Temporal naturalism

Lee Smolin – Perimeter Institute
Beyond spacetime
February 24, 2021

Projects with: Marina Cortes, Andrew Liddle, Roberto Mangabeira Unger, Fotini Markopoulou, Stuart Kauffman, Jaron Lanier, Julian Barbour, Stephon Alexander, Joao Magueio, Clelia Verde

Thanks also to: Wolfgang Wieland, Stefan Stanjovic, Michael Toomy, Will Cunningham, David Wecker, Laurent Freidel,

Dynamics of difference: arXiv:1712.04799.,

Energetic causal sets: with Marina Cortes: arXiv:1307.6167, arXiv:1407.0032, arXiv:1703.09696 , arXiv:1902.05082, arXiv:1104.2822, arXiv:1506.02938, arXiv:1205.3707

Einstein's Unfinished Revolution, Lee Smolin

https://leesmolin.com/einsteins-unfinished-revolution/related-scientific-papers/

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Prelude

Suppose that the world is based on one distinction:
that between the definite and indefinite.

C Verde

If you want to be a presentist, who believes the past and the future are unreal, you can't begin by talking about the future and the past.

Its hard to remain coherent by discussing what you declare doesn't exist You end up drawing a little green moving line on the block universe and thinking that makes you a presentist.

Similarly, if you want space to be emergent, you have to become used to imagining you are in a world without it.

We begin by positing that the world is based on one distinction: that between the definite and indefinite.

What we mean by becoming, or to happen is for something indefinite to become definite. This is what we call an event.

Only the becoming-the transition from indefinite to definite - is real

Hence, everything that is real is real in a particular moment- the present one.

This is so far a world with time and no space. The present moment so far has no structure.

Each event is endowed with energy and momentum.

By definition!

We assume laws govern their mutual exchanges which need not be imagined in space.

(Later their conservation will give rise to a kind of anti Noether theorem that helps space to emerge.)

Each becoming into definiteness, happens for a reason. These reasons come from antecedent past events, which pass their energy and momentum.

The set of antecedents of an event are also its connection to the rest of the world and can also be called that event's view of the universe.

The views of the present events make up what is real in each present moment.

Each event is then part antecedent to novel events, whose views they are part of, by virtue of their gifts to them.

In the short time between their creation and their role in the creation of their antecedent events, an event is part of the present. That is it exists.

The direction from indefinite to definite gives the universe an arrow of time.

The passage down of energy gives the universe a partial order.

Events do not persist. Becoming doesn't take very long.

They have no past, apart from the endowments they inherit.

They have no future, but the future will be created from their endowments.

All that exists (which is the same as all that is definite) are the views of the events in the present moment.

What questions is this an answer to?

Q1: What happened to space?

Notice that space has completely disappeared from the above description.

The succession of endowing create a partial order, ie a causal set.

But that isn't embedded in any "space".

We have traded near and far for similar and different.

Later in the talk we will see how the natural dynamics leads to the emergence of space, or spacetime, on which relativistic particles appear to propagate. Roughly, you are likely to see the world similarly if you are nearby.

But because similarity of views only approximately tracks nearness, locality is sometimes disordered. These we will show can give rise to entanglement.

Q11: How do we find local, but relational observables (beables) in diffeomorphism invariant theories?

Leibniz's principle of the identity of the indiscernible: The good observables are about views.

Any two events that have the same values of the physical fields are identified. i.e. no two events in spacetime have the same values of the physical fields. —> ***No symmetries***

The ***view of an event*** is the set of physical fields evaluated there.

The space of possible views in our universe is very sparse occupied, almost none of the possible views are actual. The universe is highly non-ergodic,

All views are distinct. Therefore an event's view labels it, indeed overdetermines it. So there are many local observables of the form: If there is an event whose view contains, A,B and C, it also contains D and E.

QIII: How did the universe pick its laws and the values of parameters?

Peirce: there must be evolution by some dynamical process.

In a sparse, far from ergodic universe, in which almost every possible state is absent, almost every possible history is unfollowed and almost every niche is empty; are the standard exclusively physicalist explanations sufficient?

Determinism is not enough. We need to understand why one structure is common, while a vast number of others, equally stable, are never produced. In these cases perhaps we have to take into account the functions that a system performs.

QIV Are functional explanations admissible in fundamental physics, along with deterministic explanations?

QV: Can we find functional explanations for fundamental physics, in which the laws evolve?

1) ***Cosmological natural selection (1992)***
2) ***Principle of precedent (2013)***
3) ***Can laws of nature learn? (2021)***

***QVI:* How do you formulate dynamics in a world where space isn't fudamental, where the fundamental scale has no distances, fields, derivatives…..?**

By comparing views!!!

The dynamics of difference:

Energetic causal sets

Real ensembles

The causal theory of views

- ***What is real?***

  The views of present events, which includes energy-momentum transferred by the causal processes from antecedent events.

  More precisely: ***the universe traces an energetic causal set.***

  The VIEW from each event of its causal past, consists of incoming energy-momentum vectors.

  What is fixed? the geometry of momentum space.

  The fundamental action is a function only of differences between present views.

  Variety= sum over pairs of present views of their difference.

  There is a basic evolution rule that acts repeatedly to pick the next antecedents out of the present events, chosen so that variety is maximized.

❖ ***What is emergent?***

Space, spacetime, quantum mechanics. Hence h, CCR..

❖ ***How is dynamics defined?***

- *By a path integral: a sum over causal processes and an integral over momentum and energy they transmit*

❖ ***What replaces locality and distances?***

Differences in views: Given events, I,J: D(I,J)= difference in their views

❖ ***What replaces kinetic energy?***

Differences of views of causally related events

❖ ***What replaces potential energy?***

Variety, Q: a measure of the diversity of causally unrelated views.

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$$\mathcal{V} = \frac{1}{N(N-1)} \sum_{I \neq J} \mathcal{D}(I,J)$$

- ***What does the quantum state represent?***

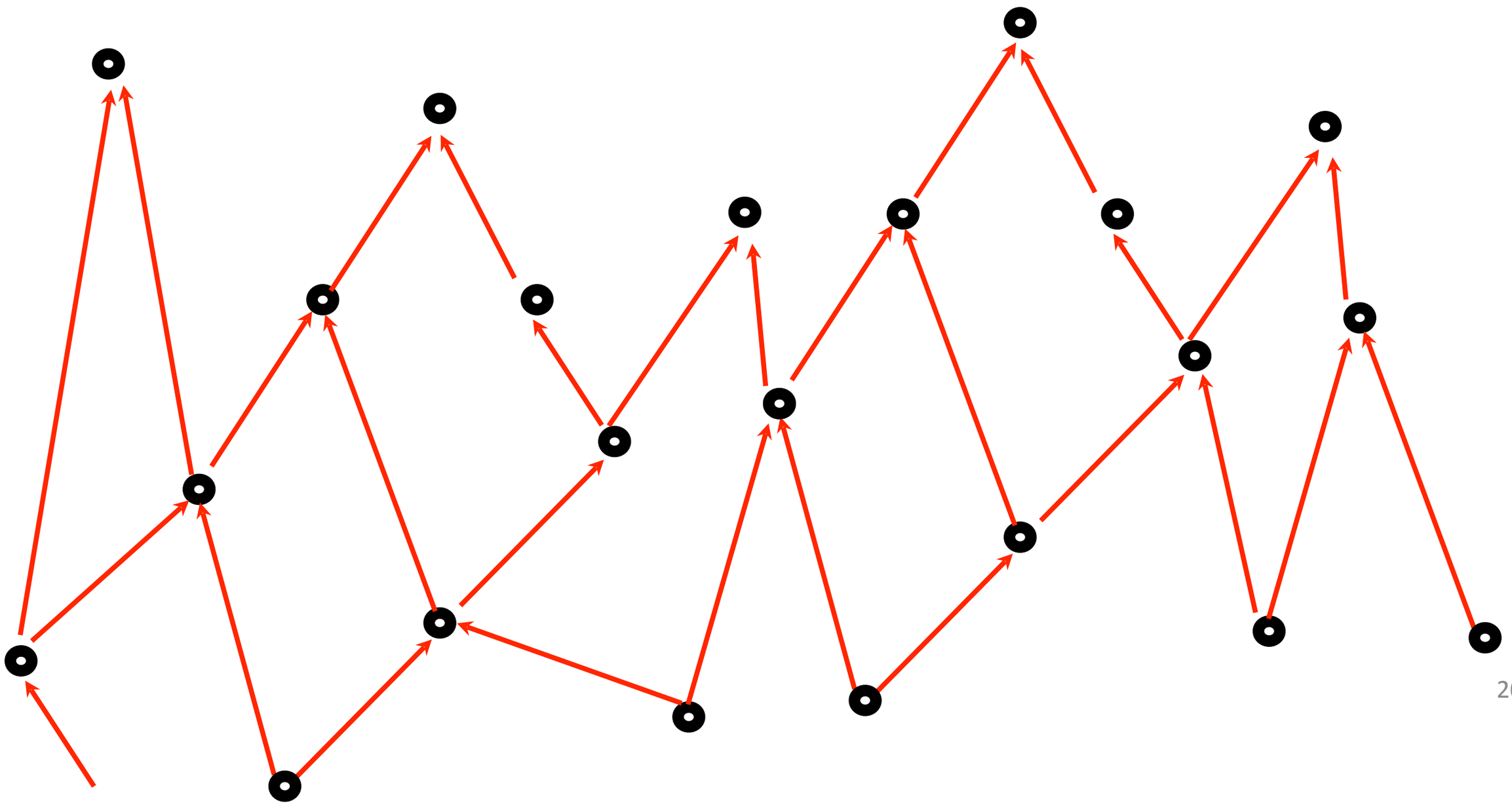
  A real ensemble of N events with similar views,
  but spread through the universe.

❖ ***What are the claims?*** *(N —> ∞, non-relativistic)*

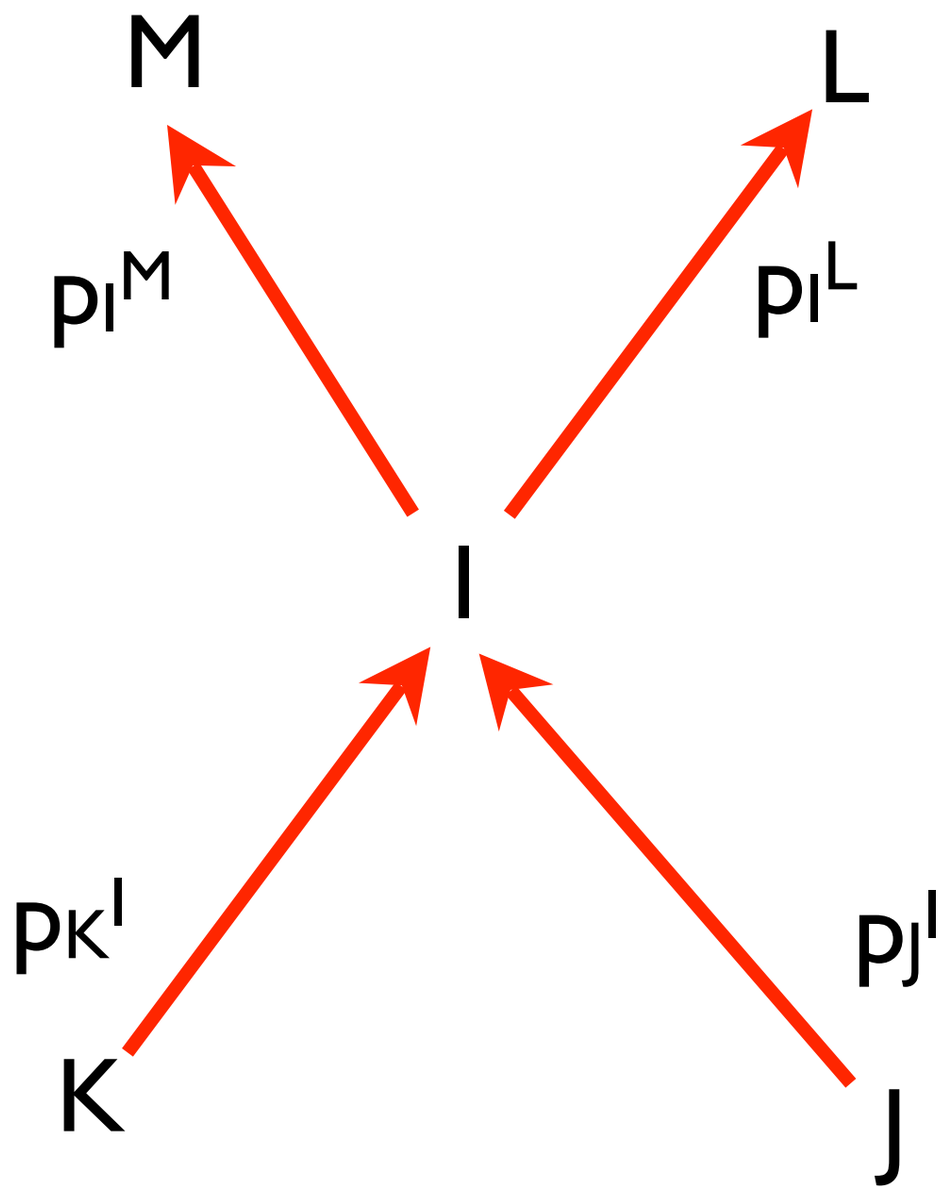
- *Space, spacetime, particle trajectories all emerge.*
- *Schrodinger QM emerges.*
- *Variety acausal relations —> Bohm's quantum potential*
- *Variety causal relations → kinetic energy*
- *For finite N there are computable corrections, which are non-linear corrections to Schoedinger dynamics.*

ENERGETIC CAUSAL SETS

CAUSAL SETS



ENERGETIC CAUSAL SETS



The total momenta of an event

$$\mathcal{P}_a^I = \sum_K p_{aK}^I - \sum_L q_{aI}^L = 0$$

The total amplitude is defined by integrating over momenta, imposing constraints, for energy-momentum conservation, weighed by the variety.

$$\mathcal{A}[P] = \int \prod_{I>J} dp_{a\,J}^{\ I} \prod_{I} \delta(\mathcal{P}_a^I)\ e^{\imath g \mathcal{Q}(p)}$$

$$\mathcal{P}_a^I = \sum_K p_{aK}^I - \sum_L q_{aI}^L = 0$$

This is the complete definition of the theory.

No hbar

No space or spacetime

No commutation relations

No uncertainty principle

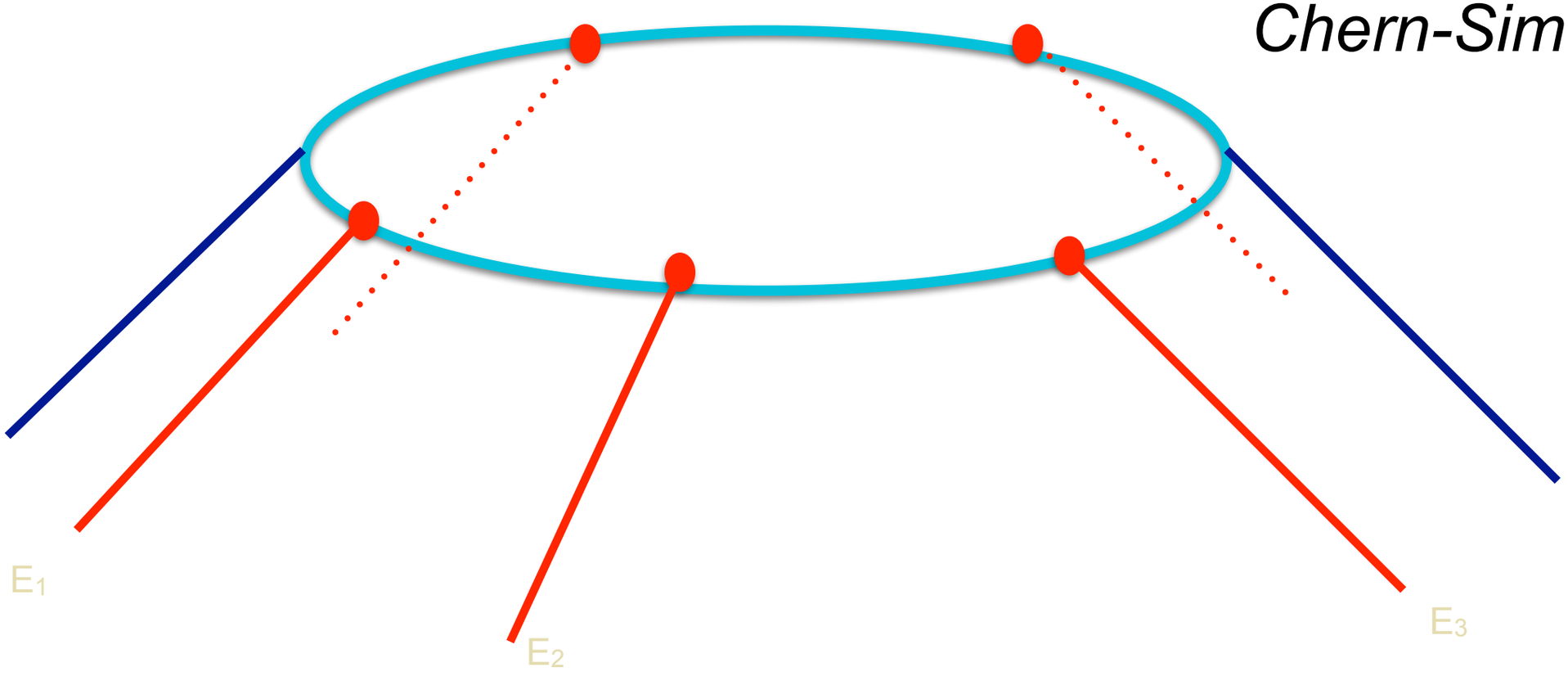
Non-local, because variety Q is.

Views as punctured two spheres

The view of an event is a collection of null or timeline energy momentum vectors, representing incoming information about the past. $\{ p_{a\,I}{}^{J} , p_{a\,I}{}^{K} , \ldots \}$.

We can represent the directional information as points on an S2, with labels which are the energy.

Connects to boundary
Chern-Simons technology



EMERGENCE OF SPACETIME FROM ENERGETIC CAUSAL SETS

Classical physics from the stationary phase approximation:

$$S = \sum_I z_I^a \mathcal{P}_a^I + \sum_{(I,K)} (x_K^{aI} \mathcal{R}_{aI}^K + \mathcal{N}_I^K \mathcal{C}_K^I - \tilde{\mathcal{N}}_I^K \tilde{\mathcal{C}}_K^I)$$

Constraints:

lagrange multipliers

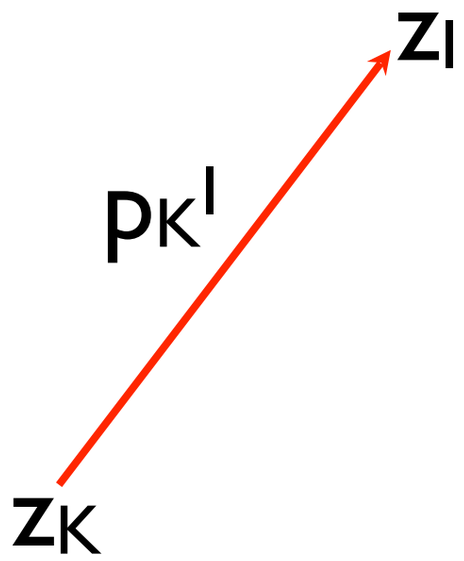
$$\mathcal{P}_a^I = \sum_K p_{aK}^I - \sum_L q_{aI}^L = 0 \qquad \mathcal{R}_{aI}^K = p_{aI}^K - \mathcal{U}_{Ia}^{Kb} q_{bI}^K = 0$$

$$\mathcal{C}_K^I = \frac{1}{2}\eta^{ab} p_{aK}^I p_{bK}^I = 0 \qquad \tilde{\mathcal{C}}_K^I = \frac{1}{2}\eta^{ab} q_{aK}^I q_{bK}^I = 0$$

Equations of motion:

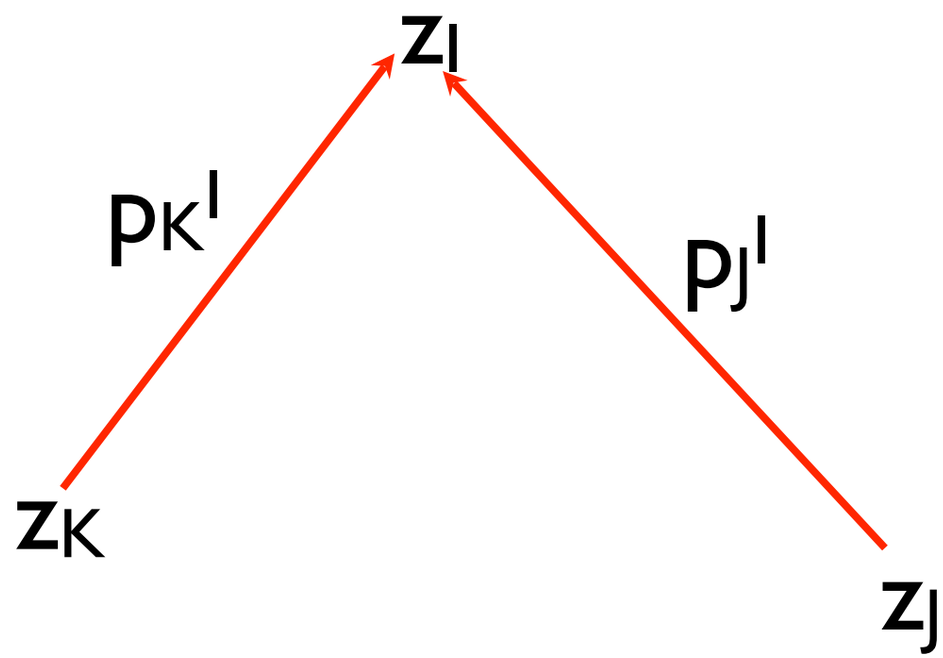
$$z_I^a - z_K^a = p_K^{aI} \mathcal{M}_I^K$$

$$\mathcal{M}_I^K = \tilde{\mathcal{N}}_I^K - \mathcal{N}_I^K$$



Spacetime emerges when there are consistent solutions to all the equations:

$$z_I^a - z_K^a = p_K^{aI} \mathcal{M}_I^K$$



Spacetime inherits its metric from momentum space:

$$|z_I^a - z_K^a|^2 = (z_I^a - z_K^a)(z_I^b - z_K^b)\eta_{ab}$$
$$= (\mathcal{M}_I^K)^2 |p_K^{aI}|^2 = 0$$

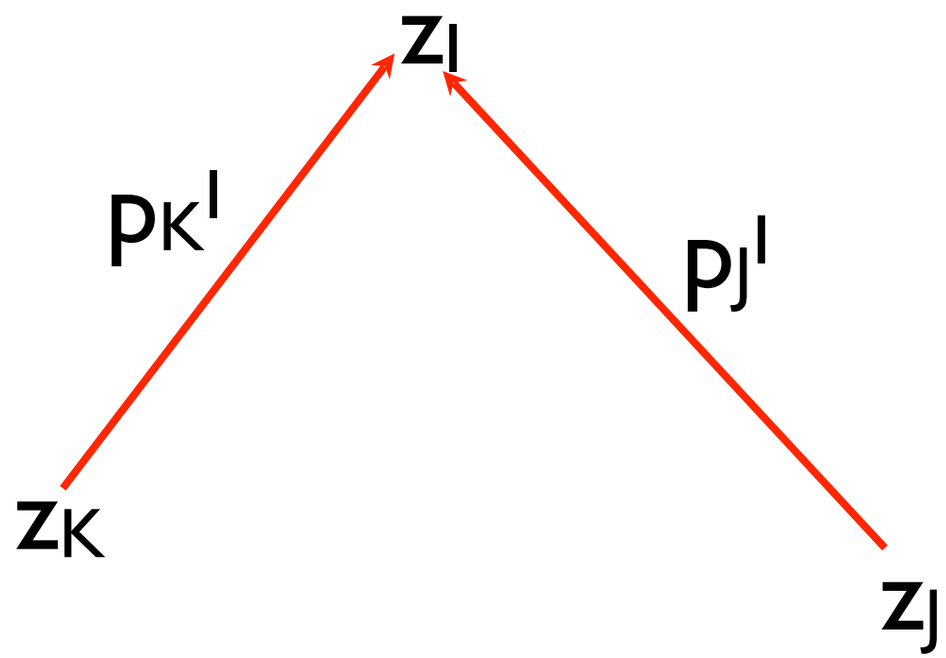
U=1 gives flat spacetime

Spacetime emerges when there are consistent solutions to all the equation

$$z_I^a - z_K^a = p_K^{aI} \mathcal{M}_I^K$$

rescale z --> z/h to give spacetime coordinates units of length.

h is purely conventional.



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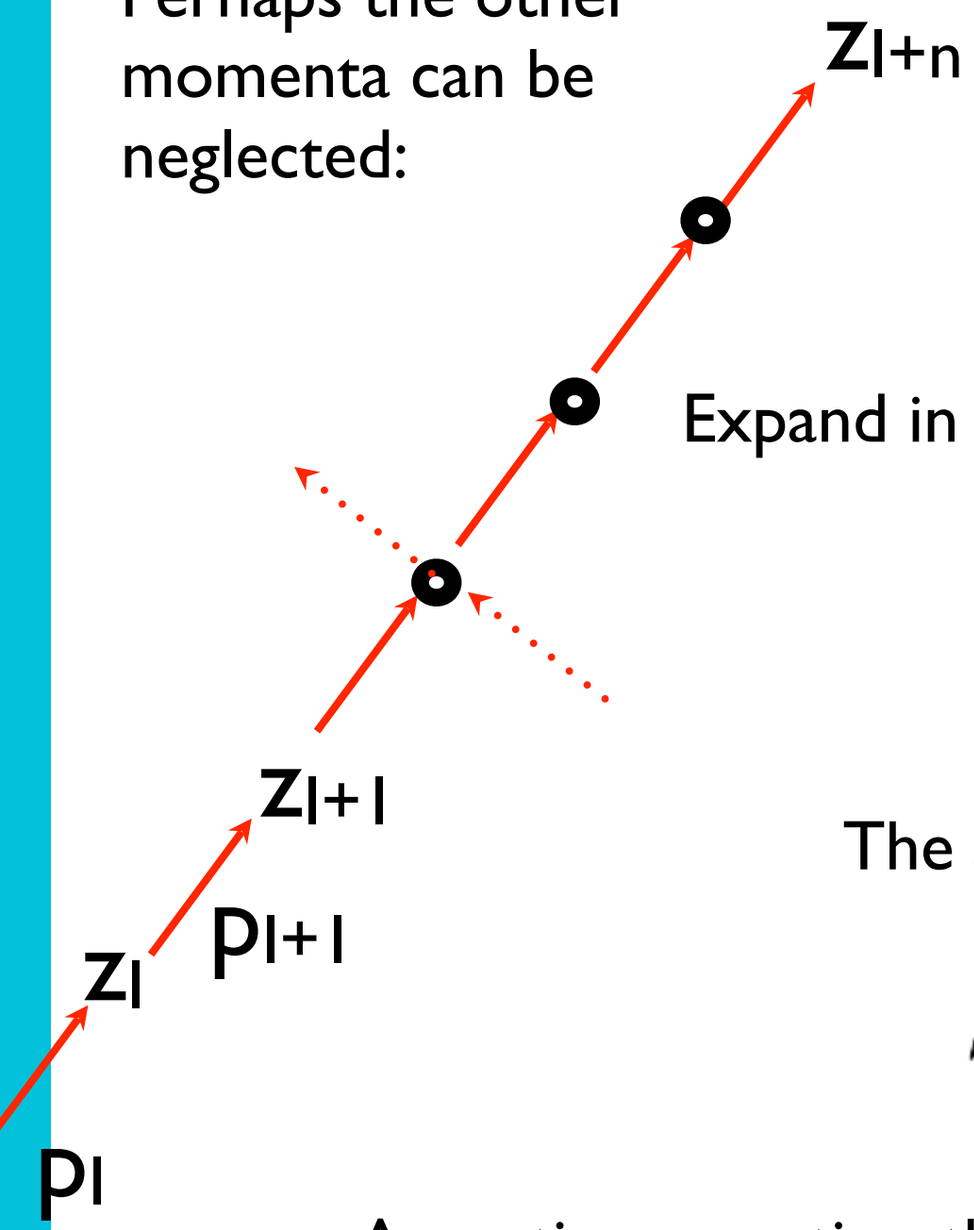
U=1 gives flat spacetime

EMERGENCE OF PARTICLES FROM ENERGETIC CAUSAL SETS

Consider a long chain of simple events (one in and one out):

Perhaps the other momenta can be neglected:



Equations of motion: $$p_a^I = p_a^{I+1} = p_a$$
$$z^a_{I+1} - z^a_I = p^{aI}\mathcal{M}_I$$

Expand in a small time interval: $$z^a_{I+1} = z^a_I + \dot{z}^a(t)\Delta t$$

The EoM is now: $$\dot{z}^a(t) = \frac{\mathcal{M}_I}{\Delta t} p^a_I = n p^a_I$$

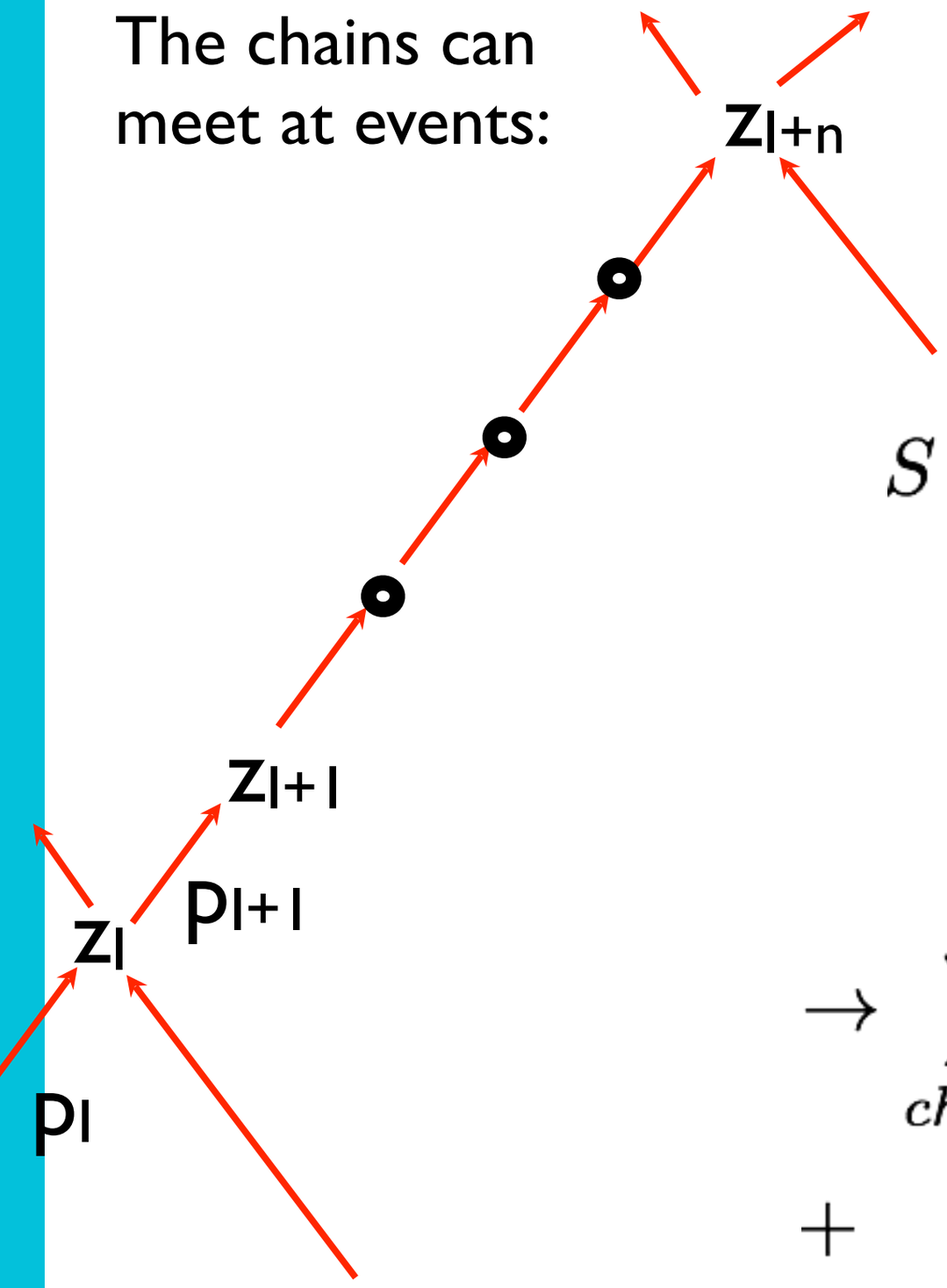
The action is now:

$$S = \sum_I p^I_a (z^a_{I+1} - z^a_I) - \frac{1}{2}\mathcal{M}_I p_I^2$$

A continuum action that gives the same classical physics: $$\rightarrow \int dt \left(p_a(t)\dot{z}^a(t) - \frac{1}{2} n(t) p(t)^2 \right)$$

which is the action for a free relativistic massless particle:

The chains can meet at events:



$$S = \sum_{chains} \sum_{I} p_a^I (z_{I+1}^a - z_I^a) - \frac{1}{2} \mathcal{M}_I p_I^2$$

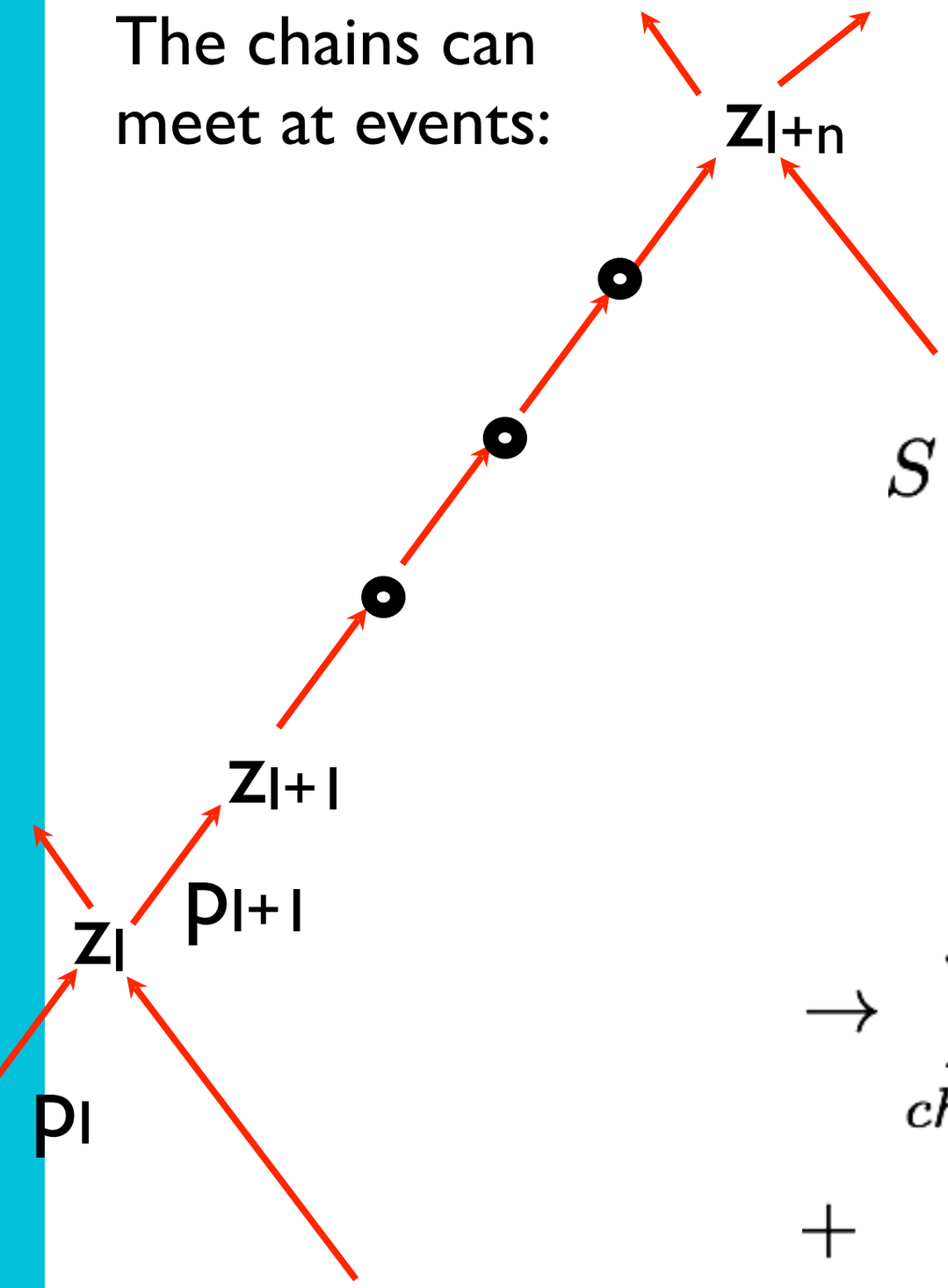
$$+ \sum_{interactions} z_I^a \mathcal{P}_a^I$$

$$\rightarrow \sum_{chains} \int dt \left(p_a(t) \dot{z}^a(t) - \frac{1}{2} n(t) p(t)^2 \right)$$

$$+ \sum_{interactions} z_I^a \mathcal{P}_a^I$$

which is the action for relativistic particles with local interactions.

The chains can meet at events:



"pre-relative locality"

$$S = \sum_{chains} \sum_{I} p_a^I (z_{I+1}^a - z_I^a) - \frac{1}{2} \mathcal{M}_I p_I^2 + \sum_{interactions} z_I^a \mathcal{P}_a^I$$

$$\rightarrow \sum_{chains} \int dt \left(p_a(t) \dot{z}^a(t) - \frac{1}{2} n(t) p(t)^2 \right) + \sum_{interactions} z_I^a \mathcal{P}_a^I$$

which is the action for relativistic particles with local interactions.

VARIETY

BASIC IDEAS

The variety of a network, G,

- $N_l(k)$ is the l'th neighborhood of node k
- This is the subgraph of G including those nodes l steps from k

- For any pair of nodes,
n_{kl} is the smallest n such that
$N_n(k)$ is not isomorphic to $N_n(l)$

- The distinctiveness of the pair is

$$D(k,l) = \frac{1}{n_{kl}}$$

- The variety of G is

$$\mathcal{V} = \frac{1}{N(N-1)} \sum_{k \neq l} D(k,l) = \frac{1}{N(N-1)} \sum_{k \neq l} \frac{1}{n_{kl}}$$

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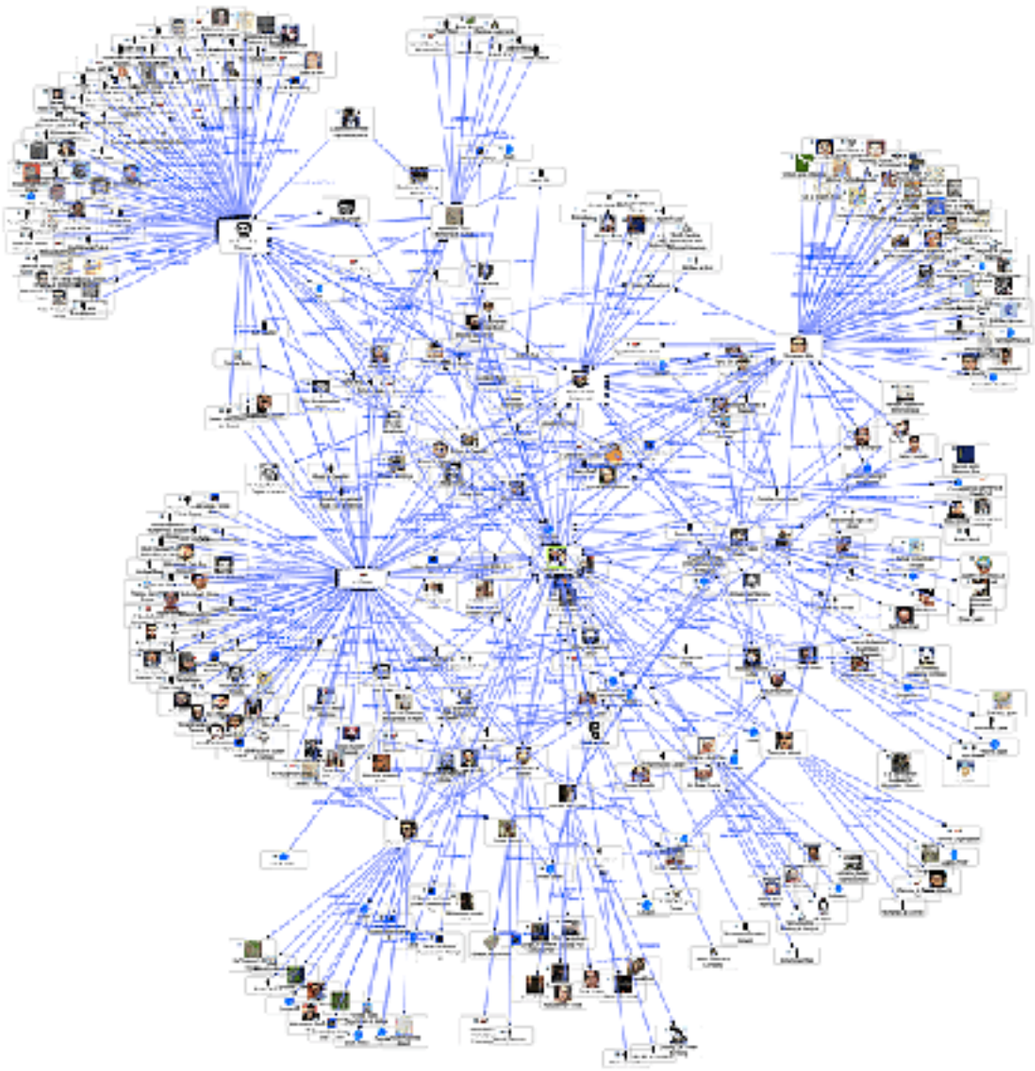


High variety

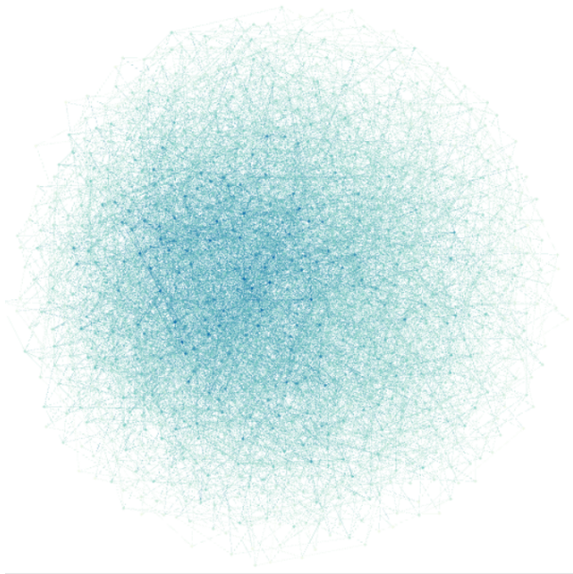
healthandsociety.columbia.edu

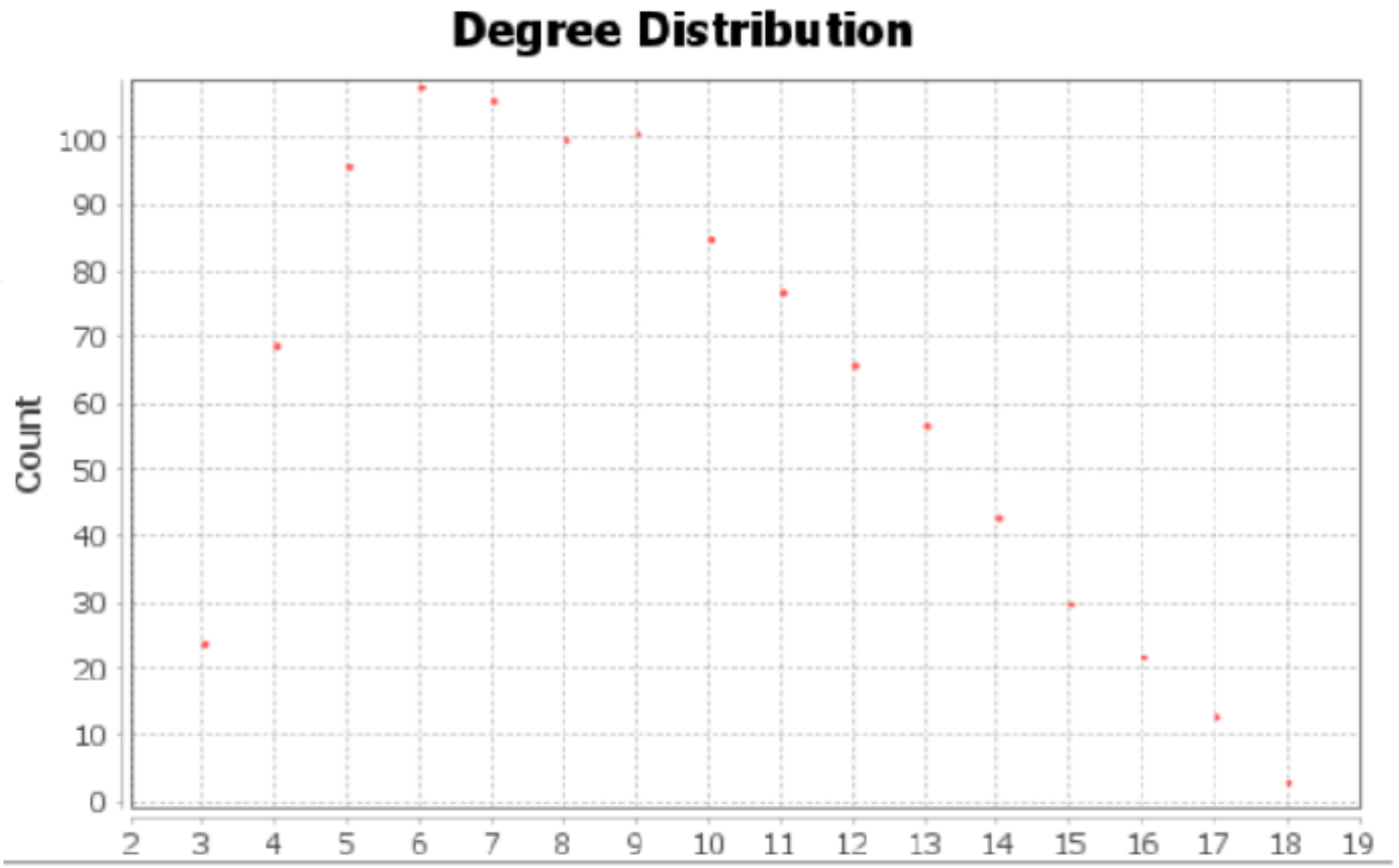
http://en.wikipedia.org/wiki/Interactome

Stefan Stanjovic, Michael Toomy, Will Cunningham, David Wecker, Stefan Alexander, Jaron Lanier, LS (MS research, PI)

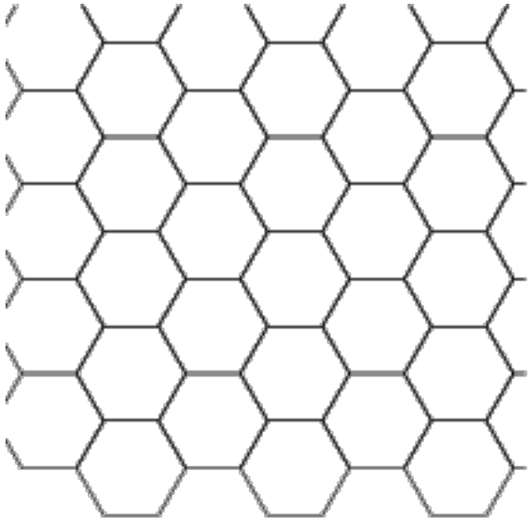
The 1000 node high-variety graph generated through a simulated annealing procedure

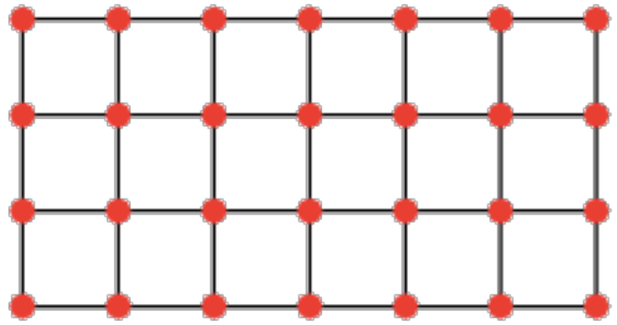
High variety





Low variety





http://mathworld.wolfram.com/HexagonalGrid.html

$$\mathcal{V} = \frac{1}{N(N-1)} \sum_{k \neq l} D(k,l) = \frac{1}{N(N-1)} \sum_{k \neq l} \frac{1}{n_{kl}}$$

"Just as the same city
viewed from different directions,
appears entirely different
and, as it were,
multiplied perspectively,
in just the same way it happens that,
because of the infinite multitude of simple substances,
there are, as it were,
just as many different universes,
which are, nevertheless,
only perspectives on a single one,"

The common completion of general relativity and QM

- The fundamental theory is a theory of the views of events. These are related by causal processes which transmit energy and momentum.
- Space is not present initially, time and causation, energy and momentum are.
- With no x^a, there are initially no commutation relations, hence no h.
- No locality, also no non-locality.
- Measures of difference of views replace measures of distance.
- Space emerges, hence local physics emerges, but with defects: locality is disordered.
- QM also emerges as there are now ccr: $[x,p]=i\,h$
- The newly non-local interactions manifest themselves as entanglement.
- Quantum states are ensembles of subsystems that are highly similar and hence very interactive in spite of being distant in the newly emerged geometry.

Thank you