On the Evolution of the Concept of Time

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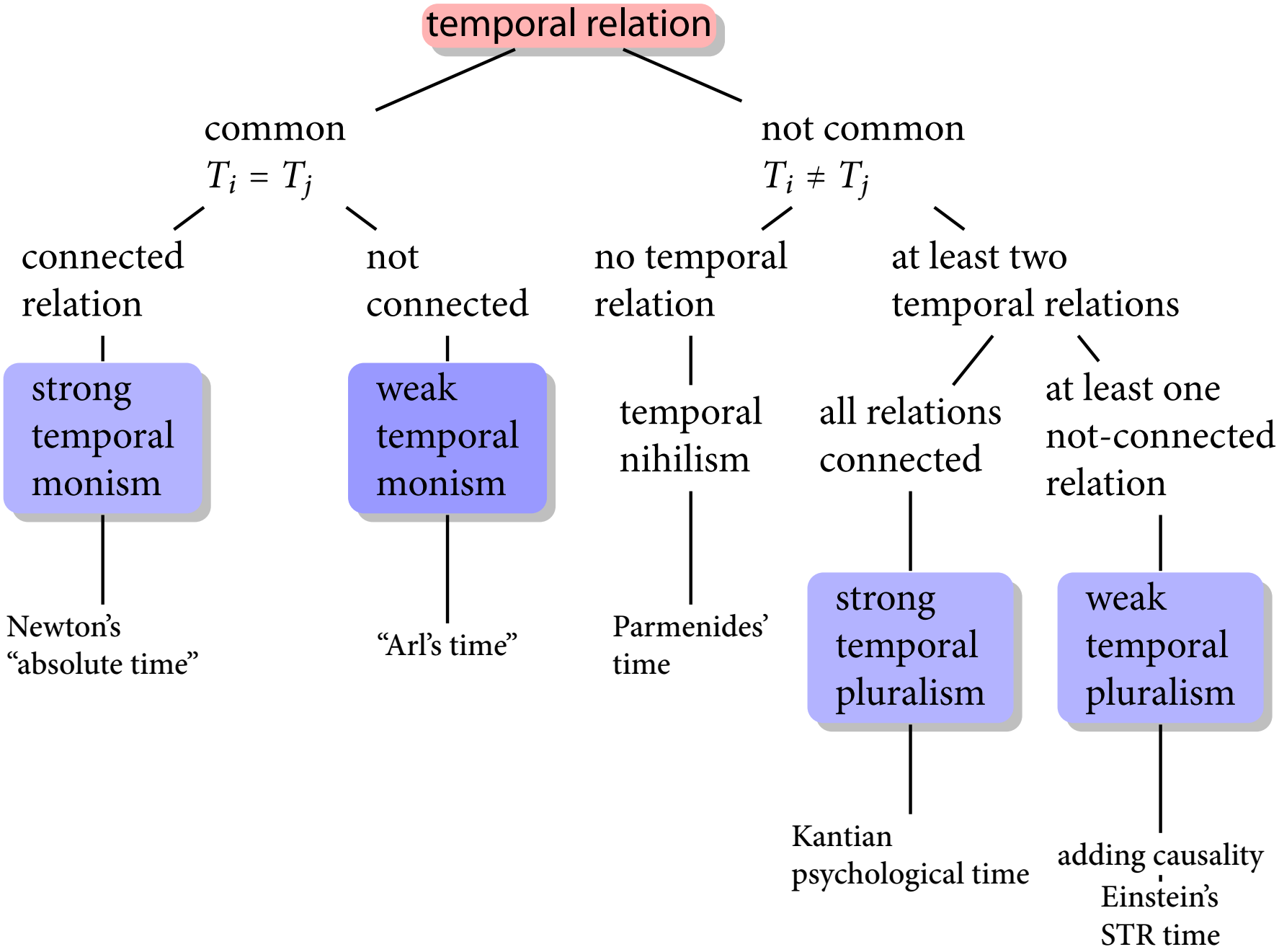
Time in reality; time in perception and thought

- In this talk a typology of temporal relations will be proposed with the aim of reconstructing the historical and cognitive development of ideas time.
- Both the theories of objective time (physical theories of time) and the theories of subjective time (epistemological theories of time knowledge and implicit theories of time) will be discussed and classified within one and the same typology. A lot of problems in the theory of time will be disregarded. Firstly, the theory of time involved in understanding of human action (branching time theory) will not be dealt with. Secondly, only the ordinal aspect of the concept of time (i.e., temporal relation) will be analysed, while the problems of duration and direction of time will be left aside. What will be taken into account is the diversity of ways in which the temporal relation is explicitly understood in history of physics and philosophy or is implicitly assumed at stages of individual cognitive development.


temporal relation
common
$T_i = T_j$
not common
$T_i \neq T_j$
connected relation
not connected
no temporal relation
at least two temporal relations
strong temporal monism
weak temporal monism
temporal nihilism
all relations connected
at least one not-connected relation
Newton's "absolute time"
"Arl's time"
Parmenides' time
strong temporal pluralism
weak temporal pluralism
Kantian psychological time
adding causality
Einstein's STR time

The main characters in the story

Figure : Einstein and Piaget at the world congress on philosophy and psychology in Davos, Switzerland in 1928. At the congress Einstein suggested to Piaget to investigate the child's concept of time. The task turned out to be a hard case for an experimental philosophy. Nevertheless, Piaget was persistent and managed to publish the research report in 1946.

A basic model of temporal order

- Domain D is a non-empty set; it can be thought of either in the objective way (as a set of events, or a set of atomic facts), or in the subjective (as a set of impressions or mental images or …). Set F is the set of objects with respect to which relations of precedence and simultaneity are defined; F can be thought of as a set of observers in inertial frames. The exact interpretation of F is not crucial for the determination of the typology of temporal relations.
- Precedence relation $<_i$ is an irreflexive, transitive and asymmetric binary relation on D, $<_i \subseteq D \times D$ where $i \in F$.
- Simultaneity relation S_i is an equivalence relation on D. i.e., reflexive, symmetric and transitive binary relation on D, $S_i \subseteq D \times D$ where $i \in F$.
- Temporal relation T is the union of precedence and simultaneity relation, i.e., events e and f stand in temporal relation T if either e precedes f or f precedes e or e and f are simultaneous. The only additional conditions that are imposed on temporal relation are: precedence implies non-simultaneity, i.e., if $e <_i f$ or $f <_i e$, then $\neg e S_i f$, and "simultaneity inherits precedence", i.e., if $e S_i e'$ and $e <_i f$, then $e' <_i f$

Temporal relation T

Temporal relation ($T_i = <_i \cup I_i$)

$i \in F$; $a, b, c \in D$; all formulas are assumed to be universally quantified.

T-axioms for $<_i$ and S_i

$\neg a <_i a$ (1)

If $a <_i b$, then $\neg b <_i a$. (2)

If $a <_i b$ and $b <_i c$, then $a <_i c$. (3)

aS_ia (4)

If aS_ib, then bS_ia. (5)

If aS_ib and bS_ic, then aS_ic. (6)

If $a <_i b$ or $b <_i a$, then $\neg aS_ib$. (7)

If aS_ib and $a <_i c$, then $b <_i c$. (8)

Definition T

aT_ib iff $a <_i b$ or $b <_i a$ or aS_ib. (9)

Some non-necessary properties of T_i

- A temporal relation T_i is *connected* if it exhausts all events in D, i.e.:

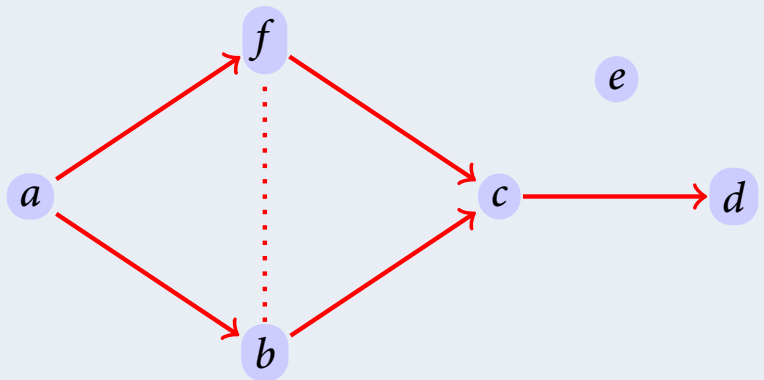
  T_i is connected iff for all $a, b \in D$, aT_ib.

- A temporal relation T_i is *common* (or absolute) if it is the same for all $i \in F$, i.e.:

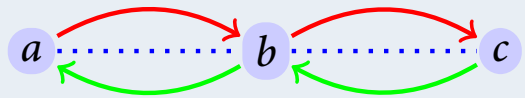
  T_i is common iff for all $i \in F$ and $j \in F$ and for all $a \in D$ and $b \in D$, $a <_i b$ implies $a <_j b$, and aS_ib implies aS_jb.

In the graphical examples: arrows represent precedence; dotted lines represent simultaneity; reflexive lines of simultaneity and transitive arrows of precedence and simultaneity are omitted.

An example: not connected T_i



An example: three non-common temporal relations.



Text analysis

What is it for two distinct events to be simultaneous? Prerelativistically, this is an assumed notion.
[*] Simultaneity is assumed to be an invariant notion, two events simultaneous for one observer are simultaneous for any other observer, and it is also assumed to be an equivalence relation, i.e., to be a symmetric, reflexive, and transitive relation among events. I assume none of this. The notion of simultaneity we end up with is not invariant, it is only defined relative to an observer in a given inertial state of motion.
[**] For any such observer, simultaneity, so relativized, is an equivalence relation, but if a is simultaneous with b relative to one observer, and b simultaneous with c for another observer, there is no reason to believe in general that a is simultaneous with c relative to either observer.

Lawrence Sklar (1974).
Space, Time, and Spacetime.
University of California Press

[p.255]

1. "Pre-relativistic time". In [*] Sklar describes a necessary condition for a common temporal relation, namely, shared simultaneity with any other temporal relation. This is an "observer independent" relation.

$$T_i = T_j \text{ for all } i, j \in F$$

2. "Relativistic time". In [**] the equivalence of simultaneity is not global but restricted to "observers in the same inertial frame". Example. Let $i \neq j$. It is possible that aS_ib and bS_jc, but $\neg aS_ic$. Here temporal relation is not a common one.

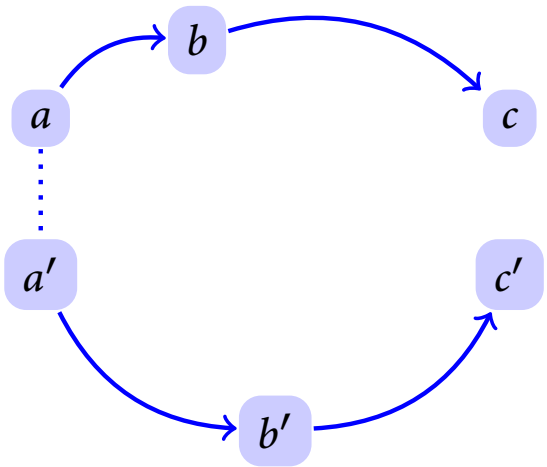
Kantian time

- Kant considered time as an innate "program", so to speak, for processing "raw date" of inner and outer experience; it is "the a priori formal condition of all appearances in general" (*Critique of Pure Reason*). Thanks to the innate time-program the content of any experience is ordered by temporal relation, i.e., by precedence and simultaneity relations.
- On one hand, Kant's concept of temporal relation is monistic with respect to form: the axioms of temporal relation, like the ones given above, hold for the experience of any subject. In addition to this, being constitutive for any experience, Kant's temporal relation is connected (total).
- On the other hand, Kantian concept of temporal relation is pluralistic with respect to matter: nothing (in the subjectivist concept of temporal relation) prevents different epistemic subjects from disagreeing on, e.g., whether two events are simultaneous or not.
- Thus, Kantian concept of temporal relation is connected (w.r.t. its form) and pluralistic (w.r.t. its matter or content).

Piaget's theory on the intellectual construction of time

- The empirical research of Jean Piaget has disproved the Kantian hypothesis on innateness of the temporal form of experience, i.e., that T-axioms + connectedness describe the temporal structure of experience.
- Piaget's theory on not innate and constructive character of (subjective) temporal relation is consistent with experiments, while the Kantian theory is not.
  - According to Piaget, "the notion of speed is more fundamental than the notion of time".
  - In the early psychological age there is a discrepancy between "perceptive time" and "intellectual time".

Figure : The coordination of the two series of (a; b; c and a'; b'; c') of events is not an easy task for the human mind. There is "no primitive notion of simultaneity" (Piaget) and so the temporal relation needs not be connected.



Speed as a primitive notion

"In the first experiment we have two tunnels, side by side. One of them is longer than the other, and children have no difficulty seeing this and pointing to the longer one. Then, for each tunnel we have a miniature doll. The dolls are set up to move on tracks at fixed speeds. In the first phase of the experiment we have the dolls enter the tunnels at exactly the same time and emerge from the tunnels at exactly the same time. It is clear that the doll in the longer tunnel must have gone faster, but the unanimous reply from my youngest subjects is that the two dolls moved at the same speeds. The children admit that the dolls went into their tunnels at the same time and came out of them at the same time and that one of them had a much longer tunnel to go through, but nonetheless they assert that the two went at the same speed because they came out at the same time. This is purely an ordinal argument. In the next phase of the experiment we take of the tunnels so that the children see the dolls moving. Once again, the dolls cover the distance in the same time but one of them has a longer distance to cover. This time the very same children say that the doll covering the greater distance goes faster because they can see it pass the other one. They are not coordinating the constant speeds with the different lengths; they are simply reacting to the fact that one of the dolls overtakes the other. In the third phase of the experiment we put the tunnels back over the tracks and repeat the first phase. A great number of our 4– and 5–year-old subjects go right back to what they said in the first phase, namely, that the two dolls go at the same speed because they come out at the same time."[pp.63–4]

"…this intuition of speed precedes any notion of speed in the classical sense as a relationship between a spatial interval and a temporal interval."[p. 63]

Jean Piaget (1970).
Genetic Epistemology.
Columbia University Press.

Experiment showing a non-connectedness of temporal relation in the child's implicit theory of time

—Situation *A*: "The experimenter has two little dolls, one in each hand, that walk along the table side by side (they do not actually walk; they go in hops, tapping the table together at the end of each hop). The child says *Go*; the two dolls start off at exactly the same time and the same speed. The child says stop, and the two dolls stop, once again side by side having gone exactly the same distance." —Situation *B*: "one of the dolls has a slightly longer hop each time than the other, then, when the child says *Stop*, one doll will be farther along than the other."

The experimenter's questiones:

?Start Did the dolls start at the same time?

?Stop Did the dolls stop at the same time?

	?Start	?Stop
The child's answer in situation *A*	YES	YES
The child's answer in situation *B*	YES	NO

Gaps within temporal relation

- (*) The child answers negatively to the questions: "When the first doll [the slower one] stopped, was the other [the faster doll] still moving?" and "When the second doll [the faster one] stopped, was the other [the slower doll] still moving?". These answer shows that the child believes the no event of the two preceded the other. The content of the child's belief can be represented by the formula $\neg s <_c f \wedge \neg f <_c s$ where: s refers to 'the event of stopping of the slower doll", f refers to 'the event of stopping of the faster doll", $<_c$ stands for temporal relation as conceived by the child.
- Suppose that according to the child's implicit theory relation T_c is connected. Then (10) represents the child's belief. (11) represents the belief expressed in the child's [*] answers. (12) ought to be child's belief, but this is not the case since the child denies the simultaneity of the two stopping-events. Therefore, *the temporal relation T_c in the child's theory is not connected*.

$$\mathrm{B}_c(s <_c f \vee f <_c \vee s S_c f) \tag{10}$$

$$\mathrm{B}_c(\neg s <_c f \wedge \neg f <_c s) \tag{11}$$

$$\mathrm{B}_c(s S_s f) \tag{12}$$

A surprising similarity

- Not connectedness:
  - is not permitted in objectivistic time characterized by the common temporal relation (Newtonian time),
  - is not permitted in subjectivistic time devoid of the common temporal relation (Kantian time).
- The adult's implicit theory of temporal reality is Newtonian with respect to the objective world and Kantian with respect to subjective worlds of the others. Nevertheless, not connectedness in the child's concept of temporal relation needs not be a mistake. Surprisingly, it can be shown that in the scientific theory of objectivistic time the temporal relation is not-connected, too.
- The theory of time in Einstein's special theory of relativity has an philosophically far-reaching interpretation in which the conceptual connection between the time and causality is reversed: causality is not defined in terms of temporal relation (as regular succession of event types) but the other way round.

A new notion of time

- In *special theory of relativity* (Einstein, 1905) simultaneity is given an "operational definition" (showing not what simultaneity is but how it is established in terms of observation). The temporal relation depends on the motion of the inertial frame within which lights emitted meet. Thus, there is no common temporal relation, but rather different inertial frames i and j t have different temporal relations, $T_i \neq T_j$.

Simultaneity as a defined notion

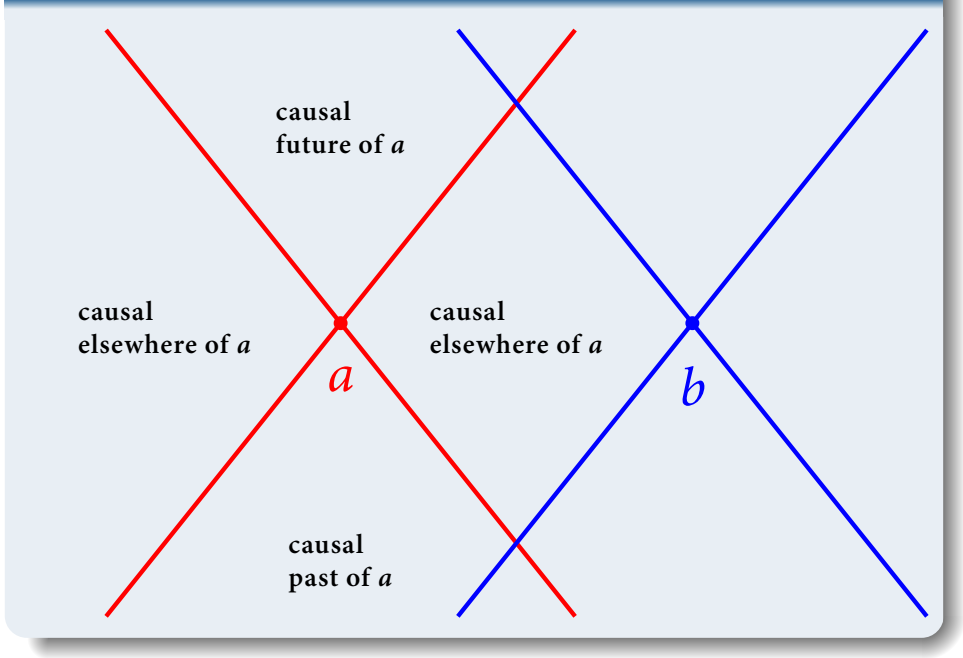
Two events e_1 and e_2, occurring at points p_1 and p_2 of an inertial frame F, respectively, are *simultaneous in* F if and only if light emitted at e_1 meets light emitted at e_2 at the midpoint m of the segment $p_1\ p_2$ in F.

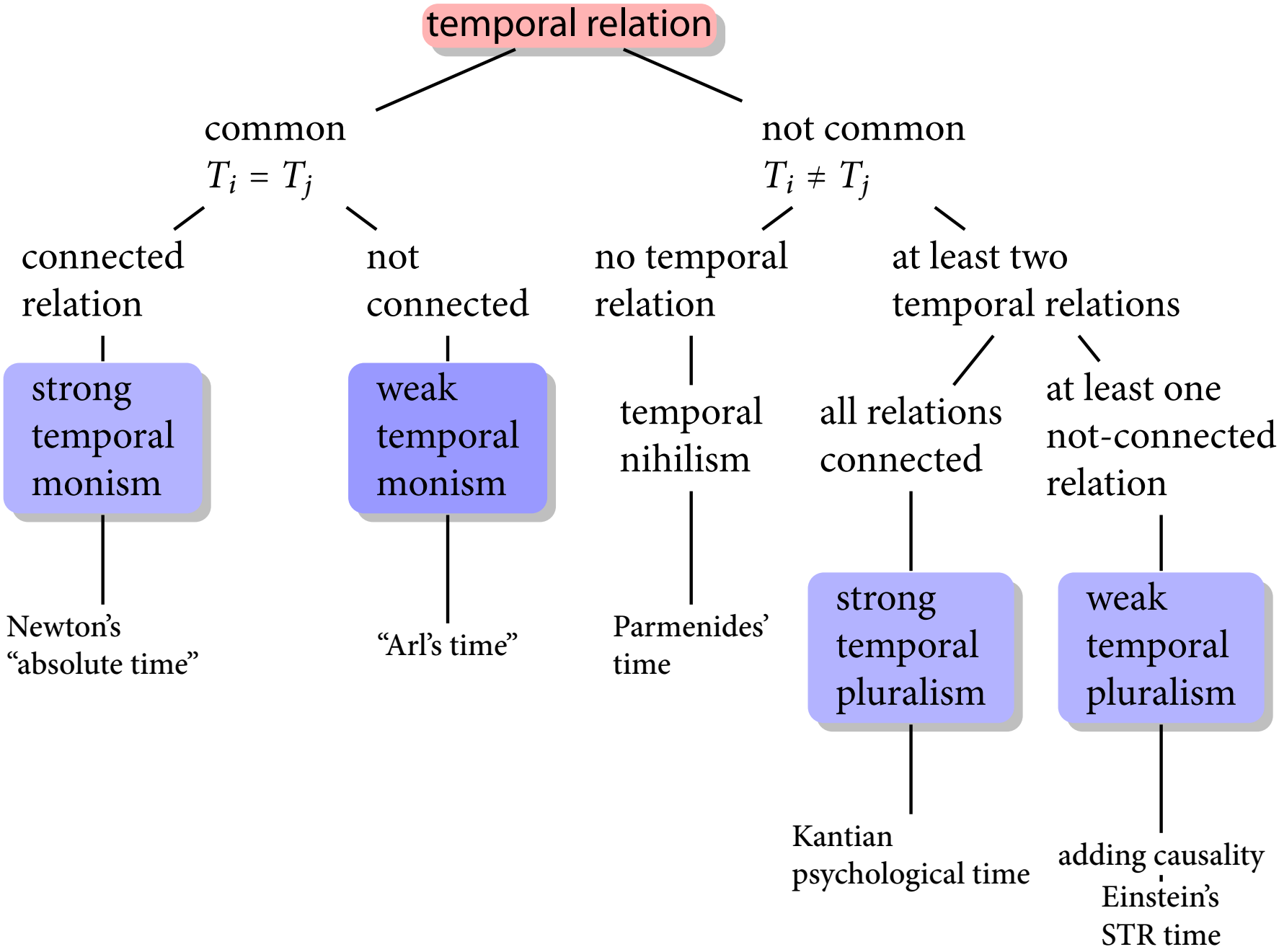
N. Rakić. 1997. *Common Sense Time and Special Relativity*, Institute for Logic, Language and Computation, Amsterdam.

Non-connectedness of causal temporal relation

The casual future of an event *e* comprises all events that can be casually influenced by event *e*; the casual past of *e* comprises all events that can causally influence *e*. Since no speed can exceed the speed of light there is a limit on possibility of causal influence. If the two events *e* and *f* are connectible only by a signal travelling faster than the speed of light, then the causal influence between them is not possible. Therefore, they are neither in the causal past nor in the causal future of each other, but belong to the "causal elsewhere" of each other.

a and *b* are not connected by causal temporal relation

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A comparison

history of science	
strong monism (Newton)	weak pluralism (Einstein)
common temporal relation	not common temporal relation
connected temporal relation	*not connected causal-temporal relation*
simultaneity as a primitive notion	*simultaneity as defined notion*
cognitive development	
weak monism (the child)	strong monism (the adult)
common temporal relation	common temporal relation
not connected temporal relation	connected temporal relation
simultaneity is not a primitive notion	simultaneity as primitive notion

1

[1]Note how some features of the anterior stage of cognitive development re-emerge in the posterior stage of history of science.

Educational consequences

- Education in science and philosophy involves care for the learning process (the care which ought to be recognized by the learner). The facts in history of science and cognitive development show that the learning process is not a cumulative process, but rather a process involving conceptual revolutions.
- Education thus involves the care for conceptual revolutions in the mind of the Other. Firstly, education is an effort in suppressing influences that might endanger the transition from one stage of cognitive development to another, and in creating the learning environment that facilitates this process. This implies discovering implicit theories of the child, such as "weak temporal monism", and relating them to theories of the next stage in cognitive development, such as "strong temporal monism". Secondly, education is an attempt in advancing cognitive development by enabling the transition form its highest stage to the current stage of best scientific and philosophical knowledge. For example, from "strong temporal monism" to "weak temporal pluralism".[2] Thus, education is an extension of psychological development with culture.

[2]Note how the aim of one educational task (=reaching strong temporal monism) becomes the object of deconstruction for the other educational task (=achieving weak temporal pluralism).

Unlearning as the primary educational task

- What teaching with respect to objective time?

	from weak temporal monism to strong temporal monism
educational task	not to disturb the process of conceptual revolution

	from strong temporal monism to weak temporal pluralism
educational task	to enable the process of conceptual revolution

- The existence of conceptual revolutions within the knowledge-process shows that education is about *unlearning* at least as much as it is about learning.
- The gap between the two scientific cultures, STEM versus arts and humanities, destroys the possibility of proper education, which requires integration of best available knowledge about nature with the best possible knowledge about knowledge.