Title: Quantum Information and holography

Speakers: Aaron Szasz, Beni Yoshida

Collection: Quantum Information and holography (2021/2022)

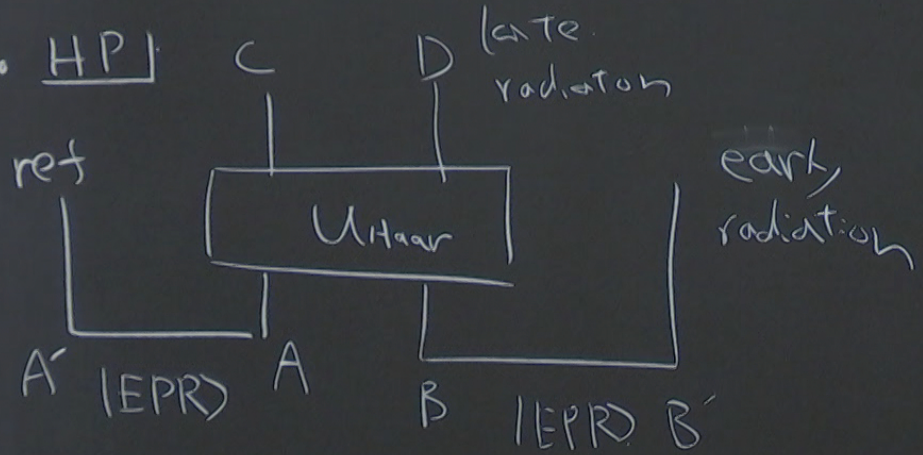
Date: April 19, 2022 - 9:00 AM

URL: https://pirsa.org/22040050

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

Review

- HPI



$$I(A', DB') \simeq \max(n_D > n_A)$$

- Scrambling.

• Scrambling $\simeq$ growth of op

$$W(t) = e^{iHT}\, \underbrace{W(0)}_{\text{local}}\, e^{-iHt}$$

$W(t)$: global

Scrambling $\Rightarrow$ Hayden-Preskill recoverability.

- Out-of-Time order correlator.

$$\langle V(0)\, W(t)\, V(0)\, W(t) \rangle \simeq \langle V V \rangle \langle W W \rangle = 1 \quad \text{(if } W(t) \text{ is local)}$$

$$\to 0 \quad \text{(if } W(t) \text{ is non-local)}$$

Measurement of OTOC

- No time machine needed

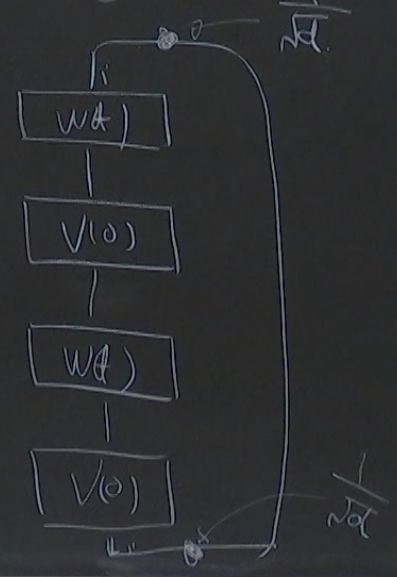
$$\langle W(t)\,V(0)\,W(t)\,V(0)\rangle \equiv Tr\left[\left(\frac{1}{d}\right) W(t)\,V(0)\,W(t)\,V(0)\right]$$

max mixed state

on $\mathcal{H}_L$

$i > j$

$=$

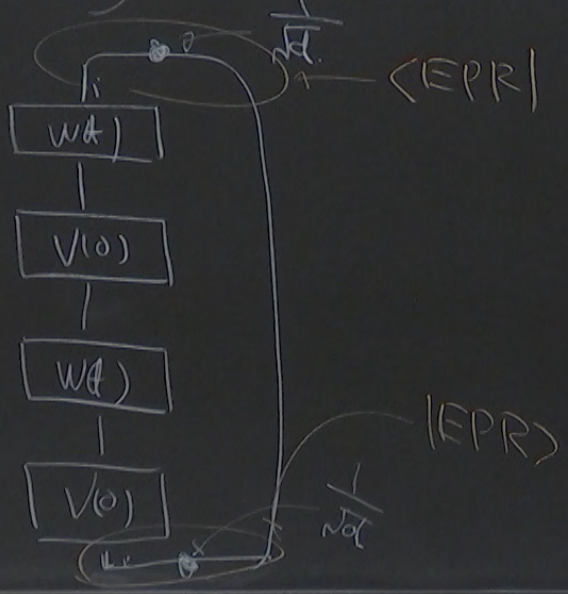


OTOC

needed

max mixed state

$$\langle O(t)\rangle \equiv \mathrm{Tr}\left[\frac{1}{d} W(t)V(0)W(t)V(0)\right]$$



"Interpretation" in doubled H

$$\text{OTOC} =$$

• "Interpretation" in doubled Hilbert space. $\mathcal{H} \otimes \mathcal{H}$.

(0)]  $= \frac{1}{\sqrt{d}} \sum_i |i\rangle \otimes |i\rangle = |EPR\rangle$ on $\mathcal{H}_L \otimes \mathcal{H}_R$

$$OTOC = \langle EPR | \underbrace{W(A)\, V(0)\, W(t)\, V(0)}_{\mathcal{H}_L} \otimes \underbrace{I}_{\mathcal{H}_R} | EPR \rangle$$

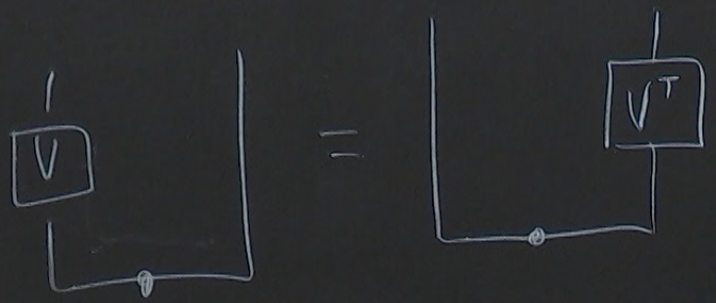
$\otimes H$. $\cdot (V \otimes I)|EPR\rangle = (I \otimes \underbrace{V^T}_{\text{transpose}})|EPR\rangle$

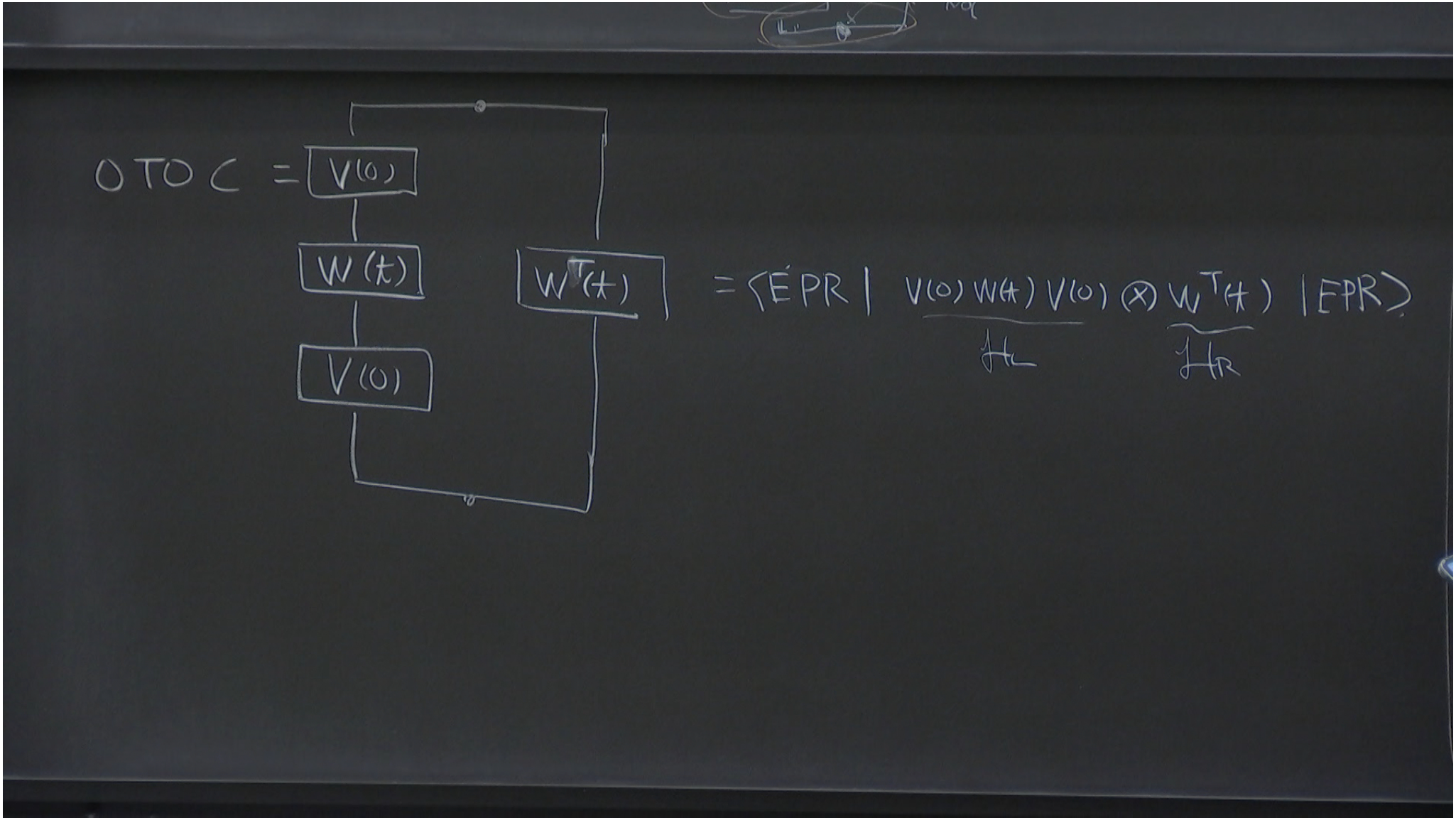
H_R

$V = V_{ij}\,|i\rangle\langle j|$

$V^T = V_{ji}\,|i\rangle\langle j|$

$\rangle$




OTOC =
V(0)
W(t)
V(0)
W^T(t)
= ⟨ÉPR| V(0) W(t) V(0) ⊗ W^T(t) |ÉPR⟩
H_L
H_R

Define $|\Psi(V)\rangle \equiv (V \otimes I)\,|EPR\rangle$

$OTOC = \langle \Psi(V)| \; W(t) \otimes W^T(t) \; |\Psi(V)\rangle$ (if $V^\dagger = V$)

Define $|\Psi(V)\rangle \equiv (V \otimes I)\,|EPR\rangle$

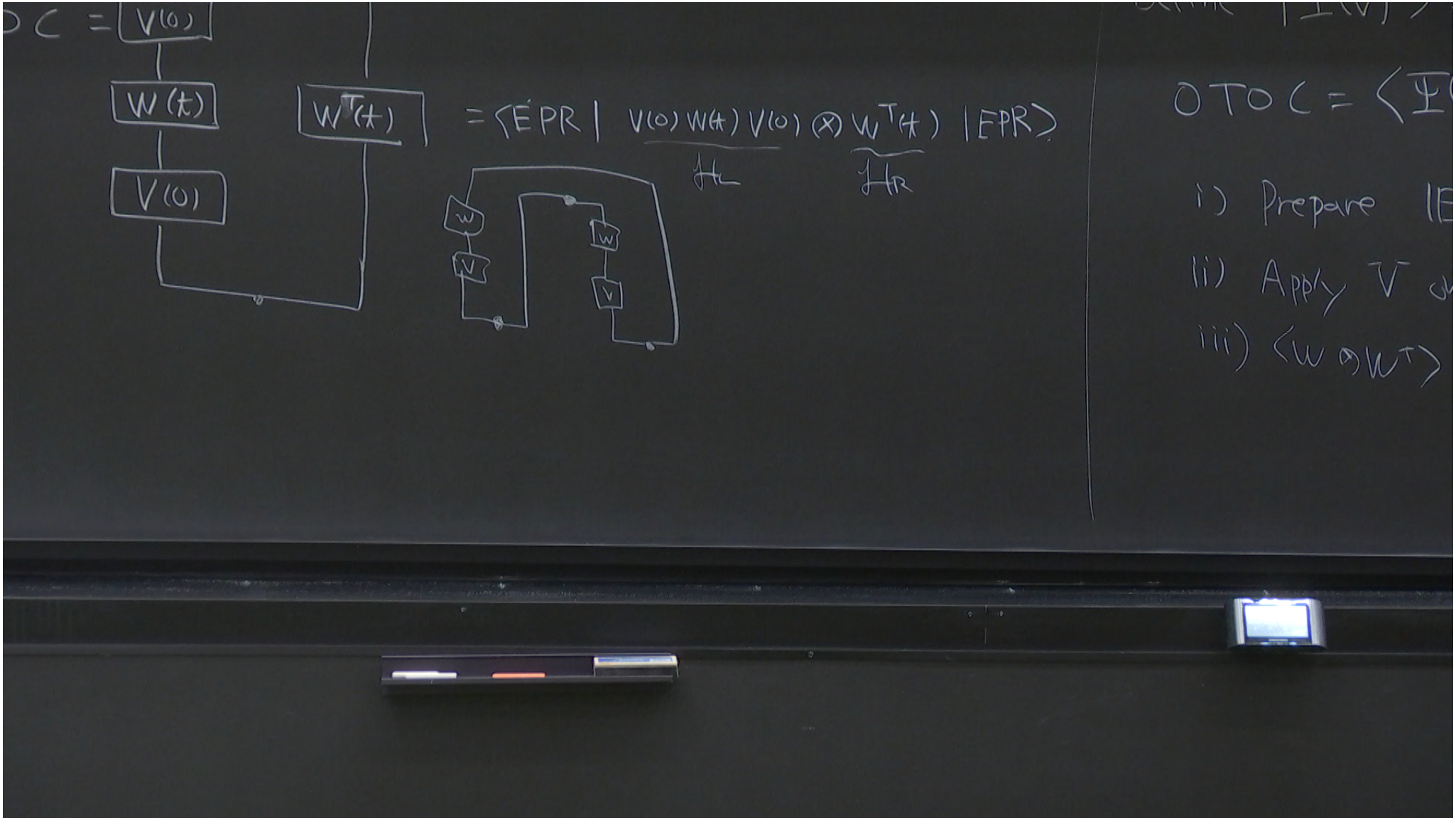
$OTOC = \langle \Psi(V) | \; W(A) \otimes W^T(A) \; | \Psi(V) \rangle$ (if $V^t = V$)

X^T

i) Prepare $|EPR\rangle$

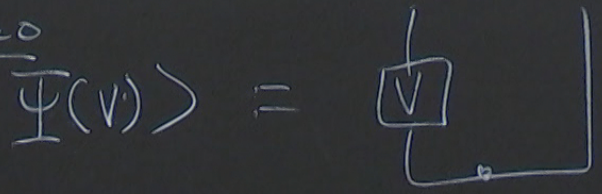
ii) Apply V on $\mathcal{H}_L$.

iii) $\langle W \otimes W^T \rangle$ at time t

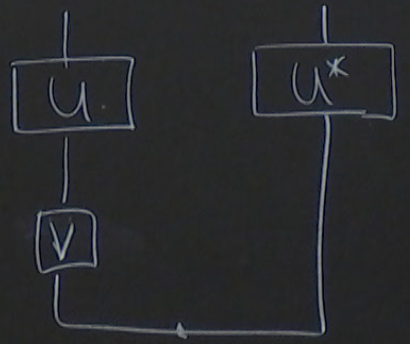

C = V(0)
W(t)
V(0)
W^T(t)
= ⟨EPR | V(0) W(t) V(0) ⊗ W^T(t) |EPR⟩
H_L
H_R
OTOC = ⟨Ψ
i) Prepare |E
ii) Apply V
iii) ⟨W ⊗ W^T⟩

Many-body chaos

$t=0$

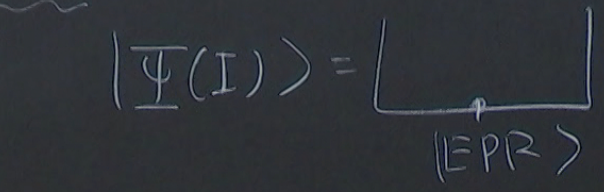
$|\Psi(V)\rangle =$ 

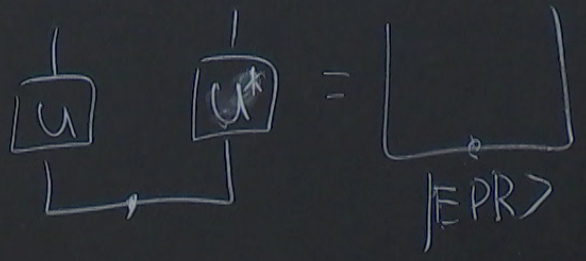
time evolve.

$=$ 

$U = e^{-iHt}$

If $V = I$

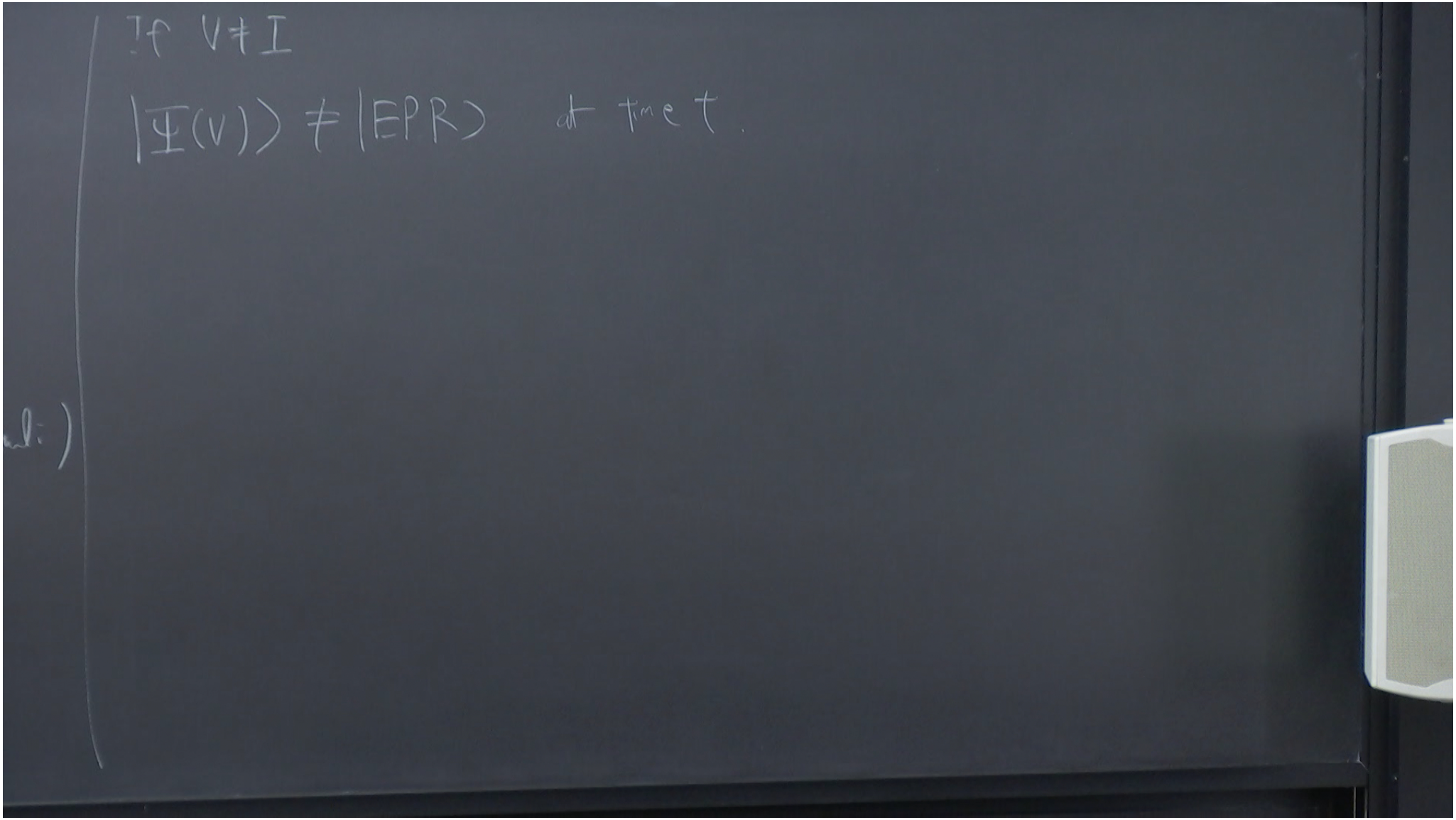
$t = 0$ $|\Psi(I)\rangle =$ 

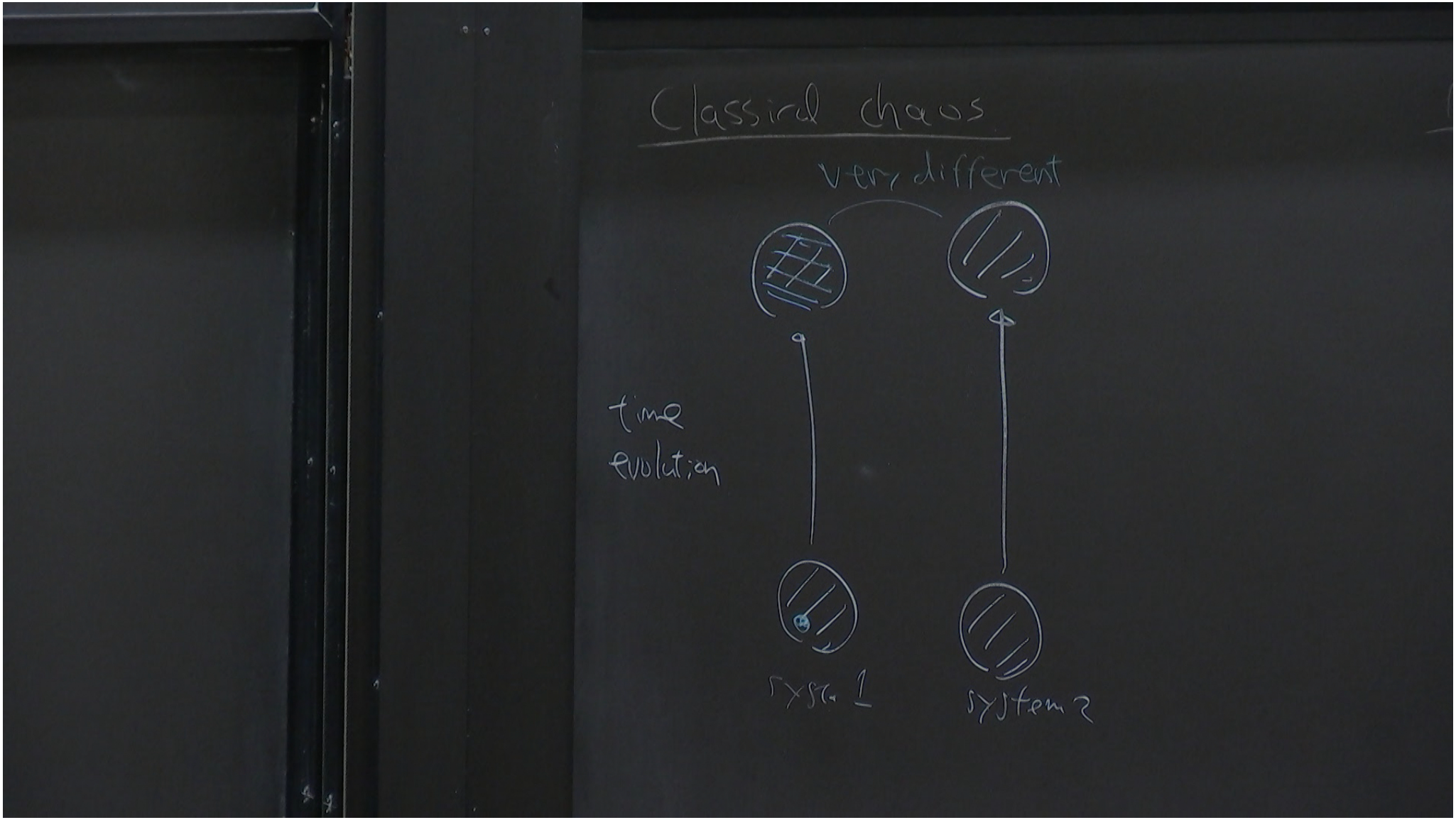
at t $|\Psi(I)\rangle =$ 

$U = e^{-iHt}$

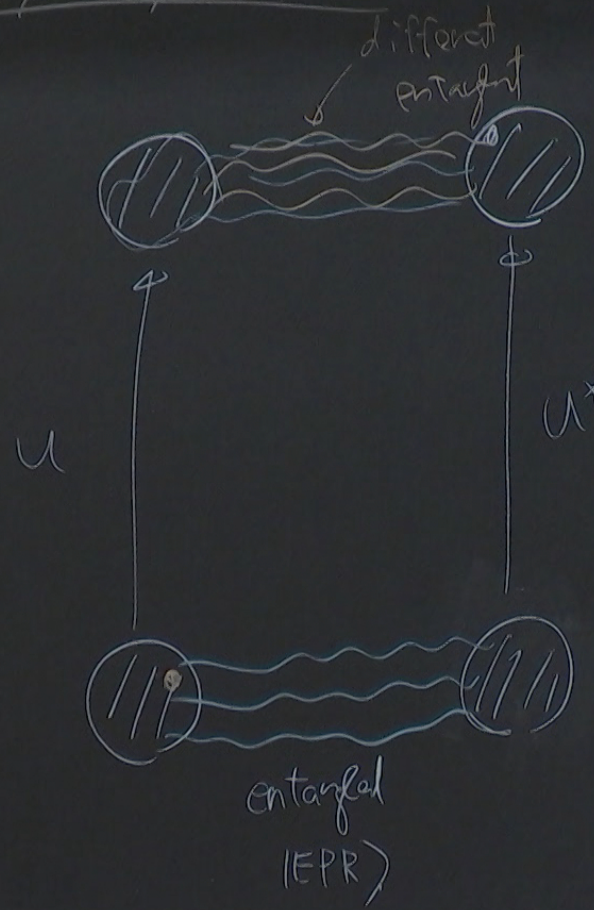
$\langle \Psi(I) | W \otimes W^T | \Psi(I) \rangle = 1$ (W is Pauli)

$\langle EPR | W \otimes W^T | EPR \rangle = 1$

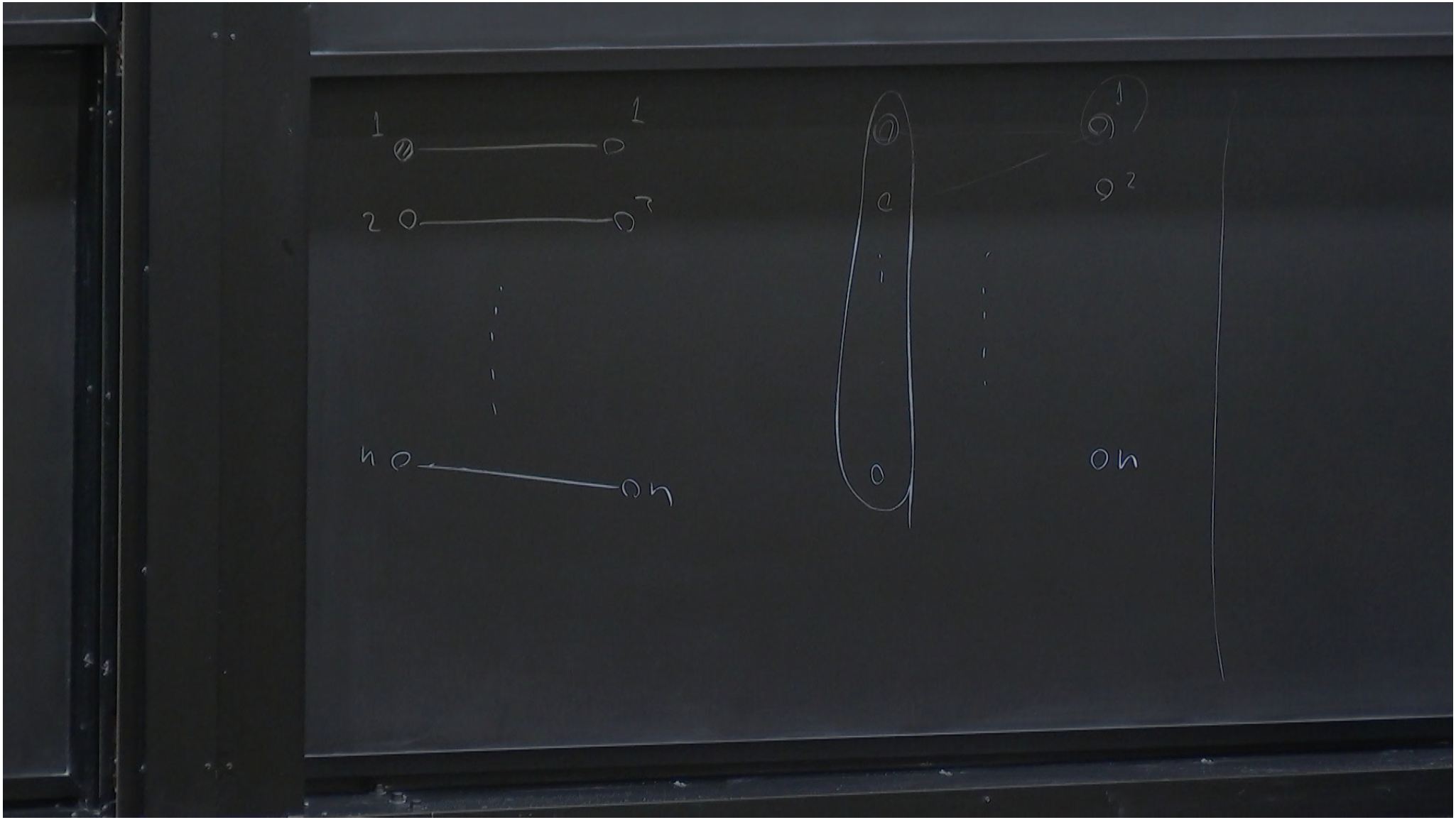

If V≠I
|Ψ(V)⟩ ≠ |EPR⟩ at time t.


Classical chaos
very different
time
evolution
system 1
system 2

Many-body chaos



$\langle W_L^{(i)} \otimes W_R^{(i)} \rangle$ checks if


1
1
2
2
n
n
1
2
n

OTOC for Haar

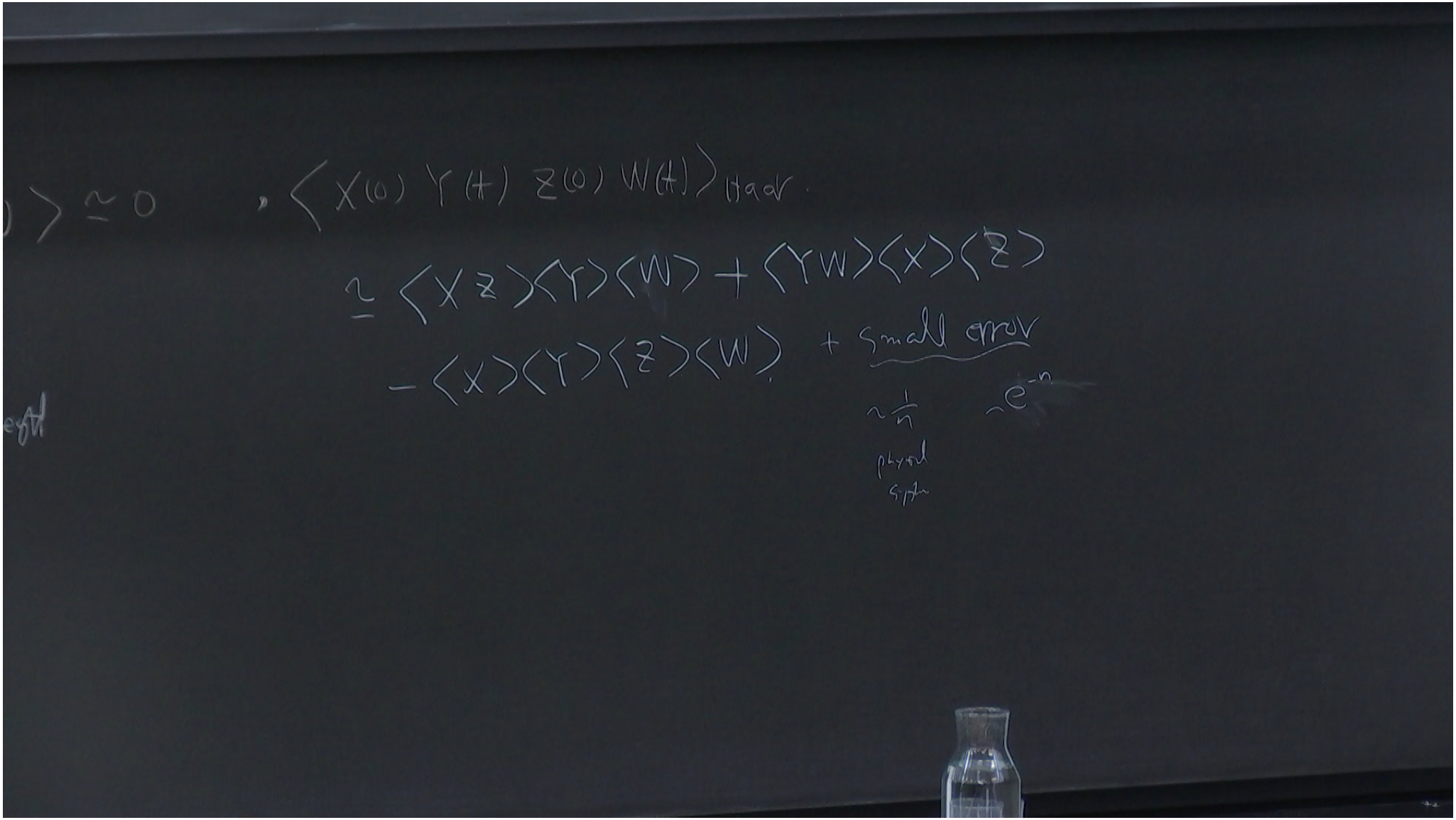
- $\langle V(0)\, W(t)\, V(0)\, W(t) \rangle \simeq 0$

$W(t) \to \sum_{P \in \text{Pauli}} \alpha_P P$

P: high weight

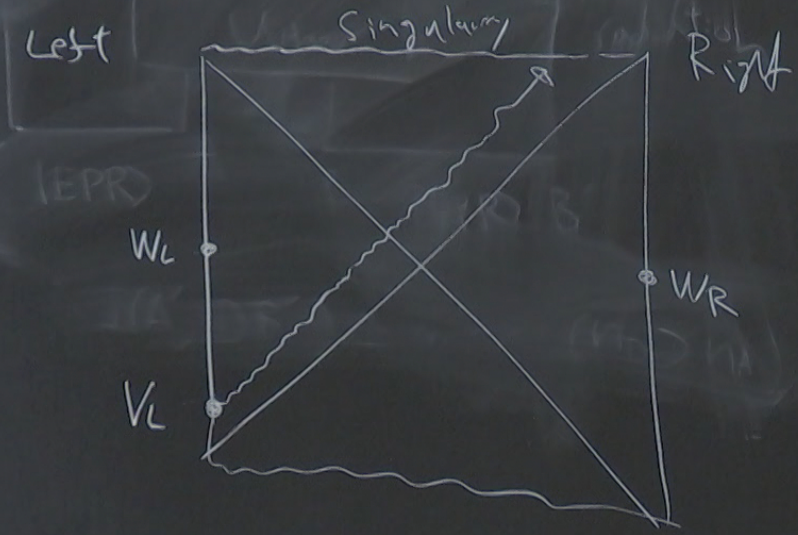
- $\langle X(0)\, Y(t)\, Z(0)\, W(t) \rangle_{\text{Haar}}$

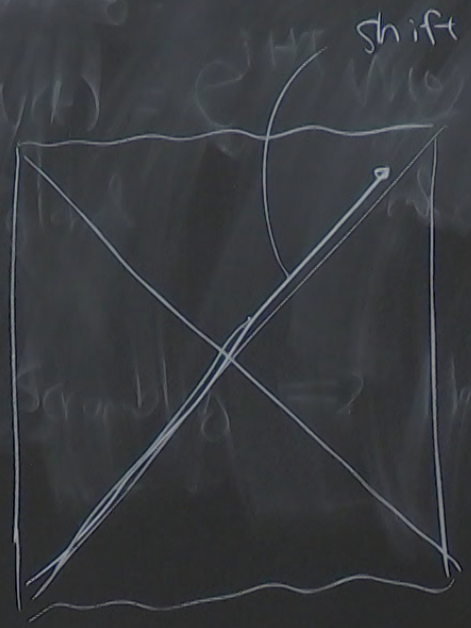
$\simeq \langle XZ \rangle \langle Y \rangle \langle Z \rangle +$

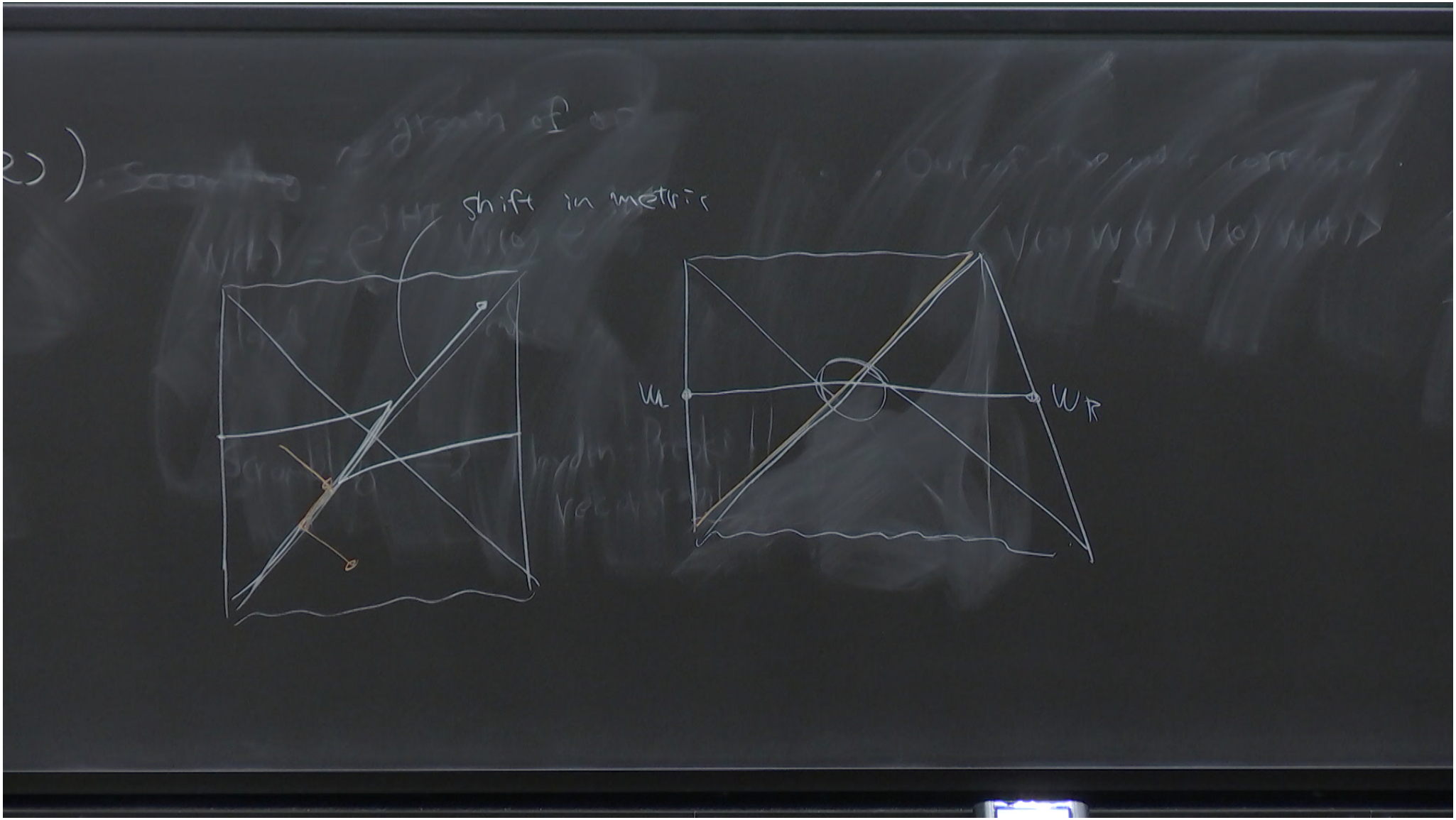

$\langle X(0)\, Y(t)\, Z(0)\, W(t)\rangle_{\text{Haar}}$
$\simeq \langle XZ\rangle\langle Y\rangle\langle W\rangle + \langle YW\rangle\langle X\rangle\langle Z\rangle$
$- \langle X\rangle\langle Y\rangle\langle Z\rangle\langle W\rangle$ + small error
$\sim \frac{1}{n}$
physical
$\sim e^{-n}$

OTOC for BHs

- 2-sided BH ($\simeq$ TFD)






shift in metric
W_L
W_R