Studies in Early Modern Philosophy

III

EDITED BY

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DELMAR, NEW YORK
1993

8. For discussion of this see Terence Penelhum, *Hume* (New York: St. Martin's Press, 1975) p. 167; and Terence Penelhum, "Butler and Hume," *Hume Studies*, Vol. 14 (1988), pp. 251-276.

9. This paper was originally presented at the Hume Society meeting at the American Philosophical Association, Washington D.C., December 1992.

The Problem of the Relationship between Time and Motion from Descartes to Newton

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Introduction

The Leibniz-Clarke correspondence on the nature of space and time is usually considered the starting point of the absolutist-relationist debate (Alexander 1984).[1] This statement, though in need of qualification, has surely some appeal to it. The maturity of the terminology used in the letters, the clarity with which the questions are set and debated are indeed unprecedented in the history of spacetime theories. This maturity was made possible both by the gigantic step that dynamics had taken under Newton's impulse and by Leibniz's great philosophical talent.

In addition, the Leibniz-Clarke correspondence is a unique document of the unity of culture so characteristic of the Age of Reason. As is well known, intricate questions on the nature of space and time that are now of exclusive interest to the mathematical physicist were discussed by Leibniz and Clarke in a wholly theological setting. Not only was physics relevant for religion but physical theories had to be judged and evaluated in accordance with their theological consequences and presuppositions. This factor should always be kept in mind by the twentieth-century scholar trying to interpret and assess the arguments presented by the two sides.

Finally, it is not by chance that Leibniz begins his letter to Caroline, Princess of Wales by lamenting the decay of natural religion in England. Significantly enough, in the second and third paragraph of the letter he mentions Locke and Newton as causes of that decay. Leibniz's opposition to Locke and to the central tenets of Newtonian science plays a capital role in the history of the movement that led—

through Goethe—to the reaction against English empiricism and Newtonian science that goes under the label of German idealism. It is perhaps a platitude to say that Newton's natural philosophy contributed to create the watershed that still divides today the continental and the Anglo-Saxon philosophical tradition.

If these reasons can at least partially explain the great importance that historians of science have attributed to the Leibniz-Clarke correspondence, they may also help us to understand why it is sometimes mistakenly considered also as a starting point or as the absolute beginning of the substantivalist-relationist controversy. The main purpose of this paper is to try to show to what extent the questions debated by Leibniz and Clarke on the nature of time have their roots in the seventeenth-century natural philosophy. I will therefore try to prove that Leibniz and Clarke, in discussing the merits of substantivalism and relationalism, were the heirs of an older tradition of philosophical discussions on the ontological nature of space and time, a discussion which is, for instance, already manifest in the Italian Renaissance philosophy (Telesio and Bruno).

If this tradition had taken substantial impetus from the Copernican revolution and from the numerous translations of works of Greek mathematicians and philosophers, it is especially in the seventeenth century, however, the period on which our analysis will be focused, that the birth of the new dynamics forced the major natural philosophers to renovate the ancient, received Aristotelian doctrines of space and time. Most of what now goes under the label 'philosophical problems of space and time' emerged in the seventeenth century as an attempt to clearly define concepts that were for the first time used as parameters in quantified laws and were therefore undergoing a revolutionary change. In a word, the early modern philosophers were facing the difficult problem of giving a new foundation to a newborn science—mechanics. To say it with I. Barrow, teacher and predecessor of Newton at the Lucasian Chair of Mathematics at Cambridge:

> Now pray tell me what Time is? You know the very trite Saying of St. Augustine, If no one asks me, I know; but if any person should require me to tell him, I cannot. But because Mathematicians frequently make use of Time, they ought to have a distinct Idea of the meaning of that Word, otherwise they are Quacks.[2]

In the following paper, and according to the suggestion of Barrow, I will focus my attention on the history of the conceptions of time rather than of space, in this way trying to bridge an existing gap in the historical literature on the seventeenth-century Natural Philosophy. While in fact the concept of space has received a great deal of historical attention,[3] time has been almost totally neglected, for reasons that will—I hope—become clear in the following.

In particular, in the first part of the paper I will offer a brief review of the main conceptions of time in the seventeenth century, as an introduction and a background in which to situate the famous theory of time exposed by Newton in the *Principia Mathematica*, to be discussed in the second. In presenting Newton's theory of absolute time as it was developed in the Scholium, I will consider the historical influences as well as the scientific motivations lying behind the postulation of this so-much criticized 'metaphysical entity'. In particular, being aware of the great extent of the literature on Newton's conception of space and time, the methodological problem I will try to stress here concerns a question that has been largely neglected in this literature, but that is central in philosophical problems of time, namely that of *how to determine a measure of time*. As we will see, this question had an important role also in the literature concerning the substantivalist-relationist debate. Newton, in particular, was acutely aware of the difficulties involved in trying to determine an accurate measure of time, to the extent that for him time had, as I will try to show, an 'intrinsic metric'.

From the viewpoint of this problem, and as an introduction to the problem itself, the difference between Newton-Clarke's substantivalism and Leibniz's relationalism is as follows: for Newton the universe *has* a clock, while for Leibniz it *is* a clock,[4] in the sense that the successive states of the universe determine its temporal order. Both Newton and Leibniz referred explicitly to the order of time (Newton says: "all things are placed in time as to the order of succession"[5]; the same expression is used by Leibniz), but Newton distinguished also between the order and the *rate* at which events succeed one another. Leibniz, on the contrary, did not seem to worry—or maybe willingly ignored—the important aspect of the rate of succession of the events. As a matter of fact, Leibniz never answered the serious problem posed by Clarke: how can a relationist account for the rate at which events succeed themselves given that the *same* succession of events can take place with different velocities? (Image a movie unrolling at different speeds.) Not only does this problem force the relationist to a conventionalist position in the choice of a clock, but it would also seem to imply a very restricted conception of time, limited to its order and completely neglectful of its durational aspect.[6]

If it is to the merit of Newton's absolutism to have recognized the importance of the problem of measuring the durational aspect of time, it is important to judge the extent to which his metaphysical position is compatible with his 'operational' criteria to determine the ticks of the absolute clock. It is to this problem that the second part of the paper will be devoted.

Before starting our discussion of the historical material, a final methodological warning is needed. In assessing the theories I am about to present and their underlying arguments, I will not presuppose facts or theories unknown to their proposers. The neat mathematization of Newtonian and Leibnizian space-time theories given by Earman (1989, chap. 3) can surely clarify problems by helping us in drawing distinctions that were not available to a scientist in the seventeenth or eighteenth century. But it will not always help us to understand the arguments actually offered by the participants to the debate. If we do not consider the larger historical and cultural background in which physical theories were situated in the seventeenth century (that is, if we do not take into account the theological and metaphysical worries of Descartes, Gassendi, Newton, and Leibniz), we will not understand their physics.

2. Descartes and the Neglect of Time in the Seventeenth Century

One of the most important facts to be explained by the historian of space and time theories in the seventeenth century is their asymmetry in the philosophical and scientific treatises before Newton's *Principia* (1687). *By asymmetry I here mean the far greater importance and attention that space received in comparison with time.*

Descartes is in this regard a paradigmatic example. His whole scientific project is based on the identification of extension as the essential property of matter, an important step toward the geometrization of the world and the foundation of mechanics. His physics could perhaps be termed with a little emphasis "a theory of space." On the contrary, in the whole Cartesian *corpus*, time was assigned no more than one paragraph, where Descartes distinguishes the concept of duration (*duratio*) from that of time (*tempus*) as measure of movement.[7]

It is interesting to briefly compare Descartes' conception of time with Newton's later theory in the Scholium and especially with Descartes' own conception of space. The less important status that space had in his work in comparison with time can be readily judged by considering the different degree of perfection associated by the scholastic philosophy respectively with an essential property (space is the principal attribute of the *res extensa*) and with a mere 'mode' of our conception (this is what duration is for Descartes).[8]

Such an undervaluation of the concept of time with respect to space has some reasons which are intrinsic to Cartesian philosophy and some that are common to other main philosophers of the seventeenth century. I will start with the former, while the latter will be explored in the next section.

Why is space and not also duration an essential property of matter for Descartes? If the duration of something "is simply a mode under which we conceive the thing in so far it continues to exist"[9] (a definition later reported almost *verbatim* by Newton in the Scholium),[10] then for Descartes it is possible to conceive anything (God excluded) without necessarily presupposing its duration in time. In other words, there is no contradiction in conceiving that a piece of matter or a body is recreated anew every instant (this in fact will turn out to be his view of the matter), while it is for him utterly impossible to conceive a body without also conceiving its extension. Therefore, matter would not be what it is if it were not extended and it is in this rather Aristotelian sense of essence that extension is an essential property of a body.

In an important passage in the Third Meditation, we find a clear formulation of a conception of time as made by atoms completely unrelated to each other, a fact that further explains Descartes' vision of time as a non-essential, accidental attribute of matter. In that passage, after explaining that each moment of our life is completely independent from the others, he adds that "it does not follow from the fact that I existed a little while ago that I must exist now." Some cause that creates me afresh every moment is needed to my preservation:

> For it is quite clear to anyone who attentively considers the nature of time that the same power and action are needed to preserve anything at each individual moment of its duration as would be required to create that thing anew if it were not yet in existence. Hence the distinction between preservation and creation is only a conceptual one, and this is one of the things that are evident by the natural light.[11]

The reasoning underlying this passage is the following. The only really self-conserving substance is God, who is *causa sui* and who does not require anything but himself to continue to exist. The other two derivative substances, the *res extensa* and the *res cogitans*, need his continuous intervention (creation) to subsist. As in a famous tale by Jorge Luis Borges, there is no connection between one atom of time (instant) or state of the world and the following. To represent the picture in a more vivid way, imagine that all particles suddenly became unstable: every world-line (if we can use only for a moment a modern terminology) would then be like a dotted line in which blanks between two successive points represent annihilation. Every particle decays and reproduces itself anew at each instant.

Let us remark that given the meaning of 'conceptual

distinction' in the Cartesian philosophy,[12] we cannot do away with this atomistic picture of time by using an alternative description of the same phenomenon referring only to continuous duration or preservation. The fact is rather that for Descartes we cannot perceive clearly the idea of preservation without that of creation because in reality they are the same thing and they are distinguished only in our way of thinking.

I do not know of any commentator who has noticed that this atomistic conception of time is the foundation for a conception of the laws of nature as depending and expressing the will of God, very much as the human laws express our will of ordering the society in a rational way.[13] If, in fact, it is only God that has the power of conserving or creating the universe at every instant, the various possible ways of connecting one temporal slice of the universe to the successive one (the causal laws or laws of nature) are a direct expression of his power. The world is ordered and comprehensible because it is an expression of God, who is order and rationality. In the end, *Descartes diminishes the role of time in his universe because he deprives material bodies of their inherent capacity for temporal endurance, an exclusive feature of God, while granting them only with the property of extension.*

In another respect, Descartes anticipates in some sense Newton's distinction between time as absolute duration and its "sensible measure." He calls the universal but God-dependent (see above) property that all things have of continuing their existence *duratio*. Different from duration is what he calls time (*tempus*), which is the duration of "the greatest and most regular motions which give rise to years and days." Our measure of the duration of all things is made possible by a comparison of this abstract duration with the most regular motions, presumably, given the examples by Descartes, those of astronomical bodies.

Clearly, Descartes is here describing the process of assigning a metric to his qualitative and metrically amorphous duration. At a closer look however, the Cartesian *duratio* is metrically amorphous only at an epistemological level. Interestingly, by his rather occasionalistic and atomistic conception of time, Descartes provides every object in the universe with an inner, incredibly precise clock, synchronized with the clocks of every other object: *the numbers of act of* *creations that God imparts to it to keep it in existence.*[14] If, in fact, we could prove that his conception of time had to be atomistic or discontinuous as a consequence of his Occasionalism, it follows that the structure of time is discrete and therefore countable in the sense of set-theory. Given his atomistic ontology of time, if we could have an epistemic access to the numbers of acts of divine maintenance, we could measure the duration of any object in the universe by counting the number of times that it has been "re-created" after the first act.

It is easy to see that assuming Descartes' Occasionalism, the structure of time must be atomistic. For it to make sense to say that any physical body is recreated anew at each successive instant, Descartes cannot suppose that for any two successive instants y and z in which body x exists (because of God's creation), there is an instant t in between them in which x also existed.[15] If time were dense in this sense, the body x would *either* have autonomous duration between y and z, *or* else must have been created anew at some instant between y and z. But the first hypothesis is excluded by Descartes' rather Maimonidian theory, and the second is excluded by the meaning of the concept of creation itself.[16]

It is part of the very meaning of the word 'to create' that if x is created at time t, then that x *cannot* exist at some time before t. We can conclude that existence for Descartes must be discrete or discontinuous, an alternation of states of being and non-being, which implies that time is not dense, even though he never argues in favor of the idea that time cannot exist without physical objects.[17] In topological parlance, in any neighborhood of any instant t, there are instants at which the body did not exist, something which, by the way, we must be unable to perceive.

We can conclude our presentation of Descartes' conception of time by saying that he had banned atomism from physics only to reintroduce it in his metaphysics of time. This atomism, however, did not present the same problems raised by an atomistic hypothesis in physics, which was made incoherent by Descartes' identification of matter with the continuous, infinitely divisible Euclidian space.

3. The Primacy of Space on Time in the Seventeenth Century

As I was saying before, Descartes is but the most evident example of what I termed the asymmetry in the theories of space and time before Newton. Besides Descartes' specific motivations for undervaluing time, the main explanation for this asymmetry lies in the process of geometrization of nature initiated with the scientific revolution, in which space obviously played a key role, and which naturally led also to that geometrization or spatialization of time lamented by Bergson in more recent times.

The importance of Euclidian geometry in the seventeenth century was immense and probably incomparable to any other century. In a famous expression by Hobbes, geometry was the only science that God had conceded to mankind.[18] Hobbes himself, Spinoza, and Grotius were so impressed with the clarity and rigor of Euclid's construction that they all tried to adopt the geometrical method as a solid foundation of their philosophy. The typical metaphysical doctrine of the seventeenth century—the division of the world into primary and secondary qualities—was an artifact that allowed the application of geometry to nature by considering the figure of an object as the only objective aspect of reality that we could build our knowledge on.

This fact, together with the peculiar conceptual difficulties traditionally associated with the concept of time,[20] explains in part why *a theory of time was considered superfluous or secondary once some sort of a conception of space had been offered.* Implicit in this more or less tacit conviction was also the idea of a natural affinity or analogy between space and time, so that every intractability of time could be cleared away through an analysis of space. As a consequence of this unstated methodological postulate, any structural feature that was reasonably attributed to space could be naturally extended to time as well: if one could establish that space was absolute, or independent of any physical object, then time had to possess the same feature.

In particular, it was a series of experiments on atmospheric pressure (the announcement of Torricelli's experiment was in 1644, Boyle and Guericke developed afterwards vacuum pumps) that led to a new discussion of the Cartesian denial of the existence of a vacuum, traditionally associated with the atomistic hypothesis. *It was the scientific possibility of a vacuum that led philosophers like H. More to the postulation and the clarification of a concept of space as independent of all physical objects.* A concept of space that, as Newton wrote in the Scholium, is "without relation to anything external." *Besides discussing the possibility of vacuum, one could ask himself whether this empty space could endure in time or not.*

As we know, Descartes denied this possibility, thereby denying vacuum by *modus tollens*: if a vessel is emptied of air inside the walls, it would collapse instantaneously. For More, the void persisting through time guaranteed the existence of absolute time. In a letter dated 5 March 1649 More wrote to Descartes:

> If God would destroy the whole Universe and much later would create it again, this interworld, or the absence of the world, would have its own duration which would be measured by so many days, years, centuries. (Adam and Tannery 1964, Vol. V: 302).

In this way, we understand why the problem of absolute space had a conceptual priority on that of absolute time: once the existence of the first was guaranteed, the one of the second would follow.

A cursory look at some of the theories proposed in the first half of the seventeenth century confirms the above picture about the asymmetry of time and space. Time was among the physicists a sort of fourth spatial dimension—as in Galileo's *Discorsi*—or a mere phantasm of the mind among the philosophers—as in Hobbes'[21] or Spinoza's philosophy.[22]

In Galileo's usage, time is just a parameter needed to give meaning to the concept of velocity and to the uniform and accelerated motion. It is interesting to note that both in the *Dialogues* (1632) and in the *Discourses* (1638), Galileo is not interested in trying to elaborate any philosophical definition of time, nor is he interested in its ontological status. In his characteristic approach, rather than asking himself what time is, he is interested in the procedures to obtain quantities to be used in the measurement of various kinds of motion. On the other hand, precisely as Descartes, Galileo is obviously more aware of the implication of geometry and the importance of extension

in the study of nature; it will be enough to recall the famous passage in the *Assayer*, where he stated that the language of nature is written in triangles and circles and if we want to understand it, we have to study geometry.[23] The problem of the relationships between time and motion, important as it is in the philosophical tradition from Aristotle and Plotinus on, does not concern Galileo. In spite of his need for more and more precise clocks, he did not arrive at postulating an ideal, absolute clock as Newton did in the Scholium.

This silence can be explained by the relative immaturity of the new science of dynamics at the time of Galileo. As already said, the need for an objective foundation of full-fledged laws of motion, together with the problem of justifying non-relative rotational motions, were probably the main impulse for a philosophically elaborate classification of space-time theories. Before getting to this aspect in analyzing Newton's Scholium, it will be necessary to refer to the two most important "precursors" of his absolute theory of time, namely Gassendi and Barrow.

4. Gassendi's Theology and the Ontological Importance of Time

In the history of foundational theories of time in the seventeenth century, giving its due to theology essentially means to identify two opposed theories on the nature of God that are faithfully reflected in two different attitudes toward the nature of time.[24]

On the one side of the spectrum, the clearest example is Spinoza, who was another enemy of time at the ontological level and not only because of his geometrizing philosophy. Like Descartes, he assigned a fundamental ontological status only to space and not also to time. The reason for this attitude lies partially in his theological tastes: his God-Nature had infinite attributes but only the two attributes of extension and thought are known to us. Time is a mere product of our imagination, that is incapable of grasping the timeless nature of the *'Deus sive Natura'*. This need of attributing atemporal eternity to God[25] is another very influential reason that explains our problematic asymmetry: the old Parmenidean tradition of the timelessness of true reality (Being) was still well entrenched in the seventeenth century.

Another example of this attitude can be found in Hobbes, who believed in an "extended" God and considered motion as the key concept of his philosophy but neglected time as a mere "phantasm" or decaying image of the mind nonetheless.

On the other end of the spectrum, we find Gassendi in 1658 (*Syntagma Philosophicum*)[26] and much later the Reverend Samuel Clarke in 1719 (*A discourse concerning the Being and the attributes of God*) defending a conception of God as a temporal, enduring being. Consequently, time is recognized by them as an objective aspect of reality. Interestingly, in the work above Clarke defends and refers directly to Gassendi's criticism of the theological view of the "Eternal Now." Gassendi's revolutionary views on time can be fully appreciated only by considering the obsessive attention to space that we have tried to delineate in almost any other great philosopher of the seventeenth century.

In the *Syntagma*, Gassendi reached an original position on time. The thrust of his argument pro-absolute time was foreshadowed by the objections of H. More to Descartes on the existence of spatial vacua. If God decided to annihilate the world and then recreate it, says Gassendi, "time would still flow in the interval between its destruction and its recreation."[27] Gassendi's argument did not depend, however, on the possibility of empty space together with the primacy of space over time. He argued in favor of absolute time on essentially theological grounds. Since it is possible for God to stop all kinds of motion in the universe (he obviously can do it, if he wills), and time would nonetheless continue to flow even if no one could perceive it, we have to conclude that *time is independent of motion and that it can exist and continue to flow even before and after creation.* The conditions for the objective existence of time do not coincide with those for our perception of its passing. From the fact that no lapse of time could be perceived without motion, we cannot infer that time did not really elapse.

The rejection of the doctrine of God as the "Eternal Now" and the acceptance of the dangerous consequence of the "divine idleness" before the creation of the world did not worry him as it worried Augustine and Leibniz before and after him. For Gassendi it is in fact an expression of the infinite power of God that he could have

created the world earlier than it was created. This basic point, fully accepted by Clarke, was, as we know, at loggerheads with Leibniz's theory of divine decision-making conjoined with his principle of sufficient reason.

5. Newton's Scholium and the Problem of Measuring Absolute Time

To fully realize Gassendi's importance in the history of the conceptions of time, it would be enough to recall that already in 1644, in his *Disquisitio Metaphysica*, he formulates the theory of absolute time in a way that is almost literally found in a passage of Barrow's *Lectiones geometricae*.[28] Knowing how much Newton's theory of time depended on that of his teacher's, we can compare Gassendi saying "Whether things exist or not, whether they move or are at rest, time always flows at an equal tenor"[29] (*sive res sint, sive non sint, sive moveantur, sive quiescent, eodem tenore fluit tempus*) with Newton's famous definition of time in the Scholium: "Absolute, true, and mathematical time, in itself and by its nature without relation to anything external, flows equally" (*Tempus Absolutum, verum, et mathematicum, in se et nature sua sine relatione ad externum quodvis, aequabiliterfluit*).[30]

In order to understand the import of these passages, and the reason why Newton was led to theorize the independence of time from anything external, that is, from all kinds of motions, it is important to recall that the need for a universal, uniform clock had been felt throughout medieval cosmology,[31] and had led to the postulation of the existence of a universal rate-measurer in the alleged uniform rotation of the last celestial sphere, the one beyond the fixed stars. Even during the Middle Ages, however, doubts had been raised concerning the existence of such a uniformly rotating sphere. Progress in astronomical and physical knowledge brought about not only the definitive abandonment of the spheres paraphernalia (recall Tycho's novae) but led to the awareness that all celestial motions are due to forces (Newton) and that every motion is therefore accelerated or retarded. Already Kepler's second law and his discovery of the elliptical orbit of the planets potentially contained this result.

Newton was therefore confronted with the following alternatives: he had either to accept "temporal relativism," admitting thereby that there are as many times as motions *(tot tempora, quot motus)* or postulate the existence of an ideal, uniform, mathematical clock, independent of any motion or change. Both alternatives had their prices; the first implied the relativity of the laws of nature to a particular, arbitrarily selected clock. Different clocks would yield in fact different values of velocity, acceleration, etc. The objectivity of every law of nature containing the parameter time would be undermined. The second alternative seemed to imply the impossibility of knowing the true rate of flow of the absolute time and Newton himself admitted that: "it is possible that there is no such thing as an equable motion, whereby time can be accurately measured."[32] As we know, Newton chose the second way, for which he had an independent, methodological ground. He had obviously good reasons to believe in the existence of absolute space, given

(1) the absolute character of rotation shown for example in the famous bucket experiment and

(2) the shared conviction, endorsed by Newton, that motion *cannot* be construed as a monadic property, but must be regarded as a relation: 'body x moves' therefore really means for Newton 'body x moves with respect to y'. Since Newton claims that the bucket experiment proves that y cannot be a body, it follows that y must be absolute space.

By symmetry arguments, if space and motion are absolute, time has to be absolute, too, being linked to distance and velocity by simple physical relations. How could time alone be relative while he had independent reason to believe that space and motion were absolute? Considering that the tradition leading up to Newton had, as we have seen, conferred a sort of primacy on space, the absoluteness of space could have been *per se* a sufficient reason to extend this feature to time as well.

The immediate problem that Newton had to face against the relationist's possible rebuttal was then the following: how do you measure the true mathematical time, or better, how do you correct our "sensible measures" of the flow of absolute time? It seems clear that this epistemological problem, directly following from Newton's

position, potentially undermines the whole absolutistic theory of time. If there is in principle no way for us to detect this equable rate of absolute time, what is the use of this ideal clock? Why postulate its existence?

It could be argued that the expression involving equal flow is just a metaphor, and that absolute time in Newton's definition does not involve an intrinsic metric. This interpretation can be defended only with considerable difficulties.

First of all: The illustration or exemplification of the difference between absolute and apparent time offered by Newton in the fifth paragraph of the Scholium shows that Newton believes in the existence of an intrinsic metric for absolute time expressed in 'the equal flow', for which he gave an argument in discussing astronomical time.

Secondly, Newton is careful in distinguishing between the real quantities (the objective, measured quantities of absolute objects) and the relative ones, that are not really quantities but only sensible measures, more or less accurate, of the real ones (see paragraph 13 in the Scholium).

Thirdly, I do not see what sense we can make of "*fluit aequabiliter*" and especially of the qualification *aequabiliter*, that indeed suggests the idea of a uniform clock (Gassendi says *eodem tenore*), if we do not believe that for Newton time had an intrinsic metric. The same remark applies to the fifth paragraph of the Scholium, where Newton says: "All motions may be accelerated or and retarded, but the flowing of absolute time is not liable to any change (*fluxus temporis absoluti mutari nequit*)."[33] Let us analyze these three points in turn.

5a. Astronomical Time and Absolute Time in the Scholium

The argument that Newton seems to use in (a) can be summarized in the following way. True astronomical time is obtained through what Newton calls *aequatio temporis*, which is the correcting factor for the apparent time. We know for example that the period of the revolution of the earth around the sun is different every year, in spite of the fact that the length of the years is "commonly considered as equal." By considering different years and by taking into account the irregularities of the motion of the earth (tidal friction, etc), the astronomer can calculate the fictitious mean solar year and correct our calendar. This is, I think, how we should interpret Newton's passage in the seventh paragraph of the Scholium, when he says that we deduce duration from the sensible measures thereof "by means of the astronomical equation."

The length of the "mean solar year" becomes then a clear example of the ontological status of absolute time in the following sense. It could be the case that no natural revolution of the earth was, is, or will be exactly as long as the averaged, calculated length of the solar year. This is, however, no reason to criticize its usefulness. As Newton himself warns in a somewhat unusual way for an empiricist: "in philosophical disquisitions, we ought to abstract from our senses, and consider things themselves, distinct from what are only sensible measures of them."[34] The temporal length of the mean interval between two consecutive passages of the mean sun becomes then just a theoretical, mathematical entity, or an ideal clock by which we can measure the actual "celestial motions by a more accurate time," in a sort of brilliant bootstrap strategy.

Once we have established that absolute time has indeed an intrinsic metric,[35] our original problem still remains unsolved. Did Newton identify the absolute flow of time with the astronomical correction given by the *aequatio temporis?* If we cannot directly identify the astronomical time as the ideal rate measurer of the absolute "flow" of time, how can we identify and meaningfully use this absolute metric? How can we be sure that the flow is equable, given that there is nothing that controls it (time has no relation to anything external)? Before concluding that time flows equably as a manifestation of the regularity of God (space and time are for Newton *Sensoria Dei*), an answer that would not make too much violence to Newton's theological views, we should try to look more carefully at the text.

The reason why Newton mentions astronomy in the fifth paragraph of the Scholium is obvious: he wants to show that his distinction between absolute and relative time is well entrenched in the use and practice of the scientists working in mankind's oldest science. While we cannot distinguish with our senses absolute and

relative places (sixth paragraph of the Scholium), everyone working in astronomy knows that the commonly accepted measures of time—day, month, year—are not equal, so that the postulation of an absolute, "corrected" time is needed. Notice, in fact, that Newton does not include time in the list of things that he wants to distinguish through "their properties, causes and effects" (in the seventh paragraph of the Scholium he refers only to "rest and motion, absolute and relative" as things to be distinguished). He therefore takes for granted that the arguments used in the fifth paragraph are sufficient to establish the distinction between absolute and relative time.

There is however no direct textual evidence that Newton identified the measure given by the astronomical correction as the intrinsic metric of absolute time. Clearly, the mathematical time obtained from the *aequatio temporis* was the most accurate measure of "the rate of the equal flow" in Newton's time. Surely Newton accepted it on a practical basis as a guide in calculation and in the problems concerning an estimation of the quantity of motion, but he would have probably refused it on a purely mathematical basis. After all, Newton knew all too well that every astronomical measure was susceptible of improvement.[36]

5b. Barrow's and Newton's "Platonic" Theory of Measure

A careful reading of paragraph thirteen of the Scholium suggests that Newton might have defended a sort of Platonic conception of Time as the quantity measured by measures—motions—that can be accurate only to an approximate degree. In this sense the real quantity does not depend on any sensible measure of it (another way of saying that absolute time does not depend on motion): "Nor do those less defile the purity of mathematical and philosophical truths, who confound real quantities with their relations and sensible measures." Using an example that Newton himself suggests, temporal measures obtained with the help of pendulum clocks and the satellites of Jupiter do not have to be confused with the real quantity that is measured by them.

Newton's teacher Barrow had an admirably clear and philosophically developed conception on this problem, based on a realistic or Platonistic philosophy of mathematics. Given the obvious influence of Barrow's *Lectiones geometricae* on Newton's own concept of time,[37] it is important to explore Barrow's view on the relation between time and quantity.

According to Barrow, Time is qualitatively defined just as "the Continuance of any Thing in its own Being" (as in Descartes and Newton). The possibility of empty time is guaranteed by the fact that "Time does not imply an actual Existence, but only the capacity or possibility of an actual existence." But time is obviously also a concept susceptible of "a less or a more, " and therefore is a Quantity. As every other absolute quantity, time possesses a Platonic Quantum which is completely independent of any measure:

> But as Magnitudes themselves are absolute *Quantums* Independent on all Kinds of Measure, tho' indeed we cannot tell what their Quantity is, unless we measure them; so Time is likewise a *Quantum* in itself, tho' in Order to find the Quantity of it, we are obliged to call in Motion to our Assistance, as a Measure whereby we can esteem and compare the Quantity of it; . . . .[38]

As a consequence of this position, Barrow has to admit that we can never be sure that the quantity measured by our most regular motion really coincides with the Quantum or rate of flow of absolute time, given that the Quantum itself is independent of any possible measure. Incidentally, it seems that any absolutist theory of time has to face this unpalatable epistemological consequence.

Interestingly, Barrow also suggested a geometrical interpretation for this Platonic notion of Quantum. For Barrow in fact, any magnitude alike in all its parts can correctly represent the structure of time because time itself consists of parts altogether similar. For this reason, he was probably the first to propose a representation of time as a one-dimensional line or circle, generated by the uniform motion of a moving point (from hence the idea of the flow, which Newton used in his calculus of fluxions). This image seemed very apt to illustrate the durational, continuous aspect of time's passing:

> For as Time consists of Parts altogether, it is reasonable to consider it as a Quantity endowed with one Dimension only; for if we imagine it to be made up, as it were, either of the simple Addition of rising Moments, or of the continual Flux of one Moment, and for that reason ascribe only Length to it, and determine its Quantity by the Length of the Line passed over: As a line, I say, is looked upon to be the Trace of a point moving forward, being in some sort divisible by a Point . . . So Time may be conceiv'd as a Trace of a Moment continually flowing."[39]

This passage is central in understanding the origin of fluxional calculus. A quantum can then be represented by—even if not identified with—the length of a part of a segment moved through with an equal motion.

The reason why Newton did not explicitly mention this interesting representation of the flow of time[40] is in my opinion clear: it would have mixed too much the idea of uniform, absolute time with that of motion, two concepts that he clearly wanted to separate. The expression "flow" in the Scholium therefore has to be read in inverted commas, and it was probably used by Newton both as a tribute to his predecessors Gassendi and Barrow, and to introduce the much more important idea of uniformity or equability. It is a case in which I think that the adjective has determined the choice of the noun.

The image of the moving point travelling equal segments in equal times used by Barrow has the merit of suggesting another interesting and deep point, which has to do with the relationship between the law of inertia and absolute time, already perceived by Lord Kelvin and Tait in their 1890 "Natural Philosophy."[41] This relationship appears quite subtle and problematic. *Kelvin and Tait thought, for example, that the law of inertia could be used as our convention to measure time.*[42] Newton had clearly seen this connection when he wrote in the fifth paragraph of the Scholium that all motion can be accelerated or retarded and that therefore "it may be that there is no such thing as *an equable motion, whereby time can be accurately measured*" (my emphasis). A perfectly inertial motion—more precisely one in which the body proceeds with uniform speed—would automatically be a perfect clock, because it would travel equal spaces *in an equal time*:

the ideal rate-measurer that we were looking for. Let us then try to analyze the relationships between the law of inertia and an ideal rate-measurer (absolute clock).

5c. The Law of Inertia and the Measurement of Absolute Time

It would seem that the existence of an inertial motion is a sufficient condition for the existence of a perfect rate-measurer, in spite of the fact that a rectilinear uniform motion, even if it could exist, would not be the best clock for practical uses.[43] Apart from this, the very fact that no truly natural inertial motion has been observed or will be observed—a microscopic observation, in fact, would amount to some sort of interaction (force) that in principle alters the inertial system that we were trying to observe while in the macroscopic world gravity is not negligible—voids the Lord Kelvin-Tait's interpretation of any practical application. A conventional choice of a law to measure time should be oriented toward a law that has practical import, as in atomic clocks' oscillations, for example, and not on a law that has an empty set of instances. Moreover, the fact that a uniformly circular motion would also constitute an ideal clock, shows that the existence of an inertial motion is a sufficient but not a necessary condition for the existence of an ideal clock.

The reason for the above digression in the logical relationships between the Law of Inertia and an accurate measure of time is twofold;

(i) As C. Neumann wrote more than hundred years ago, the law of inertia presupposes an understanding of what it means to say that a body with a constant velocity covers the same distances in *equal intervals of time.*[44] I therefore submit that an additional reason that Newton had to postulate an absolute clock lies in the attempt to avoid construals of the first law that would transform it into a definition, as in 'equal times'$=_{def}$ 'times marked by an inertial particle travelling equal distances'. By having an absolute time independent of any motion (we have shown, furthermore, that an absolute uniform clock does not necessarily presuppose an inertial motion), *Newton had independent grounds for the empirical meaningfulness of his first law.*

(ii) Considerations of the logical status of the law of the inertia suggest by analogy a reading of the status of absolute time as the quantity measured by *the limit* of the various more or less accurate sensible measures (motions) that we use to gauge absolute time in Newton's sense. It is important to note that the concept of limit in question is not the mathematical one given by calculus and developed by Cauchy in the 19th century by using the celebrated ε-δ language. The concept of 'limit' in the sense in which I use it here is rather a *Grenzbegriff,* an ideal type in Max Weber's sense, an ideal mathematical parameter or paradigm which is true only in a model, something that, however, might have been suggested to Newton by the mathematical theory of converging series. In the sense suggested here, the limit could be the point of accumulation or convergence of a sequence of measures.

To motivate this analogy between the absolute, true, mathematical time and the limit of a sequence of measures, let us go back to the Scholium one more time: in the seventh paragraph, Newton explains that it could be the case "that there is no body really at rest, to which the places and motions of others may be referred" (*Fieri etenim potest, ut nullum revera quiescat corpus, ad quod loca motusque referantur*). This assertion, together with the admission that all motion can be accelerated or retarded (no uniform velocity), yields the result that it is possible that no material body obeys the law of inertia!

The first sentence in fact entails the possibility that everything truly moves and the second recognizes that possibly everything is accelerated. From this it follows the well known fact that the law of inertia has to be expressed by a conditional statement: . . . unless it is forced to change its state by an impressed force ("*nisi quatenus a viribus impressis cogitur statum illum mutare*").[45] Now, given that the conditional clause is very probably false—there is no system of body isolated from any force because any two particles are subject to Newton's gravitational force—the law of inertia seems to be an idealization of a situation that in nature does not physically realize itself. We can imagine slowly removing the resistance of the air in an experiment in which we shoot a projectile (to use Newton's example). If we keep on reducing progressively the resistance of the air, the parabolic trajectory of the projectile will resemble more and more a straight line, until, *at* *the limit*, the projectile would continue to move in a straight line with uniform speed.

I claim that the same reasoning can be applied to the relationship between the sensible measures of the absolute rate of flow and the rate itself, so that we find a way of defining the metric of absolute time as the quantity measured by the limit or converging point of the various motions that we use to measure time.

For the sake of clarity let T be the absolute time, Barrow's straight line with the topology of the real numbers. Let p and q be any two points of T. Any "sensible measure" of T is a real-valued function $\mu: T \rightarrow \mathbb{R}$ such that for any p, q such that $p < q$, $\mu(p) \leq \mu(q)$.[46] Let us now enumerate and order all our functions μ_i, the μ_is representing motions that measure absolute time with different degrees of accuracy: $\mu_1, \mu_2, \mu_3 \ldots, \mu_n$ The criterion for ordering the various functions is the regularity of the motion: we intuitively know what it means for one motion to be more regular than another. It is enough to use a conventionally chosen, temporarily adopted clock to measure two successive periods of any two motions.

To be vivid, we can start saying that Newton's heartbeat represents the measure μ_1, his sun dial is μ_2, etc, . . . till μ_n, which is the astronomical time obtained through the correction equation. The measures in question will have to be fractions, to keep in line with Newton's fluxional definition of a limit as an ultimate ratio of 'evanescent increment'. So for any given four points in T, p, q, r, s, the n real numbers which represent the values of the various μi will be given by the formula $(\mu i(q)-\mu i(p))/(\mu i(a)-\mu i(r))$.

Even if no one of these motions accurately measures the rate of the equal flow of absolute time, we can say that by observing the character of 'the ideally converging series', we define the rate of the equal flow as the rational number to which the series would converge had we more and more precise measures—regular motions—to add to the series. The analogy between our interpretation of the law of inertia as the idealized limit of experimental situations and the metric of absolute time is now complete.[47] The intrinsic metric of absolute time is the convergence point of the ordered series formed by the various sensible measures of time that we commonly adopt.

To summarize my interpretation of the Scholium in a word, I

could say that the practical fact that we can always improve the precision of our instruments, in particular, clocks, could be a reason that led Newton to postulate his theory of absolute time: counterfactually, *if we had a perfectly inertial motion, we could measure the equal flow of absolute time.*

The problem with the theory that I have sketched is obviously its textual evidence. Newton never mentions the possibility of ordering the various sensible measures of time in a series possessing a convergence point to be identified with the quantity associated with the absolute flow of time. Though it must be obviously recognized that the interpretation offered here has no *direct* textual evidence, it can *indirectly* be defended in the following way. I submit that my theory can explain Newton's text in such a way that his theory of time becomes reasonable and coherent.

Notice first of all that the above definition reflects and is consistent with Newton's distinction between observable motions as sensible measures and absolute time as the measured quantity itself (paragraph 13). The various μ_i are what we ordinarily call times (sensible measures), while the quantity denoted by the limit is the real, mathematical rate of flow of time, Barrow's absolute Quantum.

My interpretation also explains the gist of Barrow's and Newton's realistic attitude toward space and time; if we can measure some quantities, the quantity measured (time) must exist. If the limit to the sequence of measure exists, then absolute time exists. Moreover, we can always find at least an abstract measure μ^* which yields the desired limit. It might well be the case that no real motion, as Newton said, can be associated with μ^*. In a more qualitative way, Gassendi had already defined the relationship between time and its measure in the following way:

> From these considerations it does not appear that time is something dependent upon motion or subsequent to it, but something indicated by it as the measured thing is indicated by its measure.[48]

Finally, and more importantly, there is some important evidence that we must try to explain the fluxional and mathematical aspect of time as they are theorized in Newton's Scholium by taking into account his calculus of fluxions, something that helps to establish a deep relation between the idea of a mathematical limit of a series and absolute time as something which corresponds to the measure of the 'evanescent increments'. As Bellone has recently pointed out (1989), in order to understand Newton's theory of time in the *Principia*, we must look outside them, and precisely in his *Tractatus de methodis serierum et fluxionum* (Whiteside 1969).

In this treatise, which Newton composed in the winter of 1670-1671, Newton makes it clear that time cannot be considered in its merely formal aspect of being a parameter in the expression of laws of nature. Time is a mathematical entity measuring the fluxions (*fluxiones*), that is, the instantaneous velocity of flux of a class of dependent variables (*fluentes*) whose magnitude varies continuously. These variables are treated by Newton as points describing or generating a curve with their continuous motion. Newton's problem was therefore that of characterizing time as something different from the vulgar time employed in ordinary language (year, day, etc.). *The mathematical time so distinguished is generated by a continuous flux of one of these points and is a condition for the application of his method of fluxions to determine instantaneous velocities.*

The absolute mathematical time is therefore postulated for the application of the infinitesimal calculus to physics and is obviously part of a mathematical modeling of nature. More precisely, Newton presupposes that one of the variables that he considers, an arbitrarily selected mathematical point, moves uniformly, and is therefore a measure of the motion of any other fluent variable (Whiteside 1969: 70 ff). Newton in fact claims that moments are "indefinitely small parts" of fluent quantities, so that these quantities grow thanks to the addition of moments, which then are linked to the velocity of growth.

These observations should make my proposed interpretation of the relationship between time, inertial or ideal measure of motion look much more plausible.

Coda on Leibniz-Clarke

The argument that Clarke used against Leibniz according to which absolute space and time are real because we can measure them, while order and succession are not quantities, would have been effective only if he had indicated a concrete way to measure the absolute flow, something that Clarke did not do. He just repeated Newton's argument: something that possesses the attribute of objective magnitude and number has to exist.

Leibniz on his part seemed to realize that the idea of order by itself does not provide a way of measuring time when he writes: "I answer that order also has its quantity; there is in it that which goes before, and that which follows; there is distance or interval."[49] But this answer seems to concede Clarke's point. The concept of interval between two events ordered by the relation before or after is in fact compatible with an absence of change in the interval and a consequent flow of empty time. Clarke could then object: *what* do you measure when you are referring to the interval between two events? If you assign a quantity to the interval you are thereby denoting something; you are referring your measure to something that has to exist. If we have a movie that correctly shows all the successive states of the world, that is, its order, according to Leibniz's definition, we are still free to roll it with any speed we want. The reintroduction of the concept of interval already presupposes a reference to an objective feature of the world: its duration. Unfortunately, Leibniz did not live long enough to develop a more coherent view on this point.

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NOTES

1. In this debate, the theory according to which space and time are independently existing entities (substantivalism) is contrasted with the theory according to which they are relations derivative on physical events and objects (relationism).

2. Barrow, I. "Lectiones Geometricae," quoted in Capek 1975: 203.

3. See for instance Jammer 1954, Westfall 1964, Power 1970, and Mamiani 1980.

4. I owe this expression to Whitrow 1980: 42.

5. Quoted in Earman 1989: 25.

6. Descartes had already pointed out that this durational aspect is not captured by the state of motion of an object: "If there are two bodies moving for an hour, one slowly and the other quickly, we do not reckon the amount of time to be greater in the latter case than the former, even though the amount of movement may be much greater." (Descartes 1985, vol 1: 212).

7. *Ibid.*

8. For Descartes' debts to the scholastic tradition (and vocabulary), in spite of his innovative intentions, see Gilson 1976.

9. Descartes 1985: 212.

10. See Newton's Scholium: "The duration or *perseverance of the existence of things* remains the same, whether the motions are swift or slow, or none at all . . ." (my emphasis, quoted in Earman 1989: 25)

11. Descartes 1985, vol. II: 33.

12. Descartes 1985, vol. I: 214.

13. The faith in a universe ordered by the will of God was, according to some historians of science, one of the most important presuppositions of the western scientific revolution. Whitehead (1925) is an initiator of this historiographical thesis, which for Needham also explains why the scientific revolution did not originate in the east.

14. This suggestion presupposes something that Descartes takes for granted, that is, that the identity of any object is preserved over time.

15. The possibility of finding an instant between any two ordered instants is guaranteed by what mathematicians call density.

16. For Maimonides on time and in general for Islamic Occasionalism, see Sorabji 1983.

17. Descartes doesn't deal at all with the problem of the absoluteness of time in this sense. He simply seems unaware of the problem,

but we can reason by analogy with space and conclude that if he were asked, he would have probably said that time cannot exist without reference to something else.

18. This is a famous sentence of the 1651 edition of the Leviathan, in Hobbes 1839, vol. 3: 15.

19. Endorsed by Galileo, Gassendi, Boyle, Descartes, and Locke.

20. I am referring here to the famous and influential quote of Augustine: "Quid est ergo tempus? Si nemo ex me querat, scio, si quearenti explicate velim, nescio" in Confessiones, xi, 17. See also Barrow's quotation in this paper.

21. See Hobbes 1839, vol. 1, 95.

22. Spinoza thought that it is only with the imagination, an inferior source of knowledge, that we attribute or determine past present and future: "Rerum existendi tempora sola imaginatione determinamus" (Spinoza 1915, Part IV, Scholium to prop. LXIII, 233). Our reason grasps the authentic nature of things *sub specie aeternitatis*.

23. Galileo says: "La filosofia è scritta in questo grandissimo libro che ci sta aperto innanzi agli occhi (io dico l'universo), ma non si può intendere se prima non s'impara a intender la lingua, e conoscer i caratteri ne' quali è scritto. Egli è scritto in lingua matematica, e i caratteri son triangoli, cerchi ed altre figure geometriche, senza i quali mezi è impossibile a intenderne umanamente parola; senza questi è un aggirarsi vanamente per oscuro laberinto." (Galilei 1890-1907, VI: 232).

24. On this point I am indebted to Capek's analysis (1975).

25. The opposite conception is God as "the Eternal Now." See below.

26. Gassendi 1568, vol 1.

27. See Capek's translation of the *Syntagma* (1975: 195).

28. Barrow says: "whether Things move on or stand still; whether we sleep or wake, Time flows perpetually with an equal Tenor," in Capek 1975: 204. See with this regard Rochot 1956.

29. Capek 1975: xxxiii.

30. Translation of Newton 1822: 8.

31. See Duhem, P. *Le Systeme du Monde*, Hermann, Paris, 6956, VII, p. 439-441, transl. in Capek, M, op. cit, The Problem of Absolute Clock, p. 185-6.

32. See the Scholium reported in Earman 1989, Appendix: 25.

33. Ibid.

34. See seventh paragraph of the Scholium, ibid.

35. Also Grünbaum supports this interpretation (1963:4-8).

36. Because of imprecisions in the calculation of the distance between the earth and the moon, he had to wait 21 years before publishing his theory of gravitation!

37. Whitrow writes: "Indeed, just as Newton's philosophy of space derives from the Cambridge Platonist Henry More, so his philosophy of time derives from Barrow, whose lectures he attended whilst a student."(1980: 130).

38. Barrow I, "Lectiones geometricae," translated in Capek 1975: 204.

39. Capek 1975: 208.

40. A sort of moving-now conception of time ante-litteram. For this conception, see, for instance, Horwich 1987: 15 -27.

41. Thomson W. and Tait P. G. 1890: 241.

42. Whitrow 1980: 45.

43. Clearly, a periodical, uniform circular motion of—say—a hypothetical star, would score much better for practical uses.

44. Capek 1975: 233.

45. Newton 1822: 15

46. The equality sign guarantees the possibility of empty time between p and q in which case $p = q$.

47. The definition of probability as the limit of the observed frequency in the frequency theory of probability would be another interesting example. See, for example, Reichenbach 1949.

48. In Capek, op. cit., p. 200.

49. Alexander 1984: 75.

Naturalizing Kant

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Introduction

In my experience, the typical philosophy student approaching *The Critique of Pure Reason* for the first time encounters particular difficulties with two of Kant's doctrines. The first concerns space, the second, the relationship between phenomena and noumena.

The student is puzzled by Kant's doctrine concerning space because she can only judge it in terms of her common sense epistemology ("The world is as it appears to be"). By the time a student starts to read the first critique this naive realism has been sophisticated to some degree by her study of Descartes and Locke. Her common sense (under the influence of Descartes) has now adopted an epistemology which declares that mental or phenomenal representations of the world reproduce reality without altering it. According to the Descartes of the First and Second Meditations, we may be fooled by our dreams or the demon (into believing that tables and chairs, etc., exist when they do not) but the mechanism of sense perception does not alter reality in any way when it reproduces it "in the mind" in the form of ideas or phenomenal representations. Later, in the Sixth Meditation, Descartes makes it clear that our confidence (that our perceptions of objects reproduce those objects as they actually are in reality) should be confined to those aspects of the objects we perceive which are susceptible to mathematical measurement. This Cartesian version of common sense assumes an ontology in which the familiar objects that we sense are thought to exist in Euclidean space whether or not there are observers present.

The student's common sense under the influence of Locke makes explicit what is already implicit in the Cartesian picture of the world. Objects in the world really do have length and breadth etc.,