

Title: Strings/Quantum Gravity 2

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Abstract:

PROTECTED INFORMATION
AND EMERGENT LOCALITY
IN BACKGROUND INDEPENDENT
QUANTUM GRAVITY

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APPROACHES TO QUANTUM GRAVITY

QFT-like: Black hole thermodynamics,
String theory, non-commutative
geometry, ...

Background independent:

- superposition of $\hat{g}_{\mu\nu}$
- pre-spacetime

Cond-matter:

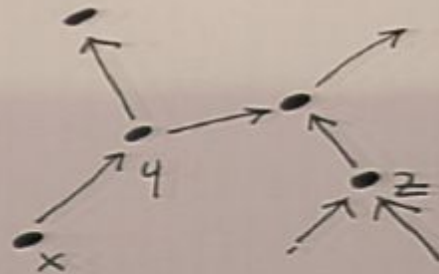
- Analogy (eg acoustic BH)
- pre-spacetime

I. QUANTUM CAUSAL HISTORY

Directed graph C ,
no cycles.

$x \leq y$ related

$x \sim z$ unrelated



FT 79
Hawkins, FT1
& Salmann
03
Kribs 05

$x \mapsto H(x)$ finite-d

$x \sim z \mapsto H(x) \otimes H(z)$

$x \leq y \mapsto \phi = A(x) \rightarrow A(y)$
completely positive

$\phi = A(x) \rightarrow A(y)$ is completely positive when:
 ϕ linear, positive, trace-preserving, and

$\phi \otimes \mathbb{1}_B = A(x) \otimes B \rightarrow A(y) \otimes B$ positive.

APPROACHES TO QUANTUM GRAVITY

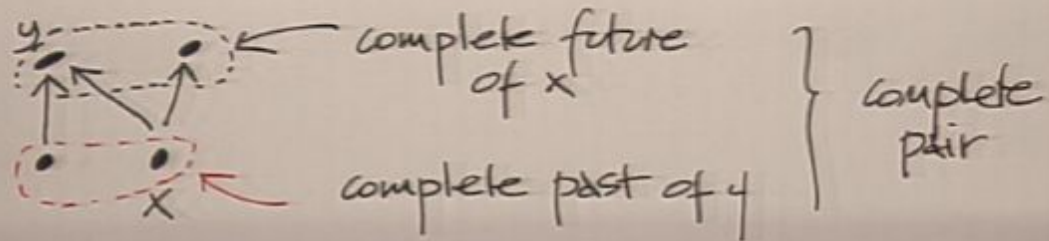
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ADD AXIOMS =

1. $\phi_P|_{A(x)} = \phi(x,y)$

2. $\phi_P|_x$ and $\phi_P|_y$ commute

3. $\phi = \phi_P \circ \phi_P$

PROVE:

- Unitary maps for complete pairs ✓
- Different micro-causality configs are distinguished. ✓

$\Rightarrow C$ is a causal structure. Of what?

2. FIXED BACKGROUND C

→ QCH is a discrete analogue of QFT.

QFT: causally complete region of cont. s/t \mapsto von Neuman Algebra

QCH: $x \mapsto H(x)$ finite-dim matrix algebra

Interesting because:

Finite no. of degrees of freedom + in finite volume \rightarrow expanding Universe \rightarrow unitarity?

HERE: CP evolution underlies unitary and is ok with above.

BUT: If C is fixed background, this is not QG...

3. BACKGROUND INDEPENDENCE AND THE MEANING OF C

C is the causal
order of $g_{\mu\nu}$



Quantum superpⁿ
of all C's



$$A(S_{in}, S_{out}) = \sum_C \sum_{\text{histories}} \prod_{\text{labels } v} A(v)$$

C is the causal
order of a pre-slt
system



GR & $g_{\mu\nu}$ are effective.

We live in a
low-energy C'.

What can we tell
about the
relationship
of C to C' ?

QCH AS A QUANTUM PRE-SPACETIME

A QCH is a quantum information processing system.

QIT notion of effective degree of freedom:
information protected under microscopic evolution.

The dynamics of the protected dofs defines the causal structure C' of our spacetime.

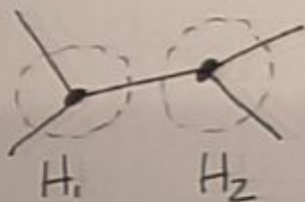
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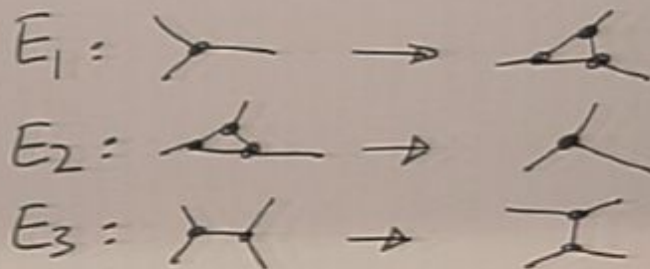
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4. PROTECTED DOFS VIA Q. INFO



$$H = \bigoplus_{\text{boundary data}} \bigotimes_i H_i$$

Generators
of evolution

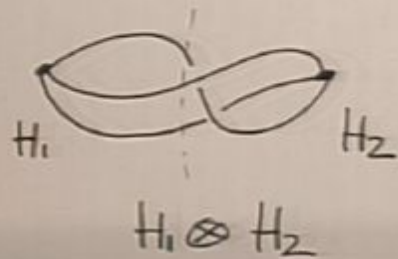


\Rightarrow Evolution algebra $A_{\text{evol}} = \{1, E_1, E_2, E_3\}$.

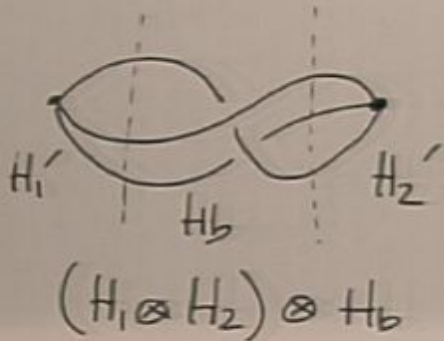
Subsystem H_B of H is protected (noiseless) under A_{evol} , if there is a decompⁿ of H
 $H = (H_A \otimes H_B) \oplus K$ such that

$$\phi(\rho_A \otimes \rho_B) = \rho'_A \otimes \rho_B$$

$$\begin{aligned} \forall \rho_A \in H_A \\ \rho_B \in H_B \\ \phi \in A_{\text{evol}} \end{aligned}$$



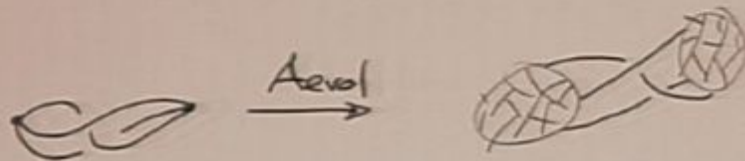
$$H = \bigoplus_{\Gamma} \sum_{b.d.} \bigotimes_i H_i$$



$$H = \bigoplus_{\Gamma} \sum_{b.d.} \left(\bigotimes_{i'} H_{i'} \right) \otimes \left(\bigotimes_b H_b \right)$$

PROTECTED
under Aevol

ie,



BRAIDING is PROTECTED under Aevol.

SUMMARY

Spacetime is dynamical because it is physical.
Events are physical processes.

QCH = quantum processes.

Spacetime geometry is an emergent concept, it describes the effective dynamics of the protected subsystems in the QCH.

Emergent spacetime means emergent locality beyond ℓ_{PLANCK} .
Observable consequences.