Materialism vs idealism in quantum gravity

or

Einstein's realism in quantum gravity

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Materialism-realism versus Idealism-positivism?
Wanna argue?

The trouble is:

It always seems to me as though such an -ism were strong only so long as it nourishes itself on the weakness of its counter-ism; but if the latter is struck dead, and it is alone on an open field, then it also turns out to be unsteady on its feet. So, away with the squabbling.

"The physical world is real." That is supposed to be the fundamental hypothesis. What does "hypothesis" mean here? For me, a hypothesis is a statement, whose truth must be assumed for the moment, but whose meaning must be raised above all ambiguity. The above statement appears to me, however, to be, in itself, meaningless, as if one said: "The physical world is cock-a-doodle-doo." It appears to me that the "real" is an intrinsically empty, meaningless category (pigeon hole) [..]

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A. Einstein in a letter to E. Study, 17 September 1918

But wasn't Einstein a realist?

Einstein in 1948, translated by Don Howard
http://plato.stanford.edu/entries/einstein-philscience/

> I just want to explain what I mean when I say that we should try to hold on to physical reality. We are, to be sure, all of us aware of the situation regarding what will turn out to be the basic foundational concepts in physics: the point-mass or the particle is surely not among them; the field, in the Faraday - Maxwell sense, might be, but not with certainty. But that which we conceive as existing ('actual') should somehow be localized in time and space. That is, the real in one part of space, A, should (in theory) somehow 'exist' independently of that which is thought of as real in another part of space, B. [...]
>
> [I]f one renounces the assumption that what is present in different parts of space has an independent, real existence, then I do not at all see what physics is supposed to describe. For what is thought of by a 'system' is, after all, just conventional, and I do not see how one is supposed to divide up the world objectively so that one can make statements about the parts.

Without "subsystems" there is no physics. Spacetime is necessary to the concept of subsystems.

What aspect of spacetime is necessary for the (Einsteinian) concept of subsystems?

Saying that subsystems must be separated in space means that they must be **spacelike separated** in the sense of being relativistically causally unrelated. Einstein (1948) again :

> If a physical system stretches over the parts of space A *and* B, then what is present in B should somehow have an existence independent of what is present in A. What is actually present in B should thus not depend upon the type of measurement carried out in the part of space, A; it should also be independent of whether or not, after all, a measurement is made in A.

Relativistic causal structure is necessary to Einstein's realism. Non-relativistic causal structure, Galilean or Newtonian spacetime for example, would not satisfy Einstein's requirements. Einstein said: "the 'real' in physics is to be taken as a type of program, to which we are not forced to cling *a priori*." But this is (coming close to) an *a priori*.

What does Einstein's realism mean for "Quantum Gravity" ?

- The phrase "quantum gravity" is a shorthand that names the biggest obstacle we currently face in our search for a unified framework for physics.
- For the purposes of this talk, materialism-realism means holding fast to relativistic causal structure and the observer independence of scientific explanation
- There are reasons to question whether Einstein's realism can be manifested in quantum gravity, in particular Bell's theorem (even in the absence of gravity) and the expectation that the differentiable manifold structure of spacetime will break down at the Planck scale.
- Nevertheless, there are approaches to quantum gravity that adhere more closely to an Einsteinian conception of reality than others. Causal Dynamical Triangulations (CDTs) (in the way I understand it) is one and Causal Sets is another. I will describe how the latter can be thought of as an attempt to embody realism and the unity of physics.

Two questions, two forks in the road on the way towards unity

- Is the arena for physics spacetime or is it Hilbert space? (Dirac's 1933 choice)
- Is relativistic causal structure primary or is it "emergent"?

“The Lagrangian in Quantum Mechanics” Dirac’s choice, 1933

Quotations from that paper

- Quantum mechanics was built up on a foundation of analogy with the Hamiltonian theory of classical mechanics
- There is an alternative [..] provided by the Lagrangian. [..T]here are reasons for believing that the Lagrangian one is the more fundamental.
- There is no action principle [..] of the Hamiltonian theory
- The Lagrangian method can easily be expressed relativistically; while the Hamiltonan method is essentially non-relativistic in form, since it marks out a particular time variable as the canonical conjugate of the Hamiltonian function

Dirac's fork

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"essentially non-relativistic"

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(Feynman, Hartle, Sorkin)

Take this path

The path integral as the foundation

- Quantum theory is akin to stochastic theory like Brownian motion
- The theory deals directly with events **in** spacetime (when there's a background) and events **of** spacetime (in quantum gravity).
- No Hilbert space to start with (though one can be constructed)
- Begin by postulating a set of histories in spacetime, or a set of histories which "are spacetime" (kinematical content)
- An event is a **subset** of the set of histories.
- The path integral gives the "quantum probability" of each event
- Quick and dirty interpretation: classical behaviour arises because the histories close to a classical one constructively interfere and the others destructively interfere (Dirac knew this in 1933).

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- causal structure is "emergent"
- Lorentz violation "in the ultraviolet"

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Relies on (a form of) idealism to reconcile non-relativistic kinematics with observational facts. e.g. if spacetime is a lattice but matter propagates with a maximum speed then it is **as if** spacetime has a relativistic causal structure and we since we only observe matter, that is good enough.

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Take this branch, not least because the other would mean The Lord is malicious

The histories have relativistic causal structure

Are they Lorentzian geometries?

$$Z = \int \mathcal{D}g \; e^{iS[g]}$$

Renate Loll calls this, "A statement of intent"

- Technical problems fearsome, so......
- Go discrete
- Another fork: take the continuum limit (e.g. CDTs) or not?

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- Another fork: take the continuum limit (e.g. CDTs) or not?
- Strong physical evidence for fundamental discreteness is provided by the finite value of the entropy of a black hole: it strongly suggests discreteness of spacetime and that its scale is Planckian.

The causal set hypothesis: the histories are discrete causal structures

'tHooft; Myrheim; Bombelli, Lee, Meyer & Sorkin

A causal set (or causet) is a set, C, with a binary relation, $\preccurlyeq$, which satisfies the following axioms:

* Transitivity: if $x \preccurlyeq y$ and $y \preccurlyeq z$ then $x \preccurlyeq z$, $\forall x, y, z \in C$;
* Acyclicity: if $x \preccurlyeq y$ and $y \preccurlyeq x$ then $x = y$, $\forall x, y \in C$;
* Local finiteness: for any pair of fixed elements x and z of C, the set $\{y \mid x \preccurlyeq y \preccurlyeq z\}$ of elements lying between x and z is finite.

The first two axioms say that C is a partial order. The third axiom is what makes the set discrete.

Causal order is a more basic organising principle than space and time. Discrete causal relations are the microscopic degrees of freedom in quantum gravity

How can something so sparse give geometry?

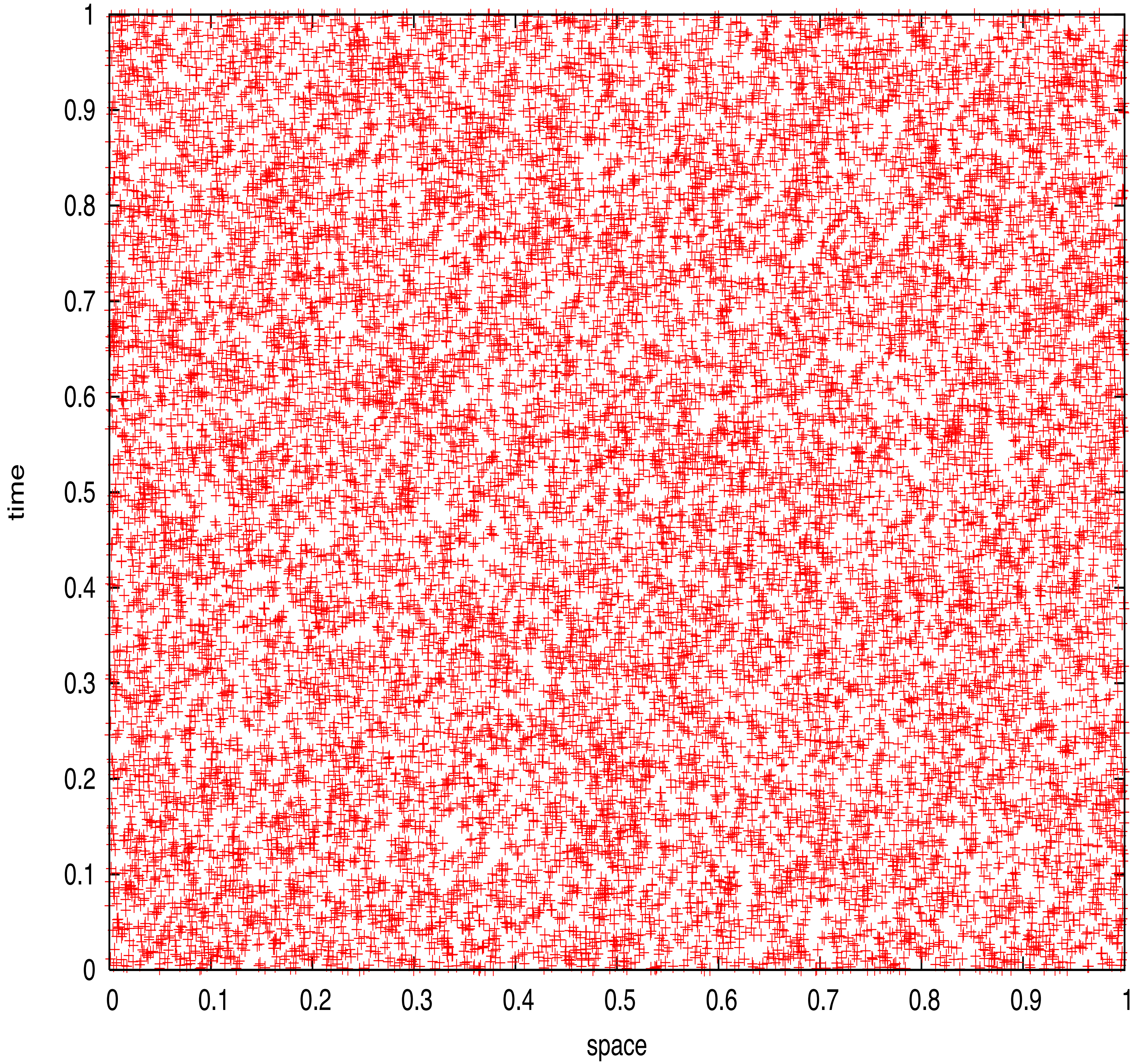
A continuum spacetime is a differentiable manifold, M, with a Lorentzian metric field, g

- Metric gives the causal order
- Conversely, causal order gives topology, differentiable structure and 9/10 of the metric (in 4-d) **(Hawking)**
- The remaining 1/10 is fixed by the volume measure.

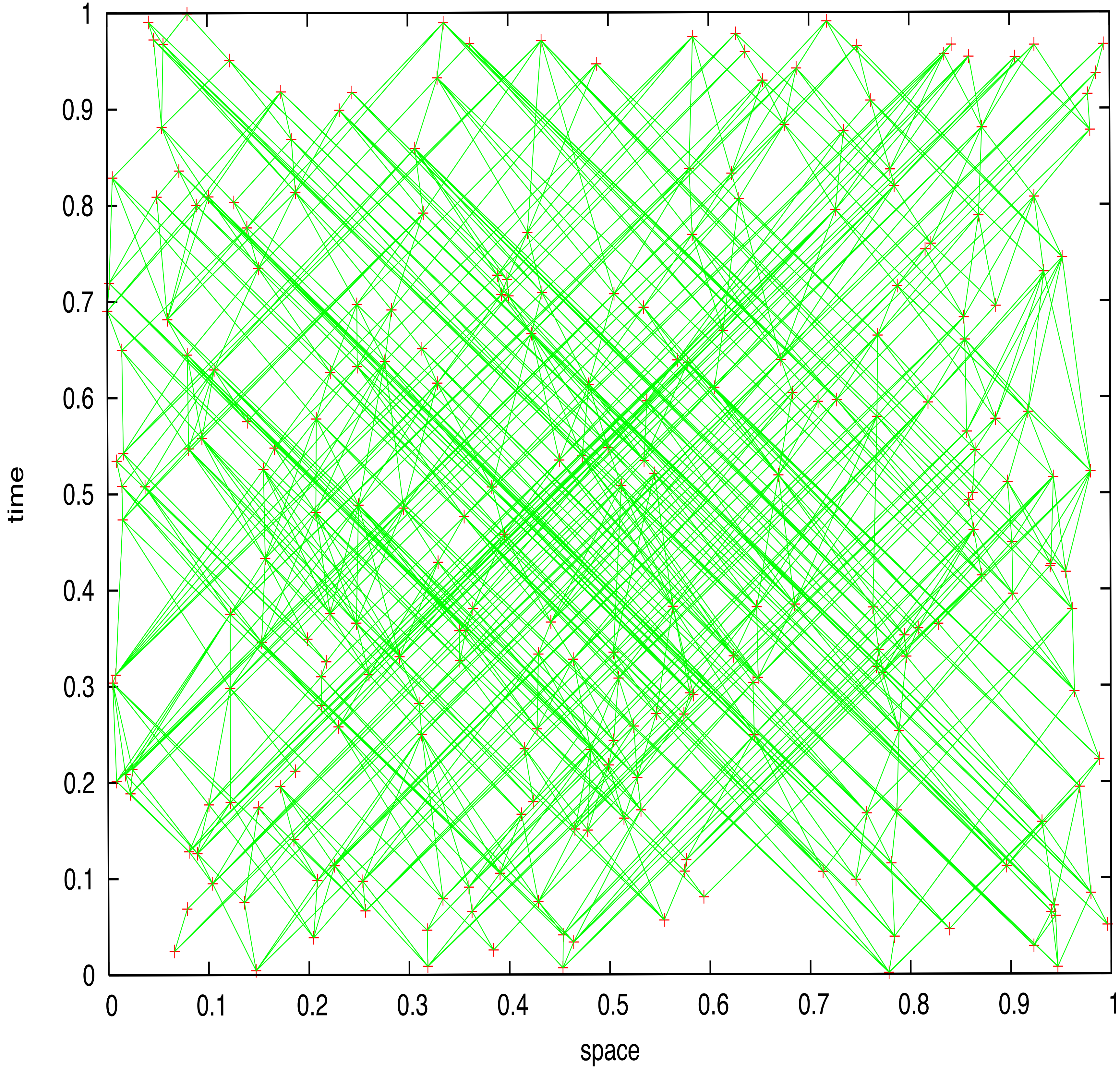
The causal order unifies within itself topology, differentiable structure and most of the metric.

In a **discrete** order -- a causal set -- the remaining geometrical information is given (as anticipated by Riemann) by counting: the **volume** of a spacetime region is given by the **number** of spacetime atoms that comprise it.

A sprinkling into 1+1 Minkowski spacetime



This distribution is Lorentz invariant: it does not pick out a frame



Causal structure is Lorentz invariant so, again, no frame is distinguished

Order + Number = Geometry

- Causal sets are Lorentz invariant but highly nonlocal
- Causal sets are maximally discrete - combinatorial data only - just need to be able to count
- Carry their own metric information (c.f. Riemann's "discrete manifolds").
- The order relation $\preceq$ unifies within itself topology, differentiable structure, metric and causal structure
- Randomness of sprinkling is kinematical only: from Number ~ Volume
- Causal sets are fluid-like rather than crystal-like
- Scale dependent topology and geometry (and covariant coarse graining)
- The approach is both conservative and radical

Einstein, to end

Einstein in a letter to Walter Dällenbach, Nov 1916 (Trans. J. Stachel):

But you have correctly grasped the drawback that the continuum brings. If the molecular view of matter is the correct (appropriate) one, i.e., if a part of the universe is to be represented by a finite number of moving points, then the continuum of the present theory contains too great a manifold of possibilities. I also believe that this too great is responsible for the fact that our present means of description miscarry with the quantum theory. The problem seems to me how one can formulate statements about a discontinuum without calling upon a continuum (space-time) as an aid; the latter should be banned from the theory as a supplementary construction not justified by the essence of the problem, which corresponds to nothing ``real''. But we still lack the mathematical structure unfortunately. How much have I already plagued myself in this way!

I suggest that in causal sets we have the mathematical structure that Einstein lacked.