Stone age tools for quantum gravity

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It is time to study Quantum Channel Capacities in RQI

- **Why study QCC in RQI?**
  - Quantum information transfer in light matter interactions
  - E.g., for ion trap quantum computing
  - Formulating Feynman rules and all else in information theoretic terms

- **There are results in the literature and several collaborations are ongoing, e.g., with:**
  - Aida Ahmadzadegan, Aidan Chatwin-Davies, Eduardo Martin-Martinez, Emily Kendall, Nadine Stritzelberger, Nick Menicucci, Petar Smidzija et al.

- **Today's talk:** A big picture quantum gravity motivation.

Some preliminary observations

- Quantum Field Theory:
  - The Feynman rules are measurable, pocket CERN
- General Relativity:
  - There are multiple formulations of GR, such as:
    - Affine connection (using Christoffel symbols)
    - Metric formulation, (M,g)
    - Through Synge world function, (M,s)
    - They are all highly redundant – it is difficult to fix a gauge.

Big picture

Quantum Gravity has now been elusive for a century.

Why?

Apart from technical difficulties, are there deeper reasons?

Are we held back by misconceptions?

Big picture:

- We still use Stone Age tools.
- To do quantum gravity, these tools may need an upgrade.

Most of what I'll say has been published, only some is new.
For technical details, see my papers.

Why is Quantum Gravity so hard?

Most approaches to QG try to be conservative. But:

- QFT and GR each required abandoning major misconceptions
- Maybe some major misconceptions are still to be overcome ?

E.g., is the dichotomy of spacetime vs. matter fundamental?

- How deep / old are the misconceptions needing to be fixed?
  - To be safe, let's dig as deep in time as to the Stone Age.

Stone Age tools

- **Arrows**

- **Measuring sticks**

- **Counting of natural rhythms**

Led to today's coordinate systems!

And why not? Any issues with rulers and clocks?

- Rulers and clocks are not Lorentz invariant
- The so-measured space and time are so similar, yet different
- Coordinate systems are ignorant of light cone drama
- No rulers or clocks exist at very small scales!

How to upgrade rulers and clocks?

Replace rods and clocks by Feynman propagator:

G(x,y)

(measure using pocket CERN, plays role of Synge function)

- G(x,y) determines the metric (AK, Aslanbeigi, Saravani):

$$g_{ij}(y) = -\frac{1}{2}\left[\frac{\Gamma(D/2-1)}{4\pi^{D/2}}\right]^{\frac{2}{D-2}} \lim_{x\to y}\frac{\partial}{\partial x^i}\frac{\partial}{\partial y^j}\left(G(x,y)^{\frac{2}{2-D}}\right).$$

- **Correlator can now be primary, distance secondary!**

Advantages over rods and clocks?

- Need for noncovariant rulers or clocks?

  G(x,y) is directly measured as a bi-scalar,
  by counting events. One measures information only.

- Space similar but different from time?

  No space or time measurements, just correlators

- Distance(x,y) impervious to drama on light cone?

  G(x,y) switches infinite correlation to anti-correlation.

Spacetime from correlations - or vice versa?

Macroscopic scales: no difference

force(distance) or distance(force)

Towards small scales: studies on limitations of quantum rods and clocks should translate to renormalization & induced gravity.

Microscopic case:

Quality of statistics for G(x,y) needs extended and repeated interactions.

Planck scale as regime of too poor stats to get metric.

Concept of spacetime dissolves at Planck scale: poor statistics.

Any benefit for quantum gravity?

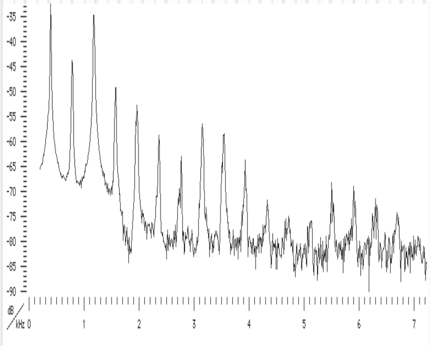
- G(x,y) knows the geometry as far as geometry exists.
- But G(x,y) too encodes the curvature highly redundantly.
- What's the basis independent info in G(x,y)? Spec(G)
- Idea: If spec(G) contains all geom info, simply path integrate over the spectra spec(G)! Diffeomorphism invariance okay.
- Not so fast! First, notice we arrived at Spectral Geometry:

Spectral Geometry:

- **“ How far is shape determined by sound ? ”**

$$-d^2\phi/dt^2 = \Delta_g \phi$$

⇔



(M,g) spec(Δ)

There are some positive results for 2-dimensional manifolds.

Relation of spec(G) to spectral geometry?

Spectral geometry: Does spec(Δ) know the geometry?

Recall: propagator = $1/\Delta$

➔ Equivalent question:

Does spec(G) = spec($1/\Delta$) know the geometry?

However:

Work, by Milnor, Sunada, Gordon et al showed:

Spectral geometry has counter examples,

at least in dimensions D>2.

Spec(G) does not know all of the geometry!

Spectral geometry needs upgrade

- Problem: we know spec(G), i.e., we know G in its eigenbasis. But we need to know G(x,y)!

- Obstacle: {Unitaries(M)} > {Diff(M)}

  => spec(G) doesn't contain all geometric info
  => spec(G) alone doesn't yield G(x,y)

- Proposal: Use the remaining Feynman rules, the vertices!

Vertices identify the position representation!

If rods and clocks are replaced by the Feynman rules:

- The 2-point correlators are diagonal in a basis other than the n>2 point correlators

- In regimes of good statistics their eigenbases recover energy-momentum and space-time representations.

- Strategy going forward:

  Path integral over Feynman rules' spectra / algebra.

Quantum channel capacities in RQI

- Path integral over Feynman rules' spectra / algebra.
- Math: Algebra of Hilbert space of fields.
- Physics: the Feynman rules are correlators
- Challenge: (since spacetime and matter now only secondary)
  - Understand propagators and vertices as expressing fundamental quantum channels
  - Evolution and interaction as information flow and processing