Craig Callender

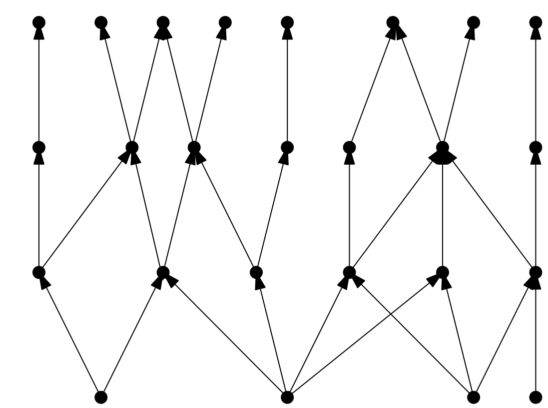
A TALE OF TWO TIMES

It was the best of times…

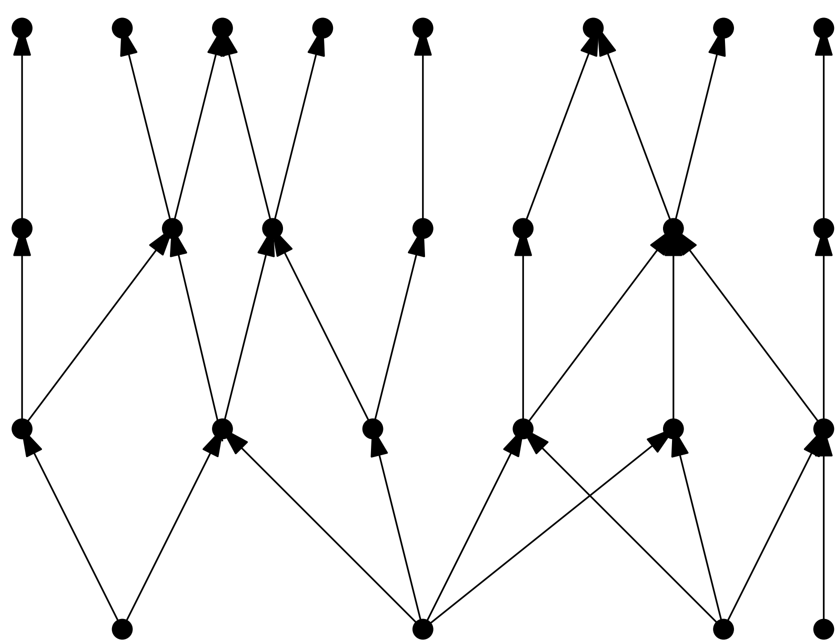
1. Time in Causal Set Theory

"One often hears that the principle of general covariance…forces us to abandon 'becoming'... To this claim, the CSG dynamics provides a counterexample. It refutes the claim because it offers us an active process of growth in which 'things really happen', but at the same time it honors general covariance. In doing so, it shows how the 'Now' might be restored to physics without paying the price of a return to the absolute simultaneity of pre-relativistic days."

Sorkin 2006



The Basics of CST



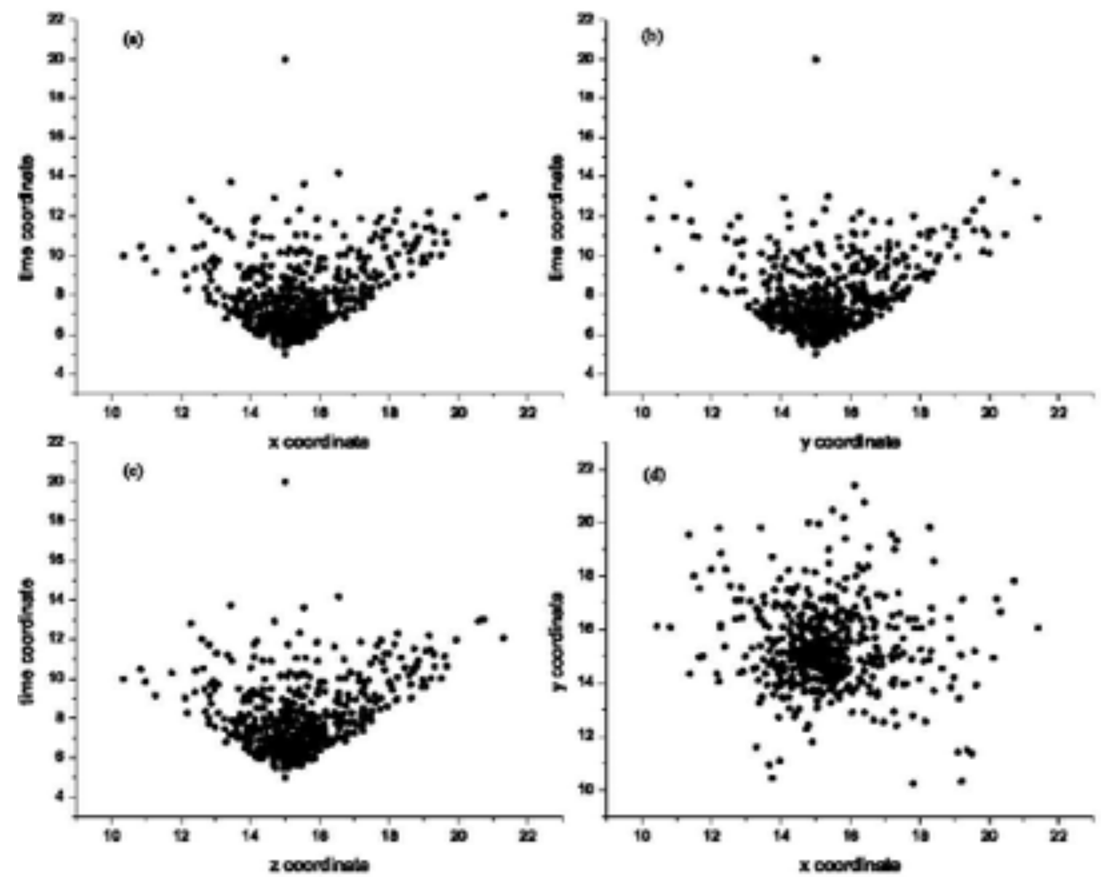
The basic structure of the theory is the **causet**, $\mathscr{C}$, i.e. an ordered pair $\langle \boldsymbol{C}, \leq \rangle$ of a set $\boldsymbol{C}$ of otherwise featureless events and a relation '≤' defined on $\boldsymbol{C}$ which satisfies the following conditions:

1. ≤ induces a partial order on $\boldsymbol{C}$, i.e., it is a reflexive, antisymmetric, and transitive relation
2. local finitude, i.e., $\forall x,z \in \boldsymbol{C},\ card(\{y \in \boldsymbol{C} \mid x \leq y \leq z\}) < \infty$

2 implies that causets are discrete structures.

A classical spacetime $<M,g_{ab}>$ is said to **faithfully approximate** a causal set $<C,\preceq>$, just in case there is an injective function ϕ: $C \rightarrow M$ such that

1. the causal relations are preserved, i.e. $\forall x,y \in C$, $x \preceq y$ iff $\phi(x) \in J^{-}(\phi(y))$, where $J^{-}(X)$ designates the causal past of X.
2. on average, ϕ maps one element of C onto each Planck-sized volume of $<M,g_{ab}>$
3. $<M,g_{ab}>$ does not have "structure" at scales below the mean point spacing

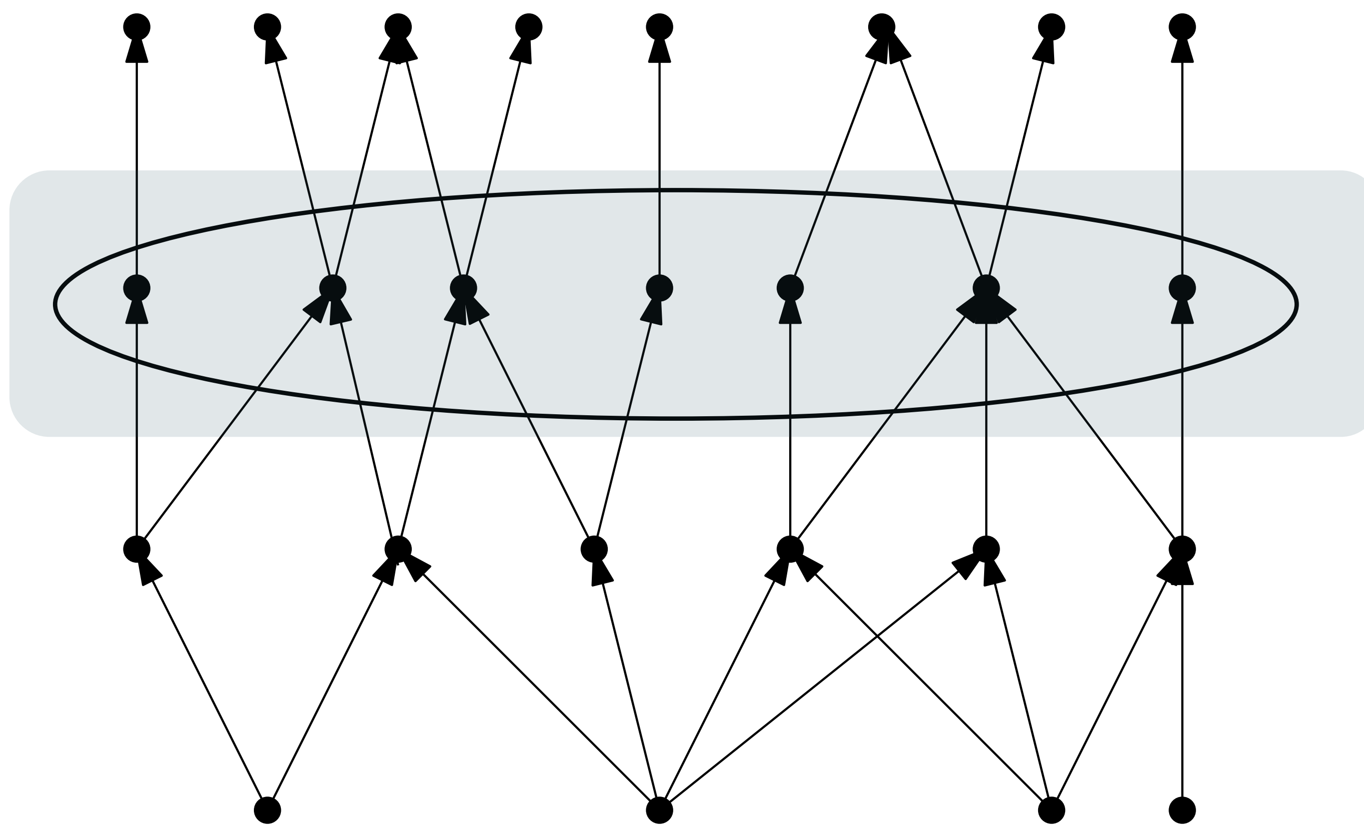


AIP Conf Proc **991**, p. 5, Fig. 1

2. Same Old Song and Dance?

Dilemma: any identification of a present in special relativity either answers to the presentist's explanatory request or is compatible with the structure of Minkowski spacetime, but not both. (Callender 2001, Wüthrich 2013)

First Try: Maximal Antichain



maximal antichain = (df) a maximal set of events such that any two events are incomparable.

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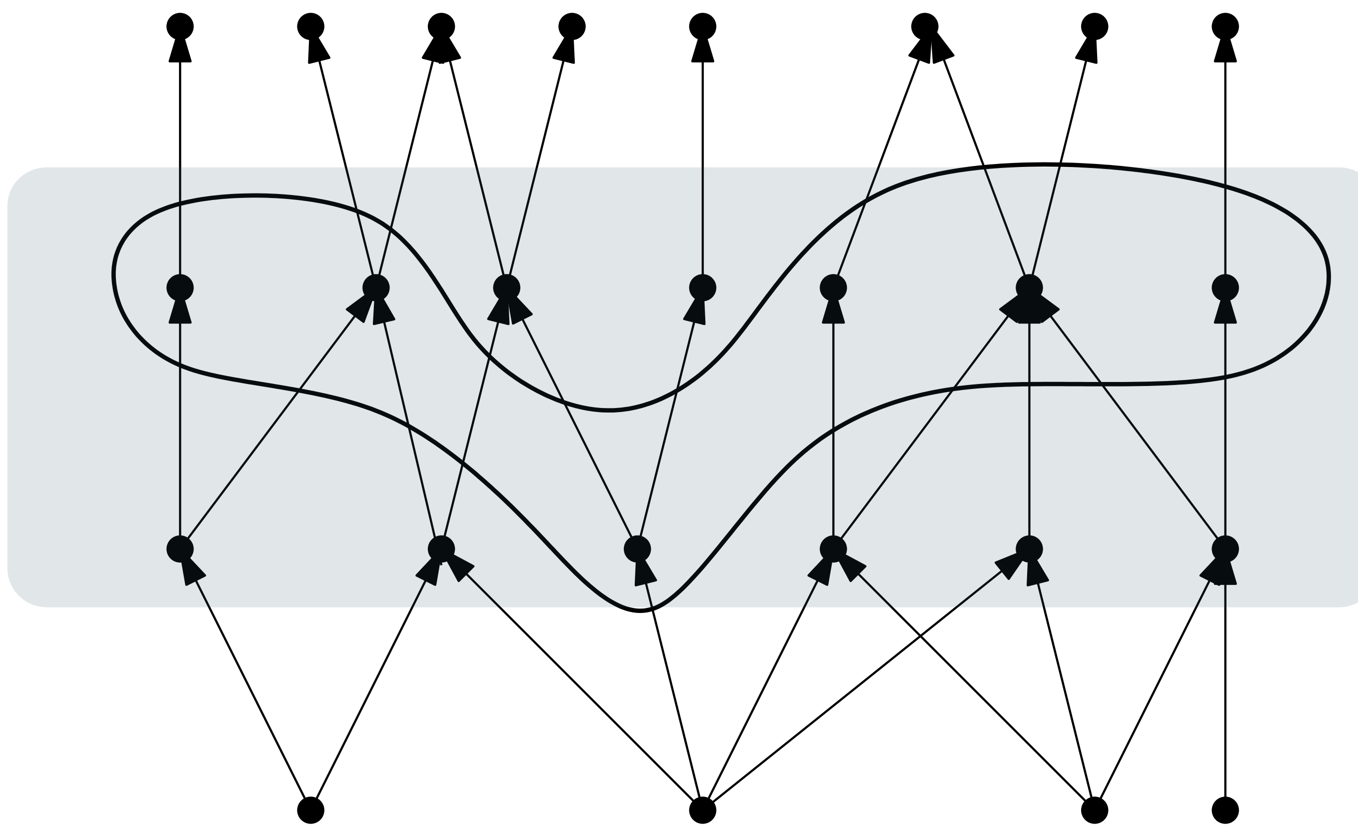
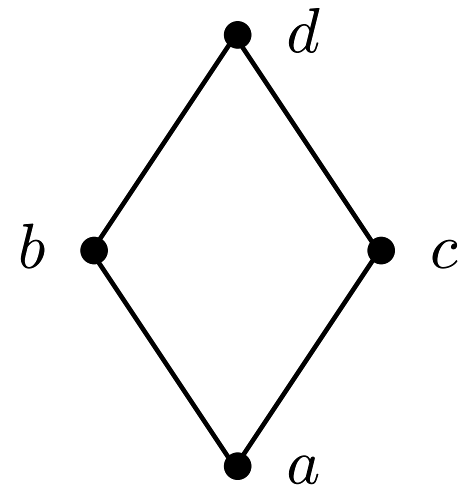


maximal antichain = (df) a maximal set of events such that any two events are incomparable.

Second Try: $R \backslash \leq$

Stein's Theorem. Assume that R is a reflexive, non-trivial, and non universal relation on a Minkowski spacetime $<\mathbb{R}^n, \eta_{ab}>$ invariant under automorphisms that preserve the time-orientation and is generally Lorentz covariant. Stein shows that if R_{ab} holds for some ordered pair of points $\langle a, b \rangle$, with a, $b \in \mathbb{R}^n$, $n>2$, such that ab is a past-pointing (timelike or null) vector, then for any pair of points $\langle x,y \rangle$ in $\mathbb{R}^n$, R_{xy} holds if and only if xy is a past-pointing vector.

Counterexample: non-Hegelian subset



On this causet a reflexive and transitive relation *R* can be defined as follows:

R = {<*a*,*a*>,<*b*,*b*>,<*c*,*c*>,<*d*,*d*>,<*b*,*a*>,<*c*,*a*>,<*d*,*b*>,<*d*,*c*>,<*d*,*a*>,<*b*,*c*>,<*c*,*b*>}

Second Try: $R\setminus\preceq$

$R\setminus\preceq$ gives an automorphically invariant way to define co-presentness.

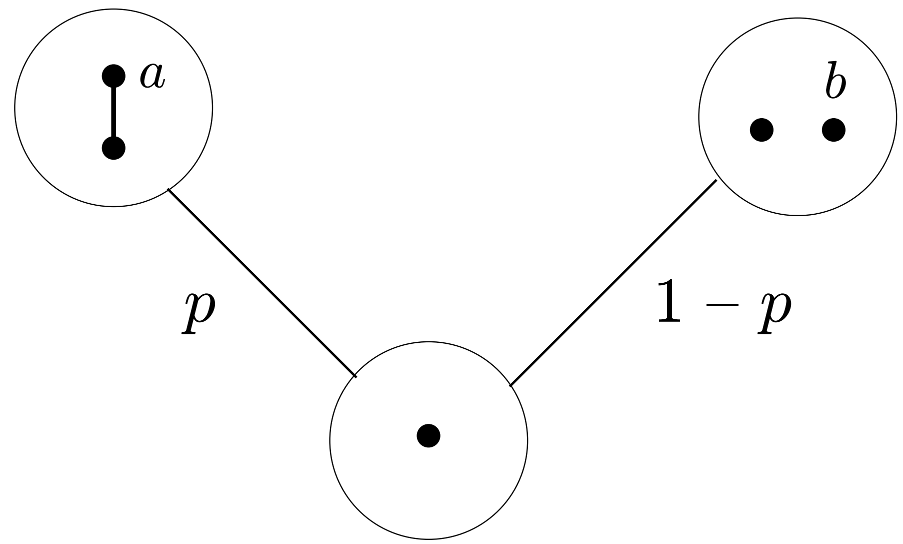
Dilemma. We would need many large Hegelian subsets consisting of nearly maximal antichains, and we expect these to be very rare; and when we have them, they will be regular lattice structures that violate Lorentz symmetry.

Tensers want becoming independent of an observer anyway (Callender 2001)...

3. Taking Growth Seriously

“The phenomenological passage of time is taken to be a manifestation of this continuing growth of the causet. Thus, we do not think of the process as happening ‘in time’ but rather as ‘constituting time’... “

(Rideout and Sorkin 2000)



Law of sequential growth. Suppose Ω(n) is the set of n-element causets. Then the dynamics specifies transition probabilities for moving from one ***C*** ∈ Ω(n) to another ***C***' ∈ Ω(n+1). Imagine an order of element births, using integers 0, 1, 2... such that they are consistent with the causal order, i.e., if x≤y, then label(x) < label(y). As each new causet ***C***'′ is born, it chooses a previously existing causet ***C*** to be its ancestor with a certain probability. Rideout and Sorkin 2000 constrain dynamics to class of *generalized percolation*.

First Remark

A tenseless picture of sequential growth is possible.

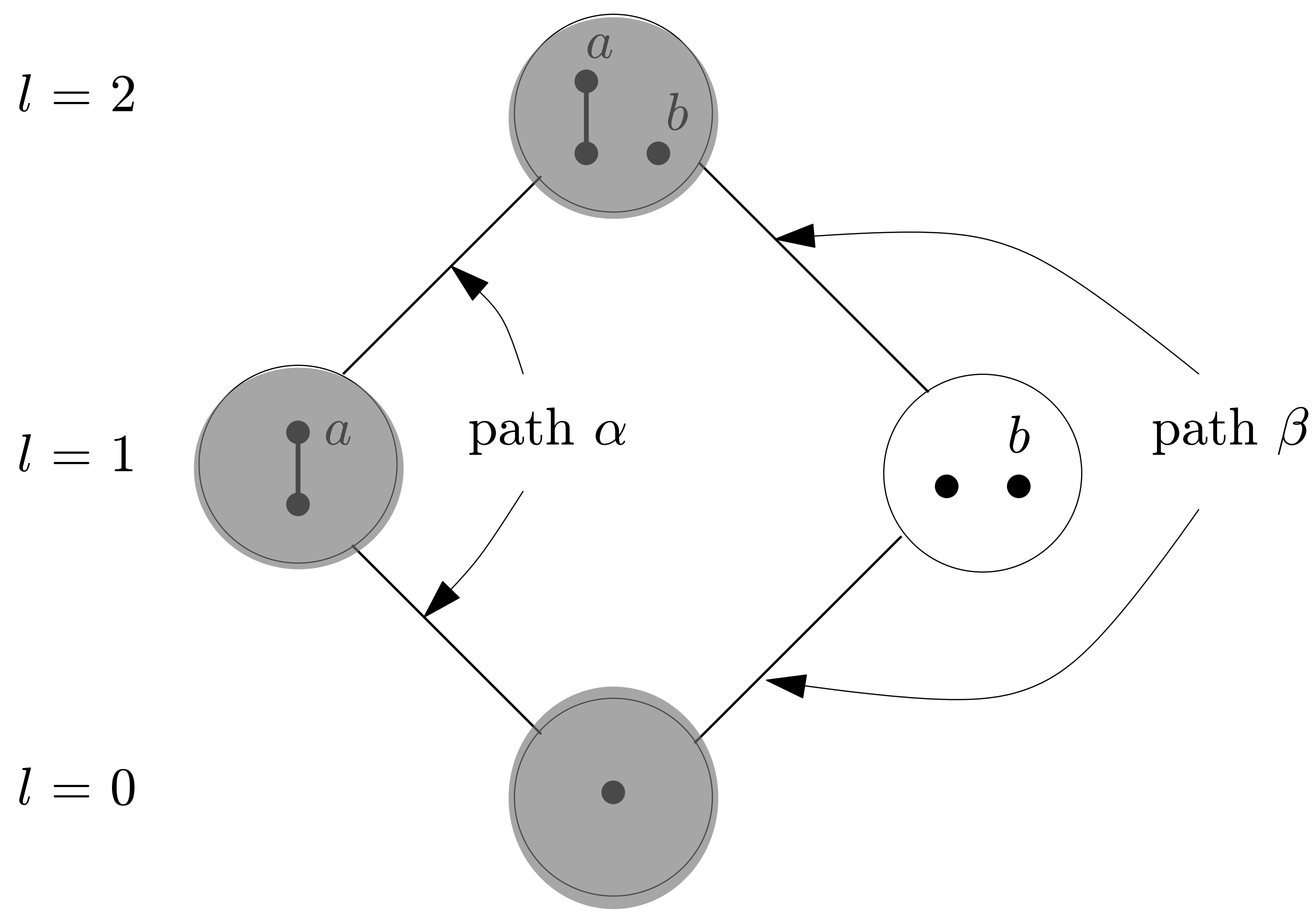
A stochastic process is defined as a triad of a sample space, a sigma algebra, and a probability measure. Here the sample space is the set $\Omega = \Omega(\infty)$ of past-finite and future-infinite labelled causets that have been "run to infinity." The dynamics is given by the probability measure constructed from the transition probabilities (see Brightwell et al 2003). On this picture, the theory consists simply of *a space of tenseless histories with a probability measure over them*.

Second Remark

There are two times here. This invites the question, how fast are elements born?

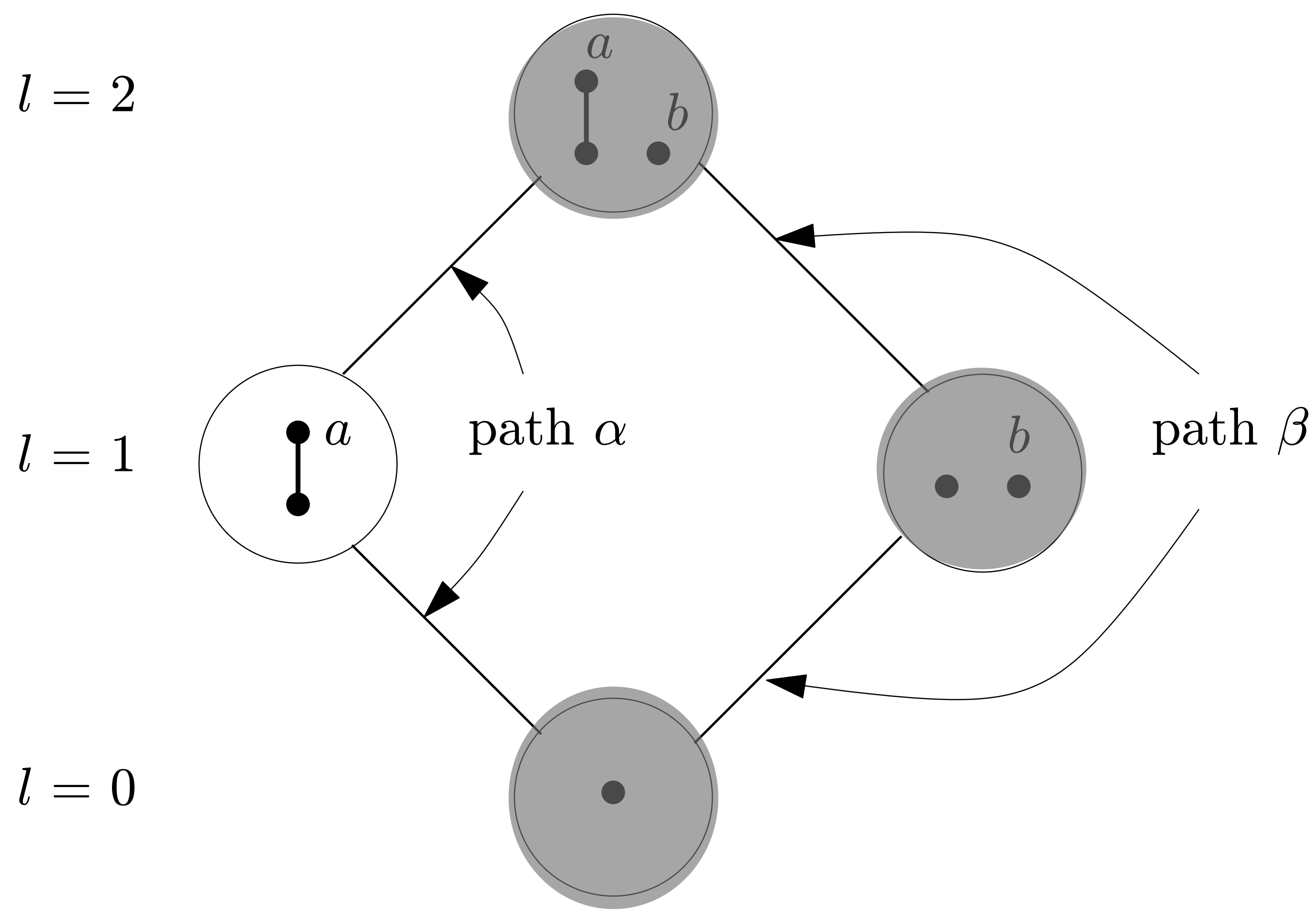
(Smart 1966 vs Broad 1938)

Problem: Discrete General Covariance



Alice and Bob's birthday parties come into being

Problem: Discrete General Covariance



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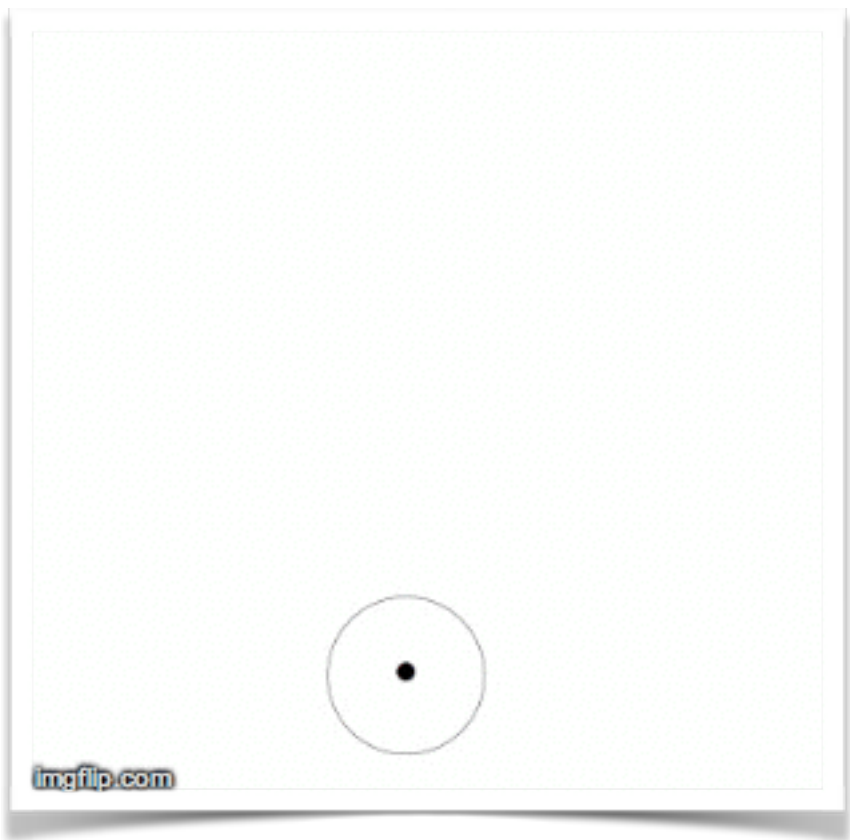
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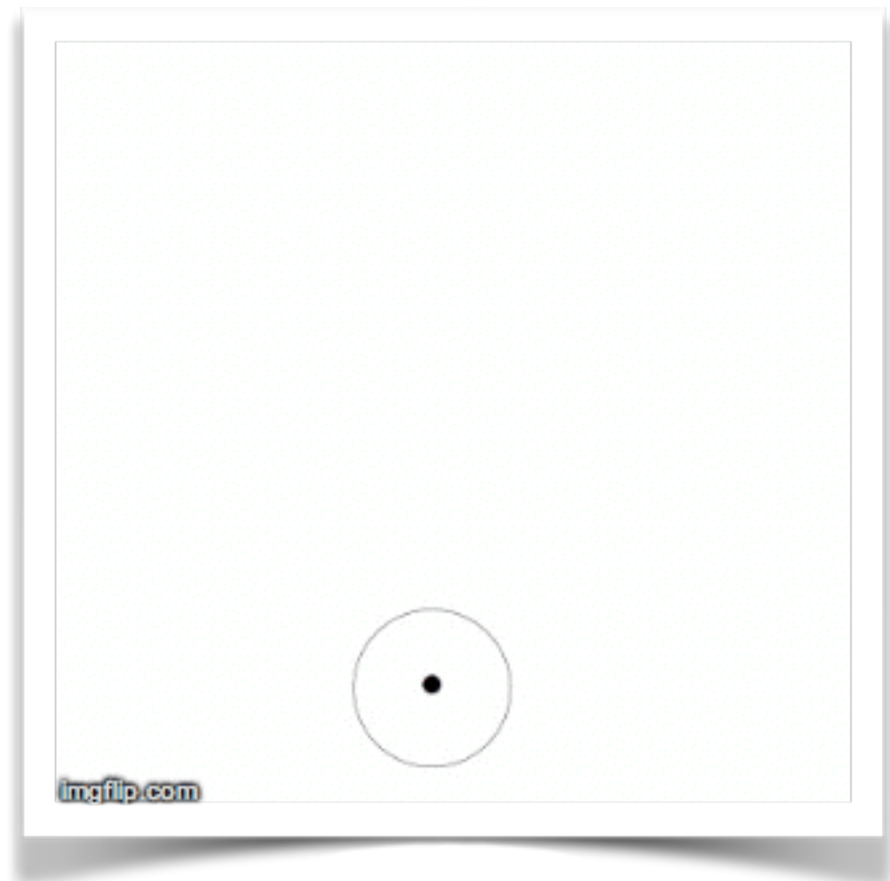
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Real Growth?

Motivation. The dynamics *can* be given a gauge-invariant formulation (Brightwell et al (2003). And one thing that we know is gauge-invariant is the number of elements in a causet. So there *is* growth, e.g.:

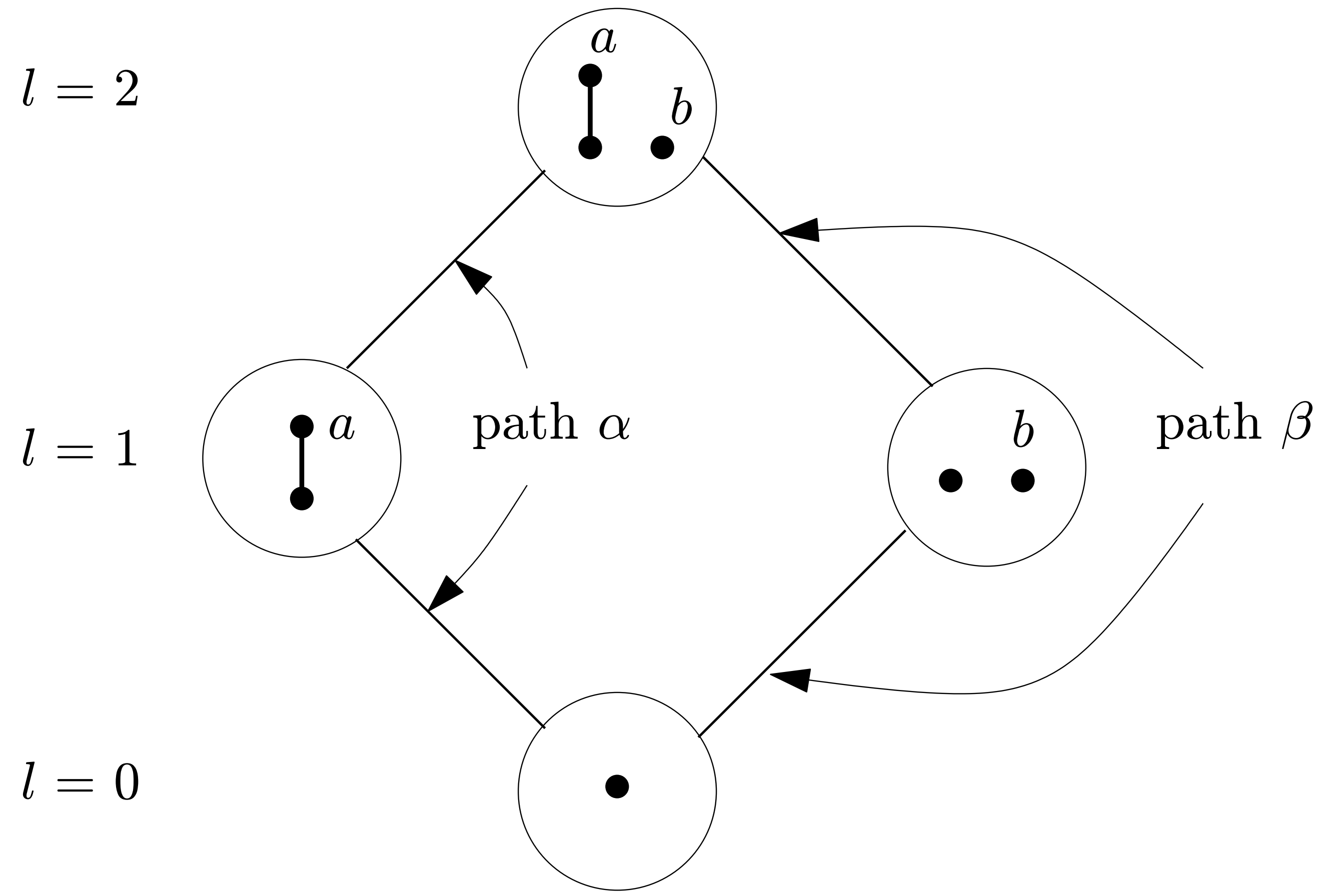
$$\mathcal{C}^1 \rightarrow \mathcal{C}^2 \rightarrow \mathcal{C}^3$$

Real Growth?

Motivation. The dynamics *can* be given a gauge-invariant formulation (Brightwell et al (2003). And one thing that we know is gauge-invariant is the number of elements in a causet. So there *is* growth, e.g.:

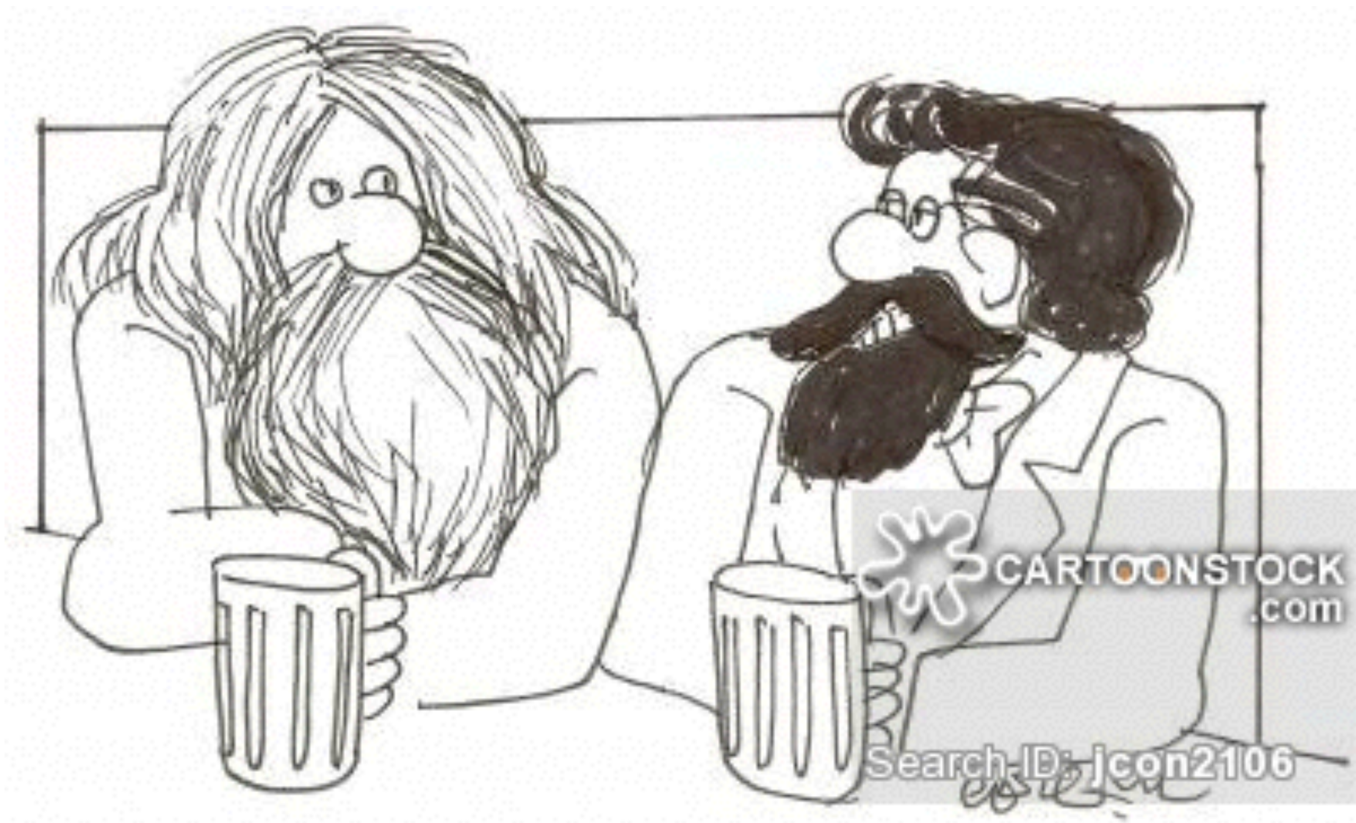
$$\boldsymbol{C}^1 \rightarrow \boldsymbol{C}^2 \rightarrow \boldsymbol{C}^3$$

The problem is that we can’t say what particular elements exist at some stages of growth.



$\boldsymbol{C}^2$ doesn't have Alice's birthday and Bob's (that's $\boldsymbol{C}^3$). Doesn't have neither (that's $\boldsymbol{C}^1$). It does have *determinately* Alice's birthday or Bob's, but not *determinately* Alice's and *determinately* Bob's birthday parties.

'Determinately' can't penetrate the disjunction, a signature of vagueness.



"IT WAS A TYPO– I WROTE, 'IT WAS THE BEST OF THE WORST OF TIMES.'"

It was the worst of times...

Time in Canonical Quantum Gravity

$$\hat{H}\Psi = 0$$

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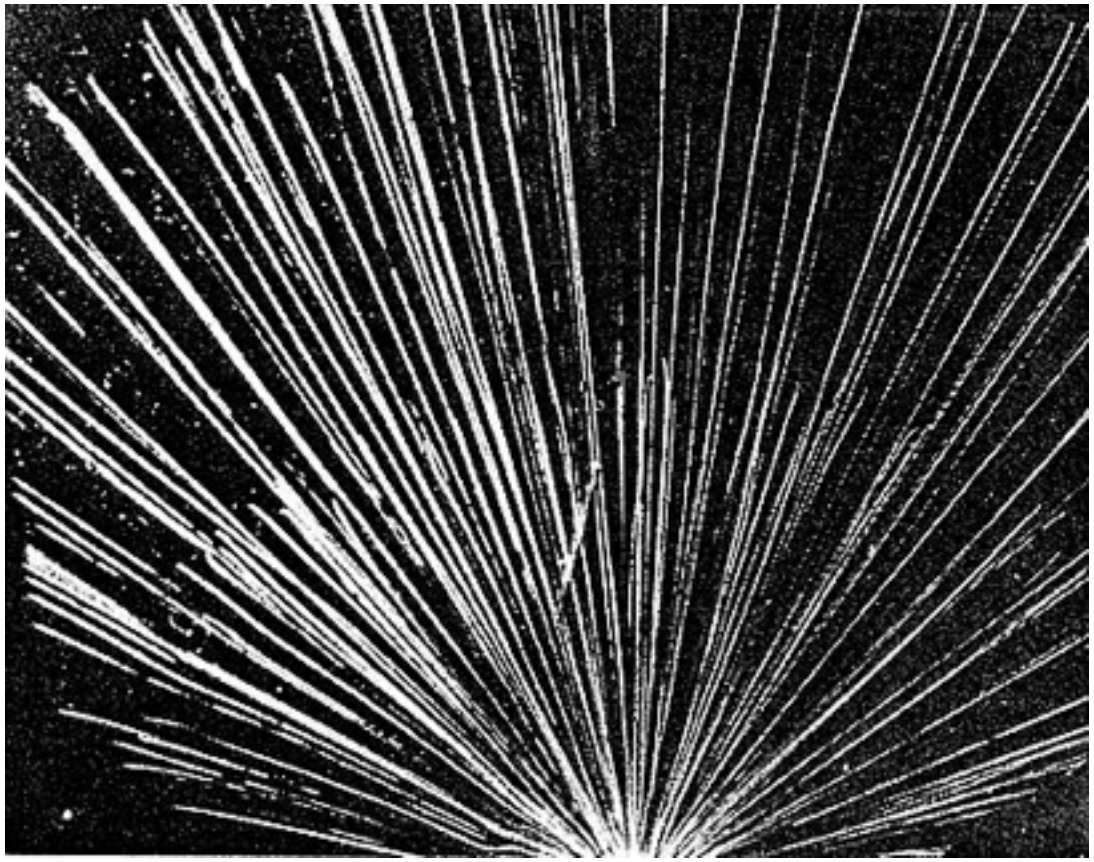
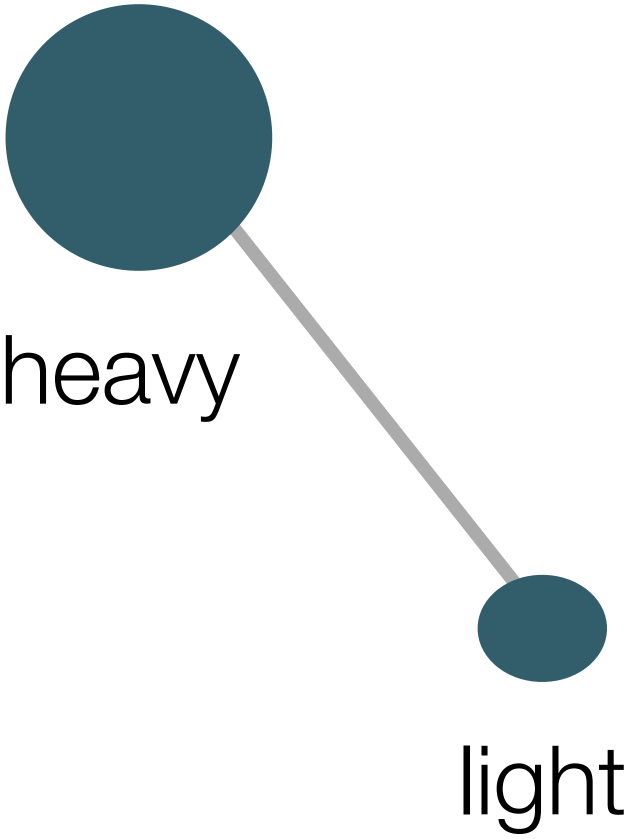
Semiclassical Time

$$\hat{H}\Psi = 0$$

$$i\hbar\frac{\partial\Psi}{\partial t} = -\frac{\hbar^2}{2m}\frac{\partial^2\Psi}{\partial x^2} + V(x)\Psi(x,t) \equiv \tilde{H}\Psi(x,t),$$



Mott 1932



$$\Psi(r, R) = \psi(r, R)e^{ikR}$$

i^{∂} $\mu ik{\cdot}\mathrm{r}_R$

$$\hat{H}\Psi=0$$

Born-Oppenheimer

+

WKB

$$\Psi \approx \exp(iS_0[h]/\hbar)\psi[h,\phi]$$

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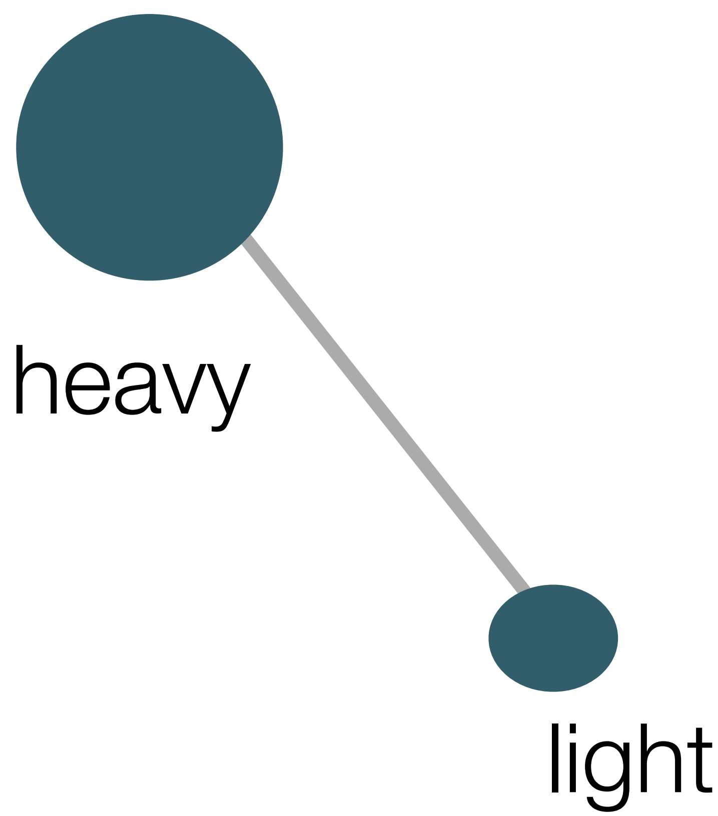
classical spacetime

quantum field

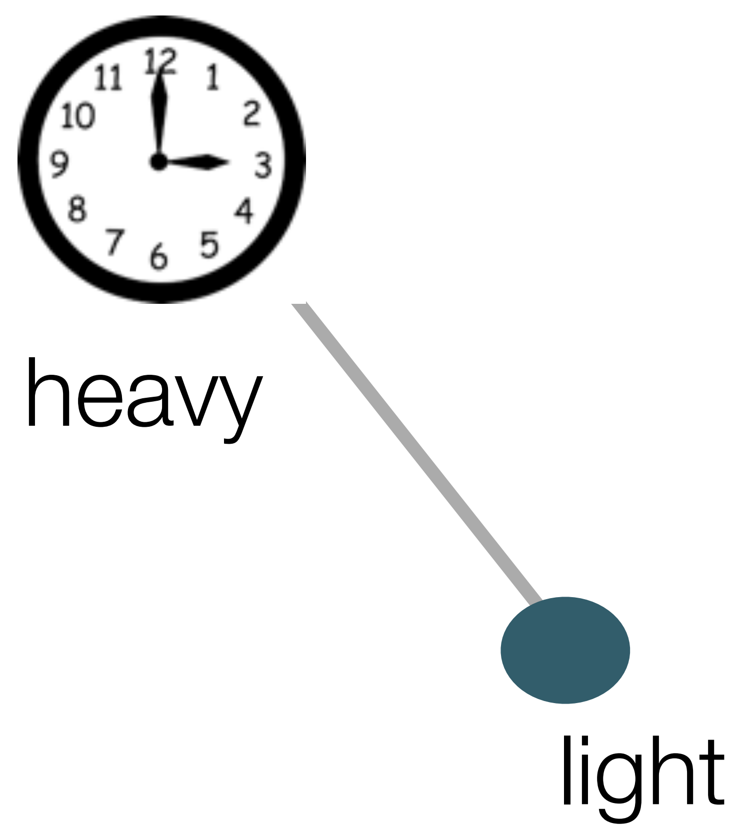
$$\Psi \approx \exp(iS_0[h]/\hbar)\psi[h,\boldsymbol{\phi}]$$

$$i\hbar\nabla S_0 \boldsymbol{\nabla}\psi \approx H_M\psi$$

$$\partial/\partial t \propto \boldsymbol{\nabla} S_0 \boldsymbol{\nabla}$$



$$i\hbar \partial \psi / \partial t \approx H_M \psi$$



$$i\hbar \partial \psi / \partial t \approx H_M \psi$$

$$\hat{H}\Psi = 0$$

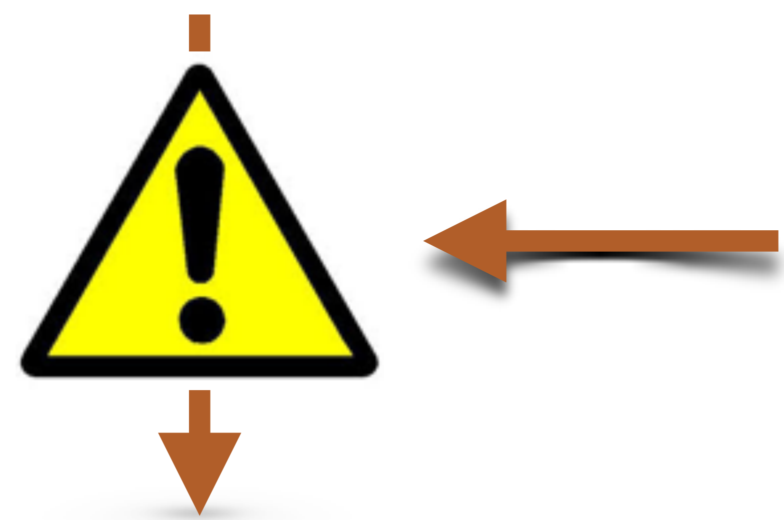
20+ Approximations

$$i\hbar\frac{\partial\Psi}{\partial t} = -\frac{\hbar^2}{2m}\frac{\partial^2\Psi}{\partial x^2} + V(x)\Psi(x,t) \equiv \hat{H}\Psi(x,t),$$

We note that the world is "semiclassical" in certain respects:

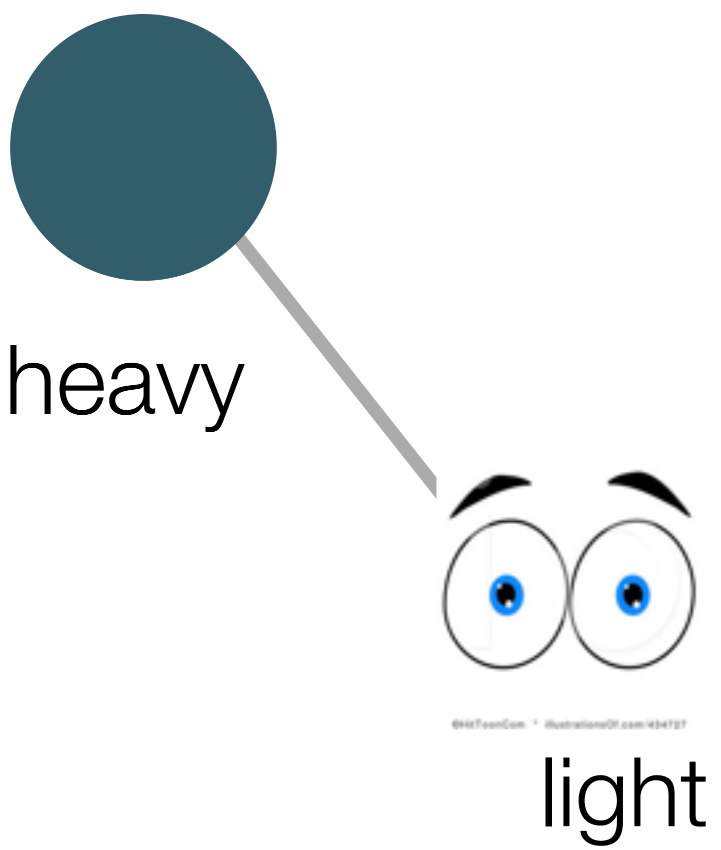
- gravity doesn't display its quantum aspects at many scales
- changes in the quantum degrees of freedom happen rapidly with respect to changes in the gravitational degrees of freedom at many scales
- spacetime is approximately flat at large scales
- the relevant masses are much larger than the Planck mass

Timeless Realm



Time assumed!

Realm of Time



$$i\hbar\partial\psi/\partial t \approx H_M\psi$$

Comments

Tim Maudlin 2007
—is derived structure physically salient?

David Baker
—decoherence and probability

6.54 "My propositions serve as elucidations in the following sense: anyone who understands me eventually recognizes them as nonsensical, when he has used them - as steps - to climb up beyond them. (He must, so to speak, throw away the ladder after he has climbed up it.)

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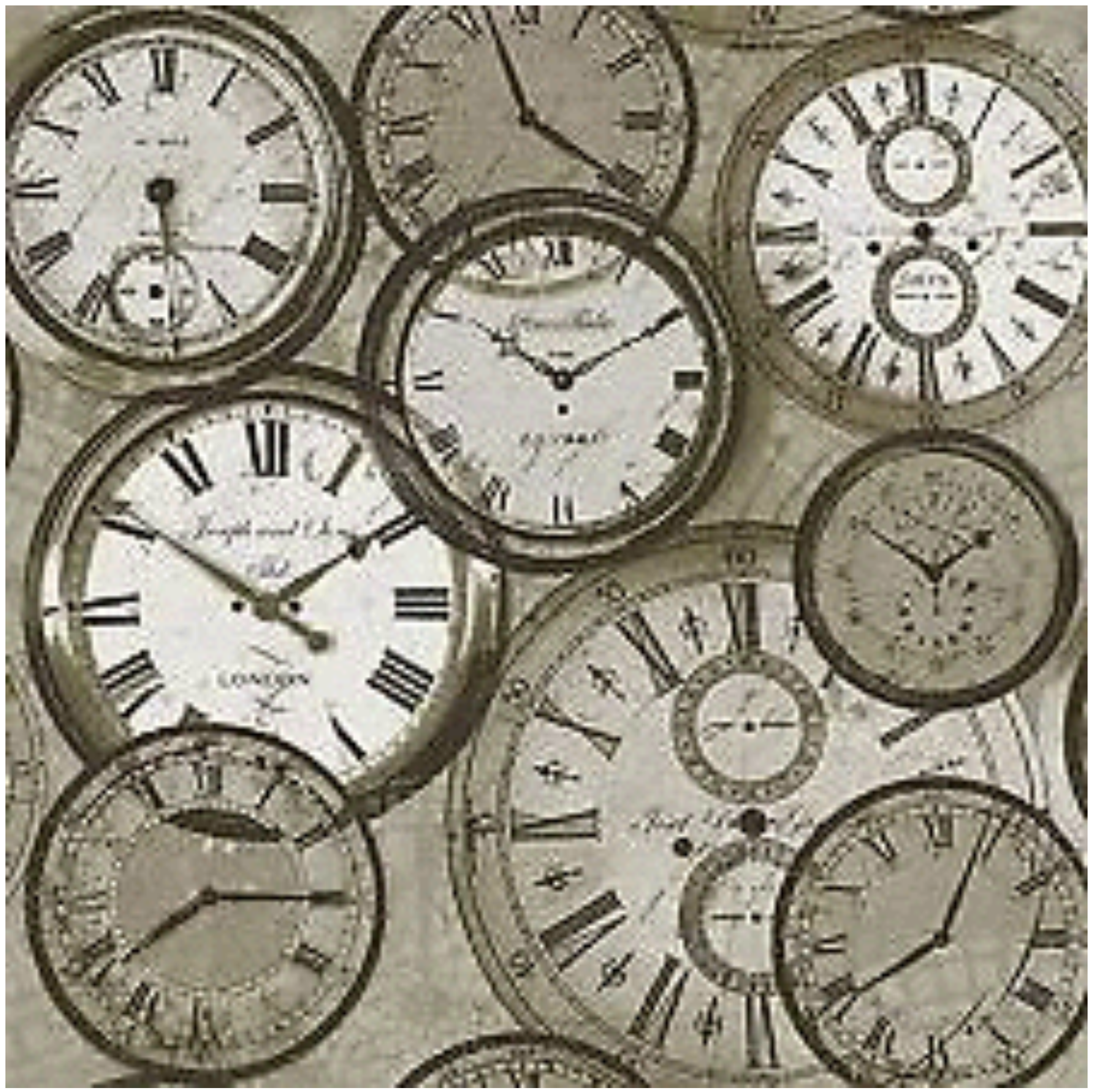
—is derived structure physically salient?

David Baker
—decoherence and probability

Me
—decoherence, probability and time



Killing time is as
hard as saving time


The End
A
Metro-Goldwyn-Mayer
PICTURE

Outposts of reality