaller scale factors, becomes rather large and peaks at a small (but non-zero) scale factor, before it decreases again to be zero for the zero-size universe at the quantum Big Bang.[16] The quantum model does not exhibit a curvature singularity.

These are merely kinematic facts and do not rely on any "dynamics". The dynamical Hamiltonian constraint equation—and that was to a significant degree the point of the program of LQC—simplifies significantly and can be solved explicitly. Quantum states of the universe which not only satisfy the kinematical constraints, but also this dynamical one, are the truly physical states according to the theory. Since these states are the possible states of a universe throughout its history, giving rise (it is hoped) to something like the four-dimensional cosmological models of GR, these states ought to be considered extended in time.

We will return in § 4 to the question of how to interpret the physics of LQC. For now, we want to note that there now seem to be two senses in which time

14 In scare quotes because this is not part of the model and so not a physically existing location in spacetime. The singularity is a "global" property of the spacetime.
15 For the caveats, see Wüthrich (2006), § 8.1.
16 See Fig. 10 in Wüthrich (2006).

emerges from the fundamental structure of LQG as suggested by LQC. First, as noted above, there are reasons to believe that the fundamental structure according to LQG is not spatiotemporal. If this is right, then it must be shown that at least sometimes, under serendipitous circumstances, the fundamental degrees of freedom must collectively act such as to bring about, at larger scales, space and time, or at least something sufficiently like them. This is the sense in which there must be an *atemporal* form of emergence of spacetime: spacetime ontologically depends on more fundamental, ultimately non-spatiotemporal degrees of freedom.

This atemporal form of emergence is central in the dissolution of the threat of empirical incoherence as articulated in the previous section. By establishing that spacetime emerges at human scales, empirical evidence can unproblematically come in a spatiotemporal form. The additional demand that the spatio-temporality be fundamental cannot be justified. Just as it is not necessary for measuring the temperature of a gas that this temperature somehow be a fundamental properties of the constituents of the gas, it is in no way required that the spatio-temporality be fundamental for the evidence collected in observations and experiments to be manifestly spatial and temporal. The menace of empirical incoherence is thus averted. As for the concern regarding the constitution of spacetime, I have recommended elsewhere that a overly spatial or spatiotemporal concept of constitution be replaced by a functionalist understanding of spacetime.[17]

To return to the emergence of spacetime, in the cosmological models of LQC, or at least in more realistic ones with many more degrees of freedom, there arises now a second, *temporal*, sense in which spacetime ought to emerge. To obtain a more faithful description of the physics of the earliest universe is, together with a deeper understanding of black holes, among the primary objectives of quantum gravity. Given the strength of the quantum effects in the very early universe, we do not expect the classical description of a smooth spacetime to remain applicable. Rather, the universe was born out of a deeply quantum gravitational *Ursuppe*. That this *Ursuppe* is not spatiotemporal, or at least *not temporal*, is further supported by recent findings[18] according to which the fundamental structures in the very early universe are *spatial*, if anything, rather than spatiotemporal: there appears to be a "signature change" from the usual *Lorentzian signature* to a *Euclidean signature*. A 'Lorentzian' signature is characteristic of a relativistic spacetime with one dimension of time and 3 (or *n*) dimensions of space, whereas a 'Eu-

17 See Lam and Wüthrich (2018).
18 See Brahma (2020).

clidean' signature indicates a purely spatial structure. Thus, time truly disappears around the Big Bang, and there is no sense in which there exists a connected time through that epoch. Time is simply not part of the *Ursuppe*.

If this is correct, then we cannot hope that the physics at that early stage is orderly and spatiotemporal. This is of course again precisely because quantum gravity is generically non-spatiotemporal. In sum, we should expect that cosmological models based on LQG encompass different "phases": an 'earlier', non-spatiotemporal, quantum-gravitational phase, as well as a 'later' phase, for which the classical spacetime description offered by GR delivers a valid approximation. Thus, it looks as if these models ought to contain a "process" of emergence, a "transition" from the first phase to the second, which involves the (at least approximate) emergence of spacetime. This is the sense in which there must be a *temporal* form of emergence spacetime: spacetime arises as an effect of an earlier state, i.e., it depends, perhaps causally, on "prior" states of affairs.

Thus, we are faced with two distinct notions of emergence and, correspondingly, two ways in which time comes to be. These two notions answer to two distinct, but equally important, questions. First, how can classical relativistic spacetime (or, ultimately, the space and time of our experience) be grounded in a fundamental structure which is non-spatiotemporal? This is arguably the most urgent philosophical question arising in the context of quantum gravity and is extensively addressed in the literature. I sketched only some central points pertaining to this first question here.

Our focus here is the second question: how can the (fundamentally non-spatiotemporal) universe "evolve" from a non-spatiotemporal phase to a spatiotemporal one; i.e., how can there be such a 'process' or, more fundamentally, a 'change' with time? In fact, how could we possibly order the phases into a 'before' and 'after'?[19]

This is the sense in which our world may contain two "times": the emergent temporal aspect of effective spacetime and the temporal aspect of the emergence of spacetime from the *Ursuppe* itself. How can we make sense of this puzzling situation? Let us outline a physical interpretation of the models of LQC.

19 The same problem arises not only in LQC, but also in string cosmology. See Veneziano (2004); Huggett and Wüthrich (2018) and in Oriti's *geometrogenesis* (Oriti, forthcoming).

4 One Time? The Twin Birth of Two Universes

It would hardly be coherent if there were indeed two distinct notions of physical time, one atemporally emerging from fundamental physics, and another one temporally emerging from earlier physics. If there were in fact two times, it would be surprising if the time of our experience, which ultimately arises from the fundamental structures on which the physics in our experiential vicinity ontologically depends, and the time of the cosmos, born in the Big Bang, were to coincide. Let us address this threat of incoherence by considering the physical interpretation of the simplest model of LQC and then by ruminating, somewhat speculatively, on extending these lessons to more realistic models. But first, let us prepare the ground for these discussions.

The propaedeutic remark concerns the standard cosmological model of GR, the FLRW spacetime we have already encountered above, and how to think about it. We have already stated that it contains a singularity, the Big Bang, marking a "beginning" of the universe. The way cosmologists interpret cosmic history like this is by starting out—'in thought'—from the present state of the universe, and to calculate things backward in time, reaching ever earlier times. In other words, the direction of the evolution of the universe *as we theorize about it* is opposite to the direction of the *actual, physical* evolution theorized about. Given that we live today, cosmologists, like Schiller's 'Universalhistoriker' (1789, 127 ff), have no choice but to infer from what is presently the case to what must have transpired before, at earlier and ever earlier times. There is excellent evidence, indirect though it may be, that the classical relativistic model of cosmology offers a surprisingly accurate description of the cosmos for most of the times it assumes to exist, retraced backward by almost 13.8 billion years. As already stated, the model is past finite and is singular.

Let us now analyse in more detail the simplest model of LQC, i. e., the one with perfect symmetry.[20] The highly regular lattice graphs of varying size are taken to represent the state of the universe at a cosmic time. The Hamiltonian constraint equation delivers the dynamics in the sense that it mandates how a set of them can be knit them together into an ordered sequence. The resulting fabric—the maximal family of compossible instantaneous states—represents the LQC-equivalent of a four-dimensional spacetime, i. e., the universe throughout its entire history. Physically, such a family can be thought of as an 'evolving quantum geometry'. In this simplest, altogether isotropic case, the family mem-

20 Physicists also consider slightly more complicated models with a small amount of anisotropy.

bers "vary" in size in the sense that the quantum property corresponding to the scale factor differs.

For the fully isotropic case, the Hamiltonian constraint equation becomes substantially simpler, and in fact turns into a difference equation, rather than a differential equation, as is the usual case for dynamical equations. This is not so surprising, given that the "time" LQC uses to stitch together the 'instantaneous' or 'momentary' states is discrete, rather than continuous. Differentiation, i. e., building derivatives, requires a backdrop of continuous variation, and hence of a continuum. For a discrete set, we are left with differences, however small they may be. it should be emphasized that the fact that time is discrete does not imply that there are only finitely many "instants" of time; rather, their number is countably infinite.

As a curious aside, it should be mentioned that this difference equation does not give a momentary[21] state at a time as a function of another momentary state at another time. Instead, it fixes a momentary state as a function of *two* other momentary states at different times one unit of time apart. Thus, in order to fully specify initial conditions, we need to specify all momentary states in a (closed) unit interval.

If the conditions for an interval are thus given, the simplified Hamiltonian constraint equation determines the states at all other times, and thus the entire time-ordered family of momentary states (barring the vanishing of the coefficients in the equation). The hope voiced above that quantum effects may wash out the dynamical singularity of the classical model is indeed borne out, at least almost.[22] If, in Schillerian fashion, we evolve a later interval of *initial* conditions backwards in time using the Hamiltonian constraint equation (which does not care about the temporal direction), we find that the evolution continues beyond what classically was the Big Bang. Beyond the Big Bang, there is a mirror universe very much like the one we know and love on "this side" of the Big Bang.

What is the physics of this newly found realm beyond the Big Bang? Although parallel und in many ways similar, the two sides are not exactly identical. In the simple model, the orientation of space turns out to be inverted between the two sides.[23] In more complicated models, one would in addition expect the probabilistic quantum fluctuations to differ.

21 As by this point in the essay, the reader should be sufficiently 'scared', I now unceremoniously drop the scare quotes around "instantaneous", "momentary", "precede", "before" and similar expressions.
22 See Wüthrich (2006), §8.1 for the exceptions.
23 See Bojowald (2010), 113 ff.

How do the two realms connect with one another at the Big Bang? In the standard interpretation, offered e. g., in Bojowald (2008) and Bojowald (2010, ch. 4), the model is one in which a large universe shrinks and ultimately collapses to zero size before it rapidly expands again. From slightly more complicated physics, it is believed that the universe heats up before its collapse, only to cool down again as it re-expands after the Big Bang. Physical time runs unidirectionally from negative infinity to positive infinity all the way through what classically was the Big Bang.

Bojowald (2010, 111–115) justifies this interpretation with the presence of an effectively repulsive force arising from the discreteness of time. The basic idea is as follows. Given that the quantum state of the universe is described by a wave function, its total energy is proportional to the frequency of the wave function. A discrete time can, however, only support frequencies larger than its characteristic scale of discreteness, thus effectively capping the frequencies. Consequently, the energy any discrete time interval can contain is bounded from above, although its bound may be very large. As the universe contracts and heats up prior to the Big Bang, the energy density increases. This increase can only be stopped from surpassing the upper bound set by the discreteness of time, says Bojowald (2010, 113), if the collapse itself is stopped and reversed, thus turning into an expansion. In this manner, the discreteness of time thus acts effectively as a repulsive force counteracting, and, for sufficiently large energy densities, dominating attractive gravity. At least given an early, i. e., pre-big-bang, state of contraction, such a bounce is thus what would be expected if time were discrete.

It thus appears as if this simple model of LQC can explain the sense in which the state around the Big Bang was prior to our current cosmic era. It ultimately does so in virtue of there being a well-defined size, which can be varied relative to a scalar quantity into the model, which assumes discrete values and acts as cosmic time. Unless more realistic models are considered and confirm the features of the simple model, it remains unclear to what extent, if any, this smooth evolution ought to be taken seriously. In the hope of obtaining a fuller view of the problem, we thus turn to our speculative ruminations about generalizing these lessons to more realistic models.

It is obvious that the exact isotropy and the perfect symmetry and regularity of the geometry of the momentary states is not a realistic depiction of our real universe. Spatial isotropy and homogeneity are only approximately valid at very large scales: only starting at the order of 500 million light years or so is the universe to a good approximation homogeneous.[24] If the universe were perfectly homogeneous, we would not be here to discuss its origin! A more realistic model will thus have to admit anisotropies and inhomogeneities and exhibit more irregular geometries. If the larger program of LQG is right, then space and time are not directly implemented at the fundamental level, as we have seen above. Thus, given that around the Big Bang, we will be in the deep quantum-gravitational regime (the reader is reminded, e. g., of the signature change in that epoch), we cannot expect that a simple scalar field will play the role of cosmic clock, as it does in the simple model of LQC with perfect symmetry. If we extrapolate the physics backwards to earlier and earlier times, at some time very soon after the Big Bang (usually given as around the "Planck time" 10^{-43} seconds after the Big Bang) we arrive at the deep quantum-gravitational regime, where quantum fluctuations are believed to have been so strong that spacetime in the usual sense evaporates.

The philosophically acute reader will naturally ask what it could possibly mean that the quantum-gravitational period lasted for something like 10^{-43} seconds when there is no physically meaningful notion of time present during that epoch. The short answer is *nothing*. In the absence of (fundamental or emergent) time, it is simply meaningless to quantify a duration —including setting that duration to zero.[25] More importantly for our purposes, in the absence of a time ticking continuously and uninterruptedly through the period, it is not meaningful to speak of a unified physical process running from an earlier (pre-Big-Bang) state to a later (post-Big-Bang) one, particularly not if there is a signature change.

However, there is a way something like this scenario would be the correct interpretation, even though the way of referring to it as a single, unified process is strictly incoherent, just as stating that the quantum-gravitational period lasted 10^{-43} seconds. Although durations are meaningless, there is a sense in which that epoch occurred *before* our era, i. e., is in our past (rather than our future or in no temporal relation to us). Locally, presently, we do have a physical (space)time with a well-defined temporal direction, owing to the second law of thermodynamics. *Our* future is distinct from *our* past in myriad ways. And if we extrapolate our local time and its direction beyond the scope of its proper applicability, we recognize that the atemporal phase at the Big Bang is in our past, before our current era. Even if by itself timeless, it is thus meaningful to say that the Big

24 To put this number in context, the closest star from the Sun, Proxima Centauri, is just over 4 light years away, the center of the Milky Way about 26,000 light years, and the closest major (spiral) galaxy, Andromeda, about 2.5 million light years.

25 As is suggested by Huggett and Wüthrich 2018, 1201 ff.

Bang is in the past relative to our local determination of the direction of time. Hence, it occurred 'before' our era.

This extrapolation of local time and its direction has two immediate consequences relevant for the purposes of this paper. First, it unifies the two times identified in § 3. The sense in which the big-bang epoch precedes ours is fully due to an extrapolation of our local, emergent time and its arrow. In other words, the temporal emergence of time derives from the atemporal one. The latter is thus prior to the former. In this way, there is an unambiguous and unproblematic way in which we can order the cosmic epoch into a 'before' and an 'after'. Even so, it should be clear that there is no process in the strict sense from a non-spatiotemporal phase to a spatiotemporal one. If the sense in which the big-bang epoch, i.e., the quantum-gravitational regime, precedes our era derives from the (atemporal) emergence of spacetime and the extrapolation of thermodynamic processes in our local region, then there is just one 'time', not two.

Second, it also implies that the standard interpretation of the bounce may not be completely meaningless. As we already noted, the Big Bang took place in *our* past. But similarly, and completely independently, denizens of the other universe may extrapolate their local time and its direction and determine that there exists a Big Crunch to *their* future. They would judge the event not a Big Bang, but a Big Crunch, since they would be observing that their universe contracts in their local direction of time, and might consequently await their fate with trepidation. Although there would thus not exist a continuous, unified physical process as usually described in the standard scenario, there would be two universes, one of which is contracting to an ever hotter and denser state, and the other expanding and cooling, *in their respective (extrapolated) local directions of time*. Although they would be separated from one another in that there is no shared sense of spacetime between them, they would nevertheless form a single physical world, connected by the quantum-gravitational physics at the Big Bang. To repeat, these connections would neither be spatial nor temporal, but they would most definitely be physical, thus challenging the venerable standard of physical existence mentioned at the outset. What their exact nature turns out to be is for a fundamental theory of quantum gravity to describe — in our case, for LQG.

However, the absence of a direct temporal relation through the Big Bang opens up the possibility of an altogether different interpretation: instead of a big bounce from a contracting to an expanding universe, we witness the birth of twin universes from the same quantum *Ursuppe*, which are both expanding in their local futures.[26,27] Instead of one single process "through" the Big Bang era, there are two parallel birthing processes from which a spacetime (each) emerges. Time arises twice over, separately and independently in each of the twin branches, though presumably in each case as the result of the propitious coalescence of a large number of fundamental, but individually non-spatiotemporal degrees of freedom.

More generally, given that for spacetime to emerge from the fundamental degrees of freedom (or, more neutrally, from the fundamental *structure*), the conditions must be just right, as indicated in §2. Just as H_2O molecules must be in the right phase for the water to flow as a liquid, the spin networks must be in a sufficiently 'geometric' state for spacetime to emerge.[28] And just as it is possible for water to be (near the phase line) in a state of an inhomogeneous mixture of liquid and gas "pockets", one and the same spin network may contain geometric (and hence spatiotemporal) and non-spatiotemporal "regions". This was the third scenario described on page 208. The result would be distinct, isolated islands of spacetime emerging from an ocean that is the fundamental structure. Generically, and unlike in the scenario of the twin birth sketched above where both branches would be connected with one another through a joint structure in their respective local pasts, it would not be the case that these spacetime pockets stand in any meaningful spatiotemporal relation to one another.

Whether the big bounce or the twin birth scenario obtains in more realistic models of LQC—and whether the loop program is onto a true quantum theory of gravity for that matter—remains to be seen. What I hope to have shown, however, is that the joint appearance of atemporal and temporal forms of the emergence of spacetime can be reconciled in a coherent interpretation of these models.

26 See Wüthrich (2006, 132 ff) for a first articulation of this idea in the context of LQC, which has been suggested to me by Carlo Rovelli. This articulation is deepened in Huggett and Wüthrich (2018), § 4. See Craig and Sinclair (2012), § 4.6 for another recurrence of this idea in the context of LQC (though their analysis differs from mine). See also Barbour et al. 2014 for a version of the same idea (of a "Janus point" in their later words) in a different physical context.
27 One might ask why *two* universes, why not three, or four, or infinitely many? While these may all be options in other models, the mathematics of the simple LQC model naturally suggests (just) two.
28 See, e.g., Wüthrich (2017).

Conclusion

Leaving aside the psychologist's time, Einstein identified two distinct notions of time in his debate with Bergson: the time of the physicist and the time of the philosopher. Whether or not we follow Einstein in denying the existence of the philosopher's time, how can we be sure that there will be exactly one kind of physical time? Contemporary research into fusing quantum physics with relativity theory into a quantum theory of gravity suggests that there may not be a physical time, at least at the fundamental level of existence. Thus, although Einstein took it for granted that there was a physical time, physics itself may end up eliminating time from its fundamental ontology. Does this mean that there may be no time at all?

It does. If LQG or a similarly non-spatiotemporal theory turns out to be the correct theory of quantum gravity, then it is physically possible that the fundamental structures do not conspire to form space and time; instead, they form a world devoid of space and time and so very much unlike ours. However, any such theory will have to contain models, which give rise to something like the relativistic spacetimes which accurately describe physical aspects of the actual world. In this sense, any such theory must permit the emergence of (space) time under the appropriate circumstances. In other words, it must bring forth the physicist's time.

In cosmological models based on LQG and other theories of quantum gravity, it appears as if the classically singular Big Bang is replaced by a quantum foam, which dissolves time (and perhaps space). Therefore, in those models, there must also be a temporal sense in which time emerges from something that is not (yet) temporal. But if time emerges twice over, how do we not end up with two separate notions of time? There is only one resulting (space)time, so whatever these relations of emergence may be, they cannot lead to distinct times. In fact, the local physical time of our era is grounded in fundamental, intrinsically non-spatiotemporal structure, making the atemporal emergence the primary notion. The way in which time emerges temporally is derivative on our local emergent time. This secured the coherence of physical time in light of its potential dual emergence, but also opened up the possibility of a different interpretation of the Big Bang as the birth of twin universes, rather than a big bounce.

Although *prima facie* more secure than the psychologist's and particularly the philosopher's time, the physicist's time remains elusive, potentially ineffable in principle, and perhaps forever beyond our ken. However, I hope to have sketched how its disappearance from the fundamental ontology and its attendant emergence at different scales is a coherent possibility, even in case various forms of emergence come together in producing time.

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Michel Weber

The Ontological Roots of Temporality

Abstract

In order to revisit the question of the nature of time in the context of the present volume, it is advisable to probe successively the following issues. 1. What is time, respectively for philosophy, science, and technoscience? 2. How have its foundations been shaken by Einstein's relativities, Bergson's duration and Whitehead's creative advance? 3. What are the available data? 4. What method should one use to make sense out of them? 5. What is the outcome of their processualization? In conclusion, we highlight the threefold root of temporality disclosed in Whiteheadian organicism

1 What is Time?

The question of the nature of time is as old as philosophy itself —but not older. This means that, before philosophy, time was not problematized, it was a pure common-sensical matter. There were various experiences of time, and, accordingly, different words to name it. The factual was simply not problematical. At most, time was probed in mythological narratives, and anthropomorphized (or divinized) accordingly.

As a matter of fact, philosophy did not spring out of a vacuum and some ancient patterns of thought have endured: Greek culture was, to simplify, both mythological and political. (The very first simplification that this paper brings about is the bracketing of the philosophy, *lato sensu*, of other cultures. India and China come to mind, of course, but there is no a priori reason to ignore the philosophies of life of Africans or Amerindians…) Hence the two main philosophical sub-territories: metaphysics and politics, each being intertwined with epistemology and ethics. More precisely, philosophy has always had a scientific tropism. Hence the need to provide such a definition of time, and to take it seriously. In other words, as Augustine claimed, as long as one does not worry about the exact nature of time, there is no problem whatsoever (Augustine, *Confessions*, 397–398, II, 14–20). But if (when) you do, Pandora's box flips wide open. Does time belong to things, to events, to the (human) spectator? What is the political time, the time of action, the time of debate, the time of solitude? Do we have any knowledge of time that could be injected in these metaphysical and political is-

 https://doi.org/10.1515/9783110753707-014

sues? Doesn't ethics presuppose time insofar as, without liberty, there is neither time nor ethical action?

When addressing the question of time, one has first to acknowledge that there are various experiences of time, and many ways to name them; e.g., in Greek: *chronos, aiôn, aidion, kairos, horai*... These concepts, that sometimes overlap, name various facets of time: physical, cosmological, psychological, linear, circular, rhythmic, pragmatic, destinal (the life-time), qualitative and quantitative. Past, present, and future have distinctive traits.[1] The past is extended, horizonal; the present seems timeless, perhaps point-like; the future is nothing but a virtual tension. If you obliterate some of these experiences, and especially if you consider that time has to be quantified, you open the floodgates to all the contradictions and paradoxes that have haunted the Western mind for centuries. This is, precisely, what philosophy has done first, science later, and theology in the meantime. The subsidiary question is thus: what, if anything, is gained by the theoretical tropism inaugurated by philosophy, endorsed by science, and pushed to the hilt by technoscience? For the sake of analysis, let us briefly peruse, respectively, time in philosophy, time in science, and time in psychology. In order to obtain a panoramic view of the history of ideas, it makes sense to "seek simplicity and distrust it" (Whitehead 1964, 163).

1.1 Philosophy

To define philosophy and to specify what it is all about is a serious matter. *Lato sensu*, philosophy embodies the quest for the meaning of life, and especially probes the harmony that exists, used to exist, or could exist, between humans and their world.[2] Since it is a quest, it should not pretend to be able to provide dogmatic answers. Since it tends towards universal harmony, it can nevertheless focus on the notion of wisdom. *Stricto sensu*, philosophy amounts to the shift

1 See Eugène Minkowski's landmark Bergsonian study. See Minkowki (1970).

2 "The two positive Socratic propositions read as follows. The first: 'It is better to be wronged than to do wrong', to which Callicles, the interlocutor in the dialogue, replies as all Greece would have replied, 'To suffer wrong is not the part of a man at all, but that of a slave for whom it is better to be dead than alive, as it is for anyone who is unable to come either to his own assistance when he is wronged or to that of anyone he cares about'. The second: 'It would be better for me that my lyre or a chorus I directed should be out of tune and loud with discord, and that multitudes of men should disagree with me rather than that I, being one, should be out of harmony with myself and contradict me'. Which causes Callicles to tell Socrates that he is 'going mad with eloquence' and that it would be better for him and everybody else if he would leave philosophy alone" (Arendt 1978, 180 – 181).

from *mythos* to *logos*, and this required, and fostered, a new political venture: direct democracy, with its founding principles —*isonomia* (all are equal before the law) and *isègoria* (all have the equal right to address the political assemblies)— and its core institutions (*ekklêsia*, the assembly of all citizens; *boulê*, the council of the 500; *heliaia*, the supreme court…). Human beings belong to the world; the human *logos* is the same as the natural logos…

Hence the following three important conceptual thresholds: Plato, Aristotle, and Plotinus. Before Plato, one can only guess what has been achieved conceptually; Plato himself "moves about amid a fragmentary system like a man dazed by his own penetration" (Whitehead 1967a, 147). Aristotle is, arguably, the first philosopher to hierarchize the concepts of time, focusing on *chronos*, giving to the *aiôn* a supralunar status, and reducing the *kairos* to a subsidiary, anthropological, matter. We recognize time when we distinguish movement, he claims, which we do by "before and after" (Aristotle, *Physics*, 219a22 sq). Plotinus reconsidered this classification and argued that *Kairos* belong to the first hypostasis, *aiôn* to the second, and *chronos* to the third. Stretching these concepts a bit leads to Trinitarian theology, that secures chronological time (i.e., time *qua chronos*), since it is created with the world and will end with it. *Mutatis mutandis*, Whitehead will provide a Plotinian ontology of time (see our § 5.3).

1.2 Science

Although common sense is perfectly able to deal with the weaknesses and contradictions of sense perception, science doubles down, so to speak, the philosophical bet, and is not afraid of creating as much epistemological problems as it allegedly solves. While philosophy, *per se*, has, sometimes reluctantly, kept the systematic relevance of qualia, on the contrary, science, *per se*, is defined by the quantification and the mathematisation of the world. Its founding moment takes place when the experimental protocol (a necessary, intellectual, perception of sorts) substitutes itself for observation (sensible perception and its contingent trail of aberrations, errors and misinterpretations) in Galilei's *Discorsi* (1638).

When Galilei writes "mente concipio" he operates an epistemological U-turn. What we observe does not really matter anymore; we have to put nature to the question. Galilei's starting point is resolutely anthropocentric (but not anthropomorphic): I conceive in my mind of something moveable that is entirely left to itself; I conceive in my mind of a body thrown on an infinitely extended horizontal plane… (Galilei 1638; Heidegger 1967). The power of imagination acquired then a scientific relevance that is still actual (remember, e.g., Einstein's photonic ride).

The consequences on the notion of time are remarkable. Time becomes, in the Greek lexicon, purely chronological. Since without measuring instruments, the notion of linear (physical) time is of course difficult to use, it could be argued that scientific progress is entirely dependent upon the availability of reliable clocks and rods. Moreover, clocks and rods are, in themselves, pretty much useless: a universal metrics is needed, and this involves a more or less explicit ontology of space and time. (A more sophisticated approach involves a philosophy of perception unfolding the conditions of possibility of measurement: that task is left to philosophy).

Newton's physics (and one should remember that Newton has apparently spent most of his life practicing alchemy rather than physics[3]) solved the metrical conundrum very elegantly: time and space are absolute, they constitute the divine organ of perception (*sensorium dei*). Past and future are perfectly symmetrical for the divine mechanics. This move is the root of Kant's Transcendental Idealism: time is a condition of experience, not one of its by-products. Time flows uniformly, independently of what happens, or not.

This being said, although science departs from philosophy in its strict mathematisation and experimental protocol, it largely keeps the philosophical deontology and works towards the common good.

1.3 Technoscience

On the contrary, technoscience is purely utilitarian, and this gives a different flavour to Kant's definition of the Enlightenment. The motto "Have courage to use your own reason!" ("Sapere aude!"), instead of urging man's release from his self-incurred tutelage (Kant 1996) names now the shift from a theological, dogmatic, reason, to an anthropological, but equally dogmatic, reason. Theology was of course alienating, but it kept some room for the opacity of experience and the mystery of life. With the Enlightenment, a total (scientific) transparency of experience is supposed to be reachable. Of course, Kant himself repeatedly tried to salvage whatever he could of the scraps of meaning ignored by scientific

3 Newton (*Philosophiae naturalis principia mathematica*, 1687) is only the tip of the iceberg: according to Keynes, who explored the unpublished works of Newton in the years 1942–1946, the most influential scientist was (also) an avid alchemist, "the last of the magicians". Newton's alchemical research made him prone to embrace pantheism.

reductionism; he certainly convinced most his readers, but did he persuade them?[4]

"Technoscience" ("TechnoWissenschaft" in German) is a concept framed by Habermas (1968) and refined by Hottois (1984), among others. It is used here in order to point at the mutual transformation that has progressively taken place between science and technology.[5] With the industrial revolution (that flourished *circa* 1830, if one takes the generalization of the use of coal as criterion), science has more and more been lured by its practical consequences, and since these have been increasingly commercial, it should be plain obvious that the synergy at work has benefited mainly to capitalists. Better: neither science nor technology has ever been axiologically neutral. Technoscience is actually a *ménage à trois!* In practice, this means that the project of mastering nature (remember Bacon, Vico and Descartes),[6] that, at one point, could pretend to be neutral (but what is the exact link between *theôria* and *episteme* in Plato? And how did Newton manage both his alchemical quest and his mechanistic worldview?) has become the capitalistic urge to bend culture: to know the world, one must first *manufacture* it.

On the one hand, measurement, and especially time measurement, is essential for technoscience. So much so that scientific progress is entirely dependent upon the availability of reliable clocks and rods. Historically speaking, the first places where time was mastered in order to manufacture the world were Catholic monasteries.[7] Technology, such as sophisticated clocks, solves practical issues, of course, but it also creates new practical and theoretical problems.[8] With the rapid expansion of the use of the electrical telegraph in the mid19th century, simultaneity became an urgent issue. Is the time of the transmitter the time of the receiver? If not, what inertial system can we use to tune in both sides? On the other, Bergsonian, hand, psychological time has two main modalities. *Lato sensu*, it refers, first, to lived time *qua* duration, and, second, to the cosmic living

4 A logical argument is supposed to convince the third party, but this does not mean that s/he will act accordingly; if one sets an example, the third party can be persuaded, and follow up in practice.

5 A distinction should be made between technics and technology, tools and machine.

6 According to, e. g., Francis Bacon (*Meditationes Sacrae*, 1597), Giambattista Vico (*De antiquissima Italorum sapientia, ex linguae latinae originibus eruenda*, 1710) and René Descartes (*Discours de la méthode*, 1637), knowledge itself is power, and, more precisely, power to become the masters and possessors of nature.

7 See Musso (2017).

8 To give contemporary exemplifications: how do you decommission nuclear power plants? How to dispose of the nuclear waste? How do you deal with the scarcity of resources, especially of rare earths?

time of the *élan vital*. *Stricto sensu*, it belongs to the science that emerged in the years 1875–1879, when Wundt was appointed to the chair of psychology in Leipzig Universität, where he opened the first laboratory of experimental psychology. Psychophysics became strongly anchored in academia; it is still there (Wundt 1896). Relativity only exacerbates the existing stakes.

To boil it down to the basics, time is now money. This is, so to speak, the price to pay for the gospel of efficiency.

2 Shaking the Foundations

With this broad horizon in mind, we can revisit the rationale for the *What is time? Einstein and Bergson 100 years later* conference held in the Università degli Studi dell'Aquila in April 2019. A meaningful parallel was indeed made between the April 6, 2009's earthquake and the April 6, 1922's cultural quake.

2.1 April 6, 2009's Earthquake

Earthquakes constitute first-rate traumatic events. Clinically, a trauma is an event during which one's life is threatened, or during which one watches somebody else's life endangered. As a consequence, the victim is likely to suffer from PTSD, making life difficult, or even unbearable.[9]

Philosophy provides broader concepts to circumscribe the consequences of earthquakes. They underline the stability that we always take for granted in everyday experiences. Body and ground are presupposed in all experiences. If the body is attacked—traumatized—, or if the ground gives way beneath us, we lose our vital confidence and life becomes a meaningless burden. Five complementa-

9 "The essential feature of Posttraumatic Stress Disorder is the development of characteristic symptoms following exposure to an extreme traumatic stressor involving direct personal experience of an event that involves actual or threatened death or serious injury, or other threat to one's physical integrity; or witnessing an event that involves death, injury, or a threat to the physical integrity of another person; or learning about unexpected or violent death, serious harm, or threat of death or injury experienced by a family member or other close associate (Criterion A1). The person's response to the event must involve intense fear, helplessness, or horror (or in children, the response must involve disorganized or agitated behaviour) (Criterion A2)" (DSM-IV-TR 1994, § 309.81). A hundred years ago, however, *hysteria* was the trendy clinical tool. While, in the popular literature, PTSD is the concept attached to veterans' impossibility to enjoy life after their mission, hysteria named, first, the state in which rape and incest leave children, and, second, an unsolved Œdipus complex.

ry concepts are outstanding, and each would deserve a paper of its own: Husserl's Ur-Doxa (*Die Urarche Erde bewegt sich nicht*, 1934), Santayana's instinctive faith (*Scepticism and Animal Faith*, 1923), Tillich's ontological security (*The Courage to Be*, 1952), Merleau-Ponty's perceptive faith (*Le Visible et l'invisible*, 1964), Arendt's Common-sense *qua* three-fold commonness (*The Life of the Mind*, 1978). All spell in their own way that life requires that we fundamentally believe not only in the cosmic harmony of all things (hence in permanent rules which underlie all events), but also in their duration. If the cosmic unity and stability is falsified by experience, anxiety prevails ever after.

2.2 April 6, 1922's Cultural Quake

Rhetorically speaking, it makes sense to draw a parallel between the loss of ontological security due to an earthquake, and the disarray following the destruction of human temporality by some well-known Nobel prize winner.[10] The meeting between Einstein and Bergson is usually understood as the turning point of Bergson's fame, but its consequences were far deeper: it meantand still means — that science's symbolic violence was powerful enough to make (some) people renounce to their own experience, and to prefer a construct condemning their life to meaninglessness.[11] This is also, by the way, the significance of Watson's *Behaviourism* (1928). Three points are important to make.

If time is only a matter to be quantified by, and for, technical contraptions, and, especially, if time must be interpreted as a purely contingent feature of our subjectivity, what happens between birth and death is anecdotal and insignificant, which means, first, that basic common sense is obliterated. When Einstein, in 1955, writes to Michele Besso's widow that his death doesn't mean much because *for people who believe in physics* the distinction between past, present and future is only a stubbornly persistent illusion, he tries to make sense of death by denying the possibility of life, and of meaning. Moreover, what sort of science

10 Einstein received the 1921 Nobel Prize in Physics for his discovery of the law of the photoelectric effect. Bergson was awarded the 1927 Nobel Prize in Literature.

11 "La violence symbolique, c'est cette violence qui extorque des soumissions qui ne sont même pas perçues comme telles en s'appuyant sur des 'attentes collectives', des croyances socialement inculquées. Comme la théorie de la magie, la théorie de la violence symbolique repose sur une théorie de la croyance ou, mieux, sur une théorie de la production de la croyance, du travail de socialisation nécessaire pour produire des agents dotés des schèmes de perception et d'appréciation qui leur permettront de percevoir les injonctions inscrites dans une situation ou dans un discours et de leur obéir" (Bourdieu 1994, 188).

requires belief? Second, the meaning of life disappears for the simple reason that time and action are correlated. If action, in the ethical and political sense, is not possible, we live in a purely deterministic universe where no change is possible. There is neither ethics, nor politics, nor psychotherapy possible because at best we can only shoulder pseudo-decisions made by the universal Logos or the local Chaos. Third, the interplay between science and philosophy becomes an empty set. Real philosophers are scientists —but real scientists are not philosophers…

2.3 Bergson's Duration & Whitehead's Creative Advance

To some extent, coping with the consequences of an earthquake amounts to be able to deal with the symbolic violence we have just introduced. In other words, the reconciliation of the human temporality with natural time is not an idle hobby, but an urgent task in societies that are shot through and through by technoscience.

What is time? Our personal experience of time imposes itself upon all scholarly debates, metrics, rods and clocks: not only does it make sense in and of itself, but it is also presupposed by all scientific protocols. Exactly, philosophers such as James, Bergson or Whitehead sought a worldview that would explain the successes of science without denying the specificities of our human existence. As a result, they provided categories that are more powerful (i.e., more coherent and applicable) than the scientific concepts shrinking the depth of our experience.

In order to contrast Einstein's physical, measured, time, with Bergson's lived, qualitative, time, we can benefit from Whitehead's own scientific expertise and philosophical intuition (no pun intended, but appropriate). In *Duration and Simultaneity* (1922), Bergson remarks indeed that there is no real conflict between science and philosophy as soon as one admits the reality of the creative advance of nature —a concept framed by Whitehead in *An Enquiry Concerning the Principles of Natural Knowledge* (1919).[12] Here is how he sketches it one year later:

12 "We thus kept as close as possible to the immediate; we asserted nothing that science could not accept and use; only recently, in an admirable book, a philosopher-mathematician affirmed the need to admit of an 'advance of Nature' and linked this conception with ours" (Bergson 1965, 62; Whitehead 1964, 54). "This work (which takes into account the theory of Relativity) is certainly one of the most profound that has been written on the philosophy of nature" (Bergson 1965, 62 ff1).

> The difficulty as to discordant time-systems is partly solved by distinguishing between what I call the creative advance of nature, which is not properly serial at all, and any one time series. We habitually muddle together this creative advance, which we experience and know as the perpetual transition of nature into novelty, with the single time series which we naturally employ for measurement. The various time series each measure some aspect of the creative advance, and the whole bundle of them express all the properties of this advance which are measurable. The reason why we have not previously noted this difference of time-series is the very small difference of properties between any two such series (Whitehead 1964, 178).

When he addresses Einstein's Relativity, Whitehead hammers basically one point: although Einstein denies the uniformity of space-time, his equations and any experimental protocol presuppose the independence and uniformity of space-time. We have to take into account our ordinary sense experience. In order to understand the meaning and significance of Whitehead's creative advance, it is expedient to remind the reader of the wealth of data involved, and of the method used.

3 Data: Radical Empiricism

What are exactly the data of speculative philosophy? Clear and distinct ideas? Scientific facts? Bare sense-perceptive evidences? Common sense beliefs? Whitehead, who scrupulously adopts the radical empiricism which pedigree was established by James, accepts them all, but not always at face value. In sum: philosophy has to accept all experiences but only experiences. This corresponds to James' *Principle* of *Pure Experience*. "*Only* experiences" means that our total experience is the sole purveyor of evidences. Anything that is not experienced has no relevance for speculative philosophy. Of course, this requirement has to be taken *cum grano salis:* in the course of his/her argument, the philosopher necessarily introduces abstractions that "makes a flight in the thin air of imaginative generalization" (Whitehead 1978, 5).

As we will shortly see, the point is to make sure these generalizations aim at the concrete experience, that they are not swallowed by a purely conceptual organism pretending, like Kant's dove, to ignore its cosmic roots and by-products in order to foster higher degrees of consistency and of coherence (applicability and adequacy are foreign categories in this case). "*All* experiences" means that basically three layers of evidence should testify during our enquiry concerning the principles of natural knowledge: exteroception, the withness of the body, and exceptional mental states.

3.1 Exteroception

Ab Jove principium, sense-perception (i.e., exteroception, which is constituted by the five senses open to the external world) has to play a major role in our data gathering. But our appraisal of its potential should not be naïve: Whitehead, following the empiricist tradition (especially Berkeley, Locke and Hume) insists on the limitedness and possible misleadingness of exteroceptive data. They certainly provide a clear and distinct picture of our immediate surroundings, but they do so by ignoring details and especially by bifurcating the perceiving subject and its environment and by neutralizing time and causation. More precisely, Whitehead underlines the (ab)use philosophy has made of the metaphor of vision, that has imposed the idea of the *spectator-subject*, i.e., of a totally passive onlooker factually unaffected by the scenery. Hans Jonas, probably under the spell of Whitehead, has shown very straightforwardly the inevitable bias of the concept of *theoria* (Jonas 1966).

3.2 The Withness of the Body

Sense perception is actually a very simplified (though sophisticated) projection established on the wealth of data in which the subject is immersed —better, that *constitutes* the subject. A first step towards these roots is made by considering interoceptive and proprioceptive data, that both occur at the fringes of our normal state of consciousness.

Interoception names the internal sensitivity complementing the exteroceptive one. Its messages, coming from receptors housed by all organs and tissues, are, through reflex (i.e., non-conscious) action, the source of a harmonious bodily life. One can distinguish internal pains (cephalalgia, colic…), internal taste (chemical sensitivity ruling various reflex activities), and internal touch (sensitivity to variations of pressure, like distension of the bladder or the rectum, stomach contractions, antiperistaltic contractions of the œsophagus, determining the nausea feeling).[13]

Proprioception names the messages of position and movement allowing, with the help of the internal ear's semi-circular canals a spatialization—i.e., a full (ap)propriation—of the body. Proprioceptive perception grows from sensorial

13 Bergson alludes to these messages when he speaks of "the sensations of 'internal touch' emanating from all points of the organism and, more particularly, from the viscera" (Bergson 1920, 111).

receptors[14] delivering data about the position and the relative movements of the different parts of our body. Through reflex action, it regulates the muscular tone and helps us to localise ourselves in space and to create a sense of depth (stereognosy). Proprioception also includes the muscular sensitivity that complements exteroceptive touch in offering estimates on the weight and volume of the prehended and/or moved object. The structuration of our proprioceptive field provides for the fundamental organic anchorage of our identity.

Whitehead's *withness of the body* (Whitehead 1978, 81; 312; 333) can be said to emerge out of the togetherness of all three of these perceptive modes, internal as well as external. Hence the motto and starting point for philosophers should be "meditate on your viscera".[15] An important consequence for the consciousness of time is that, in the everyday, 'normal' state of consciousness, we live in the past, simply because all the data take time to arrive at our senses, to be conveyed through the central nervous system, and to be synchronized by the brain.[16]

3.3 Exceptional Mental States

There remains however a third cognitive field that has been scrutinized, a bit shyly, by Whitehead's *Religion in the Making* (1926) and explored, this time extensively, by James' *Varieties of religious experience* (1902) and Bergson's *Les deux sources de la morale et de la religion* (1932): the altered states of consciousness that pave the way to mysticism (James' *first-hand religious experiences*) and thereby ground religion itself (*second-hand religious experience*). At the fringes of the Mediterranean beauty of exteroception lays not only the cognitive and emotional vagueness of the *withness of the body* but also, beyond it, the religios-

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14 Articular capsule, periosteum, tendons, joints, muscles house sensitive corpuscles and nerve endings similar to the skin's one. See Sherrington 1940, 309; Sherrington 1947, 132–133.

15 "Over the door of Emerson Hall, the Philosophy Building at Harvard, there is an inscription. I have quite forgotten what it is; I only remember that it is something very high-minded. Whitehead said to his class, "You will have noticed that motto over the door. I commend to you as a more suitable motto and starting point for philosophers 'Meditate on your viscera'. He insisted that philosophers have disdained the information about the universe obtained through their visceral feelings, and have concentrated on visual feelings" (Emmet 1948, 265 – 274). The inscription over the door is from the *Bible*, Psalm 8, reads: "What is man that Thou art mindful of him?" The Philosophy faculty chose a quotation from Protagoras: "Man is the measure of all things". Harvard President Charles William Eliot, substituted the biblical passage without consulting with the faculty.

16 See Pöppel (1988).

ity's Dark Night, during which one embraces the void *and* its heirs (*nihil videt et omnia videt*).

4 Method: Imaginative Generalization

Whitehead recommends the method of imaginative generalization, that he sketches as the flight of the aeroplane; but who is Whitehead, and why does he matter?

4.1 Whitehead, the Post-Modern Plato

Whitehead (1861–1947) can be said to be the post-modern Plato for two complementary reasons. On the one hand, like Plato he has studied, taught, and contributed to all the science of his time, from Algebra to Natural theology. Also, he has created a unified, coherent and applicable worldview, mainly in *Process and Reality. An Essay in Cosmology* (1929). His main sources of inspiration were common sense, algebra, Maxwell's field concept (1873), Spencer (1855), and Darwin (1859). On the other hand, unlike Plato, he gave a positive ontological status to the accident, the event. Whitehead is concerned with the *sumbebekos*. According to his process-organic philosophy:

> We are accustomed to associate an event with a certain melodramatic quality. If a man is run over, that is an event comprised within certain spatiotemporal limits. We are not accustomed to consider the endurance of the Great Pyramid throughout any definite day as an event. But the natural fact which is the Great Pyramid throughout a day, meaning thereby all nature within it, is an event of the same character as the man's accident, meaning thereby all nature with spatiotemporal limitations so as to include the man and the motor during the period when they were in contact (Whitehead 1964, 75).

4.2 The Flight of the Aeroplane

What does the metaphor of the flight of the aeroplane means? Whitehead writes

The true method of discovery is like the flight of an aeroplane. It starts from the ground of particular observation; it makes a flight in the thin air of imaginative generalization; and it again lands for renewed observation rendered acute by rational interpretation. […] The success of the imaginative experiment is always to be tested by the applicability of its results beyond the restricted locus from which it originated. In default of such extended application, a generalization started from physics, for example, remains merely an alternative expression of notions applicable to physics. The partially successful philosophic generalization will, if derived from physics, find applications in fields of experience beyond physics. It will enlighten observation in those remote fields, so that general principles can be discerned as in process of illustration as in process of illustration, which in the absence of the imaginative generalization are obscured by their persistent exemplification (Whitehead 1978, 5).

Two consequences are important: first, philosophy does not amount to what is often called the "philosophical culture". Philosophy should not be understood, and especially not be taught, as an historical or a cultural discipline. *Qua* history, it unfolds legacies (Kant is the heir of Aquinas, who read Augustine, who understood the consequences of the contrast between Plato and Aristotle, etc.); *qua* culture, it weaves concepts (matter and form belong together; together they are likely to require some demiurge to secure their interplay; that demiurge might have a benevolent agenda —or not, etc.) Philosophy is anchored in experience and, when it has sharpened its concepts, they should return to experience to be put to the test.

Second, the data are both immediate and mediate. On the one hand, all the experiences of a given individual—whether they are exteroceptive, proprioceptive, interoceptive, or exceptional— could bring relevant generalizations. This is the radical empiricist wager: nothing can be omitted, experience drunk and experience sober, experience sleeping and experience waking…[17] Hence the intrinsic opacity of the world for the human rationality: "You think the world is what it looks like in fine weather at noon day; I think it is what it seems like in the early morning when one first wakes from deep sleep" (Russell 1956, 39).[18] On the other, scientific experiments and theories are also eligible. If sci-

17 "In order to discover some of the major categories under which we can classify the infinitely various components of experience, we must appeal to evidence relating to every variety of occasion. Nothing can be omitted, experience drunk and experience sober, experience sleeping and experience waking, experience drowsy and experience wide-awake, experience self-conscious and experience self-forgetful, experience intellectual and experience physical, experience religious and experience sceptical, experience anxious and experience care-free, experience anticipatory and experience retrospective, experience happy and experience grieving, experience dominated by emotion and experience under self-restraint, experience in the light and experience in the dark, experience normal and experience abnormal" (Whitehead 1967, 226; James 1950, 232).

18 Russell adds: "I thought his remark horrid, but could not see how to prove that my bias was any better than his. At last he showed me how to apply the technique of mathematical logic to his vague and higgledy-piggledy world, and dress it up in Sunday clothes that the mathematician could view without being shocked. This technique which I learnt from him delighted me, ence points at a problem of simultaneity, philosophy should help contextualizing the stakes.

4.3 The Reformed Subjectivist Principle

All this presuppose what Whitehead calls the “Reformed Subjectivist Principle”, that is, and is not, subjectivist. Some form of subjectivism is of course assumed: all experiences point at the existence of a subject. But that subject is made out of these experiences, it does not pre-exist them. Moreover, subjectivity is not limited to the human, or even the animal, realm. Everything that exists experiences. We end up with a very sophisticated and critical form of panpsychism (James’“-Pure Experience” or Russell’s “Neutral Pluralistic Monism”), and, in order to avoid misunderstandings, it makes sense to talk about a “Pan-Experientialism” (Griffin 1977).

5 Outcome

Let us now specify Whitehead’s solution of the temporal conundrum. Since I have already extensively treated this ontological issue (Weber 2016) while Desmet (2010a; 2010b) has provided a detailed discussion of Whitehead’s Relativity itself,[19] I propose here only a broad framework.

5.1 Examining the Foundations

Whitehead’s very first move is to understand time in the same way he treated space, relationally. Here is what he wrote to Russell in 1911:

> Last night [...] the idea suddenly flashed on me that time could be treated in exactly the same way as I have now got space (which is a picture of beauty, by the bye). [...] The result is a relational theory of time, exactly on four legs with that of space. [...] It gets over all the old difficulties, and above all abolishes the instants in time, e. g., the present instant, even in the shape of the instantaneous group of events. This has always bothered me as much as the ‘point’ [...]. According to the theory, the time-relation as we generally think of it (sophis-

and I no longer demanded that naked truth should be as good as the truth in its mathematical Sunday best” (Russell 1956, 39).

19 Desmet especially underlies the significance, of Minkowski, Silbertein and Cunningham, for the special theory, and of de Sitter and Eddington, for the general theory.

> ticated by philosophy) is a great cook up. Simultaneity does not belong to it. That comes in from the existence of the space-relation. Accordingly, the class of all points in space serves the purpose of the instant in time. Also each object runs its own time (properly so-called) (Russel 1985, 299).

There is a breakthrough, but it is not total. On the one hand, instants of time are abolished, relationality instituted, and this paves the way to Relativity. On the other hand, Whitehead will soon realize that it makes little sense to treat time like space… His 1925 Lowell Lectures, later published, with three additional crucial chapters as *Science and the Modern World*, provides the point of inflection. The fourth chapter offers, indeed, a key discussion of Whitehead's argument against mechanicism: he depicts here the ins and outs of "Simple Location", a major instantiation of his "Fallacy of Misplaced Concreteness". By simple location, he means first one *major* characteristic which refers equally to space and to time: "that material can be said to be here in space and here in time, or here in space-time, in a perfectly definite sense which does not require for its explanation any reference to other regions of space-time" (Whitehead 1967b, 49). In one word: environmental independence. And second, a *minor* characteristic which differentiates space and time:

> as regards time, if material has existed during any period, it has equally been in existence during any portion of that period. In other words, dividing the time does not divide the material. […] In respect to space, dividing the volume does divide the material (Whitehead 1967b, 49).

In one word: temporal independence of the successive durations. Since the division of time functions, in respect to material, so differently from the division of space, it is claimed that the "transition of time has nothing to do with the character of the material. The material is equally itself at an instant of time" (Whitehead 1967b, 49) —and at any instant of time. Whitehead adds: "Here an instant of time is conceived as in itself without transition, since the temporal transition is the succession of instants" (Whitehead 1967b, 49–50).[20]

Whitehead's philosophy of organism sets the destruction of simple location and external relations as its goal, and replaces it with complex (dis)location and extero-internal relations ("prehensions").

20 See also Weber 2006, 97–118.

5.2 Contemporaneity vs. Simultaneity

If we focus on the relativistic issue itself, one contrast is decisive: contemporaneity is not simultaneity. The former is commonsensical, while the latter depends upon metrics, clocks, experiments and other contingencies. Whitehead argues that simultaneity should be understood independently of the speed of light:

> There are certain objections to the acceptance of Einstein's definition of simultaneity, […]. In the first place light signals are very important elements in our lives, but we cannot but feel that the signal-theory somewhat exaggerates their position. The very meaning of simultaneity is made to depend on them. There are blind people and dark cloudy nights, and neither blind people nor people in the dark are deficient in a sense of simultaneity. They know quite well what it means to bark both their shins at the same instant. In fact, the determination of simultaneity in this way is never made, and if it could be made, it would not be accurate; for we live in air and not *in vacuo* (Whitehead 1982, 53).

Eventually, contemporaneity has also received a metaphysical meaning within Whitehead's mature philosophy. To make a (very) long story short, the argument is the following: apparently following James's reading of Zeno and his bud theory of time and actuality, Whitehead shifts, in 1925, from a continuist phenomenology of science to what he names an *epochal* ontology. This amounts to revamping Leibniz, whose monads have now windows and a limited life-span (first the actual entities are subjective, *becoming*, or *concrescing*, then they perish and subsists objectively, *qua* being or "in transition"); if monads have windows and a life of sorts, the cosmic harmony cannot be pre-established or auto-established (actualities-subject evolve *solitude to solitude*), it needs the repeated action of a "limitation of antecedent selection" implemented by the past and a "principle of limitation" that Whitehead will soon call "God".[21] To repeat:

21 "Value is the outcome of limitation" (Whitehead 1967b, 94); "The spatio-temporal relationship, in terms of which the actual course of events is to be expressed, is nothing else than a selective limitation within the general systematic relationships among eternal objects" (Whitehead 1967b, 161); "It has already been emphasised that an actual occasion is to be conceived as a limitation; and that this process of limitation can be still further characterised as a gradation" (Whitehead 1967b, 162); "Restriction is the price of value. There cannot be value without antecedent standards of value, to discriminate the acceptance or rejection of what is before the envisaging mode of activity. Thus, there is an antecedent limitation among values, introducing contraries, grades, and oppositions. According to this argument the fact that there is a process of actual occasions, and the fact that the occasions are the emergence of values which require such limitation, both require that the course of events should have developed amid an antecedent limitation composed of conditions, particularisation, and standards of value. Thus, as a further element in the metaphysical situation, there is required a principle of limitation" (Whitehead 1967b, 178). This is the main path towards God that process thought provides: when the

what matters here is that the unison of (immediate) becoming, or “concrescent unison”, is defined by the mutual contemporaneity of the concrescing actual entities involved, and it manifests itself as a cross-section of the universe, i. e., a *duration* experienced in Presentational Immediacy (Whitehead 1978, 124–125; 320).

It is the causal independence of the concrescing actualities, their constitutional privacies, that define the mutual contemporaneity, *not* a synchronisation effected with the help of luminous signals and frames of reference (Whitehead 1978, 61; 123). The unison does not belong to simultaneity and measured time, but to a melody of durations that require a harmonising principle.

5.3 Threefold Root of Temporality

Understanding together all the experiences of time requires a wider perspective. More precisely: “epistemological difficulties are only solvable by an appeal to ontology” (Whitehead 1978, 189). So far, we have seen that measured time is the expression of some features of the cosmic growth that Whitehead calls, already in *Principles of Natural Knowledge* (1919) and in *Concept of Nature* (1920) the creative advance of nature: “The forward moving time exhibits this characteristic of experience, that it is essentially action. This passage of nature or, in other words, its creative advance is its fundamental characteristic; the traditional concept is an. attempt to catch nature without its passage” (Whitehead 1982, 14).

Let us now resume the argument made in my *Threefold Root of Whiteheadian Temporality* (Weber 2016, 211–227). It involves revisiting the three complementary modalities of the creative advance: creativity, efficacy, and vision, reframing its Greek mirror (*kairos*, *chronos*, and *aion*). First of all, the very idea of time involves change, and more precisely, novelty. In Whitehead’s lexicon, this is creativity *aka* becoming and concrescence. The bud theory is required because, as long as past causal chains hold, there is no real novelty possible, only the repetition of the same, or of a different mixture of the same. But real novelty is, by definition, totally unpredictable, wild even—whereas the world disclosed in our

decisions taken in the sepulchre of the concrescence are respectful of the cosmic tissue, it is because the initial aim has suggested the best compossibility —and because what is best for shoring up a society of actual occasions is best for one of its actualities. Depths of value, i. e., experiences of high emotional intensity, “is only possible if the antecedent facts conspire in unison. Thus, a measure of harmony in the ground is requisite for the perpetuation of depth into the future. But harmony is limitation. Thus, rightness of limitation is essential for growth of reality” (Whitehead 1926, 146).

experience is somewhat ordered and tame. Actually, creativity is always buttressed on past events, themselves integrated in some structure (in *Process and Reality*, space-time is only a superficial expression of the extensive continuum). Moreover, creativity modifies that structure: "We all remember Bergson's doctrine of the *élan vital* and its relapse into matter. The double tendency of advance and relapse is here plainly stated" (Whitehead 1958, 29).

The second modality of the creative advance is efficacy, which names memory, being, and transition. In turn, this grants the possibility of measured time. Let us linger for a moment on efficacy, that provides a clear ontological status to the past, something that is rare enough in the history of philosophy. The late Whitehead is very clear about the nature of the past. His standpoint is, as usual, informed by common sense[22] the history of philosophy, and science; he writes:

We should balance Aristotle's—or, more rightly, Plato's—doctrine of becoming by a doctrine of perishing. When they perish, occasions pass from the immediacy of being into the not-being of immediacy. But that does not mean that they are nothing. They remain 'stubborn fact': *pereunt et imputantur* (Whitehead 1967a, 237).

In sum: "This is the doctrine that the creative advance of the world is the becoming, the perishing, and the objective immortalities of those things which jointly constitute stubborn fact" (Whitehead 1978, xiv). Since creativity is wild and efficacy is blind, their togetherness is likely to bring growth just as well as teratogenesis. In order to secure a positive growth, and to prevent the eternal return of the same, a third modality is required: vision, that Whitehead names god *qua* primordial nature, i. e., superject. Many qualifications can be given to that divinity: principle of concretion, of compossibilization, of unison. It operates through the deliverance of the initial subjective aim, securing a cosmos housing the highest intensities of experience possible. Providing the initial aim is made necessary by the constraints imposed by the privacy or independence of simultaneous concrescing actualities.

Conclusion

In conclusion, our argument has led us from the polysemiality of the notion of time to Whitehead's ontological core: the creative advance of nature. Thinking

22 *Pereunt et imputantur* is the inscription on old sundials in religious houses: "The hours perish and are laid to account" (Whitehead 1958b, 47).

together rupture, structure, and adventure is a little bit like weaving again *kairos*, *chronos*, and *aiôn*. By doing so, we are allowed to make sense of the various experiences of time disclosed in everyday consciousness, to understand how technoscience has tremendously simplified the issue, and to clarify at what price this has made it extremely successful in its experiments and applications. It is Galilei's experimental standpoint, together with the definition of the principle of inertia, that made Newtonian science and a new cultural project possible. The price to pay was, and still is, the loss of the cosmic unison of immediacies of becoming and of the very meaning of time.

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Luca Vanzago

On the Notion of Processuality in Whitehead: Concrescence and Transition Correlated

Abstract

This paper is devoted to the notion of time and its derivation from a more original notion of process, as it is developed by Whitehead. The importance of the notion of process is known by to have been a constant concern in Whitehead's philosophical development from his earlier works in the fields of mathematics, logic and epistemology, passing through the philosophy of nature and reaching the metaphysical works. Time proves to be a question intimately correlated to process in Whitehead's multi-faceted approach. His final achievements concerning this question show that process is seen as a more fundamental aspect than time in order to understand what exists. Process is further divided into concrescence and transition, and also contrasted to "reality". The paper aims to discuss these notions and their mutual relevance. The scope is to provide a clue for understanding Whitehead's elusive conception of cosmology in terms of creativity and passage.

1 The Time of the Actual Entity

The study of the processuality proper to a single actual entity, as a process of concrescence, probably represents the most deeply studied aspect of the theme of temporality in Whitehead's philosophy. Without ignoring the utility of a number of the essays now available on the topic, it will be nevertheless useful to give an overall structural description of this issue. In the light of Whitehead's concept of subjectivity, the aspect to be described in the first place is the notion of process as the emergence of a subject and its individuation. It is necessary to investigate the temporal structure of this process.

In terms of the articulation of the temporal dimensions, theme which I systematically develop below, the single process of concrescence is identified by Whitehead with the present. The present is, in other words, the effect of the processual experiential activity of a subject placed in a concrescence, which means both the passage from publicity to privacy, and the synthetic reaction of the sub-

 https://doi.org/10.1515/9783110753707-015

ject to the multiplicity of the world. From the point of view of Whitehead's conception of temporality, this means that time depends on the experiential activity of the subject, and can therefore be characterised as temporalisation. This temporalizing activity, however, is in its turn conditioned, since the subject effecting the temporalisation is in itself a product of temporalisation, and produces itself exclusively as structurally affected by time, which means it is not extra-temporal. The problem whether the actual entity be *within* or *outside* time has been discussed at length: my answer is that the actual entity is neither within nor without time, but *is* time, in the sense that it institutes time through the activity of temporalisation, but does not transcend this activity, being on the contrary its effect. This thesis cannot be clarified unless one deepens the nature of the temporal/temporalizing subject in terms of emergence and finitude. In Whitehead's conception, the two aspects are inseparably connected, and cannot be isolated except at the price of the loss of their intelligibility.

To speak of the emergence of a subject within its own temporal process means to speak of the duplicity of determination of subjectivity, and, correlatively, of temporality. The subject is, according to Whitehead, always subject/superject. It is the structural unity of its two opposite determinations: it is at once cause and effect of itself.[1] Whitehead shows this notion to be intrinsically related to experience, in a passage which in its conciseness expresses the sense in which PR relates time, subject, and experience. Whitehead writes:

> The more primitive types of experience are concerned with sense-reception, and not with sense-perception. This statement will require some prolonged explanation. But the course of thought can be indicated by adopting Bergson's admirable phraseology, sense-reception is 'non-spatialized', and sense-perception is 'spatialized'. In sense-reception the sensa are the definiteness of emotion: they are emotional forms transmitted from occasion to occasion (Whitehead 1978, 113 – 114).

As Whitehead himself remarks, this thesis requires a prolonged explanation, which is what will be undertaken here. Notice that every process possesses a dual structure, according to which there are two components, one receptive and one reactive. The process itself is the articulation of this dual structure. Now, the fact that each single process is dual raises the question of the relationship between the two modes. It is possible to say that, generally speaking, this relationship is usually interpreted in terms of successive phases: each phase of

1 What Whitehead also says "to be *causa sui*". On this subject see Whitehead 1978, 149 – 51; 220 – 222. The meaning of this expression is clarified in 222 as follows: "Self-realisation is the ultimate fact of facts. An actuality is self-realising, and whatever is self-realising is an actuality. An actual entity is at once the subject of self-realisation, and the superject which is self-realised".

concrescence is followed by a phase of transition, so it is possible to represent the succession of actual entities in terms of an alternated succession of two distinct modes or segments, in this way: concrescence—transition—concrescence—transition, and so on. Recall, however, that each actual entity constitutes itself through other actual entities. From the point of view of the process, what does this consideration imply? It implies, in line with Whitehead's rejection of the fallacy of simple location or presence, that these two faces of the process are not two totally different and independent facts. The thesis I want to demonstrate in this paper is that concrescence and transition are indeed distinct, i. e., distinguished, but not separated and not independent.

I do not intend to identify concrescence and transition. I want to keep them distinguished. This distinction is important in order to clarify the process of temporalisation. However, what I intend to show is that concrescence and transition are two dual, reciprocal modes of processuality itself, and not two independent segments of a linear succession of time. To show this interdependence between the two "phases" should allow me to demonstrate what type of cohesion does exist in the succession of actual entities which characterises the "history" of the total subject. In order to clarify my interpretative thesis, I would like to start from the following text from *Process and Reality*, which has the advantage of putting in relation the two modalities of the process in a clear way:

> There are two species of process, macroscopic process, and microscopic process. The macroscopic process is the transition from attained actuality to actuality in attainment; while the microscopic process is the conversion of conditions which are merely real into determinate actuality. The former process effects the transition from the 'actual' to the 'merely real'; and the latter process effects the growth from the real to the actual. The former process is efficient; the latter process is teleological. The future is merely real, without being actual; whereas the past is a nexus of actualities. The actualities are constituted by their real genetic phases. The present is the immediacy of teleological process whereby reality becomes actual. The former process provides the conditions which really govern attainment; whereas the latter process provides the ends actually attained. The notion of 'organism' is combined with that of 'process' in a twofold manner. The community of actual things is an organism; but it is not a static organism. It is an incompletion in process of production. Thus the expansion of the universe in respect to actual things is the first meaning of 'process'; and the universe in any stage of its expansion is the first meaning of 'organism'. In this sense, an organism is a nexus. Secondly, each actual entity is itself only describable as an organic process. It repeats in microcosm what the universe is in macrocosm. It is a process proceeding from phase to phase, each phase being the real basis from which its successor proceeds towards the completion of the thing in question. Each actual entity bears in its constitution the 'reasons' why its conditions are what they are. These 'reasons' are the other actual entities objectified for it (Whitehead 1978, 214).

Let us try to bring the meaning of this quotation to light. The fundamental datum to be considered is the fact that each process of concrescence starts from what it receives, that is to say, from what it inherits from other actual entities, which are called "objectified". This means that the process of concrescence is based on the process of transition. In fact, transition is the modality which allows one actual entity to be *efficacious* for another. Obviously, this is reciprocal: only by means of the new concrescence can the potential efficacy of the objectified actual entities produce a new actual entity. It is only because a new process *re-enacts* the past that the past can be efficacious on the present, that is, the past's future. There is thus a reciprocal relationship of determination. The transition produces what, in Whiteheadian terms, is called the passage from the actual to the merely real, while the concrescence produces the reciprocal effect, the passage from the merely real to the actual. Thus, concrescence and transition do not take place one after the other, as it were, but together, and in a certain sense *simultaneously*.

The relationship between concrescence and transition is connected to that between a single actual entity and the world, and is reciprocal. The thesis is explicitly stated by Whitehead in the passage quoted above. There is thus, at the level of temporality, a confirmation of the dual and reciprocal model, which is at work on the level of subjectivity. We can, in this respect, recall the metaphor used by Merleau-Ponty in his late works: the process of expansion and contraction, systole and diastole. In this case too, the condition of being a relationship between the single and the totality is more fundamental, for each process, than the one of succession. Clearly this analysis poses some problems for common sense. But the opposite position is grounded on the separation of the substances, and their spatiotemporal individuation, which Whitehead rejects.

We must notice furthermore that, according to Whitehead, the temporal "places" of the past, present, and future, are determined with respect to the experiential activity. In other words, they do not have an absolute position and an autonomous subsistence. How can this interpretative thesis be corroborated? It seems necessary to analyse all the aspects entailed in the concept of temporalisation. We must then, in the first place, render explicit the structural characters of the concept of time progressively determined by Whitehead's analysis.

2 The Structure of Temporalization: the Criticism of the Abstract Notion of Time

In the first place, it is necessary to give an overall account of the notion of time as process according to Whitehead. Already in *The Concept of Nature*, Whitehead declares that the general concept of time, at least the one proper to the natural sciences, is an abstract concept. His position becomes progressively more explicit and more detailed as his more speculative works appear. Whitehead finally no longer wants to adopt the term "time" since it is conditioned by the comprehension proper to the *materialist* sciences he has been criticising in his epistemological works. This statement entails several different theses which must be distinguished: "true" time, that is, the time from which the materialist conception of nature abstracts,[2] is characterised by its being extended and not punctiform, by its being a succession, further determined as passage, and by its being undetermined, that is, not deterministically conditioned, and finally by its being finite.

The criticism of the instantaneous concept of time has already been discussed in many works. Whitehead in any case reiterates this criticism until the end of his scientific life.[3] To the notion of time as succession of punctiform and reciprocally unrelated instants, Whitehead at first opposes the one based on time as extension and duration. Successively, he further elaborates this concept, by remarking that the concept of duration and the concept of extension do not express explicitly enough what is the decisive aspect to be assigned to temporality: its passing. This implies the need to better clarify the processual condition of time. The aspect which must be proven to be secondary[4] is the extensionality of time. It follows that it is not enough to substitute the notion of instant with the notion of extended duration to adequately account for time: time must be differently qualified. This revision also entails the need to explain why everyday experience thinks of the temporal dimensions in terms of separated places. The mistake does not consist in conceiving this abstract time, but in its ontological absolutisation.[5] But what, according to Whitehead, is the time of common sense, in the light of the speculative investigation?

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2 See Whitehead 1985a, 183: "Time is sheer succession of epochal durations".
3 See Whitehead 1968, 199: "There is a fatal contradiction inherent in the Newtonian cosmology [...] Now assuming this Newtonian doctrine, we ask—What becomes of velocity, at an instant? Again we ask—What becomes of momentum at an instant? These notions are essentials for Newtonian physics, and yet they are without any meaning for it". See also Whitehead 1968, 207: "It is nonsense to conceive of nature as a static fact, even for an instant devoid of duration. There is no nature apart from transition, and there is no transition apart from temporal durations. This is the reason why the notion of an instant of time, conceived as a primary simple fact, is nonsense".
4 Secondary does not mean inauthentic. According to Whitehead, on the contrary, spatialization and temporalisation are two aspects of processuality. What becomes less relevant for Whitehead is the need to oppose, in the wake of Bergson's works, time and space.
5 See Whitehead 1968, 36–37: "The notion of potentiality is fundamental for the understanding of existence, as soon as the notion of process is admitted. If the universe be interpreted in terms

3 The Reification of Time

In *The Concept of Nature*, Whitehead shows that the scientific concepts of space and time are operative abstractions, performed in connection to effective experience. Space and time are necessary tools for the cognitive, and before that existential, operations characterising the life of the subject.[6] One could lead no normal life if one could not orient oneself according to a fixed and objective system of coordinates.[7] The constitution of an objective structure of space and of time obeys vital needs, and is effectuated already in the simplest of the existential activities. Language, and the symbolic systems, simply perfect this attitude, already traceable at the animal level of behaviour.

If we understand that the time and space of common sense are abstractive operations, not mirroring an immediately given reality, then we can trace their origin without falling into the error of a metaphysical hypostatisation. Whitehead very clearly explains this duplicity of time (and space) in several passages of *Process and Reality.* He furthermore distinguishes the genetic analysis of creativity, which deals with processuality, from the coordinate analysis, which deals with the logico-mathematical aspects of what is created. He writes, for example:

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of static actuality, then potentiality vanishes. Everything is just what it is. Succession is mere appearance, rising from the limitation of perception. But if we start with process as fundamental, then the actualities of the present are deriving their characters from the process, and are bestowing their characters upon the future. Immediacy is the realisation of the potentialities of the past, and is the storehouse of the potentialities of the future. Hope and fear, joy and disillusion, obtain their meaning from the potentialities essential in the nature of things. We are following a trail in hope, or are fleeing from the pursuit in fear. The potentialities in immediate fact constitute the driving force of process".

6 The same thesis is repeated in Whitehead 1978, 87: "The 'objectifications' of the actual entities in the actual world, relative to a definite actual entity, constitute the efficient causes out of which *that* actual entity arises; the 'subjective aim' at 'satisfaction' constitutes the final cause, or lure, whereby there is determinate concrescence; and that attained 'satisfaction' remains as an element in the content of creative purpose. There is, in this way, transcendence of the creativity; and this transcendence effects determinate objectifications for the renewal of the process in the concrescence of the actualities beyond that satisfied superject. Thus, an actual entity has a threefold character: (i) it has the character 'given' for it by the past; (ii) it has the subjective character aimed at in its process of concrescence; (iii) it has the superjective character, which is the pragmatic value of its specific satisfaction qualifying the transcendent creativity".

7 See this passage from Whitehead 1978, 170, very similar to the quotation from Claudel to be found two times in VI: "Every statement about the geometrical relationships of physical bodies in the world is ultimately referable to certain definite human bodies as origins of reference. A traveller, who has lost his way, should not ask, Where am I? What he really wants to know is, Where are the other places? He has got his own body, but he has lost them".

> Physical time makes its appearance in the 'coordinate' analysis of the 'satisfaction'. The actual entity is the enjoyment of a certain quantum of physical time. But the genetic process is not the temporal succession: such a view is exactly what is denied by the epochal theory of time. Each phase in the genetic process presupposes the entire quantum, and so does each feeling in each phase. The subjective unity dominating the process forbids the division of that extensive quantum which originates with the primary phase of the subjective aim. The problem dominating the concrescence is the actualization of the quantum *in solido*. [...] There is a spatial element in the quantum as well as a temporal element. Thus, the quantum is an extensive region. This region is the determinate basis which the concrescence presupposes. This basis governs the objectifications of the actual world which are possible for the novel concrescence. The coordinate divisibility of the satisfaction is the 'satisfaction' considered in its relationship to the divisibility of this region (Whitehead 1978, 283).

From passages like this it is possible to conclude that the mathematisation of reality serves pragmatic purposes. It is meaningful to ask what the measurable structure of reality is. It is not meaningful, however, to ask what the measure of a single process is. This question is exactly re-introducing the metaphysical presuppositions that the whole Whiteheadian work tries to unmask and reject.[8] The static and totally unfolded structure which, in McTaggart's terms, is called B-Series, that is, the calendarial time of the dates, is what lends itself to measurements and objective evaluations. But this structure is derivative with respect to the processuality of the actual entities, as this passage, extracted from the *fourth* part of *Process and Reality*, shows:

> A duration is a complete locus of actual occasions in 'unison of becoming', or in 'concrescent unison'. It is the old-fashioned 'present state of the world'. In reference to a given duration, D, the actual world is divided into three mutually exclusive loci. One of these loci is the duration D itself. Another of these loci is composed of actual occasions which lie in the past of some members of D: this locus is the 'past of the duration D'. The remaining locus is composed of actual occasions which lie in the future of some members of D: this locus is the 'future of the duration D' (Whitehead 1978, 320).

What immediately results from this quotation is the fact that the present proper to the duration is devoid of dynamism. It is the present considered *ex post*, or, to use an expression typical of Merleau-Ponty's philosophy, it is the present seen from nowhere, with a panoramic, kosmotheoretic gaze. The same can be said for past and future. What past, present and future as extended lack, is their most intrinsic quality, their "sense of being". Whitehead expresses this difference by speaking of a *processual time* as atomic or epochal. He does not oppose the

8 Whitehead 1985a, 183: "The epochal duration is not realised *via* its *successive* divisible parts, but is given *with* its parts".

time of physics and the time of process metaphysics as two distinct substances, since on the contrary he sees a derivation of the former from the latter; but he wants to avoid reducing one to the other.[9] It is therefore necessary to analyse closely the way in which Whitehead analyses the dimensions of time in what appears to be their sense of being. It is in fact possible to show that Whitehead, in his own way, has studied the problem in a way which is original while still close to the phenomenological one.

4 Time and Experience

If one can say that experience, according to Whitehead, cannot take place except temporally, and that it is temporally conditioned, now it is possible to evaluate the reciprocal statement. There is temporality insofar as there is experiential activity. The determination of the sense of being proper to the temporal dimensions is linked, according to Whitehead, to this fact. In particular, Whitehead connects the articulation of the dimensions of time to the two perceptive modalities, Causal Efficacy and Presentational Immediacy, which are thematised in *Symbolism* and in *Process and Reality*, and which constitute the symbolic reference. As Whitehead writes in *Symbolism*,

> Time is known to us as the succession of our acts of experience, and thence derivatively as the succession of events objectively perceived in those acts. But this succession is not pure succession; it is the derivation of state from state, with the later state exhibiting conformity to the antecedent. Time in the concrete is the conformation of state to state, the later to the earlier; and the pure succession is an abstraction from the irreversible relationship of settled past to derivative present (Whitehead 1985b, 35).

In order to bring to light Whitehead's position in all its complexity I must at this point turn to a detailed analysis of his position.

5 The Present

The process of concrescence is the place of the present. The present is not an abstract space among other abstract spaces, in turn products of a segmentation ex-

9 Whitehead 1985a, 185: "Time is atomic (i.e., epochal), though what is temporalized is divisible". Notice the presence of the adjective form deriving from the substantive temporalisation in a book dating 1925.

ternal and extraneous to the flux of time and the becoming of existence: the present is the place in which the subject constitutes itself. It is because the present is the locus of this activity that it is what it is. Whitehead clearly expresses this thought in *Modes of Thought:*

> Actuality is the self-enjoyment of importance. But this self-enjoyment has the character of the self-enjoyment of the one self. The most explicit example of this is our realization of those other actualities, which we conceive as ourselves in our recent past, fusing their self-enjoyment with our immediate present (Whitehead 1968, 161).

It follows that the present is not a point on a straight line but is characterised by its internal dialectical dynamic. Therefore, not only is the present not an instantaneous point, not only is it not simply an extended but static duration: the present is not even a linear passage, a natural event that would "take place" in order to happen. The present *is* insofar as it is a dialectical dynamic proper to experience.[10] The present is the place of the articulation of the temporal dimensions. It is the place of the very happening of the temporalizing experience. This amounts to saying, echoing Merleau-Ponty's characterisation of space, that it is time that *makes* itself by itself, *creates* itself. It is an exteriority which turns upon itself and hollows out an interiority. This means, in Whiteheadian terms, that the present is the passage from the publicity of the world to the privacy of the subject. It is a cyclic whirl, which rhythmically winds round itself to then undo itself once again. But what is properly speaking the structure of this present? It is necessary to recur to the analysis offered in *Adventures of Ideas* in order to bring to the fore the meaning of *Process and Reality.* Here, in a wonderful passage, Whitehead writes as follows

> If we keep ourselves to this short-range intuition, assuredly the future is not nothing. It lives actively in its antecedent world. Each moment of experience confesses itself to be a transition between two worlds, the immediate past and the immediate future. This is the persistent delivery of common-sense. Also this immediate future is immanent in the present with some degree of structural definition. The difficulty lies in the explanation of this immanence in terms of the subject-object structure of experience. In the present, the future occasions, as individual realities with their measure of absolute completeness, are non-existent. Thus, the future must be immanent in the present in some different sense to the objective immortality of the individual occasions of the past. In the present there are no individual occasions belonging to the future. The present contains the utmost verge of such realized individuality. The whole doctrine of the future is to be understood in terms of the account of the process of self-completion of each individual actual occasion. This process can be shortly characterized as a passage from re-enaction to anticipation. The in-

10 Obviously, to speak of experience does not entail presupposing a single separated subject.

> termediate stage in this transition is constituted by the acquisition of novel content, which is the individual contribution of the immediate subject for the re-shaping of its primary phase of re-enaction into its final phase of anticipation. This final phase is otherwise termed the 'satisfaction', since it marks the exhaustion of the creative urge for that individuality. This novel content is composed of positive conceptual feelings become integrated with the physical prehensions of antecedent occasions, and thus yield propositions concerning the past. These propositions are again integrated and re-integrated with each other and with conceptual feelings, and yield other propositions. Finally propositions emerge concerning the constitution of the immediate subject. It belongs to the essence of this subject that it passes into objective immortality. Thus, its own constitution involves that its own activity in *self*-formation passes into activity of *other*-formation. It is by reason of the constitution of the present subject that the future will embody the present subject and will re-enact its patterns of activity. But the future individual occasions are non-existent. The sole immediate actuality is the constitution of the present subject which embodies its own necessity for objective immortality beyond its own immediacy of self-formation. This objective immortality is a stubborn fact for the future, involving its pattern of perspective re-enaction. The final phase of anticipation is a propositional realization of the essence of the present-subject, in respect to the necessities which it lays upon the future to embody it and to re-enact it so far as compatibility may permit. Thus, the self-enjoyment of an occasion of experience is initiated by an enjoyment of the past as alive in itself and is terminated by an enjoyment of itself as alive in the future. This is the account of the creative urge of the universe as it functions in each single individual occasion. In this sense, the future is immanent in each present occasion, with its particular relations to the present settled in various degrees of dominance. But no future individual occasion is in existence. The anticipatory propositions all concern the constitution of the present occasion and the necessities inherent in it. This constitution necessitates that there be a future, and necessitates a quota of contribution for re-enaction in the primary phases of future occasions. The point to remember is that the fact that each individual occasion is transcended by the creative urge, belongs to the essential constitution of each such occasion. It is not an accident which is irrelevant to the completed constitution of any such occasion (Whitehead 1967, 192–193).

It has been necessary to fully quote this passage at length since it contains a lot that needs to be carefully considered. From the reading of these lines some considerations emerge:

1. that the present is the place or locus of existence, and therefore that past and future exist only insofar as they are given to a present;

2. that, on the other hand, past and future are not nothing. On the contrary, they are dimensions of the present itself, and are so since the present is not eternity but passage, not unlimited but limited, that is, the present arises, passes, and dies, and this passage is due to the fact that the present is the modality by which a finite being exists; the present, in other words, is the *mode* of the temporally finite existence of a subject.

3. It follows that also past and future are, at once, relative and absolute terms. They are relative because what is future in relation to a certain actual entity will be past for another. They are absolute, however, because their position with respect to that determined actual entity is what it is and cannot be changed by the actual entity. This is precisely what renders the past past and the future future: the past is past because its sense of being is that of having happened; reciprocally, the future is characterised by its having not happened yet, and of going to happen (sooner or later). For this reason, the objectivity of the past is distinguished by Whitehead from that of the future. The past possesses an objectivity of its own, which is proper to what has effectively happened, whereas this is not proper to the future. What is proper to the future is its imminence and its being an element of attraction for the present perspective: the present is in fact never neutral, but always in tension toward a future.

But this is not all. Past and future are not only the elements in which the present articulates itself, but are such insofar as the present constitutes their connection. According to what Whitehead writes in this passage—in so doing summarising the whole meaning of the conception of actual entity proposed in *Process and Reality*—the present is configured as the passage from "re-enaction" to anticipation. We must exactly understand *what sort of passage this is*, that is, whether it is a pure transition from a point to another in a path, or whether it possesses a very different nature.

Various considerations suggest that the second alternative is correct. In the first place, one must insist on the fact that the new process is what activates the passage. If the new process were not present, that is, if the actual entity were not characterised by its being an activity, there would be no creative advance. Here the Whiteheadian notion of causality is called into play, and it is necessary to discuss an aspect of it. If, in fact, Whitehead often recurs to the notion of efficient causation, this does not mean that the new process occurs only insofar as "generated" by means of "Causal Efficacy". It is rather the contrary: Causal Efficacy is the expression of the fact that the new process cannot take place unless in connection with its environment, into which the process finds itself, as it were, *thrown*, although being a *project*, to use the well-known Heideggerian expressions. This means that the new subject cannot purely and simply invent an ontological situation of its own, but simply reacts to what it finds as already constituted.

But on the other hand, if the process were not acting, were not action, there would be no past either. The past, in other words, is the outcome of the process of experience. The past is therefore given only insofar as it is constituted by the new present. The subject can either conform itself to the environment in which it finds its place, or it can react to and change it. Either choice depends on the present subject, which therefore cannot be determined only in relation to the initial conditions in which it arises. In this sense, Whitehead is an intransigent indeterminist.

It is in this connection that the role of the future is displayed. The future does not exist in itself. The future is the expression of the indeterminacy of the present. The future is possibility, it is the ontological expression of the fact that the new process is not deterministically conditioned by the past. If this were the case, there would properly be no future, but only a sheer repetition of what has already been, since the essence of the future is that of not being derivable from what precedes it. A mere, continuous and eternal repetition of the same is no future at all, because there is no change. It is not by chance that a completely deterministic world is a world in which the distinction between past and future is meaningless, since the direction of time (the so-called "arrow") is reversible. The future is, essentially, an anticipation of what has not been yet, and will not be exactly as it was anticipated. There could be no anticipation if the future totally conformed to its past. That the future is to conform to its past is always possible, but never necessary, since this possibility depends on the decision taken in the present process, which therefore introduces an element of unpredictability and novelty.

The future, thus, plays a role, but only insofar as it is future-for-a-present, future given as future to a present. That is, as Whitehead underlines repeatedly, insofar as it is not something subsisting autonomously. The same can be said for the past, so that there is a double determination of the past: the past is given as past only to a present, that is, *is not a past in itself*, but is given to a present as past, i.e., it is irreversibly gone, past. The determination of past and present is thus clearly shown: the past can be past only insofar as there is a present for which it represents the past; but this *does not make the past present:* it makes it only present as past. This double relationality of the past with respect to the present, which is the past's future, and reciprocally of the future, forces us to take a closer look at the way in which Whitehead determines these two temporal dimensions, in order then to examine the question, at which Whitehead hints at the end of the passage above quoted, as to what the creative push or urge is which transcends each single process of concrescence.

6 Past and Future: Non-Linearity of Process

As a matter of fact, Whitehead explicitly declares that the present does not exist as pure irrelative datum, but only as dynamic articulation. The extension of a duration is therefore clearly determined not in terms of simple, not further structured, extensionality, but on the contrary in terms of an interconnection of the temporal dimensions. This is what renders time something different from space. As far as the future is concerned, Whitehead writes:

> The past has objective existence in the present which lies in the future beyond itself. But the sense in which the future can be said to be immanent in occasions antecedent to itself, and the sense in which contemporary occasions are immanent in each other, are not so evident in terms of the doctrine of the subject-object structure of experience. It will be simpler first to concentrate upon the relation of the future to the present. The most familiar habits of mankind witness to this fact. Legal contracts, social understandings of every type, ambitions, anxieties, railway time-tables, are futile gestures of consciousness apart from the fact that the present bears in its own realized constitution relationships to a future beyond itself. Cut away the future, and the present collapses, emptied of its proper content. Immediate existence requires the insertion of the future in the crannies of the present (Whitehead 1967, 191).

The presence of the future in the present is evidently of an experiential nature, but not necessarily conscious. For the moment however we must in the first place deepen the logico-ontological structure of the codetermination between temporal dimensions, in order to support the thesis that the present is the place itself of this codetermination. We have said that it is necessary to avoid any hypostatisation or reification of the present, any naturalistic comprehension of it: the present is not a segment of the temporal line, but is what it is since it is the tension towards the future and connection to the past. Therefore, the present is not a univocal place, but receives from this correlation with the other two dimensions its definition, to the same extent that, reciprocally, the other two dimensions are defined in relation to the present. We thus obtain a complex structure of mutual interdependencies, which also explains the relativity of the temporal determinations: past and future are relative and perspectival terms, and the processual dynamic is a true activity of temporalisation and not the unfolding of something substantial. On the codetermination of the temporal dimensions Whitehead is explicit:

> The future is immanent in the present by reason of the fact that the present bears in its own essence the relationships which it will have to the future. It thereby includes in its essence the necessities to which the future must conform. The future is there in the present, as a general fact belonging to the nature of things. It is also there with such general determinations as it lies in the nature of the particular present to impose on the particular future which must succeed it. All this belongs to the essence of the present, and constitutes the future, as thus determined, an object for prehension in the subjective immediacy of the present. In this way each present occasion prehends the general metaphysical character of the universe, and thereby it prehends its own share in that character. Thus, the future is to the present as an object for a subject. It has an objective existence in the present. But the

> objective existence of the future in the present differs from the objective existence of the past in the present. The various particular occasions of the past are in existence, and are severally functioning as objects for prehension in the present. This individual objective existence of the actual occasions of the past, each functioning in each present occasion, constitutes the causal relationship which is efficient causation. But there are no actual occasions in the future, already constituted. Thus, there are no actual occasions in the future to exercise efficient causation in the present. What is the objective in the present is the necessity of a future of actual occasions, and the necessity that these future occasions conform to the conditions inherent in the essence of the present occasion. The future belongs to the essence of present fact, and has no actuality other than the actuality of present fact. But its particular relationships to present fact are already realized in the nature of present fact (Whitehead 1967, 194).

In this passage Whitehead states, on the one hand, the symmetric interconnection of past and future with respect to the present; and yet also the diversity of the essential determination of each dimension. Past and future, in other words, if on the one hand are dimensions given only insofar as they are in relation to the present, on the other are differently given from one another. The past is, so to speak, the dimension of the "no more", the future of the "not yet". That which exists, exists only in the present mode. Only the present is actively existent, that is, it possesses, to use Whitehead's lexicon, "subjective immediacy". Past and future are only objectively; they cannot be considered in terms of subjective determinations, that is, they are not "actual" in the meaning Whitehead gives to this word. If therefore the present is the place of the codetermination of past and future, this complex relationship cannot be conceived in linear terms. As Whitehead here explicitly says, the future is imminent in the present. The same thing can be said, *mutatis mutandis*, for the past.[11] This means that *the future is present as future*. In other words, the future *is not* if by "being" one understands the being of the present. However, the future is, the only way given to the future to be is that of being given as future to a present. Another aspect must be underlined: this mode of givenness of the future possesses the characteristic of being undetermined, while the one proper to the past is precisely its being completely determined and irrevocable: *pereunt et imputantur*, as Whitehead likes to say.

It would be impossible to say more explicitly that past and future depend on the experiential process and are not physical loci. Without it ever being explicitly said, Whitehead thus rejects the image of time in terms of a straight line. The image of the line is misleading since it implies that past and future are stages

11 In what follows I will constantly insist on the future, but the reader should always understand the possibility to transpose the argument to the past. I will speak about only one dimension for the sake of brevity of the analysis.

of a linear path. In reality, the future is not given unless to a present which in turn is such only insofar as it has a relation with its own past. The immanence of the future in the present is the negation of the fact that the future is what the present is not. If one defines the present in opposition to past and future, then these two dimensions lose their meaning. This, in any case, does not imply, as a possible interpretation inspired by Levinas could suggest, that in thus conceiving of the future, it would lose its most specific and intrinsic character: what makes it the irruption of unexpected novelty. On the contrary, it is only by reason of the existence of a being who is able to institute the articulation of the temporal dimensions that the unexpected can take place. The conception of temporality expressed by Whitehead in his speculative works is therefore very clearly articulated in terms of an ontology of experience. There is no becoming, which is the true form of time, unless insofar as there is an experiencing subject. The nature of this subject, however, is not that proper to a transcendental subjectivity, but on the contrary the one proper to a subject emerging from its own experiential process, a subject which therefore not only is the origin of temporality, but is at the same time its effect. It is in this sense that we must understand the concept of becoming which grounds the whole metaphysics of process:

> These various aspects can be summed up in the statement that *experience* involves a *becoming*, that *becoming* means that *something becomes*, and that *what becomes* involves *repetition* transformed into *novel immediacy*. This statement directly traverses one main presupposition which Descartes and Hume agree in stating explicitly. This presupposition is that of the individual independence of successive temporal occasions. [...] This presupposition of individual independence is what I have elsewhere called, the 'fallacy of simple location'. [...] The doctrine of the individual independence of real facts is derived from the notion that the subject-predicate form of statement conveys a truth which is metaphysically ultimate (Whitehead 1978, 136 – 137).

The interdependence of the temporal dimensions is the other side of the reciprocal relationality among actual entities. This consideration vindicates the thesis expressed at the beginning of this paper, according to which concrescence and transition are not two separated forms of process, but are correlative to one another. This, in turn, should allow me to clarify the ontological condition envisaged by Whitehead for the "total subject". In order to support in a conclusive way this thesis it is necessary, at this point, to study the concrete mode in which the present articulates in itself the other temporal dimensions, from the standpoint of the experiential act. Whitehead, in the passage above quoted, states that the single actual entities are not separated bodies, standing in succession. There is therefore a reciprocal presence of every actual entity in the others. Let us now consider the question from the point of view of temporality.

7 Concrescence and Transition Reciprocally Connected

As we have seen, Whitehead distinguishes concrescence and transition in the way above considered. In some passages of *Process and Reality* he speaks of two *types* of process.[12] But these two types are distinguished insofar as they represent the two modalities by which the process is constituted. They are in fact substantially identified with efficient and final causation, in turn reinterpreted by Whitehead in terms of perceptive experience. The model which Whitehead elaborates is thus the following: the new process of concrescence *receives* (in the active sense of this term) the determinations of what it must become from the world in which it arises. Therefore, that which, from the standpoint of the actual entities which constitute the given world of the new subject, represents a process of transition, i. e., efficient causation, becomes a process of concrescence, i. e., final causation, for the new process. Whether the process is a transition or a concrescence, it is a matter of perspective.

Thus, the relationality between actual entities is shown both in its modality and in its essential asymmetry. We should not forget, in fact, that the process of concrescence is intrinsically undetermined,[13] so that there is always only one direction for the process. It is indeed a matter of perspective, but the metaphysical generalisation must take into account *every* perspective. Therefore, that which appears, to an actual entity in phase of concrescence, as a type of process, appears as yet another type from the standpoint of the already 'concrete' actual entities (which obviously is possible only through an *ex post facto* analysis). In this way we can also illustrate the intrinsic solidarity of the world, which according to Whitehead plays such an important role for the comprehension of reality.[14] Solidarity does not mean harmonic community, but an incessant process of separation and communication. For Whitehead it is clear that what usually is con-

12 See for example Whitehead 1978, 210: "[T]here are two kinds of fluency. One kind is the *concrescence* which, in Locke's language, is 'the real internal constitution of a particular existent'. The other kind is the *transition* from particular existent to particular existent. This transition, again in Locke's language, is the 'perpetually perishing' which is one aspect of the notion of time; and in another aspect the transition is the origination of the present in conformity with the 'power' of the past. [...] Concrescence moves towards its final cause, which is its subjective aim; transition is the vehicle of the efficient cause, which is the immortal past".

13 See Whitehead 1954, 242: "Time requires incompleteness. Each occasion is temporal because it is incomplete. Nor is there any system of occasions which is complete".

14 See Whitehead 1978, 167: "The universe is at once the multiplicity of *res verae* and the solidarity of *res verae*". On the topic see Nobo 1986.

sidered as an individual, is in fact a *dividual*, a manifold community of internal subjects which are not necessarily all harmonically related to each other.[15]

It is possible, in this light, to further clarify the relationship between subject and superject: the subject is represented by the process of concrescence which effects the transposition from the *publicity* of the world, understood as the intercorporeal interrelation of actual entities, to the privacy of a subjective synthesis; but this activity is also the process of formation of the superject as the 'objectivation' of the very same process of concrescence by other subjectivities. Not that the concrescence first takes place and then gives rise to transition: to think in these terms means to see concrescence and transition as two distinct segments on a line, whereas the distinction drawn by Whitehead is to be understood in terms of the different perspective from which the process is considered, and therefore according to the different sense of being characterising the two modes. In fact there is no concrescence without transition and vice versa. The two processes are in a relation of codetermination which can also, in a certain sense, be understood through the biological-systemic concept of feedback. The temporality of this process is not linear,[16] but is characterised by continuous anticipations and retro-actions. Past and future are present in the present, in their own way, as we have seen.[17] Whitehead has tried to express this thesis with concepts which were still partially conditioned by the tradition he wants to abandon (reason why he coined so many neologisms), and yet he has stated in a sufficiently clear way what he wanted to say. For example, we possess in the following quotation a summary of the complex theme whose elements we are disentangling:

> The various primary data and the concrescent feelings do not form a mere multiplicity. Their synthesis in the final unity of one actual entity is another fact of 'givenness'. The actual entity terminates its becoming in one complex feeling involving a completely determinate bond with every item in the universe, the bond being either a positive or a negative

15 This is why, according to Whitehead, there is a need for a superior principle of harmony, which he also calls the principle of limitation, and which in his *Religion in the Making* is historically considered in its various *avatars*. I cannot enter into this question, which exceeds by far my capacities. Nonetheless it seems clear to me that the major element of disagreement between Whitehead and Merleau-Ponty resides precisely in the fact that the former sees the necessity of postulating a transcendent element of order and harmony, while the latter would rather explain order and harmony as self-generating within process.

16 Whitehead 1954, 246: "Supersession is not a continuous process of becoming. If we try to combine the notions of supersession and continuity we are at once entangled in a vicious infinite regress".

17 See Whitehead 1978, 213 where Whitehead talks about the mutual interference between phases of the process.

> prehension. This termination is the ‘satisfaction’ of the actual entity. Thus, the addition of another component alters this *synthetic* ‘givenness’. Any additional component is therefore contrary to this integral ‘givenness’ of the original. This principle may be illustrated by our visual perception of a picture. The pattern of colors is ‘given’ for us. But an extra patch of red does not constitute a mere addition; it alters the whole balance. Thus, in an actual entity the balanced unity of the total ‘givenness’ excludes anything that is not given. This is the doctrine of the emergent unity of the superject. An actual entity is to be conceived both as a subject presiding over its own immediacy of becoming, and a superject which is the atomic creature exercising its function of objective immortality. It has become a ‘being’; and it belongs to the nature of every ‘being’ that it is a potential for every ‘becoming’. […] Returning to the correlation of ‘givenness’ and ‘potentiality’, we see that ‘givenness’ refers to ‘potentiality’, and ‘potentiality’ to ‘givenness’; also we see that the completion of ‘givenness’ in actual fact converts the ‘not-given’ for that fact into ‘impossibility’ for *that* fact. The individuality of an actual entity involves an exclusive limitation. This element of ‘exclusive limitation’ is the definiteness essential for the synthetic unity of an actual entity. This synthetic unity forbids the notion of *mere* addition to the included elements (Whitehead 1978, 44–45).

It is thus possible to summarise what has been seen so far by stating that the overall processuality of reality must be distinguished into two interconnected modes, which express the solidarity between subjects and their reciprocal intercommunication, but at the same time their progressive distinction from one another. Each single process produces a synthetic perspective of the totality in which the process is arising, and this totality in its turn receives a shape from the process of concrescence which emerges from it. Each single experiential act is temporally limited, and its process gives rise to a further iteration of the overall processuality but does not amount to a higher synthesis. This processuality is anonymous and yet contains in itself the germs of a constant striving to overcome the anonymity. The question which must be posed with respect to this latter consideration is the following: why does this happen? Why the tension towards the overcoming of this anonymity? In order to do so we must finally analyse what Whitehead writes with respect to what is the normal concept of subjectivity of common sense. Human life rarely grasps itself in its continuous processuality and its plurality. Usually, each subject perceives itself, in the first place, as an individual. What is this ‘individual’ within the perspective of the metaphysics of process?

8 Succession and Temporality

It is helpful to recall here that the subject Whitehead talks about is an incarnated subject,[18] a non-un-extended corporeity, which in turn is not to be seen in terms of inert matter, but in terms of subjective body. Corporeity manifests itself immediately in temporal terms; it could be said that corporeity is intrinsically marked by temporality:

> Further, our experiences of our various bodily parts are primarily perceptions of them as *reasons* for 'projected' sensa: the *hand* is the *reason* for the projected touch-sensum, the *eye* is the *reason* for the projected sight-sensum. Our bodily experience is primarily an experience of the dependence of presentational immediacy upon causal efficacy. Hume's doctrine inverts this relationship by making causal efficacy, as an experience, dependent upon presentational immediacy. This doctrine, whatever be its merits, is not based upon any appeal to experience (Whitehead 1978, 176).

The bodily subject is a subject because it is a perceiving body. By inverting the relation of cause and effect instituted by Empiricism, by reason of its paradoxical intellectualism,[19] the philosophy of process shows in what sense corporeity means in the first place that bodily experience possesses a structure of its own, irreducible to the primacy of consciousness, which it is the task of philos-

18 The notion of dipolarity, used by Whitehead to characterise the way in which the subject perceives, is precisely meant to express this perspective. Instead of opposing mind and matter, which is the duality of substances Whitehead so often reproaches Descartes with, Whitehead says that mind and matter are to be seen together, or rather, that mind and matter are to be reconceived in terms of the inner dipolarity characterising each single actual entity as a "drop of experience". Each *drop* of experience is therefore intrinsically one, although dipolar, that is, dual. There is no room in this work to attempt a comparison between Merleau-Ponty and Whitehead on this subject, but I hope to show in another place that the notion of dimension worked out by Merleau-Ponty in VI (according to which each fact shows its dimensionality and each dimension retains an element of facticity) can help to understand in what sense experience is, in Whitehead's perspective, one (i.e., not divided into two substantial modes) and dual.

19 See for example Whitehead 1978, 141: "Hume and Locke, with the over-intellectualist bias prevalent among philosophers, assume that emotional feelings are necessarily derivative from sensations. This is conspicuously not the case; the correlation between such feelings and sensations is on the whole a secondary effect. Emotions conspicuously brush aside sensations and fasten upon the 'particular' objects to which—in Locke's phrase—certain 'ideas' are '*determined*'. The confinement of our prehension of other actual entities to the mediation of private sensations is pure myth. The converse doctrine is nearer the truth: the more primitive mode of objectification is via emotional tone, and only in exceptional organisms does objectification, via sensation, supervene with any effectiveness".

ophy to acknowledge in order to straighten an upside-down picture of experience. Thus, subjectivity is synonymous with temporality and affectivity. Whitehead writes:

> The 'causal feeling' according to that [Hume's] doctrine arises from the long association of well-marked presentations of sensa, one precedent to the other. It would seem therefore that inhibitions of sensa, given in presentational immediacy, should be accompanied by a corresponding absence of 'causal feeling'; for the explanation of how there is 'causal feeling' presupposes the well-marked familiar sensa, in presentational immediacy. Unfortunately, the contrary is the case. An inhibition of familiar sensa is very apt to leave us a prey to vague terrors respecting a circumambient world of causal operations. In the dark there are vague presences, doubtfully feared; in the silence, the irresistible causal efficacy of nature presses itself upon us; in the vagueness of the low hum of insects in an August woodland, the inflow into ourselves of feelings from enveloping nature overwhelms us; in the dim consciousness of half-sleep, the presentations of sense fade away, and we are left with the vague feeling of influences from vague things around us. It is quite untrue that the feelings of various types of influences are dependent upon the familiarity of well-marked sensa in immediate presentment. Every way of omitting the sensa still leaves us a prey to vague feelings of influence. Such feelings, divorced from immediate sensa, are pleasant, or unpleasant, according to the mood; but they are always vague as to spatial and temporal definition, though their explicit dominance in experience may be heightened in the absence of sensa (Whitehead 1978, 176).

From the standpoint of the problem that we are considering in this paper, that is, the temporal side, it is particularly important to investigate the relationship between affectivity and temporality. It is in fact from this perspective that we can hope to bring to the fore the meaning of Whitehead's conception of the succession of actual entities seen as the origin of the *enduring subjectivity*. We have seen above that the structure of the single experiential process has two faces. This structure does not depend on some decision, but it appears through description. In other words, the solidarity between actual entities is not an ethical but ontological structure (although it bears ethical meanings). This explains the meaning of Whitehead's concept of succession. The succession of actual entities as such is given, it is the structure proper to the way in which the subjects manifest themselves. But in itself, it does not grant that the subject emerging in each single process can maintain itself and thus gives rise to a structured subjectivity. In other words, succession is a necessary but not a sufficient condition in order for a true subject to be given; on the contrary, *in itself* the temporal succession is more a matter of dispersion and loss than of maintenance and evolution.

9 Mutual Sensitivity

The fundamental element to be investigated is what Whitehead calls mutual sensitivity between actual entities. Once again, it must be recalled that the structural definition of actual entity is the fact of its being the multiplicity of the world as given in perspective: “it will be presupposed that all entities or factors in the universe are essentially relevant to each other’s existence” (Whitehead 1954, 248). The connection between actual entities is thus equivalent to their ontological essence. To speak of an actual entity in isolation is a nonsense, and this makes clear how the concept of actual entity cannot be understood in terms of atoms of reality except in a metaphorical sense. An actual entity thus reflects the communitarian structure of which it is part. As such, however, this consideration does not imply any particular type of privileged order. Whitehead insists very clearly on this aspect in the following passage:

> The general common function exhibited by any group of actual occasions is that of mutual immanence. In Platonic language, this is the function of belonging to a common Receptacle. If the group be considered merely in respect to this basic property of mutual immanence, however otherwise lacking in common relevance, then—conceived as exemplifying this general connectedness—the group is termed a Nexus. Thus, the term Nexus does not presuppose any special type of order, nor does it presuppose any order at all pervading its members other than the general metaphysical obligation of mutual immanence. But, in fact, the teleology of the Universe, with its aim at intensity and variety, produces epochs with various types of order dominating subordinate nexus interwoven with each other. A nexus can spread itself both spatially and temporally. In other words, it can include sets of occasions which are contemporary with each other, and it can include sets which are relatively past and future (Whitehead 1967, 201–202).

Thus, each actual entity structurally connects itself to other actual entities, nor could it be otherwise, since, as Whitehead underlines in this passage, this is an ontological character of the actual entity and not something an actual entity, more or less consciously, decides to be. The structures to which the connections between actual entities give rise are of several kinds and different complexity. Their unique common trait is their originating a temporally extended structure:

> Any set of actual occasions are united by the mutual immanence of occasions, each in the other. To the extent that they are united they mutually constrain each other. Evidently this mutual immanence and constraint of a pair of occasions is not in general a symmetric relation. For, apart from contemporaries, one occasion will be in the future of the other. Thus, the earlier will be immanent in the later according to the mode of efficient causality, and the later in the earlier according to the mode of anticipation, as explained above. Any set of

occasions, conceived as thus combined into a unity, will be termed a nexus (Whitehead 1967, 197).

This is the general structural datum, upon which the differentiation between different types of society supervenes. The dominant general characteristic of societies is that they do not have a pre-established temporal order. Whitehead is here describing the intersubjective intercorporeal community in terms of the absence of the particular order which is proper to conscious experience. What can be said, in order to conclude, is that Whitehead explicitly declares that there is no temporal order intrinsically proper to the societies in general. More precisely, Whitehead excludes the presence of the linear form of temporality *proper to normal*, i. e., conscious, human experience. It is then possible to assume that the emergence of an enduring subjectivity through the structuration of the actual entities might be connected to the emergence of a linear type of temporality.

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Time and Experience in Physics and Philosophy: Whiteheadian Reflections on Bergson, Einstein, and Rovelli

Abstract

This paper begins by revisiting the intellectual collision between Bergson and Einstein. Their crucial misunderstanding almost a century ago did not create but has exacerbated the modern bifurcation between natural science and human experience. After trying to help Einstein and Bergson understand one another, the process-relational cosmology of Alfred North Whitehead is introduced in an effort to articulate an alternative approach to healing the split between physics and experience. While Whitehead affirmed much of Bergson's critique of scientific materialism, he did not entirely share Bergson's views on temporality and departed in critical respects from the Frenchman's vitalism. Finally, Whitehead's cosmology is compared with Carlo Rovelli's Loop Quantum Gravity model of spacetime. Instead of attempting to philosophically explicate scientific formalisms or synthesize mathematics and ontology, I invite these thinkers into dialogue around a question—"What is time?" —that cannot be properly addressed by any one discipline, as it requires us to generate and inhabit an intermediary zone between physics, philosophy, and common sense

1 Introduction: Whose Time Is It?

What is time? On the one hand, it appears to be an obvious fact of my everyday experience, and yet, on the other hand, with the slightest reflection upon its nature, I find it dissolves through my fingers into an ageless mystery. The ensuing effort to grasp and articulate time's meaning stretches my imagination in several directions simultaneously. I turn inward as my personal stake in existence leads me to consider the time of my own most direct and intimate experience of being alive. Time is who I am. I was born, I age, and I will die, necessarily in that biological order. Each year, I watch as winter frost melts to make way for spring flowers. Time is the gradual accretion of value, the lure of possibility and the memory of failures and achievements. Time is the emergence of order and pur-

https://doi.org/10.1515/9783110753707-016

pose amidst chaos and despite death. Time goads me onward as it gnaws into the future, swelling as it advances (Bergson 1965, 62).

I turn outward as my fascination with fundamental physics leads me to ponder the paradoxes of Relativity and quantum theories. I wonder what, *if any*, significance my personal biography has given the radically non-teleological and time-reversible determinism intrinsic to most scientific models of Nature. I consider the possibility that my experience of seasonal rhythms is reducible without remainder to the mechanical effect of a slight tilt in the rotation of our dust mote planet as it revolves in warped spacetime around a massive sphere of radiating plasma. Is time just an illusion of aimless relative motion?

I spin inward again as my incurable philosophical itch compels me to search for some more general metaphysical scheme or wider interpretive context within which the laws of physics might find a place alongside lived experience. Physicists, theologians, entrepreneurs, philosophers, artists—really all thoughtful human beings—have at one point or another been struck by this question and struggled to answer it in their own terms. Nearly a century ago, time was at the center of Einstein and Bergson's brief debate in Paris. Centuries earlier, another influential intellect, Benjamin Franklin, had tried to settle accounts: *time is money*. Centuries earlier still, Augustine had to confess that he did not know what time is (though he offered some potent conjectures). And Plato, as he stared in wonder at the stars above him while inwardly contemplating the perfections of geometry, offered at least a likely story: Time is "a moving image of eternity".

The passage of time is both inescapably obvious and profoundly mysterious. Nothing gets to the heart of who and what we are more than time. Stars ignite, burn their atomic fuel, and go supernova, creating the heavier elements needed for conscious lifeforms to take shape. Dinosaurs go extinct. Radioactive isotopes of carbon in their fossilized remains decay at regular intervals, leaving molecular memories for paleontologists to date their deaths. Human beings decide to take action in the present and regret mistakes made in the past. Civilizations rise and fall. None of these processes is intelligible in reverse. And yet, there has been a strong consensus among physicists for at least a century that the time of human experience, let us call it *phenomenological* or *lived time*, is, as Einstein once put it, a "stubbornly persistent illusion". In the equations of physics—whether classical, relativistic, or quantum—it doesn't matter which direction time flows, if it can even be said to "flow" at all. The one exception, perhaps, is the second law of thermodynamics, to which I return later.

As if these scientific notions of time are not strange enough already, the meaning of everyday time is also not at all what it at first appears to be. As Augustine admitted, time is plain as day until someone asks us to explain how it works: suddenly, we find ourselves wandering in the dark. A recent *New York Times* article chronicled the growing controversy (and confusion) about seasonal changes in clock-time, so-called "daylight savings" time (Johnson 2019). Back in the 1920s, changes to local clock-times in US cities like Boston and Detroit led some residents to worry that an extra hour of sunlight in the evening would dry up their gardens and disturb their farm animals. The article quotes author Michael Downing:

> The idea of losing or gaining an hour is itself such a fantastically bad philosophical proposition that nobody knows what they're talking about…Most people don't even understand whether moving the clocks forward gives them more sunlight or less sunlight in the morning. They just can't remember what it does, because it so defies logic (Johnson 2019).

In the paper to follow, I offer not a definitive disambiguation of the variety of time conceptions but merely a few potential pathways through the thicket in the hopes of finding some new perspectives on a very old question. I begin by revisiting the intellectual collision between Bergson and Einstein. Their crucial misunderstanding almost a century ago did not create but has exacerbated the modern bifurcation between natural science and human experience. This bifurcation was inaugurated by the new mechanical philosophy of Descartes, Galilei, and Newton, and was later intensified by Kantian transcendentalism. After trying to help Einstein and Bergson understand one another, I turn to the process-relational ontology of Alfred North Whitehead in an effort to articulate an alternative approach to healing the split between physics and experience. While Whitehead affirmed much of Bergson's critique of scientific materialism, he did not entirely share Bergson's views on temporality and departed in critical respects from the Frenchman's vitalism. Finally, I compare Whitehead's ontology to Carlo Rovelli's Loop Quantum Gravity model of spacetime. Instead of attempting to philosophically explicate scientific formalisms or synthesize mathematics and ontology, I invite these thinkers into dialogue around a question—"What is time?" —that cannot be properly addressed by any one discipline, as it requires us to generate and inhabit an intermediary zone between physics, philosophy, and common sense. While the convergence between Rovelli and Whitehead is by no means complete, there are some hopeful signs of alignment that bring us closer to a philosophical reconciliation between our conscious experience and the Nature known to science.

2 Einstein and Bergson: The Clash between Physics and Philosophy

The canonical interpretation of the 1922 debate that the present volume is meant to revisit is that Einstein, the mathematical physicist, won out over Bergson, the philosopher, by dismissing any role for the latter's special faculty of intuition in cosmological investigations. This view of what happened has had lasting consequences for how the general public understands the relationship between scientific knowledge and human experience. While at the time, Bergson's position may have been a contributing factor in the Nobel Prize committee denying Einstein the award for his Relativity theory (the committee officially granted him the prize in 1922 for the photoelectric effect – Clark 2012), by 1945, the standard view was cemented by Bertrand Russell's widely read *A History of Western Philosophy*, wherein Russell challenged Bergson's understanding of mathematics and dismissed his philosophy as "anti-intellectual" (Russell 1972, 803). This triumphalist interpretation continued to echo in the Science Wars of the mid-1990s, when Sokal and Bricmont published their book *Intellectual Impostures* (1998), which devoted an entire chapter to the debate between Bergson and Einstein in the French edition.

As more sympathetic interpreters have recently made clear,[1] contrary to the canonical interpretation it must be remembered that Bergson had no qualms with Einstein's mathematical logic or with the empirical data supporting it. Bergson accepted the epistemological importance of Einstein's Relativity physics and conceived of his own intuitive philosophy not as a competitor but as a metaphysical supplement. Einstein, on the other hand, rejected the metaphysical importance of Bergson's philosophy, dismissing it as a subjective psychological illusion. Bergson's main point of contention with Einstein concerned whether Relativity theory tells us more about the behavior of clocks than it does about concrete or lived time. For Bergson, the vital energy and creative metamorphosis of lived time will always remain invisible to the spatializing methods of scientific measurement and mathematical representation. For Einstein and his inheritors, the invisibility to their methods of Bergson's so-called "lived time" signals only its nonexistence. The philosopher's time does not exist, Einstein insists.

Bergson's refusal to accept Einstein's dismissal as the final word on real time does not mean he denies the practical utility of Relativity theory's spatialization

1 See e. g., Dusek (2000); Čapek (1973); Latour (2011); Canales (2015); White (2015); Sherman (2020).

of time. Clearly the measurements and models of twentieth century physics have produced amazing technological advances that have transformed human life and society. Einstein came of age just as newly erected train tracks and steam engines began to criss-cross the European landscape, forever warping the time-consciousness of pre-industrial people. Trains linked cities and towns across the continent at faster speeds than ever before. The newly linked stations needed to invent evermore ingenious ways of synchronizing their clocks in order to avoid collisions and remain on schedule. As is well known, prior to becoming the world's most famous scientist Einstein worked as a patent clerk reviewing the latest signaling technologies to assist in establishing the (at least approximate) simultaneity of clocks across long distances. In today's globally interconnected and increasingly digitized world, this convenient way of measuring time has become nearly all-encompassing. All of us have been swallowed alive by mechanical clock-time, our forms of life remodeled to fit its precisely calculated tempo. The daily and seasonal rhythms of Sun, Moon, and stars have faded away into the background of our electrified routines. It is, in Charles Dickens' words, "as if the sun itself had given in" to the ordering power of clocks and the network of machines they coordinate (Dickens 1848, 86). A convenient tool has thus become our master.

Bergson believed that an intuition of lived time is necessarily presupposed in all the physicist's intellectual operations, including his mathematical reflections and empirical measurements. Einstein, on the other hand, regarded Bergsonian intuition as an illusory artifact of our human perception and thus as irrelevant to the objective truths revealed by physics.[2] For Einstein and the physicists who inherit his way of thinking, there simply is no such thing as a "philosopher's time", that is, the living duration through which evolution continually generates novel forms, as Bergson might say. Instead, Einstein distinguished two kinds of time: psychological time, which is a subjective illusion generated by relative motion, and physical time, which is an objective quantity measured by clocks (that ultimately reduces to a four-dimensional block universe wherein all time exists eternally because no scientifically relevant distinctions can be made between past, present, and future). Given the geometry of his four-dimensional spacetime block, Einstein's can only be a deterministic universe with no room left for divine

2 This despite the fact that Einstein had his own rather Spinozist conception of the role of intuition in divining the laws of physics. The problem, as is unpacked later in this chapter, is that Einstein's bifurcated view of Nature leaves us without any coherent conception of how the intuitive human mind arises out of and comes to be linked up with the mathematical patterns underlying visible Nature. If nature is the deterministic system Einstein imagines it to be, there really should be no room left over for a conscious organism like us to intuit anything.

dice rolls, creative evolution, or real becoming. The future is just another location in the already actualized block, such that everything has, in a sense, always already occurred. Nothing is held in reserve or in *potentia*. In light of Bergson's critique of modern science's *cinematographical* method, it becomes apparent that Einsteinian physics forces us to imagine "time unrolled in space" (Bergson 1913, 342), as if the whole history of life on earth and the becoming of our universe were already recorded on a cosmic movie reel that is collecting dust in heaven's eternal film archive.

Like all modern scientists since Galilei, rather than situating scientific theory and experiment within human experience as one of the latter's possible modes of relation to cosmic reality, Einstein opposed his theoretical model of spacetime to our experience of being alive. The existence of conscious humans or any life form is thus deemed irrelevant to our understanding of the wider universe. Though Bergson said the following of Kant's transcendental philosophy, it could just as easily have been said of Einstein's gravitational epistemology:

> Knowledge is presented to us in it as an ever-open roll, experience as a push of facts that is forever going on. But…those facts are spread out on one plane as fast as they arise; they are external to each other and external to the mind. Of a knowledge from within, that could grasp them in their springing forth instead of taking them already sprung, that would dig beneath space and spatialized time, there is never any question. Yet it is indeed beneath this plane that our consciousness places us; there flows true duration (Bergson 1913, 361).

3 Einstein, Whitehead, and Bergson: Divergences and Confluences

Bergson was not the only early twentieth century philosopher to protest against this sort of greedy reductionism. In Germany, through a sort of re-charged Kantian transcendentalism, Edmund Husserl and Martin Heidegger's phenomenological inquiries undermined the epistemic and existential ground of scientific materialism. But the anti-naturalistic attitude of especially Heidegger leaves us with a rather intensely anthropocentric understanding of reality, where all non-humans are "poor" or entirely lacking in "world" (Heidegger 1995, 96). In England, Whitehead began articulating an alternative philosophy of Nature, which was neither transcendentalist nor naively realist. He attempted to avoid the abstract and false division between transcendental idealism and reductionistic materialism by diagnosing and healing the metaphysical incoherence he called the 'bifurcation of Nature'. While he would eventually leave his home country and travel to Harvard to take up the philosophical task of constructing a fully-fledged metaphysical cosmology, it was Einstein's Relativity theory that first drew Whitehead out of his early work on the foundations of mathematics and into the philosophy of Nature. While Whitehead praised Einstein for the relativistic paradigm shift he played a major role in initiating, he did not accept Einstein's identification of a curved geometrical manifold with the physics of gravitation. Further, like Bergson, he did not accept the implicitly metaphysical interpretation that Einstein attached to his theory. Whitehead wanted to save Einstein's brilliant advance in physics from Einstein's incoherently bifurcated metaphysics.

In his 1919 book *An Enquiry Concerning the Principles of Natural Knowledge*, Whitehead began to re-imagine the scientific conception of Nature in organic process-relational rather than materialistic substance-property terms. He argues that we must give up the attempt to "conceive of events as in a given Time, a given Space, and consisting of changes in given persistent material". Instead, we must come to see that "Time, Space, and Material are adjuncts of events". "On the old theory of Relativity" he continues, "Time and Space are relations between materials; on our theory they are relations between events" (Whitehead 2011a, 25–26).

In his 1920 book *The Concept of Nature*, Whitehead elaborates on his new event ontology by clarifying that space and time "are each partial expressions of one fundamental relation between events which is neither spatial nor temporal" (Whitehead 1920, 185). He calls this relation "extension". Instead of the old theory of material particles as *relata* for spatial relations, Whitehead posits concrete events as the *relata* of an ultimate but abstract "Extensive Continuum", a notion that he does not fully work out until Part IV of *Process and Reality*. In the old conception, bits of matter were imagined as simply located points that are fully present at an instant, with Minkowskian geometrical spacetime intervals providing their systematic relations. In Whitehead's new conception, material particles are replaced by events of various spatiotemporal extents, with non-metrical mereotopological relations of congruence providing their systematic relations.

In his 1922 book *The Principle of Relativity*, Whitehead explicitly rejected Einstein's bifurcation of Nature into "psychological time which is personal and impersonal time as it is in nature" (Whitehead 1922, 66). He also claimed to have uncovered a significant logical contradiction in Einstein's philosophical account of Relativity that, if left unaddressed, threatened to undermine the possibility of spatial measurement (Auxier and Herstein 2017, 99 ff). In short, if Einstein's hypostatization of a four-dimensional geometrical manifold is to be believed and spacetime really is a hyper-dimensional "fabric" warped by the presence of massive objects, then the accurate measurement of astronomical distances would require precise and complete knowledge of the distribution of all masses in the universe. The problem is that this knowledge cannot be gained in advance of measurement, so we are left having to know everything before we can know anything.

It is important to note that the measurement problem articulated by Whitehead is not just an unpleasant practical consequence of a theoretical advance, but a logical inconsistency that undermines the very possibility of accurate empirical measurement.[3] Einstein briefly mentions issues of spatial measurement raised by General Relativity in a 1921 paper *Geometry and Experience*, but he does not appear to believe they represent a problem worth dwelling on, much less a fundamental contradiction in his interpretation of Relativity (Northrop 1931, 113 – 114). In a 1923 paper on the cosmological implications of his theory, he admits that a consequence of allowing the metrical character or curvature of spacetime to be determined at every point by the matter at that point is that this spacetime must be extremely complicated. But he claims that the possibility of accurate cosmological measurement is saved so long as we believe that matter remains "uniformly distributed over enormous spaces" (Einstein 2013, 183). Whitehead was not convinced. "I cannot understand", he wrote in his book on *Relativity:*

> what meaning can be assigned to the distance of the sun from Sirius if the very nature of space depends upon casual intervening objects which we know nothing about. Unless we start with some knowledge of a systematically related structure of spacetime we are dependent upon the contingent relations of bodies which we have not examined and cannot prejudge (Whitehead 1922, 58 – 59).

To avoid what he believed was a serious problem, Whitehead built on his new event ontology to develop a set of empirically equivalent tensor equations that did not rely upon the idea of a contingently curved spacetime geometry to explain gravitational effects. Instead, he elaborated a scheme wherein space retained a uniform structure, thereby permitting the projective relations of congruence required for accurate measurement (Whitehead 1978, 332). In place of Einstein's non-uniform spacetime fabric, Whitehead offered his own theory of the propagation of gravitational potential in terms similar to electromagnetic waves, only now gravitational and electromagnetic activity was vibrating in an *ether of events* rather than the old material ether. In this way, Whitehead was ac-

3 Whitehead traces the root of the measurement problem back to Euclid, who he argues did not properly define a straight line. To say that a straight line is the shortest distance between two points is to base what should be a logical definition of "straightness" on an empirical measurement of "shortest distance" (Whitehead 1978, 303).

tually able to move physics closer to the unified field theory that Einstein spent the second half of his life searching for, but only by shifting from material points to creative events as fundamental to physical ontology.[4] The radical implications of the shift to an event (or process-relational) ontology led the physics community to reject Whitehead's approach, at least until quite recently (McHenry 2015, 139 – 140; 413n6). For one thing, accepting the fundamental nature of creative events means letting go of the quest for objective certainty that has plagued modern science since its inception. Unlike the standard conception of particles as simply located at a point in space and fully present at an instant in time, events are overlapping, have fuzzy spatial and temporal boundaries, and thus only submit to approximate measurement (McHenry 2015, 44).[5] Furthermore, events are "creative" in the sense that they emerge from antecedents and contribute themselves as novel ingredients to the ongoing genesis of a open-ended world-in-process. Temporal extension is thus not a simple succession of instants but a complex process of derivation and accumulation.

An event ontology is also at the center of Whitehead's attempt to heal what he termed "Bifurcation of Nature" (unpacked below), as the gap between the durational unfolding of an electromagnetic event and a moment of conscious experience is far easier to leap than is that between inner experience and extended matter. The former is merely a difference in degree or intensity, while the latter is an ontological chasm reminiscent of Descartes' substance dualism.[6] While Einstein definitively rejected the Newtonian theory of absolute space in favor of a relational model, Whitehead goes further by re-interpreting Relativity theory within the context of a fully relational epistemology and ontology. Whereas Einstein and the physicists who inherit his way of thinking view our experience as though we are spectators gazing in upon the world from outside it, as though the phenomenological quality of lived time is just a distorted projection onto otherwise objective physical happenings, Whitehead embeds experience within the

4 See McHenry (2015).

5 Einstein's Relativity physics builds on the work of predecessors to unite space and time with the mathematical notion of a spacetime interval. Though post-Einsteinian physicists refer to "events" in spacetime, this notion is not sufficiently relativistic from a Whiteheadian point of view. It still has the residue of the old geometrical point-instants, as these "events" are still imagined as though they were simply located within a pre-given fabric.

6 Space limitations for this chapter do not permit a fuller treatment of Whitehead's method of extensive abstraction by which so-called "primary characteristics" are derived from concrete experience, or his theory of perception in terms of three modes, "'Presentational Immediacy", "Causal Efficacy" and the integration of these in "Symbolic reference". See his *Symbolism: Its Meaning and Effect* (1927) for a fuller account of the relationship between concrete experience and the constructs of science.

world as a relational participant essential to shaping its ongoing creative advance. How, then, does Whitehead's critique and reconstruction of Einsteinian physics stand in relation to Bergson's view?

There is a rich literature trying to sort out the extent and nature of Bergson's influence upon Whitehead. Whitehead's biographer Victor Lowe downplayed the significance of the influence, while more recent scholarship by Randall Auxier, Pete Gunter, and Carl Hausman has amplified their relation by arguing for a deep confluence of ideas (1999). According to Whitehead, the measured clock-time of the physicist and of conventional civilized life "merely exhibits some aspects of the more fundamental fact of the passage of nature". On this point Whitehead claims he is in "full accord with Bergson" (Whitehead 1920, 54). Bergson took notice, writing that Whitehead's *Concept of Nature* "is certainly one of the most profound [works] ever written on the philosophy of nature" (Bergson 1965, 62ff8). Almost a decade later, Whitehead affirmed in *Process and Reality* that "the history of philosophy supports Bergson's charge that the human intellect 'spatializes the universe'; that is to say, that it tends to ignore the fluency, and to analyze the world in terms of static categories" (Whitehead 1978, 209). But, continues Whitehead, "Bergson went further and conceived this tendency as an inherent necessity of the intellect. I do not believe this accusation" (Whitehead 1978, 209). In the preface to the same book, Whitehead says he was lured into his adventure in cosmology in part to save Bergson's "type of thought from the charge of anti-intellectualism, which rightly or wrongly has been associated with it" (Whitehead 1978, xii).

According to Gunter, Whitehead is not reacting to Bergson's true view in these excerpts. Bergson is not anti-intellectual and does not believe the scientific intellect is inevitably mechanistic and bound to falsely spatialize the universe in all its attempted explanations. In *L'Évolution Créatrice* (1907), Bergson himself attempted to initiate an organic reformation of the abstractions of science. Whitehead's philosophy of organism can be understood to have brought this project closer to fruition. Nonetheless, Whitehead's and Bergson's respective views do seem to diverge on certain key metaphysical issues. Whether this is a divergence of emphasis or of substance is difficult to decide, since, as Whitehead reportedly remarked during a lecture at Harvard, while Bergson must be praised for writing so evocatively about what he "feels and sees", he must also be faulted for "[phrasing] it so that you never can be quite sure what he means" (Whitehead 2017, 299).

One of Whitehead's apparent divergences from Bergson concerns the Frenchman's emphasis upon the continuity of becoming. In contrast, by the mid-1920s, Whitehead had come to affirm an atomic or epochal theory of the "becoming of continuity" (Whitehead 1978, 35). Lowe (1949, 283) argues this is an irreconcilable difference, while Gunter (1999) and Čapek (1973, 120) insist that the divergence is only a difference of emphasis. The latter two thinkers point out that Bergson's duration was no simple continuity, but a multiplicity of overlapping rhythms. As Bergson describes his view in *Duration and Simultaneity* (1922), duration is "multiplicity without divisibility and succession without separation" (Bergson 1965, 44). While admitting some ambiguity due to Bergson's shifting positions across more than thirty years of writing on the topic, Elie During argues that Whitehead's epochal theory of becoming is systematically circumvented by Bergson's insistent isolation of a "pure experience of time" from the concept of space that is abstracted from it (During 2008, 269; 272; 277 ff11).

Whitehead's epochal theory of the becoming of continuity rejects both the metaphysical fairy tale of "nature at an instant" (which is still residual even in Einstein's notion of the relativity of simultaneity) and the idea that time is simply an unbroken homogeneous flow. Instead, Whitehead took note of the discontinuity evident in the new quantum theory, which aligned well with his philosophical inheritance of William James' notion of a concrete time that grows *drop-wise*, by discrete pulses of perception (James 1920, 232; Čapek 1973, 140). In Whitehead's mature philosophy, our experience of apparently continuous becoming is thought to be composed of historical routes of "Actual Occasions of Experience" that each arise from the settled past to achieve their subjective aim in the present before superjectively[7] perishing into the future, whence they are resurrected by subsequently concrescing occasions. Concrescence is a phasic process but it does not occur "in" an already actualized geometrical spacetime continuum. Rather, Whitehead describes a universe wherein vast societies of electromagnetic and gravitational occasions are actively weaving and reweaving the fraying fabric of spacetime as a field of potential relationship. As was mentioned earlier, Whitehead views space and time as abstractions from concrete events. The events and occasions of experience that they contain are concretely actual, while spacetime is the abstract field of their potential relations. Whitehead calls this field of potential "the extensive continuum" (Whitehead 1978, part IV).

Some Bergsonians may be tempted to view Whitehead's epochal theory of spacetime as another intellectual falsification of living duration. But White-

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7 Whitehead coins the term "superject" to distinguish the futural phase in the process of concrescence: occasions of experience are said to arise from the objective data of their past, to unify this data in a subjective form, and then to perish into "objective immortality" as "superjects", at that point serving as new data for the next round of concrescence. Each occasion thus arises from its past objectively, experiences itself in the present subjectively, and aims at its future superjectively.

head's understanding of spacetime as epochal is not another *cinematographic* model of reality, where juxtaposed instants are translated into a cartoon-like illusion of the creative flow and musical rhythm of our inner life. Whitehead affirms the reality of a continuous transition between occasions of experience, but because his speculative scheme is an effort to reform the scientific intellect so that it acknowledges the evidences of intuition, he asks us to imagine another fundamental form of process alongside that of transition: namely, the atomic process of concrescence. Reality can be conceived of as continuous in the social coordination achieved by transitions between actual occasions of experience, which though they each atomize the continuum nonetheless remain linked together in an abstract field of real potentiality. Reality can also be conceived of as epochal, as the given facts established by past actual occasions are taken up into each newborn drop of experience, wherein through some creative intervention upon the past a novel actualization of value is achieved, which then perishes to gift its unique value-intensity back to the cosmic community. There is continuity and there is individuality.

Concrescence is thus a process whereby "the many become one and are increased by one" (Whitehead 1978, 21). There is established, through the synthesis of inherited public feelings and anticipatory private aims, a cumulative movement or creative evolution from past to future along multiple more or less overlapping historical routes of experience.[8] There is a becoming of continuity rather than a continuity of becoming in this iterative growth process, which is achieved occasion by occasion through individuating acts of valuation. The spacetime continuum, like living organisms, thus grows in a cellular way. As Whitehead put it:

> Time and space express the universe as including the essence of transition and the success of achievement. The transition is real, and the achievement is real. The difficulty is for language to express one of them without explaining away the other (Whitehead 1968, 102).

Their possible divergences aside, Whitehead shared with Bergson the desire to re-imagine the relationship between philosophy and science so that the latter would no longer succumb to the temptation of "heroic feats of explaining away" (Whitehead 1978, 23). Whitehead's response to Einstein's reductionistic

8 It is important to note that, in order to overcome the incoherencies of the bifurcated image of Nature, Whitehead found it necessary to borrow some terms usually thought to be applicable only at human scales and to generalize their meaning for use in a now radically non-anthropocentric cosmology. Whitehead's metaphysics of concrescence thus repurposes terms—like "experience", "society", "public" and "private"—so that they apply at all scales of reality.

metaphysical interpretation of the physics of spacetime was really aimed at a philosophical postulate that long preceded Einstein: the so-called "Bifurcation of Nature" first articulated by Galilei in the seventeenth century. In Galilei's terms, this bifurcation was a division between primary *quantitative* or material characteristics and secondary *qualitative* or mental characteristics of reality. This bifurcation is the founding metaphysical gesture of modern scientific materialism. For centuries, it proved to be a tremendous boon to natural scientific investigation, freeing researchers from Scholastic metaphysics by encouraging parsimonious explanations based in empirical measurement and mathematical calculation. But as with all abstract models meant to capture some aspect of concrete reality, its limits are eventually reached and must be understood and accepted. While immensely useful for describing the widespread regularities and settled facts of physical Nature, the bifurcation between primary and secondary characteristics not only severely handicapped enquires into fundamental ontology, it also distorted the biological, psychological, and sociological sciences, where the role of perceptual evaluation and conscious decision-making can no longer be bracketed from relevance.

Disturbed by Einstein's dismissal of the place of consciousness in the cosmos ("For us believing physicists, the distinction between past, present, and future is only an illusion, even if a stubborn one" —Einstein 1972, 537–538), Whitehead realized he needed to challenge this founding metaphysical gesture and search for a more adequate scientific world view. In Whitehead's new organic philosophy of Nature, human perception and agency come to be understood as especially intense expressions of rather than miraculous exceptions to the more habit-bound vibratory rhythms of the physical universe. Replacing the old gesture of bifurcation, Whitehead offers the following founding proposition for a new kind of natural philosophy to undergird physics:

> For natural philosophy everything perceived is in nature. We may not pick and choose. For us the red glow of the sunset should be as much part of nature as are the molecules and electric waves by which men of science would explain the phenomenon. It is for natural philosophy to analyze how these various elements of nature are connected (Whitehead 1920, 29).

I quote Whitehead at length on this issue, as it is central to his criticism of scientific materialism's attempt to explain away time:

> In making this demand [that everything perceived is in nature], I conceive myself as adopting our immediate instinctive attitude towards perceptual knowledge which is only abandoned under the influence of theory. We are instinctively willing to believe that by due attention, more can be found in nature than that which is observed at first sight. But we will

> not be content with less. What we ask from the philosophy of science is some account of the coherence of things perceptively known. … What I am essentially protesting against is the bifurcation of nature into two systems of reality, which, in so far as they are real, are real in different senses. One reality would be the entities such as electrons which are the study of speculative physics. This would be the reality which is there for knowledge; although on this theory it is never known. For what is known is the other sort of reality, which is the byplay of the mind. Thus, there would be two natures, one is the conjecture and the other is the dream (Whitehead 1920, 29–30).

Healing the bifurcation of Nature allows natural philosophy to avoid committing what Whitehead called "the Fallacy of Misplaced Concreteness", which is what Einstein falls prey to when he dismisses lived experience as a dream and falsely concretizes a conjectured geometrical model as though it was the final word concerning actual Nature and the potentials relevant to it. Of course, as the history of modern science has made evident, appearances are often deceiving. Taking lived experience seriously doesn't mean accepting reality as it first appears to us. The Earth is not flat and is not orbited by the Sun. As Whitehead says in the excerpt above, we instinctively search for deeper realities and are not satisfied with superficial appearances. There is always *more* than what at first meets the eye. But the dismissal of our lived experience of temporal becoming in favor of an atemporal theoretical model asks us to accept that Nature is *less* than our experience reveals. To dismiss lived time would be to lose the thread of experience that makes scientific reflection and experimentation possible in the first place.

Even the mind-bending paradoxes of contemporary theoretical physics are, according to Latour, "child's play in comparison with the multiplicity and complexity of the dimensions that are simultaneously accessible to the most minimal experience of common sense" (Latour 2012, 120). Inheriting the protests of Bergson and Whitehead, Latour invites us to return from outer space to re-inhabit the solid ground of our commonsense experience. The interlacing ecological complexity of our everyday experience of standing on earth beneath the sky, enveloped within an atmosphere alongside many millions of unique species of organisms and other human beings, makes even the mathematical quantum and relativistic realms of theoretical physics look like toy models in comparison. The world of commonsense experience is even more difficult to fathom than the abstract micro- and macroscopic worlds modeled by physicists, since, as Latour reminds us, the former "has been *infinitely less explored* than the other!" We have as much to learn from artisans and philosophers as from scientists about the textures of the world we actually inhabit.

By rejecting the bifurcation of Nature, Whitehead is also rejecting the idea that time is merely *inner*. The defensive move to safely tuck time away within the mind, whether transcendental or psychological in orientation, is insufficient, since it leaves the physicist to reduce the objective external universe to a timeless block. While in his response to Einstein's Relativity theory in *Duration and Simultaneity* (1922), Bergson confusedly presents his theory of duration as a phenomenological defense of "direct and immediate experience", the Bergson of earlier works like *Matter and Memory* (1896) and *Creative Evolution* (1907) affirms that duration reaches beyond the subject and is also intrinsic to the evolution of all life on earth and indeed to the unfolding of the physical universe itself.[9] As Bergson put it in *Matter and Memory*, there is another pathway open to philosophers after the transcendental critique of experiential time as merely a form of *inner* intuition: they must "seek experience at its source, or rather above the decisive *turn* where, taking a bias in the direction of utility, it becomes properly *human* experience" (Bergson 1991, 184).

Contrary to the misreadings of some Bergsonians who suggest that Whitehead anthropomorphically extends Bergson's *élan vital* to supposedly inorganic matter,[10] and like the Bergson of earlier works like *Matter and Memory* and *Creative Evolution*, Whitehead's process philosophy attempts precisely such a return to the source to uncover a more primordial form of temporal experience that can no longer be anthropocentrically claimed as the unique province of human or even living beings but which must be understood to infect the universe to some degree at every scale of its actualization, from its simplest to its most complex evolutionary expressions. Whitehead tells us that "the primordial element" of the universe itself is "a vibratory ebb and flow…an…energy, or activity" that is "nothing at any instant" and that "requires its whole period…to manifest itself" (Whitehead 1967, 35). This vibratory activity unfolds through its concrescent phases of passion and action, or prehensive reception and creative expression. Crucially, Whitehead unambiguously rejects the dualism Bergson sometimes slips into by affirming that "ultimate concrete fact is an extended process" (Whitehead 1948, 252). "If you have lost process or lost extension", he continues, "you know you are dealing with abstraction" (Whitehead 1948, 252). Extension is essentially processual, and process is essentially extensional. This is Whitehead's metaphysical reformulation of a now even more general theory of Relativity.

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9 See Bergson (2002); Čapek 1973, 154.

10 See Kelly 2010. Here Kelly ironically complains that twentieth-century philosophers have tended to relate to Bergson by "[latching] onto one or another of [his] articulations of a problem, rather than his reformulations of problems and solutions" (Kelly 2010, 1–2, 18ff5), which is exactly what Kelly does to Whitehead by accusing him of anthropomorphism while ignoring his organic reformulation of the problems of dualistic ontology.

4 Whitehead and Rovelli: Reconciling Physics and Philosophy

The final part of this chapter marks some preliminary connections and divergences between Whitehead's cosmological scheme and the Quantum Gravity theory of Carlo Rovelli. Aside from a few comments here and there scattered across the philosophy blogosphere,[11] I have found exactly two mentions of a possible Whitehead-Rovelli nexus in academic publications. The first is a frustratingly brief footnote in Epperson and Zafiris' Whitehead-inspired *Foundations of Relational Realism*, wherein they suggest that Rovelli's Relational Quantum Mechanics is "sufficiently compatible for fruitful conversation" even if the underlying philosophical frameworks turn out to be very different (Epperson and Zafiris 2013, xxff3). The second is in Ronny Desmet's *Stanford Encyclopedia of Philosophy* entry on Whitehead, where he writes that Rovelli's relational interpretation of Quantum Mechanics is "strikingly Whiteheadian". I agree with Epperson, Zafiris, and Desmet that many passages in Rovelli's popular works align with the process-relational perspective; but it is not yet clear whether Rovelli has fully overcome the modern bifurcation of Nature.

Loop Quantum Gravity (LQG) is one of a number of competing attempts at a so-called "Grand Unifying Theory" (GUT) of the physical universe. A GUT would integrate the relativistic macrocosm and the quantum microcosm, which since their theoretical inceptions over a century ago remain entirely incompatible as models of the universe. In other words, the reigning theories inherited from twentieth century physics appear to describe two very different *cosmoi*. The primary challenger for a GUT aside from LQG is string theory (ST), and thus far the latter has garnered the most attention. Rovelli does not shy away from stating that his approach requires "a substantial conceptual revolution…[in]…the basic ontology of [twentieth] century physics" (Rovelli and Vidotto 2015, 18). In short, while ST still describes a fundamental physical ontology composed of material objects (i.e., vibrating strings) "in" a pre-given spacetime, LQG describes a universe wherein "it is the physics of the quantum fields that *build up* spacetime" (Rovelli and Vidotto 2015, 18). On the face of it, this figure-ground shift sounds similar to Whitehead's process-relational ontology, which describes the emergence of spacetime from a nexus of creative events. But a definitive synthesis between any physical model and a philosophical ontology is not that easy to establish. Synthesis certainly overstates what is possible in such a disciplinary

11 See Edwards (2014).

exchange. All I can claim to do in the remainder of this chapter is to "pilfer" a few ideas from Rovelli's scientific work (a method During suggests for guiding exchanges between science and philosophy), that is, to "feel for when he's not looking and grab something to bring back home and think about for a while" (During 2017).

Unlike many popular physicists who regularly disparage philosophy (e. g., Neil deGrasse Tyson, Laurence Krauss, Steven Weinberg, and the late Stephen Hawking), Rovelli laments the "narrow-mindedness" displayed by his scientific colleagues when it comes to considering the importance of philosophy for their discipline (Rovelli 2014, 215; 227–228). To be fair, he is equally critical of philosophers who don't heed the lessons of science. Rovelli, like Whitehead, is one of the rare thinkers who is capable of making meaningful connections linking mathematics, theoretical physics, philosophy, and human life more generally. In one of his most recent books, *The Order of Time*, Rovelli not only lucidly summarizes the latest findings of contemporary physics, including his own quantum gravity theory, he also skillfully weaves these theories together with the philosophical insights of Augustine, Kant, Husserl, and Heidegger (who each thought time had more to do with human nature than with physical nature). Rovelli criticizes some philosophers, like Parmenides, Plato, and Hegel, for allegedly fleeing to eternity in an effort to escape the anxiety time causes us (Rovelli 2017, 173). Heraclitus and Bergson, on the other hand, are criticized for allowing an overly emotional veneration of time to cloud their vision (Rovelli 2017, 174).

In Rovelli's view, contemporary physics has revealed the time of our conscious experience to be, at best, an *approximation* resulting from our thermodynamically improbable perspective on the universe. Aside from the study of thermodynamics, several centuries of modern scientific investigation at both the quantum and relativistic scales have left us with "an empty, windswept landscape almost devoid of all trace of temporality" (Rovelli 2017, 3). However, Rovelli rejects the standard Einsteinian reductionism just as soundly as Bergson and Whitehead. LQG does away with both Newton's conception of absolute time as well as the "Block Universe" idea often associated with Einstein: "The absence of time does not mean that everything is frozen and unmoving…[forming] a four-dimensional geometry"; rather, Rovelli claims, the world is an "incessant happening … a boundless and disorderly network of quantum events" (Rovelli 2017, 92). And after recounting the "epic and magical" distortions of time created by the ingestion of cannabis and LSD, Rovelli reminds his readers that "it was certainly not our direct experience of time that gave us the idea" of a purely continuous time passing "at the same rate, always and everywhere" (Rovelli 2017, 53). This is an abstract and relatively recent idea of time reflecting our immersion in a modern civilization ruled over by mechanical clocks.

Rovelli discusses the heretical view of another philosophically attuned physicist, Lee Smolin, whose recent book with Roberto Unger, *The Singular Universe and the Reality of Time* (2014, xv), argues forcefully against the scientific consensus and for the fundamental reality of time. Smolin and Unger approvingly cite Whitehead in their introduction as an exponent of the ancient but dissident tradition of becoming in Western philosophy (others mentioned are Heraclitus, Hegel, Peirce, and Bergson). Whitehead shares with Unger and Smolin the conviction that many of the so-called "laws" and "constants" of physics, far from being eternal and necessary, are in fact contingently evolved habits. Rovelli and Smolin were collaborators on LQG for a time and remain friends, but they diverge sharply on the question of time's place in physics. As we've seen, like Whitehead, Rovelli views the gelatinous spacetime continuum as a second-order *emergent* property of quantum events (Rovelli 2017, 168). Spacetime, Rovelli says,

> has loosened into a network of relations that no longer holds together as a coherent canvas. The picture of spacetimes (in the plural) fluctuating, super-imposed one above the other, materializing at certain times with respect to particular objects, provides us with a very vague vision. But it is the best that we have for the fine granularity of the world (Rovelli 2017, 80).

It is difficult not to hear resonances between Rovelli's projective topological account of the quantum network underlying space and time and Whitehead's notion of the relational complex he called the "extensive continuum" (Whitehead 1978, 66–67). But unlike Whitehead, Rovelli reduces his relational quantum events to mere transitions of "physical quantities from one to another" (Rovelli 2017, 168), thus robbing them of any experiential quality or explanatory value. Whitehead's actual occasions, in their atomization of the extensive continuum, are not timeless "quanta" mutely crunching an algorithmic program. Occasions are amenable to such quantitative analysis, but in their integral concreteness they are also qualitative expressions of value-experience. Whitehead would likely ask what sense there is in rejecting Newton and Einstein's clock-work universe only to then computerize the cosmos, instead? Whitehead lamented the way "the divergence of the formulae about nature from the appearance of nature has robbed the formulae of any explanatory power" (Whitehead 1968, 154). Whitehead's cosmos is composed not of blind abstract calculations but of social relations among creaturely occasions seeking to intensify their value-experience. These occasions do ingress certain measurable mathematical patterns, but *it is the experiential activity that explains the equations, not the other way around.*

If Rovelli's theory is not just a convenient model and there is really a network of quantum spin foams at the root of spatiotemporal Nature, Whitehead's philosophy of organism requires that there be some aim realized in this spinning, something it feels like to foam, to endure the topological looping, fraying, and folding of these creative quantum events. Physicists searching for a GUT can no longer bracket the existential questions puzzled over by philosophers: Is the lived time of human consciousness in any sense an expression of some more primordial value-experience in Nature? Or is our existence just a peripheral accident, our experiential perspectives just inessential epiphenomena somehow emergent from a blind physical reality? Rovelli appears to take the latter view, giving physical models precedence over lived experience as regards ontology. He rejects views like Smolin's because he believes they lean too heavily on an emotionally charged intuition about time's importance in the physical universe. "The choice"—Rovelli tells us—"Is between forcing the description of the world so that it adapts to our intuition, or learning instead to adapt our intuition to what we have discovered about the world" (Rovelli 2017, 190ff14). Certainly, as we saw earlier, Whitehead affirms the need to "look again" at the world, and to experiment with our perceptions, in order to assure that our ideas and abstract accounts remain in accord with the concrete happenings of actual Nature. But how are we to access concrete reality except through experience or intuition?

Rovelli is careful elsewhere to clearly reject the classical idea of a *view from nowhere:* "A point of view is an ingredient in every description of the observable world that we make" (Rovelli 2017, 132) and "the world is…a collection of interrelated points of view…there is no 'outside' to the world" (Rovelli 2017, 108). So, while Rovelli's dismissal of the evidences of intuition seems like a re-entrenchment of the bifurcation of Nature between objective science and subjective dream that Whitehead so forcefully protested against, this rejection is out of step with his own broader commitment to a relational reality. Like Einstein, Rovelli stops short of realizing the full ontological import of his relational theory. He thus separates our lived experience from a toy model of the physical world which leaves no room for it. The Bergsonian or Whiteheadian philosopher is left wondering how such a model could be *discovered or confirmed* if not via experience? Rovelli, by neglecting the relational essence of reality, succumbs to what Auxier and Herstein call "Model-Centric Thinking":

> For *what* are we left with to *test* our models, other than the formal and recondite cleverness of those models? What standards might we apply to test our models when our model-centric approach demands that we measure experience *by* those models, rather than those models *by* experience? (Auxier and Herstein 2017, 111).

According to Whitehead, "the physical world is in some general sense of the term a deduced concept. Our problem is, in fact, to fit the world to our perceptions, and not our perceptions to the world" (Whitehead 1967b, 166). This statement may seem a bit strange coming from a professed realist. But we must not misunderstand Whitehead's meaning. He is, as Auxier and Herstein make clear, a radical empiricist in William James' sense. The universe is relational and esemplastic: it grows from the inside out, each part containing the whole *in potentia*. Whatever this universe is, it is happening not just out there but *right here*, *right now* within and between us. We do not and cannot experience the universe in its integrity as a child observes a snow globe at arms-length. But the "Big Bang model" of inflationary cosmology is often discussed at least in popular science books and by science journalists precisely in this way, as though we were turning the world around in our hand to have a good look at it. Where are we as observers in these acts of cosmological imagination? *Precisely nowhere.*

If time is an illusion, what sense is there to be made of the history of our universe? Rovelli suggests that our perception of a cosmic evolution through irreversible time results from our perspective at the far end of a thermodynamic heat sink. Inflationary models of the observable cosmos suggest that our world emerged from a very low entropy state at the beginning of the universe and is gradually running down toward heat death. Our vision of the cosmos as such is *blurred* by our special position in this entropic process. Rovelli writes:

> If a subset of the universe is special in this sense, then…memories exist, traces are left — and there can be evolution, life and thought…We observe the universe from within [this subset], interacting with a minuscule portion of the innumerable variables of the cosmos. What we see is a blurred image. This blurring suggests that the dynamic of the universe with which we interact is governed by entropy, which measures the amount of blurring. It measures something that relates to us more than to the cosmos (Rovelli 2017, 130; 134).

It is not only our special cosmic position that creates this blurring, according to Rovelli. It is also our special form of biological organization powered by a web of negentropic chemical processes. Life is poised at the cresting wave of a thermodynamic gradient, feeding on light from the Sun and ultimately producing dramatically more entropy than would otherwise be possible on a dead Earth. Whitehead describes the emergence of special "cosmic epochs" from out of the metaphysically generic extensive continuum (Whitehead 1978, 91). While the laws and constants of physics, as well as the metrical properties of spacetime, the particles described by the standard model, and all larger organized bodies like stars, galaxies, planets, plants, and animals, have emerged within our epoch, the extensive continuum's generic topological properties hold across all such epochs. Whitehead thought the properties of this extensive continuum were truly metaphysical or fundamental in nature, much as Rovelli thinks his quantum network is fundamental.

Whitehead's notion of a cosmic epoch also bears some resemblance to Rovelli's account of thermodynamically improbable subsets of the wider universe. However, Whitehead does not shy away from the sort of speculative ideas that would be necessary for such an account to count as a coherent explanation. While Rovelli is content to explain away basic features of our universe like memory, causation, and the irreversible flow of time as "nothing but names" (Rovelli 2017, 147) that we give to describe our statistically improbable egress from a low entropy event in the past, Whitehead would agree with Smolin that the fact that such accounts pass as "explanation" is only a "measure of the depth of the current crisis" faced by scientific cosmology (Smolin and Unger 2014, 355). Rather than dismiss the profoundly beautiful forms of complexity achieved by our self-organizing universe as nothing but accidental smudges in the flow of entropy, Whitehead grants reality to a "counter-agency" infusing the physical universe with a tendency toward order (Whitehead 1958, 25).

At this point, many scientists are likely unable to follow Whitehead. Even he admits that this counter-agency "is too vast and diffusive for our direct observation" (Whitehead 1958, 25). But in the course of constructing his speculative cosmology, which seeks to offer a satisfying explanation for the astonishingly organized universe that we directly observe *and that produced us as observers*, Whitehead found it necessary to make reference to what some contemporary physicists are beginning to call "extropy" (Grandpierre 2012, 73–79). Which is more improbable, that our universe is erotically lured toward organizational complexity, with human consciousness being a natural outgrowth of cosmic evolution, as Whitehead wagers, or, as Rovelli supposes, that the directly observed facts of a time-developmental universe, including everything from physical causation to star and galaxy formation to mental capacities like memory and anticipation, are all just mirages arising from our blurred perspective on an exceedingly rare hot spot at the origin of our subset of the cosmos?

Even if the irreversible temporality of cosmic evolution and human life is not metaphysically fundamental, as both Whitehead and Rovelli agree, this does not mean causality, memory, and purpose are merely nominal. These are real features of an exceedingly creative cosmos, as real as energy, entropy, and indeed, should Loop Quantum Gravity turn out to be correct, as real as spinfoams. According to Whitehead, "the extreme rejection of final causation from our categories of explanation has been fallacious" (Whitehead 1958, 28). A satisfactory cosmology, he insists, must explain the dipolar interweaving of entropy and extropy, of dissipation and organization, without attempting to reduce one to an epiphenomenon of the other.

Conclusion: Whitehead and the Physics of Experience

"[The] antagonism between philosophy and natural science has produced unfortunate limitations of thought on both sides" (Whitehead 1958, 61) according to Whitehead. "Philosophy has ceased to claim its proper generality, and natural science is content with the narrow round of its methods" (Whitehead 1958, 61). While the original rejection of Scholastic metaphysics and formulation of the mechanical categories and empirical methods of physical science in the seventeenth century has proven tremendously successful, the advances of the last century and a half (including evolutionary, Relativity, Quantum Mechanics and complexity theories) have brought us into a critical period of general reorganization of the categories of scientific thought. Not only our concept of time, but that of space, matter, life, and mind must all be rethought and brought into new accord. The old mechanical definitions of these terms and their relations are simply no longer relevant. The needed reorganization of fundamental ideas is not a task that natural science can undertake on its own, as should be clear from the fact that after more than a century a coherent integration of Relativity and Quantum theories remains as elusive as ever (though LQG and ST are contenders, major obstacles stand in the way of their widespread acceptance).

Whitehead's philosophy of organism is an effort to construct a new process-relational ontology for natural science to replace the now defunct mechanistic ontology. Time undoubtedly remains as mysterious as ever in Whitehead's organic cosmology, but the bifurcation between its *inner* mental and *outer* material aspects is resolved. The passage of Nature does not unfold as a series of instants or snapshots. Such instantaneity can be approached via mathematical abstraction, but actual passage or creative advance is a process that grows from occasion to occasion in networks of relations, not a series of point-instants on a grid. Unlike Bergson's durations, Whitehead's actual occasions of experience are not made of "pure time" but each exist *stretched out* in a sort of sublime tension, what James called a "Specious Present", wherein the already actualized past is inherited and subjectively integrated with potential futures. The arising and perishing of numberless actual occasions forms what Whitehead calls historic routes or "societies", and it is at this level that what we consciously experience as the flow of time emerges.

This endlessly iterating creative process is the power that builds the cosmos and that shapes the soul. We can think of the cosmic socius of occasions as a complex network of experiential activities, all internally related but also differentiated along multiple timelines. It is difficult for our three-dimensional imagination to grasp a topological network of activities wherein each node or occasion is both a whole in itself, prehending the entire universe in its concrescence, and a part within the concrescence of other occasions. The universe as a whole thus remains in "essential incompleteness" (Whitehead 2011b, 90) as it is never finished or fully present but always advancing into novelty as "the many become one, and are increased by one" (Whitehead 1978, 21).

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Part Four **Metaphysics, Logic, Neuroscience, Biology and Cosmology of Time**

Claudio Calosi

No Time for (No) Change

Abstract

The paper provides an overview of the main metaphysical theories of persistence —that is, of three and four-dimensionalism, as applied to a relativistic setting. It then addresses and undermines one of the most powerful objections against one of those views —i. e., four-dimensionalism. That objection is labeled the No-Change objection in the literature and has it that four-dimensionalism abolishes genuine change. Finally, building on the case against the No-Change objection, I contend there is some pressure to abandon the widespread assumption that change requires reference to distinct earlier and later times, let alone the passage of time.

The aim of this paper is threefold. First, I provide an overview of theories of the metaphysics of persistence in a relativistic setting.[1] Then, I offer a new discussion of the so-called "No-Change objection",[2] —which is considered one of the most powerful objections against a particular metaphysics of persistence, i. e., four-dimensionalism, and undermine it. Finally, building on my case against the No-Change objection, I contend there is some pressure to abandon a widespread intuition and widely held philosophical thesis according to which genuine change requires reference to two distinct times, if not its passage. It should already be clear from my plan that the discussion of the No-Change argument plays a twofold role. On the one hand, it is supposed to provide a way to resist one of the objections that has been considered, and still to this day is considered[3] —for better or worse-one of the most significant objections against four-dimensionalism. On the other hand, it paves the way to address some crucial metaphysical questions about the relation between time and change[4].

Note: I want to thank audiences at *eidos* and at L'Aquila for wonderful discussions. I would also like to thank two anonymous referees and the book editors for the comments and suggestions. This work was generously supported by the Swiss National Science Foundation, Project (PCEFP1_181088/1).

1 Henceforth, by *Relativity theory* I will mean the disjunction of Special Theory of Relativity (STR) and General Theory of Relativity (GTR).

2 The name is from Sider (2001, 212–216).

3 (see §3)

4 (see §4)

 https://doi.org/10.1515/9783110753707-017

I should note from the start that some of my arguments will crucially depend upon relativistic considerations and cannot be translated in any straightforward way into a more classical setting. Also, they rely on what I shall call the *spacetime conception of time*, and although such a conception does not directly require Relativity theory, it seems to be far more palatable once the latter is accepted. If so, my arguments can also be read as a contribution to the debate about whether relativistic physics favors some metaphysics of persistence over some others.[5,6] The plan is as follows. In § 1 I start with a brief introduction about some general assumptions at work in the paper. In § 2 I provide a formulation of different metaphysical theses about persistence in relativistic spacetimes. I then sketch in § 3 the so-called "puzzle of change" and its solutions, and I show how the four-dimensionalist account is allegedly vulnerable to some variants of the No-Change objection, which I reject. In the conclusion of that section I put forward what I take to be the most interesting variant of the No-Change argument. The final section, § 4, is dedicated to undermining such a variant and to offering a general suggestion about change and its relation to time. Once again, the rebuttal of the last variant of the No-Change argument is not only interesting in itself, but also for its wide-ranging consequences.

1 Space, Time, and Spacetime

In this section I lay down some general assumptions I will rely upon in what follows. They are *assumptions* in that I will not argue for them in this paper. However, this does not mean they cannot be argued for. In fact, they have been extensively argued for in the literature.[7]

The first general assumption concerns the very *talk of time* in a relativistic setting. Following Lockwood (2005, Ch. 3), Sattig (2006, Ch. 2; Ch. 8, § 1), Skow (2015; Ch. 2), and Gilmore, Costa and Calosi (2016, § 1) we can distinguish two very general conceptions of time. I shall label them the *spacetime conception* of time and the *classical conception* of time. To give but a first intuitive characterization, according to the spacetime conception of time we inhabit a single four-dimensional manifold–spacetime, and time is just an aspect-for lack of a better word-of this more fundamental four-dimensional entity. *Contra* this, the classical

5 The literature on this topic is rapidly growing. To mention just a few, see Balashov (1999); Gibson and Pooley (2006); Gilmore (2006); Balashov (2010); Davidson (2014); Balashov (2014a); Balashov (2014b); Calosi (2015) and Sattig (2015).

6 But I will not press this point here.

7 For an introduction to the relevant arguments, see, e.g., Gilmore, Costa and Calosi (2016).

conception of time has it that we literally inhabit two different manifolds: a three-dimensional spatial manifold and a one-dimensional temporal one.[8]

A little more precisely, according to the spacetime conception of time there is only a four-dimensional spatiotemporal manifold; instants or intervals of time, on the one hand, and regions of space on the other, are simply spacetime regions of different sorts that share some constituents (that is, some spatiotemporal points).[9] By contrast, according to the classical conception of time, time is a one-dimensional manifold, and it is completely distinct from a three-dimensional spatial manifold: the two fail to share any constituents.

Though the spacetime conception of time can also be held in a classical setting, I will simply assume that it is the most natural choice once some features of Relativity are taken into account.[10] As I already mentioned, I will not argue for this claim; as a piece of evidence though, I will simply quote some passages that point in this direction. Arguably the most famous reference goes back to Minkowski (1908): "Henceforth space by itself and time by itself are doomed to fade away into mere shadows and only a union of these two will preserve an independent reality" (Minkowski 1952, 75). The same spirit is vindicated in the following, more recent excerpts: "Space and time are just different ways in which the same real thing (spacetime) appears from a given perspective" (Lange 2002, 220); "There is no one-dimensional time distinct from three-dimensional space but rather a four-dimensional spacetime of which time is merely an aspect" (Sattig 2006, 1); "I assume a spacetime framework according to which the notion of a time is not fundamental, but rather is to be defined in terms of the notion of a region of spacetime [...] region of spacetime are ontologically prior to times" (McDaniel 2014, 15). All of these passages suggest that spacetime is the *fundamental* entity in Relativity theory, so that in order to take Relativity seriously we should refer to spacetime regions rather than to spatial regions or temporal intervals.[11]

8 Skow (2015) calls them *4D view* and *3+1 view*. Gilmore, Costa and Calosi (2016) calls them *unitism* and *separatism*. I adopt the terminology in the main text mainly because I will use "4D" for the metaphysics of persistence.

9 *Modulo* Whiteadean worries about the existence of points.

10 It should be noted that this conception can be challenged in certain formulations of Quantum Gravity. See, e.g., Monton (2006).

11 The standard set-theoretic construction of the spacetime manifold is assumed throughout. "According to this view, we inhabit a four-dimensional manifold of spacetime points, where points are mereologically simple and unextended, spacetime *regions* are non-empty sets of points, any such set counts as a region, and one region is a subregion of another iff the first is a subset of the second" (Gilmore 2006, 199). Spacetime regions are thus a model of the so-called (Atomistic) "General Extensional Mereology"; since I will be using mereological notions

The second general assumption concerns *the contents* of the spacetime manifold and spacetime regions. I will assume that the physical content of relativistic physics does not mention (nor does it need to mention) frames of reference. Rather, it is simply given by the contents (of regions) of spacetime, and the latter can be described independently of any reference frames. The most vivid formulation of such a view is given by Gibson and Pooley (2006):

What is wrong with the first[12] [...] (is that) it seeks to attach metaphysical weight to frames of reference that they simply do not carry. Inertial frames of reference [...] are no more than the spatiotemporal analogues of Cartesian coordinate systems [...] But just as no one would attach ontological weight to features of an object that are relative to a choice of Cartesian coordinates, so no one *should* attach significance to properties of objects that are essentially defined in terms of canonical frames of reference. From the physicist's perspective, the content of spacetime is as it is. One can choose to describe this content from the perspective of a particular inertial frame [...] But one can equally well choose to describe the content of spacetime with respect to some frame that is not optimally adapted to the geometric structure of spacetime, or indeed, choose to describe it in some entirely frame independent manner" (Gibson and Pooley 2006, 161–162).[13]

Gibson and Pooley also declare: "It should be clear from our discussion of perdurance that the *wrong* way to relativistically re-construe all this is to *replace reference to moments and times with reference to times of inertial frames*" (Gibson and Pooley 2006, 164). Finally, I will assume that Relativity favors some sort of B-theoretic eternalist metaphysics of time, according to which all spatiotemporal regions of the entire spacetime manifold are ontologically on a par and there is nothing objectively and metaphysically privileged about one such region, called "the present".[14] I take these assumptions to suggest-to say the least-that any metaphysical thesis, insofar as it is meant to seriously engage with the hints coming from Relativity, should replace talk about spatial distances, temporal intervals and frames of reference with talk about spacetime regions of different sorts that build up the entire relativistic spacetime.

to define persisting objects already, I will use mereological notions as opposed to set-theoretic ones, to minimize ideology.

12 I.e., with the option of relativizing times to reference frames.

13 This assumption might be more controversial in the case of Special Relativity. However, it is possible to give a formulation of Special Relativity that is frame-independent as well. See, e. g., Malament (2009).

14 The literature on this last issue is simply too wide to even be briefly mentioned. For recent, opposing views, see Zimmerman (2011) and Wüthrich (2013) and references therein.

Therefore, in what follows, whenever reference to e. g., temporal facts is explicitly mentioned, an attempt should be made to identify the sort of more fundamental spatiotemporal facts behind them, so to speak.[15] I take this to be a first step towards engaging with a challenge that was raised in Gibson and Pooley (2006, 157). The goal in engaging that challenge would be to *start* with the relativistic world-picture, and then ask how things persist and change according to such a picture.

2 Persistence in Relativistic Spacetimes

In this section, I will provide a rigorous formulation of the main metaphysical theories of persistence[16] in relativistic spacetimes.[17] This formulation takes the lead from the pioneering works of Gilmore (2006; 2008; 2018) and Balashov (2008; 2010),[18] though in certain respects I will depart considerably from them.[19] I will use only two primitive notions-plus first-order plural logic with identity:[20] the mereological notion of *parthood* and the locational notion of *exact location*. Gilmore (2018) offers the following intuitive gloss on the latter: "an entity x is exactly located at a region y if and only if x has (or has-at-y) exactly the same shape and size as y and stands (or stands-at-y) in all the same spatial or spatiotemporal relations to other entities as does y".

15 This characterization, though deliberately vague, is sufficient for my aims: it is meant to point out that facts about spacetime are in some sense more fundamental than facts about (respectively) space and time considered separately, without any commitment as to the specific nature of the relation between facts of the three categories. Sattig (2006) mentions *supervenience*, while Skow (2015) seems to suggest some stronger notion of *dependence*–possibly something like the *grounding* relation. For an introduction to this last relation and cognate notions, see Correia and Schnieder (2012); Bliss and Trogdon (2014).

16 I will focus on "three-dimensionalism" (or "endurantism") on the one hand, and "four-dimensionalism" (or "perdurantism") on the other. I will not discuss the so-called "Stage-View" (or "exdurantism"). See Sider (1996) for a defense.

17 This section is not intended to be exhaustive. Interested readers are referred to Gilmore (2006); Balashov (2010); Calosi and Fano (2015).

18 To be fair, Balashov (2010) mentions frames of reference. His formulation can however be slightly modified to avoid such a reference.

19 My claims will considerably depart from Balashov's formulation. It does not coincide with Gilmore's formulation either, especially in the definition of a temporal part. I will require temporal parts to be *proper parts* of four-dimensional objects. This seemingly small difference has significant consequences. Although I cannot enter into details here, see footnotes 27 and 29.

20 From now on double signs such as "*xx*" stand for plural terms (both constants and variables).

For the sake of completeness, let me also mention that in what follows I will assume that parthood is a partial order and obeys the so-called "Weak-Supplementation Principle" (Simons 1987; Varzi 2016) and that the exact location relation obeys two axioms to the effect that everything that is located somewhere in spacetime has an exact location and that composite objects are located where their parts are located.[21] Such axioms sometimes go under the names of *Exactness* and *Expansivity* in the literature.[22]

Before approaching the metaphysics of persistence properly, some mereological notions need to be defined:[23]

(1) x is a *proper part* of y = x is part of y and x is distinct from y.
(2) x and y *overlap* = there is a z that is part of both x and y.
(3) x is the *mereological fusion* of the yy = each of the yy is part of x and each part of x overlaps one of the yy.

I will also need to define the notion of an achronal spacetime region—which can be informally understood as the relativistic counterpart of an instantaneous, temporally unextended region—and the notion of a path of an object. To this end, I shall use basic geometrical features of relativistic spacetimes:

(4) R is an *achronal* region = for any two distinct points p_1 and p_2 in[24] R, the vector connecting them is space-like.
(5) The spacetime region *Path(x)* is the path of an object x[25] = *Path(x)* is the mereological fusion of x's exact locations.

It is customary to quote Lewis at this point: "Let us say that something persists iff, somehow or other, it exists at various times; this is the neutral word" (Lewis 1986, 202). This can be elegantly captured by (6) below, for (6) entails that the

21 Note that these two axioms are in line with relativistic physics insofar as the notion of spacetime trajectory is relativistically well-defined. This is not so obvious in the quantum mechanical case.
22 See e.g., Casati and Varzi (1999); Parsons (2007). Note that the latter assumes a different primitive notion, that of "weak location". Strictly speaking, *Exactness* is a *theorem* in a theory of location that takes "exact location" as a primitive. In such theories, it is customary to define the notion of weak location as follows: x is weakly located at R = x is exactly located at R^* and R and R^* overlap. Once this definition is in place, *Exactness* follows. See e.g., Gilmore (2018).
23 In the following, simple signs such as "x" will be used as singular variables whereas double signs such as "xx" will be used as plural ones.
24 Point p *is in* region R = point p is part of region R.
25 The path of an object is–intuitively–its entire spatiotemporal career.

spatiotemporal career of an object comprises at least two points that are causally separated, i.e., either time-like or light-like separated[26] —thereby ensuring that the entity in question exists at different times, as per Lewis' request:

(6) An object x is a persisting object = *Path(x)* is not achronal

One of the great merits of Gilmore (2006) and Balashov (2010) is that of having clearly stated the difference between what we might call *locational* and what we might call *mereological* persistence. In the former case, conditions for persistence are given in terms of the exact locations of material objects; in the latter, they are given in terms of their mereological structure. When we think in locational terms, (locational) three-dimensional objects are exactly located at achronal, temporally unextended regions, whereas (locational) four-dimensional objects are uniquely exactly located at not-achronal, temporally extended regions.[27] This is supposed to capture one way of parsing the pre-analytical intuition that three-dimensional objects are not extended in time, while four-dimensional objects are. This suggests the following definitions:

(7) An object x is a *locational four-dimensional* object $4D_L(x) = x$ is a persisting object that is uniquely exactly located at its path.
(8) An object x is a *locational three-dimensional* object $3D_L(x) = x$ is a persisting object that is exactly located at achronal spacetime regions.

It follows from these definitions and the mereological and locational axioms I assumed that:

i. four-dimensional objects have a unique exact location-i.e., their paths;
ii. three-dimensional objects are multi-located at different achronal regions that are proper parts of their paths.

The metaphysical debate about persistence has been traditionally cast as a debate about the mereological structure of persisting objects. In particular, it has most commonly been approached as a debate as to whether persisting objects divide into *temporal parts* or fail to thus divide. To define a temporal part in a relativistic setting, I follow Gibson and Pooley (2006) and first define an *achronal maximal region of another region*. The easiest way to define such a notion is the

26 This ensures that photons count as persisting objects.
27 Note that this is in line with the intuitive gloss I gave for the notion of "exact location".

following:

(9) A spacetime region R is a *maximal achronal region* of a spacetime region R^* = (i) R is part of R^*; (ii) R is an achronal region, (iii) R is not a proper part of any other achronal region that is part of R^*.

Now we can define an achronal temporal part x of y:

(10) x is an *achronal temporal part* of y = (i) x is a proper part of y; (ii) x is uniquely exactly located at region R; (iii) R is a maximal achronal region of *Path(y)*[28]

The general notion of a temporal part can be defined as a mereological fusion of *some* achronal temporal parts:

(11) x is a temporal part of y = (i) x is a proper part of y; (ii) x is the mereological fusion of some achronal temporal parts of y.

Note that this definition explicitly requires that temporal parts of 4D-objects-which will be defined below-are *proper parts* of such objects.[29] Mereological four and three-dimensional objects are defined, respectively, as follows:

(12) x is a *mereological four-dimensional* object $4D_M(x)$ = x is a persisting object that is the fusion of its temporal parts.
(13) x is a *mereological three-dimensional* object $3D_M(x)$ = x is a persisting object that does not divide into temporal parts.

For my purposes here, it will suffice to define (respectively) three and four-dimensional objects as follows:

28 There are a few differences between this definition of a temporal part and others that can be found in the literature, as I already pointed out in footnote 18. Since such differences do not play any crucial role for the arguments I advance in this paper, I will not discuss them. As far as I know, the approach that gets the closest to the one I suggest here can be found in Gibson and Pooley (2006).
29 This immediately undermines Van Inwagen's infamous argument against four-dimensionalism in Van Inwagen (1990), in that the argument crucially depends upon considering a four-dimensional object a temporal part of itself.

(14) *x* is a three-dimensional object *3D(x)* = *x* is both a locational and a mereological three-dimensional object.
(15) *x* is a four-dimensional object *4D(x)* = *x* is both a locational and a mereological four-dimensional object.[30]

Usually, Three and Four-dimensionalism are construed as, respectively, the theses that all persisting objects are three-dimensional and the thesis that all such objects are four-dimensional.

3 The Puzzle of Change and the No-Change Argument

In a nutshell, the so-called puzzle of change arises from the question as to how it is possible for an object to instantiate incompatible properties. A perspicuous formulation of the puzzle was provided in Kurtz (2006, 2).[31] According to Kurtz, the puzzle consists in a tension between the metaphysical theses she calls–respectively-*Consistency*, *Change* and *Persistence*; such theses are so deeply entrenched as to be hardly negotiable, and yet they seem to be jointly inconsistent. The theses are the following:

I. Consistency: Nothing can instantiate incompatible properties;
II. Change: Change involves incompatible properties;
III. Persistence: Objects persist through change.

The tension is easily seen. If change involves incompatible properties, how can an object persist through change, given that it cannot instantiate incompatible properties? Here is how Lewis phrases the point:

Things somehow persist through time. When they do, they have some of their intrinsic properties temporarily. For instance, shape: sometimes you sit, and then you are bent; sometimes you stand or lie, and then you are straight. How can one and the same thing have two contrary intrinsic properties? (Lewis 2002, 1).

30 These definitions raise an interesting question. Is it possible for a persisting object to be locationally four-dimensional and mereologically three-dimensional? And conversely: is it possible for a persisting object to be locationally three-dimensional and mereologically four-dimensional? For different answers, see Gilmore (2006); Calosi and Fano (2015).
31 A similar presentation is provided in Hinchliff (1996).

Each one of the metaphysics of persistence I considered in § 2 provides a particular answer to the puzzle of change.[32] In what follows, let x be a persisting object that changes by instantiating incompatible properties F_1 and F_2. The *Spatiotemporal solution* has it that spatiotemporal facts mediate the instantiation of incompatible properties. This can be considered the relativistic (or spatiotemporal) counterpart of the more familiar solution offered in a classical setting–i. e., of the one according to which *temporal* (rather than spatiotemporal) facts mediate the instantiation of incompatible properties. Such a solution comes in two variants, that are known as *relativization* and *adverbialism*, respectively. I will present the more familiar temporal variant first as a paradigmatic example.

According to the relativization strategy–advocated, e. g., by Mellor (1998, 89 – 93)-x has F_1 at t_1, that is, x bears the F_1 relation to t_1, while it has F_2 at t_2, that is, x bears the F_2 relation to t_2. On the other hand, according to *adverbialism*-defended, among others, in Lowe (1988) and Haslanger (1989)[33]-x has t_1-ly F_1 and has t_2-ly F_2, where t_1-ly and t_2-ly act as adverbial modifiers.[34] This distinction within the spatiotemporal camp does not matter for the purpose of this paper. Hence, I will not get into the question whether the solution I am considering should be advanced in line with the relativization strategy or in line with adverbialism. More generally, according to the *Spatiotemporal solution:*

(16) For any persisting object x and any two incompatible properties F_1 and F_2, if x changes from having F_1 to having F_2, then there are distinct spacetime regions R_1 and R_2 which are parts of *Path*(x), such that x has property F_1-*at*-R_1 and property F_2-*at*-R_2, where "having *F*-*at*-*R*", is supposed to be neutral with respect to relativization and adverbialism.

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32 These solutions presuppose a certain metaphysics of time –*that is assumed here* as explicitly claimed in § 1—namely eternalism, according to which there is no ontological distinction between the tenses. Hinchliffe (1996) criticizes this very point, i. e., the endorsement of an eternalist metaphysics of time. He claims that presentism, roughly the view that, strictly speaking, only the present is real provides a better solution to the puzzle of change. I will grant such a point. However, the tenability of a presentist metaphysics of time in a relativistic world is problematic to say the least. The literature on the subject is literally too vast to be mentioned. See also 13.

33 See Lewis (2002) for an argument to the effect that the two variants are not as different as they may seem to be.

34 This formulation is an example of the classic "temporal variant" insofar as *temporal instants* mediate the instantiation of properties. In a spatiotemporal setting, temporal instants will be replaced by *spacetime regions*, as in (16).

Gibson and Pooley (2006) provide the more straightforward example of the spatiotemporal solution in a relativistic setting.[35] This solution is advocated by three-dimensionalists. A notable difference between the temporal and spatiotemporal variant is that the latter seems more defective, at least in the formulation I have given at first; for it does not mention *which spacetime regions mediate the instantiation of properties*. I will engage with this issue again in due time. The rival account is universally known as the *Temporal Parts solution:*

(17) For any persisting object x and any two incompatible properties F_1 and F_2, if x changes from having F_1 to having F_2, then there are two distinct temporal parts y_1 and y_2 of x, exactly located at distinct spacetime regions R_1 and R_2 which are part of *Path*(x), such that y_1 has F_1 and y_2 has F_2.

According to such a solution, a persisting object changes *vicariously* by having two distinct temporal parts that instantiate, respectively, one of the relevant (mutually) incompatible properties *simpliciter*. The passage from the temporal to the spatiotemporal context is less dramatic in the case of the *Temporal Parts* solution. For, in effect, this passage has been already addressed in the definition of the very notion of a temporal part. Needless to say, this is the solution that four-dimensionalists prefer. One of the most common objections against four-dimensionalism focuses exactly on the *Temporal Part* solution to the puzzle of change. Sider (2001, 212–216) calls such an objection the "*No-Change*" argument.[36] The point can be traced back at least to McTaggart (1927), but we can find classic variations on such an argument in Geach (1972, 304), Lombard (1986, 108), Simons (1987, 135–137), Mellor (1998, 89–90).

Before properly engaging with the argument, let me highlight (albeit briefly) its significance.[37] The argument is not confined to the classic formulations presented above. It is continuously discussed nowadays–see, among others, Kurtz (2006), Hinchliff (2006), Hales and Johnson (2007), Hawley (2015, 10–11), and Skow (2015, 24). Wasserman (2006, 52) calls it "the most familiar objection to the temporal parts approach". It is not only discussed, but also *endorsed* in,

35 They focus on particular properties, namely shape properties.
36 For the sake of precision, this paper focuses only on that part of the No-Change argument that Sider calls *the argument from spatial analogy.*
37 I will simply grant that A-theorists could advance a more radical argument to the effect that the *Temporal Parts* solution abolishes genuine change, for in their view the alleged "dynamical aspect" of change would be lost in such an account. On the other hand, it should be noted that, beginning with Sider himself, the No-Change argument is not considered as an argument against the B-theory of time *per se*, but rather as one against four-dimensionalism.

e.g., Oderberg (2004) and Alai (2016). Leading figures that have recently endorsed the argument include McCall and Lowe (2009)[38] and Simons (2014).[39] This should be enough to call for its thorough assessment. On top of that, as I pointed out in the introduction, the discussion of the No-Change argument has an *indirect significance*, so to speak, in that it will be pivotal to address some metaphysically crucial relations between time, spacetime and change in § 4. In that section, I will suggest that relativistic physics already contained the seeds of a view according to which reference to distinct earlier and later times is not necessary for change.

In discussing the argument, it will be useful to take the lead from a passage of Geach (1972) that conveys several points that I will discuss in due course. To quote Geach at length:

> The view in which time is merely a fourth dimension in which things extend is in any event quite untenable. On this view the variation of a poker's temperature with time would simply mean that there were different temperatures at different positions along the poker's time axis. But this, as Mc Taggart remarked, would be no more a change in temperature than a variation of temperature along the poker's length would be [...] We thus have a view that really abolishes change, by reducing change to a mere variation of attributes between different parts of a whole (Geach 1972, 304).

From these words we can extract a quick, preliminary, deliberately vague, formulation of the No-Change argument:

(P_1) Spatial variation is not genuine change

38 "Without enduring objects, there is no such thing as motion. A simulacrum of motion can be created by filming the two hands coming together and rapidly projecting the stationary images on the wall. In this case nothing moves" (McCall and Lowe 2009, 279). Though McCall and Lowe focus on motion, it is clear that their worry is much more general and extends to any kind of change.

39 "We standardly regard a continuant which has one property at one time and another property incompatible with the first, at a later time, as *changing* in this regard. We also standardly consider an occurrent which varies across its different times as precisely *not* changing, because the variation attaches to different (temporal) parts of the whole, not to the whole thing. So, a party which starts quietly and gets louder does not change in the literal sense, whereas a person who is dark-haired at twenty and white-haired at seventy does literally change. Proponents of occurrents as the sole inhabitants of spatiotemporal nature often try to hijack the term "change" to cover variation, but I agree with Geach and Dretske that we should resist such attempts. We do not say that the variation among the parts of a river which is fast-flowing at its source and sluggish at its mouth constitutes a change, but a spatial or geographical variation" (Simons 2014, 66–67).

(P_2) The Temporal Part solution offers an account of change that is completely analogous to spatial variation[40, 41]

(C) The Temporal Part solution yields no genuine change (from P_1, P_2)

The argument, when so loosely and vaguely phrased, does not have much bite. It can be simply answered, it seems, by claiming that it is unclear why the analogy between spatial variation and change should be thought of as problematic in the first place. Premise P_1 is in fact completely un-argued for. As such, we could simply counter it without an argument, by pointing out, e.g., some cases in which we do seem to use "change language" in the case of spatial variation. Sider (2001) mentions, for instance, the case of a road that *becomes*—a typical example of "change language"—narrow. In alternative, think of a river that—we would say—"gets" deeper and deeper.

This would undermine P_1. Yet the No-Change argument can be given a much stronger formulation. In fact, I will myself propose two different stronger versions. They are stronger in that P_1 is not left un-argued, but rather is supported by two different arguments. I will start from the following passage of Mellor:

> "Change, obviously if vaguely, is something having a property at one time and not at another. More precisely, it has *a thing* having *incompatible properties*, like different temperatures or B-places, *at different B-times*" (Mellor 1998, 70, italics added).[42]

Three crucial elements are mentioned in the passage just quoted: (i) incompatible properties, (ii) *a thing* having them, and (iii) *different times*. I will simply take for granted that change does indeed require incompatible properties as I have been doing from the beginning. The other two elements can be used to for-

40 Compare Sider (2001, 214): "the difference between merely spatial variation and four-dimensional change is vanishingly small", and Kurtz 2006, 5: "the perdurantist takes change over time to be analogous to change over space".

41 Note that all the variants of the No-Change argument that will be explored in the rest of the paper endorse P_2. P_2 -which is in fact the core of the objection and is taken almost verbatim from e.g., McTaggart (1927); Geach (1972); Sider (2001) and Simons (2014)–to mention a few–just says that "*change through time is analogous to variation to space*". Thus, *it should not be confused* with the controversial claim according to which "*time is analogous to space*" —see e.g., Skow (2007). To appreciate that these questions are orthogonal consider yet another case, i.e., the modal case. One can maintain that the modal dimension is *not* analogous to the temporal one — e.g., by holding *modal ersatzism* on the one hand and eternalism on the other—and yet insist that (persistence) and change through both the modal and temporal dimensions are importantly analogous, e.g., by endorsing counterpart theory. For the record, I do not want to commit myself to the endorsement of such theses.

42 See also Mellor 1998, 87.

mulate stronger variants of the No-Change argument. The first one strengthens Mellor's notion of *a thing* having incompatible properties-i.e., element (ii)-*via* the claim that the incompatible properties must be exemplified by the very same thing, where "the very same thing" is understood in terms of *strict numerical identity.* The argument can be formulated as follows:

(P_3) Exemplification of incompatible properties by the *very same entity* is necessary for change (or, equivalently: if something counts as a change from F_1 to F_2 then we must have: (i) $F_1(x)$, (ii) $F_2(y)$, (iii) $x = y$)[43]

(P_4) Exemplification of incompatible properties by the very same entity is not necessary for spatial variation[44]

(P_5) Spatial variation is not genuine change (from P_3, P_4)

(P_6) The *Temporal Parts* solution offers an account of change that is completely analogous to spatial variation

(C) The *Temporal Parts* solution yields no genuine change (from P_5, P_6)

P_5-P_6/C is actually the very same No-Change argument we started with. But this formulation is better in that P_5 ($\equiv P_1$) is allegedly supported by an argument, so that it will not do to simply challenge it, as I have done previously, without thereby challenging the argument supporting it. In other words. Just pointing out spatial analogues like the river and the road in which we invoke change language to describe the situation at hand is not enough. One has to undermine either P_3 or P_4. This is exactly what I will do.

The problem with such an argument is that, at least in this explicit formulation, it simply begs the question against four-dimensionalists. P_3 is basically an explicit denial of the *Temporal Parts* solution. Let me expand. It begs the question against four-dimensionalism insofar as it requires that the relation holding between the bearer(s) of incompatible properties should be *numerical identity*, whereas the *Temporal Parts* solution entails that those bearers are *numerically distinct*. No wonder the conclusion follows. So, either there is a non-question begging argument in favor of P_3 or the four-dimensionalist can simply discard it. And as a matter of fact, she should.[45]

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43 Alai (2016) explicitly endorses such a reconstruction.

44 As a matter of fact, it is even *ruled out* by spatial variation as we understood it so far.

45 Someone might try to resist the question-begging charge by insisting that even four-dimensionalists can say that the *very same* four-dimensional object instantiates "being F_1-at-R_1" and "being-F_2-at-R_2". Now, if being F_1-at-R_1 and being-F_2-at-R_2 are taken to be monadic properties it might be argued that these are not incompatible properties. The incompatible properties are F_1 and F_2 *simpliciter.* I will put forward the same argument when considering another possible

Actually, there might be another way for four-dimensionalists to resist the argument without charging three-dimensionalists of question-begging. She could remind her opponent that she could adopt a version of *de-re* spatiotemporal predication that mimics the counterpart-theoretic account of *de-re* modal predication. Some background details are in order here: Kripke (1972) famously puts forward what has become famous in the literature as the "Humphrey objection" against counterpart theory, as presented, e. g., in Lewis (1968). According to the counterpart analysis of *de-re* modal talk a proposition such as "Humphrey could have won the election" is true iff there is a possible world in which a counterpart of Humphrey (exists and) did win the election. Kripke's complaint is that while Hubert Humphrey cares very much that he might have won the 1968 U.S. presidential election, he "could not care less whether someone else, no matter how much resembling him, would have been victorious in another possible world" (1972, 45). Lewis (1986, 196) has a simple and effective answer, though: according to counterpart theory, the modal property of possibly winning is the property of having a counterpart who wins. Humphrey has a counterpart that wins, and so *Humphrey himself* has the right modal property, exactly because he has the right counterpart.

Now, four-dimensionalists might want to say that according to their metaphysics the spatiotemporal property of being F_1 at, say, region R_1 is the property of having a temporal part exactly located at R_1 that is F_1 (the same goes, *mutatis mutandis*, for F_2 and R_2). The *four-dimensional object itself* has the right spatiotemporal properties *exactly because* it has the right temporal parts. If this analysis is found compelling, the four-dimensionalist could then insist that the *Temporal Parts* solution and spatial variation are *not* analogous in a relevant respect: the four-dimensional object itself has the right sort of spatiotemporal properties whereas this is not so in the case of spatial variation. Hence, the No-Change objection loses its force.

reply on behalf of the four-dimensionalist. Alternatively, it might be insisted that the *very same* four-dimensional object bears the relation F_1 to R_1 and the relation F_2 to R_2. I am not sure whether four-dimensionalists would have any reason to say that, and there is at least one reason why they should not. One of the (alleged) advantage of the *Temporal Parts* solution is that it allows F_1 and F_2 to be *truly monadic properties*. In the end, this is what the argument from *temporary intrinsics* is crucially about. Hence what the four-dimensionalist should say is that, at best, the same four-dimensional object bears the relation F_1* at R_1 and F_2* at R_2. And it bears those relations *because* it has distinct temporal parts that instantiate F_1 and F_2. The point remains that the truly incompatible monadic properties are F_1 and F_2, and these are had by *numerically distinct* temporal parts of the four-dimensional object.

This response has some appeal. Yet it should be noted that the argument appeals to spatiotemporal properties of "being F_1 at R_1" and "being F_2 at R_2", rather than F_1 and F_2 *simpliciter.* And it might be argued that the spatiotemporal properties are not incompatible after all. Whatever the fate of this *de-re* spatiotemporal predication, it remains the fact that the very formulation of the previous version of the No-change argument, begs the question against the four-dimensionalist. In the light of this, we can safely conclude that the three-dimensionalist has failed so far in formulating a threatening variant of the No-Change objection.

(Un)fortunately, this is not the end of the story. For yet another variant of the No-Change argument can be given by focusing on element (iii) from Mellor's passage, namely the reference to *distinct* times. This is, as far as I can see, the most interesting version of the No-Change objection and the one that has the most wide-ranging implications. I will therefore conclude this section by spelling out such a variant in some detail.

We seem to have a strong pre-theoretical intuition that change requires reference to distinct earlier and later times, if not the passage of time.[46] The passages from Geach and Mellor I considered explicitly mention that reference. And the relevant examples are legion. One of the most commonly quoted passages that make such a platitude explicit is arguably in Gödel (1949, 558): "Change becomes possible only through the lapse of time". If so, the following argument can be put forward:

(P_7) Reference to distinct earlier and later times is necessary for change
(P_8) Reference to distinct earlier and later times is not necessary for spatial variation
(P_9) Spatial variation is not genuine change (from P_7, P_8)
(P_{10}) The *Temporal Parts* solution offers an account of change that is completely analogous to spatial variation
(C) The *Temporal Parts* solution yields no genuine change (from P_9, P_{10})

4 Spatiotemporal Change

This section contains a thorough discussion of the argument I just presented and of its metaphysical consequences. What has been said about the overall dialectic of the argument P_3-P_6/C applies here as well. I will eventually argue that both

46 Presentists, or A-theorists more generally, would probably disagree in that they will have an account of change in terms of tense operators that does not refer to distinct earlier and later times. However, as it is explicit in §1, this paper assumes some sort of B-theoretic framework.

three and four-dimensionalists should give up on P_7 and on our strong pre-theoretical intuition about the need to refer to distinct times in order to have genuine change. Or, at least, they should seriously consider this option. But before that, I will give another argument on behalf of the four-dimensionalist; the argument consists in rejecting P_{10} *in this precise context*. I will cast the argument in purely temporal terms first. This contravenes both the letter and the spirit of the conclusion of §1. Yet this needs to be done, for the sake of perspicuity.

As I just pointed out, when the No-Change argument is presented as I did in P_7-P_{10}/C the four-dimensionalist could, and should, simply deny P_{10} at first. The argument, so phrased, is essentially an argument by analogy. But consider the necessary requirement for change presented in P_7-i. e., the reference to distinct earlier and later times. Spatial variation and the *Temporal Parts* solution are *not analogous in that respect*. While it is true that reference to distinct and later times is not necessary for spatial variation, reference to *two distinct temporal parts* is necessary when providing a *Temporal Parts* solution to the puzzle of change. And this reference *is an indirect reference to two distinct and later times*. To appreciate this point, recall one of the most influential definitions of temporal part in the literature-the one in Sider (2001, 59). That definition is cast in purely temporal terms: *x* is an (instantaneous) temporal part of *y* at *t* = (i) *x* exists at *t* but *only* at *t*; (ii) *x* is part of *y* at *t*; (iii) *x* overlaps everything that is part of *y* at *t*. It follows immediately from clause (i)-an uncontroversial one- that reference to two distinct temporal parts entails a reference to two distinct times. This should be enough to warrant the rejection of P_{10} on the part of the four-dimensionalist.

This argument is however not immediately available to those who want to take the hints from Relativity at face value and thus aim to talk about *spatiotemporal* facts of different sorts. In this case, the spatiotemporal facts behind the temporal facts mentioned either explicitly or implicitly in the previous argument should be made clear. First of all (and naturally enough), we should replace the definition of a temporal part in the argument with the one given in (11), that mentions solely spacetime regions that are the exact locations of those temporal parts. But what about the requirement mentioned in P_7 / P_8 – i. e., the *reference to two distinct times?* Call it the "Distinct Times Requirement", DTR. This leads to the following DTR-related question (DTRQ):

DTRQ: What are the spatiotemporal facts behind DTR?

The problem of spelling out a precise answer to DTRQ constitutes the main driving force behind the arguments in this section. Before getting into details I shall just give the bare skeleton of the overall argument. I suggest that there are at least two ways to answer DTRQ, which I shall label *Weak DTR* and *Strong DTR* answers. I shall argue that (i) if the *Weak DTR* answer is endorsed then there is no No-Change objection against four-dimensionalism and, (ii) if the *Strong DTR* answer is endorsed, then the Three-dimensionalist is in no better predicament than the Four-dimensionalist, because premise P_7 of the No-Change argument above fails in both of their metaphysical pictures, respectively. This is enough to show that there is no No-Change problem that troubles the four-dimensionalist *alone*. The argument in (ii) suggests a general problem for persistence theories. Building on my case against the No-Change argument, I will then set forth yet another argument for the claim that there is indeed some pressure to abandon P_7 anyway, thus accepting a metaphysics of change that does not require reference to distinct times. This, I contend, is a suggestion that should be explored further-and that, I suspect, deserves an independent scrutiny.

To get into the dialectic I just sketched, consider first, e. g., two distinct achronal temporal parts x_1 and x_2 of an object y, that are exactly located at maximal subregions of y's path-i. e., R_1 and R_2 respectively. A weak answer to DTRQ has it that the spatiotemporal facts behind DTR are the ones captured in the following claim, that, as I said, I label Weak DTR:

(18) There exist two points p_1 in R_1 and p_2 in R_2 such that the vector connecting them is causal, i. e., time-like or null.[47]

In other words, according to Weak DTR the existence of any two causally separated points on R_1 and R_2 is enough to ensure a reference to distinct and later times. It can be easily seen that if (18) *does* provide a satisfactory answer to DTRQ, it follows from the definitions I provided that reference to distinct times *is entailed* by the reference to two distinct temporal parts. This simply follows from the fact that distinct temporal parts are exactly located at distinct maximal subregions of a persisting object's path. Thus, a *spatiotemporal/relativistic friendly* variant of the argument I started with in this section *is available* to four-dimensionalists. They could-and simply should-reject P_{10}. So, in the end, there is no No-Change argument with *Weak DTR*.

The problem with this reply is that (18) is far too weak to claim rights to be an adequate answer to DTRQ. Or so should the three-dimensionalist contend at first. That answer, she should go on, should be much stronger. In fact, it should

47 Those who wish to restrict their attention to material objects and want to claim that only fermions can be constituents of material objects, could replace causal with time-like. A photon, whose path is such that every two points in it are null-separated, is a boson, and thus will not count as a constituent of any material object given this account.

be something like the following, which, for obvious reasons, I label Strong DTR:

(19) *For every* point p_1 in R_1 there is a point p_2 in R_2 such that the vector connecting them is causal.[48]

Given STRONG DTR, the right way to ensure a reference to distinct and later times is to claim that for *every point* in R_1 there is at least one point on R_2 that is causally separated from it. Clearly enough, (19) entails (18), but the converse does not hold. This is why (19) is much stronger. Why does this answer to DTRQ give the three-dimensionalist an advantage? The reason is that nothing in the definitions we have given so far guarantees that (19) is met by different exact locations of different temporal parts of four-dimensional objects. For in effect, exact locations of temporal parts can overlap, and overlap entails the failure of (19).

Let us see the point in some details. Once again, consider the previous case, that is, consider *two distinct achronal temporal parts* x_1 and x_2 of *y*, that are exactly located at maximal subregions of *y*'s path, namely R_1 and $R_{2,}$ and suppose, furthermore, that R_1 and R_2 *do overlap*. Since they overlap, there is at least a point–call it p_1, that is part of both. Both R_1 and R_2 are achronal regions by definition of an achronal temporal part. Thus, in particular, for R_2 we will have that:

(20) For every two distinct points p, p_2 in R_2 the vector connecting them is space-like.

This holds for p_1 as well, which is, recall, part of *both* R_1 and R_2. This just means that there is at least a point in R_1, namely p_1 that is space-like separated from every other point in R_2. Hence, if (20) holds, then (19) fails. And if (19) is the right answer to DTRQ, then three-dimensionalists have indeed a No-Change argument against four-dimensionalism. This is a fairly interesting argument indeed. For it crucially depends on the fact that exact locations of *achronal temporal parts overlap*. This happens only in the relativistic case. In fact, in the classical case disjointness of distinct instantaneous temporal parts is guaranteed by, e. g., clause (i) in Sider's definition of temporal part above. Thus, if successful, the argument would give three-dimensionalism a truly relativistic argument against four-dimensionalism, contrary to the widespread agreement on the idea

48 See the previous footnote.

that relativistic physics, if it does not support directly, at least favors a four-dimensional metaphysics.[49]

But, once again, this is not the end of the story. In fact, in the following I shall argue that if (19) is the right answer to DTRQ then three-dimensionalism has no advantage over four-dimensionalism. As I pointed out, according to the spatiotemporal solution to the puzzle of change that three-dimensionalists prefer, spacetime regions mediate the instantiation of properties. But (16), the rigorous formulation of the *Spatiotemporal solution*, fails to tell us *which regions these are*. Consider a three-dimensional object. Arbitrariness considerations seem to favor the following *Exact Location Principle:*

(21) If a three-dimensional object *x* has property *F-at-R* then *x* is *exactly located* at *R*.

In other words: the spacetime regions that mediate the instantiation of properties in the *Spatiotemporal* solution to the puzzle of change are the exact locations of objects. By 'arbitrariness consideration' I mean the following. Any choice of *R* beside one of the exact locations of the three-dimensional object in question seems quite arbitrary.[50] Consider any other region R_1. distinct from any of the exact locations of the object. Why R_1 instead of, say, a region that has R_1 as a proper part? Why that, instead of a region that is a proper part of R_1? I admit that it would be better to have a stronger argument in favor of (21). Yet in the absence of any other plausible candidate, I contend that it is at least the most natural choice. Note that some philosophers that are sympathetic with three-dimensionalism, most notably Gibson and Pooley (2006, 164),[51] endorse such a principle explicitly, albeit with no argument.

Let us go now back to the definition of locational three-dimensional object in § 2, i.e., definition (9). As we saw, it follows from that definition that three-dimensional objects are exactly located at different achronal proper parts of the object's path. But the definition in itself does not suffice to *single out which ones among the many*. Following Gilmore (2006), this problem is sometimes called in the literature the location question (LQ). Roughly, the question is the following:

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49 See Balashov (1999); Balashov (2010); Calosi (2015); Gilmore (2006).

50 It might be thought that there is a less arbitrary suggestion: the entire spacetime. Yet this would contradict (16).

51 Here is a relevant quote: "The endurantist should hold that persisting objects do not (in general) instantiate properties *simpliciter*, but rather only *relative to particular spacetime regions*, viz. their locations" (Gibson and Pooley 2006, 164).

LQ: Let *x* be a persisting object. Which subregions of its path is *x* exactly located at?

Gilmore (2006) classifies the answers that a three-dimensionalist may provide to LQ as either *overlap* or *non-overlap* answers. According to the latter, exact locations of three-dimensional objects do not overlap one another, whereas according to the former they do. Gilmore convincingly argues that any non-overlap answer would not do in relativistic spacetimes. As a matter of fact, it is virtually universally held that, whatever the answer to LQ might be, it is an overlap answer.[52] Actually, *overlapping of exact locations* can be regarded as the *hallmark* of the *passage from a classical to a relativistic setting*.

We thus have the following: three-dimensional objects instantiate incompatible properties at their exact locations, and their exact locations can overlap one another. Furthermore, it follows from the definition of a three-dimensional object that these overlapping exact locations are *achronal*. Hence, the situation three-dimensionalists are in *is exactly the same situation* that was supposed to spell trouble for four-dimensionalists in the first place.

A further way to describe the predicament is the following. The No-Change objection against four-dimensionalism that I am considering crucially depends on the fact that different temporal parts that instantiate incompatible properties *overlap one another*. But the same argument would concern the three-dimensionalist as well, insofar as the relevant spacetime regions that mediate the instantiation of incompatible properties-i. e., the exact locations of the three-dimensional object-*overlap one another*.

This leads to the following conclusion: if (19) is the right answer to DTRQ, then the *No-Change argument* P_7-P_{10}/*C cuts both ways*. Before moving on to sum up the overall dialectic of the No-Change argument, it is worth spending some time on a question that naturally arises in this context. As I already pointed out, the previous argument depends crucially on the fact that exact locations of achronal temporal parts on the one hand, and exact locations of persisting three-dimensional objects on the other, *overlap one another*. Such exact locations turn out to be the major actors-so to speak-in the metaphysics of change. This raises an interesting question —one that I shall label the *possibility of overlapping change question* (POCQ):

52 The fact that LQ is such a difficult question for three-dimensionalist to answer, whereas it has a simple answer for four-dimensionalists -*x* is exactly located at the only improper subregion of its path, namely the path itself- can be taken as a starting point for an argument favoring four-dimensionalism. See Gilmore (2006).

POCQ: Is change possible at overlapping regions?

Now, either change *is* possible at overlapping regions, or it fails to be; no third possibility is given. In fact, a number of arguments seem to favor the former option. First, if change is *not* possible at overlapping regions, then we should not count relativistic length contraction as a change.[53] Yet it does seem to have all the credentials to be counted as one. As a matter of fact, according to an influential, though highly controversial, explanation of relativistic length contraction —the one that is labeled *dynamical explanation* and was advocated in Brown (2005) —the phenomenon is as genuine a change as any one we are familiar with.[54]

One needs not rely on Brown's dynamical explanation. Consider the account of relativistic length-contraction three and four-dimensionalists are likely to give. Three-dimensionalists should claim that they measure different lengths of the same rod at different spacetime regions that are both among the exact locations of the rod. Four-dimensionalists on the other hand should claim that they measure different temporal parts of different lengths of the same four-dimensional rod. Upon inspection, this fits exactly the template for a general case of change.

A second argument to the same end is more general and-I think-the most effective one available. Overlap is not transitive. Now consider, for instance, three distinct exact locations of a three-dimensional object[55] R_1, R_2, R_3 such that R_1 overlaps R_2, R_2 overlaps R_3, but R_1 and R_3 do not overlap, as in Fig.1.
If change is not possible between R_1 and R_2–that is, *x, by hypothesis cannot have incompatible properties at* R_1 *and* R_2-because they overlap, then *x* has the same

53 This is because length contraction can be understood as the difference in the rod's length at different exact locations that *overlap* each other, where "different lengths" are taken to be mutually incompatible properties. This formulation implicitly assumes a three-dimensional ontology, though: four-dimensionalists should give a different account of length contraction, perhaps along the lines of footnote 56. However, the point about overlap and the incompatibility of different length-properties would arise in this context as well.

54 I do not aim to subscribe to Brown's interpretation here. As a matter of fact, I believe that, if possible, we should stick to the so-called "geometric explanation". The point has no consequence for the sake of the dialectic here though —hence, I will not pursue it any further. For a critique of Brown's approach see Norton (2008).

55 The argument applies, *mutatis mutandis*, to four-dimensional objects as well, as can be seen by just phrasing it in terms of achronal temporal parts exactly located at R_1, R_2 and R_3. However, I will focus on the argument as applied to three-dimensional objects because I find it more interesting —in particular, given the way it connects to the answers to LQ that I discuss in this paper. The formulation of the parallel argument that can be raised about four-dimensional objects is left to the reader.

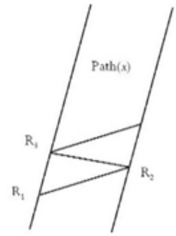

Fig. 1: Change and Overlap.

properties at R_1 and R_2. The same goes for R_2 and R_3. But then it follows that *x* has the same properties at R_1 and at R_3–regions that do not overlap.[56] No matter what region(s) we consider, the argument will run the same way. But then, given the assumptions, how can *x* change properties at all? In other words: suppose change is not possible at overlapping regions. Then, given that overlap is not transitive, it is difficult to see how a three-dimensional object could change at all. Hence, I contend that we should answer PCQ in the affirmative and conclude that change at overlapping regions is indeed possible.

There might be two ways the three-dimensionalist can reply at this point. According to the first, despite the fact that three-dimensional objects are exactly located at overlapping regions, they change only at non-overlapping ones. This would amount to saying that, for any two non-overlapping regions such that the object changes its properties at those regions, there is no other region that overlaps the two that counts as an exact location of that object. But this just means to have a Non-Overlap answer to LQ —an option that was already ruled out. According to the second, it only makes sense to ask whether change occurs along a thing's path when the path is foliated, which requires that every leaf is mereologically disjoint from every other. This is allegedly compatible with saying, e.g., that a 3D thing is exactly located at overlapping regions: for it only says that some of these regions play a role in allowing genuine change.

The problem with this proposal is that the foliation of the path that is doing most of the metaphysical work here is nothing but a reference frame in disguise. Indeed, in non-pathological spacetimes, such a foliation could easily be extended to construct such a frame. To appreciate the point, consider the following.

56 This is actually too strong. Change requires incompatible properties (or so I assumed). From the mere hypothesis that change is not possible at overlapping regions it does not follow that *x* has *all the same properties* at those regions. It might very well have different properties, *albeit not incompatible ones*. This "variation" in properties would however not count as genuine change.

Take the foliation of the path. Embed every mereologically disjoint leaf of that foliation into a globally unextended space-like hypersurface. Then construct an entire family of space-like hypersurfaces that are everywhere parallel to the ones you started with. This family of hypersurfaces counts as a foliation of the entire spacetime. A frame of reference is then obtained by taking a time-like line that is orthogonal to any hypersurface in the global foliation. This construction should be slightly modified if we want to consider non-flat foliations. The problem with this proposal is that it would run against the spirit of the conclusion of §1. Remember Gibson and Pooley's words: "no one *should* attach significance to properties of objects that are essentially defined in terms of canonical frames of reference".[57]

Where does that leave us? We saw that there is an interesting No-Change argument P_7-P_{10}/C that builds upon the intuitive claim that "change requires reference to distinct times". I considered several ways to account for such a requirement. If the requirement is accounted for in terms of what I labeled WEAK DTR, then, I argued, four-dimensionalism is not touched by such an argument. Four-dimensionalists should *reject* P_{10}. If it is accounted for in terms of STRONG DTR, then four-dimensionalism does indeed face it, but so does three-dimensionalism. In fact, suppose we do insist that DTR should be understood via STRONG DTR. Now, the following two alternatives present themselves. Either both three-dimensionalsists and four-dimensionalsists raise up their arms and claim that they cannot account for genuine change, insofar as their metaphysics cannot meet DTR, or they claim that their solution does indeed account for genuine change, but change does not require satisfying DTR. And this amounts to abandon P_7, for P_7 exactly says that satisfying DTR is necessary to account for genuine change. Indeed, I will just assume that the latter is the way both parties should go. That is to say that, should three and four-dimensionalists be confront-

57 If change is possible at overlapping regions, Four-dimensionalists better have overlapping temporal parts. In general, this follows from the very definition of general temporal part, as a sum of achronal ones, given that parthood entails overlap. It is indeed orthodoxy that four-dimensional objects have temporal parts at all maximal slices of their path. Gibson and Pooley write: "[F]rom a relativistic point of view, the assumption that a perduring object has parts at *every* proper subregion of its worldtube is overwhelmingly natural. Call this the *doctrine of arbitrary spatiotemporal parts*. From a relativistic point of view, it should be a starting point, not something that falls out from a frame-relative generalization of the non-relativistic notion of a temporal part together with unrestricted composition. Indeed, from the relativistic perspective, the existence of specifically 'temporal' parts of an object does not even warrant comment" (Gibson and Pooley 2006, 162). On top of that, the No-Change argument we are considering turns exactly on 4D objects having overlapping temporal parts. If this not granted there is no No-Change argument to begin with.

ed with an argument to the point that Strong DTR is the right answer to DTRQ, they should simply discard P_7. I will put forward a sketch of such an argument myself.

Before turning to that, however, I will consider yet another possibility on behalf of three-dimensionalists. For there might be a way to recover the asymmetry about the No-Change argument– i. e., the dialectic situation that made their view, *as opposed to* the Four-dimensionalist's, immune to the argument. The strategy would be that of providing an answer to DTRQ that would be in between Weak DTR and Strong DTR. The in-between answer should be such that (i) three-dimensionalists could build a No-Change argument in terms of such an answer, and (ii) that variant of the No-Change argument affects four-dimensionalism alone. I know of no suggestion like this in the literature, so I will just present it as a challenge. It is up to three-dimensionalists to come up with an interesting proposal in this sense. However, it would not be enough for them to provide an in-between answer that suits their aim —i. e., that satisfies (i) and (ii). They also should effectively argue that (iii) such an answer is the best way to spell out the intuitive DTR requirement in P_7.

Having said that, I will now set forth the final-yet I am afraid not fully fledged-argument of the paper. Answers to DTRQ provide different ways to account for the intuitive claim that change requires reference to two distinct times-i. e., the DTR requirement as mentioned in premise P_7 of the No-Change argument at the end of § 3 —in ways that take seriously the suggestions that come from Relativity. Now, in the light of the above, there seem to be two options. On the one hand, it can be insisted that Weak DTR is the right way to construe the intuition behind DTR. If so, I have argued, both three and four-dimensionalism can stick to the DTR requirement. This is because the No-Change argument is not a threat. On the other hand, it can be insisted that Strong DTR is the right way to go. But then, I have argued, it turns out that both the metaphysics of persistence I have considered have to abandon P_7, and hence reject the DTR requirement itself. What horn should one take?

In what follows, I will suggest that there is some pressure to take the second, but I shall admit (once again) that I here simply gesture towards an argument rather than providing a fully-fledged one.

I already argued that change at overlapping regions is possible. Regions R_1, R_2 can overlap in many different ways. One such way is depicted in Fig. 2 below.[58] I take it that the intuition behind the DTR requirement is the following: when an object changes *from* having F_1 at t_1 *to* having F_2 at t_2, t_2 is *later* than t_1. But sup-

58 The first to bring attention to this point was Gilmore (2006). See also Balashov (2014b).

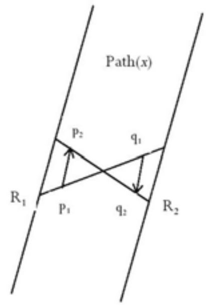

Fig. 2: Overlap and the Distinct Times Requirement DTR.

pose the persisting object *x* depicted in Fig. 2 changes from having F_1 at R_1 to having F_2 at R_2. Can we still hang on to the intuition behind DTR? It seems that we should give a negative answer to *this* question, for there are points p_1 and q_1 on R_1 and points p_2 and q_2 on R_2 such that the time-like vector p_1p_2 is *future* directed, whereas q_1q_2 is *past* directed.[59] In other words, there are parts of R_1 that *strictly temporally precede* parts of R_2 (e.g., p_1 strictly temporally precedes p_2), whereas there are parts of R_2 that *strictly temporally precede* parts of R_1 (e.g., q_2 strictly precedes p_2).

Given all this, I contend that there is some pressure to claim that Weak DTR is too weak an answer to DTRQ. For in effect, Weak DTR is not strong enough to rule out possibilities such as the one depicted in Fig. 2. And, crucially, the intuitive pressure for DTR demands exactly that possibilities such as that one *have to be ruled out*. On the other hand, Strong DTR does fill the bill. Hence, I argue, we should insist that this is the right answer to DTR-the right way, that is, to capture the DTR requirement.

And this leads to my final point. I have argued that if Strong DTR is indeed the right answer to DTRQ, it follows that, if both three-dimensionalism and four-dimentionalism have any right to claim that they provide an account of genuine change, then they both have to abandon P_7 and claim-*contra* both our pre-theoretic intuitions and a widespread philosophical agreement —that *reference to distinct times is not necessary for change.*

Now, this may sound controversial and counterintuitive. Yet there is no need to get too alarmed. Physicists and philosophers of physics have already set forth

59 Admittedly, this restricts our attention to so-called “time-orientable spacetimes”. This is no reason to get alarmed though: for in effect, *temporal orientability* is a very weak condition. Any manifold with a Lorentzian metric that admits the definition of a continuous time-like vector field is, as a matter of fact, time-orientable.

independent suggestions to the effect that change does not require time at all. Earman (2002) suggests that, if we look at the deep structure of GTR, we will indeed find cases of temporally-independent change. Rovelli (2011) develops a formalism for a Quantum theory of gravity in which dependent and independent variables are treated in one and the same way and time does not play any role; such a formalism is nonetheless supposed to account for change.

Huggett and Wüthrich (2013) consider different candidates for theories of Quantum Gravity (Loop Quantum Gravity, String theory and Causal Set-theory) where the fundamental ontology does not include spacetime and yet its items do undergo significant changes. If the arguments in this paper are right, then the seeds of such an intriguing and deep suggestion were already in classical relativistic physics, or better, at the intersection between relativistic physics and (relativistic) metaphysics.

In effect, one might find the arguments from Quantum Gravity more compelling than the ones from classic relativistic physics. I would actually agree. But it is still interesting that something that will become clear only in later theories was somehow already hidden in classical Relativity theory. The conclusion all these considerations points at is that spatiotemporal variation is change enough. And it is all around us.

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Jean-Claude Dumoncel

Between the Time of Physics and the Time of Metaphysics, the Time of Tense Logic?

Sosein, Dasein, Zeitsein

Abstract

According to Russell, Being is divided into atemporal *universals* and temporal *particulars*. But, to the extent that the Antisthene's caballeity pops up in the *topos noeton*, the ancestors of the horse must precede the horse in the sublunar. Thus, Being must be divided into *Sosein*, *Dasein* and *Zeitsein*. Only the Whiteheadian "eternal objects", such as geometrical forms and colours, are atemporal universals, while caballeity is in the *Zeitsein* together with Conquérant (one among Napoleon's horses). In this ontology, according to the Lautmanian shift, *Spatiotemporality* pertains to the *Sosein* and has a two-fold structure: logical and mathematical. The tense logic of A.N. Prior describes it, while its link with the mathematics of spacetime is fixed by the Boolean kernel in the von Neumann algebra for quantum logic. This speculation will be preceded by a narrative exposition of elementary tense logic.

* I am grateful to the all staff at the *What is time?* symposium for their invitation and generous hospitality. Great thanks are especially due to Rocco Ronchi for his marked concerns, to Elie During for the courtesy of his discussion and to Alessandra Campo for the truth of her philosophical enthusiasm. A special thanks is for the anonymous reviewer of this paper.

1 The Tale of Tense Logic

Tense logic is a variety of *temporal* logic, and temporal logic is a branch of *modal* logic. Thus, in order to give a short history of tense logic, we must start by tracing a short genealogy of the modal logic.[1] The latter has three main moments: the Leibnizian *foundation*, the Kripkean *mathematization* and the creation of *tense logic* by Arthur Prior.

1 See Blackburn, De Rijke and Venema (2001). *Arthur Prior and Hybrid Logic* is a fascinating paper which focuses on the more promising lines of thought in the area.

https://doi.org/10.1515/9783110753707-018

1.1 The Leibnizian Foundation

In a draft[2] written in 1671 or 1672, Leibniz discloses, in Russellian terms, the structural similarity between three versions of the Apulean square AEIO. This is the *Leibnizian Table of Apulean squares:*

Omnis	*Nullum*	*Necessarium*	*Impossibile*	*Debitum*	*Illicitum*
Quidam	*Quidam non*	*Possibile*	*Contingens*	*Licitum*	*Indifferens*

In symbols (or in English, where symbols are still missing):

$\forall$	$\neg\exists$	$\Box p$	$\neg\Diamond p$	Obligatory	Forbidden
$\exists$	$\neg\forall$	$\Diamond p$	$\neg\Box p$	Permitted	Optional

This table of similarities has two main consequences. The first is the well-known thesis that a necessary truth is true in all possible worlds.[3] In symbols:

$$\Box p \Leftrightarrow \forall w \models_w p$$

("Necessarily p iff for each world w it is true at w that p")

This Leibnizian analysis of necessity (generalizable to the other modes of the square) is of such significance that it deserves a name. I will call it *Leibniz's Bridge*. It is a bridge because it connects a left-side modality with a right-side quantifier. In Carnapian terms, modality is the *explanandum* and quantification is the *explanans*. Of course, the quantifier operates in the possible worlds of Molina, dubious entities surrounded by a metaphysical flavour. However, in the view of such logicians as Carnap, quantification theory enjoys a less controversial status than modal logic.

2 It was rediscovered by Blanché when he prefaced the *Etudes de logique déontique* of Kalinowski. Gardies relates : "Il a en effet trouvé les textes en question grâce à M. Serres qui dans *Le système de Leibniz et ses modèles mathématiques* cite L. Couturat, lequel résume *Definitio justitiae universalis*, c'est-à-dire le fragment N. 12_6 des *Elementa juris naturalis* de l'édition de l'Académie Prussienne des Sciences… publié pour la première fois par A. Trendelenburg dans ses *Historische Beiträge zur Philosophie*" (Gardies 1974, 265 – 275).

3 On the Leibnizian source of this theme, see Kalinowski (1985, 236 – 237) who refers to another text, edited by Couturat in the *Opuscules et fragments inédits* of Leibniz (1903): *Phil.* IV, 3, a, 1 – 4, sans titre, pp. 16 – 24.

The second consequence of the Leibnizian reformulation of Apuleio’s square is a generalisation of the concept of modality itself. According to Leibniz, beside the *metaphysical* modalities of possibility and necessity—which are well-known since Aristotle—there are also *deontic* modalities such as duty and rightness. And so, we can say that his generalisation systematizes philosophy with modal logic. Its *Begriffsschrift* is the standard symbolism of the latter: on the Apulean square, □ and ⋄ are transposed in their ethereal versions [ ] (“Box”) and ⟨ ⟩ (“Diamond”), so that the subalternation obtained is:

$$\begin{array}{c} [\ ] \\ \downarrow \\ \langle\ \rangle \end{array}$$

It may be rephrased as: “the diamond is in the box”.

1.2 The Kripkean Mathematization

With respect to modal logic, we must distinguish between its axiomatization and its *mathematization*. The well-known axiomatization of modal logic was laid down in its main lines by C.I. Lewis in 1932 (Lewis and Langford 1932). But the *mathematization* of modal logic is another story. This concept was introduced by Robert Goldblatt (2005) and the understanding of its true meaning requires a philosophical elucidation.

The mathematization of modal logic has at least two births. The first, as we shall see, is probably due to Arthur Prior. The second, instead, is due to Saul Kripke,[4] the philosopher who provided its canonical formulation. The cornerstone of the latter is a *Kripke-model* or K-model. A Kripke-model M must be written in two main versions. The original (Kripke 1963)[5] one is:

$$M = \langle\langle W, P\rangle, V \rangle$$

4 Here we cannot discuss the question of priority between authors. In addition to the already mentioned paper by Goldblatt on the evolution of mathematical modal logic, see Copeland (2002). And it is enough to say that the mathematizations of Prior and Kripke are independent from each other. The publication of the results of the young Kripke’s work has been postponed because of bad advices from his academic masters.

5 Original version but not in literal terms. The essential point is the difference between this original version, with its philosophical significance, and the new one which has vanished in the rarefied air of abstract formalism.

In this version of the model M, *W* is a set of possible worlds *w*, *P* is the relation of *relative possibility* between possible worlds, and V is the so-called "function of valuation" which takes the proposition *p* of a language L as argument and the subsets of *W* where *p* is true as values.

From a theoretical point of view, in Kripke's model the two members have a very different status (Blackburn, De Rijke and Venema 2001, Df 1.19, 17). The couple ⟨*W*, *P*⟩, i.e., the *frame* of the model, gives the mathematical picture of its ontology, while the valuation function V gives the additional information endowing this ontology with a logic. In Husserlian terms, which are derived from Aristotle, one can say that the frame is the *Ontology* of the model and the valuation is its *Apophantics*. In the frame, usually, there is no relation of "relative possibility", but a relation of *accessibility*. This, at least, is what Peter Geach suggested to Prior in a letter of 1960. Yet, relative possibility and accessibility are the converse of one another: *w* has access to *w'* if and only if *w'* is possible relatively to *w*.

Therefore, since modal logic has evolved, we may write Kripke's model in the following terms:

$$\mathrm{M} = \langle\langle E,\ R\rangle,\ \mathrm{V}\ \rangle$$

In this new version *E* is *any* non-empty set, whose members are not only the old "worlds" of Molina or Leibniz, but as well "points", instants, words, or whatnot; and *R* is *any* binary relation. This acceptation defines an *abstract* or "formal" Kripke model.

Now, when modal logic is endowed with a Kripke model, what is the effect of this model on those concepts of modal logic illustrated by the definition of necessity that we find in Leibniz? The definition of necessity becomes

$$\mathrm{M} \models_v \Box p \Leftrightarrow \forall w\ wPv \rightarrow \mathrm{M} \models_w p$$

("In M it is true at *v* that necessarily *p* iff for all *w*, if *w* is possible relatively to *v*, then in *M* it is true at *w* that *p*")

In other words, a *footbridge* is added on the right side of Leibniz's bridge. It conditions or *controls* the relevance of possible worlds in the definition of a modality as a constraint imposed on relative possibility, so that the relation *R* of an abstract model can be said to be a relation of "parametrization".

Now, why is this footbridge or parametrization a *mathematization* of modal logic? A crucial example will help us to answer this question. Yet, in order to find it, we have to return to the second modal discovery made by Leibniz, i.e., the structural similarity between the metaphysical modalities, such as possibility and necessity, on the one hand, and the deontic modalities, such as permission and obligation, on the other. Nevertheless, this structural similarity does not go without restrictions.

Indeed, when the Apulean square is decorated with metaphysical modalities, we find in its A-I side, that is between the necessity $\Box p$ and the possibility $\Diamond p$, the halfway house of the naked *p:*

$$\Box p$$
$$\downarrow$$
$$P$$
$$\downarrow$$
$$\Diamond p$$

This writing presupposes the law $\Box p \rightarrow p$ (*a necesse ad esse valet consequentia*) according to which, if Cicero is necessarily Tullius Marcus, then Cicero is Tullius Marcus. But if we resort to deontic modalities, things change. From the fact that Babbitt has the duty to pay taxes, it doesn't follow that Babbitt pays taxes, because metaphysical and normative modalities have a different meaning. But this fact has also a *mathematical* accompaniment. If the relation of parametrization *P* or *R* is compelled to be *reflexive*, then we have *wPw* and so, by applying our previous definition of necessity, we now obtain

$$\models_v \Box p \Rightarrow \models_v p$$
("If it is true at *v* that necessarily *p*, then it is true at *v* that *p*")

Nonetheless, there is no corresponding principle for the deontic modalities.

Now, reflexivity, as well as transitivity, symmetry (etc.) are *mathematical* features of a relation. So that, if one controls the modal laws using these mathematical attributes of the parametrizing relation *R*, modal logic becomes *mathematical modal logic* in the sense of Goldblatt.

1.3 The Creation of Tense Logic by Arthur Prior

Arthur Norman Prior was the main founder of temporal logic and the creator of tense logic. Overall, its work can be broken down into three major moments-movements: 1. an anachronistic encounter between Diodorus Chronos and St. Thomas Aquinas; 2. a mathematization of temporal logic and 3. the encoding of tense logic.

1.3.1 St. Thomas Aquinas Meets Diodorus Chronos

The foundation of temporal logic coincides with the erection of an *Apulean column* containing a *pedestal* (I) and a *capital* (A). Prior founds the pedestal I of temporal logic in Aquinas definition of past and future: the *Thomas Aquinas Theorem* of temporal logic:

Past is what has been present and future is what will be present (Est enim praeteritum quod fuit praesens, futurum autem quod erit praesens)

More profoundly this definition means that the present appears in the three "parts" of time: in the past as past *present*, in the present as *present* and in the future as future *present*. As a result of this, only two symbols will be required on the pedestal position I: *Pp* for "It is past that *p*" and *Fp* for "It is future that *p*"; for the present time, the simple *p* will be enough, since its illustrations will be, for example, "It rains" in order to report a *present* fact equally reported in the *p* of *Pp* and *Fp* according to the Thomas Aquinas theorem.

Here a remark is imperative. If a census of the symbols is taken as the criterion for a census of the modalities, then each post on the Apulean column will require, in temporal logic, *two* modalities, such as *Pp* and *Fp*. The capital A of temporal logic has been designed by taking a definition of necessity given by Diodorus Chronos and remedying its hemiplegia.

Thanks to Boethius we know the four definitions of the four modalities given by Diodorus Chronos. Each one fits with a position of the Apulean square AEIO. But before Prior's work, faced with these Diodorean definitions, the historians of logic were *comme une poule qui a trouvé un couteau*. Among these definitions, in fact, we find for example this definition of necessity:

Necessary is what, being true, will not be false.

If we put this Diodorean definition of necessity at the top A of our AI column, what we obtain as capital of the column is only a half-Janus which, camped in the present, can only see the future. And all Diodorean modalities are affected by this semi-blindness. Yet, from Prior's point of view, this means that Diodorus has provided only one half of the couple required in position A. Thus, the Diodorean capital must be completed with the Aquinate pedestal in order to obtain on its top a well-balanced Janus-logic. The required symbols are *Hp* and *Gp*, with the mnemonics "it always *H*as been the case" and "it is always *G*oing to be the case"; in French: *Auparavant* et *Dorénavant*.

When all this is done, we get the complete Column of Temporal Logic, with its Aquinate pedestal and its Diodorean capital:

Hp p Gp
Auparavant p p Dorénavant p
|

|
|
|
Pp p Fp

One of the laws of this logic is $Pp \rightarrow GPp$ (“Whatever has happened will always have happened”).

1.3.2 The Mathematization of Temporal Logic

On 27th August 1954, in his Presidential Address at the second New Zealand Congress of Philosophy (held in Wellington) Prior unveiled a calculus which, in its published version of 1958, contains the following formula:

$$\vdash_t Gp \Leftrightarrow \forall u \; (t < u \rightarrow \vdash_u p)$$

(“It is true at *t* that dorénavant *p* iff for all *u*, if *t* is followed by *u*, then it is true at *u* that *p*”)

Since in this formula the truth of *p* at *u* is conditioned by the relation of succession (<) between *t* and *u*, thanks to it Prior accomplished the *mathematization* of both temporal and modal logic. In other words, building a *Prior’s bridge* for temporal logic as a case of the Leibnizian bridge built for modal logic, Prior adds on the right side of the latter the *footbridge* of the “before-after relation” in its function of parametrization.

As an illustration of this function, let’s take the formula $Fp \rightarrow FFp$. Is it a law of temporal logic? Yes, if, generally, $t < u \rightarrow \exists v \; (t < v \;\&\; v < u)$.

Now this condition of *density* can be presented either as an attribute of the parametrizing *relation* (<), or as an attribute of the *set* on which this relation plays (here it is a set of temporal moments). This shows that, in a Kripke model $\langle\langle E, R\rangle, V\rangle$, the frame $\langle E, R\rangle$ which is denoting the ontology of the model, enjoys a strong unity because the mathematical attribute (such as density), that is the reason of its inclusion in the alleged model, can be attributed either to *E* or to *R*.

1.3.3 The Emergence of Tense Logic

Among Prior’s bridges, let’s now consider the following one:

$$\vdash_t Pp \Leftrightarrow \exists u \; (u < t \;\&\; \vdash_u p)$$

(“It is true at *t* that *p* is past iff there is a *u* which precedes *t*
and it is true at *u* that *p*”)

Here we must remember that, according to McTaggart (1908), any event *E* can be grasped in two series: it can be said to be *future*, *present* and *past*—the three attributes of the A-series—and it can be temporally related with other events with respect to which it can be said to come *before*, be *contemporary* with or come *after* —the three relations of the B-series. Now, as we can see if we consider, for example, the succession of births of Homer, Milton and Borges, there is no change in the B-series but only in the A-series. Only in the latter, in fact, is a future event present and then becomes past. Then, McTaggart’s distinction decides the fate of the metaphysics of time: if the B-relations prevail, we are in the timeless world of Parmenides, Spinoza and Bradley; if the A attributes prevail, we live in the moving world of Heraclitus, Leibniz, Bergson, Alexander, Whitehead or Prior.

Prior thematized this metaphysical watershed in his temporal logic. In the last equivalence, in fact, we find that, on the left side, the A *attribute P* of McTaggart has become a *modal* one, and that, on the right side, the B *relation* $<$ of McTaggart has become a *parametrizing* relation of mathematical modal logic. So, we are no more in the situation of the Kripkean models $\langle\langle E, R\rangle, V\rangle$ where *any* binary relation *R* was doing the job of the parametrizing one. In the temporal logic of Prior, in other words, not only must “$<$” have its ordering meaning, but this relational meaning has the same *philosophical* and *metaphysical* relevance given to it by McTaggart.

Arthur Prior is the logician who has introduced the metaphysics of time into temporal logic. But this contamination is only the first step of his revolution. In fact, from Leibniz to Carnap (and his followers), Leibniz’s bridge has been conceived as a path connecting left-shore modalities with right-shore quantifications. Yet, if we follow Prior, Leibniz’s bridge becomes a *palindrome* that can be crossed in both directions, with different results. If we go from the A attributes on the left shore to the B relations on the right shore, we are in temporal logic. But if we go from the B relations to the A attributes as modalities, we enter into (pure) *tense logic*.[6]

6 See Dumoncel (2018).

2 The Pythagorean Table of Physics

Physics has its Pythagorean table[7] (Table T):

	Space-time
c	Space, Time and Matter
h	Mechanical Action : $mv \times d$ $\quad mv^2 \times t$

This table represents space-time in its two main physical forms. It is a double-entry table where the abscissa opens to the general notion of space-time and the ordinate superposes both a *c* and an *h* line. Of course, the letters *c* and *h* refer to Relativity and Quantum Mechanics: *c* is Einstein's constant and *h* is the Planck constant. In short, this Pythagorean table shows that the 20th century's revolutionary physics is fully *spatio-temporal* or, more exactly, *doubly* spatio-temporal: there is a *relativistic* spatio-temporality and a *quantum* spatio-temporality. The first is notorious; the second needs to be made explicit. What is quantized in Quantum Mechanics is, in fact, the mechanical *action* and the mechanical action can be expressed in both a *spatial* and a *temporal* form. Thus, a quantized action is a link between time and space: a fact which is quite ironical with respect to the history of the development of physics.

Leibniz, as it is well-known, has made of continuity one of the most important principles of nature (*Natura non facit saltus*) and something like a quantized action, precisely to the extent that it is a discrete action, seems to refute this principle. Yet, Leibniz is also the philosopher-physicist who saw mechanical action (the so-called "moving-action") as the heart of physics. This fact is duly registered by Martial Gueroult in his *Leibniz. Dynamique et Métaphysique* (1934). Here, Gueroult has also argued that Leibniz was aware of the *spatio-temporal* character of mechanical action. What he called "action mortice", in fact, is "the product of the amount of movement multiplied by the space travelled or of the living force multiplied by time" (Gueroult, 1967, 50, our translation). So that, for the momentum and the energy, the best *Begriffsschrift* is the Leibnizian couple $\langle mv, mv^2 \rangle$.

Now, let us consider Heisenberg's relations[8] of indeterminacy transliterated in this Leibnizian *Begriffsschrift:*

7 I have presented a first version of this thesis when I was invited by Elie During to give a lecture in his seminar series on physics and philosophy at Diderot University.
8 Where *d* shortens "distance" as a coordinate of space.

$$(H1)\ \Delta mv \times \Delta d \geq h$$
$$(H2)\ \Delta mv^2 \times \Delta t \geq h$$

These relations can be viewed as a simple corollary of our Pythagorean table: H1 stating the *spatial* Heisenberg relation, H2 its *temporal* mate. But this fact can also work as the occasion for a reflection: which account does Heisenberg give for the two members in each relation? What is *common* to *d* and *t* on the one hand and to *mv* and mv^2 on the other? In brief, what is the *ratio essendi* of the spatial *or* temporal factor on the one side, *and* of the energy *or* momentum factor on the other?

With regard to this issue, Leibniz provides, if not the concepts, at least the vocabulary. As Gueroult explains: "If extension is considered in time, intensity is force; if it is considered in space, intensity is speed"[9] (Gueroult, 1967, 130, our translation). Here we have *the Leibnizian watershed of Nature:* in Nature, space and time are the *extensive* components; momentum and energy are the *intensive* ones.

This Leibnizian vocabulary will receive its full conceptual expression when it will be housed in Lautman's philosophy of science (Dumoncel 2008) and in its systematic and speculative network. Lautman, in fact, is a direct heir of Plato and it is well known that Plato, trying to give a blueprint of his allegory of the Cave, traced an analogical Line between the visible and the intelligible worlds which undergoes a second analogical division. Thus, the scale of beings or realms we obtained has the following four steps:

Ideas
——-——-——-———-
Mathematical objects
=================
Bodies
——-———-————-———-——-
Simulacra (images, shadows, etc.)

By means of Lautmanian transposition, we obtain the *Lautman* scale:

Ideas

9 Here, in *mv*, since the mass *m* is constant, the velocity *v* suffices to represent *mv* as a variable factor.

——-——-——-——-

Mathematics

=================

Natural philosophy

——-———-——-——-——-——-

Physics

From a philosophical point of view, we find that, on the Lautman Line, the mathematical and the physical floors are already given and defined by their well-known scientific status. What is problematic are the floor of the "Ideas" and the floor of Natural philosophy. The former overcomes what concerns our present[10] but the latter, according to Lautman, plays a crucial role in our theory of time. In the Lautman scale, Natural philosophy works in fact as a *lock* between Mathematics and its application in Physics. And it is here that the Leibnizian watershed of Nature plays a key-role: we leave *mv* and mv^2, as well as *energy* and *momentum*, to the physicist, keeping for the philosopher only the Leibnizian couple of *extensive* and *intensive*. This is the *Lautmanian sampling* of Natural Philosophy.

3 The *Zeitsein* in its Diagram

From Plato to Russell, passing through Leibniz, metaphysics has been crudely dualist. In the exsanguinous language of Russell, metaphysics boils down to the φx and the a to be substituted to the x in φx. So, in the vocabulary of Nicolaï Hartmann, Being is split in the *Sosein* of the "universals" φx and the *Dasein* of the "particulars" a. Yet, symbolic logic has been constructed by mathematicians, and in mathematics the typical a is a number, again in the *Sosein*. Conversely, the *Sosein* is supposed to include the caballeity.

Darwin has changed all this. To the extent that caballeity sits in the *Sosein*, the ancestors of the horse and the horses must previously pop up in the *Dasein*. According to Whitehead's vision, only geometrical forms and colours are "eternal objects". Then, the *Zeitsein* may be defined as the union of the *Dasein* and of the quiddities which, in the *Sosein*, are derived from the evolution at work

10 Deleuze has understood this point well. Barot has given a good account of it in his book on Lautman (Barot 2009), discussed in the symposium on Lautman (Marquis 2010). For more on the topic we must refer to our *Cavaillès et Lautman*, again in our scriptorium.

in the *Dasein*. The *Zeitsein* requires its *Übersistlich Darstellung* in the form of Figure 1, p. 341.
This representation is a doubled cone with its upper sheet and its lower sheet, separated by a plane. The lower sheet represents *time*; the upper sheet with the plane represents *temporality*. At the top of temporality, on the empyrean of metaphysics, we find the *Prototime:* in order to represent it we must imagine a compass rotating in the drawing of a circle.

The center of the circle, which is marked by the puncture of the compass, represents the *protopresent*. The radius of the circle, measured by the opening of the compass, represents the *protopast*. The compass' rotation represents the *protofuture*. The three parts of proto-time are divided into two subsets: the protopresent and the protopast are united in the *happened* (*advenu*), while the future is *à venir*.

In this construction, we find a first contingency: the circle can be traced either *dextrogyre*, in the sense of the hands on a watch, or *levogyre*, in the sense of the trigonometric circle. This is only a binary contingency: the two possibilities correspond to the two tickings of the *prototime-clock:* if the prototime turns dextrogyre, the ticking is *tick-tack;* if it turns levogyre, the ticking is *tack-tick*.

Now, the prototime is taken in a "bushing" operation *b*. We can have an intuitive idea of its effect only by analogy. We can imagine prototime by comparing it with an elementary particle that has to go through a Young split: before it crosses it, the path of the particle is straight; when it passes through the Young split, its localisation is determined.

Yet, we shall suppose that, because of this localisation, the velocity-vector of the particle (with its three dimensions, and so with its direction too) is underdetermined. Each state of the particle, the one before and the one after the Young split, corresponds to an effect of the bushing *b*. The first one is a *linearisation* of what has happened: the protopast is mapped onto an actualised part of the protofuture, so that the protopresent gets its chronological standard position: being *after* the protopast. The second effect is a *ramification* of the future in a fan of "future contingents".

The result of these two bushing operations on prototime is what I propose to call *Protoduration:*

$$b(\text{prototime}) = \text{protoduration}$$

From this hypostasis forth, one can conceive the genesis of the *Zeitsein* exploiting the affinities between the works of three philosophers: Elisabeth Anscombe,

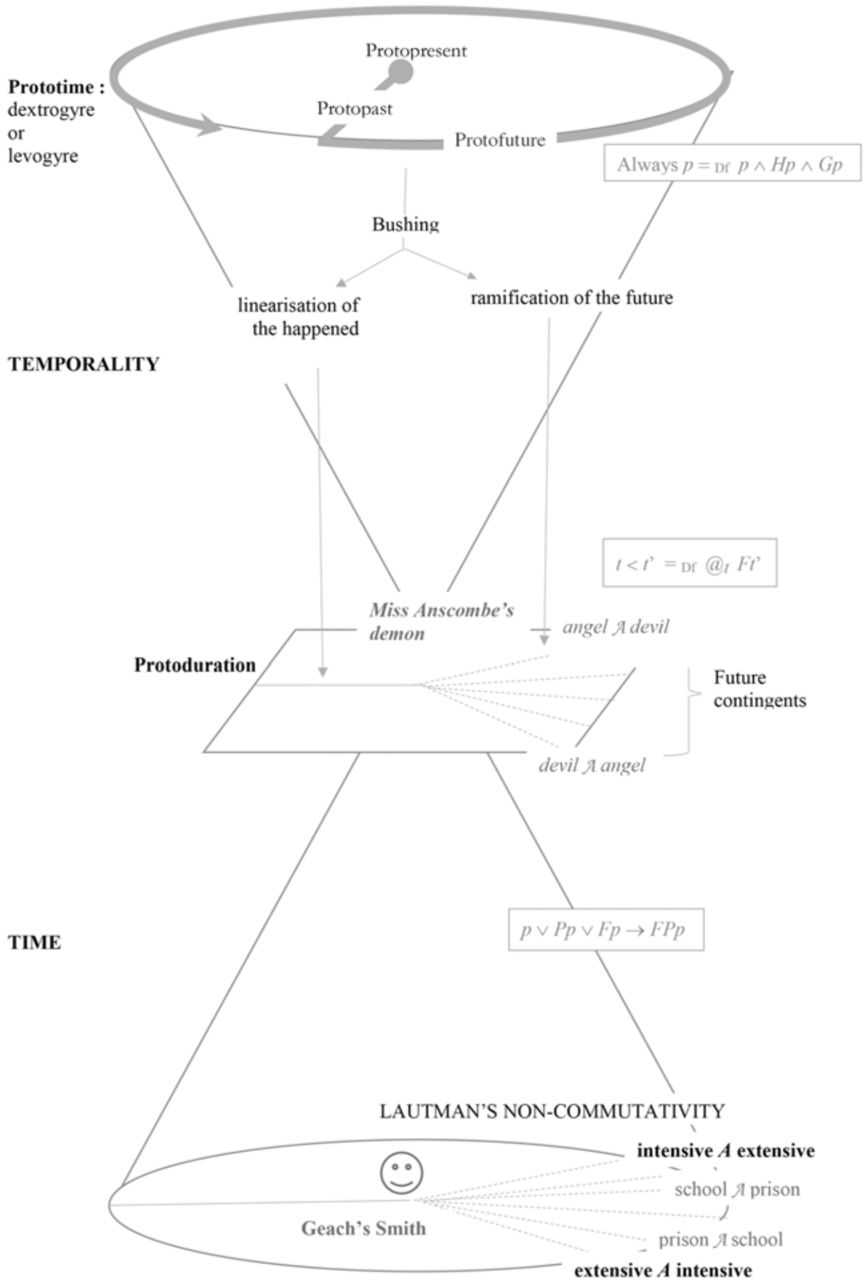

Fig. 1: Zeitsein

Peter Geach and Arthur Prior,[11] remembering that physics also has its demons: Laplace's demon, with his fatal determinism and Maxwell's demon, with his charge of neguentropy. But, since physics gives rights to its demons, we can give the same rights for metaphysics' demons.

With respect to protoduration, the tutelar demon is[12] *Miss Anscombe's one*. Her 1964's paper *Before and After* provides her contribution to tense logic. The title of the paper allows us to define *Miss Anscombe's demon*. Its essence is dipolar, that is made of two different possibilities: being an *angel* and then a *devil*; being a *devil* and then an *angel*. In symbols, *A* stands for the Anscombe tense operator "and after", so that the two main possibilities for her demon are:

angel *A* devil
("he is an angel, and then he is a devil")

devil *A* angel
("he is a devil, and then he is an angel")

Of course, these two possibilities are only two branches of a binary contingency amid the full fan of the contingents-futures opened by the protoduration. Thus, coming from *Temporality*, that is from *Prototime* and *Protoduration*, to *Time*, one has to distinguish between what is written in capitals and what is written in lower case.

In capital letters, we find the Lautman's non-commutativity (Lautman 2006, 269). And so, when Miss Anscombe's demon applies his metaphysical function to natural philosophy, the Leibnizian couple of the *extensive* and *intensive* becomes useful and relevant. The binary contingency will in fact take precisely the form of the two above mentioned natural possibilities:

intensive *A* extensive
or
extensive *A* intensive

11 For the relationship between Anscombe and Prior, see Gardies 1975, 120. It is in a letter to Prior that P.T. Geach defined the Transworlds Airlines *TWA* of his relation of *accessibility* between possible worlds in the same way as Prior did in 1962.

12 Anscombe was already married to Geach when my friend Georges Kalinowski met her at the Manchester *conclave* (*closed* colloqium) where Arthur Prior gathered together the few pioneers of deontic logic; but, as he told me later, he learned on this occasion that, in academic circles, G.E.M. Anscombe must only be named "Miss Anscombe". And it is only under this name that she has a demon.

Lautman asks to himself: is it possible to describe, in the womb of mathematics, a structure which would be like a first drawing of the temporal form able to qualify the sensible phenomena? (Lautman 2006, 277). Such a structure may be named *mathematical prototemporality.* Yet, our thesis is that there is also a *logical* prototemporality, and that *logical* prototemporality is the core of tense logic.

In lower case we register the fact that Elisabeth Anscombe married Peter Geach. And P.T. Geach tells us that: “Smith committed seven burglaries, then a murder and then he was hanged” (Geach 1957, 71). But in the *Zeitsein* Geach’s Smith becomes a concrete hypostasis of the two tickings in the prototime-clock. In miss Anscombe’s *Begriffsschrift:*

school *A* prison
(“he was at school, and then in prison”)
prison *A* school
(“he was in prison, and then at school”)

Now, our *Zeitsein* is displayed with all its hypostasises. Therefore, we can insert on its scale, each one in its proper place, the main laws of tense logic, also underlining the paradigmatic value that Prior attributed to them.[13] At the top, that is on the level of Prototime, we find the definition of the modality *Always* given by Prior. It is *not* defined by an instants-quantification (“Always *p*” = for all instants *t* it is true at *t* that *p*) but as a conjunction of temporal *modalities:*

$$\text{Always } p =_{\text{Df}} p \wedge Hp \wedge Gp$$
(“Always *p* means by definition that *p* and auparavant *p* and dorénavant *p*”)

At the level of Protoduration Prior gives the following definition:

$$t < t' =_{\text{Df}} @_t Ft'$$
“‘t is before t’’ means by definition that at t it is future that t’”

Here, we see that, on the Prior palindrome, the Carnapian order between *explanandum* and *explanans* is inverted: now, the *explanandum* is “before”, i.e., in McTaggart’s terms, a B relation of the B-series; while the *explanans* is *future*, i.e., an A attribute of the A series. The latter has become a tensed modality.

At the level of Time, we find *Findlay’s law:* the emblematic law of temporal logic which is also the first from an historical point of view. It was enunciated by

13 For a detailed exposition and explanation of this point, see Dumoncel (2018).

J.N. Findlay in a footnote of his paper on time (Findlay 1941). And, when Prior read it, he found the *impetus* to investigate both temporal and tense logic. Here is Prior's formulation of Findlay's law:

$$p \vee Pp \vee Fp \rightarrow FPp$$

("If *p* or it is past that *p* or it is future that *p*, then it is future that it is past that *p*")

Comparative Conclusion

Faced with the question "What is time?", the *Zeitsein* thesis needs to be specified in the light of both Elie During's and Etienne Klein's papers. Elie During has enunciated a new *Tertium non datur:* "There is no third time" between natural time and psychological time. But, in spite of the title of the present paper, the *Zeitsein* thesis is compatible with During's *tertium non datur*.

Yet, the thesis of During seems to entail a plain answer to Etienne Klein's question: "Who is entitled to talk about time?" If there is no third time in addition to physical and psychological time, then the answer to the question is that nobody is entitled to talk about time, except for physicists such as Julian Barbour and psychologists such as Marc Wittmann.

However, we may sustain a more balanced conception. This is because, in During's terms, there is a "'natural philosophy' stemming from contemporary physics". "Natural philosophy" is a sort of constant in the development of physics from Newton to Louis De Broglie and Albert Lautman. In the Lautman scale, as we have seen, natural philosophy finds its place, as a halfway house between mathematics and physics. Moreover, when Lautman took into account von Neumann's algebra, he recognized that the mathematical stratum of his Platonic scale is a *logico*-mathematical edifice. From Klein's viewpoint, the logical layer included in the logico-mathematical edifice defines exactly the place of *tense* logic.

Within temporal logic, tense logic runs the risk of being reduced to the logic of our phenomenal time. But this is a misunderstanding. The first mathematization of modal logic coincides, in the work of Arthur Prior, with the birth of temporal logic as a paradigm for modal logic and, in this mathematization, the frame represents the *ontology* of the modal model. Besides, since temporal logic is a kind of modal logic, the contribution of logic in answering the question "What is time" primarily concerns the part of temporal logic where the modal involvement (in Quine's sense) reaches its maximum point: *tense* logic.

Thus, if time is indisputably a feature of nature, the word *becoming*, as C.D. Broad remarked, reminds us that Time is primarily a feature of *Being*. And this is what the concept of *Zeitsein* shows.

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Marc Wittmann, Carlos Montemayor

Reinterpreting the Einstein-Bergson Debate through Contemporary Neuroscience

Abstract

We aim to recast the famous debate between Albert Einstein and Henri Bergson in 1922 in the context of contemporary psychology and neuroscience as informed by phenomenological analysis. We show that their disagreement is not as deep as has been considered previously, including Einstein and Bergson themselves. We argue that Bergson's dynamic view of consciousness as time constituting complements embodied models of time consciousness in modern neurophenomenological approaches. The phenomenological unity of time and self, including its inherent dynamism, is similar to that of recent neurophysiological conceptualizations, which suggest that the constantly ongoing integration of somatic signals over time generates a floating experience of the emotional self across moments of self-awareness. Embodied concepts of consciousness are thus grounded in the dynamic processes constituting the living body. We highlight empirical evidence informed by recent neurophysiological studies showing that the experience of time and the explicit judgment of duration are governed by emotional and visceral processes which share a common underlying neural processing system, the interoceptive system. Especially the insular cortex has shown to be related to the judgment of time as dependent on bodily and emotional states.

1 Introduction: the Debate between Einstein and Bergson

The enormous cultural and scientific significance of the debate between Albert Einstein and Henri Bergson has been amply documented.[1]As the scholarship on this momentous debate shows, academics and the public at large at the moment of the first encounter between Einstein and Bergson were quite divided, some firmly siding with Bergson against Einstein and vice versa. Einstein was probably quite concerned about the criticisms from Bergson, but eventually, Einstein

1 See Canales (2015); (2016).

https://doi.org/10.1515/9783110753707-019

gained the upper hand among both the scientific community and the public. To this day, the debate is considered as a clash between two towering figures with radically opposite views, and many would consider Bergson's perspective as either confused or not really in line with science.

Even at the time of their initial debate on April 6, 1922, and in spite of Bergson's reputation as one of the greatest philosophers at that time,[2] Bergson faced harsh criticism as a confused and irrational thinker.[3] This polarization of the debate quickly took it into dramatic proportions. Rationality and scientific methodology was associated with Einstein by his supporters, who thought of Bergson as a cult figure who promoted mystical approaches to the crucial topic of the nature of time. But Bergson's supporters thought of his criticism as an enormously important attack on a reductive and mechanistic perspective that deprived our view of the world of its natural vitality, turning it into a world of frozen relations—in the case of time, "a frozen grid that scientists call spacetime" (Montemayor 2013, xi), also known as the "block-universe".

Einstein famously took the passage of time to be a stubborn illusion. Bergson, by contrast, considered time as the foundation of vitality, or impulses, as well as of all dynamic and meaningful relations, including the sensorial properties we are conscious of. Is their debate, thus portrayed, between a view that presents reality as a set of frozen relations versus a view that reduces objective temporal properties to impulses and vital forces? A debate between the mechanistic agenda of scientific superiority and a view of the world based on the human spirit? On this superficial reading of the debate many distinctions would disappear from view; we would miss important nuances of how Einstein and Bergson clarified their views in interactions with other thinkers. In particular, we would ignore Bergson's constant interest in mathematics and physics as well as Einstein's interest in the question of what could explain the illusion of time.

Although there is some truth to the claim that this debate is a stark illustration of "a world largely split into *science* and the *rest*" (Canales 2015, 7), we believe contemporary neuroscience and current psychological approaches to phenomenology have much to offer to the project of recasting and reinterpreting this debate in new and insightful ways. It is not our purpose to settle the debate or claim a definitive interpretation of it. Our main claim is that if one understands Bergson as a phenomenologist with specific claims about the psychology of time, then the alleged chasm between Einstein's *scientific side* and Bergson's *un-*

2 See Dewey (1912).

3 See Berlin (1935); Russell (1912).

scientific and irrational side starts to close and vanish. Isaiah Berlin gives us a clue as to how we can approach Bergson's perspective in his criticism of Bergson's work. Jimena Canales writes: "The historian and theorist Isaiah Berlin associated him [Bergson] with the 'abandonment of rigorous critical standards and the substitution in their place of casual emotional responses'" (Canales 2015, 13).

Surely, there is a place for the role emotion and consciousness play in our lives, and there are certainly scientific approaches to time consciousness. Bergson is not typically considered a phenomenologist, a lineage that is associated with Edmund Husserl and his students, who actually distanced themselves from Bergson (Canales 2015, 139–152). We briefly explore this issue in section 3, but it is important to appreciate that Bergson's emphasis on time as experienced through the vitality of emotions, motivations, and conscious awareness is a central topic of contemporary neuroscience.[4] The main point of this discussion is to show that, given the current evidence on the issues Bergson's philosophy revolved around, his seemingly titanic disagreement with Einstein might be based on an unfortunate misunderstanding, given the contemporary perspectives on time in metaphysics and psychology. On the one hand, Einstein is right in insisting on the mind-independent character of temporal relations, as the next section shows. On the other hand, Bergson is also right in insisting on the importance of experienced time as essential to our understanding of ourselves, as section 3 shows. These are both plausible and even complementary perspectives on time. As mentioned, the key to appreciate how they might be complementary is to understand this debate in the light of contemporary neuroscientific approaches to the psychology and phenomenology of time. In other words, science has changed dramatically in the fields of cognitive psychology and neuroscience, providing empirical evidence that Einstein and Bergson did not have available. Recasting the debate between Einstein and Bergson under the light of contemporary psychology shows that their disagreement is not as deep as has been interpreted so far, and certainly not as deep as both Einstein and Bergson took it to be.

2 Metaphysical Implications of the Einstein-Bergson Debate

In what sense was Einstein right when he said that "the time of the philosophers did not exist" (Canales 2015, 5; *Il n'y a donc pas un temps des philosophes*). Dur-

4 See, e.g., Damasio (1999); Craig (2015).

ing the event in which Einstein met Bergson, Einstein clarified what he meant by this. Canales reports: "What Einstein said next that evening was even more controversial: 'There remains only a psychological time that differs from the physicist's. At that very moment, Einstein laid down the gauntlet by considering as valid only two ways of understanding time: physical and psychological" (Canales 2015, 5). What kind of challenge is this? Can there really be a third time, besides the physical and the psychological?

Canales describes Bergson's response to this challenge as follows: "The simple, dualistic perspective on time advocated by Einstein appalled Bergson. The philosopher responded by writing a whole book dedicated to confronting Einstein. His theory is "a metaphysics grafted upon science, it is not science" (Bergson 1999, 47). The book in question, *Duration and Simultaneity*, lays out a conception of time that identifies time with the continuity of our inner life, not as a stage with subsequent and discrete parts or transitional snapshots, but as a vital flow that determines duration itself, in opposition to everything that is rigidly and metrically determined. Kant famously also identified time with the "inner sense" of our minds, and said that it is in this inner intuition that we arrive at our knowledge of arithmetic —as opposed to geometry, which is based on our intuition of space or "outer sense". Interestingly, Bergson believes this is a recapitulation of the scientific perspective Newton favored in terms of absolute time and space (Kant's purpose is to defend the Newtonian system). Thus, perhaps the best way to characterize Bergson's account of time as the vitally creative force of duration in "our lives" is to define it as a non-metric experience, or a conscious experience that cannot be reduced to any metric relation, such as simultaneity, temporal order, or "clock-based" duration. As discussed further below, this is an approach the phenomenological movement, notably Edmund Husserl, favored and elaborated on.

But surely metric relations matter to how our perception and experience of time are structured. Bergson and Einstein could not know all the details at the time of their debate, but cognitive scientists now have provided ample evidence showing that the circadian clock and a short "stop-watch" clock are very important to how we perceive time. Both clocks are "psychological" in Einstein's sense, because they help us represent environmental relations in terms of the temporal properties of events (see Montemayor 2013, for a philosophical account of how these clocks generate representations that ground justified beliefs about time). This is psychological time, but it fundamentally depends on the activity of clocks: neurally instantiated time-keepers. So metric relations matter, and must be somehow reconciled with the vital duration we experience with emotions.

What about the phenomenology of time, or what Bergson describes as the transcendental nature of the flow and unity of our experiences? It may be more productive to think of it, not as a third kind of time, what Einstein calls "the time of the philosophers". Instead, reflections about the phenomenology of time should be informed by our knowledge concerning physical and psychological time. The phenomenology of time cannot be completely independent from physical and psychological time and in that sense, a dualistic account is foundational in order to understand the flow of time. But also, the situation is not fully reductive —the non-metric character of the flow and phenomenology of time needs to be explained. Even if Einstein is right and the flow of time is illusory, we must explain what produces such an illusion.

A dual model of time perception explains some of the key features addressed by both Einstein and Bergson. Brief scales of time in the millisecond range are directly linked to temporal features of the environment but at the seconds' stage, the phenomenology of presence starts weaving all the contents of our conscious awareness in a unity that transcends the previous metric structures (Montemayor and Wittmann 2014). The experiential and visceral vitality of our emotions and agency, which are the central focus of Bergson's account of time, can be explained in terms of a dual model that distinguish agency from early sensorial temporal processing (Montemayor 2017a), unconscious processing from visceral and arousal-related temporal awareness (Montemayor 2017b) and with respect to the present, a phenomenal present from a sensorial present (Montemayor 2013). Early sensorial processing concerning the relations of time order and simultaneity may occur without conscious awareness at the first stage of processing (a pre-agential processing). Then the agent is equipped with the necessary representational framework for integrating arousal-related information with her overall conscious experience in the phenomenal present (distinct from the sensorial present that relates stimuli in terms of simultaneity). Thus, Bergson's account of time based on emotions and agency is compatible with the perception of metric properties, associated with time in physics (involving the relations of simultaneity, temporal order, and duration).

So, what exactly are the metaphysical implications of Einstein's challenge to Bergson? One can accept Einstein's characterization of a dualistic approach to time, as well as most of what he said about physical time in opposition to Bergson, partly based on the psychological findings and proposals just mentioned. In addition, as will be explained in the next section, one can still justify the importance of the phenomenological project formulated by Bergson. These are not antagonistic or irreconcilable tasks. From an epistemic point of view, our beliefs about temporal relation need to be justified and for this we need the environmentally-based metric relations of simultaneity, duration, and time order.

Bergson's characterization of Einstein's view as "metaphysics grafted upon science" cannot be right without some clarification. As Reichenbach (1958) explains, it is because of Einstein's theory of Relativity that we have arrived at an empirically testable theory of time and space that is also susceptible of rigorous mathematical formalization, unlike all the preceding views on time and space which depended on axiomatic first principles and a priori intuitions. This is a complex issue[5] and we will examine this claim from a phenomenological perspective in the next section. But the main point is that Einstein's contribution to the study of space and time was deeply *philosophical*. Reichenbach (1958) argues extensively for the case that Einstein transformed the epistemology of space and time by updating it with ideas that are equally applicable the psychological space and time as well as physical spacetime. Reichenbach shows that coordinative definitions are essential for the empirical, rather than strictly a priori, study of space and time and that these coordinative principles must be in place any time one asks the questions concerning what is the actual geometry of a space and time given conventions about rigid bodies —again, including psychological space and time (e. g., visual, auditory, proprioceptive). Bergson's general statement that Einstein's theory is "metaphysics grafted upon science" misses entirely this point.

If Einstein is right, and there are only physical and psychological time, what follows for the metaphysics of time? As mentioned, one immediate implication is the approach to this issue, shifting from exclusively *a priori* or *armchair* perspectives to a posteriori or empirical ones (Reichenbach takes this to be the most important contribution of Einstein, particularly against Kant). We offer in the concluding sections evidence for both psychological time and the phenomenology of time, as the latter functions as the informative basis of the former, thus confirming this implication. Crucially, all of the contemporary metaphysical views of time are attempts at addressing Einstein's theory. While Einstein seems to have favored a block view of the universe in which change or passage of time have no place and the present is not unique, many recent views of time modify the strict requirements of the block universe to accommodate either change or passage.[6]

For instance, scientific theories of static time similar to the block universe explain our experience of the passage of time by appealing to neuroscience,[7] or by proposing that while events might be objectively static, change does occur in terms of temporal order in relation to the emergent macroscopic properties that we associate with psychological time.[8] So-called "Growing Block" the-

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5 See Ryckman (2005).
6 See contributions in Dolev and Roubach (2016).
7 See Barbour (1997).
8 See Rovelli (2018a); (2018b).

ories appeal to real becoming,[9] in a way that depends on a moment that can be characterized as the “now” involved in the passage of time.[10] Arguably, any theory that appeals to a moment in which time branches, or in which there is a spotlight that demarcates the Growing Block of spacetime is presumably a view that depends on a kind of objective characterization of the present moment as uniquely relevant for demarcating the boundary between the real and the possible.[11] However, there are convincing arguments showing that passage can be accommodated in a block universe view, without making our experience of passage fundamental or primitive.[12] These are all metaphysical and scientific views of time that try to accommodate the kind of passage that seems to have been, at least partly, the focus of Bergson’s theory of time. Contemporary versions of the A theory dispense with such a robust understanding of passage, for instance by emphasizing instead property instantiation.[13] While there are intricate issues concerning the topology, metric, and other metaphysical aspects of time that are relevant for the precise formulation of the A and B theories, our focus here is on how Einstein and Bergson understood the physics of time in relation to psychology.

Bergson’s charge against Einstein’s theory, namely that it inadequately injects metaphysics into physics, has not aged well. Most contemporary philosophers and scientists find various philosophical insights in Einstein’s theory, including unprecedented epistemological insights about the nature of spacetime. But the relation between the psychological and the phenomenological remains a crucial difficulty. Einstein might be right that there is no “third time” of the philosophers, but surely simply saying that there is psychological and physical time is not enough. The “stubborn illusion” of time frames our life very deeply, as Bergson described, and this phenomenon deserves careful explanation.

3 Phenomenological Implications of the Einstein-Bergson Debate

Many of the observations Bergson made in his original debate with Einstein and in subsequent exchanges are phenomenological. Interpreted as a phenomenolo-

9 See Dowker (2014).
10 See Smolin (2013); (2014); (2015).
11 See Zimmerman (2008).
12 See Skow (2015).
13 See Sullivan (2012).

gist, Bergson presents a series of epistemic points that Einstein should have taken more seriously. In particular, Bergson's characterization of time as irreducible to discrete quantities or mechanical characterizations is one that plays a very important role in the reception of Einstein's theory within the physics community. These are issues concerning the conscious basis of metric relations, coordinate systems and mathematics itself. Experienced duration is a vital unity from which all these abstract characterizations of time emerge. This section illustrates how Bergson is not alone in making these points, and in fact, he is in illustrious scientific company. The concluding sections show how contemporary approaches to neuroscience and phenomenology can be used to update and reinterpret the Einstein and Bergson debate.

Hermann Weyl explicitly addressed the problem of "how to bridge the gap or 'chasm' between the intuitive continua of space and time and the mathematical continuum. Based on the work of Edmund Husserl, Weyl opted for *phenomenal time* as the source of our intuitions of the mathematical continuum" (Montemayor 2012, 56). Bergson's emphasis on the vital and life-dependent character of phenomenal time are even more in line with current scientific evidence, as the research on interoception discussed below demonstrates. But there is much in common between the Husserlian approach and Bergson's here. One can find some of the same themes, and criticism to the mechanical view of reality initiated by Husserl and later by Heidegger in the work of Bergson. In a discussion on the idea of duration contained in *Time and Free Will* (1889/1913), Bergson proposes that consciousness presents the sequence and homogeneity of numbers in a two-fold manner, as a discrete succession for cognition and as an underlying unit, the unit of conscious awareness. In the unit of phenomenal time, nothing is discrete and succession is replaced by seamless continuity. There is a very fundamental epistemic point about physics in these remarks, including the work of Einstein, as Weyl famously argued in various scientific works:

The epistemological thesis that cognition in the exact natural sciences is the joint ('relative') product of objective characterization in precise mathematical concepts, *and* the subjective 'immediate life of intuition', belongs to transcendental-phenomenological idealism. In its terms, the very *sense* of objectivity is constituted within 'transcendental subjectivity', and accordingly, there must indeed be a vestige within the 'objective world' represented by the mathematical/conceptual theories of physics of its 'origin' in the 'absolute' being of the given-to consciousness. Through reflection on the applications of mathematics in physics, Weyl recognized an ineliminable trace of the subjective source of all objectivity in the arbitrary fixing of a local coordinate system (Ryckman 2005, 135).

The immediate life of intuition is grounded, according to Bergson, in the very vitality of emotion and creative feeling. In time, this insight became a crucial assumption of the view called "the Embodied Theory" of the mind. Ideas about embodiment also entered the debate surrounding how to best approach the phenomenological project originated by Husserl. Merleau-Ponty, in particular, explored the bodily-based forms of spatiality and temporality that were infused with expectation, emotion, and creativity, just the way Bergson envisioned (more on this below, particularly with respect to findings on interoception). On this Bergsonian account of the phenomenology of time, our experience of vitality in time, in our lives, is a source not only of creativity and visceral engagement, but also of attentive strategies towards formalizations that depend on the source of the flow of life-time for their content, such as numerical and geometric abstractions.

Thus, Einstein is partly right when he affirms there are only two times, psychological and physical. This does not mean, however, that he should have ignored Bergson's claims about the centrality of phenomenology. Weyl, who was as qualified a physicist as was Einstein, fully appreciated the importance of phenomenology, and he gave it, accordingly, a critical role in his scientific and philosophical writings. As Ryckman explains in the passage above, Weyl sees the inescapable appeal to coordinate systems as depending fundamentally on our subjective awareness of time. This obviously includes the kind of *objective* coordinative definition emphasized by Reichenbach in his work on Einstein.

Bergson, as a phenomenologist, can be vindicated in the tribunal of history. His role in his debate with Einstein was important for philosophical and scientific reasons, rather than ideological and mystical motives. But, to restate differently the previous point, what would it mean to say that the "time of our lives" associated with morality, free will and creativity is "not-psychological" and, even more puzzling, what would it mean for the time of our lives to be absolutely *unrelated* to metric relations, such as simultaneity and time order? The following sections address these two issues, first by giving an account of the perception of temporal relations and second, by providing evidence of the psychological and neural basis of the experience of time.

Bergson is right that the irreducible datum of time is the flow and passage of our inner lives, which manifests itself at its clearest in the visceral and empathic reactions we associate with the vitality of conscious awareness (see Montemayor and Haladjian 2015, for how these reactions are best understood as phenomenal consciousness, dissociated from the more strictly epistemic functions of attention). But this is not the whole story. This continuous flow is also the basis upon which more hypostatic forms of attention depend, particularly concerning mathematical objects. The foundation of coordinative systems for mathematics, physics, and science in general, can be found in this "immediate life of intuition".

But what do these phenomenological observations have to do with what Einstein called “psychological time”? As explained above, with respect to the philosophy of space and time, Einstein’s epistemological contribution was to move the debate from a strictly a priori analysis (judgments arrived at through reasoning and intuition alone) to a posteriori reasoning (judgments arrived at on the basis of empirical evidence). Perhaps a similar advancement may be necessary in the case of phenomenology and psychology of time. The next sections provide evidence that is relevant for this project; these are scientific findings that neither Einstein nor Bergson had available. Section 4 discusses evidence concerning the perceptual capacities underlying representations and inferences about metric structure, or the environmental properties of events that must be understood in terms of relations of simultaneity, duration, and temporal order. Section 5 discusses findings on the relevance of interoception for what Bergson called “lived time”.

4 Current State of Affairs in the Psychology and Neuroscience of Time Perception

The systematic study of time perception became possible in the second half of the 20th century with the advent and elaboration of internal-clock, or stopwatch, models developed in the cognitive sciences.[14] In essence, these models posit that a pacemaker sends out pulses which are sent to and stored in an accumulator by passing through a gate.[15] According to these models the number of pulses stored in working memory would represent experienced duration. Strong evidence for clock-like properties of this timing system, i.e., as counting of clock ticks, comes from empirical work showing how physiological manipulation of the assumed clock rate induces relative under- and overestimation in animals and humans (respective right- or leftward shifts in the psychometric response function).[16]

To more accurately account for human timing performance in a further developmental step, an element was added to the model pertaining to the attentional focus of a human observer. According to the attentional-gate model[17] pulses are only registered when attention is directed to the passage of time and a

14 See Wearden (2016).
15 See Treisman (1963); (2011).
16 See Meck and Church (1983); Meck (1996).
17 See AGM; Zakay and Block (1997).

switch is closed which in turn opens a gate to the accumulator. This means that the estimation of duration is always a dual task. An observer can divide attention between experienced time and non-temporal features of an event. During a period of waiting for a personally important event to occur (the phone call of a loved person) most of our attention is directed to the passing of time, which then leads to an overestimation of waiting time.[18] According to the AGM, two factors modulate the estimation of duration:[19] (1) An increased emotional (bodily) arousal level increases the pacemaker rate and in turn leads to relative greater accumulation of pulses during a given time span; (2) A stronger focus of attention to time similarly leads to more inflow of pulses in the accumulator as the postulated gate is more frequently open. Importantly, the AGM relates only to time judgments under prospective conditions in which subjects are explicitly instructed to attend to time. Under retrospective conditions, in contrast, study participants are unaware that they will later be asked to estimate time while they perceive an event. The task becomes retrospective when the participant is instructed to judge duration after the event has ended. Then memory load pertaining to that period of time defines subjective duration; the more recall of changing features of the past interval, the longer duration estimates.[20]

The AGM is used in purely behavioural studies to explain relative over- and underestimations in prospective time perception tasks in an intuitively plausible way. For example, concurrent secondary tasks lead to a relative underestimation of duration because attention is diverted from the primary timing task; with increasing work load of the secondary task an increasing underestimation of duration is detectable.[21] In one study, less attractive faces were associated with a relative underestimation of duration as compared to neutral and attractive faces.[22] This was interpreted as stemming from the dislike and therefore reduced attention to the unattractive stimuli. Regarding the factor of arousal, judging duration of emotional negative stimuli with presentation times around 2 seconds as compared to neutral stimuli in one study not only led to relatively greater physiological arousal (as measured with the skin conductance response) but the negative sounds also generated relatively longer subjective duration.[23] Using video clips with presentation times between 16 and 40 seconds, slow-motion scenes, as compared to real-time scenes, induced lower arousal (lower respiration rate

18 See Jokic et al. (2018).
19 See Burle and Casini (2001); Droit, Volet and Meck (2007).
20 See Brown (1985); Zakay and Block (1997).
21 See Brown (1985).
22 See Ogden (2013).
23 See Mella et al. (2011).

and smaller pupillary diameter) which in turn was associated with a systematic underestimation of duration.[24] Although practically speaking empirical results do not always conform to the model's predictions,[25] the AGM is popular because of its strong heuristic value in explaining everyday subjective time. In the case of experienced boredom, the focus of attention is predominantly on time, and duration expands.[26] During entertaining activities, when one is absorbed in what is happening we do not attend to time and the event passes comparably quickly, time flies.[27]

Regarding the neural basis of subjective time, i.e., the question of *how* and *where* in the brain time in the range between milliseconds and multiple seconds is processed, for many decades research focused on several distinct neural systems. Researchers are informed about the implication of certain neural networks involved in duration judgment using neuroimaging techniques (fMRI, EEG), through neuropsychological testing of brain-injured patients, by the transient interruption of neural processes with transcranial magnetic stimulation (TMS), and by assessing the effects of psychopharmacological agents. For several decades two competing models were favored for explaining the neural basis for sensory and motor timing: (1) Fronto-striatal circuits comprising recurrent loops between frontal cortex (SMA), caudate-putamen, pallidum and thalamus, which are modulated by the dopamine system;[28] (2) the cerebellum, which has non-overlapping neural modules with different neural delay properties which could encode duration.[29] Empirical evidence also points to several other regions such as the right posterior parietal cortex, which might be involved in general magnitude processing of time, space, and number,[30] and the insula, the interoceptive cortex, i.e., the primary cortical area for receiving bodily signals.[31]

Meta-analyses of functional neuroimaging studies shed light on the duration dependency of the neural correlates of time. It seems that although the identified brain areas are involved in both the processing of sub- and supra-second intervals, relative more activation of subcortical structures appears with sub-second stimuli, whereas relative more activation of cortical regions is detected with

24 See Wöllner et al. (2018).
25 See Jones (2019).
26 See Zakay (2015); Jokic et al. (2018).
27 See Wittmann (2015).
28 See Harrington et al. (2004); Hinton and Meck (2004).
29 See Ivry and Keele (1989).
30 See Bueti and Walsh (2009).
31 See Wittmann et al. (2010).

supra-second stimuli.[32] Such a duration-dependent distinction has also been detected for effects of manipulation on the serotonin and dopamine transmitter systems. For example, healthy participants in timing studies were genotyped to compare individual temporal processing performance with genetic polymorphisms. Whereas temporal discrimination variability of visual stimuli around 500 ms were associated with a polymorphism related to D2 receptor density in the striatum, timing variability with stimuli around 2 s was associated with a polymorphism related to synaptic dopaminergic metabolism in the prefrontal cortex.[33] This duration-dependent distinction between striatum and prefrontal cortex fits with the above mentioned sub- and supra-second activation for subcortical and cortical brain regions, respectively.[34] Gene polymorphisms related to the serotonin system, but not the dopamine system, were associated with duration discrimination of longer intervals, namely with several seconds duration (with an average of 4.8 s).[35] This conforms to behavioural findings of double-blind, placebo-controlled, studies using microdoses of psychedelic substances, i.e., subthreshold doses without noticeable effects on experience, which act predominantly on the serotonergic system. Two studies using psilocybin[36] and LSD[37] detected deviations of timing performance under the influence of microdoses only for intervals longer than 2 seconds. However, an entire cocktail of neurochemical systems contributes to the experience of time. The neurotransmitter GABA has been correlated with timing accuracy in the subsecond time range;[38] the neuromodulator oxytocin induced a specific time dilation and compression effect for happy female and for happy male faces, respectively, in heterosexual male viewers.[39]

To sum up these elaborations, next to the above-mentioned involvement of several transmitter systems, multiple neural networks are involved in the processing of time on different time scales.[40] Recent neuroimaging studies point to several areas in the frontal cortex (SMA, inferior frontal gyrus), right intraparietal sulcus, the basal ganglia, and the insula.[41] One could argue that starting in

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32 See Nani et al. (2020).
33 See Wiener et al. (2011).
34 See Nani et al. (2020).
35 See Sysoeva et al. (2010).
36 See Wackermann et al. (2008).
37 See Yanakieva et al. (2019).
38 See Terhune et al. (2014).
39 See Colonnello et al. (2016).
40 For an extensive discussion of empirical findings, see Wittmann (2009), passim.
41 Nani et al. (2020); Teghil et al. (2019).

the 1980ies researchers were trying to find a dedicated timing system, an internal clock in a neural network which would be solely responsible for the processing of duration. What has emerged over the last couple of years is the insight that there is not one mechanism or area in the brain responsible for encoding time, but that there is a manifold of brain functions which rely on general dynamic properties of neural circuits.[42] From the distributed neural circuits with its intrinsic neural patterns of activity there might be one circuit that is predominantly involved according to modality, task requirements, and the duration of the interval processed.[43] Alternatively, several of these neural circuits could work together in an integrated fashion to cover different functional subcomponents for tracking time.[44] The heterogeneity of neural mechanisms and brain circuits explains why many patients with a variety of diagnosed neurological disorders are often affected in the accuracy and precision of duration judgment. In those patient groups performance rarely breaks down completely, e.g., in patients with essential tremor who are diagnosed with anatomically widespread cerebello-thalamocortical dysfunctions.[45] If one neural system is damaged, other parallel systems can partially take over and compensate. Timed behaviour is still possible, albeit impaired.

5 Interoception as the Basis for the Experience of Time

In the following we focus on one functional and anatomical module of the brain related to interoceptive (bodily) awareness which, over the last few years, has been implicated in the processing of subjective time. We will discuss the connection between empirical results in the cognitive neurosciences on the relationship between time perception and interoception with phenomenologically inspired ideas of temporal experience. Starting with the systematic analysis of Maurice Merleau-Ponty, individual philosophers have held the idea that perception and action, including subjective time and motor timing, are embodied faculties of the mind. The further developments of the enactive/embodied cognition models of subjectivity accordingly claim that the phenomenal first-person perspective of

42 See Paton and Buonomano (2018).
43 See Buhusi et al. (2018); Issa et al. (2020).
44 See Tomasi et al. (2015).
45 See Pedrosa et al. (2016).

experience and behaviour depends on the dynamics of the corporal self.[46] A classic study was conducted by Martin Strack and his students (1988) which showed that feedback from facial muscles influence felt emotions: Participants rated cartoons as funnier while they were presented under the condition with a pen in the mouth that facilitated muscles expressing positive emotions (a smile) as compared to a condition where a pen inhibited smiling, i. e., a pen facilitated muscles expressing negative emotions.

Subjective feelings depend upon bodily signals, i. e., visceral and somatosensory feedback from the peripheral nervous system, which inform us about the state of the body. These somatic signals are integrated with sensory signals from the other senses and with reference to the motivational, social and cognitive situation; in sum this integration capacity leads to the conscious awareness of the momentary emotional condition of an individual.[47] One neural processing route in the multistep integration of ascending somatic signals culminates in the insular cortex, where the primary entry location for the signals is the dorsal posterior insula. This brain region has been termed the *primary interoceptive cortex*, the primary area in the cortex to process signals from all bodily organs.[48] The fact that the insula is richly connected with other brain areas (limbic, sensory-motor) substantiates the view that interoceptive (embodied) processes underlie perception, cognition, and emotion. Several studies have shown that the conscious awareness of visual stimuli depends on how close they occur to the heartbeat; the closer the external stimuli to the heart beat, the lower accuracy of perceptual detection. For example, a neuroimaging study showed that the neural signals from the heart, as recorded in the insula, suppressed visual information when it was presented too close to the heart beat.[49] Cardiac timing effects were also shown with emotional stimuli. Fearful faces were judged as more emotionally arousing when photos were presented at the cardiac systole (the actual heart beat) compared to when they were presented at the diastole (the relaxation period between heart beats); these effects were correlated with activity in the amygdala and insula.[50]

The insular cortex contributes to the experience of duration in the sub-second and supra-second time domain as repeatedly documented in reviews of neuroimaging studies.[51] In our own neuroimaging research we employed a duration

46 A prominent neurophenomenological approach is put forward by Varela et al. (1991|2016).
47 See Damasio (1999).
48 See Evrard (2019).
49 See Salomon et al. (2016).
50 See Garfinkel et al. (2014).
51 See Wiener et al. (2010); Teghil et al. (2019); Nani et al. (2020).

reproduction task with multiple-second tone intervals (3, 9, 18 seconds) in which individuals are presented first with a tone of varying interval lengths (encoding phase) which subsequently have to be reproduced in duration (reproduction phase).[52] Ramp-like increases in fMRI activation was detected in the insular cortex which corresponded to stimulus duration. Activity ended with the termination of the to-be-timed stimuli in both the encoding (dorsal posterior insula) and the reproduction period (anterior insula). The very same duration reproduction task also proved to be related to recorded body signals. Cardiac periods increased (the heart slowed down) and skin-conductance levels decreased (a sign of relaxation) progressively during encoding and the reproduction phases for auditory[53] and visual intervals.[54] In a similar duration reproduction task, but with much shorter acoustic and visual stimuli (500 to 1500 ms), activity in mid-insula (encoding phase) and the left anterior insula (reproduction phase) was reported.[55] The authors speculated that insula activity in this temporal task could be related to the feeling of time passage.

The feeling of time passing could be used in sentient beings as a way to track time. We will come back to this idea a little later. Recent work led by Alice Teghil convincingly points to the involvement of interoceptive processes in the perception of time. In their behavioural study two duration reproduction tasks with intervals lasting between 8 and 18 seconds were used, filled with (a) regular spaced and (b) with irregular spaced stimuli.[56] The regular condition thus provided external cues on presented duration which the irregular task did not. Only timing accuracy of the duration reproduction task with irregular stimuli was predicted by trait-like interoceptive awareness assessed by the Self-Awareness Questionnaire. That is, the general ability to be more aware of somatic states helped subjects to be more accurate in time perception when no regular external signals were available; they consequently had to rely on the dynamics of their bodily self to judge duration. These findings are indicative of the assumption made above that different distributed timing systems might come into play with different weights, across individuals but also within a person depending on the task given. An inter-individual propensity to be more aware of bodily processes helped subjects to be more accurate in the timing task. With fewer external cues available subjects potentially had to rely more on internal signals. This interpretation is founded on a subsequent study by Alice Teghil and coworkers

52 See Wittmann et al. (2010), (2011).
53 See Meissner and Wittmann (2011).
54 See Otten et al. (2015).
55 See Bueti and Macaluso (2011).
56 See Teghil et al. (2020a).

with the same duration reproduction task, where they showed that posterior insula connectivity, which was modulated by individual interoceptive awareness as measured with the Self-Awareness Questionnaire, correlated only with the irregular condition and not with the regular condition.[57]

In a different study using dynamic video clips with intervals between 1 and 64 seconds, duration estimates could be explained by the amount of changes in the contents shown in the scenes, and not by measured cardiac responses or eye recordings.[58] Participants in that study might have used the accumulation of perceived events stored in working memory to deduce experienced duration. These studies in combination show that, depending on the outward structure of the changing world, we can use visual or (acoustic) cues to deduce time. Or, when these cues are absent or irregular, we can rely on our internal body changes to judge duration.

What happens when the insular cortex is neurologically damaged? In a single-case study, an epileptic patient who suffered from focal damage to the right anterior insula showed severe impairments in the timing of multiple-second time intervals in the above-mentioned duration reproduction task, an impairment that did not occur in epileptic patients with damage to other cortical regions.[59] Relating to duration estimation of shorter intervals between 300 and 1500 ms, one study recruited and tested twenty-one neurological patients with a stroke in either the right or left insular cortex and compared performance with that of twenty-one control subjects.[60] Only patients with right-hemispheric lesions, and not those with left-hemispheric lesions, quite remarkably underestimated the presented durations.

A comprehensive account regarding the relationship between awareness of bodily states, emotions and subjective time has been provided by Bud Craig (2009; 2015). A link between the three objects of awareness (body, emotions, and time) was proposed because the experience of time is related to emotional and visceral processes which share a common underlying neural processing system, the interoceptive system which includes the insular cortex. Based on the constantly ongoing processing of ascending bodily signals from the periphery and the internal organs a series of conscious emotional moments is created over time. Our sense of the bodily and emotional self is informed and constantly updated through ascending somatic signals integrated in the insula (therefore Craig's programmatic book title "How do you feel?"). Accordingly, the sense of

57 See Teghil et al. (2020b).
58 See Suárez-Pinilla et al. (2019).
59 See Monfort et al. (2014).
60 See Mella et al. (2019).

time passage would evolve by the awareness of successive moments of bodily and emotional self-realization within a social and cognitive context. In essence, Craig presents an embodied theory of consciousness as grounded in the dynamic processes constituting the living body.

6 Phenomenological and Neurobiological Accounts of Temporality

What we want to put forward in the context of this chapter is that Henri Bergson's dynamic view of consciousness as time constituting complements to some extent the embodied model of time consciousness we present here. We are not discussing Bergson's metaphysical accounts of time[61], but—similar to Barry Dainton's (2017) analysis of Bergson—consider him as phenomenologist of time. According to phenomenological analyses in the 20th century (Husserl, Heidegger, Merleau-Ponty), self-consciousness and time-consciousness are inseparable. Conscious awareness can be described as an island of presence in the continuous flow of what happens (Metzinger 2004). Conscious states are inherently given to me; phenomenal experience is mine (Nagel 1974). Time as continuous flow of events in the present moment is linked to someone who experiences something, i.e., conscious perception includes a basic form of self-consciousness (Zahavi 2005). The phenomenologically deduced unity of *time* and *self* can be expressed as: "there is no time without a self; there is no self without time".[62] Julian Kiverstein (2009) summarizes this unity within the framework of Edmund Husserl's conceptualization of the tripartite structure of temporal experience encompassing past, present, and future as follows: I become aware of what is happening now *to me* through what just happened *to me* and expectations of what might happen *to me*. Self-consciousness ("what happens *to me*") is created through the temporal structure of consciousness as constituted through what has just happened (retention) and what is about to happen (protention) in an extended present.[63] This extended present which encompasses a past and future orientation however is dynamic as "…the new present is the passage from a future to the present and of the previous present to the past—time

61 For an attempt to link Bergson's metaphysical ideas of temporality with neurobiology, see Korf (2015).
62 "Time must be understood as a subject, and the subject must be understood as time" (Merleau-Ponty 2012, 483).
63 See Husserl (1928).

itself in motion [...] within a single movement" (Merleau-Ponty 2012, 442). This description thus is not about a sequence of static moments, one after the other, but the moment itself is constituted by the movement of the tripartite structure of time. A phenomenologist would accordingly deny the notion of static present moments which could be added in succession along a mathematically thought line. The now, according to Heidegger (his summer lectures of 1927—Heidegger 1975, 352), who explicitly refers to Bergson, has the character of transition, the now is not a point next to other points in time but it has an extension which is characterized by passage. Similarly, Henri Bergson states: "pure consciousness does not perceive time as a sum of units of duration [...] states of consciousness are processes and not things [...] in consequence it is impossible to cut off a moment from them without [...] altering their quality" (Bergson 1917, 196). Or, as Barry Dainton puts it: "... when we hear a sequence of notes unfolding as part of a melody, we not only hear each note seamlessly flowing into the next, but the individual notes are themselves inherently dynamic" (Dainton 2017, 95).

The phenomenological derivation of the unity of time consciousness and self-consciousness, including its inherent dynamism, is strikingly similar to the neurophysiological model by Bud Craig where the constantly ongoing integration of somatic signals over time generates a floating experience of the emotional self across moments of self-awareness. From a neurobiological perspective, the underlying neural machinery at work actually processes incoming bits of information in discrete steps as witnessed by brain oscillations with many different lower and higher frequencies.[64] These neural oscillations underlie all cognitive functions including perceptual and motor timing.[65] Multiple oscillatory neural activities are however organized and interwoven into an integrated spatio-temporal continuum of brain activity. One idea is that slow cortical potentials, spanning several seconds of duration, may generate the temporal width of experience, an extended present moment.[66] The long phases of these low-frequency fluctuations would temporally integrate oscillatory neural activity from different brain regions in order to enable conscious awareness and the feeling of an extended "now". To juxtapose the phenomenological view and the neuroscientific hypothesis of an extended present, one could state that the underlying neural machinery generates the temporal platform of a subjective present (Pöppel 2009), an island of presence (Metzinger 2004). This extended present

64 See Buzsáki (2006).
65 See van Wassenhove (2016); Roehricht et al. (2018).
66 See Northoff (2014).

moment constitutes the temporal frame within which the dynamic flow of perceived events happens over time leading to experienced temporality.[67]

In his analysis of Bergson's philosophy of temporality, Dainton (2017) sees strong evidence for an extensional account, although some passages across different works could be interpreted differently, i.e., favoring a retentional model. Dainton's elaboration of an extensional model suggests dynamic elements of experience within an extended moment and across (overlapping) extended moments which create the seamless continuity of experience. In contrasting inner duration from the time measured by clocks, Henri Bergson similarly writes in his *Essaie sur les données immédiates da la conscience* (*Time and Free Will*) that "... inner duration, perceived by consciousness, is nothing else but the melting of states of consciousness into one another" (Bergson 1913, 107). In Dainton's (2017, 101) parlance of this stream-like structure: "A is experienced as flowing into B, B is experienced as flowing into C, and C into D".

According to Bergson experienced duration (*la durée*) is experiential time as an intensive non-quantifiable entity: "psychic states seem to be more or less intense [...] looked in their multiplicity, they enfold in time and constitute duration" (Bergson 1917, 224). That is pure experience of temporality: "the deepest conscious states have no relation to quantity, they are pure quality" (Bergson 1917, 137). At a later stage subjective time may be quantified, i.e., spatialized as "length of duration", by comparing psychic states with external events, i.e., defined by clocks for measuring objective time. But the pure impression of temporality is generated through the qualitative stream-like enfolding of inner states.

Summary

The unity of time and self-consciousness has an inherent temporal dynamism as described by phenomenologists over the last 130 years. These phenomenological descriptions are mirrored by neurophysiological conceptions, which postulate a similar interoceptive dynamism associated with our feeling of time and self. It is suggested that the constantly ongoing temporal integration of somatic signals in the brain generates a dynamic experience of the emotional self across moments of self-awareness. Accordingly, the conscious feelings of emotions, self-experience, and subjective time stem from the dynamism of the same neural system related to interoceptive processing. We highlighted specific empirical evidence

67 See Dorato and Wittmann (2020).

informed by recent neurophysiological studies showing that the experience of time is governed by emotional and visceral processes which are based on the interoceptive processing system. Neuroimaging studies have repeatedly shown that the insular cortex is activated when individuals have to judge duration in the millisecond and second range. Peripheral-physiological indices such as the heartrate or breathing rate are related to the accuracy in perception of timed external events as well as to the judgment of duration. Subjective assessments of interoceptive awareness show how people who are more aware of their bodily condition are also more accurate in time perception. Henri Bergson is thereafter vindicated as he was right to emphasize the dynamism of the temporal self as becoming. Psychology and cognitive neuroscience have come to a similar, scientifically-inspired, conclusion. Seen under this perspective also Albert Einstein was right. Bergson's approach was actually psychological in the sense that psychology is informed by phenomenology.

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Giuseppe Longo

Today's ecological relevance of Bergson-Einstein debate on time

Abstract

The reflections on the nature of time in Relativity Theory will be hinted in reference to the new bridges recently proposed by Connes and by Rovelli's *perspectival* approach, two major steps towards a unification of quantum, thermodynamical and relativistic times. The so-called "time of philosophers", a time of the cognizing ego, from Saint Augustin to Husserl and Bergson, is based on a different, but relevant perspective and it has been traditionally opposed to the "time of physicists". In between these two approaches, we discuss a proper time of phylogeny and ontogeny, in biology, with their own rhythms and specific irreversibility. On the one side, biological time needs to be scientifically objectivised as an invariant of the knowing subject and thus move, as in physics, *from the subjective-absolute to the objective-relative* (Weyl's approach, extended to time). On the other, we propose a "geometry" of life's rhythms and an "extended present" that radically differ from the prevailing spatialization of physical time that Bergson soundly criticizes. The proper irreversibility and the central, "operatorial", role of time in biology will be stressed, as nothing in biology can be understood except in the light of a temporal perspective, both evolutionary and organismal. In particular, today's eco-systemic changes bring to the limelight some disruptions of the evolutionary fine-tuning of biological rhythms and physical clocks that may be better understood by highlighting their theoretical differences as well as their environmental interactions.

1 Introduction

It is to the credit of Bergson's philosophy
to have pointed out forcefully this deep division
between the world of mathematical concepts
and the immediately experienced continuity of phenomenal time (*la durée*)
(Weyl 1918)

 https://doi.org/10.1515/9783110753707-020

In the history of science, when physicists faced a change of scale or observed different (or differently) phenomena, they invented a new theory. Then, the unification of the diverse theories becomes a major knowledge aim and, if achieved, a true revolution: the proposal of another theory that "brings together" unrelated or even incompatible phenomenal descriptions. Newton unified falling apples and planetary movements, totally unrelated phenomena for Galilei; Maxwell brought together magnetism, electricity and optics; Boltzmann correlated molecular movements and thermodynamic principles. Also Einstein made a major intra-theoric unification: the equivalence of gravitation and inertia. There may be more unifications, but not many, in view of their relevance and difficulty, such as the still open issue of the quantum vs. the relativistic fields.

As a bridging example towards biology, observe that the adequate scale of analysis required the development of an autonomous and mathematically rich hydrodynamics of incompressible fluids in continua, whose properties are not derivable from particle or Quantum Physics —in spite the fact that also incompressible fluids are notoriously composed by elementary particles. Major progresses are being made in the search for unity and borderline theories between these and other frames, see Chibbaro et al. (2015) for a broad survey, Longo (2016) for a review. Then, as for biology, note that there is a lot of water in an organism and that Classical as well as Quantum Electrodynamic effects contribute to cell's semi-permeability and macromolecular dynamics in cells.[1] As a matter of fact, quantum and classical processes may blend, within a cell, and yield phenotypic consequences.[2] As these phenomena are not inter-derivable or are even theoretically incompatible,[3] none of the corresponding physical theory may allow, alone and even less in an inconsistent conjunction, to *deduce* the fundamental properties of organisms, from Darwin's principles for phylogenesis

Note: The permanent exchange with Maël Montévil continued the very stimulating work with Francis Bailly, on biological time in particular. Maël suggested to look at the disruption of the fine tuning of rhythms vs frequencies in pollinators and angiosperms, as seasonal plants. Pierre Martin-Dussaud made several constructive comments, as a physicist, and Ana Soto, as a biologist. Two anonymous referees as well as Alessandra Campo and Rocco Ronchi helped to improve the text, by a very close reading.

1 See Arani et al. (1995).

2 See Del Giudice et al. (1983); (1986). See Buiatti and Longo (2013) for more references.

3 With respect to classical or relativistic approaches, Quantum Mechanics is either incomplete or inconsistent, claims Einstein in EPR (Einstein et al. 1935), an incompatibility result with classical and relativistic physics. See Longo (2018a) for a comparative analysis with other "incompleteness" theorems.

to our modest proposals for ontogenesis.[4] A future unified theory of the fragmented physical frames, at least those witnessed in a cell, may be of major help also in biology. For the time being, it may be wise to work, following Darwin and many others, to an autonomous theorizing of biological processes, in search for a future unification, as it mostly happened in physics when facing new phenomena or observing differently old ones. Then, perhaps, it may turn out to be needed to see physics (or its mathematics in homogeneous phase spaces) as a special case of a suitable theoretical frame for biology and its *heterogenesis* (Longo 2020) —the mathematics for heterogenesis in Sarti et al. (2019) will be hinted below.

The necessary theoretical richness, that requires a permanent dialogue of theories, applies also to the different approaches to time, the focus of this paper. It is then surprising to observe, on one side, the technical depth of the debate on time in Relativity Theory and, on the other, the attitude of many physicists who consider the Relativistic (or Quantum, not both) Theory of Time as … a theoretical "absolute". Claims such that "time does not exist", because "it is not present in the fundamental equations", make us think that this is too bad for the fundamental equations that, in spite of their beauty and relevance, may thus remain confined to a specific theoretical frame and phenomena.[5] In particular, in no way they would help to discuss biological time, unless we invent a new unifying theory—a remote target—or at least some bridging ideas —the aim of this paper in relation to Rovelli's perspectival approach to time. In order to construct a bridge, though, one needs the two sides of the ditch, in particular an autonomous theory of biological time. On the one hand, we refer to Rovelli's approach to time in physics that is based on an analysis of the relativizing choice of the thermal coarse graining.[6] On the other, we develop previous work on biological time and rhythms in collaboration with Bailly and Montévil (see references) and frame it by the notions of characteristic time and time scales for biological functions, as defined by the "closure of constraints" in Montévil and Mossio (2015).

We will thus not present a historical account of the Einstein-Bergson debate, but refer to some its developments in order to propose a perspectival *epistemology* of time in the sciences of nature and hint to its relevance in the current ecosystemic crisis, partly due to a poor understanding (or little care) of the physical

4 See Soto et al. (2016).

5 The general form of a *quantum* dynamics of variables, with no time parameter, has been given by Wheeler and De Witt (see Rovelli 2008). Wheeler-DeWitt equation is a variant of Schrödinger equation in a diffeomorphism invariant (relativistic) context, a tentative formal bridge between the two theories.

6 See Rovelli (2015).

singularity and autonomy of life. A pertinent theory of biological time may also contribute to the philosophical analysis of pre-conscious or conscious (intentional) time (the "time of philosophers"): biological rhythms may induce a primary form of protension, as pre-conscious expectation; the mathematical "gluing" of retension (pre-conscious memory) and protension will point towards a simple formalization of the subjective experience of the continuity of phenomenal time. Both analyses may help to objectivize some aspects of Bergson's notion of *durée* as well as its relation to *continua* and thus to recompose the deep division stressed by Weyl (in epigraph, above).

2 The Thermal Time Hypothesis and the Regulating Objectivity of Physical Time

All a priori statements in physics
have their origin in symmetry
(Weyl 1952)

In the commonly used mathematics of modern physics, the Cantorian one dimensional continuum as a line of points with no jumps nor lacunae, identically describes and entirely displays under our eyes both space and time. Thus, Weyl's unsatisfaction in epigraph to the first section: there is no way to isolate the phenomenal/perceived time of the present as a Cantorian point; the mathematical continuum does not allow a privileged interval of measurement or of conscious access to time. Bergson's *durée* instead is an incompressible, indivisible interval, where consciousness of the present is possible as it is coextensive to memory of the past and expectation of the future (Bergson 1947, 195), an approach that permeates philosophy, from Saint Augustine to Husserl. In this perspective, future cannot be displayed as a line *given* in space, even less if made out of Cantorian points.

Moreover, Weyl, the author of *Space, Time, Matter*, the 1919 founding book for the mathematics of Relativity, is well aware that (General) Relativity Theory ((G)RT) moved the description of time even further away from the cognitive/experienced time, since it allows no preferred independent time variable: space-time may be understood as a unique "block" subject to the same transformations; up to minor differences, space and time yield the same invariant properties under these transformations (diffeomorphism invariance or general covariance). In this sense, GRT definitely *spatialized* time and erased its specificity; in particular, its orientation, as a flow from past to future, disappears.[7] Finally, and this is mathematically crucial, one cannot describe a relativistic dynamic as an evolution depending on a pre-given time parameter.[8]

However, as for the choice and the orientation (the "arrow") of the time parameter in physics, Connes and Rovelli (1994) made major contributions by proposing a triangular relation between the analyses of time in quantum (QM), thermodynamical (TD) and relativistic frames (GRT).

In short, recall first that measurement in QM does not commute: if the speed of a particle is measured *first* and the position *later* one obtains a different result from a measurement done in the inverse *time order*. This sets an orientation of time. In TD, instead, the time orientation is given by increasing entropy, which may be expressed as a move from a fine-grained to a coarser grained access to phenomena. That is, from a more to a less detailed description of its microscopic behaviour, or a description in which some of these fine details have been smoothed over.[9] In a given system, a given temperature, typically, may yield a coarse-grained, macroscopic, representation of the particles in aggregate. Energy transformations, as they tend to reduce differences in temperatures, increase entropy and lead to a coarser graining of the intended system. Thus, measurement or the choice of a coarse graining fix a dimension and a direction of time, in QM and TD, respectively, as argued next.

By building on classical results by Gelfand, which allow to reconstruct (Riemannian) geometry from commutative algebras, Connes (1994) has been reconstructing, for many years, the geometry of QM in terms of non-commutative algebras. Then, he unified, mathematically, the orientation of time due to quantum measurement and the thermodynamic understanding of the arrow of time in terms of entropy.[10] In short, the arrow of time defined by quantum non-commutativity and the one determined by macroscopic states (or coarse

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7 The view points within RT and its philosophy, beginning with Einstein late reflections on time, differ, see (Bouton and Huneman 2018) on this debate. Under all interpretations though, "you will never derive the idea of a temporal flow from Minkowski's schema" (Bergson 1965, 63).

8 See Connes and Rovelli (1994). "The general form of a mechanical theory that describes the evolutions of variables with respect to each other is given by a phase space and a constraint C. The relations between the variables are given by the orbits generated by C in the subspace C=0. The parametrization of these orbits has no physical meaning" (Rovelli 2018a, 132ff67). As already hinted, the general form of a quantum dynamics of variables, with no time parameter, is Wheeler-De Witt equation.

9 Entropy, in short, is the logarithm of the number of ways that the insides (of the intended phase space) can be re-arranged, so that from the outside it looks the same. See Feynman (1964) for an excellent introduction.

10 See Connes and Rovelli (1994).

graining) in TD may be described by the same algebraic frame —the *non-commutative* von Neumann algebras'. These define an a-symmetric "flow", which may be interpreted as an oriented time in either theory.

Now, Rovelli's *Thermal Time Hypothesis* refers precisely to the statistical state, or the statistical distribution given by the chosen coarse graining, as determining physical time and its direction (i.e., moving towards a coarser graining).[11] The coarse graining or blurring is due to the fact that we are ignorant of the microscopic details of the observed process. The time of physics is, ultimately, the expression of our ignorance of the world, or of the limitations of measurement, in particular. Note that in both QM and TD, measurement or quantitative *access* to phenomena, as indetermination or coarse graining respectively, are crucial. In this double sense of blurring then one may understand Rovelli's "time is ignorance".

However, the interaction of different subsystems may suffice to fix a "statistical state that determines which variable is physical time", with no need of an "a priori hypothetical 'flow' that drives the system to a preferred statistical state" (Rovelli 2011, 8). That is, measurement may be replaced by the interaction of different systems, in principle sub-systems of a "larger" system. After all, a measurement instrument in QM is a classical (macro) system that, by a 'friction' or coupling with micro-phenomena, co-constitute the observable properties and states of the measured particle. Similarly, as for the choice of the coarse graining in TD. Note that different choices of macroscopic observables and coarse graining, in the same process, may lead to opposing time directions.[12] In reality, this choice is not arbitrary as it depends on the specific coupling between the intended systems. But which subsystems may force an (oriented) time parameter in the interaction with other subsystems? In the next section we will discuss a fundamental one: a living cell.

In other words, time is *perspectival*, as Rovelli calls it, as it is *relative* to a specific access or coupling friction that fixes either the order of measurement of quantum observables or the coarse graining in the analysis of thermodynamic processes. Time is as relative as speed, since it similarly depends on the reference system, if we just broaden the notion of reference system to the choice of the order of quantum measurement or of the coarse graining. The analysis of the transformations and their invariants with respect to reference systems at uniform relative speed, Galilei's relativity, made the analysis of motion objective and started modern science: the laws of motion are invariant w.r. to Galilei's transfor-

11 See Rovelli (1993); (2008).

12 A simple visual example is given in Rovelli (2015).

mations. A relativizing understanding of oriented time, by considering also the access to phenomena as part of the choice of reference systems, may give the proper invariance properties and the corresponding transformations, and thus construct a new objectivity for the "order of time". By an instrumental use of a Kantian terminology, we may then say that objectivized (oriented and measurable) time acquires a *regulating* role in physics: it contributes to the intelligibility of certain phenomena, by *ordering* them. Typically, it is mathematized as a totally ordered parameter in thermodynamic diffusions and entropy. Yet, it is not *constitutive*, in the sense we will propose in biology: the underlying particles' trajectories make the processes intelligible with no need of an oriented time, which is an a posteriori result of a statistics. Note, instead, that conservation properties (of energy, momentum ...), which may be described as symmetries, by Noether's Theorems,[13] are constitutive and posited as a priori in physics, as Weyl would say. That is, they participate to the *co-constructed existence* of physical objects and allow the objectivity of mathematized laws and deductions.[14] On the contrary, the orientation and the origin of time are major symmetry breakings —and no "a-symmetric flow" may be a physical a priori, following Einstein, Weyl, Rovelli. And time has lost its transcendental, a priori status in physics.

However, in spite of the common linear-cantorian representation, the epistemology of time is a controversial one in physics, even in a regulating, non-constitutive role. From the relativistic orthodoxy on the *fundamental* non-existence of time, from McTaggart (1908) to Callender (2017), and the weak (purely relational) and reversible forms of time in GRT in Van Frassen (1985), to the proper irreversibility of thermodynamical time in Nicolis and Prigogine (1977). Now, also relativistic time needs to be revised in view of the novelties in Cosmology. Cosmology is a "historical science" and it should deal with an irreversible time with an origin, the Big Bang, in the view of many cosmologists; it then presents major challenges for timeless theories.[15] Thus, while thermodynamics analyses

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13 See Kosman and Schwarback (2010); Longo and Montévil (2014).

14 For example, an apple falls, a planet moves for "symmetry reasons", since GRT unifies gravitation and inertia in Riemann's manifolds and inertia is a conservation property. Following Weyl, gauge symmetries (Yang and Mills 1954) geometrize also non-gravitational interactions. And a physicist may say today: this particle must *exist* for symmetry reasons –and then he/she knows what and where to measure. Moreover, equations, from Newton to Navier-Stokes, Einstein and Schrödinger, are written and solved in a phase space, *a priori* given by the intended theory, a fundamental invariance or symmetry of the theory.

15 In the strict relativistic view, intersecting cones of the future with different apex points, in Minkoswki's representation, must contain identical events. These events must then be fully and a priori determined, as no coordination is possible between remote apex points. Thus, irreversible processes where time assumes a key regulating role, we are far from a unified understanding of GRT, quantum and statistical mechanics or thermodynamics. Along the lines hinted above, a possible broadening of GRT is being proposed under the form of a "general relativistic quantum statistical mechanics".[16] In this perspectival approach, the relativizing choice of the time dimension and its direction, by a coarse graining, regulates knowledge construction by an observer. Yet, it may also be analysed in terms of interacting subsystems, as mentioned above: the interaction fixes the coarse graining. A major opening towards our approach in biology.

3 The Intrinsic Objectivity of Biological Time

In physics, a lowered energy state is not necessarily disorder,
because it simply results in the identical molecule with a lowered energy state.
The fact that such a molecule might be biologically inactive
may not concern the physicist, but it definitely does concern the biologist
(Hayflick 2007).

An organism, a cell, fixes the thermodynamic coarse graining at the molecular scale: typically, it is viable only in a certain interval of temperature, a measure of energy transformation, thus of entropy production. More generally, the biological *function* of any component of an organism forces its entropic level, within an interval of viability, according to the organism and its context. The dimension and the direction of thermal time is then fixed. We call intrinsic or *constitutive* the approach to time in biology hinted in the cursory review below, following Bailly et al. (2011), Longo and Montévil (2014) and Longo (2017).

3.1 Biological Rhythms vs. Physical Frequencies

The analysis of time in multicellular organisms requires first a key distinction between physical and biological *clocks*. The spinning Earth, the relative movements of the Moon and the Sun have the dimension of (the inverse of) time (a frequen-

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not only the space of possibilities (the phase space) is given a priori, but even the potentialities are actual according to this interpretation, see the debate in Bouton and Huneman (2018).

16 See Chirco et al. (2016); Rovelli and Vidotto (2018); Dorato (2016) for a philosophical reflection on Rovelli's Relational Quantum Mechanics.

cy) and set fundamental *physical clocks* for life: days, months, seasons.[17] On top of them, many organisms constructed their autonomous *rhythms*, such as heartbeats and respirations. All mammals, say, have the same number of total heartbeats and respirations, on average $1.2x10^9$ and $0.8x10^9$, respectively, in their lifespan, a major biological invariant in wild species. So, a wild mouse or elephant, whose lifespans are of about 2 and 80 years, respectively (on average and varying with the species), have about a 40:1 ratio of heart frequency per minute (up to about 600 beats per minute for a mouse and 15 beats for an elephant).[18] Similarly as for respiration frequencies, once one scales the number $0.8x10^9$ above to a species' average lifespan. These numbers must then be understood in terms of "pure numbers": they have no physical dimension, but scale to a frequency, that is to the dimension of (the inverse of) time, once they are referred to a life span – —which has an average allometric dependence on the 1/4th power of the biomass in wild animals.[19] Thus, biological rhythms do not depend on the physical clocks mentioned above, but are tuned to them, like during night sleep or hibernation. Some frequencies and rhythms are very closely tuned, such as the day/night (circadian) frequency that forces a biological rhythm: endocrine activities (melatonin production among others) *internalize*, as a circadian *rhythm*, the external circadian *frequency*. In case of jet-lag, we need a few days to re-adjust the internal endocrine circadian rhythm to the day/night frequency.

This distinction, rhythms vs. frequencies in biology, is crucial, yet it is rarely formalized.[20] In short, evolution set organismal internal clocks, such as heartbeats.[21] These rhythms are or became independent from physical frequencies and constitute major biological invariants, as hinted above. A simple geometric representation of both may be obtained by adding to the oriented dimension of thermodynamical time a second compactified dimension (a circle), in the style of

17 A physical clock sets a frequency (dimension: inverse of time) by an oscillation, a circular movement, an irradiation. Thus, it fixes the dimension of time and a metrics on it: "time is movement that may be counted", beautifully says Aristotle.

18 Note that Galilei used his own heartbeats in order to measure the frequency of a pendulum, the lamplight in the cathedral of Pisa, and this leads to the invention of clocks regulated by pendula. Then, he used time as a parameter to describe falling bodies, a revolutionary step in physics.

19 See Günther and Morgado (2005); Longo and Montévil (2014) for details and references.

20 We tried in Bailly et al. (2011); Longo and Montévil (2014).

21 The setting up of heartbeats is not the result of a programmed oscillator, but of a systemic property: at a critical transition during embryogenesis, interacting embryonic heart membranes, ion's flows, cells' microtubules and neural oscillations resonate and set the rhythm. This gradually correlates to the entire body physiology and even regulates pertinent gene expressions. See Noble (2006); (2012).

Kaluza-Klein theory in physics as for space.[22] This yields a "cylinder", as a two-dimensional manifold or a *geometric schema* for biological time, unrelated to space. Rhythms are then described as spirals along the cylinder, an effective diagram for the interplay of irreversible physical processes (linear time dimension) and internal clocks (spiraling along the cylinder).[23] Our schematic cylinders allow to represent the independence and tuning of the two dimensions of biological time and apply to each individual organism, by a locality of time representation that resembles Rovelli's disordered, localized time-cones in Rovelli (2018, Ch. 3). However, in contrast to Rovelli's space-time cones, the inter-organismal fine tuning of rhythms and frequencies is at the core of our ecosystemic perspective on time, as hinted next.

Organisms use also *accumulators* to measure physical time. Cicadas, which live 13 or 17 years underground before hatching, use an accumulator of the sugar absorbed from the roots of trees in order to emerge with the frequency set along evolution[24]—the surprising prime numbers are probably selected since they cannot be divided by reproduction times of predators. In their dance, bees communicate to the others in the beehive the *flying time* to pollens. That time is measured by internal accumulators and rhythms, which are used also to estimate foraging time: even when the circadian frequency is experimentally disabled, foraging honeybees follow the correct interval timing, suggesting that the systems are independent.[25] With the current climate change, as angiosperms follow the seasonal temperature, an increasing temperature may force early blossoming, so that pollinators may reach different flower species with wrong timings.[26] The pollinators/flowers evolutionary fine tuning of internal rhythms vs. external frequencies, in foraging and pollination, is a very relevant phenomenon for many food chains and may then be disrupted. A mechanistic view of time or of nature does not help in seeing these ecosystemic disruptions.[27]

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22 See Wesson (1999).

23 See the figures in Bailly et al. (2011); Longo and Montévil (2014), https://www.di.ens.fr/users/longo/download.html

24 See Williams and Simon (1995).

25 See Foster and Kreitzman (2004).

26 See Memmott et al. (2007).

27 Many more cases of relevant synchronicity disruptions may be found in the literature; yet another major one is the ongoing de-sinchronization of reproductive spawning in corals (Shlesinger and Loya 2019). For a synthetic analysis of ecosystemic disruptions, including chronobiological ones (see Montévil 2020a).

Rhythms and frequencies fix *durées:* typically, the time in between two iterations of a rhythm. Accumulators add further measurable time intervals.[28] An ecosystem is *a tissue of correlated and recorded durées*, as Bergson would put it.[29] The changes in this tissue or heterochrony, as altered characteristic times in ontogeny, contribute to evolutionary changes. For example, in the three-spined stickleback (Gasterosteus aculeatus), heterochrony in the expression of adaptive traits contributed to speciation in a *limnetic* and a *bentic* form. Their

> ancestral population occupies both of the habitats observed in the descendent species pairs and exhibits both phenotypes at different times during its life cycle, a pattern that suggests that the different recurrent forms may have originated not by parallel evolution but by altered timing (heterochrony) in the expression of those traits (West-Eberhard 2005, 6546).[30]

Time scales and characteristic times are then crucial notions in biology. The "closure of constraints" describes biological functions as part of a "mutual dependence between a set of constituents which could not exist in isolation, and which maintain each other through their interactions" (Montévil and Mossio 2015, 180). Each functional closure applies at a precise time scale and for a characteristic time. Functions then define biological rhythms, such as metabolic, endocrine and cardiac rhythms: from enzymes, which have a time scale and a characteristic time related to their catalytic activity and to the (un-)binding to a substrate in a reaction, to major organismal systems, such as the vascular system, all have a proper time scale and a characteristic time.[31] During embryogenesis, the increasing levels of functional nesting and interactions in the forming organism can be analysed in terms of a complexifying closure of constraints. This provides a properly biological and *measurable* "coarse graining" of organization: an increasingly *finer* (more complex) organization sets the strictly irreversible and biological arrow of time of growing functionalities in an organism, while producing new autonomous rhythms.[32] If your pet theory of organisms allows to conceive the

28 "Wherever anything lives, there is, open somewhere, a register in which time is being inscribed" (Bergson 1922, 17).

29 See During (2009); Ronchi and Leoni (2007).

30 See Huneman (2018) for more aspects of timing and time scales in micro and macro-evolution.

31 The ions' flow of an action potential in neurons requires about a millisecond to travel a few nanometers, which is much more than the usual time scale in physics for these molecular processes (Lesne 2018). The biological functions and contexts impose their own scales and characteristic time.

32 The anatomical complexity of an organism can be measured Bailly and Longo 2009; Longo and Montévil 2014. We called "anti-entropy" this new observable whose space geometry and di-formed baby to move backwards to the unorganized morula or the zygote, you should better forget it: it has no biological meaning —only death suddenly destroys biological organization (or, locally, illness). Time irreversibility of biological dynamics is not "just a matter of probability", as physicists soundly say in thermodynamics, but of an irreversible construction of organization and its rhythms, as functional "closure of constraints". In this sense, the measurable time of biological setting up and maintenance/renewal of organization is a new observable time, which we theoretically distinguish from thermal time—similarly as one can distinguish potential and kinetic energy in the dimension of energy.[33] More will be said below in reference to evolution.

Note that organismal rhythms, such as the cardiac rhythm, force a form of protension: the preconscious expectation of the iteration of the rhythm —such as heartbeats.[34] The correlation of frequencies and retension/protension may be witness even in amoebas, which anticipate periodic events.[35] In humans, musical notes and rhythms require a join of protension and retension, in a least time durée, in order to produce musical sense—similarly as for the retension and protension required to understand language. This "gluing" (a mathematical notion) of retension and protension in an interval is a fundamental *durée* in all forms of perception and, eventually, in consciousness of time —a simple mathematical description of this phenomenon is given in Bailly et al. (2011, sect 5.4), Longo and Montévil (2011a). In our view, the "continuity" that we attribute to a trajectory (of a prey, a ball ...) results from glueing retension and protension of it, including the protensive eye jerks and brain's associated re-organization described in Berthoz (2000).[36]

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mensions matter (in contrast to negentropy as one-dimensional information). Anti-entropy adds, and does not opposes, to entropy, produced also by its very setting up, as in all irreversible processes —each cell reproduction increases anti-entropy while producing entropy, by energy transformations and by the slight disorder of the a-symmetric division. In short, philo- and onto-genesis simultaneously produce entropy and quantifiable, three dimensional and metric organization (anti-entropy). Montévil and Mossio (2015) further specified it by adding functional closure, a key notion in biology.

33 Sarti el al. 2018 consistently propose to introduce another dimension for this new observable time. This is fascinating and may require the invention of a new pertinent dimensional constant to relate the two forms of time, such as Boltzmann k in TD, say, a non-obvious step.

34 See Noble (2006).

35 See Saigusa et al. (2008).

36 A frog would never claim that movement is continuous: it sees it by scattered snapshots. We, large vertebrates, follow and precede moving preys by continuous eye jerks and, very recently, we invented continuous background spaces and their mathematics (Longo 2020). The Cantorian, a posteriori reconstruction of phenomenal continua by dimensionless points, justifies Weyl's dissatisfaction: it is very powerful and rigorous, it founds the point-wise time instants of the

Finally, organisms continually re-construct themselves, by somatic cell reproduction. Each of these reproductions has the characteristic of a *critical transition:* a re-organization of internal and external symmetries—from one to two cells; the formation of new coherence structures—the tissue matrix, re-constructed collagen fibers etc. In an immensely more complex way, this resembles to a para/ferro-magnetic critical transition, the formation of a snowflake.[37] In physics, critical transitions are formalized as a point-wise process by the divergence of (the derivatives of) some function of the dynamics on one point of the pertinent parameter. In biology instead, the *durée* of these transitions is crucial as it internally contains several, nested, critical transitions (e.g., DNA split, proteome's reorganization …) that make no sense in isolation. Moreover, a multicellular organism undergoes thousands of cell reproductions, thus of these nested, extended transitions, in short time intervals. The notion of "extended criticality" in Bailly and Longo (2011); Longo and Montévil (2011b), unknown to mathematical physics, may help to grasp the peculiarities of this continual reorganization which is proper to life; it may be viewed as a topologically dense interval of critical transitions, in a non-cantorian continuum. And, at the proper scale, extended criticality yields incompressible, non-divisible *durées* in the pertinent phase space, the extension of the interval of criticality.[38]

In summary, the analysis of biological rhythms in terms of closure of constraints provides an objectivizing-relative theoretical frame for Bergsonian *durées* as pertinent and measurable characteristic times and time intervals, at different time scales. Similarly, perception should be analysed in incompressible intervals of time or by glueing retension and protension. Moreover, critical transitions are omnipresent but extended to time intervals. All these *durées*, in order to be understood in their functionality, cannot be arbitrarily compressed nor divided, unlike a Cantorian time-segment. They set the time of Darwin's "correlated variations" and of interacting causality in all scales, as described by Noble's "Biological Relativity" (Noble 2012). We also hinted to the role of variable *durées* in phylogenetic heterochrony; more should be said as for changing time interactions in embryogenesis.[39] In short, the analysis of the network of functional *du-*

XVIII century differential calculus, but misses the a priori of perception and of its biological timing, as *durées*. Better can be done by more modern mathematics (see the footnotes in §5).

37 See Binney et al. (1992).

38 "The thing and the state are only artificially taken snapshots of the transition; and this transition, all that is naturally experienced, is duration itself" (Bergson 1965, 44). For Bergson the concept of duration encompasses both the idea of passage and of conservation.

39 See Raff and Wray (1989).

rées, at all levels of organization, and of their changes in organisms and ecosystems is a core biological investigation.

Recall then a major epistemic lesson of Einstein's GRT:

> *The geometry of relativistic spaces is a tissue of interactions: when deforming these interactions, the tissue and its geometry change; conversely, a deformation of the geometry changes the interactions, their tissue.*
>
> The constitutive role of time in biology and its deformations may be analogously synthesized:
>
> *The time of an ecosystem is a tissue of interacting rhythms and frequencies: when deforming these interactions or their tissue, rhythms, frequencies and their tuning change; conversely, a deformation of rhythms or frequencies and of their tuning modifies the tissue, the time of the ecosystem.*

Of course, a multicellular organism is also ecosystem, often inhabited by more bacteria than somatic cells. Yet, the converse does not need to hold. In particular, the resilience to time and space (metric) deformations of the tissue of interactions may be incommensurably higher in an ecosystem than in an organism. In biological ecosystems, of either type, the notion of *pathology* or of *disruption* are perfectly sound and relevant, in particular in reference to the *functional* fine-tuning of rhythms and frequencies, while they are not in physics. The current ecosystemic crisis requires a close attention also to the changes in the evolutionary network of recorded *durées*, as defined by Bergson.

3.2 The Time of Evolution

> the present moment of a living body does not find its explanation in the moment immediately before [...] all the past of the organism must be added to that moment, its heredity —in fact, the whole of a very long history.
>
> (Bergson 1922)

Another distinction is required as for the time of phylogeny and ontogeny. The *phase spaces* (pertinent observables and parameters) of physical theories may differ, but they are given a priori by each theory.[40] From Aristotle to Newton, Ein-

40 It is the theory that fixes the observables (Einstein), which, in a given physical theory, are fixed or may at most statistically change in a pre-given list. See Disertori et al. (2015); Sethna (2006).

stein and Schrödinger, *the actual is already in potentia*, in the space of all possible paths —possibly a (Cartesian) phase spaces or an infinite dimensional (Hilbert's) spaces of quantum probability's amplitudes (Schrödinger). Or, the bifurcation (ontologically) precedes the fluctuation or perturbation that induces one path or the other.[41] In a Darwinian perspective, instead, the pertinent observables and pertinent parameters, thus the space of possible phenotypes and organisms, are produced during and by evolution. "The origin of a new direction of adaptive evolution starts with a population of variably responsive, developmentally plastic organisms" (West-Eberhard 2005, 6544). Variability is co-extensive with life (Darwin's first principle) and *fluctuations*, within organisms and organisms-ecosystem, *co-constitute bifurcations*.[42] In other words, the phase space of evolution is produced by evolution itself, and this is inconceivable in existing mathematical physics.[43] In biology, thus, on one side time is ignorance not only of what will happen, in a pre-given space of all possible "trajectories", but even of what *may* happen. On the other, time is the construction of new spaces of possibilities, as evolution is *heterogenesis* not just morphogenesis in homogeneous spaces (see below), a major mathematical challenge.[44]

Moreover, *rare events* (hopeful monsters, allopatric speciation ...) crucially contribute to phylogeny,[45] in a very different way from the rare "large fluctuations" that importantly, but rarely influence trajectories in physics.[46] As a matter of fact, *any* phylogenetic path, or most of its bifurcations and changes, are marked by and result from rare events.[47]

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41 As observed by Thom in Thom (1990).

42 See Longo et al. (2012); Longo (2017).

43 Darwin, in a marvelous page on variation and the production of new phenotypes in evolution (*Origin*, ch. 5), stresses the *extreme sensitivity* of organisms, their contexts and their interactions to minor or non-detectable changes. Thom insightfully sees the relevance of this issue and, consistently with mathematical physics, observes that it "affects, very seriously, the scientific nature of Darwin's Theory of Evolution" (Thom 1990, 271). Great thinkers are at least aware of their a priori (and metaphysics: Thom's firm mathematical Platonism) –also when they are wrong. We only need new mathematics for this, perhaps the mathematical heterogenesis hinted in Sarti et al. (2019), see below.

44 In philosophy, Bergson opened the way to this perspective, see Bergson (1922); (1946).

45 See Longo (2017).

46 See Vulpiani et al. (2014).

47 See Gould (2002). One of the challenges of today's cosmology, which aims at a historical theory, is that both the observables and the fundamental physical constants may be considered as varying (Uzan 2011). Perhaps, some inspiration from theorizing in evolution, since Darwin, may help cosmologists, such as the focus on changing phase spaces and rare events. Economists, as they also work at a historical theory, have been already inspired from our approach (Koppl et al. 2015).

This approach requires a further distinction. Hurricanes, flames … and all far from equilibrium physical processes are described by an irreversible *processual* time, in a given phase space. They are all of the same "type", in a robust mathematical sense, since four billions years on Earth and a sound theory in a pre-given phase space, and its mathematics, effectively describes them. Life instead somewhat changed since its origin. It has a *historical* time, specified by changing phase spaces and by rare events. Moreover, traces of its past shape the present and the future, very differently from *path dependence* in physics.[48] This re-use of the past may be analysed in terms of, for example, but not only:

- Gould's exaptation (adaptation ex-post: the new use of an old phenotype), degeneracy[49] and overloading[50] of organs and functions;
- Degenerate and multiple use of a segment of DNA by (de-)methylation, alternative splicing or overlapping genes;[51]
- Activation of cryptic mutations *etc.*[52]

Intelligibility thus depends also on knowledge of the past and thus, possibly, on diachronic measurement. That is, a biological function, an organism, a species are understood in terms of their history: the structure and function of brain, lungs, … the absurd connectivity in vertebrates eyes (as pointed out by Helmholtz), if compared to the octopus's homologous one, or … "what is a mouse"[53] can only be understood in phylo-ontogenetic terms, that is by an analysis of their constitutive history, possibly by accessing to and measuring common ancestors.[54] The need for synchronic and diachronic measurement as well poses major challenges in biology: the specificity and historicity of each individual is a major theoretical issue and massively affects experimental reproducibility.[55] In a Bergsonian perspective, organisms may be only understood within a life flow, their ever changing evolution.[56]

As mentioned above, the historical time of onto-phylogenesis may be better described by a new observable (or an extra mathematical time-dimension, see the footnote). Following this approach, in Bailly and Longo (2009), we used a

48 See Longo (2017).
49 See Edelman and Gally (2001).
50 See Longo (2017).
51 See Pavesi et al. (2018).
52 See Paaby and Rockmann (2014); Longo (2017) for more.
53 See Montévil (2019).
54 See West-Eberhard (2003); Lecointre and Le Guyader (2017).
55 See Montévil (2019).
56 See Bergson (1922).

diffusion equation in order to formalize a remark in Gould (1996), concerning the (largely random) increasing phenotypic complexity in evolution. Intuitively, more "complex" organisms, in the sense of a notion that we formally define and measure (anti-entropy, see notes sect. 4), may construct/occupy new niches —thus they have more chances to fit.[57] The equation, with real coefficients, is analogous to Schrödinger's wave equation in QM, which may also be understood as a diffusion equationin our case, it yields an asymmetric diffusion of bio-mass over "complexity". Dually to Schrödinger's equation, and for good mathematical reasons, time turns out to be an "operator" and energy (or mass) a parameter, in agreement with the role of energy (or mass) as a parameter in allometric equations in biology.[58] It is still hard to fully grasp the biological meaning of such a duality, yet, if our analysis is correct, it seems to stress, by a new mathematical frame, the constitutive role of time transformations, whose epistemic status becomes then similar to conservation laws for energy or momentum in physics.

4 Comparing Theories of Time

In physics, from Aristotle's "time is movement that is counted" to Einstein space-localized clocks, it is commonly understood that "time is what is measured by clocks".[59] This parallels a common physico-mathematical definition of randomness: randomness is what is measured by probability (from Laplace to Kolmogoroff, in the 1930's).[60] Joining the two, as for an issue we already hinted: time reversibility is just a matter of probability.[61] These views, that may be perfectly sound in physics, are largely inadequate in biology.

First, organisms construct their own time as internal rhythms, which, at least in mammals, scale to bio-mass, as mentioned above. Biological rhythms do not just measure, but *engender* the time of organisms, a complex organismal and ecosystemic tissue constructed in evolution and embryogenesis, in relation to,

57 Anti-entropy is a different observable from negentropy: it is generated while producing entropy (Bailly and Longo 2009) and it measures phenotypic complexity as a dimensional/geometric notion, depending on fractal dimensions in organs, size of networks, such as the neural network, number of tissue differentiations. This is in contrast to *negentropy as information*, which is one-dimensional and dematerialized (independent from the "hardware").

58 See Gould (1966); Peters (1983); Longo and Montévil (2014).

59 See the papers on physical time in Bouton and Huneman (2019).

60 See Mugur-Schachter and Longo (2014).

61 See also the Einstein-Ritz debate in: Frisch and Pietsch (2016). In *Duration and Simultaneity*, Bergson argues that "the measurement of a thing is, in the eyes of the physicist, that very thing" (Bergson 1965, 159).

but differing from physical frequencies (clocks). A possible analysis requires some more geometry than just a time-line and the counting of a frequency on it, as we hinted in §.3, in reference to the breaking of the evolutionary fine tuning of biological rhythms and physical frequencies. Stressing the difference as well as the interactions provides an understanding some of the ongoing ecosystemic changes, which can then be measured. Yet, the conceptual determination may precede measurement; for example, the operatorial role of time quoted above specifies our perspective by some mathematics, in spite of the difficulties, or impossibility, in pre-defining and measuring changing spaces of possibilities (the possible phenotypes and organisms) and rare events. More in the next item.

Second, randomness mathematically differs in classical and quantum frames, as it yields different probabilities (e.g., the violation of Bell inequalities).[62] In general, randomness is unpredictability in the intended theory.[63] Since, in physical theories, phase spaces are generally pre-given, probability, as a measure of randomness (Lebesgue's measure, typically), may be a priori fixed by the observer and soundly defines randomness.[64] This is not so in evolutionary dynamics where the very space of possibilities is not pre-given —it does not precede the dynamics. Thus, no probability measure can be given on this "space". So, unpredictability (randomness) moves from a value within a space of pre-given observables to the very set of possible observables and cannot be measured.[65]

Third, as for time reversibility, does one refer to time or to the observed process as reversible? In short, a process may be considered "reversible in time", when it is parametrized over time, t, and setting -t yields a physically conceivable/possible process. Typically, Newtonian mechanics and all dynamics where the time parameter t appears as a t^2, thus inversing t in -t poses no problem (the orbits of planets can be very well be conceived to go in the opposite direction).[66] But also the diffusion of a gas can be thought as time reversible: in the atomistic perspective, since Boltzmann, the inversion of the trajectories of gaz particles is conceivable, it is just a statistical matter with very low probabilities. In some cases, the thermodynamical process (mixing gazes, say) may be reversed

62 See Aspect et al. (1982)

63 See Calude and Longo (2016).

64 However, both Poincaré's analysis (1892) and the standard interpretation of QM provide an epistemic interpretation of classical and quantum randomness, respectively, which conceptually precedes probabilities. They may be both asymptotically related to a strong form of undecidability, Martin-Löf randomness (Calude and Longo 2016).

65 See Longo (2017).

66 See Gayon and Montévil (2019) for a detailed discussion.

by some energy (a centrifuge), with no inversion of the time parameter. As mentioned above, neither chance with low probabilities nor a centrifuge would help to reverse aging nor embryogenesis, from an old man to a baby to a zygote.

In Longo and Montévil (2017), we show that in existing physical theories, the following events are invariantly correlated: a symmetry breaking, a random event and the (local-processual) irreversibility of time (in short, think to classical bifurcations, to the projection of the QM state function, to thermal diffusion …). A remarkable mathematical unity of physics. This correlation holds also in our approach to the proper irreversible time of biology, in evolution in particular. Yet, the fundamental symmetry that is also broken by the time flow is the conservation of the phase space, i. e., by the changes of the space of possible phenotypes. As already mentioned, this yields a non-measurable form of randomness —yet a very close approach to ours may be already given a mathematical representation.[67]

As for the Bergson-Einstein debate, an irreversible and universal "becoming" is at the core of Bergson's philosophy of nature. It is not being that becomes, but becoming is being:[68] life undergoes a permanent change not only in time but "enacted" by time. Can this be mathematically specified as a view of time as a (differential) operator, as mentioned above? Indeed, an organism is a becoming: if somatic cells stop reproducing, the organism is dead, it is no more. Species can only become and change: there is no way to stabilize them, not even in a stable environment, observes Darwin. Reproduction with modification is his first principle for species' evolution and our *default state* for cells also within an organism.[69] Note though that also physics, QM at least, is moving beyond classical falling stones and relativistic block-universes: "The best language for describing the universe remains a language of happening and becoming, not a language of being. Even more so when we fold quantum theory in. Loop Quantum Gravity (LQG) describes reality in terms of processes" (Rovelli 2018b, 4). Yet, LQG has no preferred time variable and its becoming is a matter of space-localized, iterating frequencies. Biology instead, needs time variables, indeed more than one time dimension, in our approach, and they are set by the theory, a priori. Moreover, life's becoming is a plastic tuning of rhythms and frequencies, as ever changing, mathematically heterogeneous, reproduction of geometric and time's forms.

67 See Sarti et al. (2019).
68 See Ronchi (2011).
69 See Soto et al. (2016a).

5 Biological Twins vs. Atomic Clocks

Thought experiments are very important in science. Yet, they must be proposed or understood at the *right* phenomenal level and possibly not based on nor forcing a philosophical bias. Archimedes imagined a "bag of water" in … water and proposed his principle. Galilei thought of a falling body in a boat in uniform movement and understood the relativity of movement. Einstein dared to take the point of view of a photon surfing on a light wave. Turing imagined himself as a "human computer" writing 0s and 1s on "a child's arithmetic book", in a perfectly "desultory manner".[70] As written and as they are commonly interpreted, in reference to the phenomena they refer to, these deep and original insights by imagination are sound and very expressive.

Consider instead the ancient Zeno's paradox about the arrow never reaching a target as it first needs to pass by 1/n-th of the distance to the target, for all $n > 1$. This is a fantastic mathematical invention, a very early reflection on infinity: the "paradox" of the infinite in the finite or of the infinite divisibility of a continuous segment. It opened the way to Euclid's geometry of continua and, later, to the infinitesimal calculus that made western science. However, it is a physical nonsense. A figure of thought should be compatible with effective observations, as the four founding thought experiments above, in particular with measurement, the only form of quantifiable access we have to (physical) reality. No length of a physical object, no position of a tip of an arrow, may be given by a rational or real number, *exactly:* classical measurement is always approximated, it is an interval, at least because of thermal fluctuations. A fortiori, if one refers to or measures the position of a moving arrow, one always obtains an interval, both in space and time. That is, the arrowhead is in an interval of space and a moving one will be even more grossly approximated, in time, as time measurement yields always a *durée*. And the physical "paradox" vanishes.

Bergson, since the 1880's, stressed that the Zeno's mathematical invention is based on a lack of understanding of physical movement.[71] Bergson criticizes the implicit identification of space and time and the missing appreciation of the *durée*, which is proper, in particular, to the understanding of movement.[72] And

70 See Longo (2018c).
71 See Bergson (1910).
72 "More generally, in that continuity of becoming which is reality itself, the present moment is constituted by the quasi-instantaneous section effected by our perception in the flowing mass; and this section is precisely that which we call the material world" (Bergson 1947, 178).

he was right: the paradox is *physically* meaningless, while being one of the founding remarks of western mathematics.[73]

Similarly, Bergson is not at ease with the "twins' paradox" as it was later called Langevin's example of relativistic delays of clocks under different accelerations, described as differently aging humans. Unfortunately, Bergson tries to criticize the paradox in physical terms, by claiming that each twin equivalently (symmetrically) moves w.r.to the other —this is wrong since one is in an inertial system (sitting on Earth), while the other is accelerated. However, Bergson's critique is also based on his understanding of the time of consciousness as a tissue of interacting *durées*. From our perspectival epistemology, his view of time as a dialogue of consciousness is beyond biology and its proper scientific objectivization. Moreover, Bergson searches for a universal time, if not an absolute, by referring to an identity of intimate *durées* in subjectivistic terms.[74] However psy-

73 For the reader who considers this argument too "physicalist" or even simplistic, more philosophical insights may be found in Ronchi (2011); Miquel (2013); During (2014). I entirely share, in particular, Ronchi's Bergsonian critique of the identification of space and time and his analysis of Bergson's and other philosophers' deep reflections, since Greek philosophy, on continua and movement, also inspired by Zeno's paradox. However, some ambiguities do not allow to focus on properly mathematical and physical theorizing on these matters. For example, Bergson claims that one can always divide *une chose* (matter? an object?), but not an action. Also, a *chose* though cannot be divided indefinitely, nor can space or time, both in a classical and in a quantum *physical* understanding of "dividing" –only pure mathematics allows it, in particular in the Cantorian Universe of Sets, a piling up of dimensionless points. More recent Topos Theoretic approaches, since Grothendieck (Verdier et al. 1972), may provide a better fit with the relativizing objectivity of physics, beyond the Absolute and Stratified Universe of Sets and Points still prevailing in the mathematics and philosophy of physics. Diverse Universes (categories and sheaves), "with no points" nor stratified (not "predicative") in Johnstone (1977); Asperti and Longo (1991); and their relative transformations may allow to revisit the debate in physics and philosophy (see Zalamea 2012; Longo 2015). In particular, Categories and Toposes provide an analysis of invariant concepts in mathematics methodologically much closer to Einstein's *Invariantentheorie*, as he preferred to call his own theory, than the Cantorian-Russellian stratified absolutes still prevailing, even in physics. These absolutes provide an image of or a mathematical projection on nature of a foundation built on point-elements as solid bricks on top of solid bricks, a parody of complexity as the stacking of the simple. A recent category-theoretic approach, where Lagrangian submanifolds in symplectic geometry form the indivisible, but complex elements, proposes interesting bridges between relativistic gauge and quantum indetermination (Catren 2014). We did and may invent more mathematics beyond the fantastic one which leads from Zeno to Cantor.

74 In Bergson's long argument, Pierre and Paul measuring relativistic time in S and S', live the same *durée:* "Hence, the time lived and recorded in the system, the time inside of and immanent in the system, in short, real time, is the same for S and S'" (Bergson 1965, 71). Thus, la *durée* is the same for the two conscious beings and only by mathematics one may abstractly understand the different speed of the clock of the other, that is that they are in differently accelerated referchological, his views are grounded on living organisms, our reference here, with their own rhythms, as internal clocks, and their *durées*. Let's then develop our focus on biological rhythms, which allow to measure aging. As we noticed, they are a condition of possibility for Bergson's *durée* in consciousness.

The "paradox" of time measurements in different reference systems is a fantastic physical insight since the early days of RT and empirically corroborated by astronomical measurements and human made atomic clocks —the time of GRT applies to the clocks on our satellites (GPS uses it). Yet, it is *biologically* misleading. Biological rhythms are either resilient to differences in nano-seconds or it makes little physical and biological sense to imagine a viable ecosystem sufficiently accelerated as to be taken close enough to the speed of light and obtain biologically relevant time differences w.r.to an inertial one. As for the first issue, quantum phenomena and their timing may be relevant in biology as they may have phenotypic effects,[75] but nano-seconds are irrelevant in *relating* organisms' biological rhythms.[76] They are as irrelevant as measuring micro-fluctuations in meteorology or as integrating Schrödinger's equation for the quanta composing water in the hydrodynamic analysis of the El Nino oceanic current, a dynamics of incompressible fluids better understood in continua.[77] Secondly, no complex organism can stand much more than 1 g acceleration beyond a short time lapse. Then, what kind of viable ecosystem and how much energy is it needed to accelerate such an ecosystem at about 1 g for years, once away from Earth? Energetic considerations and the tissue of correlations of biological rhythms and frequencies, required for life, are out of the scope of this theatrical thought experiment. Bergson may be technically wrong, but he is sending us a warning not to conflate the two dimensions of time (rhythms vs. frequencies), similarly as he had suggested not to confuse mathematics and physical movement in Zeno's paradox.[78]

ence systems: "What is it then, if not a mere mathematical expression meant to indicate that Peter's not Paul's system has been taken as the system of reference?" (Bergson 1965, 72). Bergson, while appreciating Einstein's *Invariantentheorie*, warns against giving an ontological status to mathematical invariants.

75 See Buiatti and Longo (2013) for examples.

76 In photosynthesis, picoseconds may matter as for energy transfer. But this fundamental interface inert/life is far from biological *rhythms*.

77 See Chibbaro et al. (2015).

78 Montévil and a biologist and physician friend, a collaborator of the European Space Agency (ESA), suggested that "it is the *traveling* twin that will get old sooner! Whatever we do to reconstruct an artificial ecosystem in a spaceship, by the time (his biological rhythms) required for the experiment at 1 g acceleration (an animal cannot stand more, nor less, for long), the bio-psychic stress will heavily affect his health, thus aging and life expectancy". By the periodic experience of much less isolated and stressing environments, merchant ships, navigators happen to have

In summary, the choice of the right scale of access and measurement as well as the analysis of the pertinent observables and interactions, are at the core of the scientific investigation. After 1945, Einstein went back to the issue of time: "what about the psychological origin of the concept of time?" (Einstein 1954, 79). His answer refers to different observers comparing lightnings that would appear in different order of time according to different distances, in view of the bounded speed of light: "In order to arrive at the idea of an objective world, an additional constructive concept still is necessary: the event is localised not only in time, but also in space" (Einstein 1954, 79). A very pertinent argument in astronomy or for timing by atomic human made clocks, but a biologically irrelevant issue as for interacting organisms in their niches and ecosystems on Earth. Jokes are fun (*drolligsten*) also said Einstein in reference to the twins' paradox, but they must be limited at their scale of pertinence —so, in his late years, Einstein often and more openly reconsidered Bergson's arguments.[79]

Thus, in our view, Bergson disagreed with the abuses of many physicists who considered and still now consider a quantum or a relativistic *theory* of time as the theory to which all other theories should be reduced or even as a theoretical absolute – this theory "is a metaphysic grafted upon science, it is not science" (Bergson 1965, 63). Note finally, that, without following Bergson's universalistic-metaphysical argument, organisms on Earth do have a universal or global clock, coordinating also their autonomous rhythms, their *durées:* the spinning of Earth on itself, its movement around the Sun, the turning Moon, three fundamental physical frequencies beating the "a priori" background time of life.[80]

five years shorter life expectancy (https://syndicoop.info/marine-marchande-un-constat-alarmant/). The physicist may observe that he/she does not deal with these issues. Then, he/she should better compare only physical clocks.

79 See Canales (2015), Ch. 28 – 29.

80 As observed above, Bergson, while rejecting Newton's absolute time, focuses on the unity of material time within a universe characterized by a plurality of rhythms of duration (*durée*), but also on the idea of an absolute of movement captured in *durée*, irreducible to the reference framework imposed by the principle of the relativity of movement, as stressed in During 2014, 7. This would provide a global or universal time-framework, as a principle of coordination and homogenization of flows of heterogeneous *durées* (During 2014, 7; Bergson 1965, 47), which is our approach as for life, on this Earth.

Conclusion

Our critique joins Bergson's not because of some physicists' lack of attention to the *evidence* of time, since science is a constant fight against evidence and common sense, but because we reject a view of science as the occupation of reality by already mastered tools, with little theoretical care for the specificities of different phenomenal domains. And this, against the extraordinary history of inventiveness which is proper to physics. Biology instead, the most difficult scientific discipline as Einstein wrote in a letter to Schrödinger, should be grounded just on some physics of macromolecules —plus some vague references ("metaphores") to DNA centred information and programming with heavy consequences on research.[81]

We must acknowledge though that our objectivizing interpretation of Bergson's *durées* is not straightforward, as it is instrumentally forced in order to discuss today's approaches to biological time. Poincaré (1917), soundly describes it differently, that is, in his views, the conception of time in Bergson is that *durée* which, far from being a pure quantity free of any quality, is the very quality itself whose various parts partly penetrate each other and differ qualitatively from each other. For Poincaré, this *durée* could not be an instrument for scientists; it could only play this role by undergoing a profound transformation, by spatializing itself, as Bergson says. It had to become measurable, since what cannot be measured cannot be an object of science. Now, measurable time is also essentially relative. Moreover, psychological time, the Bergsonian *durée*, from which the scientist's time has come out, serves to classify the phenomena that occur in the same consciousness. Poincaré concludes by observing that it is powerless to classify two psychological phenomena that have two different consciences as their theater or, a fortiori, two physical phenomena.

We tried here to set the notion of *durée* at the core of a tissue of objective-relative correlations in *biology*, as a science, following Relativity's main epistemic teaching, yet without identifying/subordinating time to space. In this attempt, we did not need to assume a universal consciousness nor to attribute "consciousness" to all forms of life (consciousness is coextensive to life for Bergson). The changing evolutionary and historical nature of "consciousness" must instead be acknowledged: this notion requires an analysis of the "critical transitions" that may help to single out its constitution. For example, the invention of human language and of … writing, which allowed to see the invisible, language and our own thinking, to "reflect" on them, are two of these most recent transi-

81 See Longo (2018b).

tions. Then the western consciousness of time, from the vision of a circle, an iteration with no novelty in ancient Greece, in Pytagora's school and in the tragic iteration of events in Aeschylus, became an open-ended line from Sophocles to Kant.[82] A uniform or universal conception of consciousness, of time in particular, for all living entities, independent from biological and human history, is beyond our scientific perspective.

However, does a scientific concept strictly need to be "measurable"? Joining Poincaré, both Bergson and Einstein would say so. Thus, Bergson's principial denial of the scientific nature and measurability of notions such as time *durée* and randomness justifies Poincaré's critique and drives Bergson's analysis towards a metaphysics away from biology, as a science. Metaphysical investigations are very interesting, but are a different, highly needed, framing job —if the molecular biologists of the Central Dogma were at least conscious of their metaphysics, we would perhaps have some better genetics, from GMOs to cancer research.[83]

In our scientific attempt, we first tried to specify *durées* by biological rhythms and characteristic times and, thus, suggested possible tools to measure them. Moreover, we singled out and qualified with enough, we hope, scientific rigor the notion of historical time and of biological randomness – as relative unpredictability (see the references more than the cursory presentation in § 3). In our approach, as we pose the dynamics of the very phase spaces and stress the role of rare events, evolutionary randomness is not measurable, by probabilities typically. Science though may also proceed by first singling out conceptual contours and qualifications at the interface with phenomena, then, perhaps, but not necessarily, provide new mathematical spaces for measurement. These spaces, yet to be invented (but Hilbert spaces for QM were also a late invention), may be a forthcoming development of the work in (Sarti et al 2019), as for historicity and randomness.

Finally, the constructed objectivity of time proposed here, with its different roles (regulating vs. constitutive, in physics vs. biology), does not exclude the knowing subject. There is always a residual of it in the choice of the reference system and its metrics, such as the choice of the coarse graining, as for time, as well as in defining the transformations that single-out the invariants w.r. to that choice. On the one side, though, a living organism does objectively fix the thermal time coarse graining, as we observed. On the other, *we* decided to work at the organismal and evolutionary levels, as for their timing: the theoretical choice is perspectival and its empirical grounding requires fixing also ob-

82 See Redondi (2007); Deleuze (1978).
83 See Longo (2018b).

servables and measurements, as Einstein observed. Thus, a philosophical reflection on consciousness of time, à la Bergson, may help to historicize our perspectival construction: our own open ended, creative appreciation of the biological time operator is the result of a historical formation of sense. In order to set it on sufficiently robust grounds, we tried to raise the *epistemological question* of its scientific pertinence by an analysis of the

> "... oppositional pair: subjective-absolute and objective-relative [that] seems ... to contain one of the most fundamental epistemological insights that can be extracted from natural sciences [...] But perhaps this question can be answered by pointing toward the essentially historical nature of that life of the mind of which my own existence is an integral but not autonomous part. It is light and darkness, contingency and necessity, bondage and freedom, and it cannot be expected that a symbolic construction of the world in some final form can ever be detached from it" (Weyl 1949, 62).

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The Age of the Universe

Abstract

The belief that the universe as a whole is ageless and unchanging has largely prevailed in human thought since ancient times, with few notable exceptions, and even survived the Copernican and the Newtonian systems. In the 1920's, the pioneering work of Georges Lemaître and Edwin Hubble set the foundations of evolutionary cosmology within the frame of General Relativity. Since then, the concept of cosmic age has entered the domain of physical science, opening up a rich and highly debated motif of modern cosmology. Today the age of the universe is estimated from a variety of independent observational probes. The most accurate measurement comes from recent observations of the cosmic microwave background by the Planck satellite, indicating a cosmic age of 13.8 billion years with an accuracy of ±0.2%. This result is consistent with independent lower limits from the age of the oldest known astrophysical objects, such as globular clusters, white dwarfs and low-metallicity stars.

1 Time and Timeless: the Birth of Astronomy

Our perception of the passage of time has been largely shaped by the astronomical environment of our planet. The daily and seasonal rhythms of sunlight and the repeatable motion of the stars in the sky, in contrast with the ephemeral movements of earthly objects, were essential for our ancestors to develop a notion of duration and time flow. While Sun-related periodicities were most apparent, it was probably the Moon, with its mysterious recurring phases, that most deeply fascinated early sky watchers.[1] The emergence of agricultural societies and the development of navigation made astronomical time measurements even more crucial. The Babylonians and the Egyptians carefully recorded the movements of stars and planets for millennia, producing some of the first precise calendars complete with seasonal and lunar phases, even including prediction of eclipses. The stability of the sky was a reassuring mystery. The brightness and relative positions of the stars did not change for countless generations.

1 A number of archaeological records suggest that the lunar cycle was observed in the Upper Paleolithic by several independent human groups (e. g., Marshack 1991, Barrow 1995).

 https://doi.org/10.1515/9783110753707-021

The silent and perfectly repeatable trajectory of celestial objects was clear evidence of their divine nature. So, while astronomical motions stimulated early measures of time, the sky as a whole was perceived as timeless.

Remarkably, although the cosmic dance of stars and planets was lacking any hint of time direction, nearly all ancient civilizations developed some legendary accounts for an *origin of the world*. These were stories populated by innumerable gods and goddesses, whose births were intertwined with the creation of earthly creatures.[2] It is unclear to what extent these myths were thought to refer to some historical past, but in some cases, it is possible to speculate on the age of the world according to the different traditions. For the Egyptians, based on the age of their first god Ptah, the world would be 50,000 to 150,000 years old, depending on interpretations.[3] The Sumerian cosmos, as reconstructed from the ancient Sumerian King List, was as old as 400,000 years (See V*an De Mieroop (2004)*.[4] Greeks and Romans hardly mentioned any creation date.[5] Censorinus, starting up his history of the world, modestly stated: "If the origin of the world had been known to man, I would have begun there".[6] Interestingly, however, even peoples advanced in astronomy such as the Babylonians developed their mythical cosmogonies with no reference whatsoever to observed astronomical phenomena. Once created, the physical universe was imagined to remain perfectly changeless.

Two notable exceptions are worth mentioning. The first is the Hindu tradition, which held time itself to be cyclic. Hindus did not contemplate a single creation event, but an everlasting cosmic cycle with a succession of global deaths and rebirths. They extrapolated the regular patterns observable at human

2 Most Mesopotamian cultures in the period 3000 – 1000 BC developed creation myths with significant similarities (Kragh 2007, 7–13). The Egyptians, for example, held that *Geb*, the god of the earth, and *Nut*, goddess of the sky, were originally united, and that the world was formed when their bodies were separated by *Shu*, god of the air and of the atmosphere. This separation initiated the proliferation of living creatures and human beings, together with a complex hierarchy of deities of different ranks. The world was shaped from a primordial substance, a limitless expanse of a waters —likely a reminiscent of the life-bearing inundations of the Nile.

3 According to Diogenes Laërtius, the Egyptians believed that Ptah lived 48,863 years before Alexander the Great (Verbrugghe and Wickersham 2001), thus dating the creation 49,219 BC; Theophilus of Antioch, on the other hand, reported an age for the Egyptian cosmos of 153,075 years (Grant 1958).

4 However, it has been argued that these ages should be understood in units of lunar cycles rather than years, thus making the age of the Babylonian universe in line with the Egyptian tradition (Olson 1995).

5 Greek and Roman scholars traditionally identified the first era of history as the "obscure" *ádelon* period, but did not attempt a systematic dating of its beginning.

6 Censorinus, *De Die Natali*, Chapter 1.

scale by huge factors and conceived an amazingly wide range of time units, spanning from microseconds to billions of years.[7] In their view, the stability of the sky was not evidence of a static universe, but a sign of how insufficient our human condition is to appreciate the reality of the mutable cosmos.

A second exception were the Jews. While their image of the physical universe was very much in line with other middle-eastern cultures of the time,[8] their notion of *creation* was radically different. The intricate genealogy of gods and semi-divine beings typical of polytheistic religions was sharply contrasted by the free act of a unique and personal God. The *beginning* of the first verse of Genesis[9] was not simply temporal, but ontological. Creation was not shaping something out of some primordial substance, rather, it was meant as calling into being every creature. All material things were considered ephemeral and contingent. Nothing, even the whole universe, was understood as absolute and self-sufficient: The heavens will vanish like smoke, the Earth will wear out like a garment (Isaiah 51, 6). Cosmic time was seen as limited, both in the past and in the future. According to ancient Jewish chronologies, the creation of the world dated back 4339 BC or 3761 BC, depending on tradition[10]. Later on, the medieval Christian culture would inherit the Jewish vision of time, and the world beginning was believed to be between 5300 and 5500 BC.

2 Greek and Medieval Spheres

Mesopotamian and Egyptian astronomers, while unmatched in observational skill, did not reach—and perhaps never sought—a geometrical synthesis of celestial motions. This step was to be taken by the ancient Greeks. The prevailing Aristotelian school held that the perfect repeatability of the motions of the stars demonstrated their superior nature. Any change or irregularity was consid-

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7 A single global period (one day and night of Brahma) is about 8.64 billion years long, remarkably close to the order of magnitude the age of the universe according to present-day scientific cosmology. But even such a Brahma day-night period is but a sub-cycle of a much longer era of cosmic death and rebirth, comprising 100 “cosmic years”, each composed by 360 “cosmic days”. Thus, the time elapsed since the start of the current Brahma creation is about 3.1×10^{14} years (22,000 times larger than the age of the universe based on contemporary science). See *Teresi (2003)*.

8 A detailed reconstruction of the universe according to the Old Testament was done by Schiaparelli (1905).

9 “In the beginning God created the heavens and the earth” (*Genesis* 1,1).

10 The date 3761 BC marks the start of the traditional Hebrew Calendar since the 4th century AD.

ered a symptom of incompleteness. The universe was ageless and its natural order was eternal. The divine nature of celestial bodies implied that they were perfectly spherical and made of an everlasting pure substance. Their trajectories could only derive from combinations of *circular and uniform* motions, i.e., motions without beginning nor end. Therefore, not only the universe as a whole, but also every single movement in the sky was eternal. This was equivalent to requiring that *time* be marginalized from the celestial world. Beyond the outer boundary of the *primum mobile*, Aristotle believed that "there is neither place nor void nor time" (Aristotle, *De Caelo*, I, 9). The outer edge of the universe was also the end of time.

The most refined version of Aristotle's cosmos was the Ptolemaic model, completed around 150 AD.[11] It was an ingenious and sophisticated geometrical structure combining a vast number of nested spheres, capable of accurately accounting for *all* celestial trajectories observable by naked eye. It remained the standard model of the universe for fifteen centuries. The medieval cosmos largely inherited the spatial structure from the Ptolemaic model. However, the notion of time was taken from the Jewish tradition. Time, as any other creature, was regarded as finite and contingent. In his *Confessions* (ch. XI and XIII) St. Augustine pointed out that it is impossible to conceive a time that is not part of God's creation.[12] Furthermore, Thomas Aquinas made an explicit distinction between *creation* and *beginning* of time.[13] In his notion of *creation ex nihilo* he affirmed creation as the radical, ontological dependence from God of every creature, including time and the universe as a whole (see Carroll 2013). Coherently, he concluded that even an everlasting cosmos would be a created universe just as one with a finite age.

Conceiving time as finite and the universe as contingent, the English Franciscan scholar Robert Grosseteste was inspired to think of something that would have horrified Aristotle. Relying on the principles of Scholastic physics, around 1220 he developed an account of the formation of the Ptolemaic universe

11 In the *Almagest* Ptolemy introduced secondary motions (epicycles, eccentric, equant) which made the model quite intricate. The equant (*punctum equans*) was an off-center point about which the epicycle moved with uniform *angular* velocity, thus representing some compromise with the founding principle of the model.

12 Also, in *The literal meaning of Genesis* (Book 4, Ch. 20, n. 37), where he states: "A period of time is concreated with creatures subject to time, and hence it is also undoubtedly a creature. For there are not and there could not have been and never can be any periods of time that God did not create".

13 "Things are said to be created in the beginning of time, not as if the beginning of time were a measure of creation, but because together with time heaven and earth were created" (St. Thomas Aquinas, 1997, Q46, 3, 456).

in time.[14] He suggested that an initial seed of light *instantaneously* propagated into an expanding sphere, thereby giving rise to *spatial extension* and starting a physical process *in time*. Interestingly, light was conceived of a more fundamental nature than space and time. Matter was dragged by the expanding light, thus decreasing in density. Since according to Aristotelian physics vacuum is impossible, there has to be a lower limit of possible densities. Grosseteste thought that when the expanding sphere was maximally rarefied, it stabilized to form the outer cosmic boundary. Then every part of the newly formed sphere became a source of light propagating towards the center. Matter was again dragged by the light front, reaching a new limit of rarefaction and producing a second sphere (that of Saturn). Similarly, by means of successive light fronts emanating inwards, all other spheres were formed, completing all the orbs of the Aristotelian universe.

While Grosseteste's cosmology may appear naïve to us, it represents a rare early attempt to describe the development of a finite-age universe based on a conceptually coherent physical system.

3 Newton and the Darkness Paradox

The most revolutionary aspects of the Copernican vision concerned the periphery of the universe, rather than its center. As the movements of the stars were explained in terms of Earth's motions, the lack of any measurable parallax soon required stars to be placed at huge distances, floating in boundless space. The Greek principle of circular uniform motion was still maintained by Copernicus, but was soon destroyed by Kepler's three laws of planets motion. The advent of Newtonian physics eventually consolidated the concept of absolute space and time. As he wrote: "Absolute, true, and mathematical time, of itself, and from its own nature flows equably without regard to anything external" (Newton 1846, 77) and similarly for space.

The extraordinary success of Newton's universal laws seemed to establish the definitive cosmic framework, convincing in its simplicity and prediction power. More than ever, time played the role of an inflexible and eternal axis. The Newtonian universe was spatially infinite in all directions, everywhere filled with stars and subject to the same physical laws, without temporal beginning nor end. However, an annoying detail was disturbing the picture: in such uni-

14 The cosmological vision of Grosseteste is found in his works *De Luce*, *De motu corporali et luce* and *Hexameron*. For some more discussion, see Bersanelli (2012).

verse the night sky can't be dark. This remarkable circumstance, first noted by Kepler and occasionally discussed by astronomers along the centuries,[15] is quite simple to see. Since the luminosity of a star scales as the inverse square of the distance, $\phi \propto 1/r^2$, and the number of stars in a thin spherical shell at distance r grows as $n \propto r^2$, the luminosity contributed by each shell is $L \propto n\phi = L_0$, independent of distance.

As a consequence, in an infinite and eternal universe the overall luminosity of the sky would diverge and reach everywhere the brightness of the sun. Interestingly, the first appropriate suggestion of a way out of this dilemma came not from a scientist, but from an artist and writer. In 1848 Edgar Allan Poe suggested that the paradox would be solved by "supposing the distance of the invisible background so immense that no ray from it has yet been able to reach us at all" (Poe 1848, 62). The darkness of the sky would be explained if the universe itself had a finite age.

4 Towards a Beginning of Time

The vision of an ageless universe was about to crumble at the beginning of 20th century. Between 1912 and 1924 Vesto Slipher, from Lowell Observatory, Arizona, measured the spectra of 41 spiral nebulae, enigmatic faint diffuse objects whose nature was much debated at the time, and found that nearly all of them showed a well-measurable shift towards longer wavelengths, or *redshift*. Interpreted in terms of Doppler effect, this observation implied that those objects were receding with velocities of several hundred km/s, much larger than typical stellar or planetary velocities. Something weird was going on. In the early 1920's Edwin Hubble, at Mount Wilson Observatory, using an ingenious method based on a particular class of variable stars called *Cepheids,*[16] was able to estimate the distance of a few spiral nebulae. He found that they were as far as a million light years or more,[17] demonstrating that they are indeed external galaxies similar to our Milky Way.

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15 The darkness of the night sky became known as "Olbers' paradox". A full account is given in Harrison 1987.

16 The use of Cepheids as distance indicators, discovered in 1912 by Henrietta Leavitt, is still crucially important today. Cepheids variables are a specific class of pulsating stars that vary regularly in brightness with a period that correlates with their intrinsic luminosity. Once calibrated, measurements of the period allow astronomers to derive their brightness and, combined with the flux received on Earth, to derive their distance.

17 Today the distance to M31 is measured to be about 2.5 times more.

By 1929 Hubble had measured the distance of several galaxies of Slipher's sample, whose redshift was known, and by correlating their distance d with recession velocity v_r he famously found evidence of a linear relationship, $v_r = H_0 d$, where H_0 is known as the *Hubble constant* (Fig. 1). Although Hubble himself was cautious about attaching a strong cosmological meaning to this result,[18] his finding was about to change our cosmic vision. Not long before, in 1916, Albert Einstein had published his theory of General Relativity, whose cosmological solutions could naturally explain the observed recession velocities. General Relativity predicts a dynamic space, either expanding or contracting, with an evolution controlled by the gravitational content of the universe. However, Einstein was not prepared to recognize an evolving cosmos. In 1917 he introduced an additional term in his equations, without violating their mathematical coherence, and attributed to this "cosmological constant" precisely the value required to restore a static space.

However, Einstein's solution turned out to be unstable. Before Hubble's empirical discovery, the Russian physicist Alexandre Friedmann and the Belgian cosmologist Georges Lemaître, independently derived a family of relativistic solutions for an expanding universe (Fig. 1). Lemaître in particular, who was well aware of Slipher's redshift measurements, went beyond and using the available data found evidence of cosmic expansion two years before Hubble's result.[19] Although based on less accurate data, he correctly interprets the redshift of galaxies as due to cosmic expansion, as opposed to a classical Doppler effect within a static Newtonian space.[20]

Lemaître realized that if we live in an expanding universe, then its average matter-energy density must decrease and the universe as a whole may be subject to a dramatic evolution history. By extrapolating back enough in the past, the density of the universe would reach extremely large values. By 1931 he was convinced that the expansion we observe today should indeed be regarded as the aftermath of such an early, ultra-compact phase, that he called the "primeval atom". For those who were ready to take seriously this possibility, the question would naturally arise: when did cosmic expansion begin? And can we observationally constrain such primordial era? In Lemaître's vision, for the first time, the concept of an *age of the universe* became an element within a solid physical

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18 See, e. g., Luminet 2014 and references therein.

19 Lemaître (1927) assumed the visual brightness of galaxies as distance indicator, which introduced a large spread in his data points.

20 In recognition of Lemaître's fundamental contribution in 2018 the IAU decided to rename the expansion law, traditionally known as Hubble law, as "Hubble-Lemaître law".

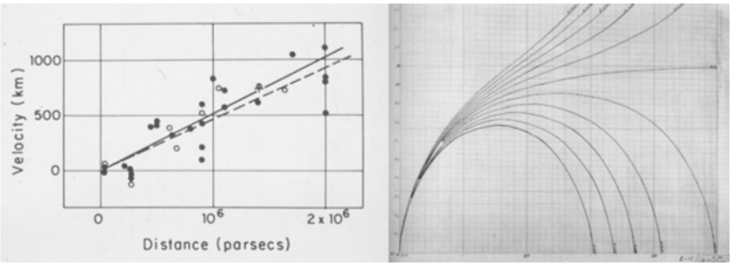

Fig.1: Left: The plot by Hubble (1929) showing the first solid evidence of linear correlation between recession velocity and distance of galaxies. Right: A family of solutions for the expansion history of the universe, as calculated by Lemaître (here, the horizontal axis is cosmic time, the vertical axis is an expansion scale factor).[a] Lemaître Archive, manuscripts (1927), Louvain University.[a]Lemaître Archive, manuscripts (1927), Louvain University.

theory—General Relativity—and, at least in principle, subject to experimental verification.

Assuming that the expansion rate did not change much in the past, a crude estimate of the age of the universe t_0 can be inferred as the inverse of the Hubble constant, $t_0 = v_r/d = 1/H_0$. The sample of galaxies measured by Hubble yielded a value $H_0 \approx 500$ km $s^{-1}Mpc^{-1}$, which corresponds to $t_0 \approx 1.8 \times 10^9 \text{yr} = 1.8$ Gyr.[21] Lemaître's estimate resulted in an even younger universe, $t_0 \approx 1.4$ Gyr. These cosmic ages, however, were too short to be true. The conflict was not with other astronomical observations, but with geological data.

In 1927 Arthur Holmes, a pioneer in the measurement of rock ages from uranium-lead radiometric dating, showed the age of the Earth to be at least 3.0 Gyr.[22] And of course, no object in the universe can be older than the universe itself! Lemaître was aware of this problem and considered in his relativistic solution a non-zero cosmological constant,[23] with a generic small value, as he realized it would have the effect of increasing the present age of the universe. Lemaître's defense of the cosmological constant, however, was mostly ignored and set aside until recent times.

21 This means that for every mega-parsec (Mpc) in distance the recession velocity increases by 500 km/s. A parsec (pc) is 3.26 light years. The unit Gyr (giga-year) is a billion years.

22 See Dalrymple 2004, 52.

23 This is the same parameter that Einstein initially introduced with an *ad-hoc* value in his attempt to keep the universe static. Later on, Einstein claimed that introducing the cosmological constant was "the worse blunder of his life", and since then most cosmologists assumed that it is simply zero.

The cosmic age dilemma contributed to some skepticism against the concept of a finite-age universe by most eminent scientists in the field. Sir Arthur Eddington stated that "Philosophically, the notion of a beginning of the present order of nature is repugnant to me… I should like to find a genuine loophole" (Eddington 1931, 447–453). The fact that Lemaître was a catholic priest raised suspicion that his idea of a *primeval atom* may be forced in by his religious belief. However, while it's likely that Lemaître's philosophical background made him prepared to such a possibility, he was never driven by theological prejudice but by scientific evidence (Lambert 2015). Einstein, in particular, was quite reluctant to consider cosmic expansion, let alone a beginning of the universe. When he met Lemaître for the first time at the 1927 Solvay Conference, after some appreciation for the mathematical results of the Belgian priest, he bluntly concluded that, however, "from the physical point of view, [those results] appeared completely abominable"; and in a letter to Dutch cosmologist Willem de Sitter he wrote "This circumstance [of an expanding universe] is irritating… To admit such a possibility seems senseless" (Lemaître 1958, 129–132).[24]

Recently, an unpublished work by Einstein was uncovered which further confirms his aversion to an evolving universe (O'Raifeartaigh et al. 2014; *Castelvecchi 2014*). In 1931, as the observational evidence of expansion gained strength, Einstein conceived a cosmological solution in which the expansion was counter-effected by the creation of new matter from empty space, in such a way that the global average density would remain unchanged in time. This work was never published. Almost two decades later, a conceptually similar scenario was independently proposed by Fred Hoyle, Herman Bondi and Thomas Gold, named "steady state" model (Hoyle 1948; Gold 1948), which rivalled the 'Big Bang' scenario up to the early 1970's. The theory was openly motivated by philosophical and aesthetic preference for a homogeneous and isotropic universe with no beginning and no change—the so-called "Perfect Cosmological Principle"—and was capable of sound specific falsifiable predictions (Kragh 2007, 184–200). In these *stationary* cosmologies the flow of time would drive all sorts of processes on local scales, but the universe as a whole, though expanding, would not have any beginning, thus radically solving any age issue.

Indeed, besides philosophical inclinations, the "young" universe problem required a scientific explanation. In the 1940's the dilemma got worse, as thermonuclear reactions were recognized to be the energy source of stars and placed stellar ages up to several Gyr. Finally, in the 1950's the fog started to dissipate. It was realized that the Cepheids and other standard candles that Hubble used to

24 See also Luminet (2014) and references therein.

measure galaxy distances were affected by systematic calibration errors.[25] That bias led to an overestimate of H_0 by a factor ~3, and to a corresponding underestimate of the age of the universe. Allan Sandage (Tammann and Reindl 2012) greatly improved the techniques to measure distances and in the early 60's he obtained values for H_0 between 75 and 100 km $s^{-1}Mpc^{-1}$. The age of the universe was now in the range 10 to 13 Gyr, compatible within uncertainties with geological and astronomical limits.

The fascinating and fruitful debate between finite-age and age-less universe reached a definitive turning point in 1965, when Arno Penzias and Bob Wilson at Bell Labs, New Jersey, serendipitously discovered a background of microwave photons coming from every direction of the sky with a temperature[26] of ~3K. Robert Dicke's cosmology group at nearby Princeton University readily interpreted the radiation as a remnant of the primordial hot universe.[27] Within a decade or so, further observations confirmed that the radiation had the main features expected for a field of fossil cosmological photons. As we shall see, this ancient light, called *cosmic microwave background* (CMB), not only provided a definitive evidence that we live in a historical universe, but since then it has offered a unique opportunity to measure cosmic age to unprecedented precision. To see how that is possible, we have to consider in some more detail how gravity affects cosmic expansion.

5 Gravity vs. Expansion

Estimating the age of the universe as the inverse of the Hubble constant assumes that the expansion rate has remained constant in the past. But is this a realistic assumption? And how can we tell? Here is where General Relativity demonstrates its amazing power. As Lemaître first understood, expansion is a property of space itself, not a motion of galaxies within a static space. Cosmic expansion

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25 It was realized that there are two classes of Cepheids, with different period-luminosity correlations. The local Cepheids used by Hubble to calibrate the correlation were systematically fainter than those in external galaxies, which resulted in an overestimate of their distance. Furthermore, for some of the most distant galaxies, star clusters were confused with individual stars, further contributing to an overestimate of H_0.

26 In radio and microwave astronomy it is convenient to express electromagnetic brightness in terms of the temperature of an equivalent blackbody source.

27 The key original discovery papers are Penzias and Wilson 1965; Dicke et al. (1965). Penzias and Wilson received the Nobel Prize in 1978 for their experimental discovery. Jim Peebles's Nobel Prize in 2019 was largely in recognition of his theoretical work in the interpretation of the CMB. For a complete historical account see Peebles, Page and Partridge (2009).

is quantified by an adimensional scale factor, $a(t)$, which is normalized so that its present value is unity, $a(t_0) = 1$. A universe that expands at a fixed rate is simply described by $a(t) = H_0 t$, and its age is $t_0 = 1/H_0$. Gravity, however, makes things much more interesting. According to Einstein's field equation, expansion is influenced by gravitational effects produced by the different matter and energy components that are present in the universe. The total matter-energy density, Ω_0, can be expressed as the sum of in three terms:

$$\Omega_0 = \Omega_R + \Omega_M + \Omega_\Lambda$$

The first term, Ω_R, is the energy density of radiation, which includes photons and relativistic particles such as neutrinos. The second term, Ω_M, includes ordinary baryonic matter (the stuff that makes stars, planets and ourselves) as well as dark matter.[28] The third term, Ω_Λ, dubbed "dark energy", incorporates the energy density associated with a non-zero cosmological constant. General Relativity shows that the value of $\Omega_0$determines the global curvature of space, so it's convenient to normalize these parameters so that $\Omega_0 = 1$ corresponds to a zero-curvature (Euclidean) space. The three contributions $\Omega_R, \Omega_M, \Omega_\Lambda$change in different ways with the scale factor $a(t)$ and therefore become dominant at different epochs of cosmic history. Radiation has the fastest decrease, proportional to a^{-4}, thus it dominated in the young universe but it rapidly became negligible. Then matter density (which scales as a^{-3}) took over, and the universe entered the phase when local gravitational collapse was able to form galaxies, stars, planets, opening the way to the complexity we see and experience today. Finally, the term Ω_Λ is independent of the expansion rate. Therefore, a positive value of Ω_Λ, even if small, at some point will make dark energy the dominant form of energy with the effect of accelerating the expansion.

General Relativity shows precisely how the density parameters, combined with a value of the Hubble constant, determine the function $a(t)$. Fig. 2 shows a few solutions for $a(t)$, assuming a fixed value of H_0. The age of the universe is the intersect of each model curve with the horizontal time axis. The red line corresponds to an ideal 'empty universe', in which all density parameters are set to zero. In this case of course gravity has no effect, the expansion rate is constant and $t_0 = 1/H_0$. For any non-zero choice of the density parameters the expansion is influenced by the gravitational effect of the respective mass-energy

28 There is strong observational evidence that about 80% of the matter contributing to the gravitational fields of galaxies and clusters of galaxies is in some form of non-baryonic particles, called "dark matter", whose nature is yet unknown.

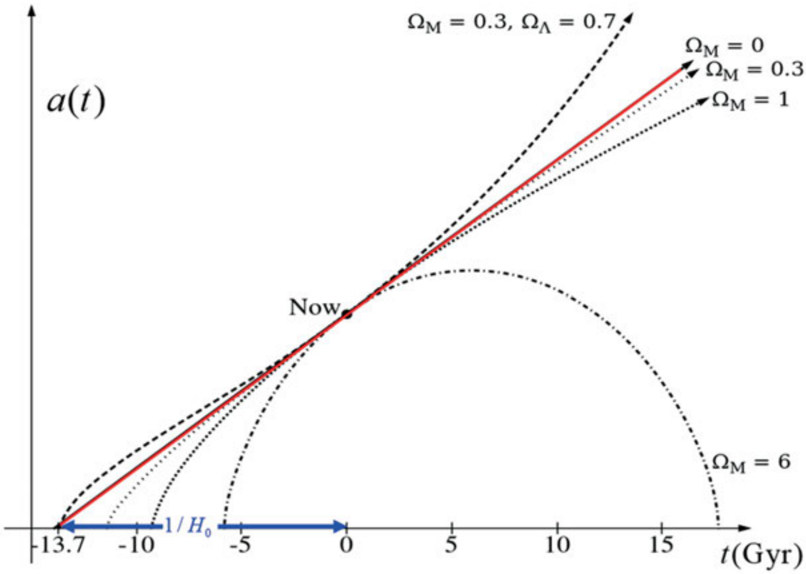

Fig. 2: World models for a given value of the present expansion rate (the Hubble constant H_0 =70 km s^{-1} Mpc^{-1}) and for different choices of density parameters ($\Omega_R = 0$ for all models, while the values of Ω_M and Ω_Λ are shown in the plot). The red linear model is an empty universe ($\Omega_R = \Omega_M = \Omega_\Lambda = 0$) for which cosmic age is simply the inverse of the Hubble constant (shown in blue).

contributions, resulting in different cosmic ages. For example, if $\Omega_R = \Omega_\Lambda = 0$ and $\Omega_M = 1$ (the so-called "Einstein-De Sitter Model"), calculation shows that $t_0 = 2/(3H_0)$. Higher values of matter density lead to shorter cosmic ages. In the case shown ($\Omega_M = 6$, with $\Omega_R = \Omega_\Lambda = 0$) gravity is strong enough to win over expansion and the universe will eventually contract and collapse in a finite time in the future. Note that the effect of $\Omega_\Lambda > 0$ is to introduce an acceleration at late times (dotted curve), which implies an *increase* of the present cosmic age.

In general, it is convenient to express the age of the universe as the inverse of the Hubble constant times a factor, f, which incorporates the gravitational effects of the density parameters:

$$t_0 = \frac{1}{H_0} f(\Omega_R, \Omega_M, \Omega_\Lambda)$$

General Relativity specifies the function f, as shown here for completeness:

$$f = \int_0^1 da \left(\frac{\Omega_R}{a^2} + \frac{\Omega_M}{a} + a^2 \Omega_\Lambda - (\Omega_0 - 1) \right)^{-1/2}$$

The values of the four free parameters—Hubble constant and the three density parameters[29]—is not fixed by the theory. If we are able to accurately measure their values, then the age of the universe can be derived with a comparable accuracy.

In the mid 1990's a number of studies of galaxies distribution suggested a value $\Omega_M \approx 0.3$, corresponding to an open universe with $t_0 \approx 12$ Gyr. Although the uncertainties were large, such cosmic age was hardly compatible with the age of some old stellar clusters (Spergel et al. 1997),[30] measured to be 13–14 Gyr. Cosmology seemed to enter another embarrassing age crisis. Quite timely, however, another unexpected discovery came on stage. Two independent groups using a specific class of distant Supernovae as standard candles,[31] realized that the present expansion rate is *higher* than it was a few billion years ago (Perlmutter et al. 1999; Riess et al. 1998).[32] In other words, cosmic expansion is *accelerating*, which implies a positive value of Ω_Λ (Fig. 2). Their fit to relativistic models suggested $\Omega_M \approx 0.3$ (compatible with previous estimates) and $\Omega_\Lambda \approx 0.7$. The discovery that $\Omega_\Lambda > 0$, a possibility nearly forgotten since the times of Lemaître, was a major surprise for the physics community at large. The effect on the age of the universe was an increase by ~2 Gyr, thus resolving the age tension with globular clusters.

A coherent picture seemed to emerge, but the measurement uncertainties were very large, over 30 %, and the issue of cosmic age was still wavering. Since then, observations of the relic CMB photons have played a central role in pinning down the value of the cosmological parameters, including those controlling the age of the universe.

6 Cosmic Age and Cosmic Edge

The discovery of the CMB transformed the bold hypothesis of an initial hot state of the universe into a unique observational opportunity. The primordial hot and compressed plasma progressively cooled and rarefied under the effect of expansion. After about 380,000 years, when the temperature dropped below ~3000 K, neutral atoms could form from the primordial mixture of electrons and light nu-

29 The total density Ω_0 is just their sum.

30 We will come back to age of globular cluster later in this work.

31 These were a specific class of exploding stars, called Supernovae type-Ia, which result from very repeatable process and therefore present a nearly standard peak luminosity which can be used to infer the distance of the host galaxy.

32 The discovery led to the 2011 Nobel Prize to Saul Perlmutter, Brian Schmidt and Adam Riess.

clei (essentially hydrogen and helium). As matter became electrically neutral, suddenly the universe became transparent to light and the CMB photons could freely propagate. At that time, known as 'recombination epoch', the wavelength of the photons was ~ 0.5 – 1 micron, i.e., in the visible to near-infrared. Since then, the expansion has stretched their wavelength by a factor $z \sim 1100$, shifting them into the microwave range (~few mm). The low energy of the relic photons, combined by the finite age of the universe, fully explain the darkness paradox.

We see the CMB emerge from a sort of cosmic photosphere, called "last scattering surface", surrounding us near the edge of the observable universe. Such space-time surface represents a physical barrier to direct observation with light, as beyond that limit the universe is opaque to electromagnetic radiation.[33] Despite the enormous number of galaxies, the voids between them are huge and the CMB traveled nearly unperturbed for almost the whole cosmic time, bringing to us a remarkably faithful image of the last scattering surface.

Since its first discovery, the CMB has been a generous source of cosmological information. Its thermal origin is brilliantly confirmed by its purely blackbody spectrum, measured to exquisite precision (Mather et al. 1994) at a temperature $T_0 = 2.725 \pm 0.001$ K. The corresponding radiation energy density[34] turns out to be, $\Omega_R \approx 10^{-4}$, which is very small compared to the other density parameters. As a consequence, the gravitational effect of radiation can be ignored in the calculation of the factor f, a welcome simplification in our attempt to measure the age of the universe.

The CMB intensity is highly isotropic, but not completely. This was expected because, in order to explain the formation of galaxies and of other cosmic structures under the action of gravity, primordial density perturbations needed to be present at the last scattering. Since the CMB photons are influenced by the gravitational potential, their intensity traces the early density perturbations and must appear to us as temperature differences from one direction to another in the sky. In 1992, NASA's COBE satellite first detected such CMB *anisotropies*[35] at a level of 0.001 % at all angular scales larger than ~ 7°. In 2000, NASA launched the

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33 In some future, we might be able to detect the background of low-energy cosmic neutrinos, which cross unimpeded the hot primordial plasma and reach us directly from a universe only ~ 1s old. And if primordial gravitational waves could be measured, these would get us a directly to a tiny fraction of a second of the beginning.

34 The radiation density parameter includes also the contribution of neutrinos, about 68 % of the photon energy density.

35 The discovery of CMB temperature anisotropies and the high precision measurement of the CMB frequency spectrum obtained by the COBE satellite in 1992 granted the 2006 Nobel Prize for Physics to George Smoot and John Mather. See: Smoot et al. (1992); Mather et al. (1994).

WMAP satellite[36] which obtained full-sky maps of the CMB fluctuations with sub-degree angular resolution and much improved sensitivity. The Planck satellite, launched in 2009 by the European Space Agency, represents the current state of the art of full-sky CMB observations.

The amplitude of CMB anisotropies at different angular scales depends on the physical conditions in the hot primeval medium, as well as on the geometry of the expanding space in which the photons have travelled to reach us. For this reason, CMB anisotropies encode a wealth of cosmological secrets that can be unveiled by accurate, high resolution measurements. The fundamental statistical information contained in a CMB map is captured by the so-called “angular power spectrum”, a spherical harmonic expansion of the measured temperature fluctuations in the sky. The power spectrum quantifies the amplitude of the anisotropy as a function of angular scale θ, or multipole $\ell \sim 1/\theta$. On scales below $\sim 1°$, primordial fluctuations were processed by acoustic oscillations driven by gravity and photon pressure in the baryon-photon fluid. The oscillations that happened to be in maxima of compression or rarefaction at the time of decoupling, produce peaks in the anisotropy power at specific angular scales. Therefore, the theory predicts a characteristic harmonic pattern (Fig. 3) whose details are very sensitive to the physical characteristics of the primordial plasma, including the value of the density parameters and of the Hubble constant. In turn, accurate measurement of the CMB can be used to extract the value of those parameters.

7 The Very First Light

The precise measurement of the main cosmological parameters was one of the key scientific objectives of the ESA Planck satellite,[37] launched by an Ariane 5 rocket from the launch pad in Kourou, French Guiana, on 14 May 2009. The satellite took data uninterruptedly for four years, scanning the sky from an especially suitable orbit at 1.5 million km away from Earth. The telescope, instruments and observing strategy were designed to reach an unprecedented combination of angular resolution (up to 0.1°), sky coverage (100 %), wavelength range (from 0.3 to 10 mm), sensitivity ($\Delta T/T \sim 10^{-6}$), calibration accuracy (< 0.1 %). Local astrophysical emissions contribute to the observed microwave signal and must be accurately removed. The extreme sensitivity of Planck called for pre-

36 For the excellent WMAP results see Bennett et al. (2013) and references therein.
37 https://www.cosmos.esa.int/web/planck.

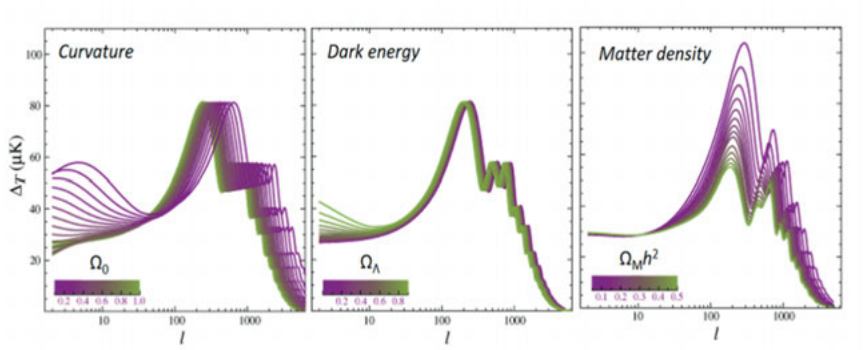

Fig. 3: CMB temperature angular power spectra, showing the sensitivity to the value of density parameters that control the age of the universe (adapted from Hu and Dodelson 2002, with permission from the Authors).

cision measurement not only at wavelengths dominated by the CMB (~ 3–4 mm), but also in spectral bands where the foregrounds are strong. To cover such wide wavelength range, two complementary instruments were developed, using radiometric and bolometric detectors in their best windows of operation, cooled to cryogenic temperatures.[38] The two instruments shared the focal plane of a 1.5-m off-axis telescope (Fig. 4). The ambitious performance of Planck was verified in a demanding ground calibration campaign before launch, and has been wonderfully confirmed by in-flight data.

To calibrate the CMB maps, Planck (as well as WMAP and COBE/DMR) used the effect of the proper motion of our local rest frame with respect to the CMB itself. In fact, as for any other cosmic observer, our local motion produces by Doppler effect a slight increase of the CMB temperature in the direction of our velocity vector, and a symmetric decrease in the opposite direction.[39] Interestingly, therefore, the CMB represents a natural global rest frame to evaluate the local velocity of any cosmic observer relative to the expansion flow. This philosophically intriguing circumstance has also the very practical advantage of providing a nearly perfect calibrator for CMB observations.

38 For an overview of the results of the Planck mission see Planck Collaboration (2018a). The satellite and the two Planck instruments are described in Tauber et al 2010; Bersanelli et al. 2010; Lamarre et al. 2010).

39 Planck measured a dipole anisotropy with an amplitude of 3.362±0.001 mK corresponding to a velocity 369.82±0.11 km/s, in the direction of a precisely identified point (±0.6 arcmin) in the constellation of Leo (Planck Collaboration 2018a).

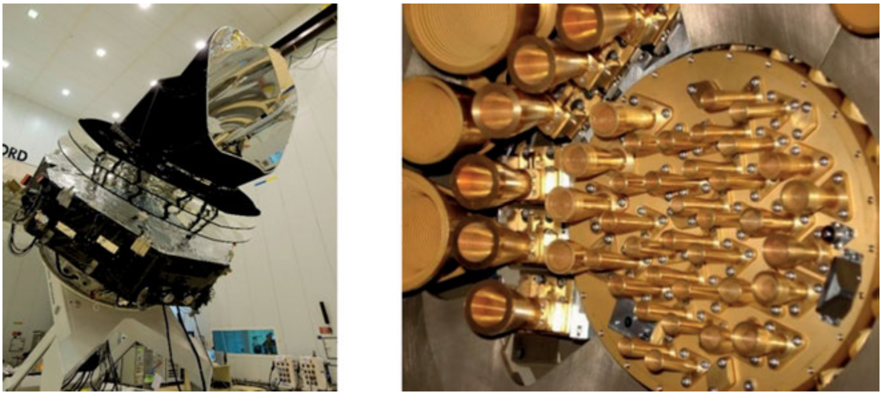

Fig. 4: Left: the Planck satellite during system ground tests, just before launch. Right: a view of the Planck focal plane, including two integrated instruments: Low Frequency Instrument, operating in the 30–70 GHz bands, and the High Frequency Instrument, covering the 100–850 GHz range. (Credit: ESA, ASI, CNES).

The final analysis of the Planck data has been recently completed (Planck Collaboration, 2020a-b). The Planck data also include polarization and gravitational lensing, which provide further leverage to extract cosmological parameters. Fig. 5 shows the full-sky map of temperature anisotropies after removal of the foreground emissions. The corresponding angular power spectrum is shown in Fig. 6. The blue solid line is the best fit to the simplest cosmological model, which includes six degrees of freedom encoding the values of cosmological parameters. The red points are the Planck data. Here one can appreciate the amazing agreement between the experimental data and the theoretical model. The Planck results on polarization and lensing beautifully confirm the best fit parameters and help break internal degeneracy.

The six-parameter fit yields a Hubble constant of 67.4 ± 0.5 km s^{-1} Mpc^{-1}, somewhat lower than previous estimates based on traditional methods. The matter energy density[40] gives $\Omega_M = 0.315 \pm 0.007$, consistent with previous estimates but greatly improved accuracy. Allowing the total density as a free parameter[41] provides very stringent limit on curvature, which is further tightened by combining Planck data with recent measurements of large-scale structure, yielding $\Omega_0 = 0.9993 \pm 0.0019$. We seem to live in a very Euclidean universe: even with

40 Planck also measured the independent contributions from baryonic and dark matter components, which account for 4.9% and 26.5%, respectively, of the total energy density.

41 The standard 6-parameters fit assumes a flat geometry ($\Omega_0 = 1$), so fitting for Ω_0 is an extension of the basic model.

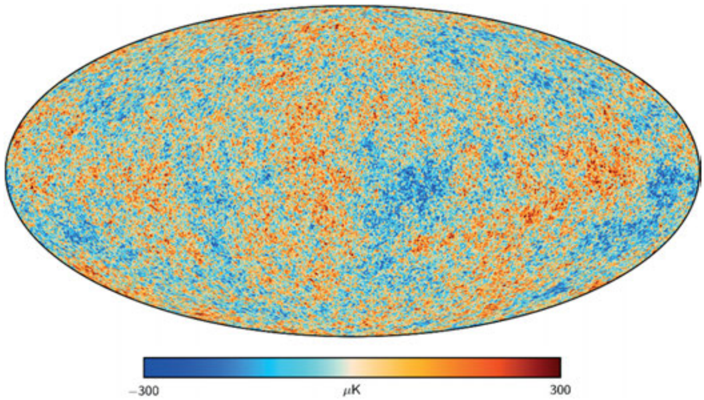

Fig. 5: Planck all-sky map of the CMB. Thanks to Planck's nine frequency bands and to sophisticated analysis techniques, the foregrounds emissions were accurately subtracted. (Planck Collaboration, 2018. Credit: ESA, LFI Consortium, HFI Consortium).

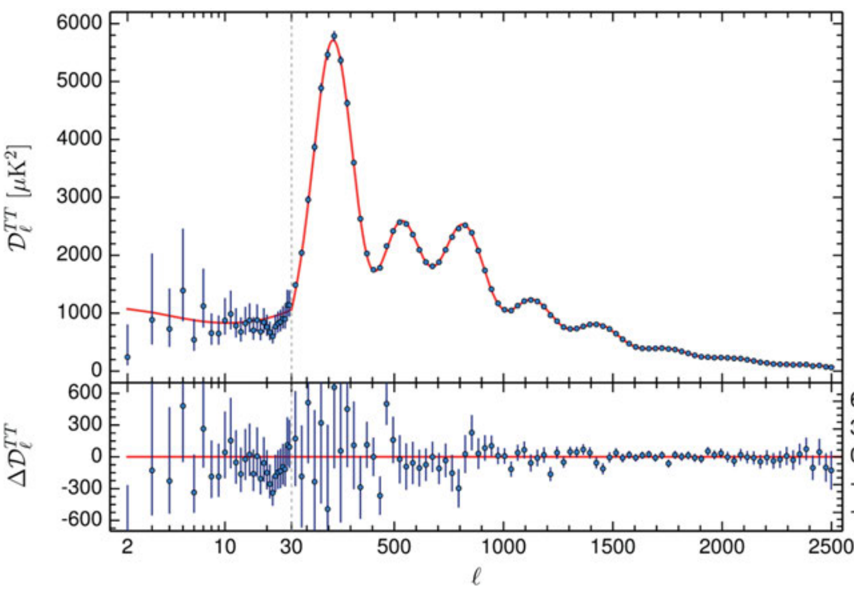

Fig. 6: Planck power spectrum of the temperature anisotropies of the CMB. The horizontal axis is the multipole number, inversely proportional to the angular scale (left to right: 180 degrees to 7 arcmin). The vertical axis is the anisotropy power in μK^2. Bottom panel: residuals to the best fit model. (Planck Collaboration, 2018a. Credit: ESA, LFI Consortium, HFI Consortium).

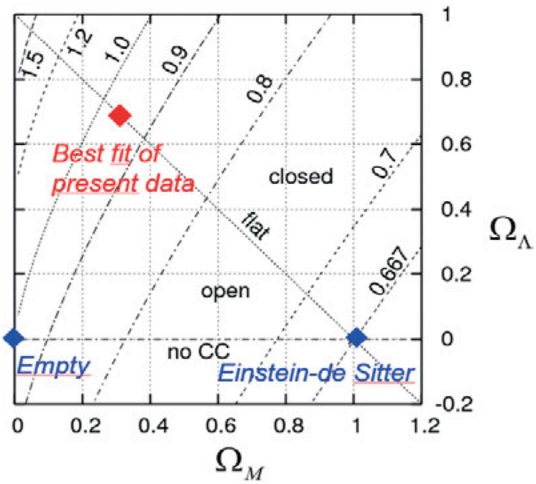

Fig. 7: Values of the function *f* for different values of dark matter and dark energy density parameters. Highlighted in blue are the values for the "empty universe" ($f = 1$) and for the Einstein-de Sitter model ($f = 2/3$). In red is the value for the best fit model from Planck 2018 data.

< 1% precision we can't detect any global curvature. The remaining energy density is contributed by dark energy, with $\Omega_\Lambda = 0.685 \pm 0.007$, in agreement with the independent estimate of the accelerated expansion from type-Ia Supernovae, but again with much improved precision. The combination of these results yield an age of the universe of $t_0 = 13.797 \pm 0.023$ Gyr. This level of accuracy (~0.2%) is quite remarkable: it's like guessing the age of a 50-years-old person with the precision of 1 month.

8 The Oldest Objects in House

These high precision results call for independent crosschecks. Results from previous CMB experiments and other cosmological probes, while less accurate, are generally in good agreement with those of Planck.[42] Recently, however, improved measurements of the Hubble constant from traditional Cepheid-calibrated red-

42 The WMAP data yield a cosmic age fully consistent with Planck, 13.772±0.059 Gyr (Bennett et al 2013), with an uncertainty larger by a factor of 3. Data from galaxy redshift surveys such as 6-degree Field Galaxy Survey (6dFGS) and Sloan Digital Sky Survey Main Galaxy Sample (SDSS MGS) have provided excellent and consistent parameter estimation (Carter et al 2018).

shift-distance methods[43] yielded values ~8% higher than CMB-based results (both Planck and WMAP), and of course a correspondingly younger universe, t_0 ~ 12.7 Gyr. Whether this tension, significant at ~3.5 standard deviations, is a symptom of new physics, or it is due to undetected systematic effects, is the subject of a renewed debate on the value of the Hubble constant.

A radically independent verification may come from the limits imposed to the age of the universe by the oldest stars (Fig. 8). Even a single object older than t_0 would represent a serious challenge. On the other hand, we have evidence that the first stars were born just ~0.6 Gyr after recombination (Planck Collaboration 2018a), so we expect the oldest stars to be ~13.2 Gyr or ~12.1 Gyr old, depending on the scenarios. Exploiting at best our understanding of stellar physics we have an opportunity to test cosmology-based estimates.

How can we identify very old stellar objects? A first way is to look at globular clusters, families of 10^5 to 10^6 stars known to have formed very early on. Astronomers can measure the age of a star cluster by studying their stellar population. Since more massive stars live shorter lives in their equilibrium state (called "main sequence"), by looking at the most massive stars which are still in the main sequence one can infer the cluster age. A recent study of 22 clusters shows ages in the range 10.8–13.6 Gyr with typical uncertainty ±1.6 Gyr. A detailed work on the cluster HP-1 yields an age of 12.8 ± 0.9 Gyr (O'Malley et al. 2017; Kerber et al. 2019). Independent measures of globular clusters age come from white dwarfs, compact stellar relics slowly cooling down as they radiate their internal heat. A classic study (Hansen et al. 2002) of white dwarfs yield 12.7 ± 0.7 Gyr, fully compatible with main sequence age estimates.

Another age test comes from single, very old stars. We can recognize them by studying their composition. Just after recombination, 380,000 years after the Big Bang, the only elements in the universe were hydrogen and helium, as Carbon and heavier elements (called "metals" by astronomers) would only form in thermonuclear reactions in stellar cores. New stars were continuously born from the ashes of previous generations, with increasing abundance of heavy elements. Therefore, stars with very little "metallicity" must be very old, and astronomers can quantify their age form detailed analysis of their spectra. A study of three sub-giant ultra-low metallicity stars (Vanden Berg et al. 2014) gave ages of 12.08, 12.56, and 14.27 Gyr with an uncertainty of ±0.8 Gyr.

The latter star (HD140283, known as *Methuselah Star*) at face value has an age even older than the value of t_0 measured by Planck, but well compatible within the uncertainty, while it is somewhat in tension (~2.7 standard deviations)

43 These programs used Cepheid-calibrated Supernovae type-Ia (Riess et al. 2018).

with the younger universe implied by the recent Cepheid-based estimates of H_0. Overall, stellar ages seem to prefer the CMB-driven estimates, but the uncertainties are still too large. Future progress in stellar astrophysics, as well as on other independent approaches[44] to measure H_0, will surely contribute to the cosmic age debate.[45]

Fig. 8: *Right:* One of the oldest known objects in the universe. *Left:* The globular cluster HP-1 (Credit: Gemini Obs./AURA /NSF/M. Libralato, STScI). *Middle:* The dimmest stars in the image are white dwarfs in the globular cluster M4 (Credit: HST, NASA and H. Richer, Univ. of British Columbia). *Right:* The low-metallicity star D140283 (Credit: DSS, STScI/AURA, Palomar/Caltech, UKSTU/AAO).

9 A Wonderful Space-Time Vista Point

For millennia the notion of an ageless and unchanging universe has been deeply rooted in human minds. The Aristotelian-Ptolemaic model encoded the vision of an eternal cosmos into a complex geometrical structure that successfully reproduced all visible trajectories in the sky. The Copernican revolution and the establishment of the Newtonian system represented two enormous paradigm shifts, however, neither of them even touched the vision of a globally immutable universe. It is not surprising, therefore, that when theoretical and observational hints of an evolving universe emerged, the transition to the new view was troubled and highly debated, resisted even by some of the very same actors of the new emergent paradigm. The most shocking element was the notion that the universe itself may have a beginning. In spite of Einstein's reluctance his General Relativity, as proposed by Lemaître and Friedmann and combined with observations by Hubble and others, brought the concept of cosmic age into mainstream

44 A promising avenue is to use gravitational wave "standard sirens" (Feeney et al. 2019).
45 For further discussion, see Jimenez et al. (2019).

science. Since then, evaluating the age of the universe has become an ambitious objective of experimental work. Today, just a century later, observations of the primordial CMB photons have led to an estimate of cosmic age of t_0 = 13.8 Gyr with sub-percent accuracy, in good agreement with most independent probes.

The time t_0 is the present age of the universe not only for *us*, but for *any* cosmic observer. Furthermore, the CMB temperature provides a natural *cosmic clock*, in a similar way as it offers a natural reference frame to measure local velocities. As the universe expands, the CMB temperature slowly cools down as $T_{CMB}(t) = T_0/a(t)$, a known monotonic function of time. This is indeed a very slow clock hand: with our current technology, to appreciate the smallest conceivable temperature drop, say 1 μK, it would take 4,700 years. Of course, we can't wait that long, however, it is possible to measure *now* the temperature of the CMB *as it was in the past*, by indirectly measuring its temperature in regions that are sufficiently far away.[46] These observations have been carried out and confirm the expected change $T_{CMB}(t)$, further proving the reality of our evolving cosmic scenario.

Our measurements of cosmological parameters not only determine t_0, but also the epoch of a number of global events that took place in cosmic history. Going backwards, these include the start of the accelerated expansion ($t \approx$ 9.8 Gyr), the formation of the first stars ($t \approx$ 0.6 Gyr), photon decoupling ($t \approx$ 0.38 Myr), primordial nucleosynthesis ($t \approx$ 100 s), electron-positron annihilation ($t \approx$ 30 s), decoupling of neutrinos ($t \approx$ 2 s), protons and neutrons formation ($t \approx 10^{-4}$ s), and more. In some sense, all these events are present to us *now*, as they are imprinted in space-time layers at different depths into the observable universe. We can't see most of them directly (a notable exception is photon decoupling, beautifully visible to us through the CMB), but in principle they are all out there. Interestingly though, as a direct consequence of cosmic expansion, we would see them to last a much longer time than they actually took for a hypothetical local witness. Indeed, as observations confirm,[47] the duration Δt of a past cosmic event is observed to last $\Delta t_0 = \Delta t/a(t)$. For example, primordial nucleosynthesis, which lasted ~5 minutes, if observed now in the distant universe would appear to last some ~120,000 years. Seen through our eyes, or through the

46 This has been done in two ways: by exploiting the scatter of CMB photons off the hot gas in clusters of galaxies, known as thermal Sunyaev-Zel'dovich effect; and by measuring the excitation by CMB photons of C, CO or CN absorption lines in the spectra of distant quasars (Luzzi et al. 2015).

47 Cosmological time dilation was observed in SN Ia (Foley R.J. et al. 2005); and in Gamma Ray Bursts (Zhang et al. 2013).

eyes of any other cosmic observer, time indefinitely slows down as we approach the beginning of time.

In retrospect, it is absolutely remarkable that today we are discussing slight tensions at the few percent level about the age of a 13.8 Gyr old universe. On the other hand, we should not forget that our understanding of the universe is still incomplete, and becomes particularly uncertain when approaching the very beginning of cosmic time. As history has shown, our notion of what we mean by "universe" has deeply changed in different epochs. It is entirely possible that cosmologists of the next century will regard our views as naive steps toward a new and deeper cosmic vision, hopefully incorporating (not rejecting!) what we have learned so far. If some of the current speculations will turn out to be correct, we might be brought back to a new incarnation of the traditional image of an everlasting and ultimately unchanging cosmos;[48] or perhaps the next revolution in cosmology will be entirely surprising and far from current ideas. But surely for the time being we can enjoy the awesome space-time panorama we have come to understand and contemplate.

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48 Examples are some versions of inflation models, such as eternal inflation (e.g., Guth 2007), and new versions of a cyclic models (e.g., Steinhard and Turok 2002).

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 https://doi.org/10.1515/9783110753707-022

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 https://doi.org/10.1515/9783110753707-023