Title: In Search of Lost Spacetime

Speakers: Chris Smeenk

Series: Colloquium

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Abstract: The classical spacetime manifold of general relativity disappears in quantum gravity, with different research programs suggesting a variety of alternatives in its place. As an illustration of how philosophers might contribute to an interdisciplinary project in quantum gravity, I will give an overview of recent philosophical debates regarding how classical spacetime "emerges." I will criticize some philosophers as granting too much weight to the intuition that a coherent physical theory must describe objects as located in space and time. I will further argue, based in part on historical episodes, that an account of emergence needs to recover the structural features of classical GR responsible for its empirical success. This is more demanding than it might at first appear, although the details of recovery will differ significantly among different approaches to quantum gravity.

Zoom link: https://pitp.zoom.us/j/98331676824?pwd=VTNOakMxWWUzT2ZFZFYwYzBRdWxBUT09

In Search of Lost Spacetime

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Quantum Spacetime in the Cosmos
Perimeter Institute: May 2023

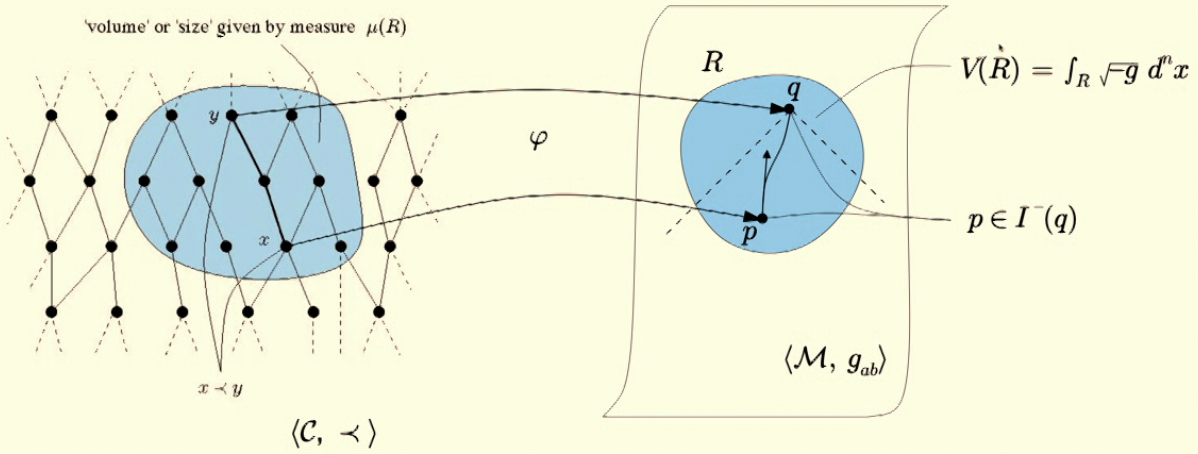
Rotman Institute
of Philosophy
ENGAGING SCIENCE.

Spacetime Lost

Arguments that "spacetime disappears" in quantum gravity

- Planck scale measurements
- Dualities
- Discreteness
- Holography

  (... among others ...)



(Causal sets; image from Lam and Wüthrich 2018; cf. Dowker and Butterfield 2021)

... but Emerges?

- *Fundamental Level*, T_f: discrete, non-spatiotemporal
- *Higher Level*, T_i: classical spacetime

Terminological Warning!

Many different senses of emergence, e.g.:

- *Strong*: T_i autonomous, not derivable from T_f
- *Weak*: T_i qualitatively distinct from T_f, unexpected features

(e.g., Bedau 1997)

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This talk: attempts to derive T_i from T_f; elucidate contrast and novel, robust features

Challenge

How can a non-spatiotemporal theory represent Nature?

What could possibly constitute a more essential, a more ineliminable, component of our conceptual framework than that ordering of phenomena which places them in space and time? The spatiality and temporality of things is, we feel, the very condition of their existing at all and having other, less primordial, features. A world devoid of color, smell or taste we could, perhaps, imagine. Similarly a world stripped of what we take to be essential theoretical properties also seems conceivable to us. We could imagine a world without electrical charge, without the atomic constitution of matter, perhaps without matter at all. But a world not in time? A world not spatial? Except to some Platonists, I suppose, such a world seems devoid of real being altogether.

(Sklar 1983, p. 45)

Challenges

How can a non-spatiotemporal theory represent Nature?

- *Physical*: recover classical general relativity (GR) as a limit, satisfy core principles of GR and QFT, ...

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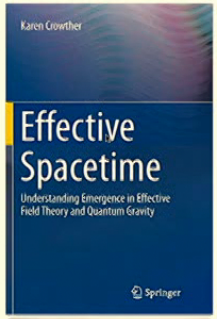
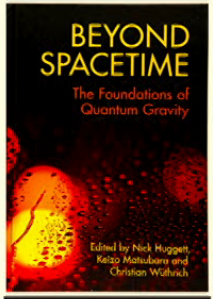
How can a non-spatiotemporal theory represent Nature?

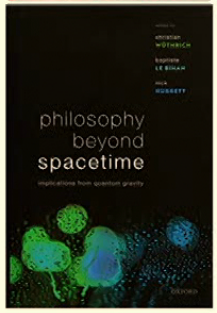
- *Physical*: recover classical general relativity (GR) as a limit, satisfy core principles of GR and QFT, ...
- *Philosophical*: revise central ideas that implicitly rely on spacetime (laws of nature, causation, composition, nature of evidence...)

Philosophers Beyond Spacetime

Crowther, Huggett, Wüthrich, Oriti, Le Bihan, ...







Spacetime Regained?

Approaches to QG

- String Theory and Holography
- Loop Quantum Gravity and Spin Foams
- Asymptotic Safety
- Causal Dynamical Triangulation
- Causal Sets
- Horava-Lifshitz Gravity

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Distinctive Derivations

- Perturbative
- Non-Perturbative
- "$N \to \infty$" limit

...

(See Huggett and Wüthrich, *Out of Nowhere* (forthcoming))

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  1. How much does current theory T_i constrain, shed light on T_f?
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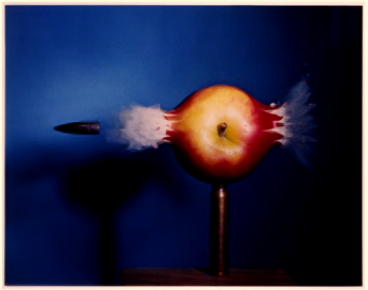
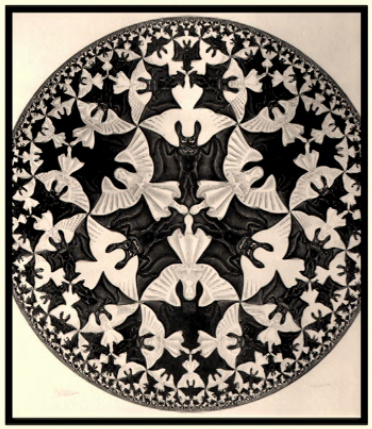
  3. What is needed to establish physical significance?

How Constrained?



Empirical Coherence



Beyond Correspondence

How Constrained?

What is the relationship between new fundamental theory T_f and "emeritus" theory T_i?

Contra Two Philosophical Myths

- Underdetermination
- Incommensurability

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- Underdetermination

  ... cases of clear empirical guidance

- Incommensurability

  ... critical analysis, continuity of evidential reasoning

The Determination of Theory by Evidence (Norton 1993)

$\approx$ 1910 Quantum discontinuity $\rightarrow$ Planck distribution for BBR

Open question: other theoretical possibilities?

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1911-12 Ehrenfest & Poincaré:

Observations of black body radiation +
Statistical mechanics (applied to radiation and resonators)
... *implies* quantum discontinuity

Empirical Guidance

Common type of argument in history of physics:

T_i (or part of it) + empirical results → new principle

(Arguments of this kind in QG?)

Transition from T_i to T_f

- Kuhnian "revolution"
  - Prompted by accumulated anomalies
  - Scientists unable to communicate, "living in different worlds"

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- Kuhnian "revolution"
  - Prompted by accumulated anomalies
  - Scientists unable to communicate, "living in different worlds"
- Driven by critical reflection on T_i (Stein 1994, DiSalle 2006)
  - T_f arises from refinement of core physical ideas of T_i
  - Challenge in determining what is actually responsible for empirical success

Correspondence Principle

"...the requirement that any acceptable new theory T_f should account for the success of its predecessor T_i by 'degenerating' into that theory under those conditions under which T_i has been well confirmed..."

(Post 1971)

Success: including evidential reasoning and inferences, not merely predictions

Correspondence Principle

Recover T_i as a limit of T_f in some domains, basis for partial interpretation of T_f

- No requirement to recover full space of solutions for T_i
- Possibility of new solutions / regimes extending beyond T_i

Status of Emeritus Theories

[...] But approximate theories [superceded by new fundamental theories] are not merely approximately true. They can make a statement that, though it refers to an approximation, is nevertheless precisely true. For instance, although Maxwell's equations give only an approximate account of electric and magnetic fields, it is precisely true that the error introduced by using Maxwell's equations to calculate these fields can be made as small as one likes by considering fields that are sufficiently weak and slowly varying. This is part of the reason that Maxwell's equations are a permanent part of physical science.

(Weinberg, in NYRB (1998))

Relationship between T_f and "emeritus" theory T_i?

- Ideally, empirical results force *specific* revisions of T_i
- Correspondence principle: limiting relationship $T_f \to T_i$

Empirical Coherence

Incoherent theory: theory that, if true, undermines evidence taken to justify it

Is a fundamental theory without time, or without spacetime, incoherent?

Importing an Argument

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- Debates regarding wave function realism (Albert, Ney, Maudlin, ...)
  - Realist commitment to wavefunction (complex valued function on configuration space, $\mathbb{R}^{3n}$)
  - How can we recover localized entities, space within this picture?

Local Beables and Evidence

- Local beables =: physical quantities defined on bounded regions of spacetime (Bell 1987)
- Role of local beables

  [T]he evidential connection is made between the physical description and a certain class of local beables, such as the positions of macroscopic objects. [...] [T]he contact between theory and evidence is made exactly at the point of some local beables: beables that are predictable according to the theory and intuitively observable as well.

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An argument for Incoherence?

P1 In fundamental theories without spacetime, there are no "local beables" at the fundamental level

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P2 Local beables are necessary to make the connection between theory and evidence

P3 ... Correspondence / limiting relationships / derivation of T_i from T_f not sufficient?

CNC Fundamental theories without spacetime are incoherent

... [O]ne might also try instead to derive a physical structure with form of local beables from a basic ontology that does not postulate them. This would allow the theory to make contact with evidence still at the level of local beables, but would also insist that, at a fundamental level, the local structure is not itself primitive. [...] This approach turns critically on what such a derivation of something isomorphic to local structure would look like, where the derived structure deserves to be regarded as physically salient (rather than merely mathematically definable). Until we know how to identify physically serious derivative structure, it is not clear how to implement this strategy.

(Maudlin 2007, 3161)

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- *This is exactly what correspondence principle / limiting relationships aim to provide!* (Huggett and Wüthrich 2013)
- How would *a priori* constraints on what qualifies as "physically serious" be justified?

Related Debate: Nature of Time

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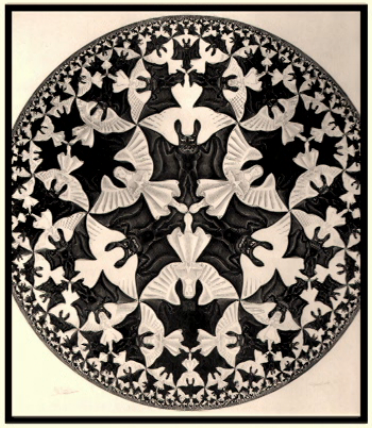
- Coherence of a Parmenidean Theory (no change, no flow of time)? (Healey 2002, Smolin and coauthors)
- What does temporal experience imply regarding features of time in fundamental theory?
- Risk neglecting naturalistic account of human observers, our role in constructing temporal experience (Ismael 2011, Callender 2017)



Beyond Correspondence

Suppose that we have found a limiting relationship, and can recover T_i from T_f.

This gives us only partial insight into the physical significance of T_f.

Example: Interpretative Principles in GR (Malament 2012)

Specify the connection between Lorentzian geometry and (idealized!) physical systems, starting point for further physical interpretation.

- *Length*: For spacelike curves, the magnitude of the curve represents length.
- *Duration*: Clocks record the passage of elapsed proper time along their (timelike) worldlines.
- *Massive Particles*: The images of (smooth) timelike curves represent possible trajectories of massive "test particles".
- *Free Particles*: The images of timelike geodesics represent possible trajectories of free (i.e., net non-gravitational force $= 0$) massive particles.
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  - Derivations of geodesic motion (for test particles and light rays) from the field equations
- Novel applications (in regimes that extend well beyond T_i), requiring conceptual innovation (singularities, event horizons, ...) and empirical tests

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   ... But limiting relationship only provides partial interpretation of T_f.