Title: Summaries and closing remarks

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Abstract:

Time in Cosmology:

A personal perspective

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Should I think more about “time” now or can it wait until my retirement?

Learn from juxtaposing “times”?

- heard about many “times” and from different perspectives
- many a priori logically independent …
- … can we gain insights from relating them?

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"Does the present moment have an objective, physical meaning?"
— Perhaps not.

Time asymmetry of the universe?

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- … how does this constitute an *explanation* of the initial conds.?
- regard initial conditions at part of the law! — does not help
- we may be able to derive the current initial conditions by slightly earlier ones taking into account full quantum gravity
- same problem, but many more degrees of freedom

"Is time fundamental or emergent?", or The challenges of "emergence"

- bottom-up vs. top-down causation, reduction vs. emergence
- these are not mutually exclusive, but explicit examples of emergence of time (or other aspects of spacetime) are rare (don't mean the "arrow of time")
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- QG as ultimate saviour: "I hope quantum gravity will explain X!", X = your favourite outlandish property of spacetime at the Planck scale
- key problem: *How do locality, causality, unitarity, spacetime as we know it emerge on larger scales from such a quantum dynamics?*

Quantum Gravity from Dynamical Triangulations

- DT and Causal DT (CDT) provide insights into generic mechanisms of the emergence of "time" and "causal structure"
- nonperturbative path integral of gravity from the continuum limit of a regularized "sum over histories" (curved spacetimes)

$$Z(G_N,\Lambda) := \lim_{\substack{a\to 0\\ N\to\infty}} \sum_{\substack{\text{inequiv.}\\ \text{triangul.s}\\ T\in\mathcal{G}_{a,N}}} \frac{1}{C(T)}\, \mathrm{e}^{iS^{\mathrm{Regge}}_{\mathrm{G_N},\Lambda}[T]}$$

$C(T)$: |Aut(T)|

- Euclidean version (DT) has Boltzmann weights $exp[-S^{Regge}[T_{eu}]]$
- DT building blocks are equilateral four-simplices with edge length a (= short-distance cutoff; not l_{Pl}); simple gluing rules

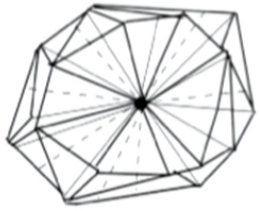
- one is only interested in universal properties at scales >> a (N.B. no fundamental discreteness postulated/implied)

Results from DT (Euclidean quantum gravity)

From investigating this timeless stat mech model of dynamical geometry with Monte Carlo methods in the continuum limit, do we find evidence for the emergence of time or causal structure? - NO!

Even worse: there is no tuning of the bare couplings for which extended 4-dimensional geometry emerges at a macroscopic scale! Instead, the quantum geometry of the system's nonperturbative ground state polymerizes or crumples (entropic effects):

branched polymer phase
(small G_N^{bare}), $d_H = 2$



crumpled phase
(large G_N^{bare}), $d_H = \infty$

$\Rightarrow$ *have falsified a QG theory, due to non-existence of classical limit*

Results from CDT (Lorentzian quantum gravity)

Change: Minkowskian building blocks and gluing rules that forbid "ill-behaved" causal structure of individual path integral histories

We suppress the occurrence of such branchings w.r.t. a discrete proper time τ_{CDT}, labelling layers of our universes.

N.B.: singular "trouser points"

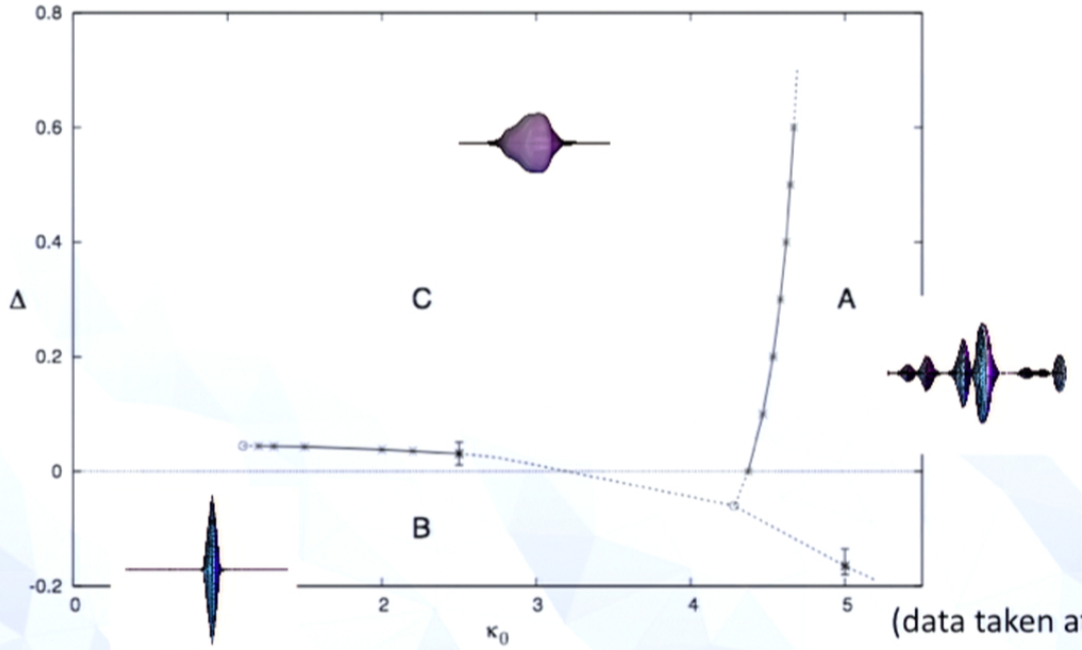
What becomes of τ_{CDT}, in an infinite-volume or scaling limit? — If we put time in, it must come out, surely?

Not necessarily! In order to have "time", need also space!

(N.B. still have strong quantum fluctuations of geometry)

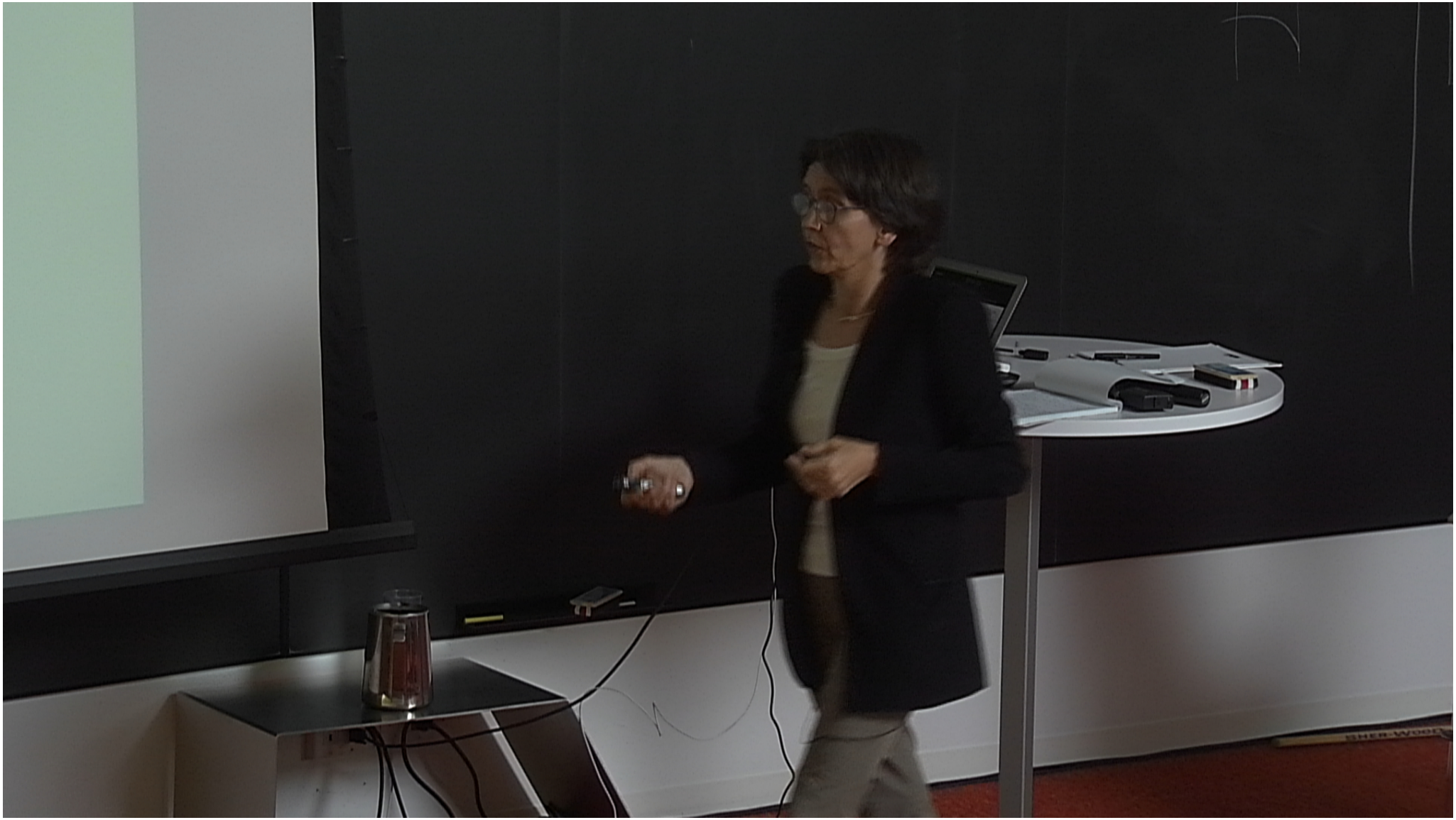
Results from CDT (Lorentzian quantum gravity)

Only in one of the phases (C) is there an extended spacetime, where "time" seems to assume a standard meaning of global, proper time! This is seen when measuring "volume profiles" $V_3(\tau)$.



(data taken at N=80.000)

System has a "potentiality of time", but it does not emerge automatically.



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Moreover, timeless formulations tend to be complicated or intractable.

From this, a tentative conclusion:
some notion of global time is essential (at least in quantum gravity), and therefore fundamental.

TIME IS HERE TO STAY.

Time in Cosmology

My biased summary

St. Augustine

- **What then is time? If no one asks me, I know: if I wish to explain it to one that asketh, I know not.**

- Is time indeed inarticulable?
- Or perhaps time is even inconceivable?
- And which time: time of philosophers or time of physicists?

Time of philosophers

- Questions about time philosophers ask:
  - What is time, and is it real? If it exists, does it have an independent existence or is it a property of something else?
  - Are future and past as real as the present?
  - Is time dependent on relations among things, or independent of those relations?
  - Is present objectively real and time flows; or now is not objectively real and time does not flow; or perhaps something else?
  - What is the relation between time and mind?
- These are not the questions that physicists ask!

Time of physicists

- Physics is a natural science aimed at discovering how nature works, and all notions used must be operationally defined.
- Thus, e.g., the time used in Newton's equations (and in all equations of physics for that matter)

$$m\frac{d^2x}{dt^2} = F$$

- refers to the reading of some "clock". Thus in physics we relate evolution of an observed system with evolution of a reference one (the clock).
- **Thus in physics there is no room for time, in the philosophical sense! NO TIME, NO PROBLEM.**

Emergent vs. fundamental

- Stuart Kaufmann has stressed that "*you cannot reduce Darwin to Einstein*". That's intuitively obvious, but the argument seems not clear to me .
  - "Cannot" in principle or in practice? If in principle, why?
  - There seems to be some quite deep relation between emergent and time (emergent must have time to emerge). What does it tell us about time?

Lee Smolin's & Roberto Unger's

cosmological theory

- The challenge is here to find a theory of everything that exist, i.e. the theory of a the system with nothing outside it.
- This goes far beyond the subject matter of contemporary physics (because contemporary physics **is** about local systems and outside observers).
- This is very ambitious and exciting project. But it seems to require going back to pre-Newtonian (meaning pre-scientific) times and construct everything from scratch.
- In particular, the fundamental question is: if universe is everything there is, and time is, what is the ontology of time vs. the ontology of the universe?

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Marina, Lee, Roberto

. . .

Thanks for this exciting week!

THE CASE FOR ANARCHY
OBSERVATIONS FROM THE OUTSIDE

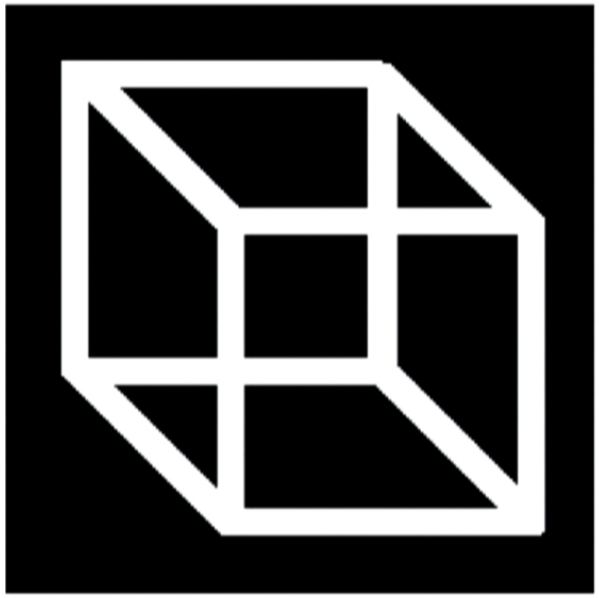
Adam Frank
University of Rochester

Metaphysics: Spoken and Otherwise

Emergence

Reductionism

Downward-Causality



Status of Present

Upward-Causality

Reversiibilty

Why Explore New Metaphysics/"Meta"-physics

- It's a Hard Problem so It Takes Time
- Absolutely True!
- SM extensions/QG historically unprecedented (aether?)
- Even so, all the more reason to explore other metaphysics+physics.

Why Explore New Metaphysics/"Meta"-physics

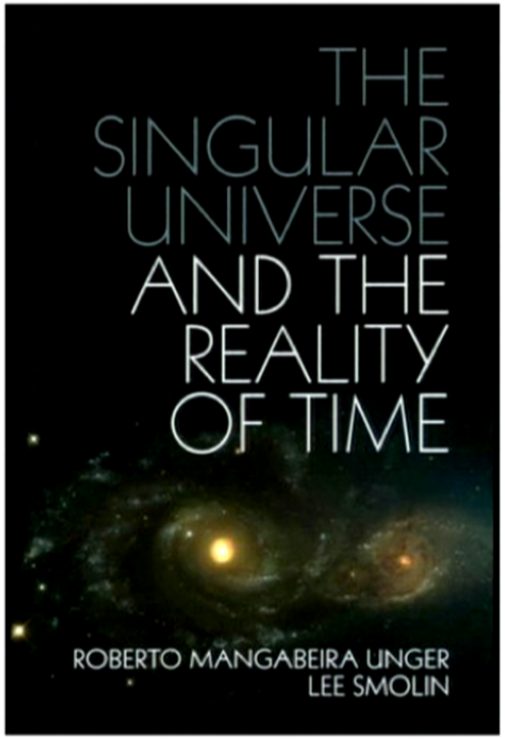
Ontological Exuberance

- Models in the field are deemed successful yet contain ontologically "volume filling" new actors. (Other Universes, Hidden Dimensions)

- Existence of these new actors (may) not be observable in principle, or in practice.

Smolin-Unger Program

- Singular Universe
- Time is Real
- Mathematics is Selectively Real



Eternal Laws and Mathematics

"As the law of circles is to all circles so is God to the Universe"

-Einstein describing Spinosa

(Durant, Story of Philosophy)

Law and Structure lives "above" or apart from Universe it determines.

Beyond Eternal Laws:
The Biological Metaphor (w/ Stu Kaufmann)

Genotype → Phenotype → Selection → Genotype

Note DNA alone yields nothing ("sterile")
Must have egg i.e. must exist in the world.

- Survival is at level of whole which carries along the parts.
- *Kantian Whole*: parts exist for and by means of the whole

Beyond Eternal Laws: The Biological Metaphor (w/ Stu Kaufmann)

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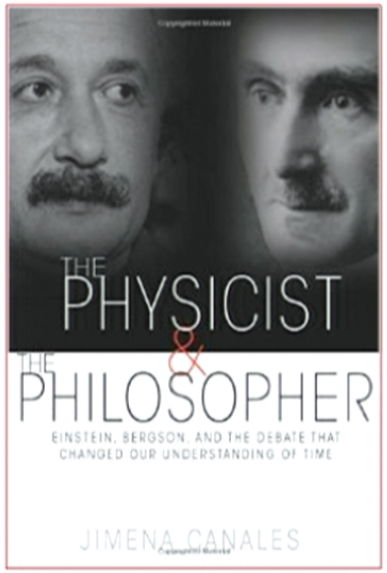
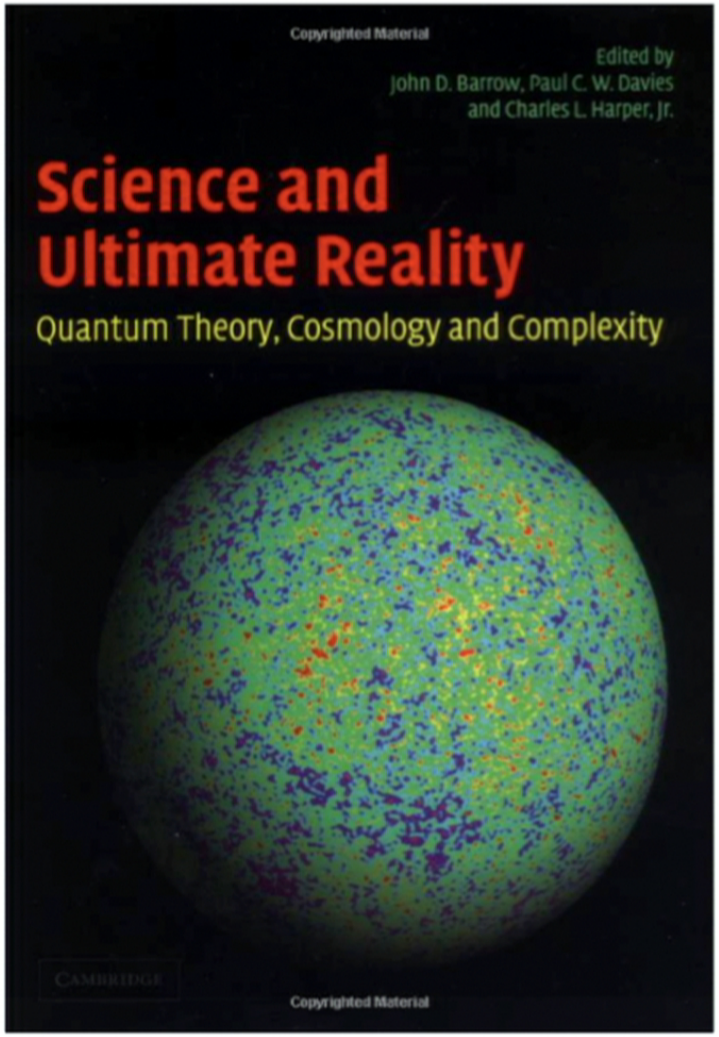
"What Breaths Fire Into the Equations?"
- Hawking

How Far? How Deep?

- Philosophy and Physics: draw from limited line of dialogue
  - Anglo-American analytic
- "Continental" School
  - Bergson
  - Phenomenology: Husserl, Heidegger…





Thank You!!!

Lee
Roberto
Marina
Stephanie
And
all participants

BIG FUN Eh!