Only a unified ontology can remedy disunification

Avril Styrman

The Finnish Society for Natural Philosophy, Kirkkokatu 6, 00170 Helsinki, Finland
Physics Foundations Society, Vasamatie 25, 02630 Espoo, Finland

E-mail: avril.styrman@gmail.com

Abstract. Contemporary theoretical physics is divided into diversified theories of different phenomena. These are characteristically frameworks for giving mathematical descriptions of perceptions, in the absence of understandable explanations or a unified worldview. This is not an optimal state of affairs, for people by nature desire to understand; this sets a major obstacle for an optimal progress rate of physics, for understandable explanations are more prolific of new predictions and applications than non-understandable explanations. Disunification in physics can be remedied only by discovering an understandable ontology and applying it as the basis of unifying explanations of phenomena that were earlier explained by different theories. Due to disunified physics and the nature of traditional analysis in philosophy, there is no consensus about central concepts such as time, possibility and truth. It is suggested that philosophical analysis would be more prolific of understandable and applicable concepts, were it complemented by a method of unification.

1. Introduction

In the manifest image, development of physics in the 20th century is a success story where legendary scientists developed the theory of relativity and quantum mechanics. We see success when we look at the incredibly accurate predictions of the standard theories. When we look at their basic structures, law hypotheses or assumptions about the world, we see incomprehensibility, heterogeneity, incoherence and great metaphysical weight. In effect, there is no commonly accepted unified and understandable scientific worldview. Fundamental theories in physics are formalisms developed for giving mathematical descriptions of phenomena, without intuitive and unifying explanations of why nature behaves as predicted. Since the early 20th century, predictions and explanations of new phenomena have continuously and regularly required new law hypotheses and hypothetical entities. In the Kuhnian model such development leads into a paradigm shift, whereas a successful theory yields novel predictions and explains new phenomena by its basic structure, without additional hypotheses. Further, attempts at unifying quantum mechanics and the theory of relativity by string theory or some other mathematical construction have not yielded positive results and their speculative nature has been widely criticized.

The state of theoretical philosophy is roughly analogous to the state of theoretical physics. Due to its reliance on the theory of relativity, its focus on detached details and the confused role of metaphysics, traditional conceptual analysis has not yielded consensus about the meanings of some of the central concepts such as time, possibility and truth.

It is therefore intelligible to investigate another path of unification: to seek out an ontology that functions as an understandable basis of explaining heterogeneous phenomena. In physics we are seeking out a theory that predicts accurately the behavior of nature in the micro and macro scales, and explains

why it behaves as predicted, based on very few intuitive and simple fundamental laws of nature. In philosophy we aim to replace heterogeneous theories of specific aspects of a concept, with a unified theory that incorporates all or several aspects of the concept.

Unfortunately, theories that differ fundamentally from the standard theories are typically rejected by mainstream journals, disregarding their merits. We have arrived at *the basic conflict of progress and dogmatism*:

1) we can overcome defects of standard theories only by replacing them with different theories;
2) new theories are rejected exactly because they are different from the standard theories;

To overcome dogmatism, constitutional criteria that favor unified theories are of utmost importance. In order to understand why the scientific community should respect criteria that favor more unified theories, even when these are different from the standard theories, one must understand that *it is a tautology that unification in science is beneficial*. One who understands this notion also understands that the roots of contrary ideologies lie in dogmatic attitudes: physics and philosophy have been each internally disunified for more than 100 years now, as well as mutually disunified in the sense of the separation of mathematics and deep intuition; in both disciplines, the tradition has evolved into the mode of focusing on formal details, coping with disunification, and repelling the idea that something is fundamentally wrong.

These notions become understandable by a historical study of how physics and philosophy arrived at their present states, and by opening up the evaluation criteria of scientific theories.

Analytical table of contents

§2. Evaluation criteria of scientific theories are contemplated. It is argued that *unifying power*, also called *economy* and *parsimony*, is an objective, effective and natural central criterion, as it interrelates other virtues into a comprehensible whole. Evaluation of the unifying power of standard theoretical physics forces us to conclude that the standard theories have been in decline ever since their birth in the early 20th century, whereas the 20th century criteria were tailored to support the 20th century physics.

§3. Historical development of the relation of physics and philosophy is outlined, starting from antiquity, going through the rise of mathematical physics in the Copernican Revolution, and ending at the 20th century where physics became primarily the task of giving mathematical descriptions of perceptions, in the absence of understandable explanations.

§4. Traditional philosophical methodology is contrasted to a method of unification, with truth, consciousness, time and possibility as case examples. It is shown how the method of unification answers the central questions of the methodology of metaphysics, or metametaphysics.

§5. The tautology that unification is progressive is presented and applied in emphasizing that the outright rejection and silencing of more unified theories is a clear case of contemporary dogmatism. Suggestions are given of how the society could tackle dogmatism.

§6. The main challenges of contemporary theoretical physics and philosophy are summed up and their suggested resolutions are outlined.

2. Evaluation of scientific theories as evaluation of their unifying power

Evaluation of scientific theories is a matter of evaluating virtuousness of their predictions and explanations: a more virtuous theory is preferred over a less virtuous theory. The focus here is on showing that unifying power functions as an objective and transparent main virtue which interrelates other virtues into a comprehensible whole: explanatory virtues as its components; methodological and aesthetic virtues as its partial implications; development of theories over time as development of their unifying powers.

The unifying power of a theory is the ratio E/M of its evidentiality E and metaphysical weight M [1] pp. 77-83. The most evidential theory is preferred; if two theories are equally evidential, the metaphysically simplest is preferred. The basic form of unifying power directly captures most of the explanatory virtues, which are traditionally left more or less detached: evidentiality, simplicity, unifying power itself, and coherence [2-4]. For, unifying power is the ratio of evidentiality and metaphysical weight, where metaphysical weight is the main measure of simplicity.[1] This leaves over coherence, which is best seen as a component of unifying power (§2.3).

2.1. Evidentiality, underdetermination and metaphysical weight

Evidentiality is measured by comparing a theory's predictions and explanations to empirical data. Evidential virtues are accuracy of predictions and causal depth of explanations (accuracy or the level of detail in which an explanation describes the data, and the degree of variability it can manage). On one hand, accuracy of predictions is the directly functional and the most urgently needed end result of natural science; on the other hand, a scientific theory is crippled without an intuitive explanation of why nature behaves as predicted. On one hand, actual production of accurate predictions guarantees the scientific value of an explanation; on the other hand, deep explanations are prolific of accurate predictions and applications —this is one of the main reasons why unified physics is more progressive than disunified physics. In the following, 'explains and predicts' is abbreviated as 'explains'.

Evaluation of evidentiality only faces the problem of *underdetermination*: we cannot choose between theories that are equally evidential with respect to the central phenomena to be explained, based on their evidentialities only, but we must evaluate other virtues too. Yet, evidentiality is the primary virtue of scientific theories, i.e., the most evidential theory is preferred, disregarding other virtues. Accordingly, the other virtues *are measured only if* we have two equally evidential theories, and due to underdetermination, the other virtues *must be measured if* we have two equally evidential theories.

In the unificatory approach to theory evaluation, metaphysical simplicity is next in priority after evidentiality: of two equally evidential theories, the simplest is the best, i.e., the one that commits to a smaller number of different types of metaphysical entities and/or to a smaller quantity of each type of a metaphysical entity. The metaphysically simpler of two equally evidential theories has a greater unifying power, i.e., the same evidentiality E divided by a smaller metaphysical weight M. By explaining phenomena with a unified postulate base, a theory's quantity and variety of independent metaphysical hypotheses is minimal, whereas a collection of heterogeneous theories that explains the same phenomena applies a greater quantity and/or variety of hypotheses.

It is therefore essential to define what are metaphysical hypotheses in scientific theories and how their weight is measured. A scientific theory is a fusion of ontology and all that is founded on the ontology, including concepts defined in terms of the ontology and semantics mapped to the ontology. Ontology of a theory consists of commitments to existence of specific things, including *verified commitments* to existence of concrete objects such as particles, people, planets and stars, and *unverified commitments*. All unverified commitments, existence postulates or hypotheses that are supposed to correspond to reality but their correspondence is not empirically verified, are metaphysical.

[1] Syntactic simplicities of equally evidential theories are partially derivative from their metaphysical simplicities (§2.5.1). Measurement of syntactic simplicity is notoriously difficult, whereas measurement of metaphysical simplicity is mainly about the challenge of explicating metaphysical commitments of rival theories (§2.2, §2.6).

Metaphysical commitments of a scientific theory typically consist of hypotheses of laws of nature whose universal validity is merely supposed, and hypothetical entities whose existence is merely supposed.

One might argue that a law hypothesis which is exactified by mathematics and verified conclusively by hundreds of experiments is not a piece of metaphysics, but an empirical fact. This claim can be easily shown to be unsustainable. First, Karl Popper famously noted that no law hypothesis can be verified with absolute certainty in all conditions; it follows that every law hypothesis is eventually unverified, which makes law hypotheses metaphysical by definition. Second, that a law hypothesis is very well confirmed, does not exclude the possibility that a slightly different law hypothesis is equally well confirmed, in the limits of our capabilities of measurement; as there are such law hypotheses,[2] the rule that a very well confirmed law hypothesis is an empirical fact would entail the existence of mutually contradictory empirical facts. Interrelatedly, if all hypothetical laws that are locally verified would be empirical facts, the number of empirical facts could obviously increase without a limit, as it has in the 20th century. This leaves over the question of how can another theory explain exactly the same phenomena with less empirical facts?

The notion that a well confirmed law hypothesis is not a metaphysical hypothesis but a statement of an empirical fact is a piece of positivist rhetoric, which is still applied in protecting standard physics (§2.6). A mathematically exactified metaphysical hypothesis is still a metaphysical hypothesis.

2.2. Is the evaluation of simplicity too complex?

The classical allegation against simplicity as a criterion is that its evaluation is vague and subjective.[3] Consider MacAllister's [13] and Benovsky's [23] two-step argument for subjectivity of simplicity: (i) there are several types of simplicity and one type has no priority over another; (ii) when different theories have different degrees of these types of simplicity, it is impossible to make an objective theory choice on the basis of simplicity. MacAllister and Benovsky classify four main types of simplicity.

1. Ontological simplicity: qualitative and quantitative
2. Simplicity of the structure or the laws of a theory
3. Simplicity and quantity of independent primitives in a theory
4. Syntactic simplicity

Types 1-3 are partially redundant formulations of ontological simplicity, for hypothetical laws, primitives and entities are metaphysical commitments —they are supposed to hold or to exist but this is unverified— and thereby parts of a theory's ontology. As the verified part of ontology should be the same for all competing theories, ontological simplicity can be written as metaphysical simplicity. Thus, we get by with two types of simplicity, where type 2 is partially derivative from type 1 (§2.5.1):

1. Metaphysical simplicity: qualitative and quantitative
2. Syntactic simplicity

It turned out that the classification of different types of metaphysical simplicity does not prevent us from measuring it. But there are other arguments against simplicity evaluation. MacAllister [13] argues that simplicity is subjective, on the basis that physics can be unified under different metaphysical frameworks and one cannot objectively decide which kind of a framework has greater unifying power. He uses as examples the Newtonian kinematic approach and the Leibnizean-Machian holistic and

[2] For instance, the general theory of relativity and Suntola's Dynamic Universe (see this volume) give equally accurate predictions of tests made with atomic clocks, applying different mathematics and different postulates.

[3] Perhaps the allegation that simplicity is too complex to measure results from the ambiguity of the role and the definition of metaphysics in philosophy? Perhaps it results from the belief that metaphysical hypotheses of standard theories are empirical facts? Perhaps it results from giving too much attention to syntactic simplicity, which may be notoriously difficult to measure (§2.5.1)?

dynamic approach that is based on conservation of energy. However, nothing prevents us from evaluating theories that are unified under different frameworks, in explaining the same phenomena. For instance, we can evaluate relativistic physics as a modern kinematic approach, against a modern dynamic approach that is based on conservation of energy, in explaining central phenomena from the planetary to the cosmological scale [24].

Finally, Hillman [25] notes that many authors consider simplicity to be "much too heavily dependent on aesthetic and pragmatic considerations to be genuinely analyzable." In other words, the objectivity of simplicity evaluations is jeopardized because scientists tend to consider theories that are familiar to them as beautiful and simple. This is a genuine challenge, but the likes and dislikes of physicists should not make philosophers conclude that comprehensive theory evaluation is too difficult. Although the evaluation of metaphysical simplicities of standard contemporary theories and their rivals may not always be trivial, this should not prevent philosophers from doing exactly what they should.

Once we are in the hold of two equally evidential competing theories, the primary challenge is to open up their structures, and to count the number and quantity of their independent hypotheses, including law hypotheses and hypothetical entities. Thereafter, we can compare their metaphysical weights and their development over time. If one theory is clearly excessive, we can make a selection. If the theories have equal metaphysical weights or we cannot decide which one is simpler, we can evaluate their other virtues. In either case, we would have gained a deeper understanding of the evaluated theories.

2.3. Coherence as a component of unifying power

Coherence is a natural component of unifying power, for the main features of coherence (consistency and inferential-explanatory relations [5-6]) are natural components of unifying power.[4]

Start with consistency. Internal consistency of a theory means that its predictions, commitments and defined concepts do not contradict themselves nor one another. Internal consistency is a prerequisite for a unified theory, for an inconsistent theory does not genuinely explain perceptions. All theories in an internally consistent collection are individually and mutually consistent, i.e., externally consistent with all other theories in the collection. Consistency of a theory (or a collection of theories) can be considered as a component of E and thereby a component of E/M, in the sense that inconsistent predictions and explanations reduce E: if a theory (or a collection of theories) gives two predictions that agree down to the fourth decimal but disagree at the fifth decimal, its accuracy is on the level of the fourth decimal only. Consistency of a collection of theories can also be considered as a component of M, in the sense that contradictory theories have different postulates, which increase M and thereby decrease E/M.

Continue with inferential-explanatory relations. Strength of inferential-explanatory relations between theories is parallel to unifying power of their collection: a unified theory of two scales of phenomena manifests stronger inferential-explanatory relations between explanations of these phenomena, than two theories which need different postulates in explaining the phenomena. In Mackonis' [5] definition inferential-explanatory relations appear very close to reductive relations: "an explanatory hypothesis would cohere with background knowledge if it explains the background knowledge or if the background knowledge explains the explanatory hypothesis." When the hypothesis is considered as theory T, and the background knowledge as the collection of theories C against which external coherence of T is evaluated, strong inferential-explanatory relations between theories are parallel to great unifying power of their fusion C+T. First, if T reduces/explains theories in C, E(T) increases by E(C) while M(T) remains constant, and so E(T)/M(T) increases. Second, if C reduces/explains T, E(C) increases by E(T) while M(C) remains constant, and so E(C)/M(C) increases.

Consider theory a_1 of the planetary scale, a_2 of the galactic scale, and two equally evidential theories a_3 and a_3' of the cosmological scale. The challenge is to decide which of a a_3 and a_3' is more coherent with respect to the collection a_1a_2. If the metaphysical weight of $a_1a_2a_3$ is smaller than that of $a_1a_2a_3'$ — and if the unifying power of $a_1a_2a_3$ is greater than that of $a_1a_2a_3'$— then a_3 is more coherent than a_3',

[4] Were coherence stretched far enough, one could also consider unifying power as a component of coherence. However, it is much easier to consider coherence as a component of unifying power.

with respect to a_1a_2. Consider a third cosmological theory b_3 which is equally evidential to a_3, but which contradicts all theories in $a_1a_2a_3$. a_3 is more coherent than b_3 with respect to a_1a_2. However, if another collection of theories $b_1b_2b_3$ is available, whose unifying power is greater than that of $a_1a_2a_3$, then we should prefer $b_1b_2b_3$ over $a_1a_2a_3$, and therefore b_3 over a_3: we should not look only at consistency with standard theories, if another framework of theories has a greater unifying power or if it is evident that such framework could be built. Then again, even if b_3 were more evidential than a_3, this does not guarantee that its basic structure explains phenomena of any other scale. If the extension of b_3 to theories of the planetary (b_1) and galactic (b_2) scales requires additional hypotheses, so that the unifying power of $b_1b_2b_3$ is less than or equal to $a_1a_2a_3$, then b_3 does not challenge the standard theories. To illustrate, Milgrom [7] argues that by supposing that gravitation weakens slower than the inverse square law of gravitation states, one can get by without dark matter in the scale of individual galaxies. However, it is an open question whether and how the modified law can be extended to the cosmological scale.

Bartelborth [6] acknowledges the affinity of coherence and unification: "Good explanations in the unification sense create substantial connections between our observational beliefs." For Bartelborth, belief-system X is the more incoherent, the more "isolated subsystems of beliefs" X contains, "between which we can only find few connections" and thus "coherence of the whole system will be diminished" proportionally to the number of subsystems. Likewise, a collection of isolated theories with heterogeneous postulates has a smaller unifying power than an equally evidential collection of theories with less heterogeneous postulates. According to Keas [8], an internally coherent theory lacks ad hoc hypotheses. Likewise, ad hoc hypotheses increase a theory's metaphysical weight: if E increases slower than M which contains the ad hoc hypotheses, then E/M decreases; if E increases at the same rate as M, then E/M remains constant.

2.4. Development of unifying power over time

Unifying power of a theory —as the ratio E_D/M_D of its evidentiality E_D with respect to data D and metaphysics M_D that it applies in explaining D— develops as a function of D that increases over time. E_D is supposed to increase proportionally to the increase of D, i.e., only theories that explain the new data are investigated here, whereas theories that plainly fail in explaining new data are excluded. This allows focusing on how M_D develops when E_D increases.

A theory that evolves successfully over time is called consilient, fruitful or diachronically virtuous. It yields novel predictions and explains new phenomena by its basic structure, or manages to reduce or unify some theories and interacts harmoniously with others. As illustrated on the left side of figure 1, unifying power of a theory grows during a period of success, when its basic structure manages to explain new phenomena: M_D remains constant while E_D increases, and thereby E_D/M_D increases. Such progress took place e.g. with Newtonian Mechanics, with Mendeleyev's periodic table when it enabled predicting the existence of new elements, and with quantum mechanics when it predicted the existence of neutrinos and positrons. There are not so many examples of long-lasting positive development, because science has taken progressive leaps by means of theory shifts, which are preceded by periods of decline.

As illustrated on the right side of figure 1, unifying power of a theory remains constant (or decreases) during a period of decline. Theory T explains data available at the time of its formation by its basic structure but does not manage to explain new data. In effect, T is either rejected or complemented by additional hypotheses that help it to accommodate new data. When new phenomena are accommodated continuously and regularly by the aid of new hypotheses, E_D and M_D increase at the same rate and E_D/M_D remains constant, or M_D increases faster than E_D and E_D/M_D decreases. In either case, it becomes apparent that T does not provide natural explanations of the new phenomena. Some lose confidence in T and make efforts to developing better theories. In Kuhn's [9] words: "Failure of existing rules is the prelude to a search for new ones." T is eventually replaced by T′, where T and T′ are mutually inconsistent and T′ is more unified than T. After T′ has become the new paradigm, the cycle is eventually repeated, unless at some point a theory is discovered which explains new data by its basic structure indefinitely.

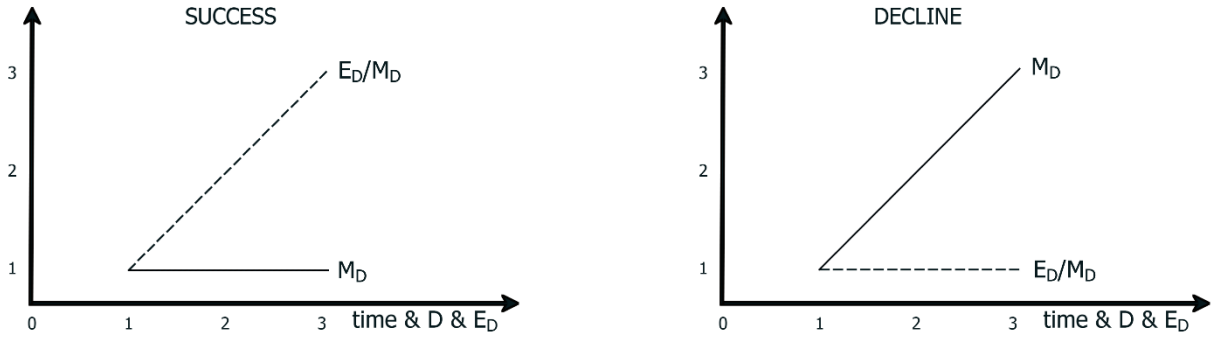

Figure 1: The solid lines represent development of a theory's metaphysics M_D, and the dashed lines represent development of its unifying power E_D/M_D, as functions of the increasing data D. On the left, a period of success where M_D remains constant while E_D increases. On the right, a period of decline where M_D increases at the same rate as E_D.

Theory shifts are needed until we have arrived at mutually consistent theories. Thereafter we will have no obstacles for traversing the path of reductions and partial unifications. Nagelian [10] reductions where a secondary science is derived from a primary science are steps toward more unified science: the primary science incorporates evidentiality of the secondary science, while metaphysical weight of total science decreases, as extra hypotheses of the secondary science are dropped. Also partial unifications increase unifying power of total science: a common postulate is discovered for previously isolated theories, but the theories have non-overlapping postulates even after this. Psillos [2] considers the atomic hypothesis as such postulate, for it functions as a bridge between "the kinetic theory of gases and the molecular theory of the chemical elements, and gains support from both."

2.5. Partially derivative virtues

Relative methodological virtuousness or usability (labor-saving capability, understandability and testability) and aesthetic virtuousness (beauty or elegance) of equally evidential theories are at least partially derivative from their unifying powers.

2.5.1. Syntactic simplicity. Relative syntactic, notational or mathematical simplicities of equally evidential theories are partially derivative from their unifying powers. It is to be expected that an optimal mathematical or logical formulation of a metaphysically simpler theory is simpler than an optimal formulation of a more complex theory. In turn, a more unified and syntactically simpler theory is likely to be more labor-saving or methodologically virtuous than an equally evidential but less unified and syntactically more complex theory: it is easier to calculate by simpler mathematics [11] and it is easier to test simpler hypotheses [12]. MacAllister [13] maintains that as different measures of syntactic simplicity —such as the magnitude of exponents and the number of variables— are of equal intrinsic worth "any judgment that one theory is simpler than another is arbitrary." This supports the notion that it is more reliable to evaluate ontological and syntactic simplicities together than separately. When hypotheses and empirical facts are cleanly separated, and when we rely on the dependency of syntactic and ontological simplicity, an ontologically simpler but syntactically heavier theory appears as a bad or an early formulation of a good theory, whereas an ontologically heavier but syntactically simpler theory appears as a good or finalized formulation of a worse theory.

2.5.2. Understandability. Relative understandability or intuitiveness of equally evidential theories is partially derivative from their unifying powers and their associated syntactic simplicities. Start with internal consistency, which is a prerequisite for great unifying power and understandability. Two internally consistent but mutually inconsistent theories can be understood individually, but their fusion and the worldview it conveys cannot be understood. According to Keas [8], components of an internally

coherent theory "are coordinated into an intuitively plausible whole." Likewise, a unified theory — which explains phenomena by its basic structure or with less additional hypotheses— is relatively more understandable and intuitively plausible than an equally evidential theory with more additional hypotheses. Similarly, understanding of a greater number of isolated theories requires more work than understanding of one theory or fewer theories —theories in a collection with a greater unifying power hang together better than theories in an equally evidential collection with a smaller unifying power. An ideally unified theory provides an understandable picture of reality because it does not leave central aspects of nature unexplained and its explanations of different aspects cohere with one another, whereas the comprehension of heterogeneous laws and principles of several isolated or even mutually contradictory theories is not only harder, but it does not yield a unified picture of reality either.

2.5.3. Beauty. Before the 20th century, beauty was considered derivative from unifying power or its components. Copernicus found beauty and harmony from the simple and unifying heliocentric theory. The dependence of beauty on unifying power is expressed in Hutcheson's [14] remark that the "figures which excite in us the ideas of beauty seem to be those in which there is uniformity midst variety" and by Adam Smith [15] who appreciates "the beauty of a systematic arrangement of different observations connected by a few common principles." The status of beauty changed dramatically in the 20th century, when the founding fathers of new physics made it a fundamental criterion in theoretical physics. Dirac [16] and Weinberg [17] even considered beauty above evidentiality.

MacAllister [13] gives five criteria of beauty. The first two criteria, (1) simplicity and (2) visualizability, are classical signs of beauty, but criteria (3-5) are in fact assessments of how familiar a theory is to a scientist. According to criterion (3), a theory is beautiful if it "posits an analogy between the domain of phenomena that it is attempting to describe or explain and a certain other domain of phenomena, typically one that is better understood or more familiar." For instance, Rutherford's theory of atoms may be considered beautiful because it is analogous to the standard theory of the Solar System: in both theories objects orbit a central mass. According to criterion (4), a theory is beautiful if it is compatible with a familiar metaphysical framework. For instance, mechanicism became fashionable along with Newton's mechanistic descriptions. According to criterion (5), a theory is beautiful if it possesses symmetry, i.e., if it preserves invariance under specific transformations. Lorentz invariance of special relativity was the role model for symmetry. Symmetry was found also from Maxwell's equations and the Planck equation. In this volume, Wang criticises symmetry as a general criterion e.g. on the basis that many empirically successful theories do not possess it.

Philosophers are consistent in that beauty is not a reliable criterion. MacAllister [13] maintains that when making a theory choice "scientists will regard their current aesthetic predilections—whichever they are—as natural and proper" and that therefore the bridge from scientists' aesthetic evaluations of theories to their explanatory virtues is extremely weak. Kragh [18] maintains that "beauty is essentially subjective and hence cannot serve as a commonly defined tool for guiding or evaluating science" and Mackonis [5] that different scientists give contrary meanings to beauty.

It can be safely concluded that unifying power is a more reliable arbiter between equally evidential theories than the contemporary conception of beauty as familiarity with standard theories.

2.6. Ad hoc hypotheses or empirical facts?

Throughout the history, failure in explanation has either falsified a theory, or led into a new hypothesis which saves the theory from falsification and attempts of its empirical verification. In the 20th century, this principle changed into considering additional hypotheses of standard theories as automatic truths: they are not only considered empirically verifiable, but they are given the status of facts before their actual verification. The most famous example is the addition of *dark energy* into the standard model of cosmology (FLRW), which is based on the general theory of relativity. As illustrated by the lowest curve in figure 2, when it was supposed that all matter is gravitationally attractive, FLRW's predictions did not match observations of Ia supernovae, which were available in the end of the 1990's. In order to make its predictions match observations, the density parameter was complemented by the hypothesis that

about 73% of the total energy or matter is gravitationally repulsive dark energy (Ω_Λ=0.73) and only 27% of matter is gravitationally attractive (Ω_m=0.27), as illustrated by the highest curve in figure 2. Estimations of the proportion of dark energy have slightly varied. In the future more accurate measurements will show whether the current estimation of dark energy suffices, or whether the density parameter must be readjusted once again.

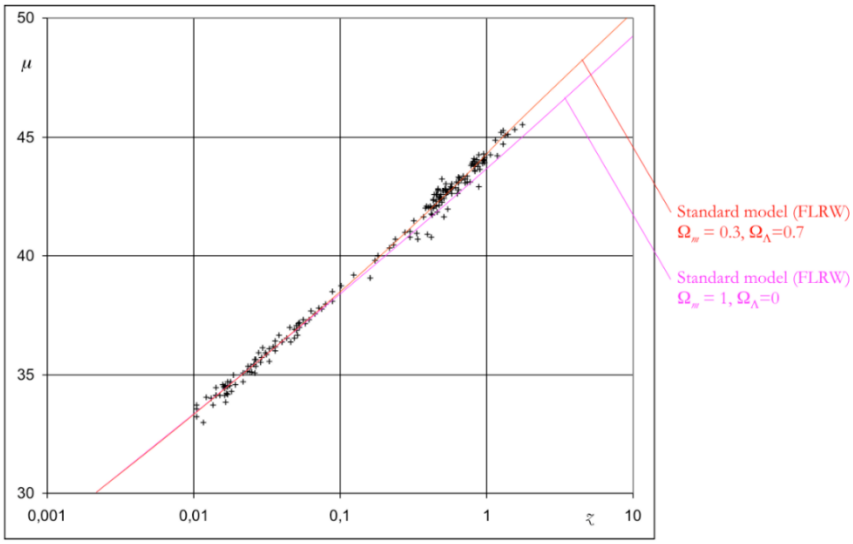

Figure 2: Redshift or distance of Ia supernovae from the Solar System (x-axis), and their distance modulus or apparent magnitude (y-axis) [19].

Instead of doubting FLRW and before even a remotely direct measurement of dark energy, one half of the 2011 Nobel Prize in Physics was awarded for the supernova measurements, and the other half for deducing the hypothesis of dark energy and the resulting hypothesis that the expansion of the Universe is accelerating. Many multi-billion-dollar projects for detecting dark energy are on a planning stage, and the KWISP detector functions currently at CERN. It may seem strange that the price for its discovery was given before its actual verification. However, this becomes natural when it is understood that in the mindset of a scientist who believes in relativistic physics, dark energy is an empirical fact, awaiting to be discovered by more direct measurement, analogously to discovery of the planet Neptune (§3). This thinking is supported by the positivistic idea that there is no metaphysics in relativistic physics: the special (SR) and general (GR) theories of relativity merely postulate general empirical facts and apply them in predicting particular empirical facts in high accuracy; the GR-based FLRW is also to be considered as a description of facts; if FLRW's predictions fail to match perceptions, there surely must exist something (dark energy) in nature that causes the mismatch.

Yet, such practice is directly opposite to Popper's falsificationism. The hypothesis H about dark energy meets Leplin's [20] conditions of ad hocness. If hypothesis H (about dark energy and the resulting accelerating expansion) is incorporated in theory T in response to an experimental result E (data about Ia supernovae), then if H is ad hoc, E is evidence for H but:

1. No empirical data except E supports H.
2. Explanation of E is the only application of H in T.
3. H has no theoretical support independent of T.

Apparently, faith on standard physics overrides falsifiability and the conditions of ad hocness. Similar manifestations of institutional faith on standard theoretical physics were seen when inventors of the Higgs boson hypothesis were awarded the physics Nobel in 2013 after its 'discovery' in CERN, and

when ‘discoverers’ of gravitational waves by the LIGO experiment were awarded the physics Nobel in 2017. In both cases, we are dealing with a very susceptible mechanism:

1. A hypothesis in the context of a standard theory is initially supposed to correspond to nature.
2. Something extremely vague or minor is measured and interpreted to conform to the theory.
3. The existence of the hypothetical entity is institutionally ‘confirmed’ by a Nobel.
4. The threshold of admitting that a prized theory is false is even higher than before.

In the case of LIGO, it was perceived that an interference graph is oscillating, and it was interpreted that gravitational waves cause this, i.e., that they exist. See Wang’s criticism concerning the Higgs boson in this volume.

One of Feyerabend’s [21] central insights was that rival theories make evaluation of standard theories more objective: “The weaknesses of a theory often do not appear if the theory is confronted with the facts as seen from its own perspective, but may only appear if facts as seen from the perspective of an alternative theory are allowed” (Hoyningen-Huene [22]). The classical case is that proponents of a paradigmatic theory do not admit that its additional hypotheses or corrections are ad hoc parameters that save the theory from falsification, but insist that their natural remedies will appear in the future, or that they denote objects comparable to Neptune, awaiting discovery. However, if an equally evidential rival theory is invented, that comes without the additional hypotheses, the ‘empirical facts’ of the paradigm soon start looking ad hoc. Diachronic evaluation complements this notion: when a paradigm has been kept standing by ad hoc hypotheses for a long time, a unified rival that is equally evidential in all central areas may be preferred —even if it lacks nuanced mathematical descriptions of the paradigm that have been developed for specialized areas— if it has become apparent that mathematics for specialized areas can be derived from it, and that it is methodologically more beneficial in the long run.

2.7. Summary: the unificatory vs. the 20th century criteria

Apart from the preference for evidentiality, the valuation of virtues in the 18th and 19th centuries was quite different from their valuation in the 20th century. Apparently, their valuation in one era conforms to standard physics of that era. Until the late 19th century physics was unified internally and with an understandable worldview, whereas in the 20th century physics became driven by mathematics, patched up with additional hypotheses, and it remains without understandable foundations. Compare the unificatory and the 20th century criteria.

The unificatory criteria	**The 20th century criteria**
The focus is on unifying power of a theory, as the ratio E/M of its evidentiality E and its metaphysical weight M, where E has the highest priority and M has the second highest priority. Coherence is a component of unifying power. Syntactic simplicity, methodological virtues and beauty of equally evidential theories are partially derivative from their unifying powers. Increasing unifying power is a sign of success, whereas constant or decreasing unifying power is a sign of decline. All hypotheses are classified as metaphysical and thereby parts of M.	The primary virtues are evidentiality, beauty as analogy with standard theories and coherence with them. The dependency of coherence and unifying power is not understood. Metaphysical simplicity and unifying power are degraded from central explanatory virtues into aesthetic virtues[5] and simplicity is considered too complex or subjective to be measured. Law hypotheses of standard theories are considered as empirical facts, and their additional hypotheses are declared as facts before their actual verification.

The 20th century criteria are in a symbiosis with the nature, status and state of the theories invented in the 20th century. The standard theories are generally embraced and their hypotheses are considered as

[5] Simplicity and ‘unification’ are aesthetic virtues e.g. in Keas’ [8] classification.

empirical facts, which makes coherence with them and beauty as familiarity with them natural criteria. If metaphysical simplicity were honestly measured, theoretical physics would appear utterly disunified and in this sense ugly. But due to its next-to-the-truth status, one avoids making negative claims about it. It would be too revolutionary to admit that we are not dealing with empirical facts, but with a cumulative structure of metaphysical commitments, with a good portion of ad hoc hypotheses.

3. Separation of physics and philosophy

In antiquity the focus of natural philosophy was on characterizing overall systems or searching for intuitive laws of nature that explain natural phenomena. Apart from applying geometry in characterizing orbits of stellar objects, hypothetical laws of nature were not formulated mathematically but by natural language, such as behavior of the basic elements: Earth falls and is cold and dry; Fire rises quickly and is hot and dry; Air rises slowly and is hot and wet; Water is cold and wet.[6]

Astronomy stood on the idea that the Earth is the stationary center of the Universe. This is the first grand example of the *observed-oriented* or local approach, where the observer is considered to be at rest, and mathematical descriptions of perceptions are given from the observer's perspective. In effect, astronomy was about giving mathematical descriptions of orbits of stellar objects around the stationary Earth: an observer on the surface of Earth perceives stellar objects with a bare eye, characterizes the geometry of their orbits and measures their orbiting times. Geocentricity resulted in the epicyclic model of planetary orbits, whereas the orbits of the Moon and the Sun were considered circular. Eudoxus (390-337 BC) created the epicyclic model as a mathematical description of planetary orbits around the Earth, whereas Aristotle (384-322 BC) interpreted that the perceived orbits are also the real orbits. Ptolemy (c. 100-170 AD) collected achievements of geocentric astronomy into *Almagest*. The simple philosophical idea that the Earth is at rest led into a very complex overall system. The number of epicycles increased from the time of Eudoxus to the time of Ptolemy, i.e., unifying power of the system decreased or remained constant, which is a sign of decline (§2.4).

The intellectual burst of antiquity was followed by 1500 years of stagnation into Ptolemaic astronomy, without significant developments in natural science. The stagnation was ended by Copernicus' heliocentric model (1543), which was refined by elliptical orbits and laws of motion by Kepler in the early 17th century, and finalized by Newton in his Principia (1687). The shift from the geocentric model to the heliocentric model is a grand example of a shift from an *observed-oriented* to a *system-oriented* model. Namely, the shift of the primary viewpoint from a stationary observer to the mass centre of the system, which allowed a simpler and eventually more evidential explanation.

Simultaneously, mathematics was developing rapidly, and the old Aristotelian model of scientific explanation that was based on primary metaphysical reasons or premisses in the absence of mathematics or predictive capabilities was losing ground. The Copernican Revolution and its completion in Newton's *Mathematical Principles of Natural Philosophy* in 1687 started the era of mathematical physics. Newton gave mathematical principles *for* natural philosophy, i.e., we were dealing with a seamless fusion of philosophy and mathematics. Newton gave a mathematical formulation of the law of gravitation within the clearly understandable and visualizable heliocentric system (that already had definite geometry and Kepler's laws) plus three intuitive laws of motion, where The Second Law is exactified by mathematics:

- The Inverse Square Law of Gravitation: $F=Gm_1m_2/r^2$. Gravitational attraction force F between two objects is the gravitational constant G multiplied by masses m_1 and m_2 of the objects, divided by their distance r squared.
- The First Law: An object will remain at rest or in uniform motion in a straight line unless acted upon by an external force.
- The Second Law: $F=ma$. The force F that acts on an object is equal to the mass m of the object multiplied by acceleration a of the object.
- The Third Law: When one body exerts a force on a second body, the second body simultaneously exerts a force equal in magnitude and opposite in direction on the first body.

[6] Suntola [27] and Juti [28] describe the development of the relation of physics and philosophy or metaphysics.

Newtonian Mechanics faced two challenges in the 18th and the early 19th centuries. First, it was perceived in the mid-18th century that orbital velocities of the Moon and Jupiter had decreased, which suggested that they will eventually fall into the Sun; the orbital velocity of Saturn had increased which indicated that it would eventually escape the Solar System. Laplace resolved the challenge in 1776 by showing that the other planets cause 900-year cycles of perturbation in orbital periods of Jupiter and Saturn. Second, the orbit of Uranus was measured to deviate from predictions in 1781 and in 1821. It was supposed that a stellar object caused the deviations, and as a result of the search the planet Neptune was discovered in 1846. Due to its success, there was a sense of finality around Newtonian Mechanics, and there were no other significant advancements in physics in the 18th century.

Newton's work however motivated intense development of mathematics, especially differential and integral calculus and statistics, which were applied in developing thermodynamics and electromagnetics in the 19th century. Thermodynamics and electromagnetics are founded on the conservation law of energy, where the total energy of a closed systems is conserved: the sum of the energy of motion and potential energy in their many manifestations.

The transition from Newtonian Mechanics to relativistic physics and quantum mechanics, and the separation of physics and philosophy was triggered by the Michelson-Morley experiment in 1887, which was supposed to confirm that light moves with respect to *world-aether* or Newtonian *absolute space*, and honors linear summation of velocities (Galilean transformations) like all mass objects were supposed to honor. Against expectations, the velocity of light seemed to be always the same, disregarding velocity of the frame of reference where light is emitted or observed.

It was concluded that velocities in general do not sum up linearly, but instead the velocity of an inertial frame of reference affects the flow of time and/or length in the frame.[7] This initiated the search for *coordinate transformations*: a mathematical solution that indicates how *time* and *length* within an inertial frame of reference change as a function of the frame's velocity with respect to a perceiver at rest. This is the second grand example of the observer-oriented approach: phenomena are explained by letting length and the flow of time vary locally from the observer's perspective. Walter Kaufmann's 1902 experiments showed that when approaching the velocity of light, constant force does not give a constant acceleration to an electron. This falsified Newton's Second Law and all Newton's laws of motion along with it. Hendrik Lorentz formulated the finalized version of the coordinate transformations in 1904, which accommodated Kaufmann's results.

The coordinate transformations and the phenomena behind them required new ontological foundations. This resulted in modification and complementation of Newton's laws by The Special Theory of Relativity (SR) in 1905. SR postulates the Relativity Principle according to which all laws of nature including the velocity of light are the same in all inertial frames of reference. SR continues the observer-based path: objects moving relative to the observer's frame of reference are subject to coordinate transformations, which means e.g. that the moving object is subject to relativistic mass increase.[8]

In 1908, Hermann Minkowski introduced the concept of *spacetime* as a mathematical structure and overall geometry for SR, where the three space dimensions and the time dimension are intertwined. This was enough to make the scientific worldview non-understandable: after more than 100 years of efforts, the relativistic conception of time remains to be completed, and many of its common interpretations increase its metaphysical weight (§4.3).

---

[7] An inertial frame of reference is at rest or moves at a constant velocity. It was open whether the flow of time or length or both change in a moving frame, and whether the unit of length decreases in the direction where the frame is moving, or whether objects *in* the frame are contracting. Lorentz sought an ontological interpretation for length contraction from contraction of electrons.

[8] The closer an object is to the velocity of light, the less constant force accelerates it, and the more it increases its relativistic mass. Coordinate transformations in SR are identical to Lorentz transformations, but not typically considered as a postulate but rather as an empirical fact, whose ontological foundation is the Relativity Principle.

In 1915, SR was extended into The General Theory of Relativity (GR) by the Equivalence Principle, which equates gravitational and inertial acceleration. GR is thus an extension of SR for frames of reference in gravitational or inertial acceleration, whereas SR deals only with inertial frames of reference that by definition do not accelerate.[9] SR and the Equivalence Principle were applied in deriving the GR field equations that characterize gravitational interactions in terms of the curvature of spacetime, which results from mass and energy density in space. Explanation of gravitational phenomena in the context of GR became a matter of finding solutions to the field equations. The first solution was Schwarzschild metric in 1916, which enabled precise predictions of new gravitational phenomena, including gravitational time dilation and the bending of light due to gravitational curvature of spacetime, and complemented the prediction for Mercury's perihelion advance. Schwarzschild metric faces challenges in the vicinity of very large masses. Schwarzschild's solution of the field equations gives a minimum orbital period of about 28 minutes around the gigantic black hole Sagittarius A* in the center of the Milky Way. This is at odds with the 16-minute orbits that were observed in 2000's. The 12-minute discrepancy was explained away by Kerr metric, that was introduced in 1963 as another solution of GR field equations, which allows space around the black hole to rotate, which resolves the discrepancy.

Alexander Friedmann's solution of GR field equations in 1919-22 laid the basis to development of GR-based cosmology, the Friedmann-Lemaître-Robertson-Walker model (FLRW), which adds e.g. the density parameter and the Cosmological Principle on top of GR. Local gravitationally bound systems such as the Solar System and Galaxies were not thought to expand, and therefore Hubble Flow or the idea that only the space between galaxies or galaxy groups expands was incorporated in FLRW. Later, FLRW was complemented by the hypothesis of early inflatory expansion, and the density parameter was complemented by the hypothesis of gravitationally repulsive dark energy which results in accelerating expansion (§2.6).

Quantum mechanics (QM) was developed in the first three decades of the 20th century. QM introduces the wave function for the description of the quantum state of an isolated quantum system. In a quantum mechanical system, central physical quantities like energy, momentum, and angular momentum get discrete, quantized values as solutions of the Schrödinger equation. The wave function associated with the Schrödinger equation gives the probability amplitude of detecting a particle at a certain position. The mathematical equations that are postulated as laws of nature in QM work perfectly, but do not have a consensual ontological interpretation. For instance, the relation of the wave- and the particle-aspect of matter is open.

Quantum field theory (QFT) and the standard model of particle physics were developed by the mid 1970's. The standard model of particle physics classifies elementary particles, gives an account of what kinds of particles result from collision and decay of particles, and applies QFT in describing force-interactions between sub-atomic particles. The standard model does not predict mass, charge nor magnetic moment of electron or any other particle, but these are empirically measured.[10] QFT respects QM and may apply SR,[11] but does not unify them. QFT equations that describe strong force interactions are not derived from QM nor SR, but they are mathematical descriptions of the effects of strong forces, i.e., new hypothetical laws of nature.

In sum, mathematics and philosophical intuition were separated in the early 20th century, along with modifying and complementing Newtonian Mechanics by relativistic physics and QM. Theoretical physics became essentially a matter of giving mathematical descriptions of perceptions, in the absence of understandable explanations of why nature behaves as predicted. It is characteristic that basic

[9] Although GR manages to explain phenomena in the context of accelerating and non-accelerating frames of reference, SR is still applied in explaining phenomena in the context of non-accelerating frames, such as at constant gravitational potential without inertial acceleration. Moreover, some argue that SR applies also for accelerating frames of reference. In effect, it is sometimes hard to choose whether SR or GR should be applied.

[10] In contrast, Lehto [26] shows that by assuming the Planck units and period-doubling process in non-linear dynamic systems as universal laws of nature, we can derive mass, charge and magnetic moment of e.g. electron, proton and neutron.

[11] GR is not applied, for differences in gravitational potential are nil in the context of micro systems.

explanations of new phenomena were not derived from pre-existing theories, but new laws of nature and additional hypotheses were needed. The 100-year project of completing ontological interpretations of relativistic physics and QM has failed, as has the project of unifying them by means of a yet another mathematical construction.

When we measure development of unifying power of theoretical physics as a whole since the early 20th century, as development of its ratio E/M of evidentiality E and metaphysical weight M over time, SR, GR, FLRW, QM and its sub-theories each increase M, and the phenomena they explain each increase E. This development gives approximately the curve on the right side of fig. 2 in §2.4. This suggests that we have been heading toward a paradigm shift throughout the 20th century. All that is needed in perfectly matching the Kuhnian picture is the replacement of relativistic physics with a unified theory that coheres with QM and contributes to its ontological foundations.

It is doubtful that such theory could be built on the Newtonian base, for recall that relativistic physics and QM are modifications and complementations of the Newtonian base, rather than its total replacements. When we evaluate the development of unifying power of the gradually cumulating theory structure —disregarding if we start from the Newtonian base or from its initial complementations in the early 20th century— this has been a process of decline, for it is indeed the project of explaining new phenomena by categorically adding new law hypotheses and other hypotheses, not a project of deriving new predictions and explanations from law hypotheses that were postulated earlier.

It is instructive to summarize the development of physics in terms of oscillation of the observer-based and system-based approaches: first we had the observer-based geocentric model; it was replaced by the simpler system-based heliocentric model that culminated in Newton's work; Newtonian mechanics was unable to explain new phenomena, and was modified and complemented by the observer-based relativistic physics. When we seek a replacement for the Newtonian base and the resulting observer-based relativistic physics, we are once again seeking a simple overall system. To secure coherence with QM, such system must respect absolute simultaneity and the conservation law of energy.

4. Methodology of philosophy

Contemporary philosophical methodology appears as a modified version of logical analysis or the methodology that logical positivists put forth in the early 20th century. Unification by collaborative efforts was a central goal of the Vienna Circle, the leading positivist society:

> The goal ahead is unified science. The endeavour is to link and harmonise the achievements of individual investigators in their various fields of science. From this aim follows the emphasis on collective efforts, and also the emphasis on what can be grasped intersubjectively; from this springs the search for a neutral system of formulae, ... and also the search for a total system of concepts. Neatness and clarity are striven for, and dark distances and unfathomable depths rejected. In science there are no 'depths'; there is surface everywhere: all experience forms a complex network, which cannot always be surveyed and, can often be grasped only in parts. .... Step by step the common fund of conceptions is increased, forming the nucleus of a scientific world-conception around which the outer layers gather with stronger subjective divergence.
> *The 1929 manifest of the Vienna Circle* [29]

The fund of conceptions has increased remarkably since 1929, but it has had no chance of forming the nucleus of a unified scientific worldview in the context of disunified physics, and logical analysis practically repelled the formulation of unified concepts. Logical analysis was a formalist approach of dealing with details of isolated topics, which focused on logic, language and new physics, and where all metaphysical commitments were rendered meaningless.[12] The rejection of metaphysics and system-

[12] Reliance on new physics and rejection of metaphysics can be fit together by the ideology that the laws of nature postulated by the new theories are empirical facts. Positivists' anti-metaphysics was rejected by the 1960's, but

building made unification impossible. For, it is very hard to build a totality without explicitly aiming at it, and without planning to unify details by metaphysics. And again, even if there were no methodological obstacles, disunified physics would have tackled the project.

Like physicists, philosophers have advanced various topics since the early 20th century, but problems that are caused by disunifies theories cannot be resolved by focusing only on details of isolated topics. The failure of contemporary standard analysis —that descends from logical analysis— in harmonising achievements of individual investigators is verified by the 20th and 21st century literature: virtually all focal concepts including time, possibility and truth are aggregates of isolated and rival sub-concepts.[13]

Isolated details yielded by traditional analysis can be fused together by a method of unification [30] where evaluation, ontology and applications are interconnected:

Evaluation → Ontology → Applications

Alternative ontologies that are sufficient for an application —such as the concept of truth, time or possibility— in a specific context or domain —such as natural science and human social interaction— are evaluated. The most virtuous ontology is selected and used as the foundation for the application in the focal context: concepts are defined in terms of the ontology; semantics is mapped to the ontology; logic and mathematics exactify the ontology; problems are resolved by fitting them to the ontology.

The method of unification transforms the logical positivists' anti-metaphysics into preference for simplest sufficient metaphysics, and their rejection of system-building into identification and application of a unified ontology that suffices for physics and philosophy.[14] New metaphysical hypotheses are not invented unless this is necessary: if empirical science leaves something crucial open, a minimal and sufficient answer needs to be found. For instance, economy demands preferring finite divisibility of matter over infinite divisibility, and existence of only one world over the supposed existence of several causally isolated worlds. Then again, if a scientific theory or its ontological interpretation portrays a non-understandable worldview, it is the duty of a philosopher who respects unificatory ideals to criticise it, and to seek for an understandable alternative theory or interpretation.

4.1. Truth

What is the definition of true proposition? Contemporary philosophy gives a list of different definitions according to different theories as the answer: correspondence-, pragmatist-, coherence-, identity- and deflationist theories of truth. In contrast, Ingthorsson [31] implicitly follows the general characterization of the method of unification, when he shows that we do not have to have a bunch of different truth theories, but applicable features of the other truth theories can be incorporated in the correspondence theory of truth. The method of unification is explicitly applied on truth in [30]:

1) Mental realism and ontological realism are postulated: human minds exist; a proper part of the Universe is independent of human minds.
2) The correspondence theory of truth is defined in terms of the ontology: a proposition or an idea in the mind of a human being is true if it corresponds to reality, i.e., if the reality is in the way the proposition states. For instance, the proposition that a glass is on the table in the mind-independent reality is true if the glass actually is on the table in the mind-independent reality.
3) Applicable features of other theories of truth are incorporated in the correspondence theory. For instance, in the coherence theory, the truth of a proposition is defined as its coherence with a set

---

this led into bipolarisation rather than consensus. Metaphysics was hidden in many important areas in philosophy of science such as in theory evaluation; elsewhere neo-scholastic or *a priori* metaphysics rose into prominence (see Ingthorsson's article in this volume). Recently, we have seen rules for restraining metaphysics once again.

[13] The *2009 PhilPapers Survey* gives an informative synopsis of the state of the art.

[14] We do not need to have the same ontology for all applications. However, when evaluating rival collections of theories, coherent or more unified collections are preferred over less coherent or less unified collections (§2.3).

of propositions. The crux of the coherence theory is incorporated in the correspondence theory by asserting that all correspondence truths are mutually coherent. Applicable features of other truth theories are included in a similar manner.

4.2. Consciousness

How is consciousness to be explained? Consider three theories that explain consciousness in terms of different postulates about the basic substance.

Cartesian dualism: mind and body are separate basic substances.
Physicalism: the basic substance is fully physical, not mental.
Dual-aspect monism: the basic substance has physical and mental aspects.

The basic approach in the 20th and the 21st century philosophy of mind has been to reject Cartesian dualism and to deal with problems of physicalism. In contrast, Benovsky [32] starts by concluding that physicalism and Cartesian dualism are indefensible: Cartesian dualism cannot connect mind and body without some additional hypothesis, whereas physicalism fails to properly explain consciousness. Second, he postulates dual-aspect monism as a solution to their problems; although the above formulation of physicalism is metaphysically simpler than dual-aspect monism, we are looking for the simplest axiom that suffices for the application, and therefore dual-aspect monism conforms to economy. Third, he shows that dual-aspect monism resolves the central problems in philosophy of mind and conforms to unificatory ideals. Benovsky thereby implicitly follows the general characterization of the method of unification.

4.3. Time

Contemporary philosophy of time is almost entirely subjugated to relativistic physics. SR and Minkowski spacetime is the typical point of departure.[15] This approach is troubled by overall confusion: no sense can be made of a worldview whose foundations make it non-understandable. Namely, relativistic physics violates absolute simultaneity which is implicit in basic human understanding. Absolute simultaneity allows talking about wholes whose parts exist at the same time, such as people, star systems, and totality-states or temporal states of the Universe as wholes. In contrast, if relativistic physics is true, objects in different states of motion and gravitation do not exist at the same time. In effect, absolute simultaneity and the manifest image of reality is false: the Moon and the Earth do not exist at the same time, nor your head and your feet, nor your upper and lower lip.

Consider the case in terms of atomic clocks. In the context of relativistic physics where the velocity of light and the ticking frequencies of identical atomic clocks are constant, a clock at the sea level ticks at the same frequency as a clock on a mountain, but the clocks are in different time frames and they experience different flows of time; this violates absolute simultaneity. In the context of a system of physics that commits to absolute simultaneity and allows the velocity of light and ticking frequencies of identical atomic clocks vary in different states of motion and gravitation, a clock at sea level ticks at a different frequency than a clock on a mountain, but they exist at the same time: they are ticking simultaneously at different frequencies [33].

One may argue that the simultaneity-approach contradicts the Leibnizian relational conception of time as the measure of change [34]. For, if the local rate of change determines the local rate of the passage of time, then time should pass at different rates in different locations. The simultaneity-approach is relational in the sense that a change in the Universe as a whole takes time forward, i.e., a change in any part of the universe takes the universal time —which is the only time— forward for all parts of the universe. Differences in local rates of change or rates of physical processes do not mean that time passes at different rates in different locations, for universal time gives a common measure for the rates of all physical processes. Yet, we can compare the rates of physical processes, and in doing so, we must choose

[15] GR and FLRW with cosmic time are typically not mentioned in philosophers' speculations about time.

some measure. Let us choose that one second means 9192631770 oscillations of the caesium-133 atom on the sea level on Earth. We can talk about processes elsewhere in terms of the selected measure, such as that within one sea-level-second on a mountain, a caesium-133 atom went through more than 9192631770 oscillations.

Although the relativistic conception of time has a viable alternative, it remains the mainstream point of departure in philosophy, and it has resulted in on-going debates about all major questions, including those that are analysed below: Which of these exist: past, present, future? Does time pass and what makes it pass, or is it merely an illusion and what causes the illusion? What is the foundation of the direction of time?

4.3.1. Temporal existence. Which of these exist: past, present, future? *Presentism* where only the present exists was challenged originally by McTaggart [35], before relativistic physics rose into prominence. However, relativistic physics is the chief reason why the question is still alive. Arthur Eddington [36], a leading protagonist of relativity, interpreted in 1928 that relativistic spacetime is eternalist, i.e., that the past and the future of every event in spacetime exists as strongly as the present which we experience. Rietdijk [37] and Putnam [38] put forth arguments in the 1960's that SR implies eternalism. More recently, different interpretations have emerged. Rakic [39] exemplifies a fusion of SR and the *growing block theory* [40] where the past and the present exist but the future does not, whereas Hinchliff [41] exemplifies fusions of SR and presentism. In overall, temporal existence in the context of relativistic physics remains an open question, and different authors keep on making different interpretations about it. Presentism is the most economical axiom for temporal existence, but one cannot genuinely understand what presentism means when absolute simultaneity is violated.

4.3.2. No-passage interpretation: entropy. Eddington [36] supposed that time does not pass in the eternalist spacetime, but the apparent forward direction time had to have a solid foundation. Eddington initiated the project of founding the forward direction of time on statistical entropy: that entropy increases implies that time goes forward. The entropy mapping requires the additional *past-hypothesis*, i.e., the hypothesis that the Universe was in a state of a very low entropy right after the singularity. The past-hypothesis is widely criticised [42-44] but some philosophers commit to it, without worrying that it increases metaphysical weight and therefore unifying power of the resulting framework [45-46].

4.3.3. No-passage interpretation: illusions. The no-passage interpretation, even when coupled with the entropy mapping, does not explain why time *seems* to pass, i.e., it does not explain our experiences of the passage of time (EPs), motion or change. Many have tried to explain EPs away as illusions by the *at-at theory of motion*: "a stage of the brain collects static inputs of earlier stages and then a successor stage of the brain modifies them, producing a neural state in yet another stage that gives the subject (I) an experience as of passage and as of change" (Paul [47], cf. [48-50]).

Apparently, pro-passage theorists can apply exactly the same *at-at description* of motion as the no-passage theorists, for it is a description of a process that follows from a pro-passage theory. Namely, people experience transitions through time and have memories of the past, *because they move along with the passage of time*.

No-passage theories do not explain why people experience transitions through past states and have memories of them, in terms of a natural process. Thereby, no-passage theories are additional postulates or require thus far hidden postulates, such as primitive memories of the past. In either case, a no-passage theory decreases unifying power of the resulting framework. Norton [51] maintains that the illusion-project is desperate, and oriented entirely by philosophers' confidence in relativistic physics. In contrast, Loewer [46] trusts that the at-at theory renders EPs illusions and that the entropy mapping with the past hypothesis gives a direction to time.

4.3.4. Pro-passage interpretation: by postulates. Recently, many philosophers have postulated the passage of time on top of spacetime. Maudlin [52] postulates the passage as "a fundamental, irreducible

fact about the spatio-temporal structure of the world" which also gives a direction to time: "If all one means by a 'direction of time' is an irreducible intrinsic asymmetry in the temporal structure of the universe, then the passage of time implies a direction of time." Many others [53-55] apply versions of the *moving spotlight theory* [40] where a moving present moment is added on top of eternalism to explain the passage. The problem of these approaches is that the passage of time is an additional hypothesis, not derived from the applied physics.

4.3.5. Pro-passage interpretation: by derivation. In a unified approach, the passage of time is derived from the overall system: law hypotheses of any viable system of physics entail causal succession of events or objects; the passage of time is identified with their causal succession; the direction of time is defined as the direction of their causal succession [56]. This is congenial with the Leibnizian definition of time as a measure of change [34]. In the context of absolute simultaneity, the causally successive events are temporal states of the Universe, i.e., discrete and instantial states of the Universe. In the context of relativistic physics, we have seen arguments that the passage of time may be identified with *temporal becoming*, which is founded on causal succession of point-events in spacetime [57-58].

4.3.6. Summary of the project of interpreting the relativistic conception of time. Should philosophers carry on with the project of interpreting relativistic physics? Or should they conclude that the 100-year failure is enough to show that the relativistic conception of time will never be completed, and take a critical attitude toward relativistic physics? The latter option does not mean that philosophy of time should be practiced on purely a priori basis. Instead, philosophers should switch into completing a minimal conception of time that is compatible with understandable physics, that gives at least as accurate predictions as the non-understandable relativistic physics. These proceedings remind that such a system is available. Who has the courage of applying it?

4.4. Possibility

What does the proposition <It is possible that it will rain tomorrow in Helsinki> mean? Contemporary philosophy does not give a straightforward answer. We have had *possible worlds semantics* —a set of possible worlds and an accessibility relation that may hold between two worlds— as the formal framework of handling possibility since the 50's but the ontological interpretation of the possible worlds remains open. Are they logically possible worlds or metaphysically possible worlds, and what does it mean e.g. that it is metaphysically possible that it will rain tomorrow in Helsinki? The confused relativistic conception of time has blocked clear answers to this question.

In contrast, a unified conception of time functions as an ontological foundation for possibility: the present temporal state of the Universe determines what is possible, necessary, impossible or contingent at a specific point of time in the future [59]. In this approach, von Wright's [60] diachronic modalities are founded on causal presentism, i.e., on the fusion of presentism and forward-directed causal succession of temporal states of the Universe (*T*s). In this scheme, the proposition <It is possible that it will rain tomorrow in Helsinki> is true only if it rains in Helsinki in at least one *T* that is *realizable tomorrow from the aspect of the present moment*, i.e., the present moment is the truthmaker/falsemaker of the proposition. Possible worlds semantics is mapped to causal presentism: the possible worlds are mapped to *T*s that are realizable now or have been realizable from the aspect of a past *T*; causal successors of a *T* are forward-accessible from that *T*, and causal predecessors of a *T* are backward-accessible from that *T*. Every *T* is accessible from every other *T* by a combination backward and forward accessibility relations.

4.5. The method of unification as a method for metaphysics

As a general method of philosophical analysis, the method of unification functions also as a method for philosophical metaphysics and answers its central questions.

1. *Are the criteria that are commonly used in scientific theory choice (for example, simplicity and theoretical integration) applicable in metaphysics?* [63] Theories in philosophy (including those labelled as metaphysics), theories in physics, and their fusions are to be evaluated by the same criteria: evidentiality, simplicity, and so on. When evaluating philosophical metaphysics independently of physics or predictive abilities, accuracy of predictions may be replaced by preciseness and applicability of concepts, semantics and logic in a specific context.

2. *How can these criteria be articulated clearly? And what hope is there that that criteria will yield a determinate verdict?* [63] The criteria can be organized elegantly as components and partial implications of unifying power, and its development over time. Evaluation of competing theories in philosophy and physics is sometimes hard. But philosophers should accept the challenge, instead of raising hands in the air and complaining that evaluation of simplicity is too complex.

3. *What is the best procedure for arriving at the answers to the questions of metaphysics? Common sense? Conceptual analysis? Or assessing competing hypotheses with quasi-scientific criteria?* [64] The method of unification, that applies unifying power and the related virtues as the quasi-scientific criteria, is the suggested path of arriving efficiently at the answers. Traditional conceptual analysis is not enough, for we cannot remedy disunification by focusing only on details of isolated topics.

4. *Are the answers substantive or just a matter of how we use words?* [64] If one defines concepts in terms of a minimal ontology that suffices for natural science and human social interaction, the answers are substantive and not just a matter of how words are used. If concepts are defined in the absence of a unified ontology, it may be hard to say how the answers connect to what is important to people. For instance, the concept of future possibility is substantial and understandable when it is defined in terms of the present state of this word, but when it is defined in terms of worlds that are causally inaccessible to this world, applicability of the concept is an open question (§4.4).

5. Contemporary dogmatism in light of the tautology that unification is progressive

On one hand, it is a tautology that unification in science is progressive. On the other hand, non-standard theories are typically rejected by mainstream physics journals without further investigation, and mainstream philosophy journals typically reject works that build on non-standard theories of physics. Once we admit that contemporary dogmatism is real, we can start considering ways of tackling it. But let us first consider the tautology that unification is progressive.

5.1. The tautology that unification is progressive

Examples are given of how the tautology that unification is progressive may appear in physics and philosophy. In overall, the main challenge here is that unification and progress are so closely related that it is easy to stumble over words when explaining why unification is progressive.

First, when unification takes place, a progressive leap in theories takes place, by means of deriving a new explanation from a pre-existing theory, by a reduction or by a theory shift. Such leaps make science a better aide to society. An anti-unificatory ideology is therefore counter progressive, as is the exaggeration of the importance of coherence with standard theories and beauty as familiarity with them.

Second, since physics and philosophy have been separated for a long time, many have come to think of this as a natural state. But it is obvious that the fusion of evidentiality or empiricism and understandability is more satisfactory than either one of them alone. Even though evidentiality is primary, science is always more or less crippled without understandable explanations. Understandable and deep explanations are more prolific of accurate predictions than non-understandable and shallow explanations. Therefore, exaggeration of the importance of coherence with standard theories and beauty as familiarity with them in fact means shooting one's own leg in the long run.

Third, in physics as well as in philosophy, there are huge advantages in working with a single theory that is founded on a unified ontology and that incorporates applicable features of previously competing theories, and proportional disadvantages in working with several isolated theories.[16]

The unified whole of ontology and everything founded on it constitutes an understandable axiomatic system. The difference between ontology and defined concepts is clear, and the roles of different concepts are understood: it is seen what can and what cannot be omitted, what presupposes what, what entails what, which concepts are wrongly supposed to play any role at all, and which concepts are redundant. This facilitates an understanding of what has been achieved, which in turn allows investing efforts to relevant challenges and more advanced questions. By letting us understand how things hang together, unification yields inter-field synergy, reduces redundancy and confusion, and makes the analysis avoid pseudo-problems which result from the absence of a unified ontology.

Identifying and understanding connections between different concepts and specialized domains of inquiry and applying them in resolving problems is an alternative to leaving the connections unacknowledged and suffering from the resulting confusion. The absence of an openly explicated ontology leaves the meanings of concepts open and blurs their relations. Inter-field synergy is replaced by redundancy, confusion and struggle around pseudo-problems of several micro-industries. For instance, it is much easier to engage into theorizing about truth when the basic theory is known to be the correspondence theory, in contrast to pondering constantly about which theory should be applied. The same holds in physics: it is much easier to apply the same theory in dealing with cosmology, celestial mechanics and even QM, than to ponder whether to apply SR or GR to a specific problem, and to apply a completely different theory to another problem.

5.2. Tackling dogmatism by objective criteria

Once we understand that unification in science is progressive, we also understand that conscious rejection of theories that are more unified than the standard theories stalls the optimal progress rate of science. The absence of commonly accepted evaluation criteria that prefer more unified theories practically gives mainstream scientists the freedom of evaluating theories on the basis of their coherence with a paradigm. In effect, there is a real danger that theories which are incoherent with a given paradigm are rejected, disregarding their merits.

In order to facilitate proliferation of better theories, each branch of science should give public and institutional criteria by which theories in that branch are to be evaluated. Constitutionalization of the criteria would make them open for public criticism, which would lead to a rapid convergence into transparent, objective and effective criteria, that are respected by people who present rival theories as well as people who evaluate them. This would remove criteria that one-sidedly protect standard theories. Transparent and objective criteria would allow scientists a fair trial: if a theory is better by common criteria, it is beyond the reach of dogmatism. This kind of a system could be strengthened by giving a governmental agency the power of inviting official representatives of a branch of science to openly discuss and debate with representatives of rival theories.

I have suggested the following criterion: prefer more evidential theories, or at least as evidential but metaphysically simpler. Consider how such criterion could tackle dogmatism in philosophy and physics.

5.2.1. Tackling dogmatism by objective criteria in philosophy. In philosophy, the absence of criteria that favour unified theories leaves debates around technical details and equally relevant metaphysical possibilities wallowing without effectively converging into consensual conclusions. Philosophers' basic mode of working resembles the process of interpreting religious texts. The philosophical corpus is the measure of relevance, not novelties or unified solutions: we have some basic interpretation dating back e.g. to Russell or Moore, and the task is to interpret the historical flow of interpretations until today. Literature reviews are far more important than unified and understandable solutions.

[16] These characterizations are inspired by Bunge [61] and Poland [62].

It is instructive to formulate the dichotomy of *corpus-relevance* and *external relevance*. A corpus-relevant work follows the traditional methodology and is relevant with regard to the philosophical corpus; it elaborates what is found from the corpus about a specific detailed topic, trying to form an overall picture of the history and the contemporary state of the art. An externally relevant work is beneficial to both philosophers and non-philosophers, e.g. by being applicable in natural science and in human social interaction; this means e.g. the portrayal of an understandable conception of time, truth or consciousness that is applicable in the focal context.

There are four combinations of corpus-relevance and external relevance. A work may be (1) corpus-relevant & externally relevant, (2) corpus-relevant & externally irrelevant, (3) corpus-irrelevant & externally relevant, or (4) corpus-irrelevant & externally irrelevant. Combination (4) may be dropped, which leaves over (1-3). This classification helps to understand why the strict tradition of interpreting texts about detailed topics is not only ineffective, but practically blocks inquiry by the method of unification, even when the result is novel, unified and externally relevant. Any work in category (3) is rejected by default, because it does not directly touch the current interests in the field. A very large portion of contemporary philosophy falls under category (2), where we find all sorts of literature reviews and contemplations about pseudo problems that do not touch anything outside the corpus. It is striking is that also works in category (1) may be rejected, if the applied methodology is non-standard. Even though a work touches a contemporary topic, it is not about details of a specific aspect of a specific topic, but about unifying some aspects and dropping others that do not find a natural place in the whole. The exceptions are rare and they typically require a lot of sweat and tears. For instance, before Ingthorsson's work [31] on a unified conception of truth was accepted, it was rejected by 12 high-ranking journals during 7 years.

If unification were the official goal and criterion, it is certain that philosophers would in general produce unified and applicable concepts.

5.2.2. Tackling dogmatism by objective criteria in physics. The tradition drives mainstream physicists into rejecting virtually all non-standard theories. Consider the chief reasons why this is so.

(a) Theoretical physicists are literally groomed into the culture of standard theories,[17] where the main criteria are evidentiality, beauty as familiarity with standard theories, and coherence with them. The basic mode of working is to develop mathematical details in the context of standard theories, and to develop hypotheses that keep them standing. Metaphysical commitments of standard theories, from hypothetical laws to additional hypotheses, are considered as empirical facts.

(b) Due to (a), standard theories are not thought to have big problems but are instead considered beautiful. That QM and relativistic physics are mutually disunified is not considered as a problem of working physicists, for their mathematics works, and that part which does not work alone, is made to comply by new hypotheses, such as dark energy and Kerr metric, which are considered as empirical facts.

(c) Due to (a-b), standard theories are initially considered better than non-standard theories. Since there are so many new suggestions that are initially believed to be no good, without a purpose and in the class *we get a dozen of these in a week*, very few are willing to use time to carefully study any new suggestion. In effect, a reviewer may reject any new theory with a good consciousness.

For one, Feyerabend saw that rejection of non-standard theories is common practice:

[17] Fayerabend [21] suggests that the minds of the young should be strengthened against any easy acceptance of comprehensive views.

> empirically minded scientists at once confront it with *status quo* and announce triumphantly that 'it is not in agreement with facts and received principles'. They are of course right, and even trivially so, but not in the sense intended by them. For at an early stage of development the contradiction only indicates that the old and the new are *different* and *out of phase*. It does not show which view is the *better one*. A judgement of *this* kind presupposes that the competitors confront each other on equal terms. How shall we proceed in order to bring about such a fair comparison? Feyerabend [65] p. 113

Unifying power and the related virtues are the suggested criteria for fair comparison. Such comparison does not supress big innovations, but it also saves time from journals and guides authors into seeking out unified solutions. On one hand, it allows journals to righteously reject the biggest class of new suggestions: modifications of relativistic physics that apply to one scale of phenomena, and which are not shown to be extensible to other scales. On the other hand, it prevents evaluators from rejecting *every* new suggestion, even if it is more unified.

We can of course understand that a person who has been groomed into exactly one way of thinking about physics or another subject, from childhood to adulthood and through school, university and career, is unwilling and even unable of making a sudden change even if he wanted to, similarly as an oblique tree cannot be straightened up. Planck [66] saw this: "A scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die and a new generation grows up that is familiar with it." But the problem does not get fixed because new generations of physicists are strictly taught the old dogma. The problem could be remedied in the long run by constitutionalizing objective criteria. This would give new generations a genuine incentive to investigate alternative theories.

5.3. Other ways of tackling dogmatism

Henry Bauer [67-69] maintains that dictatorially behaving *knowledge monopolies* are more common in science than one might think. The knowledge monopolies control the funding of research and mass media, and are strong enough to censor minority views. Bauer [67] concludes that society "needs new arrangements to ensure that public information about matters of science will be trustworthy." Bauer has given several suggestions of how to tackle dogmatism.

1. Competent people who hold contrarian views should be allocated a share of total funds whenever government agencies support research or development ventures, and they should participate in advisory panels and grant-reviewing arrangements. Where legislation is being considered about public policy that involves scientific issues, a Science Court might be established to arbitrate between mainstream and variant views. [67]

2. Ombudsman offices should be established by journals, consortia of journals, private foundations, and government agencies to investigate charges of misleading claims, unwarranted publication, unsound interpretation, and the like. [67]

3. Vigorously investigative science journalism is needed, so that mainstream propaganda is not automatically passed on. To make this possible, the media needs to know about and have access to the whole spectrum of scientific opinions on the given issue.[18] [67]

4. Anonymity should be removed from peer reviews and grant reviews. [68]

It is likely that these kinds of suggestions are considered by many scientists as harmful restraints on academic freedom. However, dogmatism is real and it must be tackled in *some way*, for less dogmatic

[18] Although philosophy of science can be considered as investigative science journalism, the critical aspect is mostly missing. For instance, philosophy of time is almost entirely subjugated to relativistic physics.

science would be a better aide to society. Therefore, we must give politicians and legislators concrete suggestions.

6. Conclusions

The story of how physics and philosophy drifted apart is short. Scientific explanation was all about metaphysics without empiricism throughout antiquity, until predictive and descriptive capabilities became a prerequisite for scientific theories in the Copernican Revolution. In Newton's synthesis the predictive capabilities were coupled with intuitive laws of nature and an understandable worldview. Phenomena discovered in the late 19th and the early 20th century falsified Newtonian Mechanics. It was gradually modified and complemented by relativistic physics and cosmology, QM and its sub-theories. This process made physics a matter of giving mathematical descriptions of perceptions in the absence of intuitive ideas, and resulted into non-understandable and heterogeneous theories that are patched up with additional hypotheses and experimental parameters. Natural philosophy was divided in two: contemporary physics is primarily about giving mathematical descriptions of perceptions, whereas in naturalist metaphysics the goal is to complement empirical science by understandable explanations.

Why have philosophers not completed the worldview behind standard physics? Is it because they are not up to the task, or perhaps because reality is in fact non-understandable? Or perhaps we are on the right track after all, and we must let physicists and philosophers work for another 100 years with the current theories? Or is it rather so that reality is an understandable totality, but one cannot form an understandable picture of it on the basis of modifications and complementations of Newtonian Mechanics? If you suppose that reality is understandable, and if you appreciate honest theory evaluation, it is easy to find the biggest culprit. On one hand, relativistic physics is non-understandable and requires additional hypotheses in order to give correct predictions. On the other hand, QM stands firmly but remains without consensual foundations. On the third hand, there is little hope for unifying relativistic physics and QM into an understandable whole. It is thereby reasonable to conclude that we are looking for a theory of gravitation that replaces relativistic physics and contributes to the ontological foundations of QM.

Philosophy remains devoid of unified concepts, due to its loyalty to standard physics and its positivist roots. The time is ripe to seriously consider the possibility that metaphysicians have not completed the ontological interpretation of relativistic physics *because it cannot be completed*. We have seen some promising examples of formulating unified concepts in areas that are not completely twisted by relativistic physics, but clarity can be brought upon strongly time-related concepts only after relativistic physics has been replaced by a viable alternative that commits to absolute simultaneity. Then again, philosophers with a good conscience will also have to admit that the positivist roots of philosophical analysis are even more totally wrong than has been already accepted. Namely, the heart of the methodology is completely false: the idea that unification happens by itself when philosophers hassle long enough with details. The contemporary state of analysis is a direct proof of this. It is reasonable to demand that philosophers should produce understandable concepts that are applicable in natural science and human social interaction; it is thereby also reasonable to demand positive attitudes toward a methodology that manages to produce such concepts.

This account would be helplessly incomplete without the rather unpleasant topic of dogmatism in physics and philosophy. Recall the basic clash of progress and dogmatism: we need better theories; but there is a very strong tendency of thinking that the tradition is on the right track, and accordingly that anything non-standard is initially wrong.

The situation in physics is a lot worse than in philosophy. The edifice around standard physics is like any strong political movement or deep tradition. Standard physics *itself* has the highest priority, and all else is bent to support it. From schools to universities, only one tradition is taught, and its founding fathers are idolized as universal geniuses; achievements of standard theories are embraced and their alternatives are silenced away. The primary requirement for predictive abilities is objective, but when the predictions of a standard theory fail, they are corrected by hypothetical entities; all evidence is interpreted positively for standard theories, and their fallacies are ignored. Beauty as familiarity with

standard theories and coherence with them come in priority right after evidentiality. Unificatory ideals have lost significance because they do not conform to disunified physics.

In contrast to physicists, philosophers have learned valuable lessons from the mistakes made in the early 20th century. However, the development of philosophical methodology is an on-going process. Main-stream analysis has lost one half of the logical positivist heart and sustained another. On one hand, the general mood seems to be that the unificatory project of logical positivists and some remarkable scientists failed; reasons for the failure are not sought from physics, but it seems to be accepted that unification is a dead end. On the other hand, the idea that philosophical analysis is a collaborative effort of investigating details is sustained. In effect, philosophical analysis is essentially about interpreting and creating texts that deal with various nuanced details of isolated topics and different angles to them, and where the quest for intuitive solutions is replaced by corpus-relevance.

In a nutshell, the tradition practically fights against unification, because of its own failure in unifying science. Once we suppose that the reality is a whole, we can formulate criteria accordingly, in order to facilitate bringing forth better theories in physics and philosophy: we should commonly prefer more evidential theories; if two theories are equally evidential, we should prefer the metaphysically simpler.

We have lived through *the century of disunification*. Let's make this one *the century of unification*.

Acknowledgements

I thank Tuomo Suntola, Riku Juti, Valdi Ingthorsson, Ari Lehto and Jan Dabek for helpful comments.

References

[1] Kaila E 2014 Human Knowledge: A Classic Statement of Logical Empiricism, ed J Manninen, I Niiniluoto and G A Reisch (Chicago, Illinois: Open Court, 2014)
[2] Kuhn T 1977 Objectivity, Value Judgment, and Theory Choice. *The Essential Tension: Selected Studies in Scientific Tradition and Change* (Chicago: University of Chicago Press) pp 320–9
[3] Psillos S 1999 *Scientific Realism: How Science Tracks Truth* (London and New York: Routledge)
[4] Nolan D 2015 The A Posteriori Armchair *Australasian Journal of Philosophy* **93** 211–31
[5] Mackonis A 2013 Inference to the Best Explanation, Coherence and Other Explanatory Virtues *Synthese* **190** 975–95
[6] Bartelborth T 1999 Coherence and Explanations *Erkenntnis* **50** 209–24
[7] Milgrom M 1983 A modification of the Newtonian dynamics—implications for galaxies *Astrophysical Journal* **270** 371–89
[8] Keas M N 2018 Systematizing the Theoretical Virtues *Synthese* **195** 2761–93
[9] Kuhn T 1970 *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press)
[10] Nagel E 1961 *The Structure of Science. Problems in the Logic of Explanation* (New York: Harcourt, Brace & World, Inc.)
[11] Newton-Smith W 1981 *The Rationality of Science* (London and New York: Routledge & Kegan Paul)
[12] Quine W W O and Ullian J 1998 Hypothesis *Introductory Readings in the Philosophy of Science*, ed E Klemke, R Hollinger, D Rudge and D Kline (Amherst: Prometheus Books) pp 404-14
[13] MacAllister J W 1996 *Beauty & Revolution in Science* (Ithaca and London: Cornell University Press)
[14] Hutcheson F 1973/1725 *An Inquiry Concerning Beauty, Order, Harmony, Design*, ed P Kivy (The Hague: Martinus Nijhoff)
[15] Smith A 1976/1776 *An Inquiry into the Nature and Causes of the Wealth of Nations*, ed R H Campbell, A S Skinner and W B Todd (Oxford: Clarendon Press)
[16] Dirac P 1965 The Evolution of the Physicist's Picture of Nature *Scientific American* **208** 45–53
[17] Weinberg S 1972 *Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity* (New York, London, Sydney, Toronto: John Wiley & Sons)
[18] Kragh H 1990 *Dirac: A Scientific Biography* (Cambridge: Cambridge University Press)
[19] Riess A G et al. 2004 Type Ia Supernova Discoveries at z>1 from the Hubble Space Telescope: Evidence for Past Deceleration and Constraints on Dark Energy Evolution *The Astrophysical Journal* **607** 665–87
[20] Leplin J 1975 The concept of an ad hoc hypothesis *Studies in History and Philosophy of Science* **5** 309–45
[21] Feyerabend P K 1975 How to Defend Society Against Science *Radical Philosophy* **11** 3–9
[22] Hoyningen-Huene P 2000 Paul K. Feyerabend: An Obituary *The Worst Enemy of Science?: Essays in Memory of Paul Feyerabend*, ed J Preston, G Munévar and D Lamb (New York and Oxford: Oxford University Press) pp 3–15
[23] Benovsky J 2013 Philosophical theories, aesthetic value, and theory choice *Journal of Value Inquiry* **47** 191–205
[24] Styrman A 2014 The principle of economy as an evaluation criterion of theories *Scientific Models and a Comprehensive Picture of Reality*, ed T Suntola and A Styrman. La Nuova Critica, **63-64** pp 63–90
[25] Hillman D J 1962 The Measurement of Simplicity *Philosophy of Science* **29** 225–252
[26] Lehto A 2014 Period-Doubling as a Structure Creating Natural Process *Scientific Models and a Comprehensive Picture*

of Reality, ed T Suntola and A Styrman. La Nuova Critica, **63-64** pp 91–116
[27] Suntola T 2018 *The Short History of Science, or the long path to the union of metaphysics and empiricism*, third edition (Espoo: Physics Foundations Society. Helsinki: The Finnish Society for Natural Philosophy). https://physicsfoundations.org/data/documents/History_EN_978-952-68101-7-1.pdf
[28] Juti R 2019 *Lyhyt metafysiikan historia* (Tallinn: Gaudeamus).
[29] Hahn H, Neurath O and Carnap R 1929 *The Scientific Conception of the World: The Vienna Circle.*
[30] Styrman A 2016 *Economical Unification as a Method of Philosophical Analysis* (PhD Thesis, University of Helsinki, Finland) http://urn.fi/URN:ISBN:978-951-51-2697-9
[31] Ingthorsson R D 2019 There's No Truth-Theory Like The Correspondence Theory *Discusiones Filosóficas* 20 15-41
[32] Benovsky J 2016 Dual-Aspect Monism *Philosophical Investigations* **39** 335–52
[33] Styrman A 2018 Relativity vs. absolute simultaneity: Varying flow of time or varying frequency? *Physics Essays* **31** 256–64
[34] Ballard K E 1960 Leibniz's Theory of Space and Time *Journal of the History of Ideas* **21** 49–65
[35] McTaggart J M E 1908 The Unreality of Time *Mind* **17** 457–73
[36] Eddington A S 2007/1928 *The Nature of the Physical World* (Cambridge: Cambridge University Press)
[37] Rietdijk C W 1966 A Rigorous Proof of Determinism Derived from the Special Theory of Relativity *Philosophy of Science* **33** 341–4
[38] Putnam H 1967 Time and Physical Geometry *Journal of Philosophy* **64** 240–47
[39] Rakic N 1997 Past, Present, Future, and Special Relativity *British Journal for the Philosophy of Science* **48** 257–80
[40] Broad C D 1923 *Scientific Thought* (London: Kegan Paul)
[41] Hinchliff M A 2000 Defense of Presentism in a Relativistic Setting *Philosophy of Science* **67** Supplement S575–S586
[42] Earman J 2006 The 'Past Hypothesis': Not Even False *Studies in History and Philosophy of Modern Physics* **37** 399-430
[43] Esfeld M 2006 Popper on irreversibility and the arrow of time *Karl Popper: A Centenary Assessment*, ed I Jarvie, K Milford and D Miller (Aldershot: Ashgate) pp 57–70
[44] Unger R M and Smolin L 2015 The Singular Universe and the Reality of Time: A Proposal in Natural Philosophy (Cambridge: Cambridge University Press)
[45] Albert D 1960 *Time and Chance* (Cambridge, MA: Harvard University Press)
[46] Loewer B 2012 Two Accounts of Laws and Time *Philosophical Studies* **160** 115–37
[47] Paul L A 2010 Temporal Experience *Journal of Philosophy* **107** 333–59
[48] Skow B 2011 Experience and the Passage of Time *Philosophical Perspectives* **25** 359–87
[49] Dainton B 2012 Time and Temporal Experience *The Future of the Philosophy of Time*, ed A Bardon (New York: Routledge) pp 123–48
[50] Hoerl C 2014 Do We (seem to) Perceive Passage? *Philosophical Explorations* **17** 188–202
[51] Norton J 2010 Time Really Passes *Humana.Mente – Journal of Philosophical Studies* **13** 23–34
[52] Maudlin T 2007 *The Metaphysics Within Physics* (Oxford: Oxford University Press)
[53] McCall S 1994 *A Model of the Universe: Space-time, Probability, and Decision* (Oxford: Clarendon Press)
[54] Skow B 2012 Why Does Time Pass? *Noûs* **46** 223–42
[55] Cameron R P 2015 *The Moving Spotlight: An Essay on Time and Ontology* (Oxford: Oxford University Press)
[56] Styrman A 2019 *Causal Explanation of the Passage of Time* (in preparation)
[57] Savitt S 2002 On Absolute Becoming and the Myth of Passage *Time, Reality, & Experiences*, ed C Callender (Cambridge: Cambridge University Press) pp 153–67
[58] Leininger L 2013 *B-Coming: Time's Passage in the B-Theory Blockworld* (PhD Thesis, University of Maryland, USA) https://drum.lib.umd.edu/handle/1903/14102
[59] Styrman A 2019 *Tense Logic and Ontology* (in preparation)
[60] Von Wright G H 1984 Diachronic and Synchronic Modalities *Philosophical Papers of Georg Henrik von Wright, Volume III: Truth, Knowledge and Modality*, ed G H von Wright (Oxford: Basil Blackwell) pp 96–103
[61] Bunge M 1967 *Foundations of Physics* (Berlin, Heidelberg, New York: Springer-Verlag)
[62] Poland J 1994 Physicalism: The Philosophical Foundations (Oxford: Clarendon Press)
[63] Sider T 2009 Ontological Realism, *Metametaphysics: New Essays on the Foundations of Ontology*, ed D Chalmers, D Manley and R Wasserman (Oxford: Clarendon Press) pp 384–423
[64] Manley D 2009 Introduction: A Guided Tour of Metametaphysics *Metametaphysics: New Essays on the Foundations of Ontology*, ed D Chalmers, D Manley and R Wasserman (Oxford: Clarendon Press) pp 1-37
[65] Feyerabend P K 1993 *Against Method*, third edition (London and New York: Verso)
[66] Planck M 1949 *Scientific Autobiography and Other Papers* (New York: Philosophical Library)
[67] Bauer H H 2004 Science in the 21st century: Knowledge monopolies and research cartels *Journal of Scientific Exploration* **18**.4 643–60
[68] Bauer H H 2012 *Dogmatism in Science and Medicine: How Dominant Theories Monopolize Research and Stifle the Search for Truth* (USA: McFarland)
[69] Bauer H H 2017 *Science Is Not What You Think: How It Has Changed, Why We Can't Trust It, How It Can Be Fixed* (USA: McFarland)