Back to main course page

Philosophical Significance of the Special Theory of Relativity
or
What does it all mean?

Morals About Time

John D. Norton
Department of History and Philosophy of Science
University of Pittsburgh

- 6. Time is the fourth dimension
- 7. Change is illusion
- 8. Causal Theory of Time (H. Reichenbach)
- 9. Conventionality of Simultaneity
  - For Conventionality: Einstein's Argument of 1905
  - Connection to the Causal Theory of Time
  - Reichenbach's ε
  - Weakness of the case "For"
  - The Case Against: Malament's Result
  - Weakness of the Case "Against"
  - Why does the disagreement persist?
- My Picks
- What you should know

This chapter continues the discussion of the last chapters on morals that we might try to draw from special relativity. This chapter collects morals pertaining to time.

For a discussion of philosophical morals that can be drawn from relativity theory concerning space and time, see my paper, "What can we Learn about the Ontology of Space and Time from the Theory of Relativity," on philsci-archive. **Beware.** The discussion is at a more advanced level than presumed in this class, so it is only for the adventurous.

6. Time is the fourth dimension

With the transition to relativity theory, we no longer conduct our physics in a three-dimensional space; we now employ the four-dimensional spacetime introduced by Minkowski.

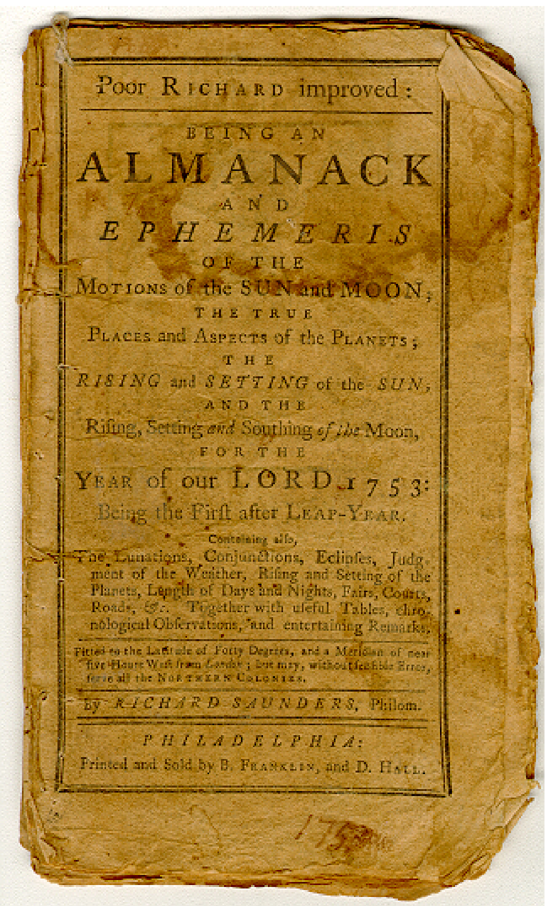
This slogan "time is the fourth dimension" is a mischievous slogan, used, as far as I can tell, to intimidate novices. They are supposed to be awed by the apparent profundity of the claim while at the same time never being able quite to grasp its content at the insightful depth apparently accessible to the mischief making sloganeer. If you meet such a sloganeer, you should ask "*what precisely* do you mean?" Keep in mind the confusion favored by sloganeers sketched below

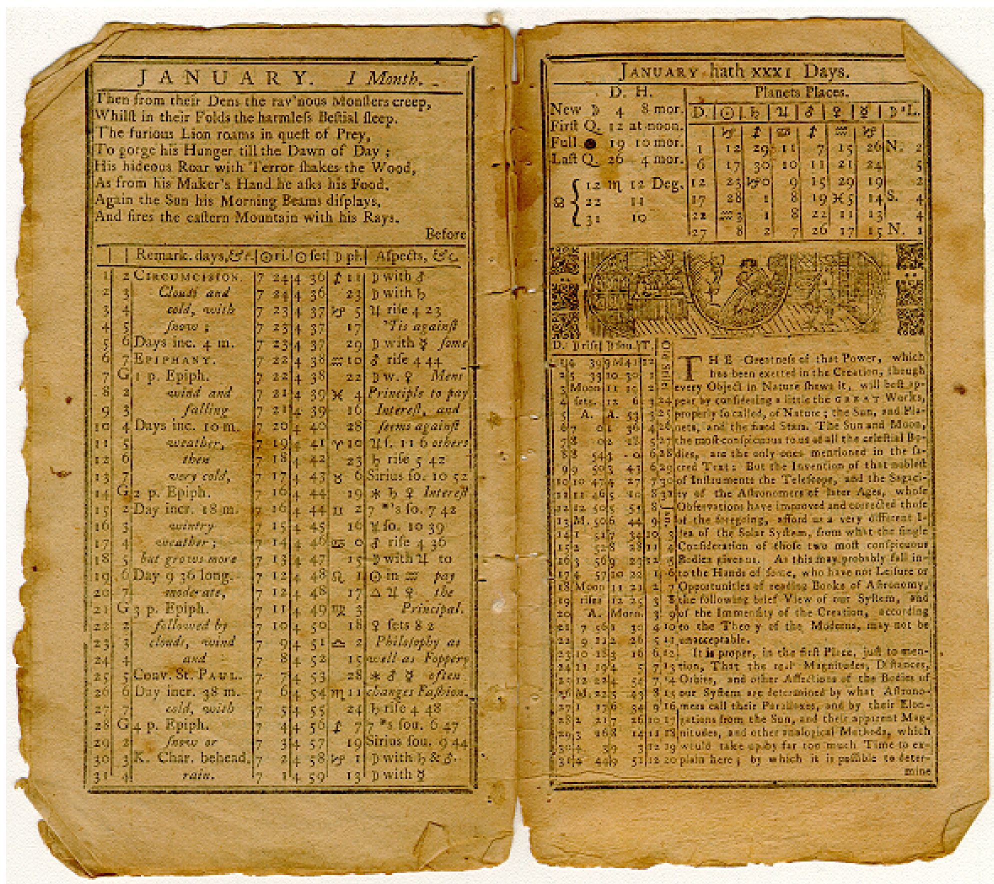
The power of the slogan comes from it suggests but does not say. It suggest something like: "In 1903, the Wright brothers liberated us from the two dimensions of the space of the earth's surface and opened a new, third dimension, altitude. In 1905, Einstein did it again with a new dimension, time." Spelled out bluntly like this, the suggestion is obviously nonsense.

and insist on a precise answer!

There is no interesting content to the claim. The problem lies in the vagueness of the statement of the thesis. There are two readings possible for it and neither yields results of importance.

In a trivial and true reading, we allow that space and time taken together form a manifold of four dimensions. What that just means is that four numbers are needed to locate an event in spacetime. Three of them are the usual spatial coordinates and the last is a time coordinate. That is true and was always true in classical physics as well. There is nothing of novel interest in this reading beyond the usual banalities about how things change with time. The idea that this sort of spatial representation of time is possible is as old as a pocket book calendar in which the passage of time is represented by a sequence of boxes or list of dates.


Poor RICHARD improved:
BEING AN
ALMANACK
AND
EPHEMERIS
OF THE
MOTIONS of the SUN and MOON;
THE TRUE
PLACES and ASPECTS of the PLANETS;
THE
RISING and SETTING of the SUN;
AND THE
Rising, Setting and Southing of the Moon,
FOR THE
YEAR of our LORD 1753:
Being the First after LEAP-YEAR.


JANUARY. I Month.
Then from their Dens the rav'nous Monsters creep,
Whilst in their Folds the harmless Bestial sleep.
The furious Lion roams in quest of Prey,
To gorge his Hunger till the Dawn of Day;
His hideous Roar with Terror shakes the Wood,
As from his Maker's Hand he asks his Food.
Again the Sun his Morning Beams displays,
And fires the eastern Mountain with his Rays.

JANUARY hath XXXI Days.

There is a profound but false version of the slogan. What if time were a fourth dimension *just like the three dimensions of space*? That would be extraordinary. It mean that we could move about in the time dimension just as we move about in the space dimension. But time is not just like space in relativity theory. The theory keeps the timelike direction in spacetime quite distinct from the spacelike; the light cone structure does this quite effectively. So relativity theory contradicts this profound reading.

Underlying the profound reading is a simple fallacy. We note that in a spacetime formulation of relativity theory, time is usefully represented spatially in a diagram. So we can infer time must be like space in some aspects or this device would fail. It does not follow that time is like space in all aspects. Analogously, we can represent the spectrum of colors spatially with color wheels and rainbows. That does not mean that colors are spatial. Red is not the fifth dimension of space.

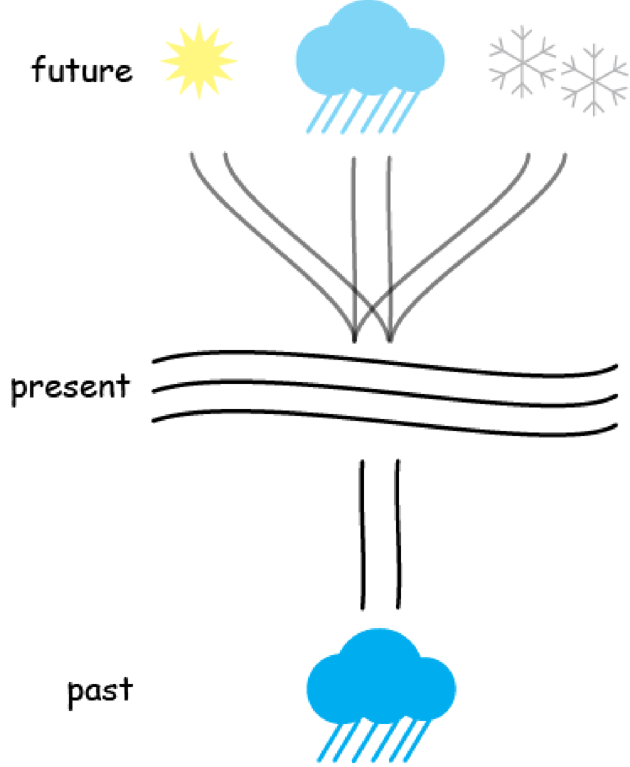
There is an interesting entanglement of space and time in relativity theory captured in the relativity of simultaneity. But the slogan of time as the fourth dimension is a defective and misleading way of expressing it.

7. Change is illusion

The relativity of simultaneity establishes that the future is as determinate as the past and present.

This moral is intended to negate a common sense idea we have about the future. It is the idea that the future is unresolved, whereas the present and past are or have happened and so are fixed. The notion is captured well enough by comparing the outcome of the last presidential election with the next. The outcome of the last election is known and fixed; it is a part of the determinate past. The outcome of the next election is open; it is a part of the indeterminate future.

We popularly imagine that the moment of the now advances through history converting the indeterminate possibilities of the future into the fixed actualities of the present and the determinate facts of the past. That there was a rainstorm on February 1 last is a determinate fact. Whether there will be one on February 1 next year in open. It may also be sunny or snowy. Which it is will become a determinate fact when our present has advanced to February 1 next year.



The Moving Finger writes; and, having writ,
Moves on: nor all thy Piety nor Wit
Shall lure it back to cancel half a Line,
Nor all thy Tears wash out a Word of it.

This notion of determinateness and indeterminateness will figure prominently in what follows. That is awkward since the notions are not supplied as a theoretical term in special relativity. In the theory, we simply have a spacetime of events. Which are past, present or future depends on where we locate the present moment. Future events are later than present events; past events are earlier than present events. The theory does not tell us where to locate the present and has no physical property that corresponds to determinateness or indeterminateness. The notions are supplied by us externally.

Determinateness and indeterminateness should be distinguished from determinism and indeterminism, where the latter arises in quantum theory. Here's how determinism works. In a deterministic theory, the state of the present fixes the state of the future. That is, at the present moment, the future is determined in the sense that there is only one future possible. But that future has not yet happened, so it remains indeterminate at the present moment. It is determined but indeterminate. The notion of determinism is supplied by the theory; the notion of determinateness is not.

What is determinateness? Perhaps the best we can say is this:

> If we conceive of past and present events as fixed and future events as open, determinateness is that property of past and present events that distinguishes them from future events with regard to fixity and

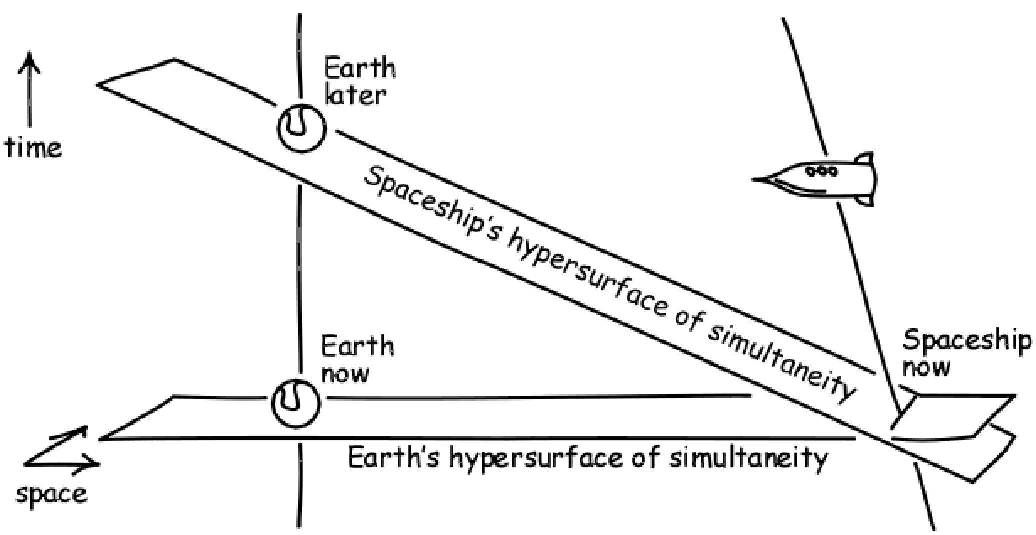
openness.

It is sometimes thought that merely employing a four dimensional spacetime in physics is already enough to overturn the idea that the future is indeterminate. For in a spacetime diagram, we see past, present and future laid out as equally real. This argument is flawed. It depends essentially on confusing the reality of a picture of a thing with the reality of the thing. My diary has equally real squares in it for yesterday and tomorrow. We would not infer from that, that yesterday and tomorrow are equally real (or squares).

The argument from spacetime is also less relevant in the present context since spacetime can also be used with classical physics. So whatever moral we might get from it is equally available from classical physics. Putnam, Rietjdk and others have tried to use what is distinctive about the Minkowski spacetime of relativity theory, the relativity of simultaneity, to get a stronger result about the determinateness of the future. They combine the way the relativity of simultaneity tangles up future and past with two observers in relative motion to get the result.

In brief, their argument goes as follows. Consider some possible event in our future: will there be a blizzard next February 1? We can always find a position and motion for a possible observer who would in our present, judge next February 1 to be in his present. For that observer, whether or not there is a blizzard here on February 1 is a present fact--it is determinate. Since that is true now of that observer, should we not also assume that the blizzard (or otherwise) of next February 1 is determinate?

The figure shows the spacetime diagram that goes with the argument.



The argument is:

Earth observer:
Event "Spaceship now" is simultaneous with respect to event "Earth now."
Therefore Event "Spaceship now" is determinate with respect to event "Earth now."

Spaceship observer:

Event "Earth later" is simultaneous with respect to event "Spaceship now"
Therefore event "Earth later" is determinate with respect to event "Spaceship now."

Combining:
Event "Earth later" is determinate with respect to event "Earth now."

There are two weaknesses in the argument.

First, we must accept that simultaneity and determinateness go hand in hand. That is, we must accept that:
"Spaceship now" is simultaneous with respect to event "Earth now."
entails that
"Spaceship now" is determinate with respect to event "Earth now."
I see no good reason to accept this. The notion of determinateness itself is sufficiently unclear as to leave me uncertain of its connection to simultaneity.

Second, it is not clear that determinateness is transitive. Transitivity is the property that allows us to chain together judgments of determinateness as is done in the little argument above. Again, whether it is admissible depends on what "determinate" means and I am unsure. Certainly simultaneity judgments from different observers cannot be chained together. We cannot infer that the events "Earth later" and "Earth now" are simultaneous. Why should it be different with determinateness?

How serious are the weaknesses? In my view, they are very serious. To resolve them, we need to find some independent basis upon which to judge the properties carried by determinateness, so that we can decide if determinateness coincides with simultaneity and is transitive. Yet, as the earlier discussion showed, determinateness is a notion we supply from outside relativity theory and in a way that its properties are left vague.

The one property that seemed secure is:

Future events are indeterminate with respect to past and present events.

If we conjoin this as an additional premise to the above argument, we end up concluding a contradiction:

Future event "Earth later" is AND is not determinate with respect to present event "Earth now."

If our premises lead us to a contradiction, we know that at least one of them is false and should be rejected. (This is a *reductio ad absurdum.*) Which should it be? There are three choices:

Simultaneity coincides with determinateness.

Determinateness is transitive.

Future events are indeterminate with respect to past events.

Given our slender grasp on determinateness, I see no reason to protect either of the first two from rejection. They entered in the first place as unsubstantiated suppositions.

People who favor the determinateness of the future, however, are likely to want to keep the first two and reject the third. Absent an independent characterization of determinateness, that rejection looks like circular reasoning. The prior commitment to the determinateness of the future is merely being reasserted.

8. Causal Theory of Time (H. Reichenbach):

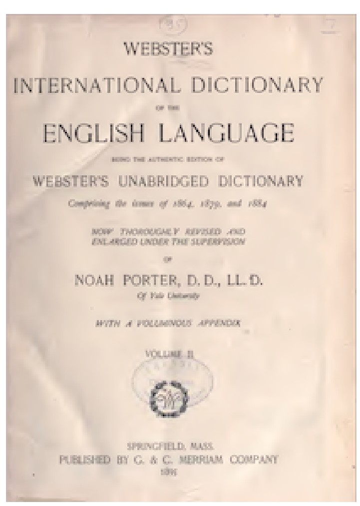
Einstein defined simultaneity in terms of a light signaling operation. We can generalize his procedure to define the nature of time in terms of signaling with any causal process. To say that "an event P is earlier than an event Q" simply means that it would be possible for some causal process to pass from P to Q.

Reichenbach here attempted to solve an old problem in philosophy, rather nicely expressed in a lament by Augustine:

"What, then, is time?
If no one asks me, I know:
if I wish to explain it to one that asketh,
I know not."

This traditional problem is already captured in the dictionary game. You want to know what time is? Look up the definition of time in the dictionary. And then look up the definition of the definition and soon enough you are back at time, in a closed circuit. There seems no, simple, non-circular way to finish the defining sentence "Time is..."

In my Concise Oxford English Dictionary, "time" is defined as "duration"; and "duration" as "continuance in, length of, time."


WEBSTER'S
INTERNATIONAL DICTIONARY
OF THE
ENGLISH LANGUAGE
BEING THE AUTHENTIC EDITION OF
WEBSTER'S UNABRIDGED DICTIONARY
Comprising the issues of 1864, 1879, and 1884
NOW THOROUGHLY REVISED AND
ENLARGED UNDER THE SUPERVISION
OF
NOAH PORTER, D. D., LL. D.
Of Yale University
WITH A VOLUMINOUS APPENDIX
VOLUME II
SPRINGFIELD, MASS.
PUBLISHED BY G. & C. MERRIAM COMPANY
[illegible]

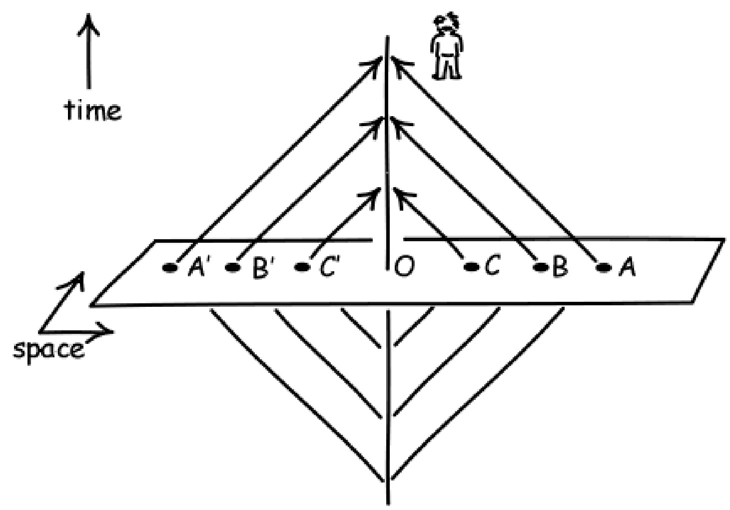
[Definition of time]

[Definition of duration](#)

Reichenbach's causal theory of time aims to solve this problem. It will complete the "Time is..." sentence with talk of causes. To be more precise, it looks at the time order of events, the notions of earlier and later. Just what does it mean to say that two events are separated in time? Reichenbach's answer is in terms of causal connectibility.

Event P is earlier than event Q	just *means* that	event P could causally affect event Q by, for example, the transmission of a light or signal from P to Q.

The inspiration for this approach is Einstein's 1905 treatment of simultaneity. In Einstein's special theory of relativity, two events A and A' are simultaneous if they are hit by light signals emitted at the same moment from their spatial midpoint; or if light signals they emit arrive at their spatial midpoint at the same time. The figure shows the propagation of light signals. Events A and A' are simultaneous; as are B and B'; and C and C'. Einstein turned this result into a definition. Two events are defined as simultaneous if they could be hit by such light signals. A variant form of this definition was the centerpiece of the first section of Einstein's paper.



The later version of the definition shown here is better suited to Reichenbach's project of reconstructing time from causal relations. The original 1905 version (described below) has one light signal traveling from place A to place B and back to A. Einstein's definition required us to identify the event at place A midway in time between the departure and return of the light signal. That event is defined as simultaneous with the reflection event at place B. Identifying that event midway beween departure and return presumes that we have a well-functioning clock at place A, so that it already presumes a notion of temporal passage prior to the operations with light signals.

Reichenbach extended this thinking to all the time relations between events, being before and being after. It is a truth that P is earlier than Q just if a causal signal could pass from P to Q. Reichenbach now proposed that this truth be a definition.

There is something important and right about the approach. We cannot allow notions like time to become too distant from the physical processes of the world. Special relativity has reminded us that our notions of time must respond to those processes and the physical theories that govern them. Time is deeply entangled with causation. We will see just how much more profound that entanglement is when we deal with the spacetimes of general relativity.

However, in my view, Reichenbach's approach goes too far. We do not just see the entanglement of space and time in his theory. We see the *reduction* of time order to causal order. Causation becomes the fundamental idea and time order is derived from it. The difficulty is that we end up with a primitive notion, causation, that we seem to understand less well than the thing we started with, time order. So now we must ask "what is causation?" We will have a harder time answering. Theories of the nature of causation remain diverse and controversial. (For my diatribe on causation see "Causation as Folk Science.") Time remains far less problematic; our theories of time are some of the best developed of all physics. A theory that reduces the less problematic to the more problematic seems to me to be most problematic.

9. The Conventionality of Simultaneity

We learn from special relativity that judgments of simultaneity are not just dependent on the inertial frame. Within a single inertial frame, the judgment of which spatially separated events are simultaneous is a matter of convention; that is, we are free to stipulate it as we like.

The relativity of simultaneity is one of the central results of the special theory of relativity. We have analyzed it here at length. There is a second thesis concerning simultaneity deriving from special relativity, which we have barely discussed so far. It is the thesis of the conventionality of simultaneity. The two are different and should not be confused.

The relativity of simultaneity asserts that judgments of the simultaneity of distant events must change as we move between inertial frames of reference. However it presumes that within a single inertial frame there is one correct judgment to be made.

The conventionality of simultaneity pertains to judgments of simultaneity of distant events in just one inertial frame. In asserts that there is no single, correct judgment of simultaneity. Rather, in each inertial frame, we have broad freedom in assigning simultaneity to pairs of events. In the same frame of reference, one person may assign relations of simultaneity one way; another person may do it differently. Within some limits, neither is factually wrong, according to the conventionality thesis, for there is no unique fact of simultaneity in the world.

The table summarizes the difference.

Relativity of Simultaneity		Conventionality of Simultaneity	
Inertial frame 1	Unique relation of simultaneity 1	Inertial frame 1	Many candidate relations of simultaneity 1a, 1b, 1c, ...
Inertial frame 2	Unique relation of simultaneity 2	Inertial frame 2	Many candidate relations of simultaneity 2a, 2b, 2c, ...

... ...

The term convention in the thesis is intended to convey the idea that the selection is freely chosen. That many people make the same choice is no reflection of a factual state of affairs.

> Think of the conventions concerning the side of the road upon which we drive. In the US and most of Europe, we drive on the right hand side of the road. In Great Britain and many Commonwealth countries, we drive on the left hand side of the road. Neither choice is factually correct; there is no cosmically pre-ordained, correct side of the road upon which to drive. We have just agreed in some countries to drive on one side of the road; and in others we agree to drive on the opposite side.

The thesis of the conventionality of simultaneity asserts that the selection of just which events are simultaneous, even in just one inertial frame of reference, is a convention in the same sense.

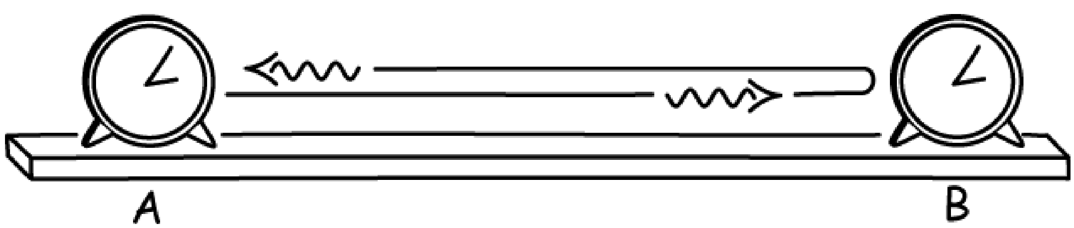
or

Image: http://fr.wikipedia.org/wiki/Fichier:Beijing_traffic_jam.JPG

For Conventionality: Einstein's Analysis of 1905

The argument for the conventionality of simultaneity draws directly on Einstein's analysis of simultaneity in his famous 1905 "On the Electrodynamics of Moving Bodies." In the first section of the paper, Einstein introduces the relativity of simultaneity. To do it, he considers two clocks, an A clock and a B clock at different places in space and at rest in the same inertial system.

> He then asks how can we synchronize the two clocks, so that the A-time of clock A agrees with the B-time of clock B. That is, how can we know that we have set the clocks in proper synchrony so that clock A ticks 0, 1, 2, ... and clock B ticks 0, 1, 2, ... at exactly the same moment.

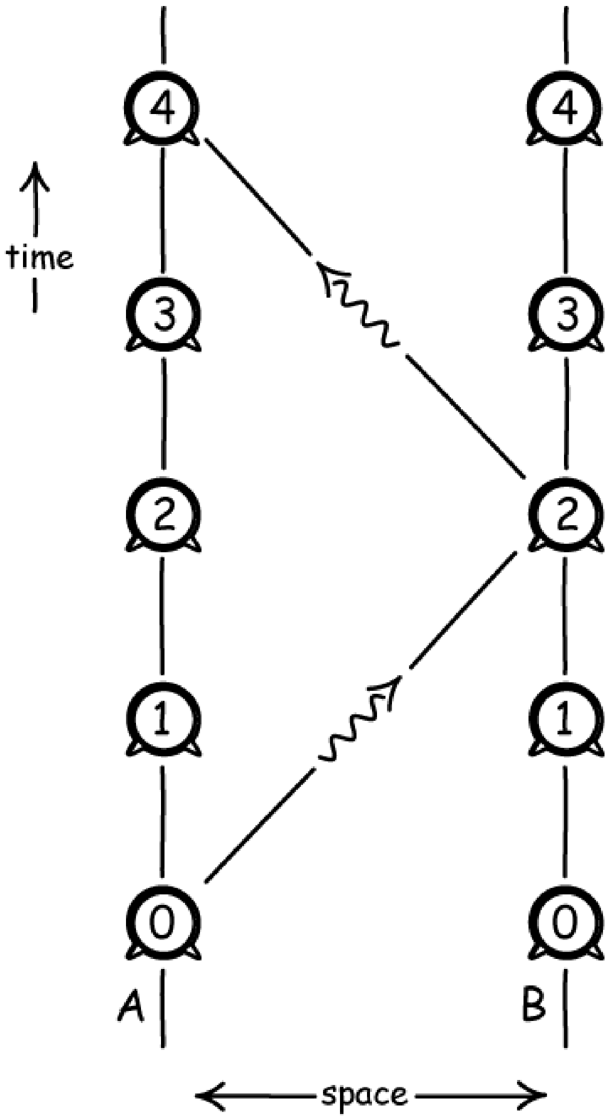


> Einstein plans to synchronize the clocks by means of light signals exchanged between the clocks. At this crucial moment in the development, Einstein asserts that there is no factually correct way

to set the clocks. We set them by introducing a definition:

> "So far we have defined only an 'A-time' and a 'B-time,' but not a common 'time' for A and B. The latter can now be determined by establishing *by definition* that the 'time' required for light to travel from A to B is equal to the 'time' it requires to travel from B to A."

To underscore that he is using a definition, Einstein has emphasized the words "by definition" and he calls the section "The Definition of Simultaneity."



The definition works in the familiar way. A light signal is sent from the A clock to the B clock. When it arrives at the B clock, it is immediately reflected back to the A clock. The definition requires that the two trips, forward and return, take the same time. That means that the reflection at the B clock is simultaneous with an event temporally half way between the emission and return of the light signal from the A clock. Hence the clocks are set to the same time for these two events.

This synchronization is shown in the figure. A light signal leaves the A-clock at A-time 0 and returns at A-time 4. Hence the reflection occurs at A-time 2. The clock at B is set to B-time 2 for this reflection event.

If Einstein intends that this procedure implements a definition of simultaneity, then it must be the case that other definitions are possible. That is, it is chosen conventionally. It is not a discovery, for then only one simultaneity relation can be found. For example, we define an ordinary or statute mile as 5,280 feet. That is a definition, since others are possible. There is an alternative nautical mile, which turns out to be around 6,076.1 feet. In contrast, the height of Mount Everest is 29,029 feet. It is discovered. We cannot choose a different value.

The claim of a convention is clear. However Einstein has offered rather little argumentation in its favor. Rather he mostly declares that the rule used to synchronize the clocks is a definition. He does not show that no other definitions are possible.

Einstein considers only one other possibility, that the A-clock sends out a signal at A-time 0 and that the B-clock and all other others in space set themselves to 0 when that signal arrives. The flaw in this arrangement, he notes, is that it treats the A-clock as somehow special, making its time control everyone else's.

Einstein himself seems to have given little more attention to the notion that the simultaneity of distant events must be introduced as a definition. While he gave many later accounts of special relativity, they rarely mention the need for a definition. The important exception is his 1916 popular book on relativity theory. ([Relativity: The Special and the General Theory](#).) In Part I, Section 8, he elaborates. One might expect that no other definition is possible since all

Einstein's definition amounts to is this: light takes the same time to travel from A to B as from B to A. That is, the speed of light in the direction AB is the same as in the direction BA.

Einstein responds that this equality of times or equality of speeds cannot be known factually, for we need to have clocks already synchronized at different places to know what is the speed of light when light travels from one place to another. He concludes:

> "It would thus appear as though we were moving here in a logical circle."

From the short treatment given by Einstein, it is far from clear that there really is no definite fact as to which events are simultaneous within one inertial frame. It is also far from clear that we must always be trapped in the sort of logical circle Einstein sketched. Can we really use other definitions?

Two elaborations supported the conventionality thesis, Reichenbach's causal theory of time and his ε.

Connection to the Causal Theory of Time

An early appeal of the conventionality thesis was that it appeared to conform especially well with Reichenbach's causal theory of time, discussed above. It asserts that temporal relations simply are nothing more that causal relations: For event E_2 to be later than event E_1 just means that a process at E_1 can causally affect a process at E_2. Reichenbach understood relativity theory to assert that no real propagation goes faster than light; light is what he called a "first signal."

Returning to Einstein's clocks A and B , it follows that none of the events at clock A between the emission of the light signal and its return can causally affect what happens at clock B at the event of the reflection of the light signal. For any such causal influence, in either direction, would need to propagate faster than light.

To complete the analysis, we merely need to understand simultaneity to consist in failure of possible causal interactions. Then all the events at A between the emission and return of the light signal could be deemed simultaneous with the reflection of the signal at the B. We are free to choose which we declare simultaneous; any choice is as good as any other, just as the conventionality thesis asserts.

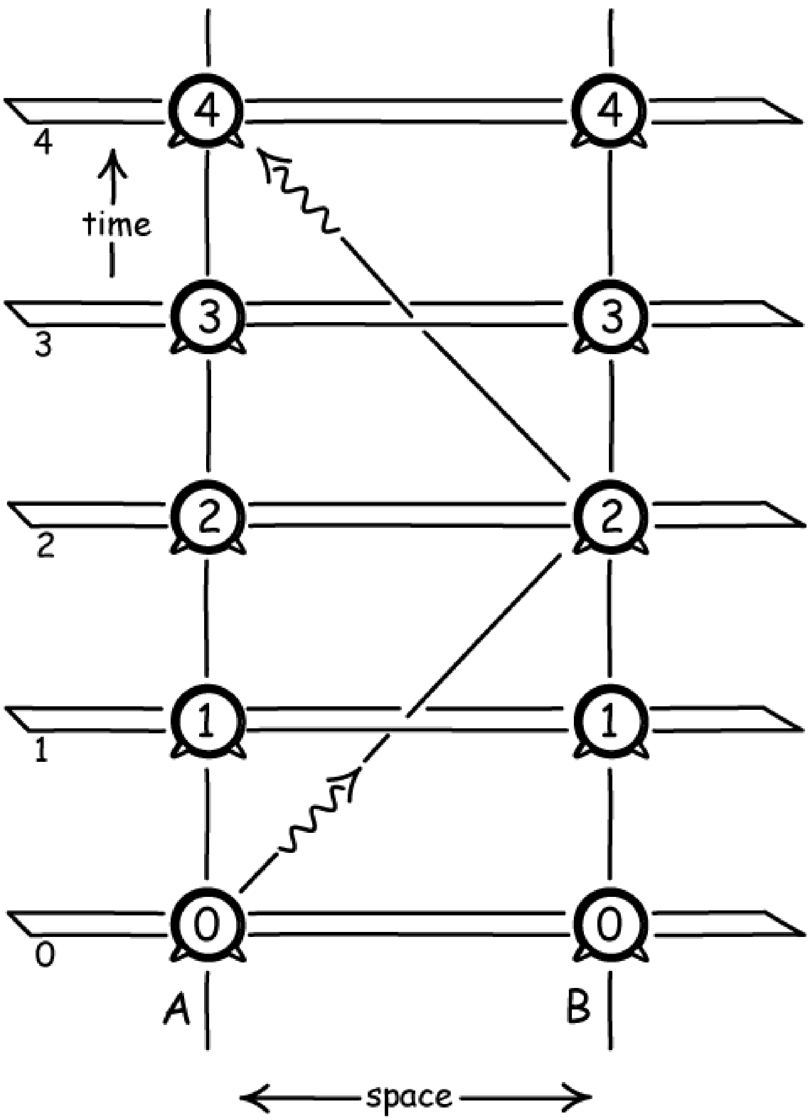
In brief, the causal structure of the Minkowski spacetime, that is, the catalog of which events can causally affect which others, leaves the relation of simultaneity incompletely determined. That incompleteness is the conventionality of simultaneity. It results from the finiteness of the speed of causal propagation, which is limited to the speed of light.

Reichenbach's ε

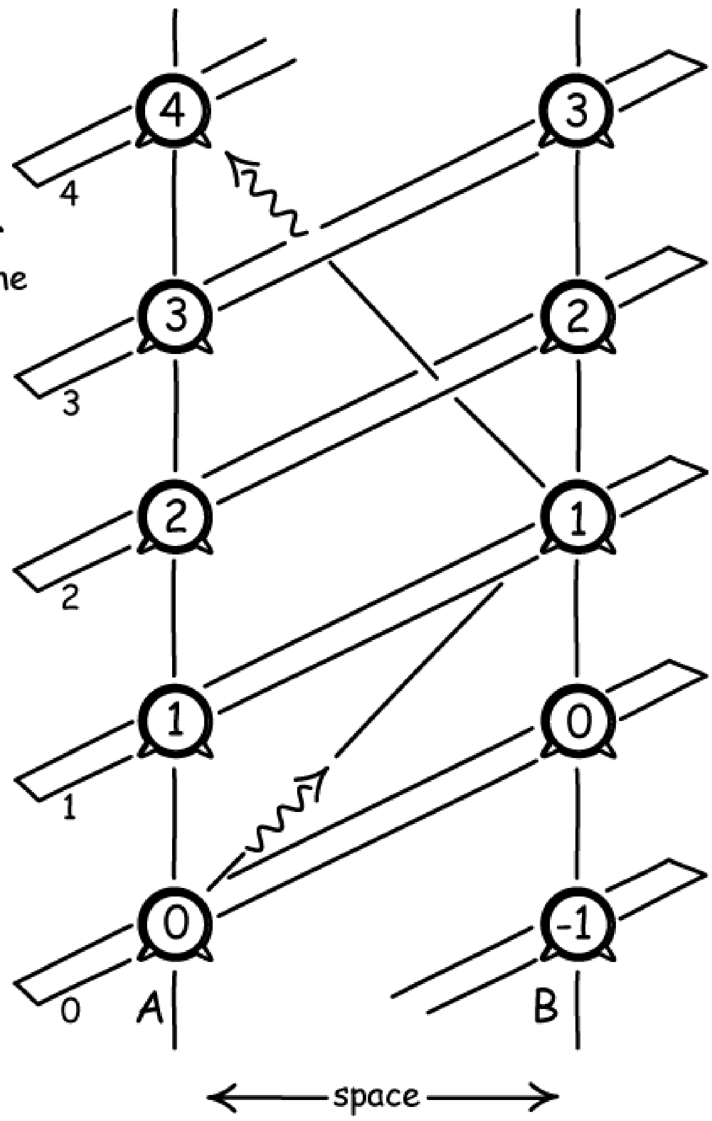
Adolf Gruenbaum

http://www.pitt.edu/~pittcntr/Images/Donuts/2007-08/grunbaum_11-30-07/grunbaum19_hi-res.jpg

The possibility of using other synchrony conventions was explored by Hans Reichenbach, Adolf Gruenbaum and others at some length. They looked at what happens if we try to use another definition. Instead of selecting a time half way between the emission and return of Einstein's 1905 procedure, what if we choose one that is, say, ε ("epsilon") fraction along, where ε is just some number we pick between 0 and 1. The figure shows the difference between the standard synchrony of ε=1/2 chosen by Einstein (on the left) as his definition and another choice of ε=1/4 (on the right).



ε = 1/2



ε = 1/4

The figures show how the standard and non-standard judgments of simultaneity propagate through the spacetime. Standard ε=1/2 synchrony gives us the familiar hypersurfaces of simultaneity. Non-standard ε=1/4 synchrony gives us the tilted hypersurfaces shown.

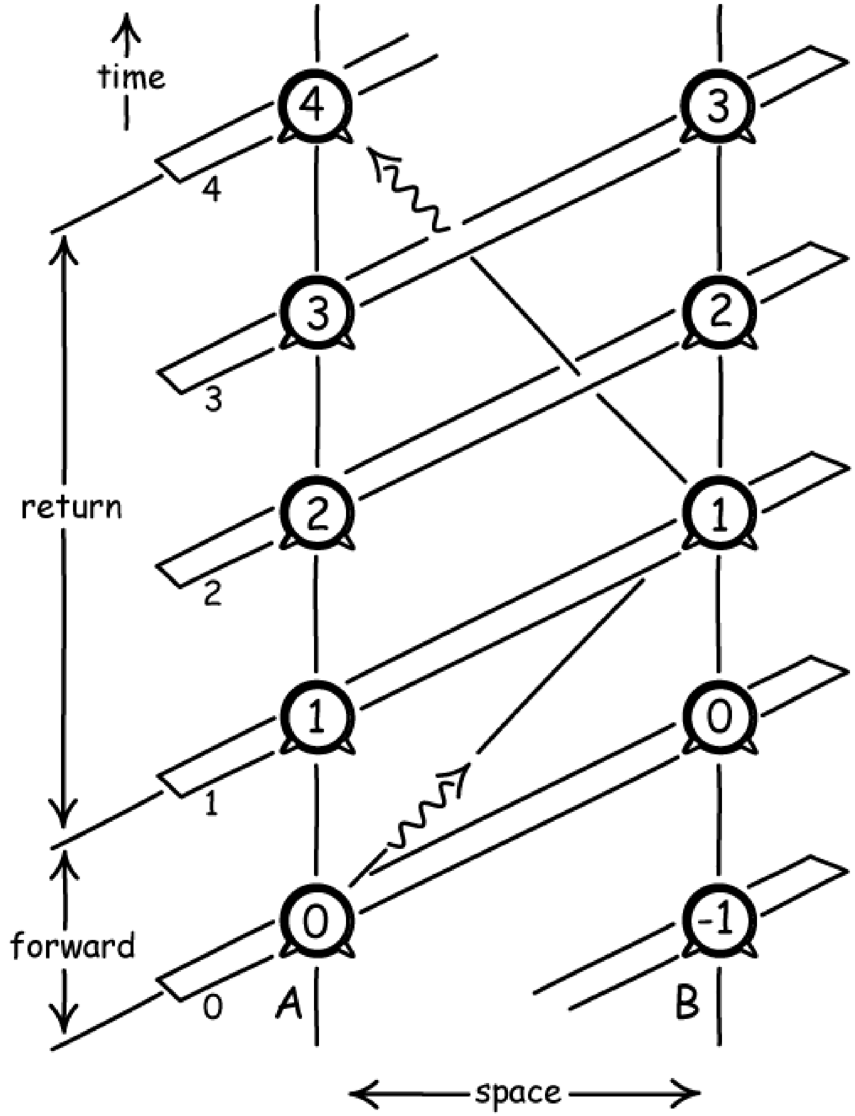
If the standard choice of ε=1/2 really is freely chosen, then the alternative choice of ε=1/4 should not get us into any trouble. That is, we should generate no contradictions within the theory, although we may arrive at some unexpected results.

Strange things do happen when we use a non-standard synchrony convention, such as ε=1/4. One is shown in the figures. With ε=1/2, light takes 2 units of time to go forward from A to B and 2 units to return from B to A. With the non-standard ε=1/4, things are quite different. Light takes one unit of time to go from A to B. (Departs A at A-time 0; arrives at B at B-time 1; 1-0=1) But the light takes three times as long to return from B to A. (Departs B at B-time 1; arrives at A at A-time 4; 4-1=3.)

Therefore, the speed of light in the BA direction is three times greater than in the AB direction.

What happened to the light postulate and the constancy of the speed of light? According to the conventionality of simultaneity, the one-way speed of light, such as from A to B, varies according to our conventional choice of ε. The two-way speed of light, such as the average speed for the round trip from A to B to A, is not affected by the choice of ε. The constancy asserted by the light postulate applies to this two-way speed. It retains the familiar average value of c.

What has happened here is that judgments of simultaneity play a role in determining the speed of light. We measure its one-way speed over some distance with two, synchronized clocks, one at each end. So if we change our conventions for synchronizing clocks, we end up changing our judgments of the speed of light.

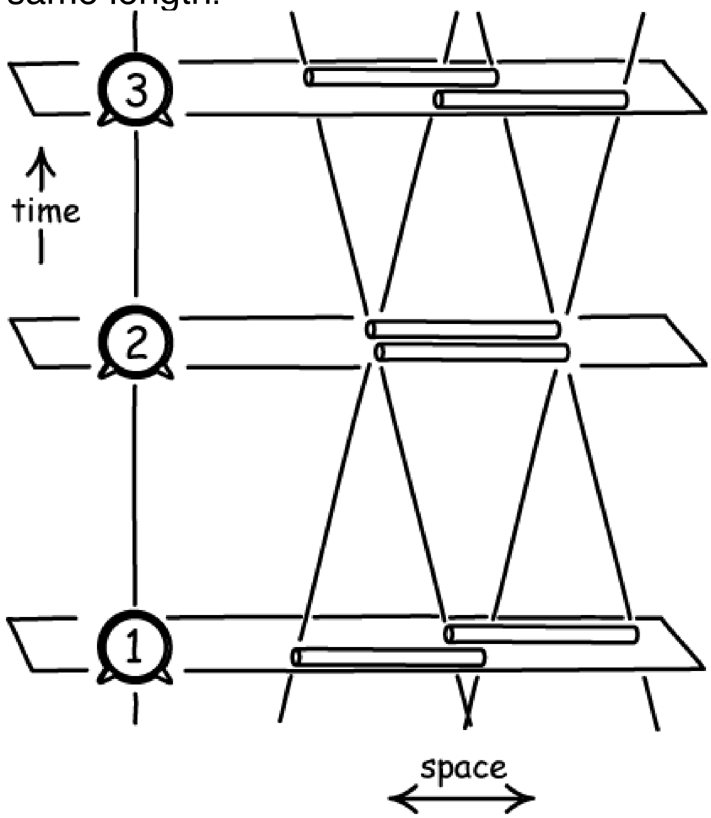


This strangeness will be repeated in many places. We have seen the judgments of simultaneity play a role in determining many physical magnitudes. All these magnitudes will manifest analogous strange effects if we use a non-standard synchrony.

All speeds will be altered, not just that of light. The length of a moving rod will vary according to the direction in which it moves. The figures below show show two rods moving uniformly in opposite directions. The rods and their motions are the same in both figures. All that has changed is that we are judging their lengths at some instant using different synchrony conventions in thte two figures.

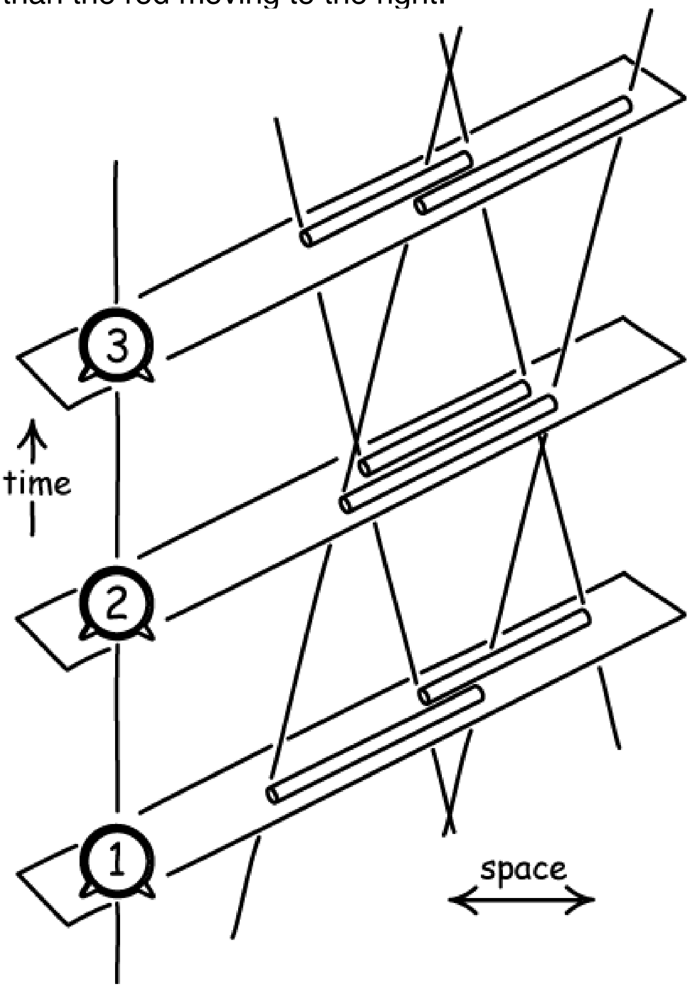
The figure below shows the same two rods, moving in exactly the same way. However we are now surveying their motions and lengths with a non-standard synchrony of ε=1/4. The two rods coincide

This figure below shows the case of standard synchrony, ε=1/2. We see that, under standard synchrony, the two rods are moving in opposite direction at the same speed. The two rods coincide at the instant of time 2 and have the same length.



ε=1/2

at the instant of time 2. However it is clear from the figure that they do not have the same length. The rod moving to the left is now found to be longer than the rod moving to the right.



ε=1/4

The slowing of clocks will also vary according to their direction. Under standard synchrony, we can reduce the amount of slowing of a moving clock to as small an amount as we like just by moving the clock very slowly. That means that a very slowly moving clock will remain synchronized with the other clocks in the frame, as long as those clock are synchronized by the standard rule. What if we had synchronized the clocks non-standardly, that is, with an ε other than 1/2? Then the slowly moving clock would no longer remain synchronized with the other clocks it passes in the frame.

Turn this around and describe it from the perspective of the clocks spread through the frame: under non-standard synchrony, there is an additional direction related shift in the reading of a clock that slowness of transport cannot eradicate.

We need not go into further details of the many changes that non-standard synchrony requires. For our purposes, all that matters is that there is a simple procedure for determining what these changes are. One first describes the process using the space and time coordinates of standard synchrony. One then replaces these standard coordinates with those coordinates associated with the non-standard synchrony. What results is a new description that conforms with the non-standard synchrony.

The new descriptions will be strange. Light will be propagating at different speeds in different directions. But that strangeness is all there is. Mere strangeness does not make them incorrect. There will be no contradictions, if the original descriptions were contradiction free. Equally importantly, everything measurable will come out the same in the two descriptions, so that no observation of a matter of fact can decide which is the correct one.

Finally, one might be inclined to insist that we must employ standard synchrony, for no account of light can be accepted if it has light propagating at different speeds in different directions. Space, we believe, is isotropic, that is, the same in all directions. The conventionalist response is that the anisotropy of the one way speed of light is merely an oddity of description, not a factual error, for the differences in the one-way speeds reflects nothing physical. The differences merely reflect our decision to synchronize clocks in different ways.

Weakness of the Case "For"

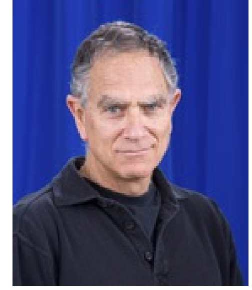
If one does not subscribe to the causal theory time, then recovering the conventionality thesis from it is unpersuasive. Then, the strongest support of the conventionality of simultaneity might be the ε procedure sketched above. It assures us that we can always find a consistent redescription of processes that conforms with any chosen non-standard synchrony.

However that procedure reveals a great weakness. Choosing different synchrony conventions has been reduced to assigning time coordinates to events in arbitrary ways. There is something quite trivial about that. We label events with four numbers: 3 space coordinates and one time coordinate. They are just labels and, as long as we keep track of the system used, we can relabel the events any way we please.

If all the thesis is about is the freedom to label events as we please, then the thesis is much less than it initially seemed. It is not a thesis specifically about time. We can also relabel the spatial coordinates as we please, as long as we keep track of the system used. We can relabel any physical magnitude in any odd way we please. The descriptions that result will seem strange, but as long as we keep track of the system used, the strangeness is merely an oddity of description, not the revealing of an important, overlooked convention.

The Case Against: Malament's Result

The relativity of simultaneity is regarded as settled physics and is accepted by anyone competent in relativity theory. The thesis of the conventionality of simultaneity, however, remains controversial. Most prominent among objections to the thesis is a result proved in 1977 by David Malament. His result creates difficulties specifically for the connection between the causal theory of time and the conventionality thesis.



David Malament

Malament showed that, once we have specified a particular inertial frame of reference, there is only one (non-trivial) relation of simultaneity definable from the causal structure of a Minkowski spacetime. That reverses the expectation of the causal theorists. The causal structure seemed to leave a lot of freedom for the assignment of the relation of simultaneity. Malament showed that there was no freedom. The one definable relation proves to be standard ε=1/2 synchrony.

For a simple account of the proof, see my "Philosophy of Space and Time" Ch. 5, Part III, in M. H. Salmon et al, Introduction to the Philosophy of Science.

The talk of "definable" may at first seem abstruse. The notion is pretty simple, however, and another example gives the basic idea.

We believe that ordinary gases are nothing more than a lot of molecules in rapid motion. As a result, all the factual properties of gases ought to be traceable back to molecular properties. Take the temperature of the gas. If two gases have different temperatures, then there must be something different about the molecules. A familiar result for ideal gases is that the temperature of the gas just is fixed by the average of the squared speeds of its molecules.

That is, gases are nothing but molecules in motion, so all their properties can be defined in terms of molecular properties. (For experts in philosophy of physics: may I be permitted to set aside the present, fierce debates over reduction and emergence in the interests of simple pedagogy? Thank you!)

The same reasoning applies to time. If temporal relations are nothing more than causal relations, then we ought to be able to define a temporal relation like simultaneity in terms of causal relations. When we carry out the exercise, Malament shows, we find that there is a unique simultaneity relation definable in causal terms. Just as the molecular constitution of a gas fixes its temperature, it seems that the causal structure of a Minkowski spacetime fixes the unique simultaneity relation appropriate to each inertial frame of reference.

Malament's result turns the original intuition of the conventionality thesis on its head. The thesis came originally from the fact that causal connections in a Minkowski spacetime are more limited than in classical, Newtonian spacetimes: nothing propagates causally faster than light. That opened a freedom in assigning relations of simultaneity that is the conventionality thesis. Malament's result now suggests that the causal structure does not admit that freedom after all. Only one simultaneity relation, standard synchrony, is definable non-trivially by it.

Weakness of the Case Against

The weakness of Malament's result resides in the delicate selection of just which structures are allowed when we define a simultaneity relation. The analysis only returns a unique result if we keep pretty much precisely to Malament's list. Small deviations from it are sufficient to destroy the uniqueness, whether we add or subtract from the list.

For example, Peter Spirtes showed that uniqueness is destroyed merely by allowing the definition to distinguish past from future.

Adolf Gruenbaum has objected that Malament's analysis assumes that a simultaneity relation will divide the spacetime into non-overlapping sets of mutually simultaneous events. (These turn out to be the the familiar hypersurfaces of simultaneity.) Drop this assumption, he points out, and the uniqueness fails. What results, however, is an odd relation of simultaneity that is not transitive. That is, if event A is simultaneous with B and event B with C, then it does not follow that event A is simultaneous with event C.

Why does the disagreement persist?

For a helpful survey, see Allen Janis, "Conventionality of Simultaneity", *The Stanford Encyclopedia of Philosophy*.

For a recent addition to the literature, see Robert Rynasiewicz, "Simultaneity, Convention, and Gauge Freedom."

The conventionality of simultaneity has been the focus of protracted debate in the philosophy of science literature. It is difficult to come to a clear conclusion on it. The debate has faded in recent years, but not because one side has won. Rather the combatants have just become weary of the fight. On each side are philosophers of physics with a deep and rich command of relativity theory. So the real question is why the disagreement can persist. The two sides must differ over something so foundational that it is not entering explicitly into the discussion.

Two remarks may help.

First is an oddity of the notion itself. The conventionalists urge that the conventionality of simultaneity is an important physical insight. It is, purportedly, something more important than the many minor conventions routinely employed in science, such as our decision that a mile is 5,280 feet. Yet the conventionality of simultaneity seems to have no consequences outside the debate over the conventionality itself.

Compare that to another result that may be characterized as a non-trivial convention. According to special relativity, when we select an inertial reference, we do so for descriptive convenience. There is no factually preferred inertial reference frame. That contrasts with a Lorentz-style ether theory. In it, there is a special frame of reference, the ether rest frame. In making the choice of inertial frame conventional, we convey the fact that there is no ether rest frame. We thereby force our physics to become relativistic. That is, we must reformulate the laws of physics so that they come out the same in all inertial frames of reference.

If the choice of a simultaneity relation is conventional, there is no corresponding consequence for our physics. That means that no further issue has emerged that can decide the debate. Here it is unlike the issue of an ether reference frame. Ether theories fell from favor because no one could find a way to discern just which was the preferred ether frame of rest. There is no corresponding failure associated with conventionality of simultaneity. Indeed we have the reverse situation. Standard synchrony is readily distinguished from all others by the Einstein synchrony rule.

Second, I suspect a connection with a different issue in philosophy of science. It concerns competing views of the structures posited by spacetime theories.

At one extreme is an antirealist attitude. According to it, all that matters is what we observe. This observational content is exhausted by catalogs of facts like "this light signal arrives here when this clock reads 2." The geometry of the spacetime plays a subsidiary role only in helping us to catalog which observations are possible and which are not. In the most extreme construal, the geometry is just a useful fiction.

At the other extreme, a realist construes spacetime theories as giving a literal account of the world. So when a spacetime theory posits a Minkowskian geometry for spacetime, we are to understand that factually the spacetime has that geometry. The geometry is as real as tables and chairs.

The difference between conventionalists and non-conventionalists is definitely NOT merely the difference between these two views. However there is a partial alignment.

The conventionalists would incline to more antirealist views. This is clearest with Reichenbach's causal theory of time. All there really is to time, according to that theory, are the causal relations among events, which are in turn mapped out by light signals. Anything more is factually superfluous. That applies to relations of simultaneity and, presumably, much else in the Minkowski spacetime geometry.

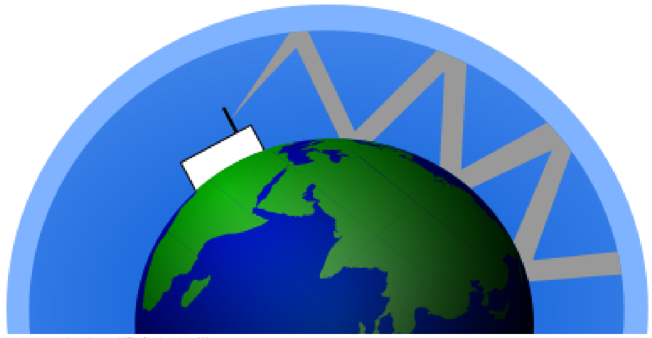
Similarly, the different ε based descriptions of processes in spacetime are judged equally good, even though some are more complicated, because they conform to the same observations. That conformity is a major source of support for the conventionalist thesis.

The non-conventionalists would incline towards realist views. If one takes Minkowski geometry as factually the geometry of spacetime, as real as tables and chairs, then one automatically takes its natural simultaneity relation as factual. That natural relation is just standard synchrony.

In geometrical terms, it comes out as the spacetime analog of the ordinary geometrical notion of perpendicularity, here usually called "orthogonality." If we take the worldline of an inertially moving body, there is only one set of hypersurfaces of simultaneity orthogonal to it under a Minkowskian spacetime geometry: those of standard synchrony.

In brief, the more of a realist you are concerning spacetime geometry, the less you can incline towards the conventionality of simultaneity.

In balance, my view is more sympathetic to the non-conventionalist view. I incline towards the realist view of Minkowski geometry. So I find our collected observations in spacetime strong evidence for something factual behind the observations. The situation is not so different from our detection of the ionosphere in the earth's upper atmosphere. We know it is there, even though we cannot see it, since it reflects radio waves back to earth. We can map its shape and location by those reflections. Correspondingly, we use observations in space and time to map out the geometric structure of the spacetime. What we map out is a geometry that includes an orthogonality relation, which I take to be the unique notion of simultaneity provided the spacetime geometry.



http://commons.wikimedia.org/wiki/File:Circuit_ondes_réfléchies.svg

My Picks

Among the candidate morals of this and the last two chapters, everyone will find their own favorites, although it can be quite hard to make the selection. For what it is worth, here are my picks. They have actually mostly been embedded in the earlier critical discussion.

Common sense tracks the latest science. That is, common sense lags behind our latest science, which is very slowly incorporated into that nebulous "what everyone knows." Doesn't everyone now know that matter is made of atoms; or that the air is part oxygen and that oxygen is the bit that matters for our survival? Yet all this was once the most advanced science. The process seems to be continuing with special relativity. Many people somehow know that "nothing goes faster than light" but they are not sure where is comes from. The moral is not solely derived from special relativity, but special relativity does supply a nice instance of it.

Mature theories are very stable in the domains for which they were devised. They are fragile elsewhere. This is what I think should be learned from the long history of fragility of scientific theories, with the advent of special relativity an excellent example. While theories do not retain unqualified validity when we move to new domains, the mature theories remain essentially unaltered in their original domains. We need relativity theory for motions close to the speed light, yet we still use ordinary Newtonian theory for motions at ordinary speed. That does not seem likely to change.

Beware of theories or parts of theories that are designed to escape experimental or observational test. This is the part the verificationists got right. There is something very fishy about theoretical entities with properties so perfectly contrived that we cannot ever put them to observational or theoretical test. We should treat them with the highest suspicion. Asking for the means of verification or falsification is a good test if one is suspicious. Finding clear conditions for verification or falsification is an assurance that a healthy connection between the theory and experience is possible.

Be ready to abandon concepts that hide empirical content. This is the part that the operationists got right. One cannot develop conceptual schemes without making presumptions about the world, yet those very presumptions can be contradicted by emerging science, making acceptance or even formulation of appropriate new theories difficult. A related concern is that some concepts may have no real basis in experience at all (e.g. ether state of rest!). Asking for an operational definition of the concept is a healthy but not final test. If it admits an operational definition, then at least we know it has a connection to possible experience.

Infer to common causes. When you have the choice, the better explanation is the one that posits fewer coincidences and that is the one you should infer to.

Space isolates us causally. The novel results about space and time itself provide some of the most interesting results of special relativity. If we try to look beyond the theory and still have outcomes that pertain to space and time, I think the most important is simply the idea of upper limit of speed of light to causal interactions. That tells us that we are quite powerfully causally isolated from other parts of the universe. Nearby galaxies are already *millions* of light years away. That means that just sending a signal from our galaxy to another will require eons of time. Conversely, something happening there now will not affect us for the corresponding eons.

If one wishes to press further, special relativity has revealed a relatedness of space and time that we did not formerly suspect. It is hard to know how best to express this entanglement. I think the best way is still our familiar relativity of simultaneity.

What you should know

- The various philosophical morals people have tried to draw from relativity theory.
- How to identify a clear thesis and the argument that supports it.
- How to criticize the statement of a thesis and the argument that supports it.
- Your own view of which philosophical morals can be drawn from relativity theory.