# If processes are fundamental, what does this tell us about the nature of time?

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I will not argue that processes *are* fundamental.

Instead, taking this as given, what follows?

In particular: What are the implications for **time** and **change**?

# The "at-at" theory of motion and change

*Motion is the occupation, by one entity, of a continuous series of places at a continuous series of times. Change is the difference, in respect of truth or falsehood, between a proposition concerning an entity and a time $T$ and a proposition concerning the same entity and a time $T'$, provided that the two propositions differ only by the fact that $T$ occurs in the one where $T'$ occurs in the other."*

Bertrand Russell, *Principles of Mathematics* (1903), §442

## Change and difference

The at-at theory is a *reduction* of **change** to **difference**: Change means that *different* states hold at *different* times, *and nothing more than this*.

For this to be a genuine reduction, the primitive terms — "different", "state", and "time" — must not themselves presuppose any prior notion of change.

In particular, the **states**, differences between which at different times constitute change, must be **static**.

## Mathematical modelling of change

The at-at theory harmonises well with the standard (and *highly fruitful*) mathematical practice of modelling change by means of **functions over time**.

Variation in a quantity $q$ over time is captured by modelling $q$ as a function from times to values, so that for some times $t_1$ and $t_2$, say, we have $q(t_1) \neq q(t_2)$.

It is important here that the definition of "function" in mathematics does not refer to change: rather it is defined as a *set* (typically infinite) of pairs of values: e.g.,

$$\{\langle t_1, q(t_1)\rangle, \langle t_2, q(t_2)\rangle, \ldots\}.$$

## Mathematical Idealisation of Times as Instants

Empirically determined values for $t$, $q(t)$, etc, are expressed as *rational* numbers, with (implicit or explicit) error bars.

To apply mathematical theories such as the integral and differential calculi to these values it is usual to accept the idealisation that they range over the *real* (= rational $\cup$ irrational) numbers.

Ignoring the error bars, *times* are correlated with real numbers. As such, they are conceptualised as *point-like* or *durationless* — in other words, as **instants** rather than **intervals**.

## No change in an instant

Within an instant there is no room for change, which is why the states associated with time instants must indeed be static, as required by the at-at theory.

Russell himself insisted that there was no such thing as a **"state of change"**: the world at an instant is truly static, and change only exists by virtue of different static states holding at different instants.

(Here there are obvious — much-discussed — connections with Zeno's Arrow Paradox, but I shan't spell them out here.)

### Instantaneous states of change?

Some authors have flirted with the idea that, *contra* Russell, there are *instantaneous states of change*.

But this idea can be understood in two ways, one of them fully in accord with the at-at theory, the other not.

## The first way

The at-at theory need have no quarrel with the standard mathematical definition of the **rate of change** of a variable at an instant, as given by the first derivative of the function which delivers the values of the variable at different times.

If this rate of change is non-zero at a particular instant, it is natural (and harmless) to say that the variable *is changing* at that instant . . .

. . . and is thus in a certain sense in a state of change then.
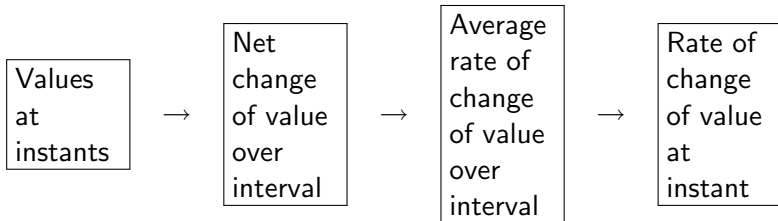
## The first way (continued)

*But* the mathematical rate of change of a variable is a somewhat complex logical construction, by which the notion of **rate of change at an instant** is logically reducible to that of **average rate of change over an interval**.

The former is the *limit* of the latter in a precise mathematical sense.

And the latter is easily defined as the *net* change over the interval, divided by the length of the interval — where the net change over the interval is defined as the difference between the values at the end points of the interval.

## Explanation of motion in the at-at theory

The order of explanation is thus as follows:

$$\boxed{\begin{array}{l}\text{Values}\\\text{at}\\\text{instants}\end{array}} \rightarrow \boxed{\begin{array}{l}\text{Net}\\\text{change}\\\text{of value}\\\text{over}\\\text{interval}\end{array}} \rightarrow \boxed{\begin{array}{l}\text{Average}\\\text{rate of}\\\text{change}\\\text{of value}\\\text{over}\\\text{interval}\end{array}} \rightarrow \boxed{\begin{array}{l}\text{Rate of}\\\text{change}\\\text{of value}\\\text{at}\\\text{instant}\end{array}}$$

Very roughly:

— *"Why is it moving?"*

— *"Because it's in different places at different times."*

# Reversing the order of explanation

It might seem more satisfactory to reverse this as follows:

— *"Why is it in different places at different times?"*
— *"Because it's moving."*

For this to work, while adhering to the instant-based model, it must be possible to define a state of change as an intrinsic primitive property of an instant, not reducible to a prior notion of net change over an interval.

This idea might lead us to a **Second Way**, in direct conflict with the at-at theory. It has had its advocates, and forceful detractors.

# "Changing form" vs "Change of form"

Bigelow and Pargetter 'Vectors and Change' (1989) discuss the late mediaeval debate between the doctrines of "changing form" (*forma fluens*) and "change of form" (*fluxa formae*):

- **Changing form** (Ockham) — essentially the "at-at" theory: *Motion is no more than just the occupation of successive places at different times.*

- **Change of form**: *The motion vector explain[s] the sequence of positions a body occupies ... The vectors explain the sequence of positions, not vice versa.*

# Against the Ockhamist view

One argument Bigelow and Pargetter advance against the
Ockhamist view concerns a meteor crashing onto Mars:

> *At the precise moment of impact, the meteor exerts a specific
> force on the surface of Mars. Why does it exert precisely that
> force? Because it is moving at a particular velocity. On the
> Ockhamist view, what this amounts to is that it exerts the
> force it does because it has occupied such-and-such positions
> at such-and-such times. In other words, the Ockhamist appeals
> to the positions the meteor has occupied in the past. But why
> should a body's past positions exert any force now? This
> requires the meteor to have a kind of 'memory' . . .*

By contrast, on the flux theory:

> *the meteor exerts a given force, at a moment, because of the
> property it has at that very moment. This property is an
> instantaneous velocity, a vector, with both magnitude and
> direction.*

# The Options on the Table

Arntzenius (2000) discusses three positions we might take:

1. The "at-at" theory: *To be in motion is just to be at different places at different times. There is no question of one's motion, or velocity, at a given time.* [Here 'time' means *instant*.]

2. The impetus theory: *[A] body in motion has some kind of internal property, called "impetus," that provides, or is, the driving force to keep the object going in the direction that it is already going.*

3. The "no instants" theory: *There are no such things as instants in time, no 0-sized temporal "atoms".*

Arntzenius refuses to come down in favour of one or other of these positions, offering arguments for and against all of them.

In what follows I shall pursue the third option.

## Changes and times

In substance-based ontologies, the primitive temporal notion is the **obtaining of a static property at a time**.

But if processes are ontological primitives, then since processes intrinsically involve change, the primitive temporal notion should rather be the **occurrence of change at a time**.

Which leads to the urgent question:

**What kinds of time can one primitively ascribe change to?**

# What are the primitive constituents of time?

Let us assume that the only viable way of assigning change to an instant is by the method of the differential calculus, by which a state of change at an instant is derived from actual changes over intervals.

Then there is no primitive assignment of change to instants.

If change can only derivatively be assigned to instants, it follows that then *primitive* ascriptions of change must be to intervals.

Therefore, if processes — which involve change — are primitive, it follows that **the primitive constituents of time are intervals, not instants**.

# Back to Aristotle

This is nothing new!

Aristotle: *Time does not seem to consist of nows.* (Phys. IV.10)

This thought needs constant reiteration to counter the bewitching power of mathematical analysis which makes instants primitive, with intervals somehow constituted from them.

If an interval is *made of* nothing but durationless instants, it is a mystery where its **duration** comes from.

Aristotle again: *The now is not a part of time, because a part measures the whole and the whole must consist of its parts; time, however, does not seem to consist of nows.* (ibid.)

So what *is* an instant, if not the "raw material" of time?

Continuing the Aristotelian theme, if instants exist at all, then they are either **limits** or **boundaries**.

## The instant as a limit

An instant could be the limit of an infinite nested series of ever-shorter intervals whose lengths tend towards zero.

To specify such a limit we have to specify the intervals which converge to it.

In the physical world this would mean picking out an infinite nested series of ever-shorter *events*.

Since this is (clearly?) impossible, all we can do in practice is to define a *sufficiently short* event to be a representative of such a series.

This is what we do when, e.g., we take individual ticks of a clock as approximations to instants.

# The instant as boundary

An instant could be the meeting point of two contiguous intervals: it is simultaneously the end of the first and the beginning of the second. (Though Brentano held these to be distinct but simultaneous.)

In practice we pick out such boundaries using *instantaneous events* such as

- ▶ the inception or cessation of a body's motion;
- ▶ the attainment of the highest point in the trajectory of a projectile;
- ▶ the first contact between two bodies in collision.

### How discontinuity arises from continuity

An instantaneous event marks a **qualitative discontinuity** in the course of some process or event.

A qualitative discontinuity occurs when the continuous quantitative variation of some variable crosses a **salient boundary**.

## Example: The Ball Thrown Upwards

The ball's vertical velocity ranges continuously over real-number values. These values can be partitioned into three salient subsets:

- ▶ **Positive** (the ball is moving upwards)
- ▶ **Negative** (the ball is moving downwards)
- ▶ **Zero** (the ball is moving neither upwards nor downwards)

The highest point of the trajectory marks the boundary between an interval of positive velocity and an interval of negative velocity.

In idealisation it has *zero* velocity just at that one instant, the point of discontinuity when the ball is moving neither up nor down.

(In reality it is much messier: the velocity of the ball is the average of velocities of all its constituent molecules . . . )

## Infinite precision is impossible

Assuming the possible values of a variable being measured are densely ordered, a perfectly precise measuring device would have to deliver answers to infinitely many decimal places in order to distinguish values arbitrarily close together.

Since this is clearly impossible, it is impossible — *even in principle* — to pinpoint an "instantaneous" event to a mathematically exact moment.

In reality the best we can do is to identify an approximate interval within which, e.g., the ball's velocity is not measurably different from zero.

## Putting instants in their place

An uncritical acceptance of the real (or even rational) numbers as our model for time and other physical continua, and as the basis for scales of measurement, implies a belief that only infinite-decimal-place precision can provide a true description of reality.

The times of real-world phenomena can only be modelled by intervals, which are indeterminate to the extent that their beginnings and endings can also only be given as intervals of the same kind.

Let us leave instants where they belong, in the realm of abstract mathematical idealisations, not that of physical reality itself.

## The Present Moment

Surely the present moment — which is one of Aristotle's nows — is an instant?

Aristotle suggests that time does not consist of nows, but how can we reconcile this with the thought that **the past consists entirely of former presents**? Every part of the past contains parts that were once present.

But the extended past cannot be made of unextended presents: so the present must be extended too. We seem forced to conclude that the present is not an instant but an interval.

# But how could the present be an interval?

St Augustine: *The only time that can be called present is an instant, if we can conceive of such, that cannot be divided even into the most minute fractions, and a point of time as small as this passes so rapidly from the future to the past that its duration is without length. For if its duration were prolonged, it could be divided into past and future. When it is present it has no duration.*

*Confessions*, Book XI, 15

Robin Le Poidevin: *Assuming time to be infinitely divisible, the present can have no duration at all, for if it did, we could divide it into parts, and some parts would be earlier than others. But something that is present cannot be earlier that anything else that is also present! So the present cannot have earlier and later parts, which is to say that it can have no duration.*

*Travels in Four Dimensions*, p.156

# The Argument Formalised

| | | |
|---|---|---|
| 1. | Any duration can be divided into parts. | (Stated premise) |
| 2. | The present is a duration. | (Assumption to be refuted) |
| 3. | If a duration is divided into parts, some of those parts are earlier than others. | (Unstated assumption) |
| 4. | The present has parts some of which are earlier than others. | (1, 2, 3) |
| 5. | If A is earlier than B then A and B cannot both be present (i.e., parts of the present). | (Unstated assumption) |
| 6. | The present cannot have parts some of which are earlier than others. | (5) |
| 7. | The present has no duration | (2 refuted: contradiction 4+6) |

# The Contradiction Defused I

▶ Both unstated assumptions use the term "earlier than". How should this be defined?

▶ "X is earlier than Y" means "X is past when Y is present".

▶ Disambiguation:

  ▶ "X is **strongly earlier** than Y" means "X is past *whenever* Y is present".

  ▶ "X is **weakly earlier** than Y" means "X is past *at some time* that Y is present".

## The Contradiction Defused II

**Assumption 3** (*"If a duration is divided into parts, some of those parts are earlier than others"*) is reasonable if "earlier" is read as "at least weakly earlier".

**Assumption 5** (*"If A is earlier than B then A and B cannot both be present"*) is reasonable if "earlier" means "strongly earlier", but *not* if it means "weakly earlier".
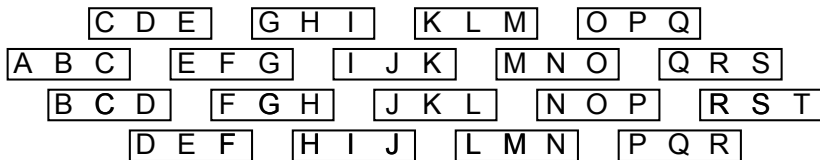
Hence what the argument establishes is

(4) *the present has parts some of which are weakly earlier than others*, and

(6) *the present cannot have parts some of which are strongly earlier than others.*

**There is no contradiction!** The argument fails to establish that the present has no duration.

# Weak and Strong Succession

| C D E | | G H I | | K L M | | O P Q | |
|---|---|---|---|---|---|---|---|

A B C | | E F G | | I J K | | M N O | | Q R S

B C D | | F G H | | J K L | | N O P | | R S T

D E F | | H I J | | L M N | | P Q R

The boxes represent (a selection of) presents;
A, B, C, . . . are "events".

Each event is weakly earlier than the next two in the series, and
strongly earlier than all the later ones.

- ▶ B and C can be present together (as in the presents ABC and
  BCD), but B can also be past when C is present (as in the
  present CDE) — so B is weakly earlier than C.

- ▶ B is past whenever E is present, so B is strongly earlier than E.

# Overlapping Presents

The "overlapping presents" model has been proposed by various authors, notably:

- **William James**, *The Principles of Psychology*, Chapter 15, 1890

- **Michael Dummett**, 'Is time a continuum of instants?', *Journal of Philosophy*, 1969.

- **Barry Dainton**, 'Sensing change', *Philosophical Issues*, 2008.

and even:

- **Bertrand Russell**, 'On the Experience of Time', *The Monist*, 1915.

The overlapping presents model has historically arisen from the idea that the present is in some degree subjective.

- James — the **specious present**, a psychological entity postulated to capture the idea of what is present *in experience*.

- Dainton — the **stream of consciousness**.

- Dummett — **measurement**:

  *The duration of a moment [is] at most as small as twice the margin of error of our most accurate measurements of time.*

- Russell drew a sharp distinction between **physical time** and **mental time**. The former has instants, the at-at theory, etc, the latter is much more like the picture we have been moving towards.

## Process and Experience

There cannot be such a thing as an instant of experience because:

- experience is a process
- processes require change
- change requires duration

But now we can factor out experience and conclude that a world constituted by processes, irrespective of the presence or absence of experiencing subjects, will be subject to the same logic:

**Change and temporal succession cannot be built out of instantaneous building blocks.**

## Subjectivity vs Intersubjectivity

The subjectivity of the present seems to be at odds with the sense we have of a *shared* present:

### "We're all in this together".

When we interact with other people, we seem to have a strong sense of a common present, a synchrony of all our individual presents, evolving through time together.

How can this be, if the present has no objective significance?

## The shared present

Butterfield, 'Sensing the Present' (*Mind*, 1984)
Callender, 'The Common Now' (*Philosophical Issues*, 2006)

Typical changes in our environment happen much more slowly than the speed at which we can monitor them.

This means that we can monitor them in "real time".

In particular, we can monitor *each other*.

This mutual monitoring can take place within the duration of an extended present: the "common now".

# Spatio-temporal Separation in STR

If observers $O_1$ and $O_2$ assign to two events spatial and temporal distances $\delta x_1, \delta t_1$ and $\delta x_2, \delta t_2$ respectively, then the invariant squared space-time distance between the events is

$$\delta s^2 = \delta x_1^2 - c^2 \delta t_1^2 = \delta x_2^2 - c^2 \delta t_2^2.$$

▶ If $\delta s^2 > 0$, the separation between the events is **spacelike**. No causal influence can pass either way between the events.

▶ If $\delta s^2 = 0$, the separation is **lightlike**. A light signal could pass from the earlier event to the later.

▶ If $\delta s^2 < 0$, the separation is **timelike**. A slower-than-light signal (or a moving body) could pass from the earlier to the later.

# The Light-cone
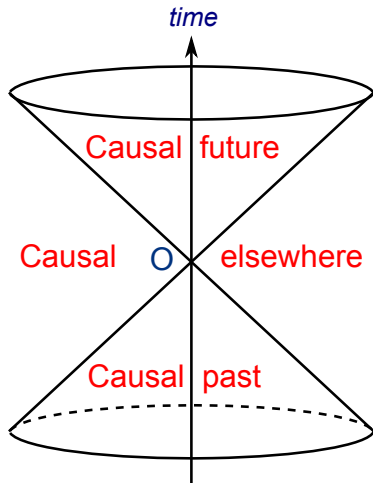


At space-time point O one can identify a **light-cone**.

The surface, interior, and exterior of the cone comprise all points whose space-time separation from O is respectively lightlike, timelike, and spacelike.

The light-cone divides all of space time into the **causal past**, the **causal future**, and the **causal elsewhere**.

# A relativistic shared present

*The "graining" of time with respect to which a percipient organism can experience conscious interaction with its environment must be such that the "moments" of time (the specious presents) are long enough to allow ... light signals ... to travel very many times the maximum spatial dimensions of the organism together with its (relevant) environment. ...*

*[I]n all our ordinary experience, the time that we experience as a "moment"—a specious present—is ... contemporaneous with events as far distant, spatially, as we ever normally have to do with at all.*

Howard Stein, 'On relativity theory and openness of the future' (*Philosophy of Science*, 1991)

## The spatial extent of the present

*When a soldier at roll call responds "Present!" upon hearing his name, he is not merely announcing that he still exists; he means that he is on the spot.*

H. Stein, ibid.

Following Butterfield, Callender, and Stein, I propose that

*My present has a **spatial** extent determined by the limits of a two-way exchange of signals within the **temporal** duration of my specious present.*

We're in it together when our spatio-temporal presents overlap, enabling mutual communication in a shared present.

Whereas the classical picture is of a present that is unbounded in space and unextended in time, this is a present that is finitely extended in both space and time.
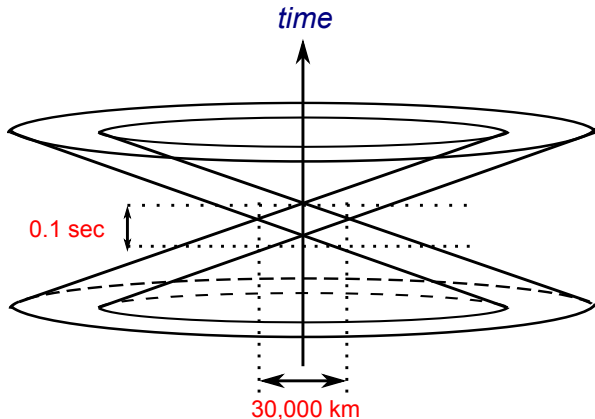
# The Relativistic Spatio-temporal Present



*time*

Temporal extent
of O's present

Spatial extent
of O's present
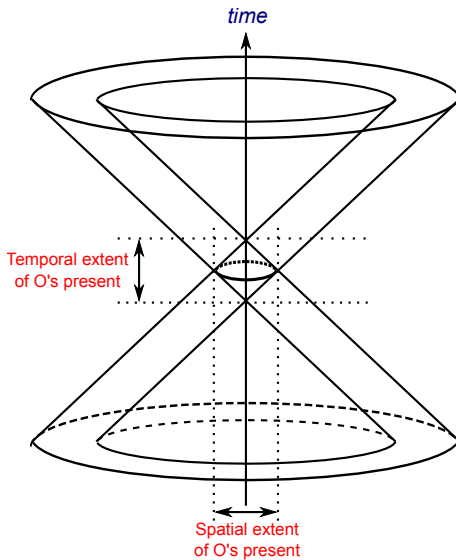
## The extent of the present

The speed of light is close to 300,000 km/sec. If my specious present has a duration of, say, 0.1 seconds, then it has a spatial extent of 30,000 km — more than enough to overlap with the presents of everyone on earth.



*time*

0.1 sec

30,000 km

## Presentism?

It seems natural that Process Ontology, with its emphasis on *change* as a fundamental, primitive feature of the world, should be friendly to **presentism** (*"only what is present is real"*), or at least to **possibilism** (*"only what is present or past is real"*).

Does this picture of the finitely bounded present spell the end of presentism and possibilism? *I don't think so.*

Even a "classical" presentist has to admit that *past* people (including our former selves) had different presents from us now. All we have to add to that is that *spatially distant* people have different presents from us here and now.

But those presents will eventually *come* to be past for us — even those which were never present *for us*.

# Thank you for listening!

## ANY QUESTIONS?