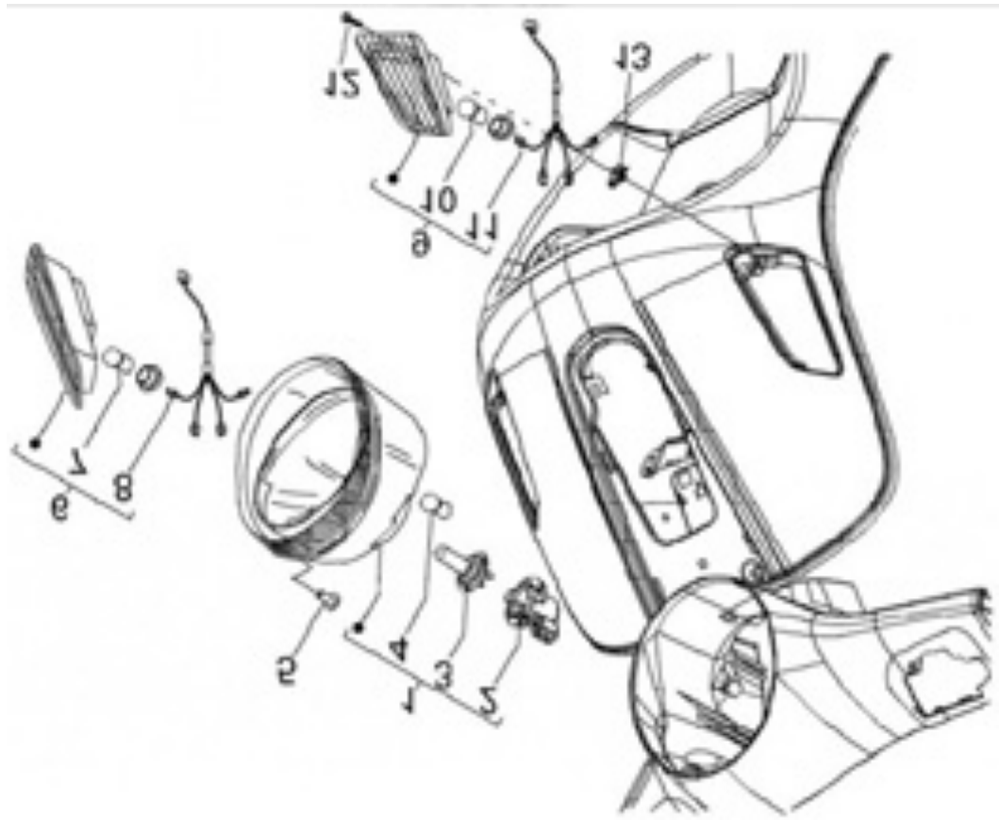
What is Time?

Carlo Rovelli

La Jolla, 3/5/18

What is a Vespa scooter?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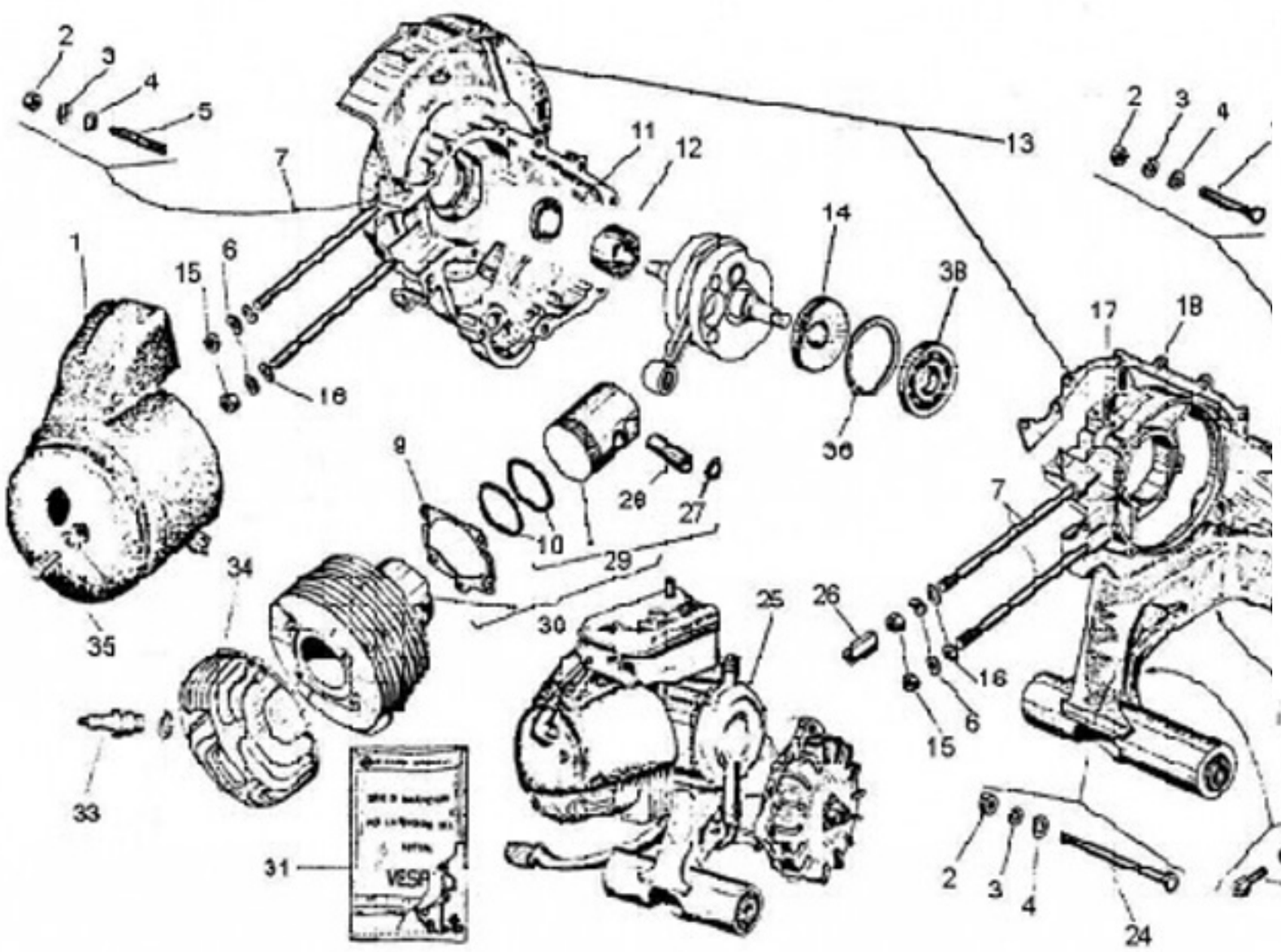
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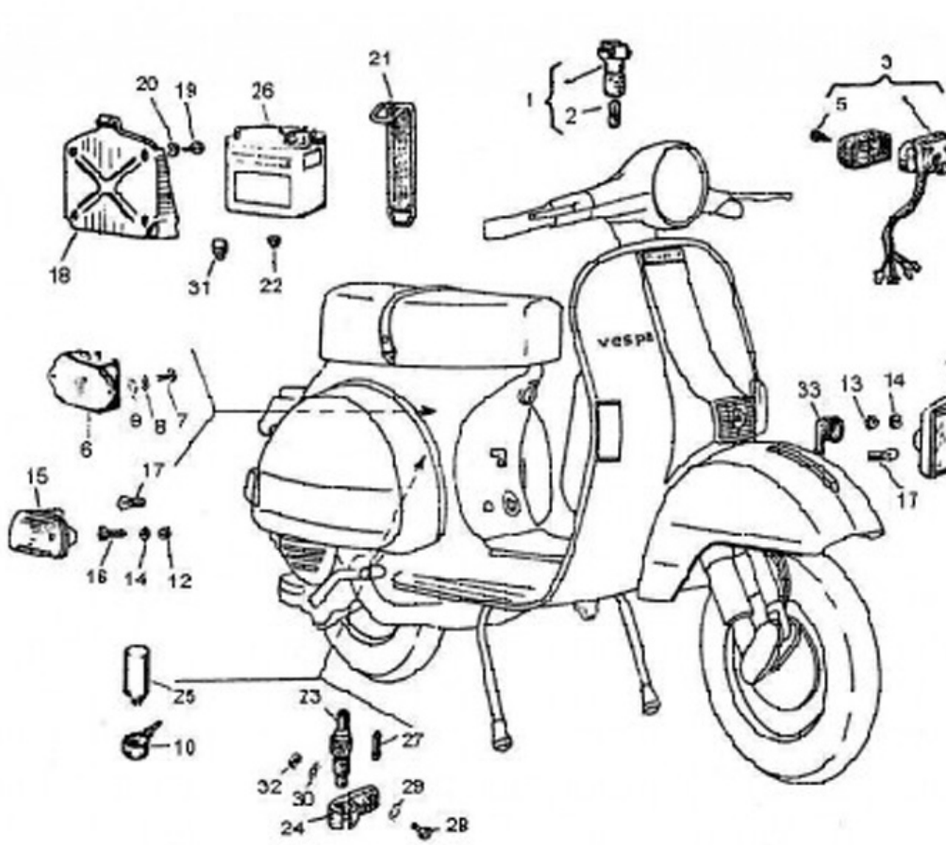
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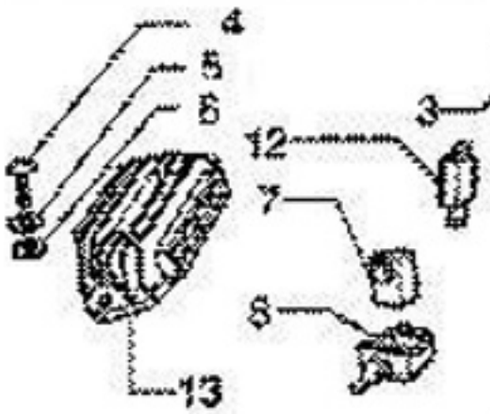
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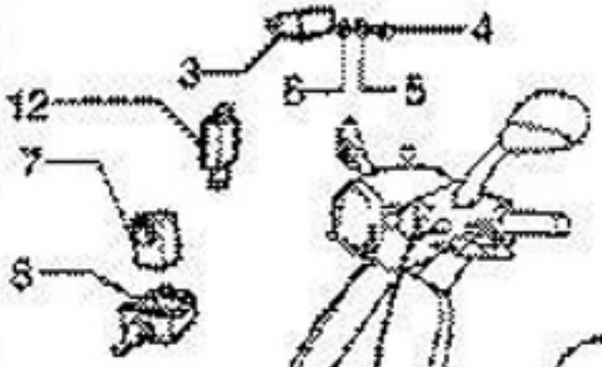
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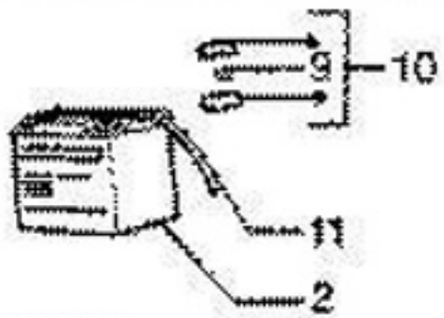
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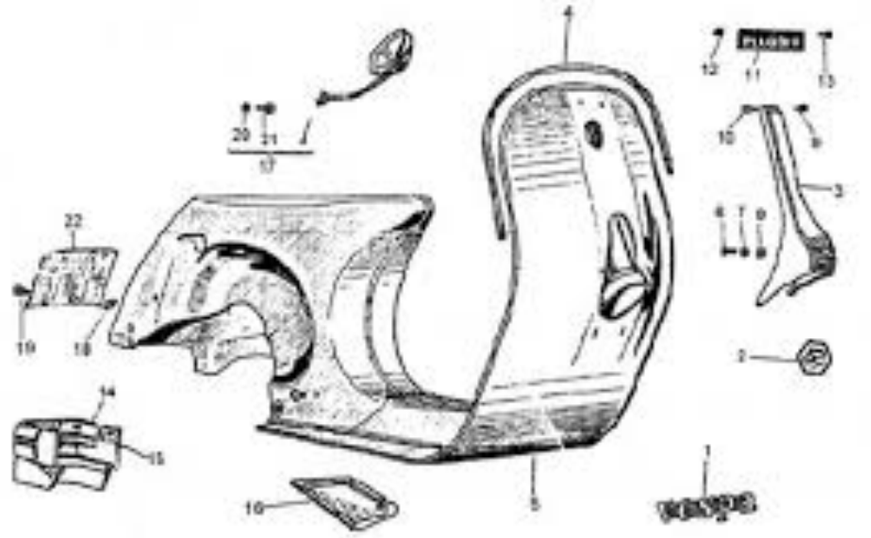
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A “Vespa scooter”
is no more than the concept we associate
to the structured and functional ensemble
of its components and its various properties

Time is like the Vespa

The common notion of time is heavily loaded, like a well-equipped Vespa:

- Time ***flows***, it passes; in fact, it runs in a disquieting way.
- It is a ***one-dimensional*** sequence of instants.
- We happen to be somewhere, at a point of it, the "***present***".
- The line is long and we loose track of it in their future, and the far past.
- It is ***oriented***: has a direction. Past is very different from future.
- It is the same for everybody, it is ***universal***.
- We ***share the same present***, wherever we are, whatever we are doing.
- Physical theories give ***evolution in time.***
- It has ***metric*** properties: we can say that two interval of times have the same ***duration***.
- it flows ***continuously***: between any two instants of time, we can always find intermediate instants.
- Time is ***a way of numbering events***.

This well loaded concept of time is well appropriate
and useful to deal with reality
in our most common human regimes.

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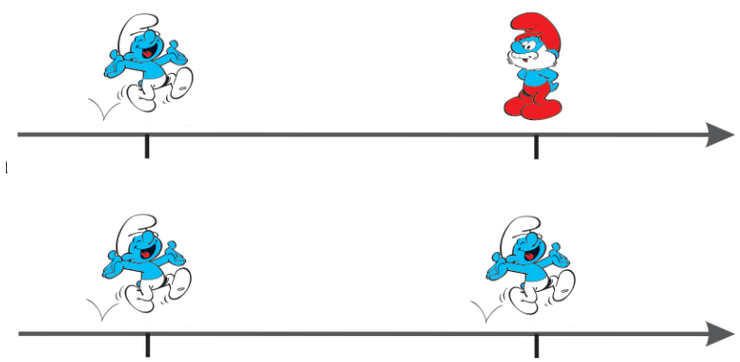
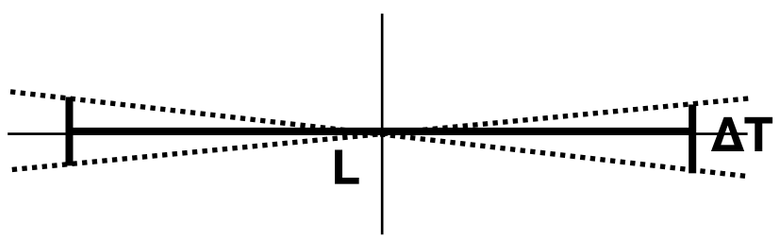
This well loaded concept of time is **not** appropriate
and **not** useful to deal with reality
in more general regimes.

- Between two events duration (measured by a clock, by ageing, by anything) can vary.
  Time is **not unique**.



- **Present** is a **local** notion
  (in a bubble of size L=cΔT).



- The difference between future and past is only grounded in statistics: low past **entropy**, under our coarse graining (including traces, memories and the direction of causation).

ΔS>0

- Presumably (quantum gravity): clock duration is **discrete** and can be in quantum superposition.
  There is **no manifold**.

Wheeler deWitt equation (quantum)

$$-\hbar^2 G_{abcd} \frac{\delta}{\delta g_{ab}} \frac{\delta}{\delta g_{cd}} \Psi[g] + R[g]\Psi[g] = 0$$

Hamilton Jacobi equation for GR (classical)

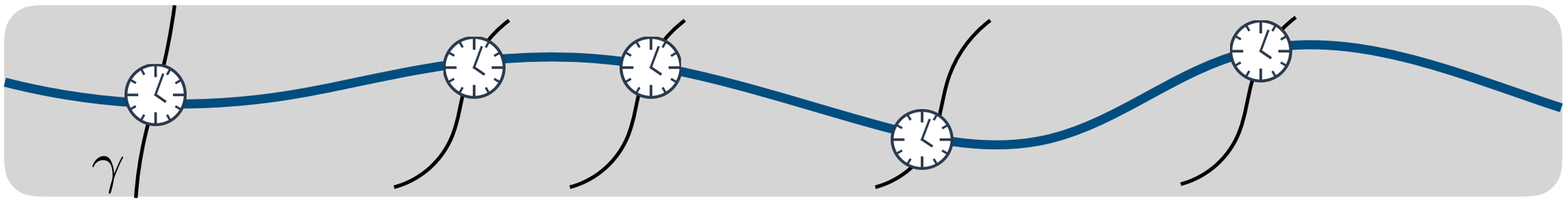
$$G_{abcd} \frac{\delta S[g]}{\delta g_{ab}} \frac{\delta S[g]}{\delta g_{cd}} \Psi[g] + R[g] = 0$$

Wheeler deWitt equation (quantum) $\Psi[g, T_1, ..., T_n]$

$$-\hbar^2 G_{abcd} \frac{\delta}{\delta g_{ab}} \frac{\delta}{\delta g_{cd}} \Psi + R[g]\Psi + H\Psi = 0$$

Hamilton Jacobi equation for GR (classical) $S[g, T_1, ..., T_n]$

$$G_{abcd} \frac{\delta S}{\delta g_{ab}} \frac{\delta S}{\delta g_{cd}} \Psi[g] + R[g] + H[g, T_1 ..., T_n, \frac{\partial S}{\partial T_1}, ... \frac{\partial S}{\partial T_n}] = 0$$



- The "*absence of time*" in quantum gravity is a **false problem: Quantum gravity has exactly the same temporal structure as classical GR**.

- There is no single physical time variable in quantum gravity because there is **no single physical time variable in classical GR**.
- There is no coordinate t, because **the coordinate t can be dispensed off also in classical GR**.

- GR expresses the **relative evolution** of several variables, including the gravitational field, other fields, and any conceivable clock along any conceivable world-line.

- ***General relativistic physics describes how variables change with respect to one another, not with respect to a single preferred time variable.***

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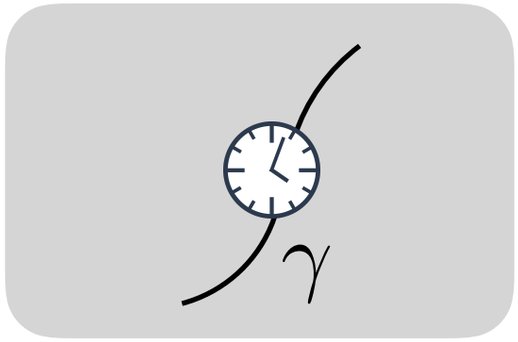

duration is really a property
of the gravitational field more than
time itself

$$T = \int_{\gamma} \sqrt{g_{\mu\nu} dx^{\mu} dx^{\nu}}$$

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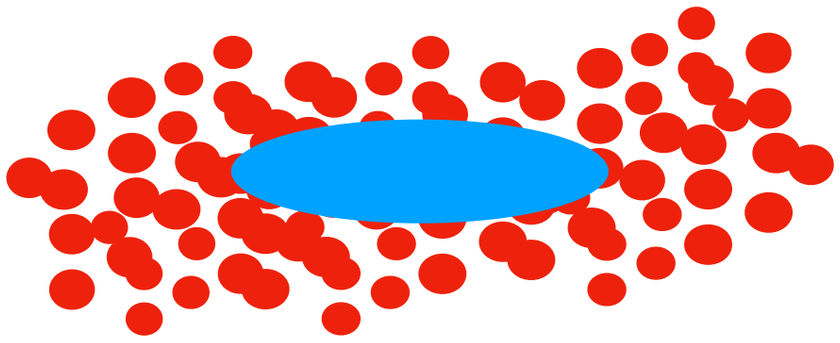
Aristotle

The temporal structure of reality at the most elementary level we presently know



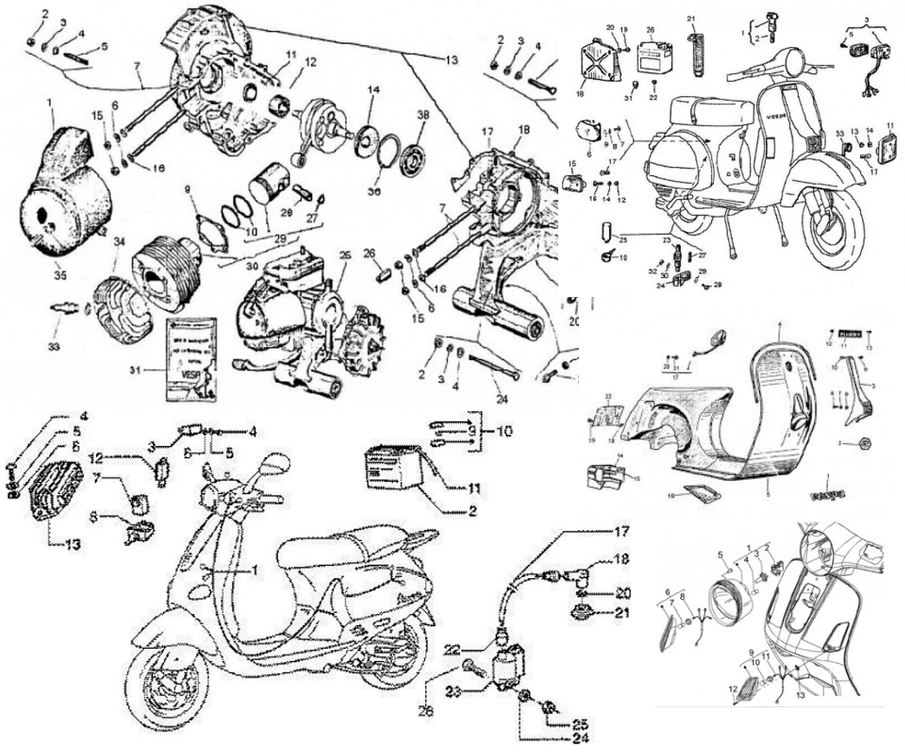
$$W[\psi] = (P_{sl2c} Y_\gamma \psi)(\mathbb{1})$$

An ensemble of (quantum) events, connected to one another, described by variables that change with respect to one other, following probability laws.

Not ordered along a line, nor as a 4d Riemann geometry.

...the foggy ruins of time

Back



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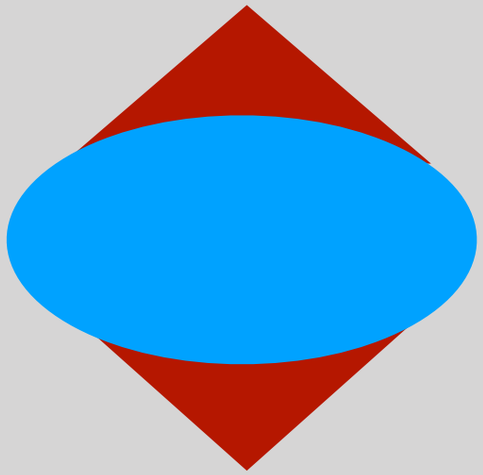
- *Flows*
- *One-dimensional*
- *Present (local)*
- *Orientation*
- *Universal*
- *Shared present*
- *Metric* ← Gravitational field
- *Evolution in time* ← “Great Informer”
- *Continuous* ← We are large with respect to Planck time
- *(local) numbering of events*. ← Quantum Gravity



“Great Informer”

- *Flows*,
- *One-dimensional* ⬅ **v << c**
- *Present (local)* ⬅ **Perspectival (we are “Situated Selves” in the world)**
- *Orientation* ⬅ **Statistics (perspectival?)**
- *Universal* ⬅ **v << c**
- *Shared present* ⬅ **L < c ΔT**
- *Metric* ⬅ **Gravitational field**
- *Evolution in time* ⬅ **“Great Informer”**
- *Continuous* ⬅ **We are large with respect to Planck time**
- *(local) numbering of events*. ⬅ **Quantum Gravity**

Thermal time

$$\rho = e^{-\beta H}$$

time → hamiltonian → equilibrium state

$$H = -\beta \ln \rho$$

time ← hamiltonian ← equilibrium state

Perspectival past low entropy

Perspectival past **low** entropy

Perspectival past **low** entropy

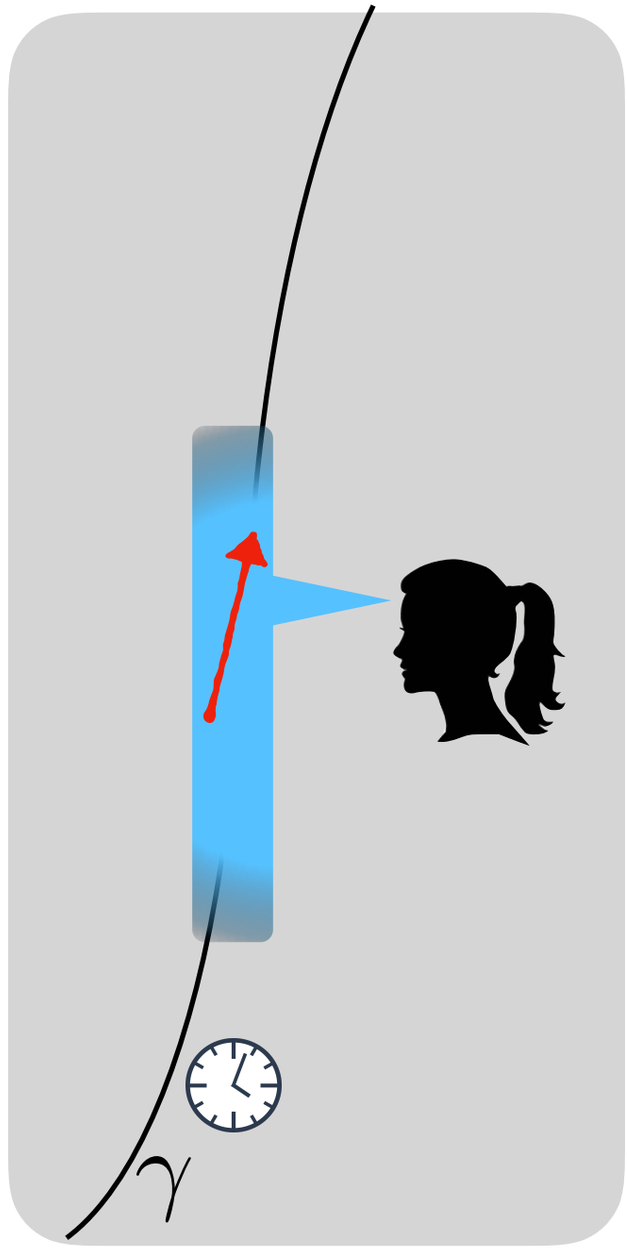
- *Flows*, ← **Brain**
- *One-dimensional* ← **v << c**
- *Present (local)* ← **Perspectival (we are located in the world)**
- *Orientation* ← **Statistics (perspectival?)**
- *Universal* ← **v << c**
- *Shared present* ← **L < c ΔT**
- *Metric* ← **Gravitational field**
- *Evolution in time* ← **“Great Informer”**
- *Continuous* ← **We are large with respect to Planck time**
- *(local) numbering of events*. ← **Quantum Gravity**

“Our brain is a time machine”

- The entropy gradient generates traces of the past in the local present

- The brain is a mechanism that continuously anticipates the future on the base of memories.

- The brain *in the present* (Augustin, Husserl) holds memories of the past and anticipations of the future. Hence the brain *in the present* holds a sort of “clearing” (Heidegger), which is an **emotionally charged** (because the anticipation of the brain are emotionally charged) connection with temporally continuous, but near, ensemble of events.



This is the time of our everyday .

The time of our everyday experience is heavily emotionally charged

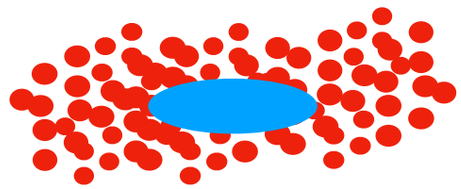
(Buddhism second Noble Truth: The single source of our sufferance is our difficulty of accepting impermanence, that is: time.)

This emotion of time colours, and to a good extent determines what we call “time”.

1. Time is a complex **multilayered** notion.

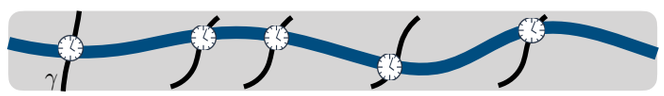
- **Flows**
- **One-dimensional**
- **Present (local)**
- **Orientation**
- **Universal**
- **Shared present**
- **Metric**
- **Evolution in time**
- **Continuous**
- **(local) numbering of events.**

2. Different layers and different properties pertain to different approximations/regimes and concern **different sciences** (quantum gravity, general relativity, special relativity, Newtonian mechanics, statistical mechanics, thermodynamics, biology, neurosciences, psychology). Confusing levels is the source of many apparent mysteries.

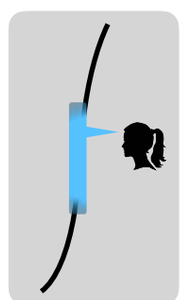


3. In elementary physics, time is not “frozen” nor “block universe. Reality is events, happenings, not things. time is any manner of locally **numbering change**.

4. **No preferred time variable is needed**. No great mystery.



5. **Thermal time** is relational. Low **past entropy perspectival**?

$$H = -\beta \ln \rho$$

6. **Experiential time depends on brain** structure, is based on memory and anticipation, is emotionally charged and structural in the formation of identity and consciousness.