

Title: Causality at the End-of-World

Speakers: Beni Yoshida

Collection: Quantum Spacetime in the Cosmos: From Conception to Reality

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Abstract: The success of the AdS/CFT correspondence motivates a holographic approach for spacetime beyond AdS, including our own universe. One possible method involves using an asymptotically-AdS holography and introducing a finite radial cutoff by inserting an End-of-World (EoW) brane. However, previous studies have shown that this leads to nonlocal effects on the boundary and violates entanglement sub-additivity. In this work, we address these issues by examining a two-particle scattering process through the lens of holographic quantum tasks. Our findings suggest that connectedness of entanglement wedge does indeed require nonlocal domain of dependence, but that violation of sub-additivity can be avoided. We also discuss an important question that arises from our results, namely whether the non-locality on the EoW brane is real or apparent. We argue that it is the latter. This talk is based on ongoing work with Takato Mori.

Zoom Link: <https://pitp.zoom.us/j/98277900018?pwd=SW92OWYrRFpkWC9QOS9NeTlQWkY5dz09>

Causality at the End-of-World

Beni Yoshida (Perimeter)

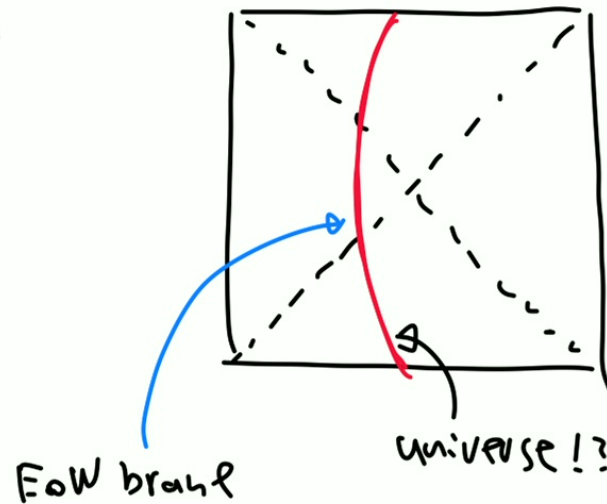
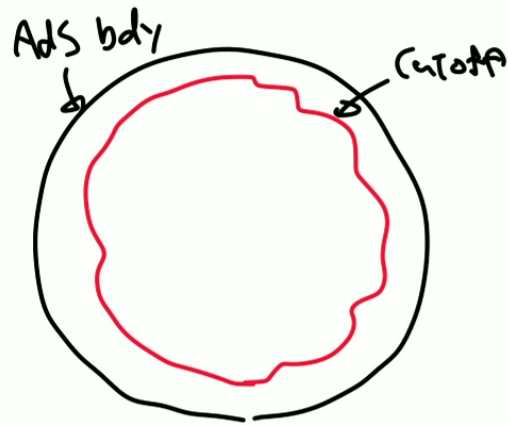
w/ Takato Mori (Kyoto)

arXiv:230X.XXXXX

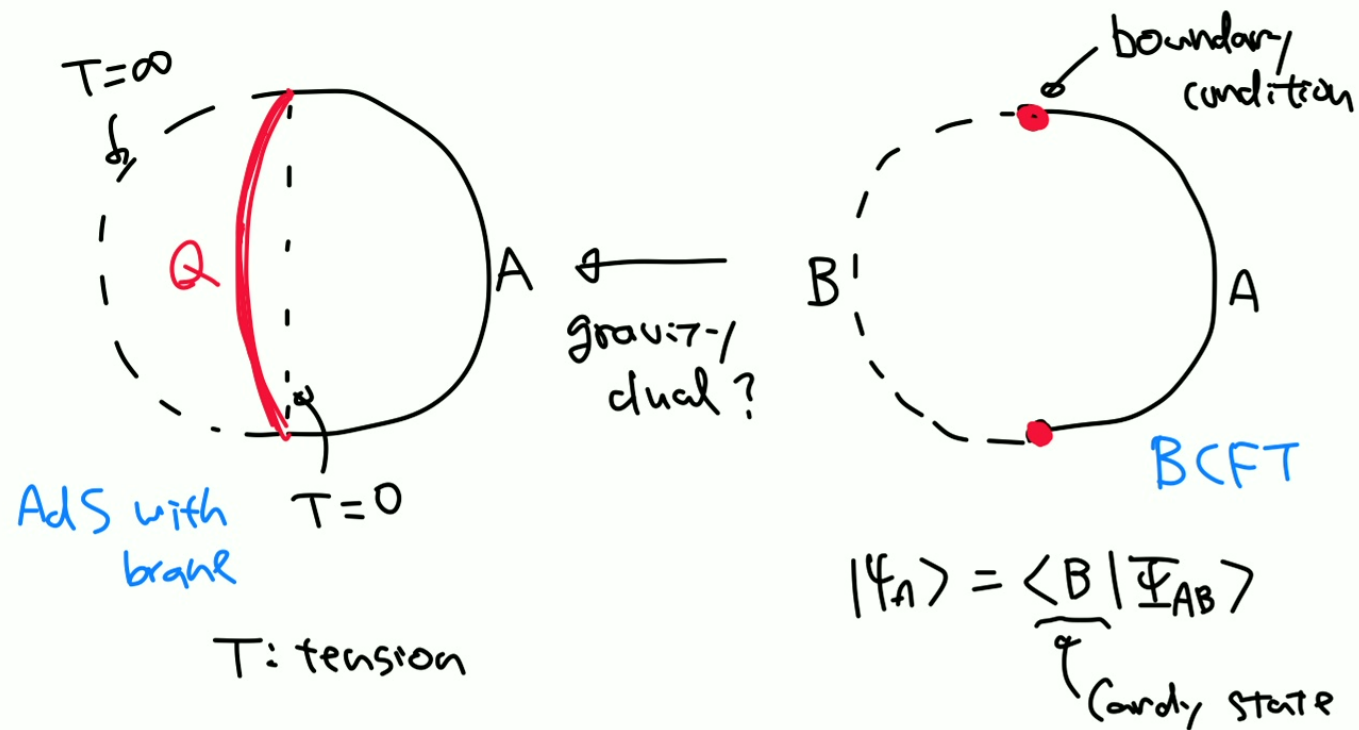
Holography for our universe?

Holography with finite radial cutoff

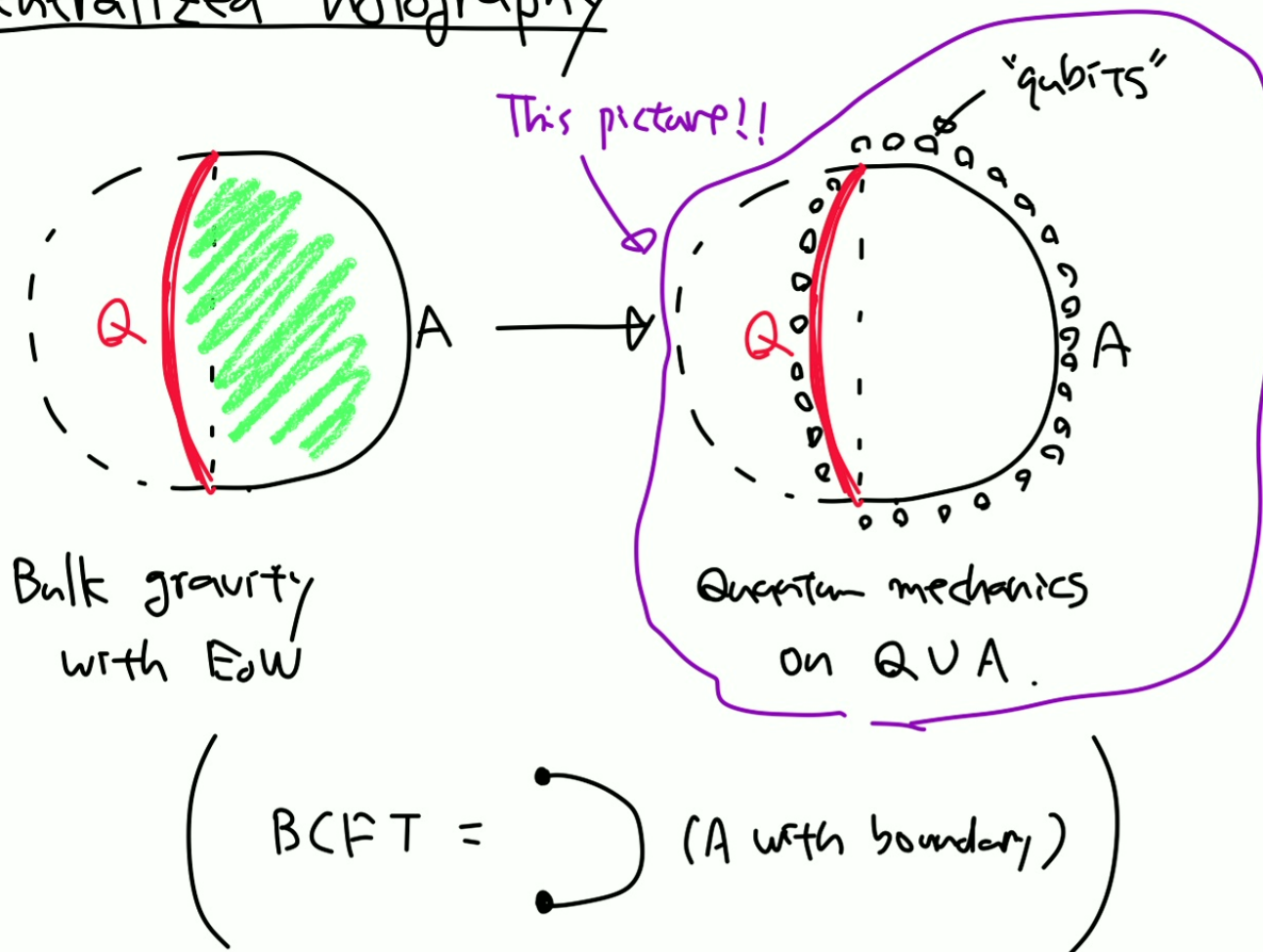
e.g. $T\bar{T}$, EOW brane, Randall - Sundrum etc
 ↖ this talk !!



AdS/BCFT (Takayanagi)

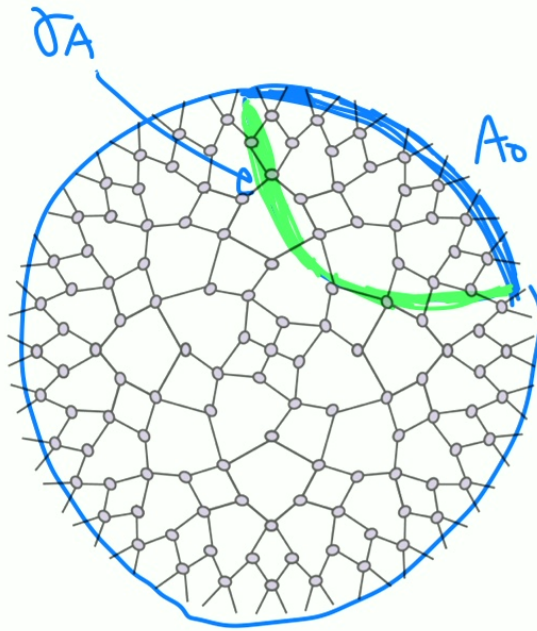


Generalized holography

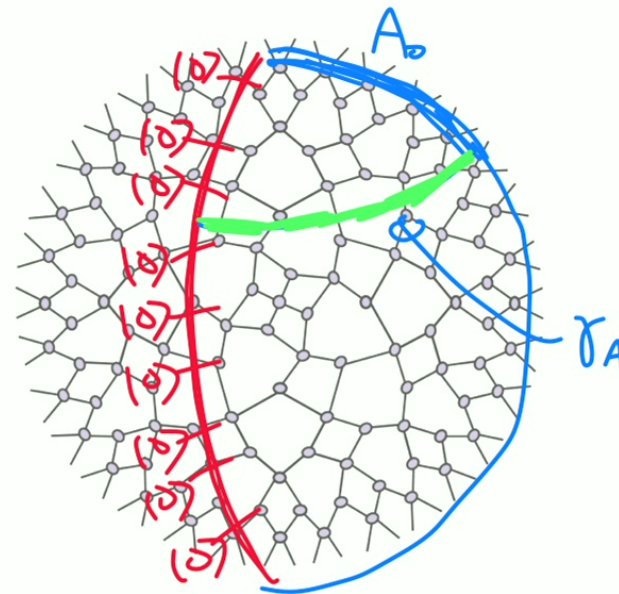


Tensor Network for Fow brane

"Product state" on Fow \rightarrow RT for BCFT



AdS/CFT



AdS/BCFT

(move in our upcoming paper)

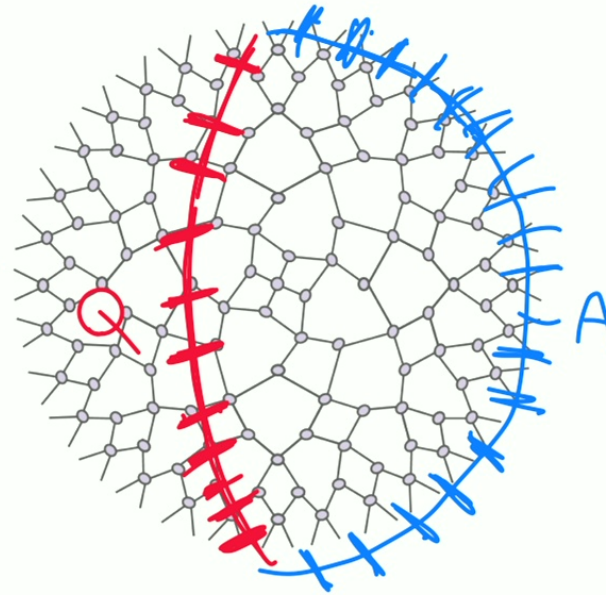
Tensor Network for generalized holography

Leave tensor legs on EW open.

Question

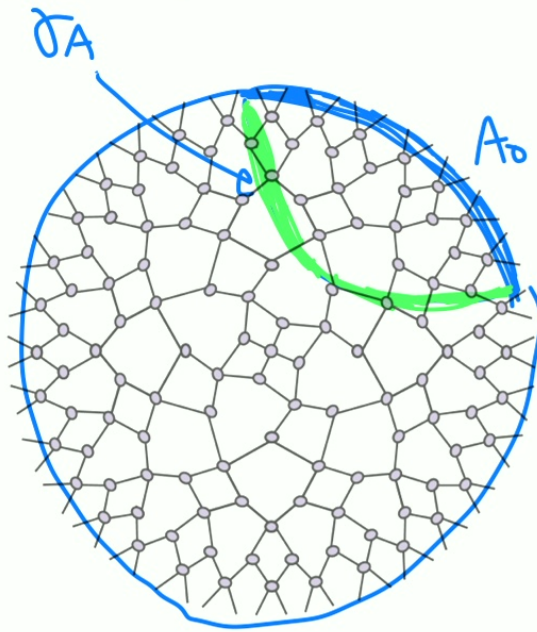
Quantum Theory on Q and A.

Does it make sense?

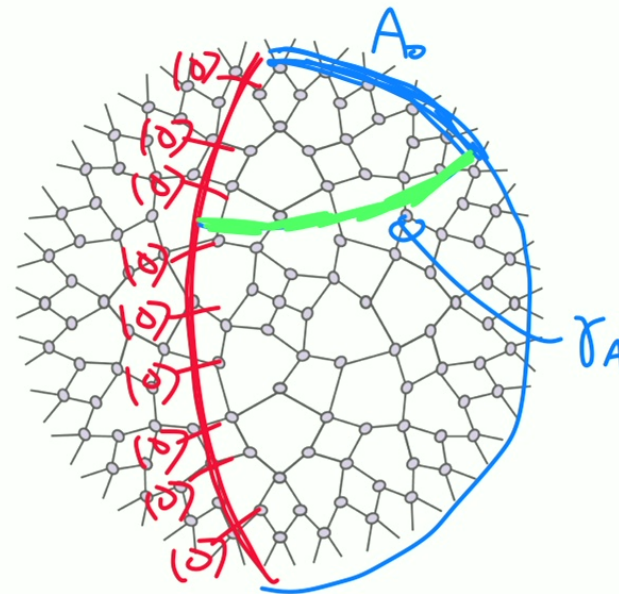


Tensor Network for EOW brane

"Product state" on EOW \rightarrow RT for BCFT



AdS/CFT



AdS/BCFT

(move in our upcoming paper)

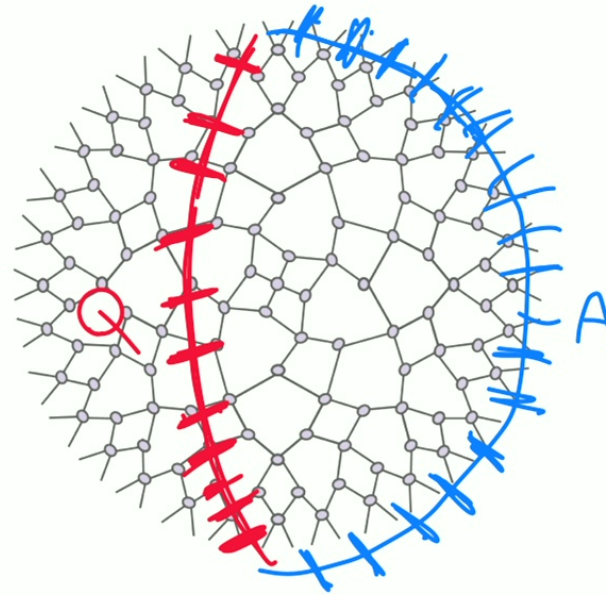
Tensor Network for generalized holography

Leave tensor legs on EW open.

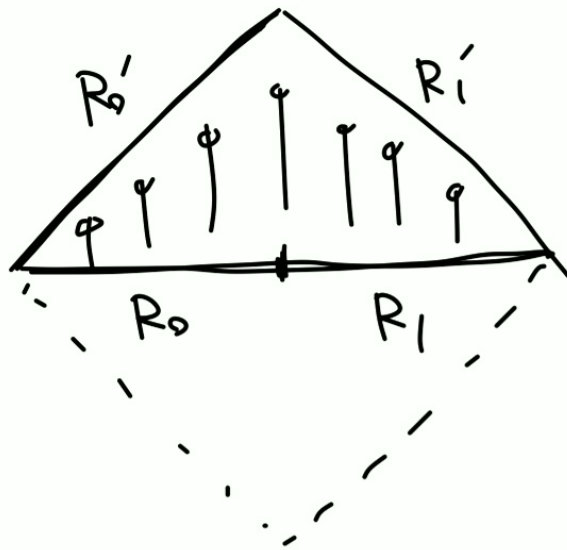
Question

Quantum Theory on Q and A.

Does it make sense?



"Violation" of sub-additivity (Mori-BT)



On F0W brane
(small T)

$$I(R_0, R_1) > 0$$

but

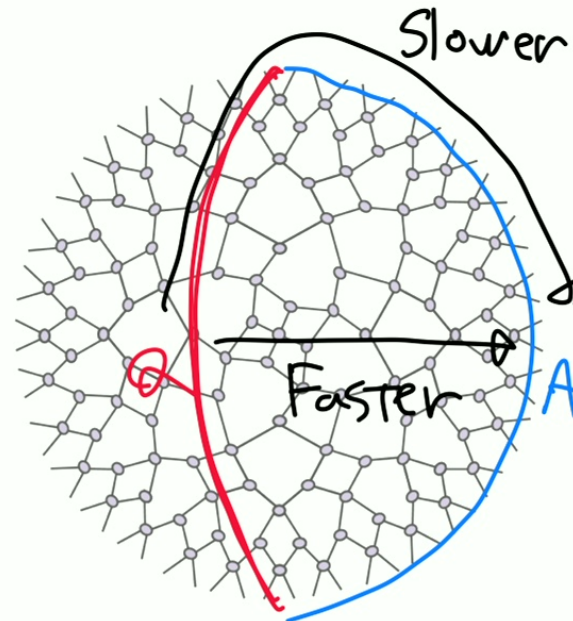
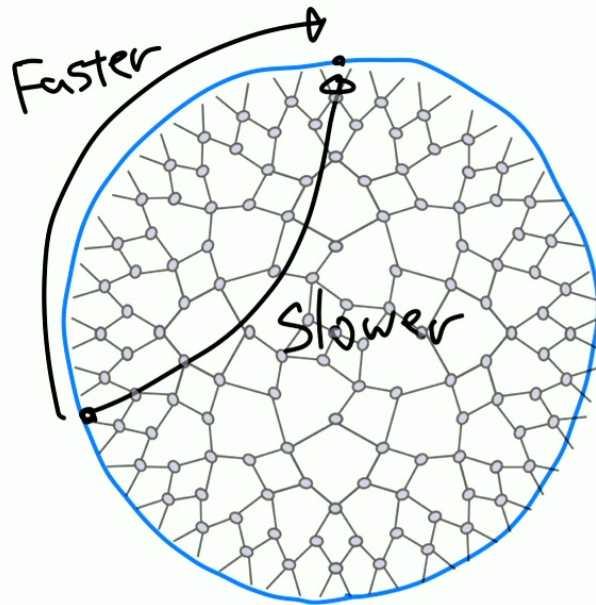
$$\underline{I(R'_0, R'_1) < 0}$$

violation of SA

Also by
Srivastava - Neuenfeld (upcoming)

"Violation" of Gao-Wald theorem

No shortcut through the bulk ... ?

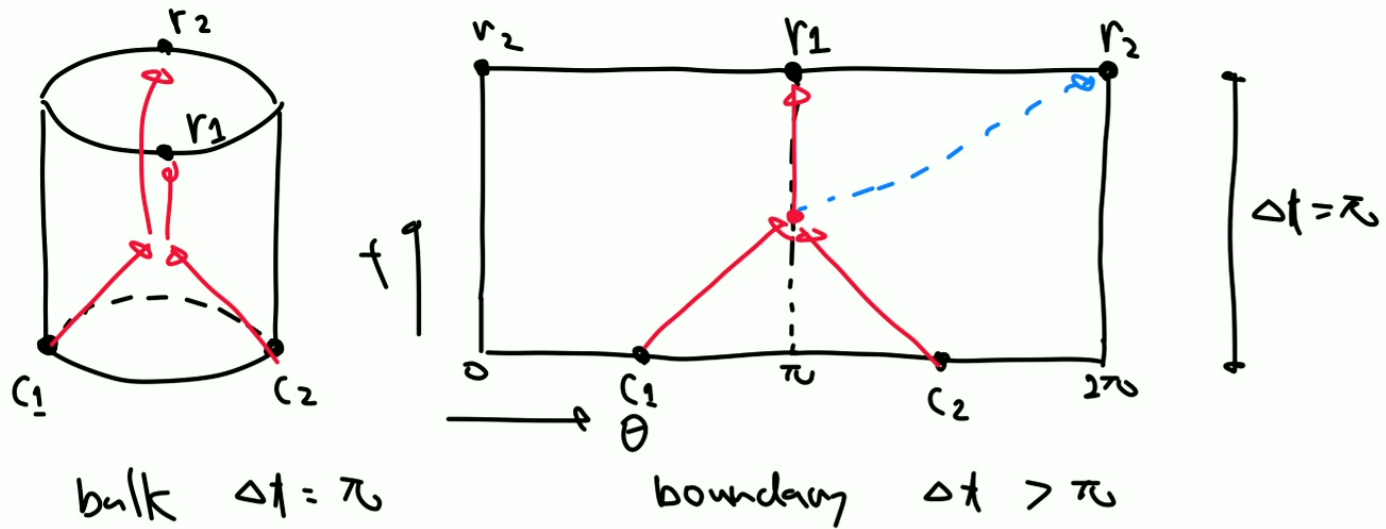


Faster-than-light signalling ... ??

(Wei - Omiya)

Holographic Quantum Tasks

2 particle Scattering Puzzle

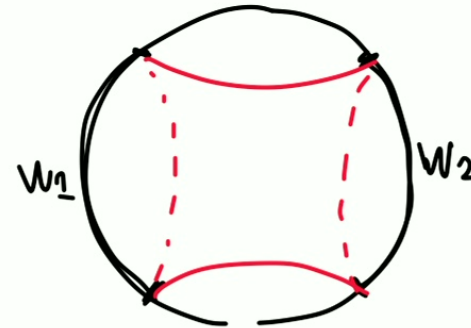
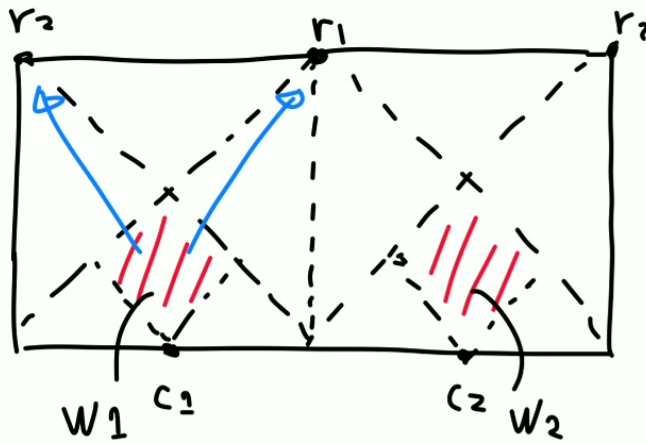


Not enough time for boundary scattering !!

(Alex Meyer, 2019)

Resolution: Entanglement as resource

[Alex May 2019]



$$W_1 = J_+(c_1) \cap J_-(r_1) \cap J_-(r_2)$$

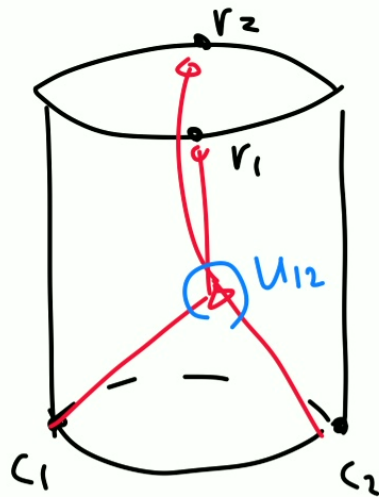
W_1 can signal to r_1, r_2

$$I(W_1, W_2) = O\left(\frac{1}{\epsilon N}\right)$$

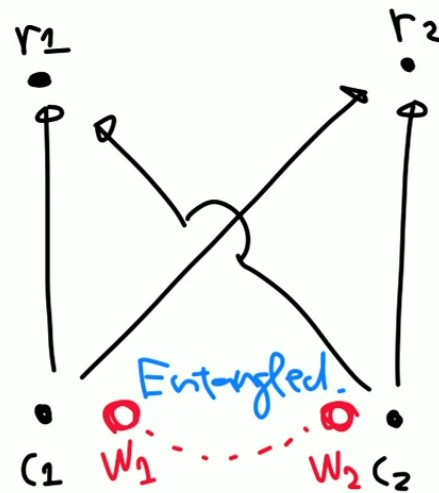
W_1 & W_2 entangled!

(via Ryu-Takayanagi formula)

With entanglement ...



bulk



boundary

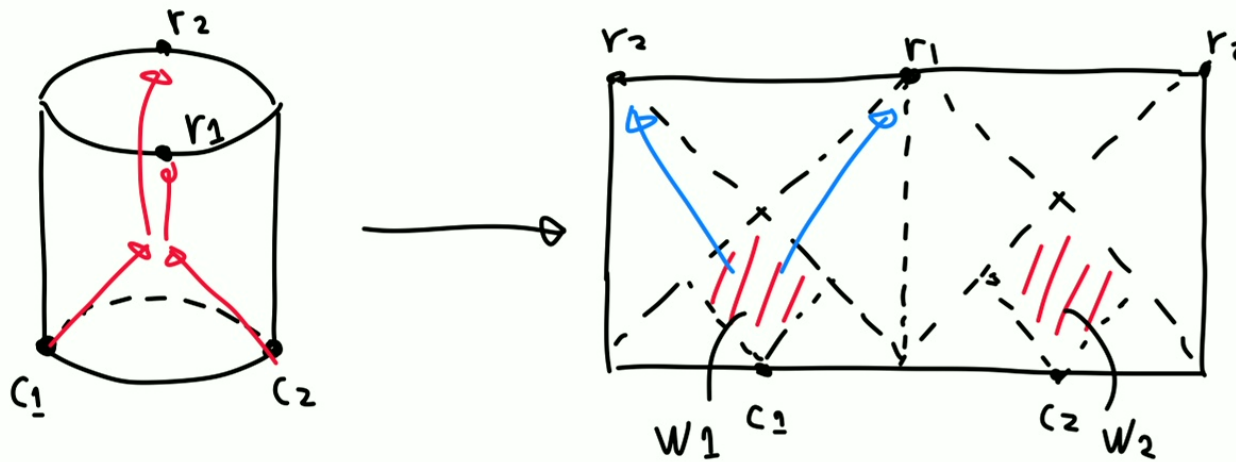
Idea

Somehow use $W_1 - W_2$ entanglement to implement U_{12}

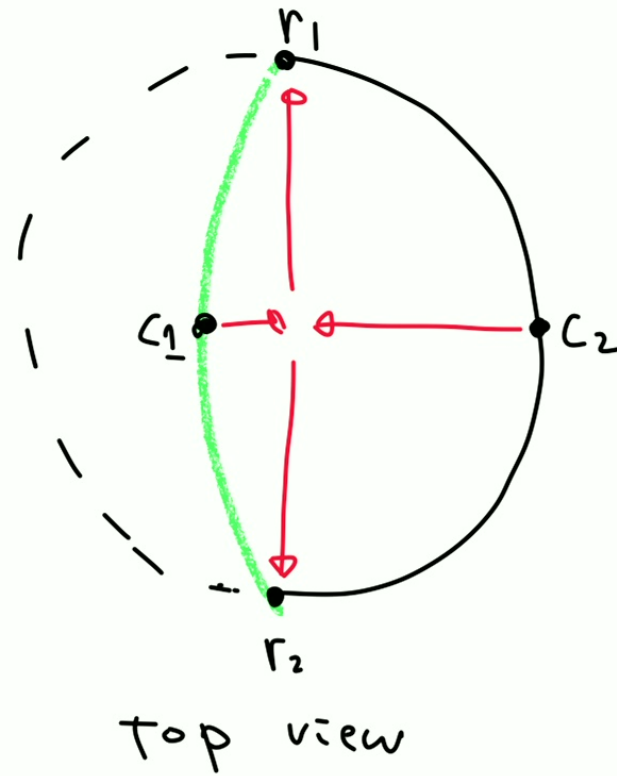
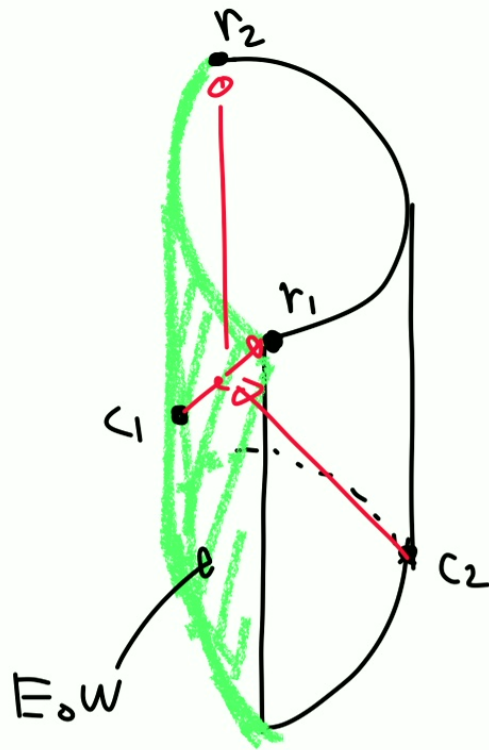
Connected wedge for $E_0 W$?

Upshot is ...

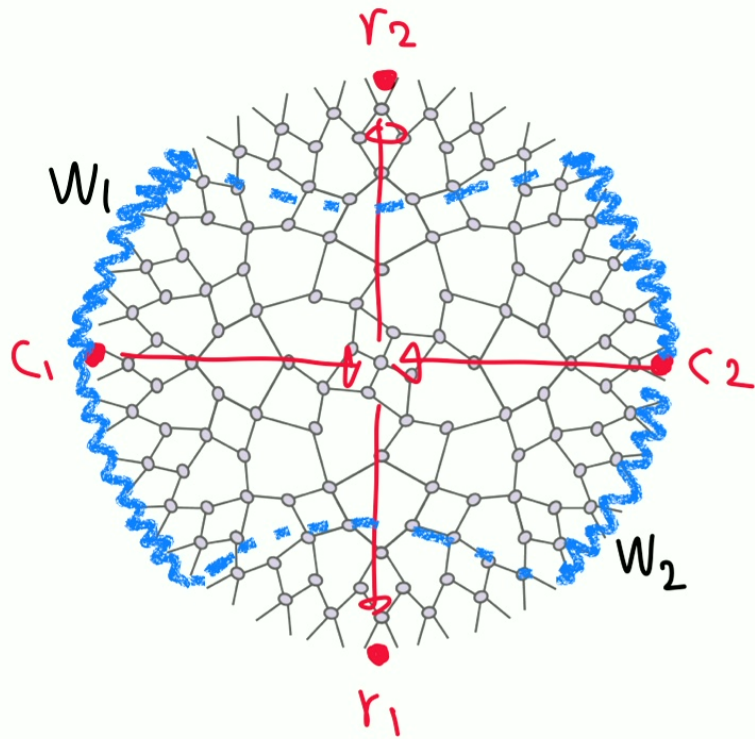
- Holographic scattering is possible due to entanglement.
- Some insights on entanglement and causality on EoW brane !?



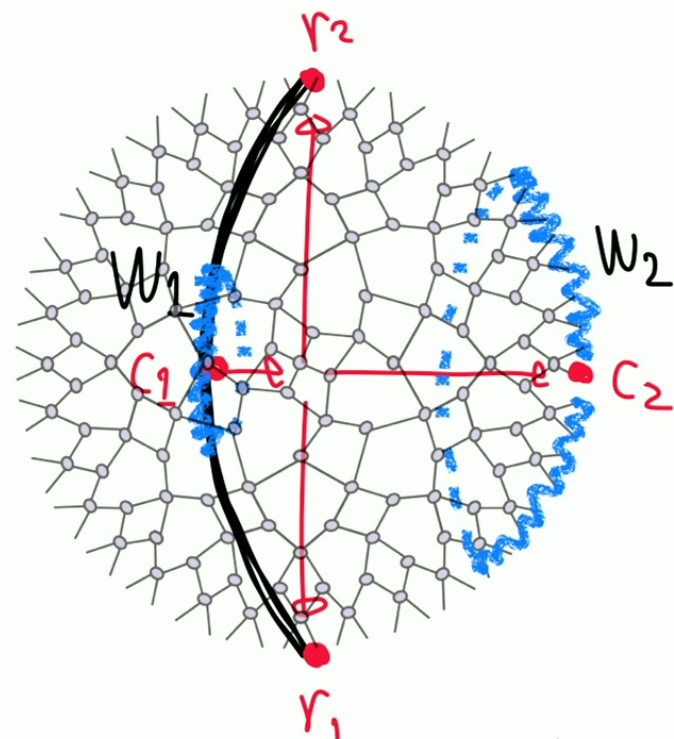
Scattering with E₀W



Connected Wedge for $E_0 W$?



connected



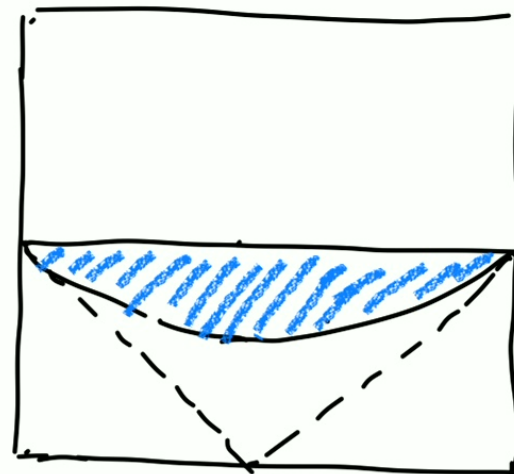
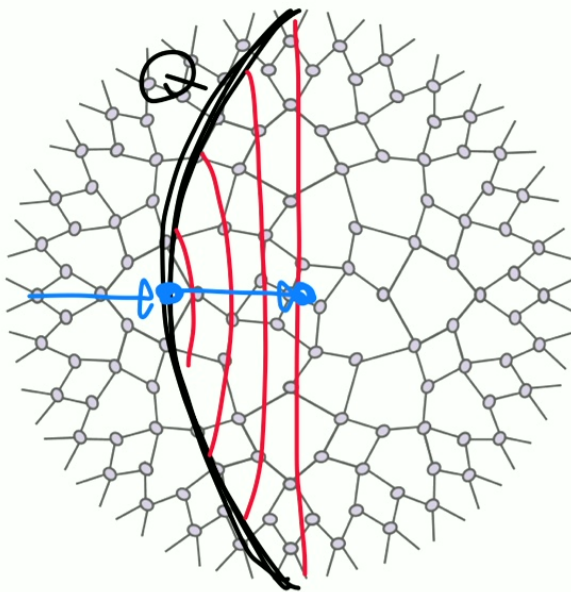
Not connected

(Non-local coupling does not change W_1 or W_2)

Entanglement Wedge (Superluminal!?)

Grow superluminally.

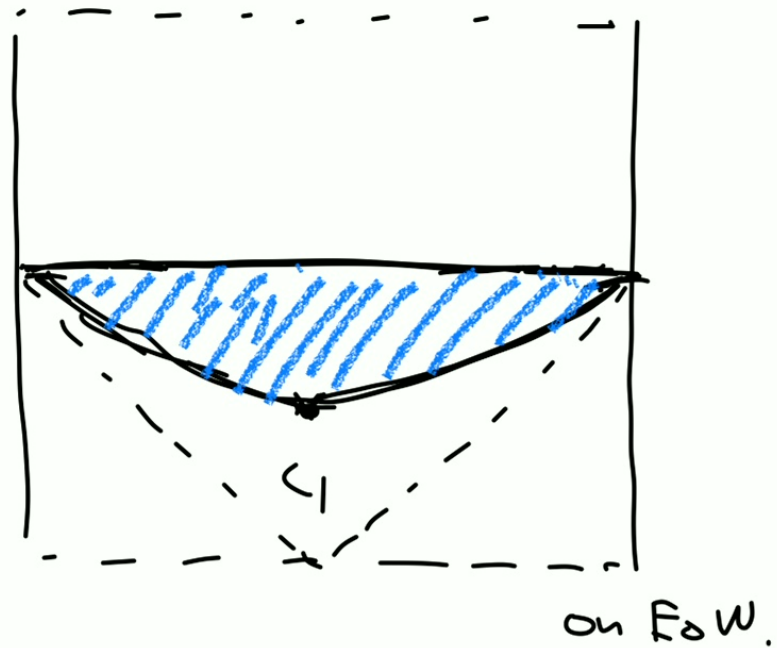
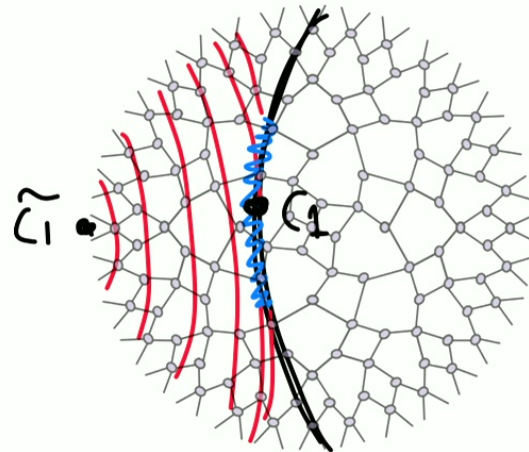
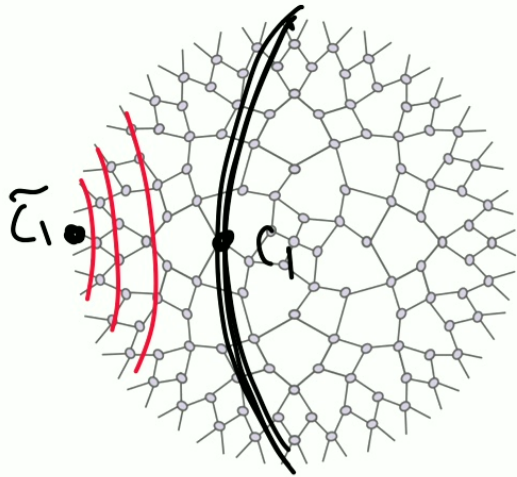
—e Some "memory" about "behind" EoW?



(Relevant idea: see TT paper)

Induced lighttrone

Let's accept some non-locality
(for now)



Connected wedges for induced lightcone

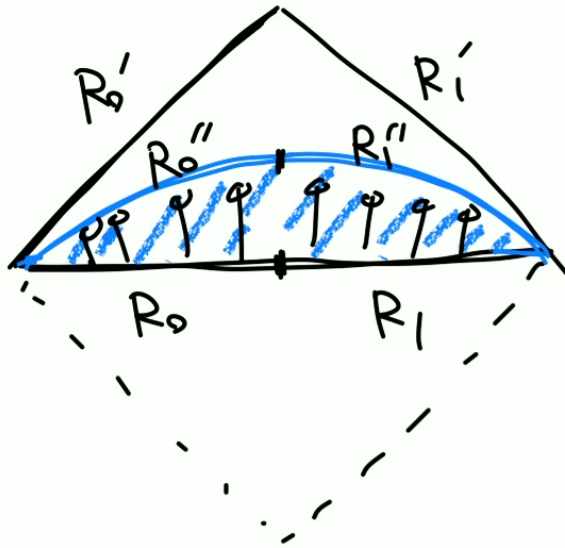
AdS + E.W geometry

Entanglement wedges are connected if we consider induced lightcones.

- Explicitly checked for various configurations.
- Connected wedge theorem holds?

Proof idea: Use focus theorem for light-rays
from asymptotic AdS boundary

Subadditivity is safe!



Sub-additivity is safe
because

$$R_0 R_1 \simeq R_0'' R_1''$$

but

$$R_0' R_1' \neq R_0 R_1$$

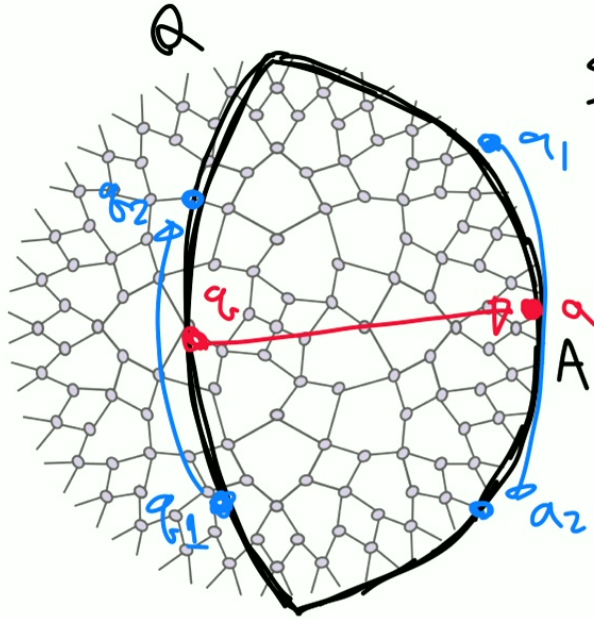
- Non-locality just enough to save sub-additivity
- Induced light cone always satisfies SA.
(Due to thm by Grado-White, Merolf, Weinberg)

Non-locality ; real or apparent ?

Recap of Omiya-Wei (perspective 1)

$q \rightarrow a$ leads to causal communication.

$q_1 \rightarrow q_2, a_1 \rightarrow a_2$ are causal.

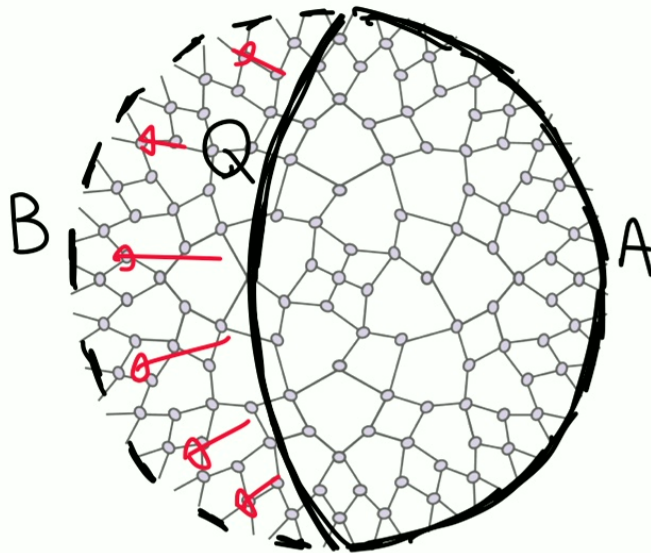


Suggesting ... ?

- Local on Q and A?
- Non-local between Q and A?

Going back to AdS/CFT (perspective 3)

H_{AB} is local, so H_{QA} must be local?

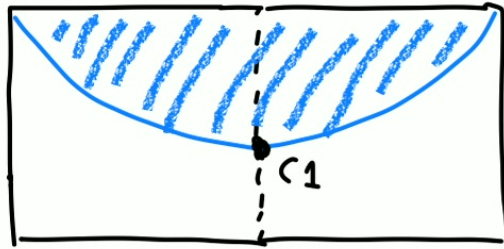


isometry/
 $B \longleftrightarrow Q$

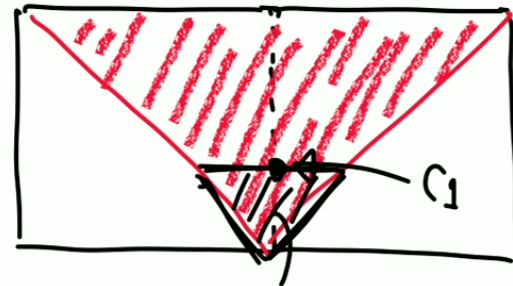
projection
 $H_{QA} \longrightarrow H_{BA}$

Complexity scenario?

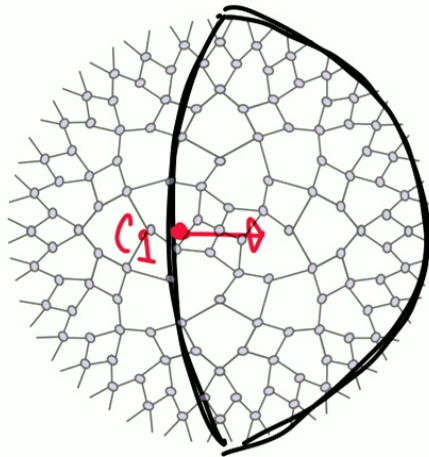
Theory on EoW should be local, Non-locality is apparent?



"non-local" light trap



Needed to create local excitation

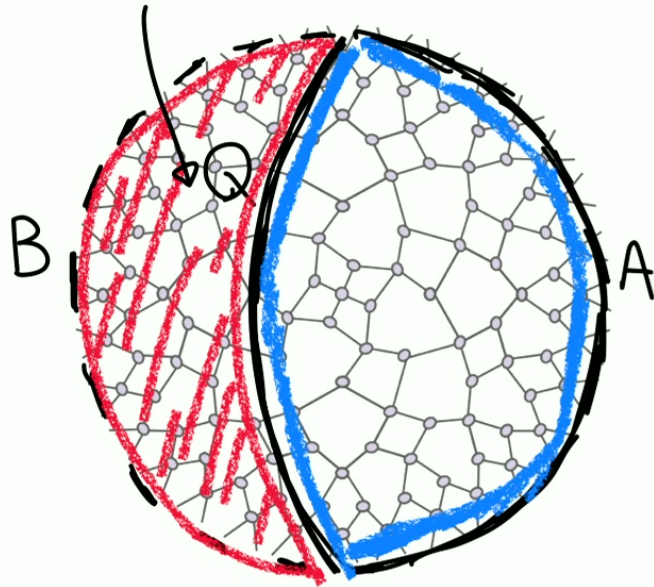


high-complexity op?

Ancilla scenario?

$B \rightarrow Q$ is projection. Some info is lost?

like "thermal bath"?



Radial movement
requires operations on
thermal bath?

- Superluminal (induced) lightcone resolves
 - 1) Sub-additivity violation
 - 2) Connected wedge for scattering
- Connected wedge theorem for holography with radial cutoff ??
- Local theory may be possible, but some local excitation cannot be created locally and/or ancilla is needed?

