

Title: Talk 79 - Measurements in holographic systems: current status and future directions

Speakers:

Collection: It from Qubit 2023

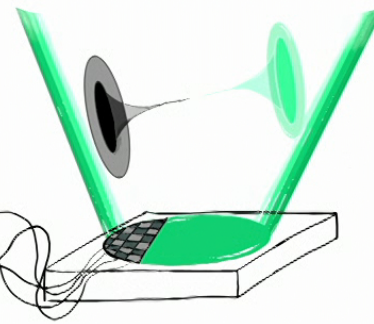
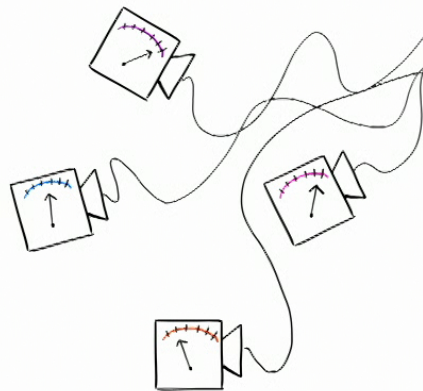
Date: August 02, 2023 - 10:30 AM

URL: <https://pirsa.org/23080011>

Abstract: Holography has taught us that spacetime is emergent and its properties depend on the entanglement structure of the dual boundary theory. At the same time, we know that local projective measurements tend to destroy entanglement. This leads to a natural question: what happens to the holographic bulk spacetime if we perform strong local projective measurements on a subsystem A of the boundary? In particular, I will explain the effect of measurements performed both on subsystems of a single CFT in its vacuum state, which is dual to pure AdS spacetime, and on various subsystems of two copies of a CFT in the thermofield double state, which is dual to a double-sided AdS black hole. The post-measurement bulk is cut off by end-of-the-world branes and is dual to the complementary unmeasured subsystem A^c . The measurement triggers an entangling/disentangling phase transition in the boundary theory, corresponding to a connected/disconnected phase transition in the bulk dual geometry. Interestingly, the post-measurement bulk includes regions that were part of the entanglement wedge of A before the measurement, signaling a transfer of information from the measured to the unmeasured subsystem analogous to quantum teleportation. Finally, I will discuss open questions and future directions related to our work, with a particular focus on its consequences for the complexity of bulk reconstruction.

Holographic Measurements in Thermofield Doubles

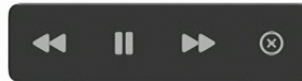
IFQ: Aug 2 23



Brianna Grado-White
Brandeis University

with Stefano Antonini
Shao-Kai Jian
& Brian Swingle

[2209.12903] & [2211.07658]



Slogan: "Spacetime Emerges from Entanglement"



↳ Q: How do manipulations of the boundary entanglement structure modify the bulk?

Generally: \rightarrow Measurements of a subregion can extract information from the entanglement wedge.

\rightarrow More highly correlated, non-local, measurements can extract information deeper in the entanglement wedge.

Here: Focus on the effects of Local Projective Measurements (post-selection) on the boundary



Overview

We show how **Local Projective Measurements (LPMs)** of the CFT modify bulk connectivity & the bulk-to-boundary map in eternal black hole spacetimes, by **destroying the Einstein-Rosen bridge** & **"teleporting"** information from the entanglement wedge of one CFT into another

Outline

→ Review: Local Projective Measurements in Holography & AdS/BCFT

→ TFD Measurements: Path Integral description, Conformal maps & bulk saddles

→ **Result 1:** Bulk Connectivity & Mutual Information

→ **Result 2:** Bulk "teleportation": Heavy Operator Insertions

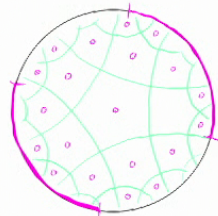
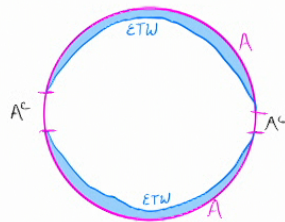
→ Future Questions & Summary



Previous Work

→ Vacuum AdS_3 & Tensor Network Models

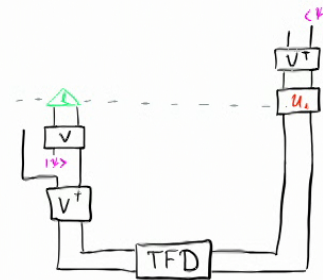
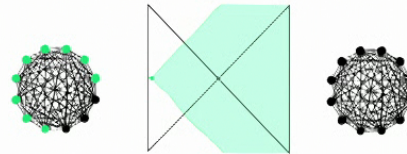
Antonini, Bentsen, Cao, Harper, Jian & Swingle
[2201.12903]



Today: TFD_2 [2211.07658], Antonini, G-W, Jian & Swingle

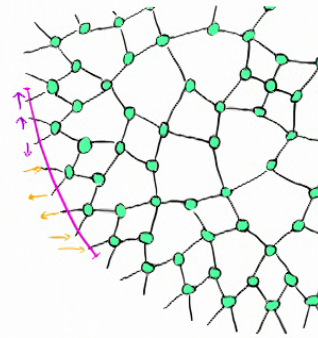
→ SYK TFD & JT Gravity

Antonini, G-W, Jian & Swingle
[2209.12903]



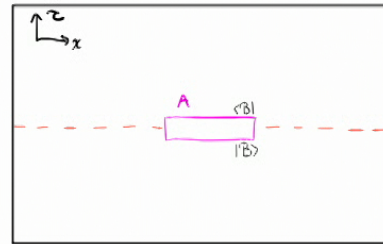
Local Projective Measurements

- In a tensor network or lattice regularization:
 - > Project onto a local product state on different sites
 - > Choice of different bases/post-selected states



- In a CFT:

- > UV Local measurement with no spatial entanglement in the projected region
- > Choice of different Cardy State $|B\rangle$ [Miyaji et al. '19]



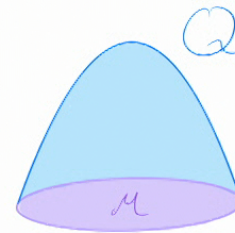
- > Measurement is described by inserting a slit with conformal boundary conditions in the Euclidean path integral preparing the state. [Numasawa et al. '16]
- > This corresponds to a BCFT



The Dual Spacetime: AdS/BCFT

→ The bulk dual to our measurement can be built via the proposed AdS/BCFT correspondence, [Fujita et al. 11] where the bulk dual contains a dynamical boundary modeled by a constant tension end-of-the-world (ETW) brane Q

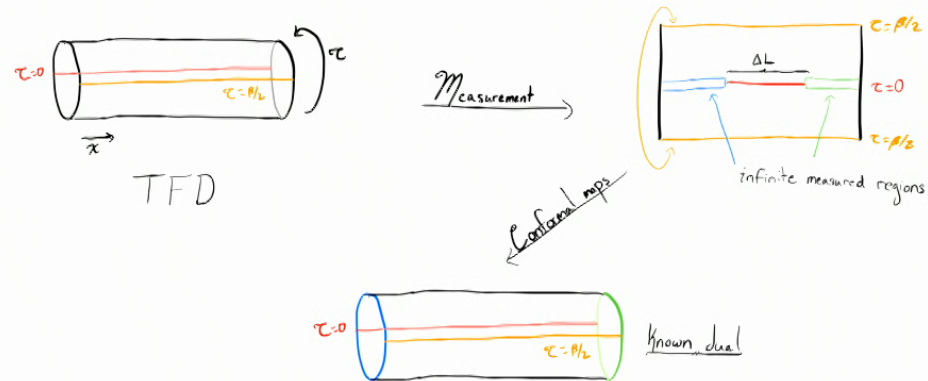
→ The tension T is related to the boundary entropy of the Cardy state



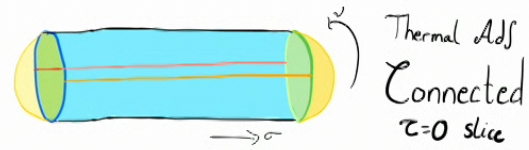
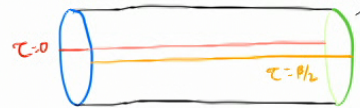
Conformal Mapping

→ To invoke AdS/BCFT, and avoid directly dealing with divergences, use conformal maps

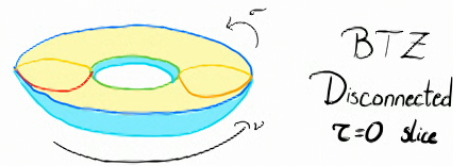
→ Map the Euclidean TFD cylinder with 2 slits to a finite cylinder with a known dual



Bulk Dual

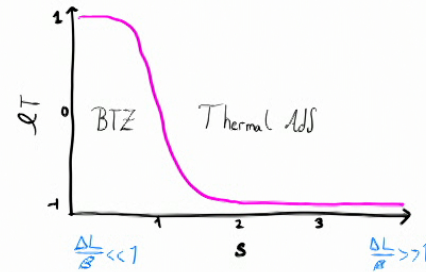


Bulk can be filled in 2 ways, with
 $ds^2 = \frac{R^2}{z^2} \left(\frac{dt^2}{h(z)} + h(z) d\sigma^2 + dz^2 \right), h(z) = 1 - \frac{z^2}{z_h^2}$



Where the brane trajectory & dominant saddle are determined by the Euclidean action

$$I = -\frac{1}{16\pi G_N} \int_M \sqrt{g} (R - 2\Lambda) - \frac{1}{8\pi G_N} \int_{\partial M} \sqrt{h} (k - T)$$

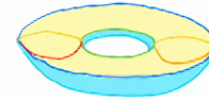


Bulk Connectivity & Entanglement

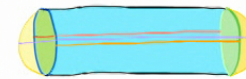
→ This "measurement induced" Hawking-Page transition between a connected/disconnected bulk corresponds to an entangled/disentangled phase transition

→ Via RT formula:

→ In BTZ phase, $RT(l) = \phi$
 $\Rightarrow S(l) = S(r) = S(lr) = 0$ & $I(lr) = 0$



→ In Thermal AdS phase, $RT(l) \neq \phi$
 $\hookrightarrow I(lr) = \frac{1}{2G_N} \left[\pi l + 2 \sinh^{-1} \left(\frac{l}{r_+ - l} \right) \right]$



→ Can be verified by a CFT replica trick up to $1/N$ effects
in various limits, following [Rajabpour '15]



Bulk Teleportation

→ Where bulk information is encoded can be modified via measurement

→ Portions of the bulk encoded in large boundary subregions can become encoded in small subregions after measurement

→ Previously studied in:

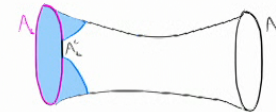
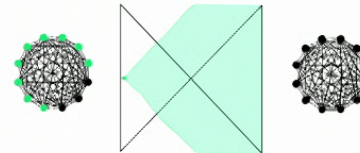
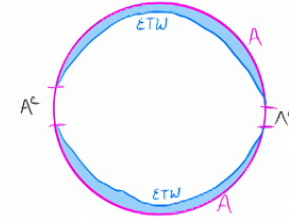
→ vacuum AdS [Antonini, Bentsen, Cao, Harper, Jian, Shingler]

For sufficiently large tension, the bulk can be teleported even when $|A| \gg |A^c|$

→ TFD₂ [Kourkoulou, Maldacena] [Antonini, Gil, Jian, Shingler]

Teleportation elucidated with explicit protocol

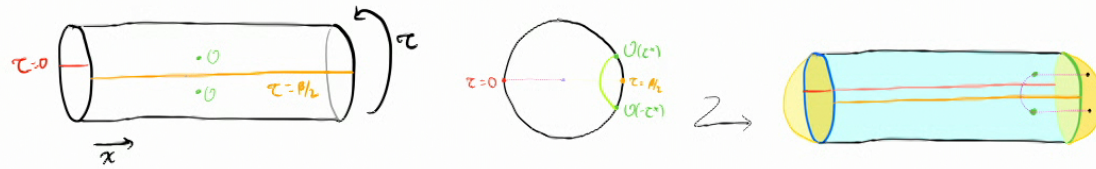
→ Trickier to check here whether information becomes accessible to the right CFT after partial measurement of the left CFT.



Heavy Operator Insertion

→ How much of the original left wedge becomes accessible from the right after measurement?

→ Insert CFT \mathcal{O} (bulk ϕ of mass m $1 \ll mR \ll \frac{l_p}{\ell_p}$) ^{Correlators via geodesic approximation} & determine where geodesic intersects _{Neglect backreaction} time reflection symmetric slice



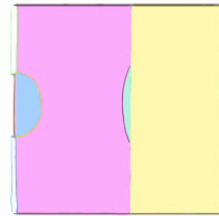
→ Map to finite cylinder

If the shortest geodesic ends on the brane, information is "erased"

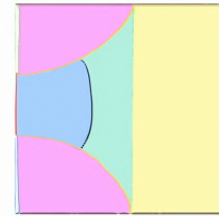
If the shortest geodesic is connected, can determine which boundary sees insertion



Schematic



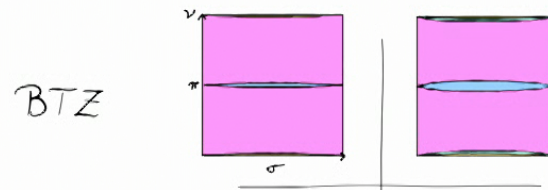
BTZ



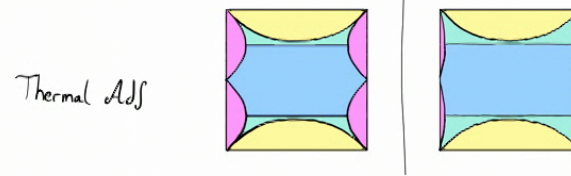
Thermal AdS

- Erased
- Teleported
- Left
- Right

Numerical



BTZ



Thermal AdS

$T \ll 1$

$T \sim 1$



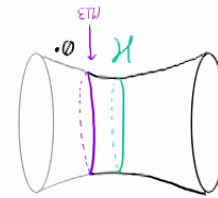
Open Questions:

→ Complexity of reconstruction behind the horizon?



→ Reconstruction of operators behind the horizon can be done simply if measurement outcome is known:

Evolve CFTR with the Hamiltonian modified by a measurement-dependent term [Koukoulou, Maldacena]



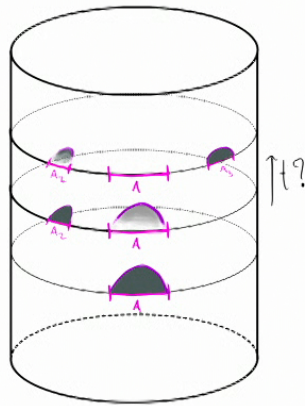
→ Python's Lunches & Non-isometries?



Open Questions:

→ Complexity of reconstruction behind the horizon?

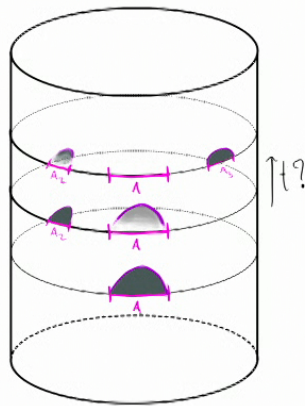
→ Dynamics: Measurement Induced Phase Transitions?



Open Questions:

→ Complexity of reconstruction behind the horizon?

→ Dynamics: Measurement Induced Phase Transitions?



Open Questions:

- Complexity of reconstruction behind the horizon?
- Dynamics: Measurement Induced Phase Transitions?
- Regularization & Other Measurements?
 - Weak Measurements?
 - Non-local Correlations?



Summary

Thanks for listening!

We show how **Local Projective Measurements (LPMs)** of the CFT modify bulk connectivity & the bulk-to-boundary map in eternal black hole spacetimes, by **destroying the Einstein-Rosen bridge** & **"teleporting"** information from the entanglement wedge of one CFT into another

Overview

- TFD Measurements: Path Integral description, Conformal maps & bulk saddles
- Result 1: Bulk Connectivity & Mutual Information
- Result 2: Bulk "teleportation": Heavy Operator Insertions
- Complexity, Pythons & Non-Isometry?
- Dynamics & Measurement-Induced Phase Transition?
- Regularization & Other Measurements?

