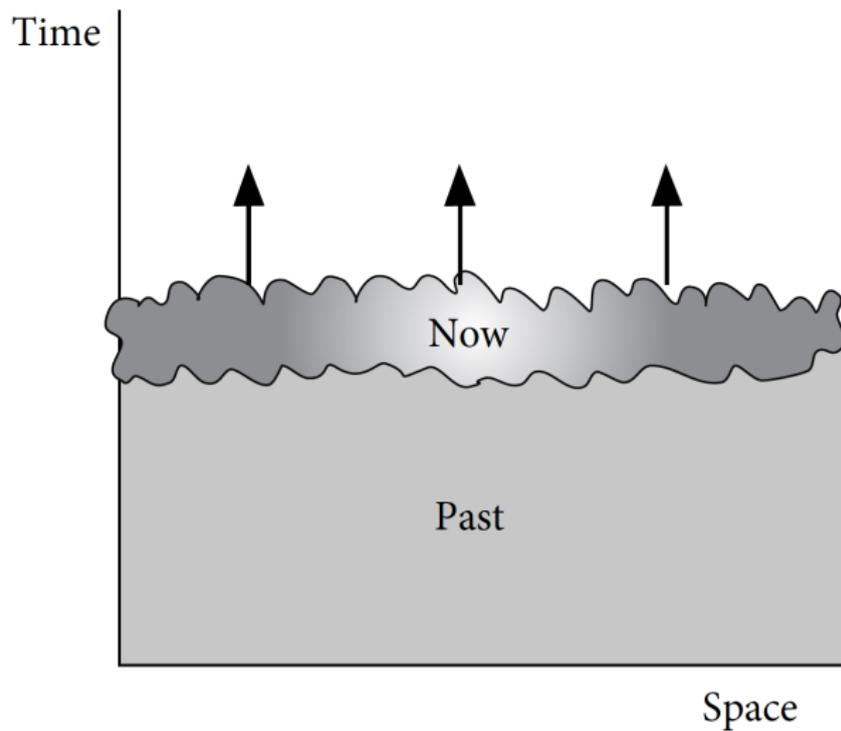


TIME IN PHYSICS

Gábor Hofer-Szabó

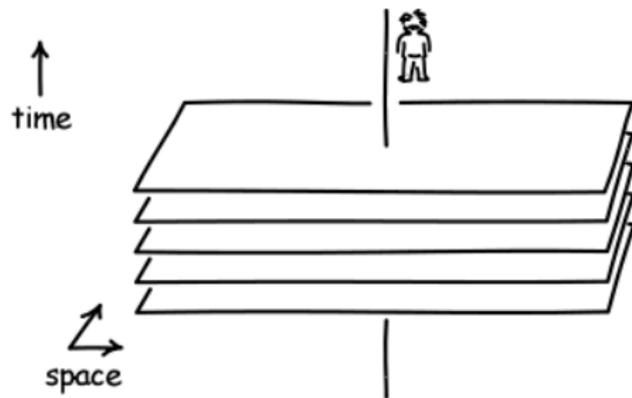
Research Centre for the Humanities, Budapest

Manifest time



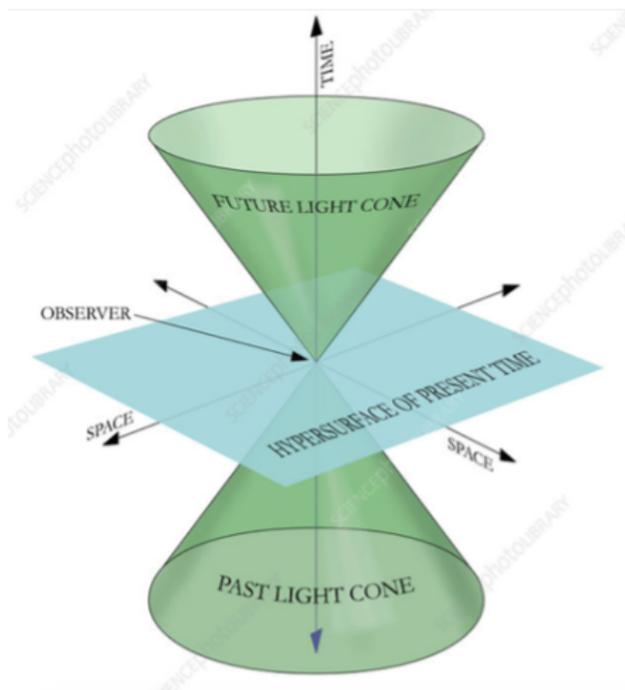
- **Einstein:** "People like us who believe in physics know that the distinction between past, present, and future is only a stubbornly persistent (*hartnäckige*) illusion"
- **Carnap:** "all that occurs objectively can be described in science"

Classical spacetimes



- Spacetime = Space \times Time
- Absolute time
- Duration is path-independent
- One master-clock is enough
- Classical spacetimes:
 - Aristotelian
 - Newtonian
 - Galilean
 - Leibnizian
- No manifest time!

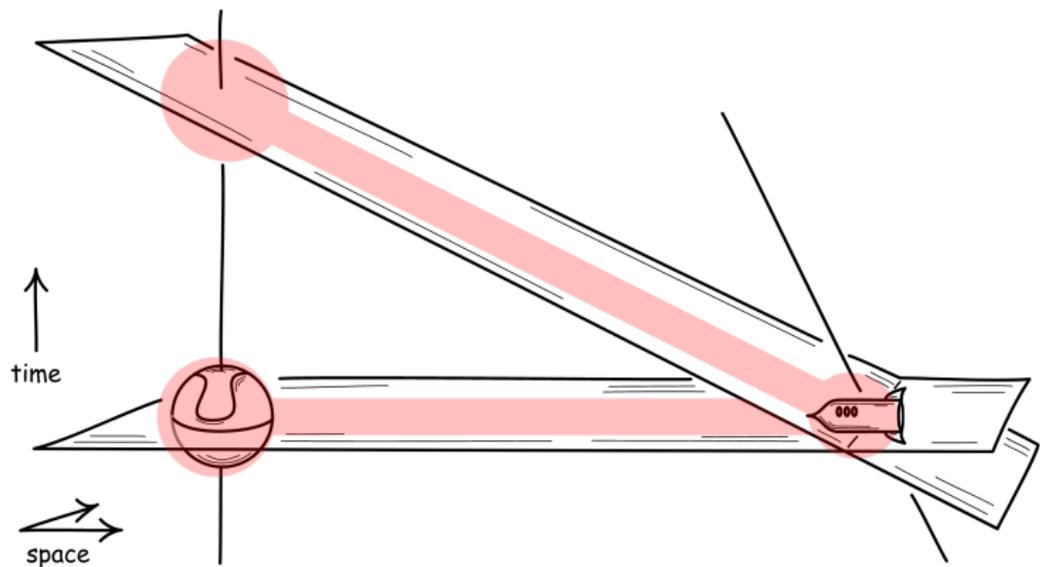
Special relativity



- Distance is spatiotemporal
- Proper time is path-dependent (twin-paradox)
- Clock hypothesis
- Lightcone structure
- Simultaneity (present) is observer-dependent

- Composed of simultaneous events
- Bisects the universe into past and future
- Achronal
- Productive
- Radar-synchronous
- Equivalence relation

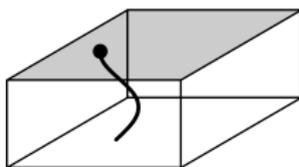
Relativity and becoming



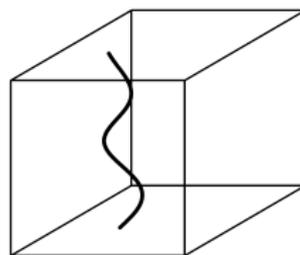
Presentism, possibilism, eternalism



Presentism



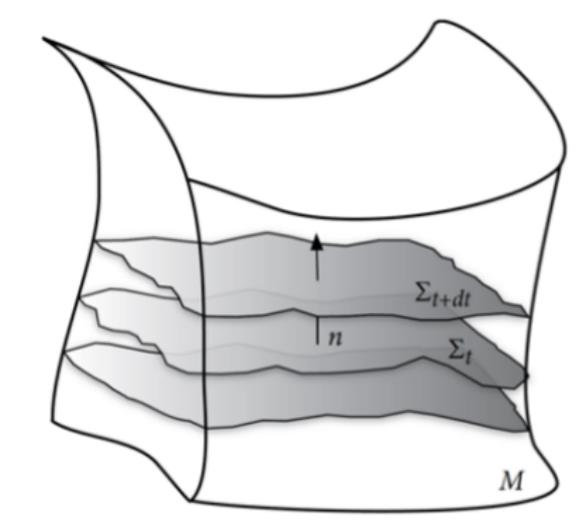
Growing Block



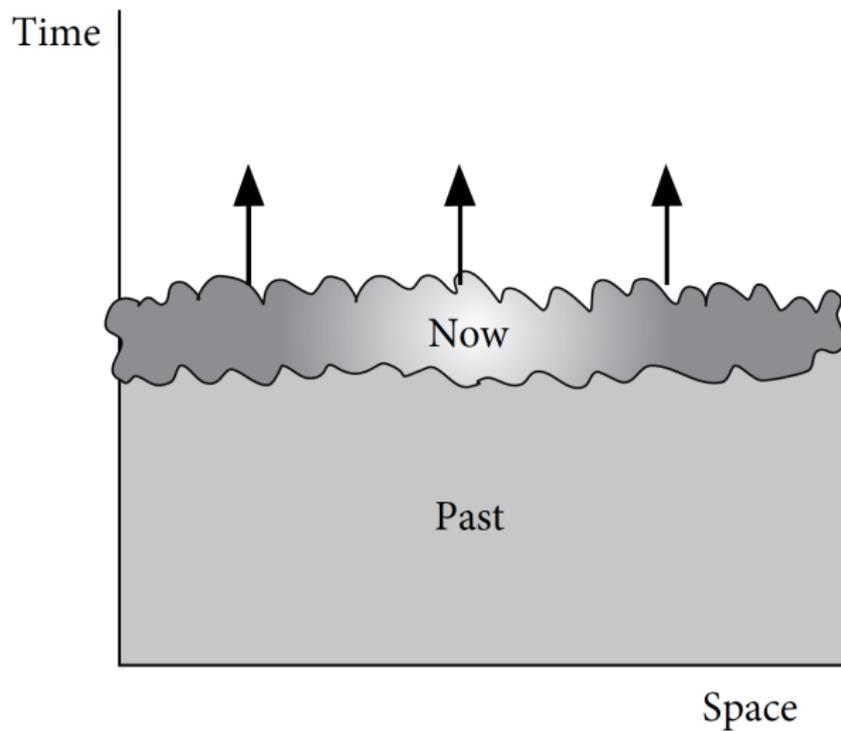
Block Universe



General relativity

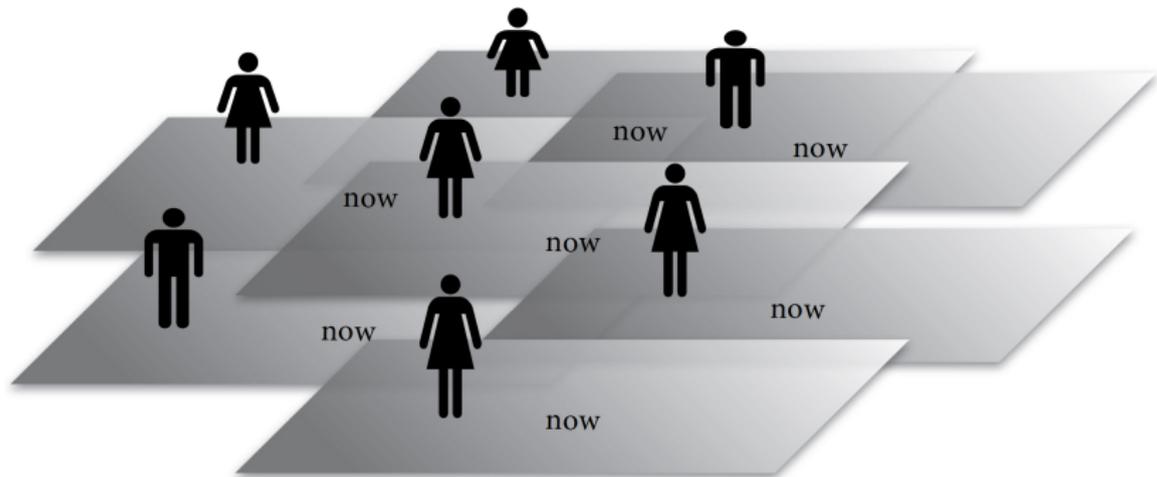


Manifest time



- **Slowly changing macro-world** with respect to light and sound
- **Reliable beliefs** to act upon
- **No time stamp** needed for successful communication
- **Egocentric** temporal representation
- **Tensed language**
- **No disagreement:** we treat the "now" as a monadic property, omit its relata and regard it as objective

Present



Past-future asymmetry

Upper level: Past-future asymmetries

- **Epistemological:** we know more about the P than about the F
- **Psychological:** we have different attitudes toward the P and F
- **Openness:** the F is open/indeterminate, the P is not
- **Causal/Counterfactual:** F counterfactually depends on the P
- **Explanation:** the *explanandum* occurs before the *explanans*

Middle level: Irreversible processes

- **Thermodynamic:** dissipating gasses
- **Electromagnetic:** radiation spreading out from charges
- **Cosmological:** expanding Universe

Basic level: Time-reversal invariant laws

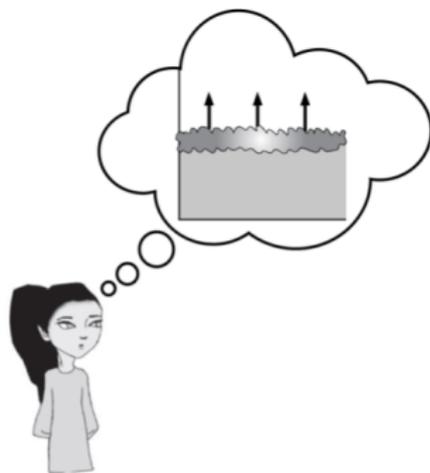
- Intrinsic temporal orientation of spacetime?
- Quantum measurement?

- **Worldlines:** identificating objects across time
- **Self:** an evolutionary advantageous fiction
- **Memory** is crucial to constructing selves
- **Selves endure** to accommodate plans and social interactions
- **Narratives:** the self is identified in narratives; it is the subject of our first-person perspective story-telling
- **Ego-moving vs. time-moving schemas**

"Next Wednesday's meeting has been moved forward two days"

Conclusion

Physical "hooks"
+
Environment
+
Embedded
subject
+
Evolution





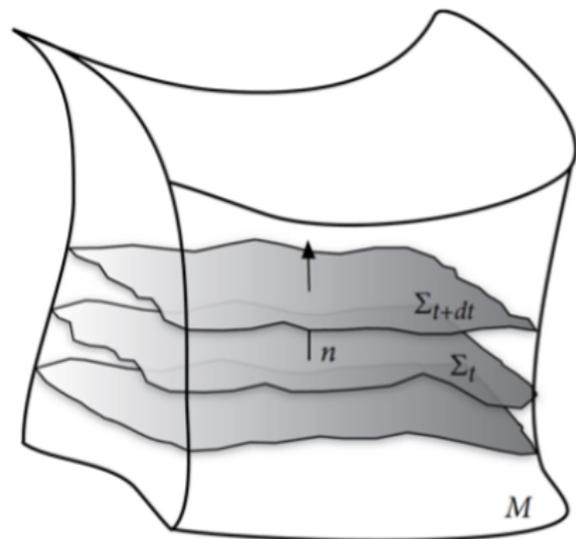
Craig Callender: *What makes time special?* (Oxford: Oxford University Press, 2017)

Eddington's two tables



Classical spacetimes

<i>Spacetime</i>	<i>Privileged Frames</i>	<i>Symmetries</i>	<i>Indistinguishable worldlines</i>
Aristotelian	Rigid Euclidean frame with position at origin, zero velocity, zero acceleration, zero rotation.	$x \rightarrow x' = \mathbf{R}x$ $t \rightarrow t' = t + \text{const.}$ <i>Rotate in space; translate in time.</i>	
Newtonian	Rigid Euclidean frame with zero velocity, zero acceleration, zero rotation.	$x \rightarrow x' = \mathbf{R}x + \text{const.}$ $t \rightarrow t' = t + \text{const.}$ <i>Rotate and translate in space; translate in time.</i>	
Galilean	Rigid Euclidean frames with zero acceleration, zero rotation.	$x \rightarrow x' = \mathbf{R}x + \mathbf{v}t + \text{const.}$ $t \rightarrow t' = t + \text{const.}$ <i>Rotate, translate and boost velocity in space; translate in time.</i>	
Maxwellian	Rigid Euclidean frames with zero rotation.	$x \rightarrow x' = \mathbf{R}x + \mathbf{a}(t)$ $t \rightarrow t' = t + \text{const.}$ <i>Rotate, translate, boost velocity and acceleration in space; translate in time.</i>	
Leibnizian	Rigid Euclidean frames.	$x \rightarrow x' = \mathbf{R}(t)x + \mathbf{a}(t)$ $t \rightarrow t' = t + \text{const.}$ <i>Rotate in space and time, translate and boost velocity and acceleration in space; translate in time.</i>	



- Metric is dynamic and varies from point to point
- Radar-synchrony holds only for static spacetimes
- Present:
 - Lighcone
 - Donut
 - Private
 - Alexandroff
- Spacetimes without foliation

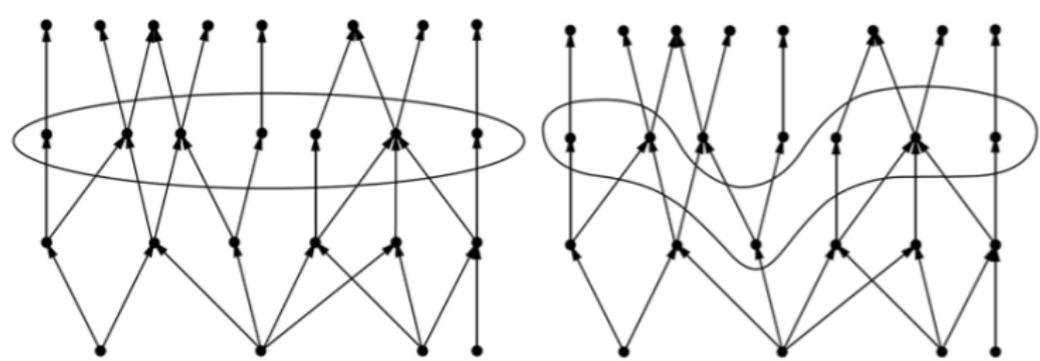
Shadows of spacetime



- Operation
- Metric
- Dimension
- Mobility
- Direction
- Genidentity

Quantum theory

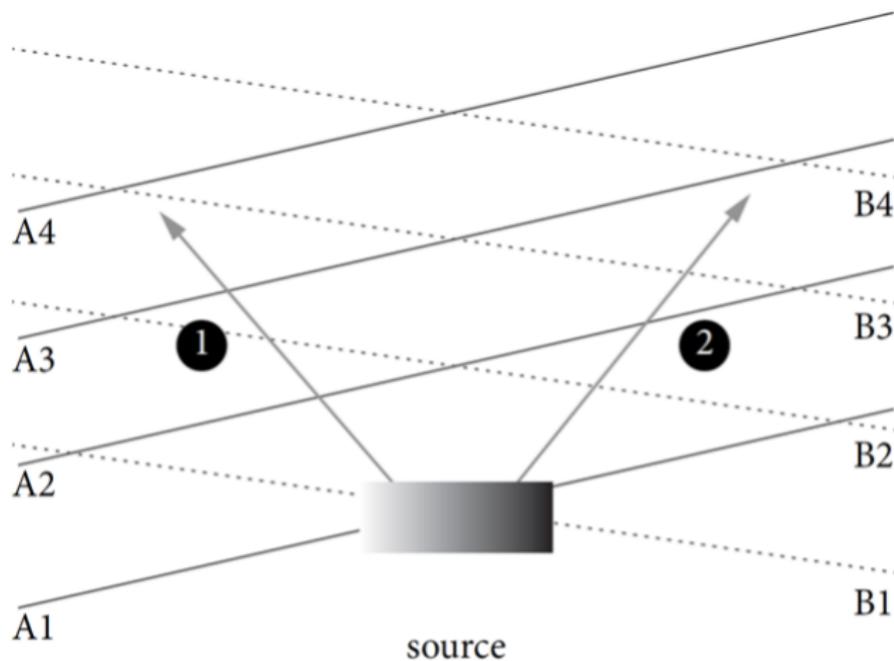
- Quantum theory assumes a background spacetime
- EPR nonlocality?
- Collapse and becoming?
- Quantum gravity?



Quantum time and uncertainty

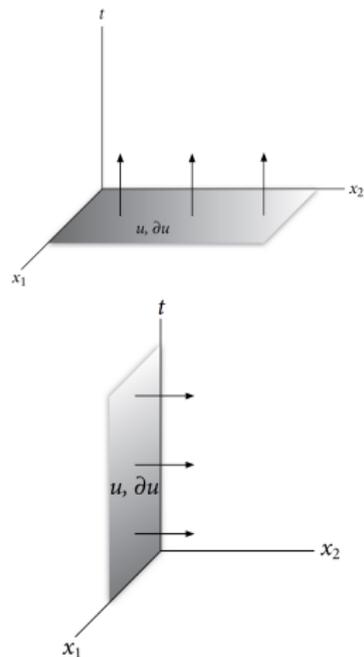
- **External time:** parameter
- **Internal time:** dynamic variable
- **Observable time:** operator

Quantum mechanics



Best system approach: The laws of nature are the axioms of a deductive system which best balances simplicity and informativeness

A **temporal direction** at a spacetime point is the direction in which our best system tells the most informative story (we get the most determinism/Markovity)



- Determinism: **well-posed Cauchy problem**
- Fundamental equations: second-order **hyperbolic** partial differential equations
- Strong connection between the **signature** of the metric and the partial differential equations
- Well-posedness picks out **temporal direction**

"When physics tells its story of the world, it writes on spatial pages and we flip pages in the temporal directions"