Title: Quantum Information and holography

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Collection: Quantum Information and holography (2021/2022)

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URL: https://pirsa.org/22040048

Abstract: Topics will include (but are not limited to):
- Quantum error correction in quantum gravity and condensed matter
- Quantum information scrambling and black hole information
- Physics of random tensor networks and random unitary circuits

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Quantum information Scrambling

(Lec 5)

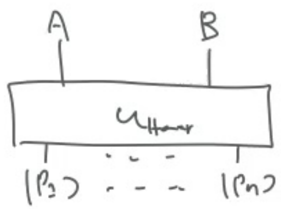
a) HP for real BH ?

b) How do we recover info ?

"Scrambling" is the key. What is scrambling ?

Early Attempt (thermalization)?

- Start from $|P_1\rangle \otimes \cdots \otimes |P_n\rangle$ (product state)



Page's theorem

$$\rho_A \simeq \frac{I_A}{d_A} \qquad \left(n_A < \frac{n}{2}\right)$$

$\longrightarrow$ Info about initial state "appears" to be lost.

- In general, $\rho_A \sim \mathrm{Tr}_B(e^{-\beta H})$

"thermalization" $\approx$ "growth of entanglement"

- Scrambling $\neq$ Thermalization

In BH, thermalization takes longer than $r_s \log r_s$!!

(Peter Shor 2018)

(Hosur et al 2015)

Scrambling = growth of operators

- 1D chain of qubits, evolve by H

$$W(t) = e^{iHt} W(0) e^{-iHt}$$

$\longrightarrow$ "size" of $W(t)$ gets bigger!!

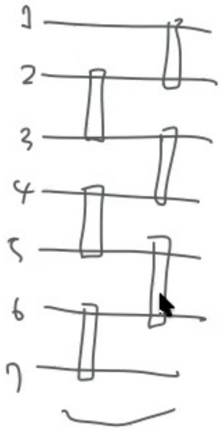
- Baker-Campbell-Hausdorff intuition

$$W(t) = \sum_{j=0}^{\infty} \frac{(it)^j}{j!} \underbrace{[H \cdots [H, W] \cdots]}_{j} \quad , \quad H \text{ 2-body}$$

$$\begin{array}{rl} W & \text{1-body} \\ [H,W] & \text{2-body} \\ [H,[H,W]] & \text{3-body} \\ \vdots & \end{array}$$

- Quantum circuit intuition

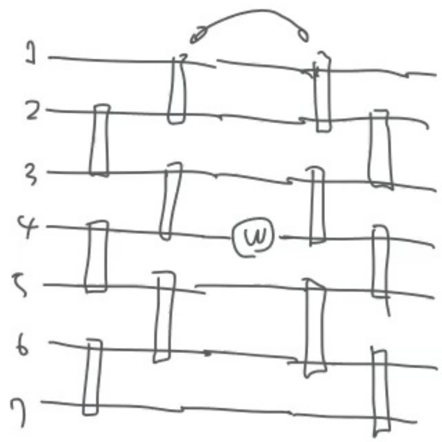
$U =$



2 steps (depth)

$UWU^\dagger =$

cancel



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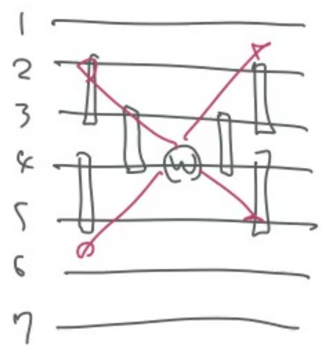


Size of unitary operator

Fact

a) Unitary O can be written as sum of Pauli ops:

$$O = \sum_{P \in \text{Pauli}} \alpha_P P$$

b). $\sum_P |\alpha_P|^2 = 1$ (O: unitary)

$P = I \quad X \quad Y \quad \cdots \quad I \quad X$

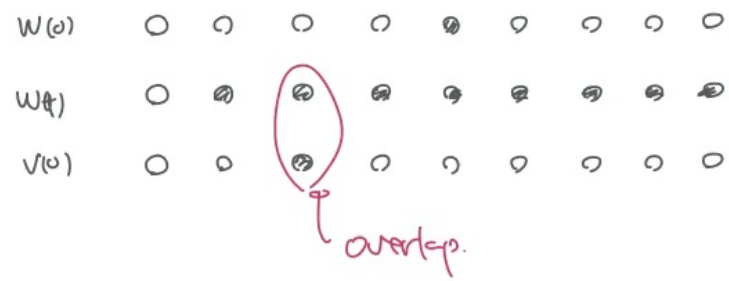
$$\text{Size} \equiv \sum_P |\alpha_P|^2 \, \text{weight}(P)$$

# of non-identity Paulis.

Scrambling

Local op $W(t)$ grows to large size ops.

Out-of-time-order correlator (OTOC)



- Measuring the size.

$$\langle V(0)\, W(t)\, V(0)\, W(t) \rangle = \mathrm{Tr}\Big[\underbrace{\tfrac{1}{d}}_{\text{maximally mixed}} V(0)\, W(t)\, V(0)\, W(t)\Big]$$

Small t $\simeq \langle V(0) V(0) W(t) W(t) \rangle$

$= \langle V(0) V(0) \rangle \langle W(t) W(t) \rangle$

large t $=$? ? ?

- Let P, Q be Pauli ops.

$[P,Q]=0 \qquad \langle PQPQ \rangle = 1$

$\{P,Q\}=0 \qquad \langle PQPQ \rangle = -1$

$t=0 \qquad \langle V\,W\,V\,W \rangle = 1$ (no overlap)

large $t \qquad \langle V(0)\,W(t)\,V(0)\,W(t) \rangle \simeq 0$ (overlap)

$W(t) = \sum_P \alpha_P P$ overlap with $V(0)$

$\longrightarrow$ OTOC becomes small if $W(t)$ has overlap with $V(0)$

$\boxed{\text{Scrambling, in a sense of OTOC decay} \quad \nRightarrow \text{ HP recoverability}}$

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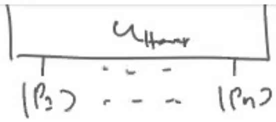

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