# THE ENTANGLEMENT ENTROPY OF TYPICAL PURE STATES AND REPLICA WORMHOLES

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מכון ויצמן למדע
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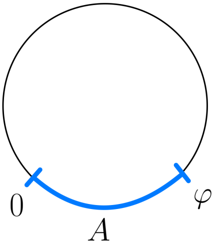
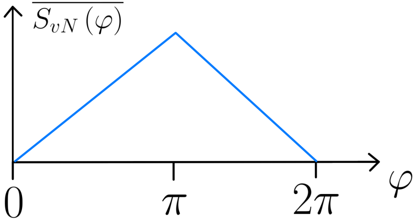
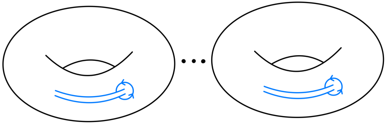
# The goal

- In a 1+1 dimensional QFT on a $S^1$, we consider the von Neumann entanglement entropy of an interval $A = [0, \varphi]$ for typical pure states.
- Typically expect a "Page curve" in $S_{vN}(\varphi)$.
- We will reproduce it using a holographic calculation of "$\overline{S_{vN}(\varphi)}$": the entropy averaged over a specific ensemble of high energy pure states with $E \sim \frac{1}{\beta} \gg 1$.

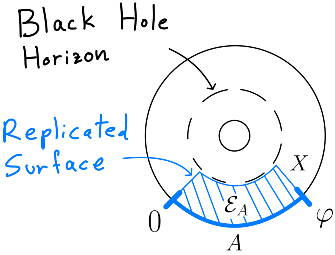


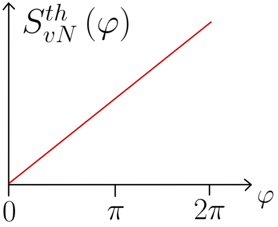



For $\rho_{th} = \frac{1}{Z}\exp(-\beta H)$, the replica trick reduces to

$S_n^{th}(\varphi) \sim$ 

The holographic dual of the replica trick [Lewkowycz, Maldacena] gives [Azeyanagi,Nishioka,Takayanagi]



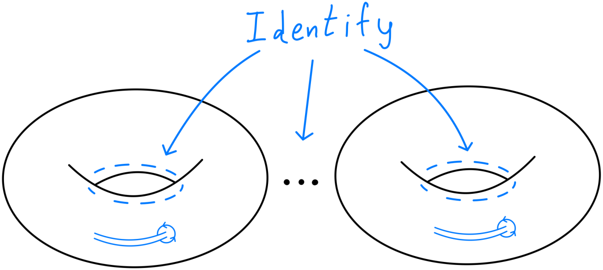



# Typical pure state - CFT side

For a specific ensemble of pure states, the averaged entropy is given by a similar path integral in the CFT replica trick.

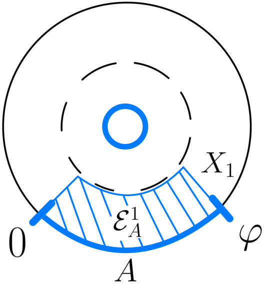
Singular geometry that further identifies all the replicas together:

$$\overline{S^n(\varphi)} \sim$$

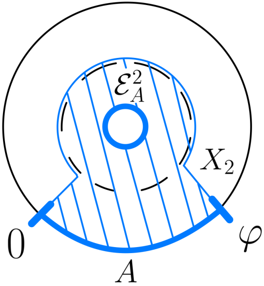


# Typical pure state - gravity side

The dual gravitational calculation has two saddles due to the singular geometry:



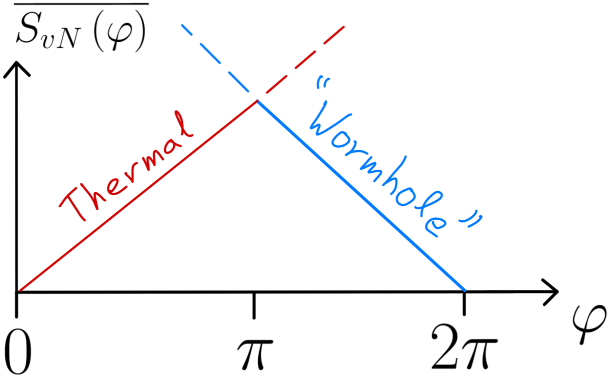

A thermal saddle with increasing entropy.




A “wormhole” saddle with decreasing entropy. Connects the replicas “behind the horizon”.

Reproduce the Page curve in $\overline{S_{vN}(\varphi)}$!

# Result - a Page curve




(This is not an evaporation process!)

THANK YOU!

QUESTIONS?