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The History of the Concept of Distant Simultaneity

Although ancient and modern theories of space and time have been the subject of numerous detailed historical investigations, the conceptual development of one notion, included in all these theories, seems never to have been studied heretofore, and this in spite of the fact that precisely this notion is the object of a wide-spread controversy in current physical and philosophical discussions.

It is the notion of *intrasystemic simultaneity of distant events*, that is the relation of contemporaneousness of spatially separated events within one and the same space-time reference frame, in contrast to intersystemic simultaneity, the contemporaneousness of events with respect to different reference frames. Our notion has, therefore, nothing to do with the relativistic time dilatation or with the relativity of temporal intervals and temporal order. In fact, since from here on I shall never make reference to intersystemic simultaneity I shall omit the term « intrasystemic » in the sequel and sometimes even the term « distant » for the sake of brevity.

Let me first stress, without entering into details, the non-triviality of the notion of simultaneity and its importance in philosophical and physical thought.

Although the idea of an all-pervasive « now » is probably as old as human thought, an explicit mention of the simultaneous occurrence of two distant events seems never to have been made in pre-Aristotelian literature. In Biblical Hebrew, for instance, which acknowledges only two tenses, past and future, there is no term to express such a relation.

The Greek word ἅμα (hama), etymologically related to the Sanscrit « sem », the Latin « simul », meant originally « being together », not necessarily in the temporal sense.

Aristotle, in his theory of time, was probably the first to feel that the use of the notion of distant simultaneity needs some justification. The Aristotelian and scholastic explication of this notion, based on a reference to a common time-determining factor was, as we shall see, in principle the same as the Newtonian explication, the difference being only that in the former the *tertium comparationis* was a cosmic process while for the latter it was an absolute entity.

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The earliest explicit analysis of simultaneity was given by Leibniz who defined it in terms of an absence of causal connectibiliy. But since causal connectibility was for Leibniz an instantaneous actual or potential action, his analysis was logically circular. In any case, the Newtonian dogma in an objective meaning of simultaneity prevailed until the beginning of the present century.

" It was the great achievement of Einstein in the field of the theory of knowledge that he banished this dogma from our minds " wrote Hermann Weyl (1).

Einstein's operational definition of distant simultaneity, which was to play an important role in his derivation of the Lorentz transformation and hence in his establishment of special relativity, was soon regarded, rightly or wrongly, as being merely a convention. According to the conventionality thesis, proposed primarily by Reichenbach and Grünbaum, no epistemological criteria or no ontological data exist for a *unique* determination of distant simultaneity. The controversy between proponents and opponents of this thesis constitutes a dramatic chapter in the history of modern physics. These introductory remarks were made only to show that the concept of distant simultaneity fully deserves to be studied in its historical perspective.

Let me then start by pointing out that, if notions like " the present " or " now ", as usually employed, denote sets of simultaneous events, then we find that our concept can be traced back to antiquity. Thus, for example, Damascius, the famous Neo-Platonist and head of the Academy of Athens before it was closed by the Emperor Justinian in 529 A.D., is reported to habe said: ἄλλοις γοῦν ἄλλος ὁ ἐνεστώς (" different people have a different present ") (2).

Can Damascius' statement be regarded ad an anticipation of the modern conventionality thesis of distant simultaneity? To answer this question it is worthwhile to recall certain facts in the history of physics intimately related with our topic.

As is well known, in contrast to Empedocles' argument for a finite velocity of light, Aristotle taught that light is not a gradually progressive process with a finite velocity of propagation, but rather an instantaneous qualitative change of the medium. It is a kind of change, he said, which conceivably takes place in a thing all at once without that one half of it changes before the other, as e.g. water freezes instantaneously in all its parts. ἐνδέχεται γὰρ ἀθρόον ἀλλοιοῦσθαι, καὶ μὴ τὸ ἥμισυ πρότερον οἷον τὸ ὕδωρ ἅμα πᾶν πήγνυσθαι (3).

This Aristotelian doctrine of the instantaneous propagation of light prevailed throughout antiquity and the middle ages. It was supported *e.g.* by Aurelius Augustine (354–430) in his *Epistola ad Deogratias* (4) on the ground that if light had a finite velocity of propagation and if an extended landscape is viewed by the eye or suddenly illuminated, near objects would be seen prior

(1) H. WEYL, *Space, Time, Matter*, Methuen, London 1922, 174.
(2) *Simplicii in Aristotelis Physicorum libros quattuor priores commentaria*, Reimer, Berlin 1882, 798, line 8-9.
(3) ARISTOTLE, *De Sensu*, 446 b 27 – 447 a 3.
(4) J. P. MIGNE, *Patrologia latina*, vol. 33, Paris 1945, col. 372.

to far-away objects, in contrast to experience. It should be mentioned that this argument was severely challenged by Blasius of Parma (Biagio Palacani da Parma, d.c. 1416), who taught at Bologna, Padua and Florence, by pointing out that " antequam diriges oculum ad ista obiecta, diffusae erant species istorum obiectorum usque ad oculum " (" before you directed your eye toward those objects, their species (radiation) were diffused to the eye ") (5).

On the assumption of a finite light velocity any perceived configuration of moving objects, like that of a stellar constellation, is always a « retarded », and hence distorted, image of reality, more distant objects appearing at positions earlier occupied. But if the velocity of light and that of the objects are known, one could in principle reconstruct the situation as it really is at the moment of perception, by mathematical calculation.

Let me remark in parentheses that such a reconstruction requires knowledge of the relevant *one-way* velocities which according to the conventionality thesis are never convention-free. It thus follows from this thesis that man can never know the " true " or factual simultaneous positions of moving bodies in his near and distant surroundings. It looks almost as if Blasius was aware of this conclusion when he wrote: " Si visio non fieret subito, sequitur quod astronomus non posset deprendere verum locum astri " (" If visual perception is not instantaneous, it follows that the astronomer can never obtain the true location of a star ") (6).

In any case, Blasius could not yet have known whether light propagates instantaneously or with a finite velocity. Only 250 years after his death did Olaf Romer (1644–1716), in 1676, succeed to measure the velocity of light. Let me point out, again in parenthesis, that Romer did not measure the one-way velocity of light although his astronomical method made use of only one clock.

What has all this to do, you may ask, with the notion of simultaneity? The most pungent answer was given in 1928 when Arthur Stanley Eddington (1882–1944) wrote what is one of the most profound statements in the philosophy of physics: " Time, as we now understand it, was discovered by Romer " (7).

In order to fully understand the issue under discussion in its historical perspective we have to go back to Aristotle and his definition of time.

In chapter 10 of Book IV of his *Physics* he presents his famous theory of time which he defined: *τοῦτο γάρ ἐστιν ὁ χρόνος, ἀριθμὸς κινήσεως κατὰ τὸ πρότερον καὶ ὕστερον* "This, then, is time: the number of motion with respect to before and after" (8).

He also discusses in this context the role and nature of the "now" (τὸ νῦν) which appears to divide the past and the future, but he is primarily

(5) G. F. Vescovini (*ed.*). " Le questioni di ' perspectiva ' di Biagio Pelacani da Parma ", *Rinascimento*, *1*, 1961, 221.
(6) *Ibidem*, f 40 v b.
(7) A. S. Eddington, *The Nature of the Physical World*, Cambridge University Press, Cambridge Mass. 1928, 43.
(8) Aristotle, *Physica*, Book IV, 219 b 1-2.

interested in the question whether this "now" is always one and the same or whether it is continuously changing. Aristotle's "now" here is not the extended " present " but rather the point-like " now " of one who counts motion or time and, so to say, carries it in himself forward through the " flow " of time. In fact, this " now " is not part of time at all: τὸ δὲ νῦν οὐ μέρος (9).

But in another passage Aristotle declares that time is ubiquitous and unique in the sense of being the same for all who count or measure it. " Movement or change is in the moving or changing thing itself or takes place only where that thing is; whereas the passage of time is current everywhere and in relation with everything "; ὁ δὲ χρόνος ὁμοίως καὶ πανταχοῦ παρὰ πᾶσιν (10).

The idea of a distant simultaneity seems to be in his mind only when he says at the end of this chapter: τῶν ἅμα περαινομένων ὁ αὐτὸς χρόνος (" Of all moments determined together the time is the same ") (11).

Aristotle does not tell us how to understand the term ἅμα (together) in this context. If we take it as synonymous with " simultaneously " the statement becomes a pleonasm.

Let us call vision, that is " to see " or " to be seen ", perception or similar processes which in Aristotelian physics are instantaneous, briefly " interactions ". Two events, observations etc. are ἅμα (" together ") just in case they interact with the same part or phase of the celestial motion the number or measure of which determines time.

The above-quoted statement then says: two phenomena or events, which are ἅμα (" together ") in this sense, are simultaneous.

Whether Aristotle had really this in mind or not, Avicenna (Ibn Sina) (980–1037), in his *Sufficientia*, gives precisely this interpretation (12).

Subsequently, Averroes (Ibn Rushd), the great commentator of Aristotle, generalized this idea by pointing out that, instead of observing the celestial motion, every terrestrial motion can be used for this purpose. Albertus Magnus (1200–1280) endorsed this generalisation on the ground that " hic motus (primi mobilis) percipitur in omni motu sicut causa in suo effectu " (13).

Finally, Thomas Aquinas (1225–1274), in his *Sententiae*, includes even the observer as human being in the range of possible objects for the determination of simultaneity, since « sentimus tempus secundum quod percipimus nos esse in esse variabili ex motu caeli " (" We feel the time in accordance with perceiving in ourselves the change caused by the motion of the heavens ") (14).

According to certain interpreters Aristotle in said to have defined the simultaneity of temporally extended phenomena or events as follows: two such

(9) *Ibidem*, 218 a 7.
(10) *Ibidem*, 218 b 13–14.
(11) *Ibidem*, 223 b 6–7.
(12) Cf. A. Mansion, " La théorie aristotélicienne du temps chez les péripatéticiens médiévaux ", in *Festschrift für De Wulf*, Louvain 1934, 275–307.
(13) A. Magnus, *Commentarii in Physica*, Book IV, tract. 7, cap. 4.
(14) Th. Aquinas, *Sententiae*, Book 1, dist. 19, quaestio 2, articulum 1.

events are simultaneous if they are, so to say, cut by the *same* " now ". This definition, however, seems not to be adequate. For even if we allow, contrary to common usage especially in physics, events to be temporally extended, the definition is circular. In order to cut distant events the " now " has itself to be spatially extended, a property which presupposes distant simultaneity (15).

The Aristotelian and scholastic philosophy of time based its notion of distant simultaneity on the instantaneity of interactions and on the unity of time. If we employ the expression " spreading time over space ", coined by Percy Williams Bridgman (1882–1961), we can say that in Aristotelian and scholastic physics time was spread over space by an instantaneously operating mechanism composed of visual perceptions, or what we have called " interactions ", with the celestial sphere or with other motions regulated by it.

Two pieces of information are still required in order to understand what Damascius meant when he said, as mentioned before, that " different people have a different present ". The first point is this.

The relation of distant simultaneity allows to define the " present " as the set of all those events which are simultaneous with a certain event in the individual " now ". The second item is this. Damascius denied the pervasiveness of a global causality and adopted, instead, an extreme egocentrism according to which the division of time into past and future is merely relative to us (πρὸς ἡμᾶς) so that everybody can put the " now ", separating the past from the future, where ever he likes. Damascius' statement is a logical consequence of the combination of these two ideas.

I have deliberately used some modern terminology in the description of Damascius' reasoning in order to emphasize its similarity with the conventionality thesis. For this thesis, expressed in technical language, claims that the hyperspace of simultaneity to the inertial trajectory or world-line of an observer at a given point or given value of his proper time can be constructed with a large extent of arbitrariness. But, of course, the justification of the arbitrariness involved is a different one in each of these two cases.

The transition from the scholastic to the Newtonian conception of distant simultaneity, a transition mediated by the Italian natural philosophers Bernardino Telesio (1509–1588), Franciscus Patritius (1529–1597), and Tommaso Campanella (1568–1639), and subsequently by Pierre Gassendi (1592–1655), proceeded smoothly without major changes. For the notion of distant simultaneity continued to be based, as it had been already in Aristotelien physics, on the assumption of an instantaneous connection in nature. It was only the nature of this instantaneous connection which changed.

When Gassendi stated: " Quodlibet temporis momentum idem est in omnibus locis " (" Every instant of time is the same everywhere ") (16), he would

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(15) See *e.g.* R. Torretti, *Relativity and Geometry*, Pergamon Press, Oxford 1983, 220.
(16) P. Gassendi, *Opera Omnia*, Florence 1728, 198.

probably still have repeated the scholastic argument had he been called upon to justify his words.

But when Isaac Newton (1642–1727) declared: " [...] unumquodque durationis momentum per universa spatia " (" [...] every moment of time is diffused throughout all spaces ") or " Idem est durationis momentum Romae et Londini [...] ") (" An instant of time is the same in Rome and in London [...] "), as he did in his "*De Gravitatione et Aequipondio Fluidorum*" (17), written between 1664 and 1668, or when he declared in the General Scholium, Book III of his *Principia*: " Unumquodque durationis indivisible momentum *ubique* " (" Every indivisible moment of duration is *everywhere* ") (18) his reasoning was different.

Instead of invoking an almost astrological instantaneous global connection with the rotating celestial sphere as done previously, Newton could have used the newly discovered instantaneous gravitational interaction as a mechanism of spreading time over space. Still Pierre Simon Laplace (1749–1827) thought to have proved that gravitation propagates at least 50 million times as fast as light (19).

But Newton, viewing absolute space and time as attributes of God, had no need of such an argument. For God, " in whom are all things contained and moved " (" In ipso continentur et moventur universa ") and who " endures for ever and is everywhere present " and who, " by existing always and everywhere constitutes duration and space" (20), was for Newton the ultimate justification of the concept of distant simultaneity. For once the absoluteness of time was thus recognized, two events could be defined as " simultaneous " if they occur at the same moment of absolute time.

When it was realized, in the 19th century, that one has to demetaphysicize Newton's absolute time in order to make it operationally meaningful, recourse was taken to dynamical principles, such as the First Law of Motion. Thus, for example, Carl Neumann (1832–1925), in his influential work " Über die Principien der Galilei – Newtonschen Theorie " (Teubner, Leipzig, 1870), reasoned as follows. If according to the Law of Inertia a free particle, moving along a graduated straight line, traverses equal distances in equal times, it is possible, to construct an inertial-motion clock which defines time in terms of the distance marks, passed by a body in inertial motion. Neumann did not notice that his clock defined only local time, namely only that of the place where the moving particle happens to be. Also Ludwig Lange (1863–1938) and even Ernst Mach (1838–1916) who, like Neumann, tried to metaphysicize Newtonian time, were

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(17) Cf. A. R. Hall, M. B. Hall (eds.), *Unpublished Scientific Papers of Isaac Newton*, Cambridge University Press, Cambridge Mass. 1962, 104.

(18) *Newtoni Opera* (ed. Horsley), vol. 3, 8; *Newton's Principia* (ed. F. Cajori), University of California Press, Berkeley 1947, 545.

(19) For the error underlying Laplace's calculation see W. Wien, " Über die Möglichkeit einer elektromagnetischen Begründung der Mechanik ", *Recueil de travaux offerts par les auteurs à H. A. Lorentz*, Nijhoff, The Hague 1900, 96–107; reprinted in *Ann. Phys.*, *5*, 1901, 501–513.

(20) *Newton's Principia*, *quot.*, 545.

still captivated by the Aristotelian-Newtoninan dogma of the instantaneous ubiquity of time.

Before we discuss present-century conceptions of distant simultaneity which no longer are subjected to the Aristotelian-Newtonian presupposition, we have to mention an early 18th century definition of simultaneity which already was free of that presupposition. It was introduced by Gottfried Wilhelm Leibniz (1646-1716), who rejected Newton's theory of absolute time and proposed, instead, was is called the causal theory of time. In his *Initia rerum mathematicarum metaphysica*, written about 1715, Leibniz defined time as " the order of things which are not simultaneous " (" tempus est ordo existendi eorum quae non sunt simul ") and temporal order by stating that " if one of two states which are not simultaneous involves a reason for the other, the former is held to be *prior*, the latter *posterior* " (" si eorum quae non sunt simul unum rationem alterius involvat, illud prius, hoc posterius habetur ") (21). Briefly, propter hoc, ergo post hoc.

The definitions of " time " and " temporal order " presuppose, as we see, the notion of " simultaneity ". To avoid a vicious circle, " simultaneity " must be defined by something logically prior to " time ". Leibniz's definition " Si plures ponantur existere rerum status, nihil oppositum involventes, dicentur simul ", which *verbatim* seems to apply to different states or properties of one and the same object, must nevertheless also be interpreted as follows: two events which are not causally connected are simultaneous. Leibniz defined, indeed, " simultaneity " in these words: " Si plures ponantur existere rerum status, nihil oppositum involventes, dicentur simul " (" If several states of things are supposed to exist, which do not involve opposites, they are said to be simultaneous ").

" Nihil oppositum involventes " may refer to properties of one and the same object, in which case the simultaneous presence of different properties in the same object would be defined; or it may be interpreted somehow as implying that no oppositely directed causal efficacies are active, neither from a first to the second nor from the second to the first. Immanuel Kant, who in principle endorsed the causal theory of time, wrote in his *Critique of Pure Reason* (1781, 1787), Book II, Section 3, under the heading " Principles of the Succession of Time, according to the Law of Causality ":

> Damit das objektive Verhältnis [einander folgender Erscheinungen] als bestimmt erkannt werde, muss das Verhältnis so gedacht werden, dass dadurch als notwendig bestimmt wird, welcher derselben vorher, welcher nachher, und nicht umgekehrt, müsse gesetzt werden. Dieser Begriff aber, [...] ist der Begriff des Verhältnisses der Ursache und Wirkung, wovon die erstere die letztere in der Zeit, als die Folge [..] bestimmt (22).

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(21) G. W. Leibniz, *Mathematische Schriften*, ed. J. C. Gerhardt, Halle 1860, vol. VII, 17-29.
(22) I. Kant, *Kritik der reinen Vernunft*, J. F. Hartknoch, Riga 1787-, 234.

In the subsequent section, entitled "Principle of Coexistence, according to the Law of Reciprocity or Community" ("Grundsatz des Zugleichseins nach dem Gesetze der Wechselwirkung oder Gemeinschaft"), Kant proposed a criterion of simultaneity as follows:

> Nun ist aber das Verhältnis der Substanzen, in welchem die eine Bestimmung enthält, wovon der Grund in der anderen enthalten ist, das Verhältnis der Gemeinschaft oder Wechselwirkung. Also kann das Zugleichsein der Substanzen im Raume nicht anders in der Erfahrung erkannt werden, als unter der Voraussetzung einer Wechselwirkung derselben untereinander [..] (23).

Kant, interestingly, explains his criterion by pointing out "dass das Licht, welches zwischen unserem Auge und den Weltkörpern spielt, eine mittelbare Gemeinschaft zwischen uns und diesen bewirken, und dadurch das Zugleichsein der letzteren beweisen [...]" (24).

The causal theory of time, as we see, offered two criteria of distant simultaneity: 1) the Leibniz criterion: events x and y are simultaneous if neither x is the cause of y nor y the cause of x; 2) the Kant criterion: events x and y are simultaneous if both x is the cause of y *and* y the cause of x. Obviously, once physics imposes a finite upper limit to the propagation velocity of causal efficacy, Kant's criterion will have to be given up and only Leibniz's criterion will survive.

After this digression let us continue the account and turn to the 20th century which, also with respect to our notion, has been greatly influenced by Albert Einstein. The first theoretician to stress the conventionalistic aspect of distant simultaneity was Henri Poincaré (1854–1912). In a paper entitled "La mesure du temps", published in 1898, he declared:

> La simultaneité de deux événements, ou l'ordre de leur succession, l'égalité de deux durées, doivent etre définies de telle sorte que l'énoncé des lois naturelles soit aussi simple que possible. En d'autres termes, toutes ces règles, toutes ces définitions ne sont que le fruit d'un opportunisme inconscient (25).

As is well known, Poincaré anticipated quite a few of Einstein's ideas and came tantalizingly near to establishing the theory of relativity. But, mathematician as he was, he failed to see the physical implications and to draw the corresponding conclusions. This applies also to Poincaré's anticipation of Einstein's definition of simultaneity, which Einstein proposed in his monumental paper of 1905, entitled "On the electrodynamics of moving bodies" (26).

It took only a few weeks for Einstein to write this paper, which establishes almost the whole special theory of relativity; but it took a long time until he found the weak spot in Newtonian physics, until he realized — as he put it

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(23) *Ibidem*, 257–258.

(24) *Ibidem*, 260.

(25) H. Poincaré, "La mesure du temps", *Revue de Métaphysique et de Morale*, *6*, 1898, 1–13; *The Foundations of Physics*, The Science Press, New York 1913, 223–234, reprinted in M. Capek (*ed*), *The Concepts of Space and Time*, Reidel, Dordrecht 1976, 317–327.

(26) A. Einstein, "Zur Elektrodynamik bewegter Körper", *Ann. Phys.*, *17*, 1905, 891–921.

to his friend Michelangelo Besso — that " time is the suspect ". In fact, a close study of the paper shows that it was precisely Einstein's operational definition of intrasystemic distant simultaneity which, in conjunction with the relativity and light postulates, enables him to derive the Lorentz transformation and thereby the whole theory of special relativity. That, indeed, the notion of distant simultaneity played the key role in his work has been best emphasized by himself in a talk " How I created the theory of relativity " which he gave on 14 December 1922 at Kyoto University in Japan (27).

Said Einstein:

> An analysis of the concept of time was my solution. Time cannot be absolutely defined, and there is an inseparable relation between time and signal velocity. With this new concept I could resolve all the difficulties completely for the first time.

In the very first section (of his paper) entitled " Definition of simultaneity ", Einstein stated:

> We have to take into account that all our judgements in which time plays a part are always judgments of *simultaneous events*. If, for instance, I say, ' That train arrives here at 7 o'clock ', I mean something like this: ' The pointing of the small hand of my watch to 7 and the arrival of the train are simultaneous events '.

Leopold Infeld once called this " the simplest sentence I have ever encountered in a scientific paper " (28).

Simple as it is, the sentence has far-reaching consequences. First of all, by insisting on the priority of events it renounces Newton's theory of absolute space and time according to which time is ontologically and logically prior to events; it reduces simultaneity to clock synchronization and, consequently, raises the question of how to synchronize spatially separated clocks by means of physical events.

How can a clock at place A, or simply " clock A ", be synchronized with clock B, both at rest in a reference frame F and separated from each other by a distance d? This was the question which Einstein now asked himself. The usual answer would have been this: Send at t_A (A-clock time) a signal with a certain velocity v to clock B; Clock B is synchronized with clock A if it reads (B-clock time)

$$t_B = t_A + \frac{d}{v}$$

at the moment it receives the signal. Einstein realized that this procedure involves a vicious circle, for it assumes that we know the signal velocity v. But to know it, we have to measure it; and to measure it, we have to have two synch-

(27) Cf. T. Ogawa, " Japanese Evidence for Einstein's Knowledge of the Michelson-Morley Experiment ", *Jap. Stud. Hist. Sci.*, *18*, 1979, 73-81; see also *Phys. Today*, August 1982.

(28) L. Infeld, *Albert Einstein, His Work and Influence on our World*, Scribner's Sons, New York 1950, 27.

ronized clocks — just as in the case when we measure the speed of a runner in a race.

Einstein therefore proposed the following procedure:

At (*A*-clock time) t_A clock *A* emits a light signal, the fastest signal known in physics; it arrives in *B* when clock *B* reads (*B*-clock time) t_B, is immediately reflected to *A* where it arrives when clock *A* reads (*A*-clock time) t'_A. Clock *B* is synchronized with clock *A* if $t_B - t_A = t'_A - t_B$ or equivalently

[1] $$t_B = t_A + \frac{1}{2}(t'_A - t_A)$$

This so-called " Einstein-synchronization ", as we see, makes no reference to the velocity of the signal and can be consistently generalized for any number of clocks; for it can be shown empirically to be an equivalence relation, that is, to be reflexive, symmetric and transitive; the set of the equivalence classes thus establishes a common, or universal, or spatially " spread out " time, determined by readings of synchronized clocks. Distant simultaneity can now be defined as follows: A event e_B at place *B* is simultaneous with event e_A at place *A* just in case clock *B*, synchronized with clock *A*, reads, when e_B occurs, the same time as clock *A* reads, when event e_A occurs.

Einstein's simultaneity criterion has far-reaching implications. First of all, it implies the impossibility of ordinary clock transport as a means for establishing distant simultaneity; for otherwise this much simpler method should be used. By a similar token, it implies the impossibility of an infinitely fast causal efficacy, which in turn implies the rejection of Newton's Second Law of motion and the Newtonian velocity-independence of mass, for otherwise it would be possible to impart to a particle an arbitrarily great velocity by applying on it an appropriate force for a sufficiently long time interval. For none of these implications was empirical evidence available in 1908. Clearly, the causality requirement " cause precedes effects " is satisfied since $t_A < t_B < t'_A$ as follows easily from equation [1] and the fact that $t_A < t'_A$.

Let me make a few explanatory remarks at this juncture in order to prevent any difficulties in understanding the sequel. It is easy to see that the causality requirement is satisfied also if instead of the Einstein or standard synchronization expressed by equation [1] we chose a non-standard synchronization in conformance with the equation

[2] $$t_B = t_A + \varepsilon(t'_A - t_A)$$

where ε differs from ½ but lies between zero and unity. In this case instead of $t_B - t_A = t'_A - t_B$ implying that the signal velocity from *A* to *B* is equal to that from *B* to *A*, we obtain

[3] $$t_B - t_A = \frac{\varepsilon}{1-\varepsilon}(t'_A - t_B)$$

implying that the latter velocity is equal to $\frac{\varepsilon}{1-\varepsilon}$ times the former. Were it possible to empirically verify that the velocity from A to B is equal to that from B to A, the Einstein synchronization would no longer be an arbitrary definition but would be a dictate of experience.

Conversely, if the relation of velocities in opposing directions cannot be empirically established, non-standard synchronization will never come in conflict with experience. This, precisely, is the contention of the conventionality thesis of distant simultaneity according to which the choice of the numerical value of ε between zero and unity is merely a matter of convention and not decreed by experience.

Finally, it should be clear that the conventionality thesis implies that, contrary to a round-trip (or to-and-fro) velocity, a *one-way velocity*, whether of light or of any object whatever, can never be measured in a convention-free fashion; for if it could, it could be employed for the synchronization of clocks and would yield a convention-free synchronism, contrary to the thesis.

In fact, the relation between the one-way velocity v, measured by standard synchronization, and the one-way-velocity v_ε, measured by ε- synchronization is given by the equation

[4] $$v_\varepsilon = \frac{cv}{c + v\,(2\varepsilon - 1)}$$

where c denotes the round-trip velocity of light. Clearly, $v_{1/2} = v$.

After the preceding preliminary remarks we are now ready to discuss the history of the conventionality thesis.

In our context it is useful to distinguish between the *precursors*, that is, those who presaged the thesis under discussion or made a statement equivalent to it, but without realizing the import of their announcement or its general significance, and — on the other hand — the actual *originators* who proposed the thesis in full awareness of its implications. The earliest intimation, though only cursorily, seems to have been made by the Canadian-American astronomer Simon Newcomb (1835–1909) when he collaborated with Michelson on measurements of the velocity of light. As we know from his correspondence, in September 1880, shortly before Michelson left for Europe to start his famous interference experiments, designed to measure the ether drift, Newcomb and Michelson had a long discussion about the possibility of measuring this drift by measuring the one-way velocity of light in one direction and in its opposite direction.

The experimental method suggested was similar to that later proposed by Wilhelm Wien (29) and consisted of two identical light sources, two rotating Fizeau wheels and two photometers, one set of them placed opposite the other;

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(29) Cf. W. Wien, " Über einen Versuch zur Entscheidung der Frage, ob sich der Lichtäther mit der Erde bewegt oder nicht ", *Phys. Z.*, *5*, 1904, 585–586; " Experiment to Decide Whether the Ether Moves with the Earth ", *Report of the 74th Meeting of the British Association for the Advancement of Science* (1905), Section a, 433–434. Cf. also A. Schweitzer, „ Über die experimentelle Entscheidung der Frage, ob sich der Lichtäther mit der Erde bewegt oder nicht ", *Phys. Z.*, *5*, 1904, 809–811.

the problem was how to assure that the tooth wheels rotate with the same angular velocity; only an optical control work could do. Newcomb was convinced, as reported by Michelson, that the experiment would fail for " the effect which this method is proposed to measure is exactly the same as the effect on the light which is to furnish the test of synchronism " (30).

Newcomb, in fact, was convinced that it is experimentally impossible to detect a difference between the velocities of two light beams propagating in opposite directions.

In 1898 Poincaré, in his above mentioned essay " La mesure du temps " made a similar, but slightly more general statement:

[...] que la lumière a une vitesse constante et in particulier que sa vitesse est la même dans toutes les directions [...] c'est là un postulat sans lequel aucune mesure de cette vitesse ne pourrait etre tentée. Ce postulat ne pourra jamais vérifié directement par l'expérience [...] (31).

Poincaré did not draw those far-reaching conclusions at which Einstein seven years later arrived; otherwise Poincaré would have been the originator of the special theory of relativity.

Now, recalling Einstein's definition of distant simultaneity or rather synchronization of distant clocks, you probably expect me to say that the first who was fully aware of the conventionalistic character of this definition and should therefore be called the originator of the conventionality thesis, was Albert Einstein (1897–1955). Why, otherwise, would he have underlined the words " durch Definition " (" by definition ") when stating that the equality of the to and fro velocity of light between two points is a matter of " definition ", a point which conventionalists like Hans Reichenbach (1891–1953), Adolf Grünbaum (born 1923) and Wesley C. Salmon (born 1925) become never weary of emphasizing in order to show their backing by Einstein.

True, in his " Autobiographical Notes ", published in 1949, Einstein has written: " There is no such thing as simultaneity of distant events " (" Es gibt keine Gleichzeitigkeit distanter Ereignisse ") (32). But as a close study of his writings reveals, Einstein's position on this issue was somewhat ambivalent — and perhaps justifiably so. In any case, it is far from clear whether in 1905 he used the term " definition " as synonymous with " convention ".

The problem of whether the one-way velocity of light is experimentally measurable became again the subject of a controversy when in 1921 the periodical *Nature* published a special issue on relativity in honour of Einstein's expected visit to England. James Hopwood Jeans (1877–1946), the renown mathematician and astronomer, contributed a paper in which he claimed to demonstrate empirically the isotropy of light propagation, following a suggestion made by Q. Majorana. C. O. Bartrum argued against Jeans that

(30) A. A. Michelson, „ Relative Motion of Earth and Aether ", *Phil. Mag.*, *8*, 1904, 716-719.
(31) H. Poincaré, " La mesure... ", *quot.*, 11.
(32) P. A. Schilpp (ed.), *Albert Einstein, Philosopher-Scientist*, The Library of Living Philosophers, Evanston, Illinois 1949, 61.

[...] the experiment has not yet been devised that will enable a comparison to be made between the velocity of light on its outward and return journey along the same path, or that will give a measure of the velocity on a single journey [...]. I fear such an experiment is impossible (33).

The empirical inaccessibility of distant simultaneity was also cursorily mentioned by the philosopher Herbert Wildon Carr (1857–1931), when on July 13, 1923, he addressed the Durham meeting of the Aristotelian Society (34) in joint session with the Mind Association and the Scots philosophical Club. The meeting which convened to discuss the notorious " twin paradox " of special relativity, was also attended by Alfred North Whitehead (1861–1947) who later, in his *Science and the Modern World* (35), wrote that there is no such thing as " nature at an instant ".

It is interesting that the list of our precursors also includes the mathematician Alfred Arthur Robb (1873–1936) the importance of whose early work — and especially his treatise *The Absolute Relations of Time and Space* (36) — for the construction of causal space-time theories has only recently been fully recognized.

Let us suppose, he wrote, that today I were to observe the outburst of a new star which, in astronomical language, was at a distance of 100 light years, then according to Einstein's view the outburst was simultaneous with terrestrial events which occurred before I was born. It is evident that this could not be a fact of observation, so far as I am concerned: so that it would be incorrect to speak of such events as simultaneous for one observer.

For this reason Robb thought it justified to conclude:

[...] there is no identity of instants at different places at all [...] the present instant, properly speaking, does not extend beyond here (37).

Turning now to what we have called the " originators " of the conventionality thesis, the first who explicity announced this thesis, even though he showed that two apparently independent methods of defining distant simultaneity agree in their results, was the Cambridge astrophysicist Arthur Stanley Eddington (1882–1944). In sections 4 and 11 of the first chapter of his treatsi *The Mathematical Theory of Relativity* (38) Eddington discussed the method of establishing distant simultaneity by slow clock transport as well as Einstein's method and proved that they lead to the same formula. Nevertheless he declared:

We can scarcely consider that either of these methods of comparing time at different places is an essential part of our primitive notion of time in the same

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(33) C. O. Bartrum, " Relativity and the Velocity of Light ", *Nature*, *107*, 1921, 42.
(34) *Aristotelian Society*, *Supplementary Volume* 3, London 1923.
(35) A. N. Whitehead, *Science and the Modern World*, Macmillan, New York 1926, 172.
(36) A. A. Robb, *The Absolute Relations of Time and Space*, Cambridge University Press, Cambridge Mass. 1921.
(37) A. A. Robb, *Geometry of Time and Space*, Cambridge University Press, Cambridge Mass. 1936, 12–13.
(38) A. A. Eddington, *The Mathematical Theory of Relativity*, Cambridge University Press, Cambidge Mass. 1923.

way that measurement at one place by a cyclic mechanism is; therefore they are best regarded as conventional (39).

Subsequently he wrote:

[...] this convention takes in the two alternative forms
1) A clock moved with infinitesimal velocity from one place to another continues to read the correct time at its new station, or
2) The forward velocity of light along any line is equal to the backward velocity. Neither statement is by itself a statement of observable fact, nor does it refer to any intrinsic property of clocks or of light; it is simply an announcement of the rule by which we propose to extend fictious time partitions through the world.

And in a footnote Eddington added:

All experimental methods of measuring the velocity of light determine only an average to-and-fro velocity (40).

It is interesting to note that Eddington insisted on the conventionality of either of these two methods, in spite of their agreement, in contrast to what Brian Ellis and Peter Bowman in 1967 contended when they declared:

[...] the conventionality thesis is false. The existence of two logically independent ways of defining distant simultaneity each of which... appears to define the same relationship of distant simultaneity, provides a good physical reason for adopting one of these definitions (41).

Eddington's conventionality claim, raised within the context of his mathematical treatment of special and general relativity which was studied primarily by physicists not particularly interested in philosophical problem, was not given much attention at his time.

This explains why Hans Reichenbach (1891–1953) is generally credited with having been the first to direct the attention of philosophers of science to the conventionality thesis. Studying Reichenbach's early writings on space and time and the sources to which he referred, we can safely conclude that, rather than Eddington, it may have been Moritz Schlick (1882–1936), the founder of the Vienna Circle who may have prompted him to announce the conventionality thesis (42).

In any case, Reichenbach mentioned the conventionality of distant simultaneity for the first time when he stated, in his *The Theory of Relativity and A Priori Knowledge*.

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(39) *Ibidem*, 15-16.
(40) *Ibidem*, 29.
(41) B. Ellis, P. Bowman, "Conventionality in Distant Simultaneity", *Phil. Sci.*, *34*, 1967, 116–136: 135.
(42) Cf. M. Schlick, "Die philosophische Bedeutung des Relativitätsprinzips", *Zeitschrift für Philosophie und philosophische Kritik*, *156*, 1915, 129–175, where it is written: "... Gleichzeitigkeit an verschiedenen Orten wird niemals unmittelbar anschaulich erfahren, weil mindestens der eine von zwei räumlich getrennten Vorgangen nur durch Vermittlung räumlich-physikalischer Prozesse zu unserer Kenntnis gelangt (Telegraph, Licht, Schall)", ("... Distant simultaneity is never immediately experienced, since at least one of two spatially separated events can reach our knowledge only if it is mediated by intervening spatio-physical processes (telegraph, light, sound)...").

There is [...] a certain arbitrariness (Willkür) contained in any " coordinate time ". This arbitrariness is reduced to a minimum if the speed of propagation of the process is assumed to be constant, independent of the direction, and equal for all coordinate systems (43).

Two years later, in an essay entitled " Der gegenwärtige Stand der Relativitätsdiskussion " (44) in which he rebutted objections raised by Oskar Kraus, Friedrich Lipsius, L. Höpfner, Joseph Petzold and Hugo Dingler, Reichenbach warned:

It would be a mistake to believe that the definition of simultaneity given in the special theory of relativity claims to be " more correct " than any other definition of simultaneity.

The first elaborated presentation of the conventionality thesis is found in his *Axiomatik der relativistischen Raum–Zeit–Lehre* (45).

Reichenbach's motivation for writing this study was the following consideration. Einstein's point of departure in establishing his special theory of relativity was, according to Reichenbach, a philosophical critique of the methods of obtaining physical knowledge. A profound undestanding of this theory requires therefore ana analysis of its epistemological foundations. Such an analysis has to separate empirical or factual content (" Erfahrungsgehalt ") from arbitrary concept-formation (" willkürliche Begriffsbildung ") of the theory which distinction can best be expressed by the differentiation between " Axioms " and " Definitions " in a deductive construction of the theory. For only an axiomatic treatment can fully reveal the logical structure with perfect clarity.

It was in this work where (46) Reichenbach presented Einstein's method by the equation $t_B = \frac{1}{2}(t_A + t'_A)$ and added in a footnote:

Einstein treated definition 8 as a *definition* (convention); he noted, however, that the symmetry and transitivity of the resulting synchronism is not a matter of definition but a *matter of fact*. He is therefore the originator of this important distinction.

After having worked on it for over three years, Reichenbach completed his *Axiomatik* in March 1924. In December 1924 he published an essay "Die relativistische Zeitlehre " (47) which dealt almost exclusively with the notion of distant simultaneity. Starting with exposing the logical fallacy in establishing-distant simultaneity by means of signals of presumable known velocity of pro, pagation, Reichenbach stressed the impossibility–in–principle, on logical grounds

(43) H. Reichenbach, *Relativitätstheorie und Erkenntnis Apriori*, Springer, Berlin 1920, 9–10.

(44) H. Reichenbach, " Der gegenwärtige Stand der Relativitätsdiskussion ", *Logos*, *10*, 1922, 316–378; „ The Present State of the Discussion on Relativity ", in H. Reichenbach, *Gesammelte Werke*, (eds. A. Kamlah, H. Reichenbach), Vieweg, Braunschweig 1979; *Modern Philosophy and Science*, Routledge and Kegan Paul, London 1959; *Selected Writings 1909–1953*, Reidel, Dordrecht 1978, vol. 2,3–47: 39.

(45) H. Reichenbach, *Axiomatik der relativistischen Raum–Zeit–Lehre*, Vieweg, Braunschweig 1924; *Axiomatization of the Theory of Relativity*, University of California Press, Berkeley 1969.

(46) *Ibidem*, Section 10, Definition 8, 34 (original German text), 44 (English text).

(47) H. Reichenbach, " Die relativistische Zeitlehre ", *Scientia*, 1924, 361–374; „ The Relativistic Theory of Time ", in H. Reichenbach, R. C. Cohen (*eds.*), *Hans Reichenbach – Selected Writings 1909–1953*, Reidel, Dordrecht 1978, 69–80.

of measuring simultaneity, in contrast to the technical impossibility of, *e.g.*, measuring the number of molecules in a cubic meter of air. Whereas in the latter case approximations of increasing precision are meaningful and possible, this approach fails in the former case, because — reverting to the Einstein procedure — the interval at A between t_A and t'_A cannot be decreased due to the finite velocity of the fastest signal. Hence Reichenbach concluded; that " the possibility of a univocal determination of simultaneity has to be renounced ".

We cannot know the simultaneity of distant events at all, but can only define it. Simultaneity is arbitrary; we can lay down whatever definition we wish concerning it, without giving rise to any error (48). (Man kann die Gleichzeitigkeit überhaupt nicht erkennen, sondern nur definieren. Sie ist willkürlich; ich kann irgendeine Festsetzung darüber treffen, ohne dass ein Fehler entsteht) (49).

Reichenbach's most influential plea for the conventionality of distant simultaneity is found, of course, in his well-known classic *Philosophie der Raum-Zeit-Lehre* (50), which Wesley C. Salmon once called " the greatest work in the philosophy of science of the 20th century ". (" Das grösste Werk der Wissenschaftstheorie des zwanzigsten Jahrhunderts ") (51).

It is here that he generalized Einstein's criterion to the equation (52) $t_B = t_A + \varepsilon(t'_A - t_A)$ which served as the point of departure for almost all subsequent discussions of distant simultaneity. Richenbach's epistemological foundation of the conventionality claim, based as it was on the causal theory of time, had soon to yield ground to an ontological justification as professed *e.g.* by Adolf Grünbaum. Since then, many papers have been written pro and con the conventionality thesis. But it must also be mentioned that Reichenbach's formulation, due to its algebraic character, diverted attention, until most recently, from the relevant geometrical considerations. But this is a story which cannot be told today.

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(48) *Ibidem*, 71 (English text).
(49) *Ibidem*, 364 (Original German text).
(50) H. Reichenbach, *Philosophie der Raum-Zeit-Lehre*, Walter de Gruyter, Berlin 1928; *The Philosophy of Space and Time*, Dover, New York 1958.
(51) H. Reichenbach, *Gesammelte Werke*, Introduction to vol. 1, 25.
(52) H. Reichenbach, *The Philosophy...*, *quot.*, 127.