Title: Localizing Information in Quantum Gravity and State-dressed Local Operators in AdS/CFT

Speakers: Alexandre Belin

Series: Quantum Fields and Strings

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Abstract: It is well known that quantum information can be strictly localized in quantum field theory. Similarly, one can also localize information in classical gravity up to quantities like the ADM mass which are fixed by the constraints of general relativity. On the other hand, the holographic nature of quantum gravity suggests that information can never be localized deep inside some spacetime region, and is always accessible from the boundary. This is meant to hold as a non-perturbative statement and it remains to be understood whether quantum information can be localized within G_N perturbation theory. In this talk, I will address this problem from the point of view of the AdS/CFT correspondence. I will construct candidate local operators that can be used to localize information deep inside the bulk. They have the following two properties: they act just like standard HKLL operators to leading order at large N, but commute with the CFT Hamiltonian to all orders in 1/N. These operators can only be constructed in a particular class of states which have a large energy variance, for example coherent states corresponding to semi-classical geometries. The interpretation of these operators is that they are dressed with respect to a feature of the state, rather than to the boundary. I will comment on connections with black holes and computations of the Page curve.

Zoom link: https://pitp.zoom.us/j/94678968773?pwd=NUJhOEJmRWxLa3pCVUtVVi9DdkE3QT09

Localizing Information in Quantum Gravity and State-dressed Local Operators in AdS/CFT

Alex Belin - U. of Milano Bicocca

Based on:

2209.06845 + WIP

w/ E. Bahiru, K. Papadodimas, G. Sarosi, N. Vardian

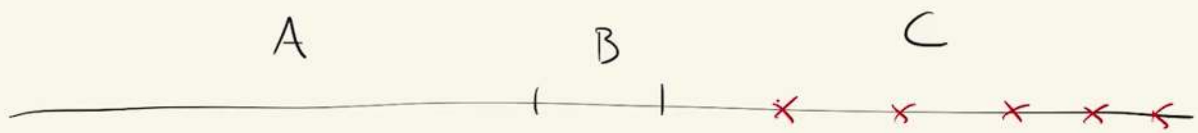
Perimeter Institute - Nov 11^{th} 2022

Can we localize information in Q.G.?

Localizing information:

- QFT ✓ $[\phi(x), \phi(y)] = 0$ x, y spacelike

split states



A, C completely un-entangled

$\langle \text{split} | O_A \cdots O_A | \text{split} \rangle$

⚠ Even true in a gauge theory

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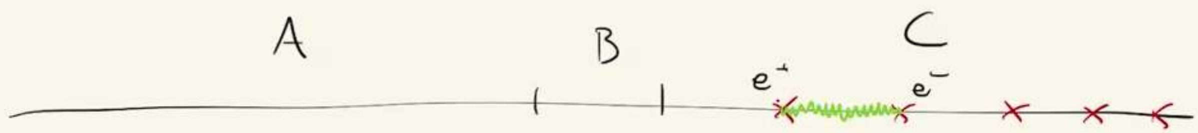

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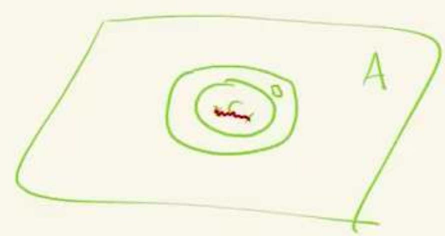
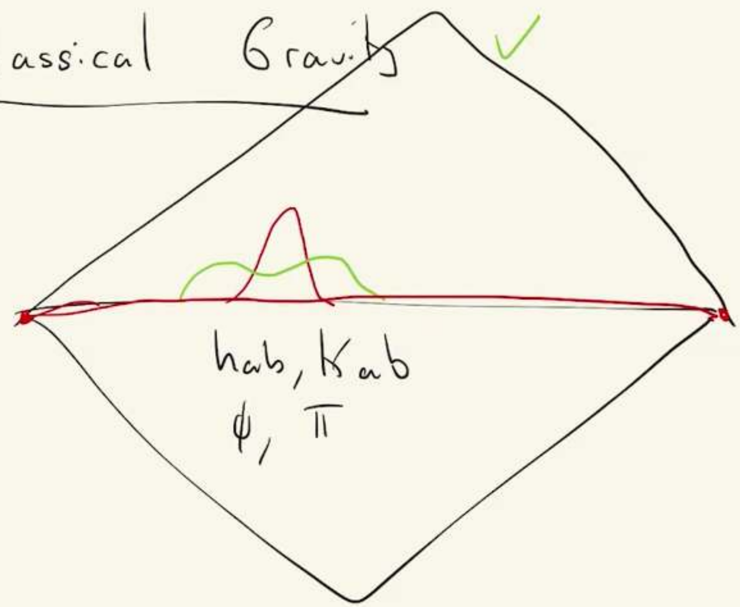


⚠ Even true in a gauge theory

- Classical Gravity ✓



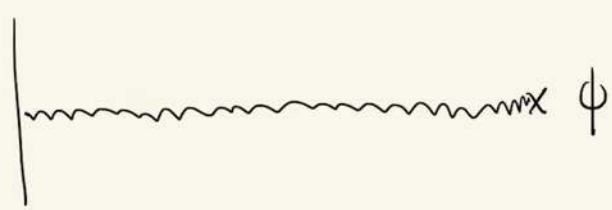
Σ

Read off total mass from ∞

- Quantum Gravity

Non-perturbative Q.G. ✗

In G_N perturbation theory ??



$[H, \phi] \neq 0 \quad \mathcal{O}(G_N)$

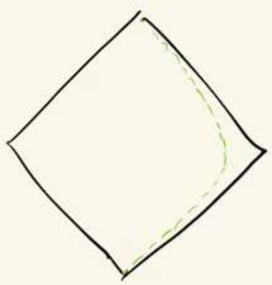
Gauss Law

Goal for today:

- Evidence can localize information in G_N pert. thy.
- Construct approx. local operators
- ⚠ Only works for a class of states

Comments

① This is relevant for the information paradox



$S_{out}(\;)$

② Connections with VN algebras

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1. Introduction
2. Define local operators, properties
3. Interpretation

Candidate local operators

In the bulk

Difficult

In the CFT

manifestly diff-invariant

non-pert. defined

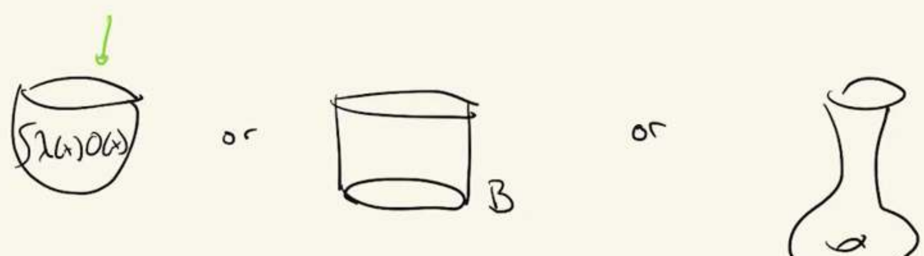
But does it act right?

$|\Psi_0\rangle \to$ semi-classical states $\Leftrightarrow$ semi-classical geometries

$$\langle \Psi_0 | H | \Psi_0 \rangle \sim O(N^2) \quad \left(\sim \frac{1}{G_N}\right)$$

$$\langle \Psi_0 | \Delta H^2 | \Psi_0 \rangle \sim O(N^2)$$ $\Rightarrow$ Physically, macroscopically time-dependent

Various example:

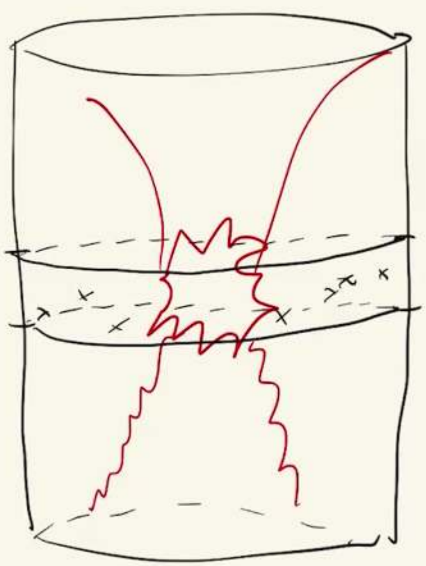


or ...

$$\langle \Psi_1 | \Psi_0 \rangle = e^{-\gamma N^2} \qquad \gamma > 0$$

$$R(t) = |\langle \Psi(t) | \Psi(t=0) \rangle|^2 = e^{-N^2 f(t)} \underset{t \to 0}{\sim} e^{-N^2 t^2}$$

$$|\Psi_0\rangle = |TFD\rangle \qquad R(t) \to \text{SFF}$$



Supernova explosion in AdS

$\mathcal{A}$ = time-band algebra of S.T. operators

$\exists\ O$ s.t. $[O, \mathcal{A}] = 0$

→ No → can localize information

Yes → interp.

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Non-perturbative : $\mathcal{A} \to \mathcal{A}_{CFT}$ $\nexists\ \mathcal{O}$ s.t. $[\mathcal{O}, \mathcal{A}_{CFT}]$

Pert. thy : ?

$$\Phi_{HKLL}(t, r, \Omega) = \int dt' \, d\Omega' \, K(t', t, r, \Omega, \Omega') \, \mathcal{O}(t', \Omega')$$

$$[H_{CFT}, \Phi_{HKLL}] \neq 0 \quad O\left(\frac{1}{N}\right)$$

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Result

$\hat{\Phi}$ has the following 2 properties:

1. $[H, \hat{\Phi}] = 0$ to all orders in $1/N$

2. $\hat{\Phi}$ acts like the HKLL to leading order.

O(1) in the large N limit

$$\hat{\Phi} = c \int_{-t^*}^{t^*} dT \, e^{-iTH} P_0 \, \Phi_{HKLL} \, P_0 \, e^{iTH}$$

Projector onto code s.space of $|\Psi_0\rangle$

Work for $|\Psi_0\rangle$

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① $[H, \hat{\Phi}] = -i \frac{d}{ds} \left(e^{isH} \hat{\Phi} e^{-isH} \right) \Big|_{s=0}$

$$= c(-i) \frac{d}{ds} \int_{-t^*+s}^{t^*+s} d\tilde{T}\, e^{-i\tilde{T}H} P_0\, \Phi_{HKLL}\, P_0\, e^{i\tilde{T}H} \Bigg|_{s=0}$$

$$= ic \left(P_{t^*} \Phi_{HKLL}(t^*) P_{t^*} - P_{-t^*} \Phi_{HKLL}(-t^*) P_{-t^*} \right)$$

$$\langle \Psi_0 | [H, \hat{\Phi}] | \Psi_0 \rangle \sim \mathrm{Tr}\, P_{t^*} P_0 \sim \langle \Psi(t^*) | \Psi_0 \rangle$$

$$\sim e^{-f(t^*) N^2}$$

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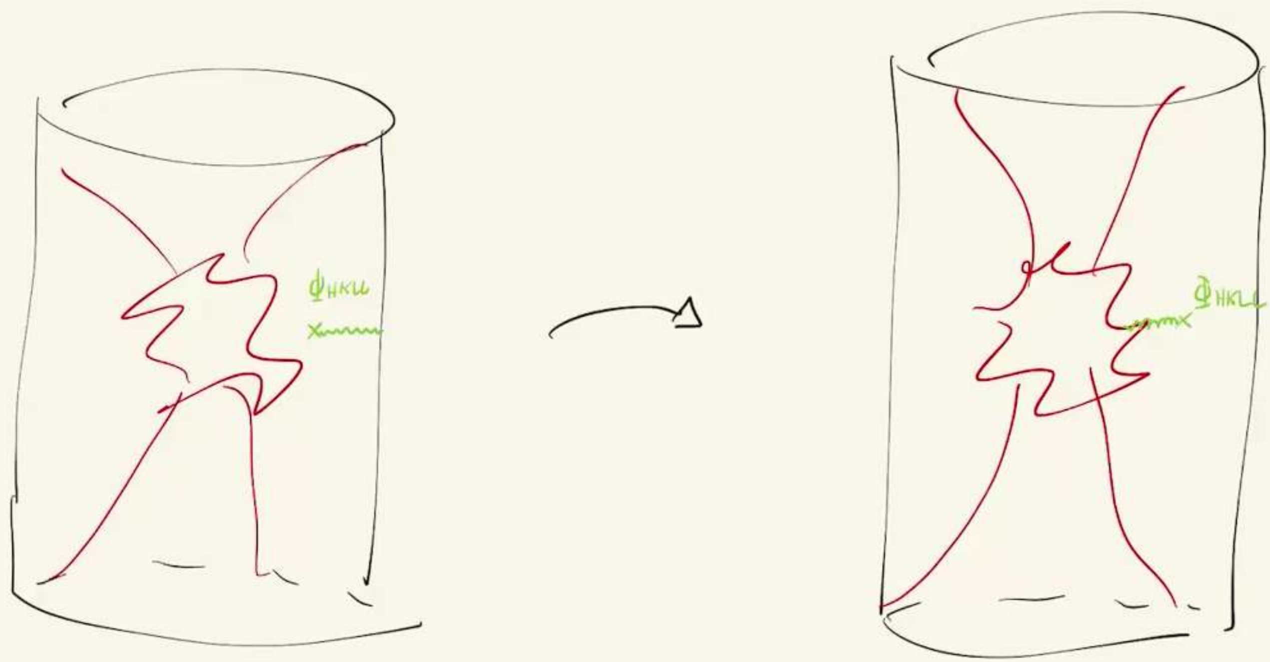
(2) $\langle \Psi_0 | \, \mathcal{O} \ldots \hat{\Phi} \, \mathcal{O} \, | \Psi_0 \rangle$

$$= C \int_{-t^*}^{t^*} dT \, \langle \Psi_0 | \, \mathcal{O} \ldots e^{-iTH} P_0 \, \Phi_{HKLL} \, P_0 \, e^{+iTH} \, \mathcal{O} \ldots \mathcal{O} | \Psi_0 \rangle$$

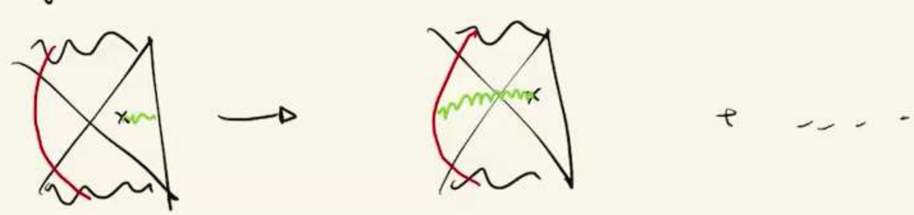
$$= C \underbrace{\int_{-t^*}^{t^*} d\bar{T} \, \langle \Psi_0 | \, \mathcal{O} \ldots P_+ \, \Phi_{HKLL}(\bar{T}) \, P_+ \, \mathcal{O} \ldots \mathcal{O} | \Psi_0 \rangle}_{e^{-t^2 N^2}}$$

$$\approx C \langle \Psi_0 | \, \mathcal{O} \ldots \Phi_{HKLL} \, \mathcal{O} \ldots \mathcal{O} \, | \Psi_0 \rangle + \mathcal{O}(1/N)$$

Interpretation



State-dressed operator



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Comments

- Evidence?

$$[\hat{\Phi}, H]$$

$$[\hat{\Phi}, O_{S.T.}] \stackrel{?}{=} 0$$

$\hat{\Phi}$ ×

TBC

- Which states?

$|\Psi_0\rangle \to |0\rangle$ our construction doesn't work

$\langle \Psi(t) | \Psi(0) \rangle$ doesn't decay

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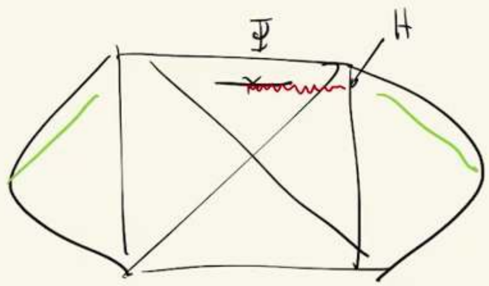
- Islands

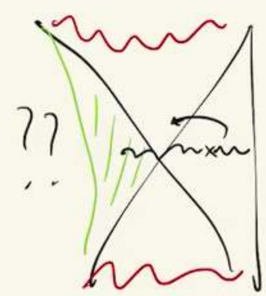


$[\Phi, H) = 0$

If you give me Φ

$\longrightarrow [\hat{\Phi}, H] = 0$

- Typical State $\Delta H^2 \sim O(N^2)$



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$$|\Psi_0\rangle = \sum_{i=1}^{e^S} c_i |E_i\rangle = \sum_i c_i \mathcal{O}_i |0\rangle$$

QFT

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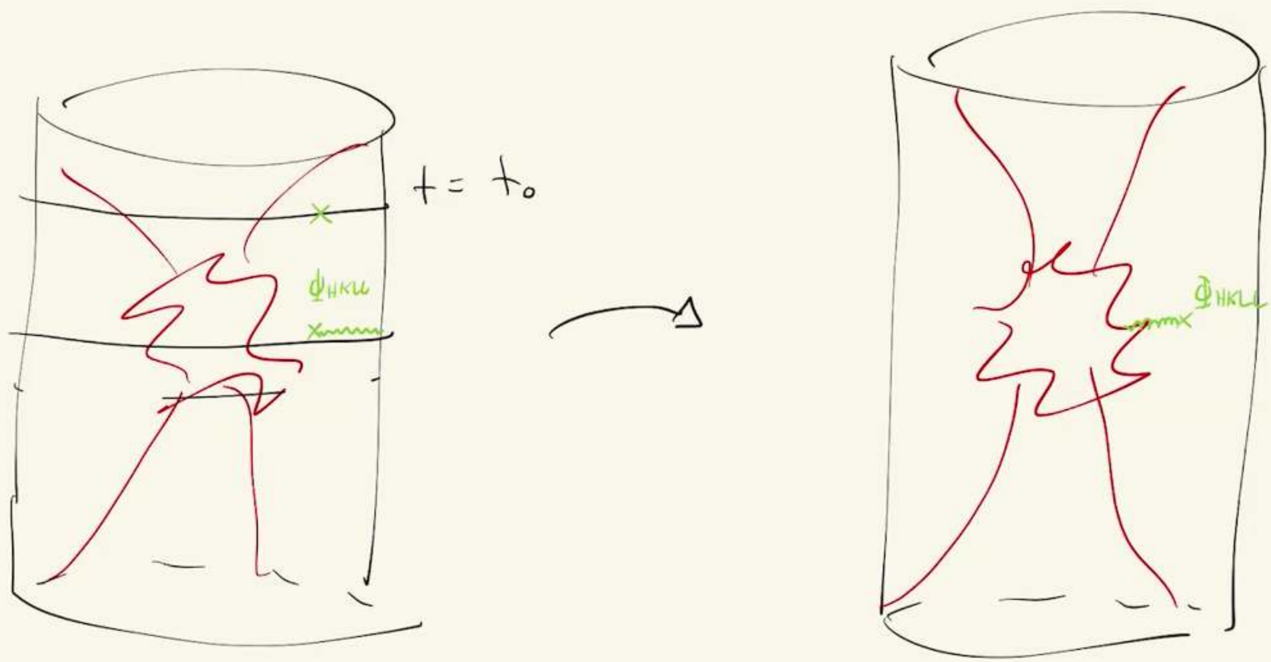

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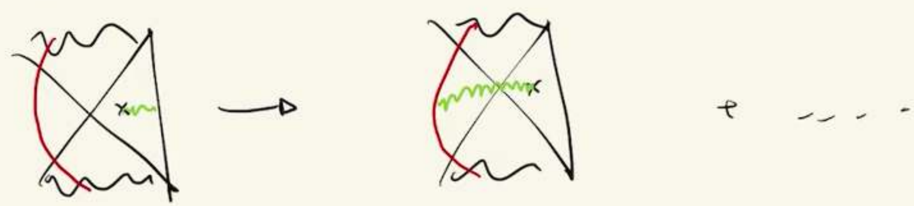

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time-band algebra $\quad O_{S.T.}$ in t.b.

$$H \in \mathcal{A}$$

$$e^{iHt}\, O(0)\, e^{-iHt}$$

h_{ab}

K_{ab}

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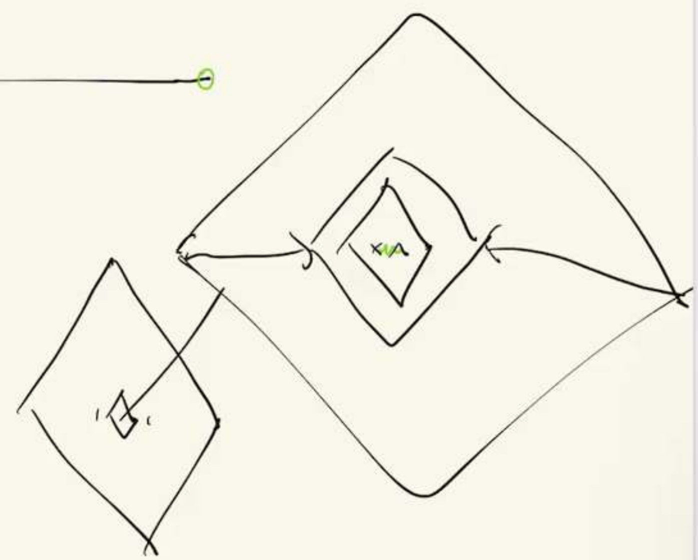

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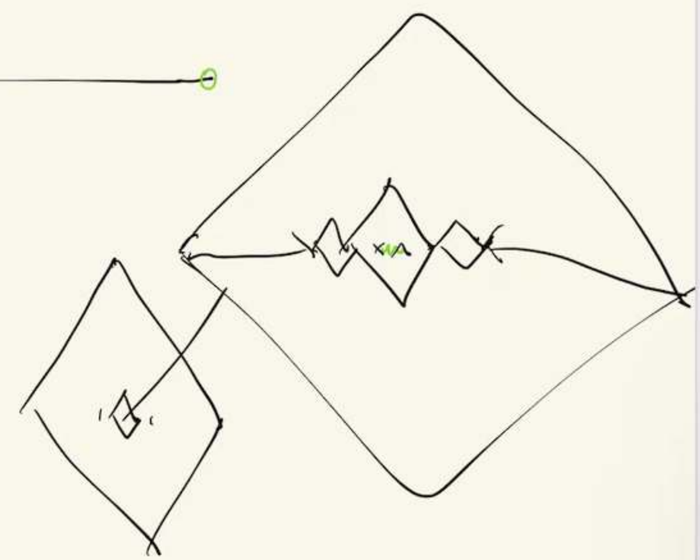

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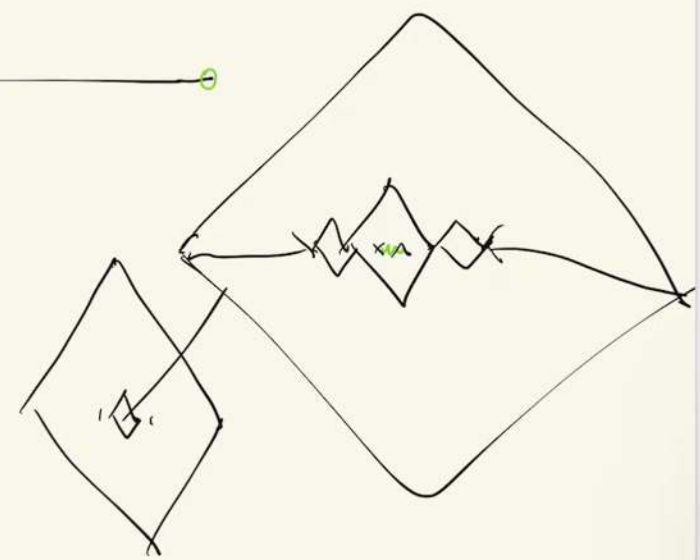

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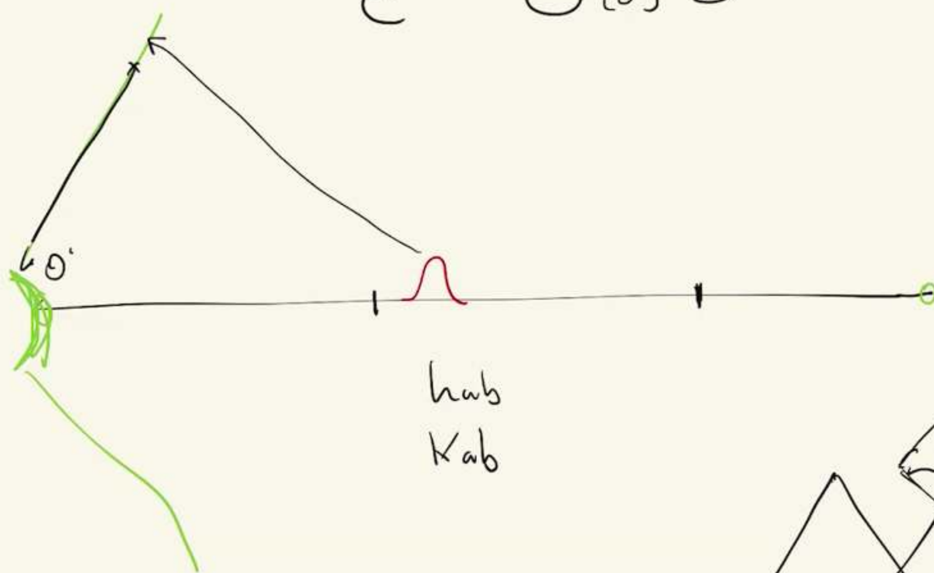

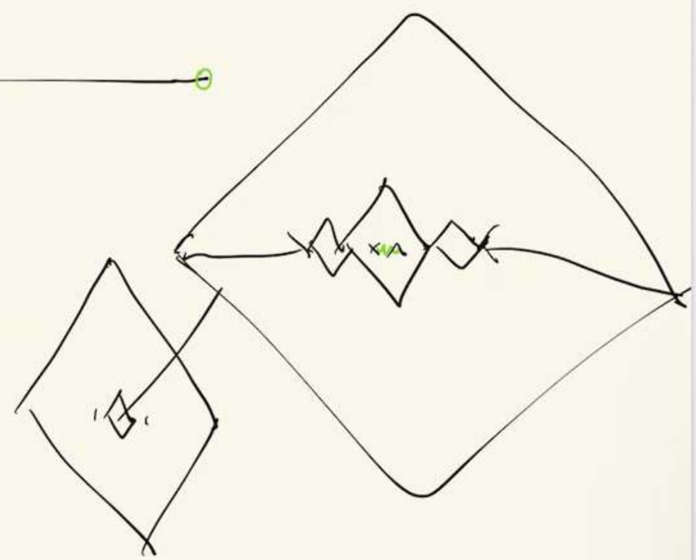

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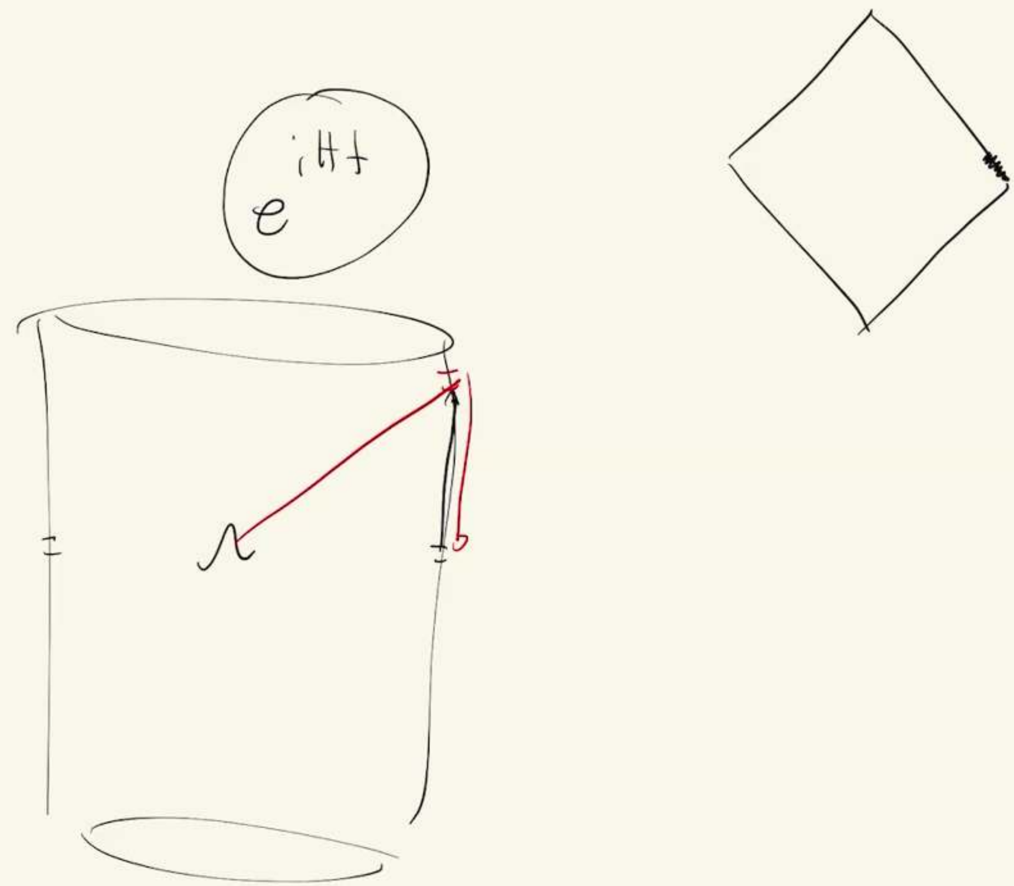
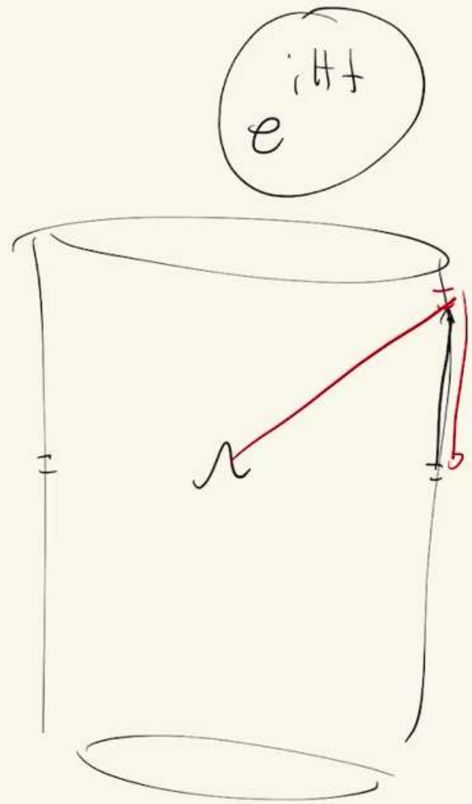
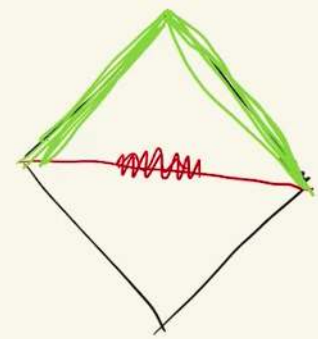



e^{iHt}



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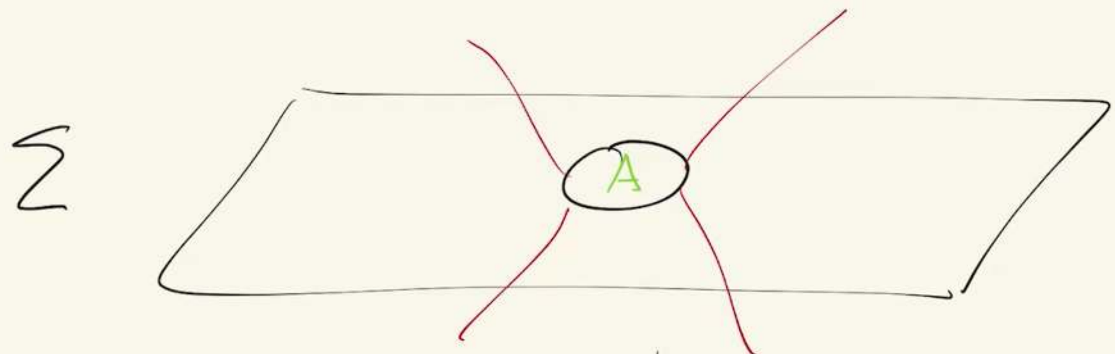

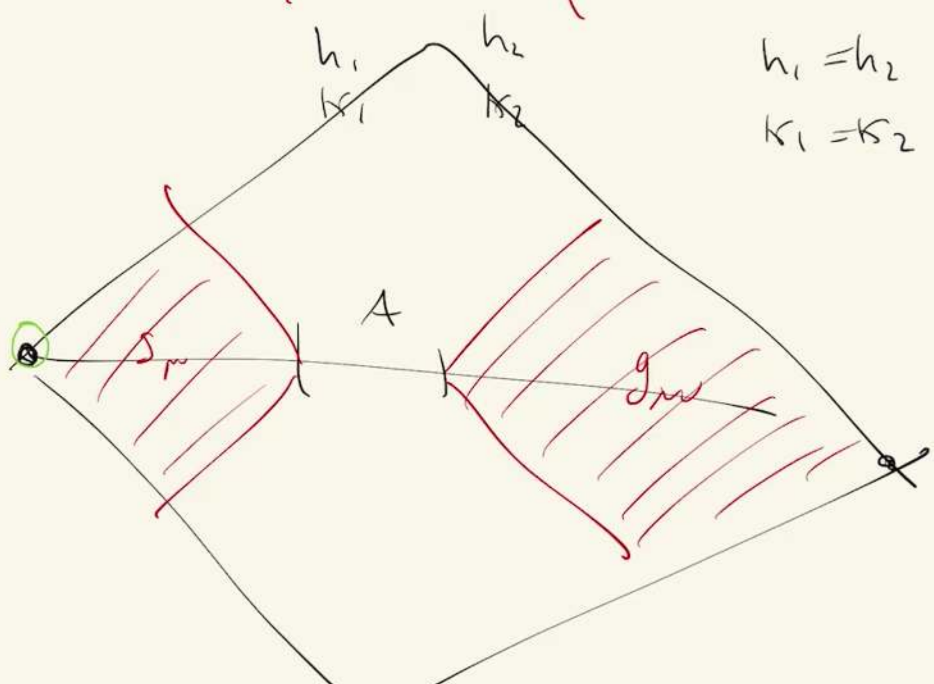

$h_1 = h_2$ outside A

$K_1 = K_2$ outside A