Holography and Entanglement of Flat Space

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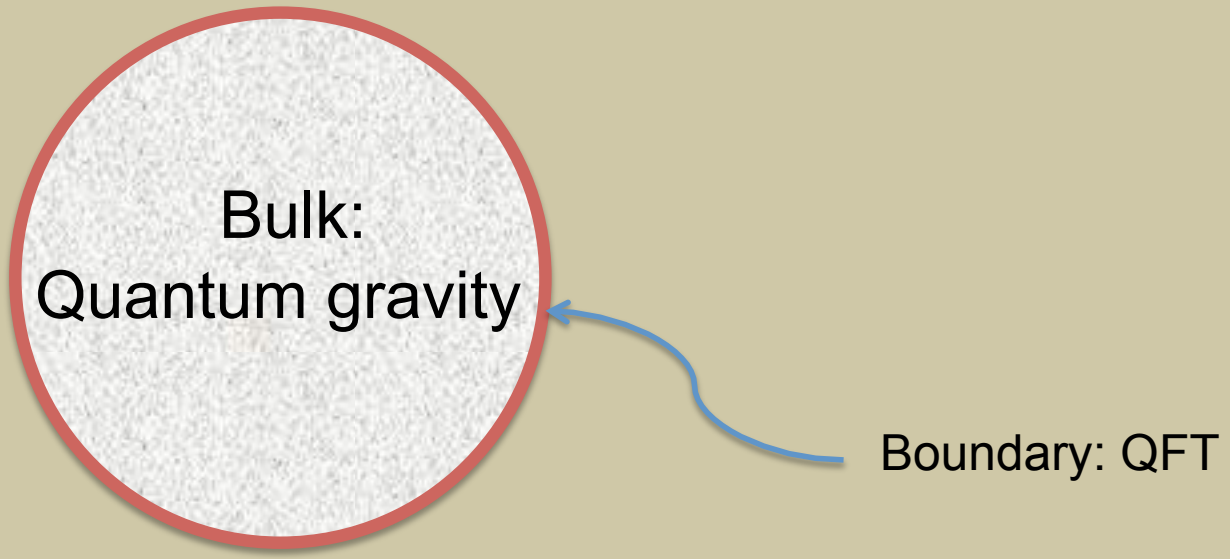
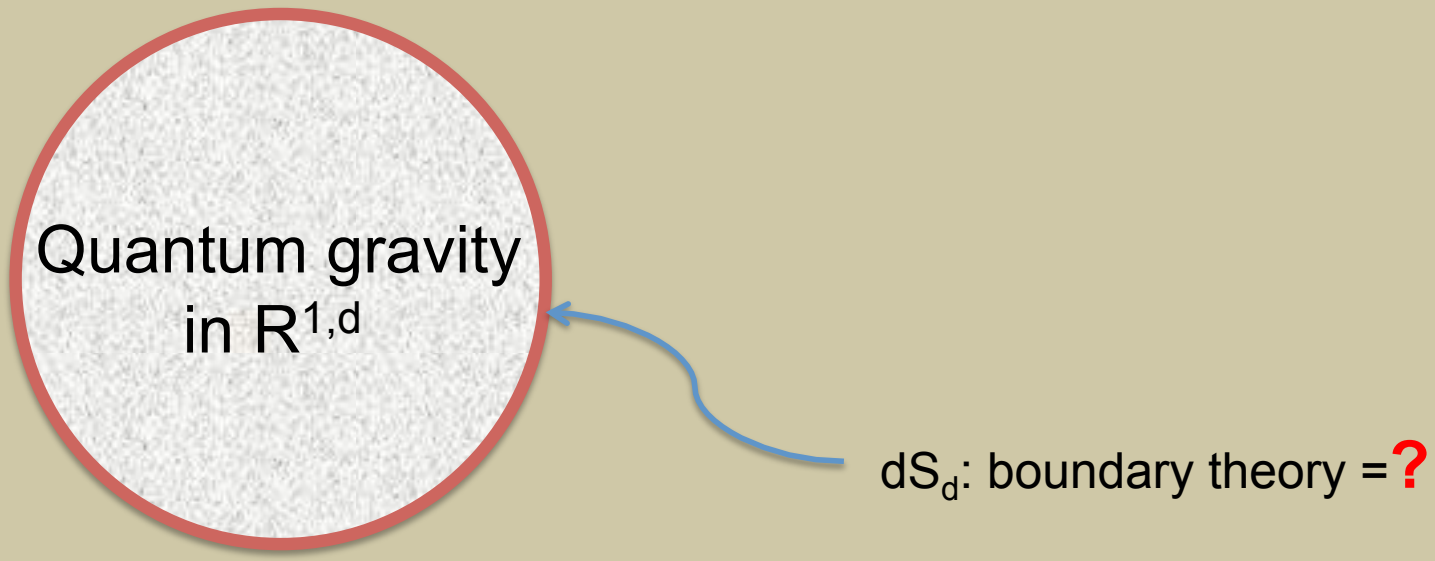
Holographic Duality

- Quantum gravity in the bulk = QFT on the boundary.
- Best known incarnation: AdS/CFT.



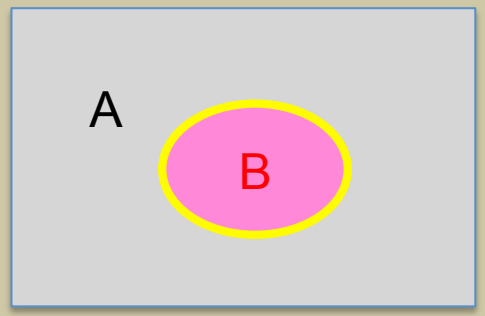
Holography for Flat Space

- Minkowski space: $ds^2_{\mathbb{R}^{1,d}} = d\rho^2 + \rho^2 ds^2_{dS_d}$
- What is the dual boundary theory on dS_d?
  - Handles:
    1. Correlation functions
    2. **Entanglement entropies**



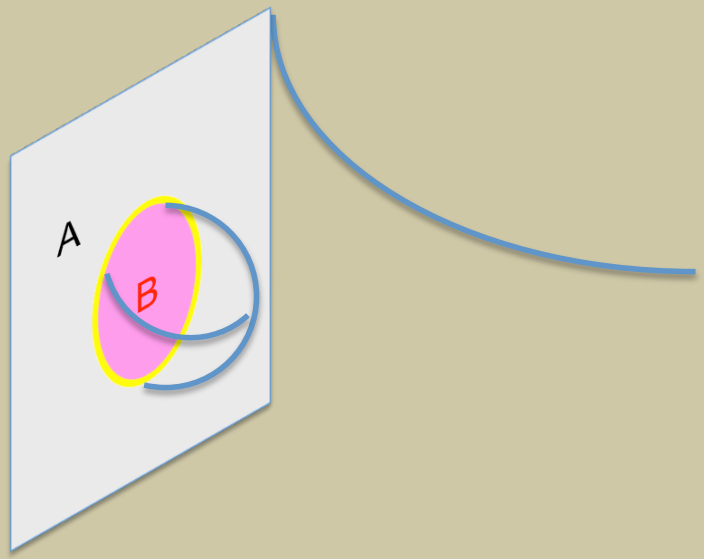
Entanglement Entropy

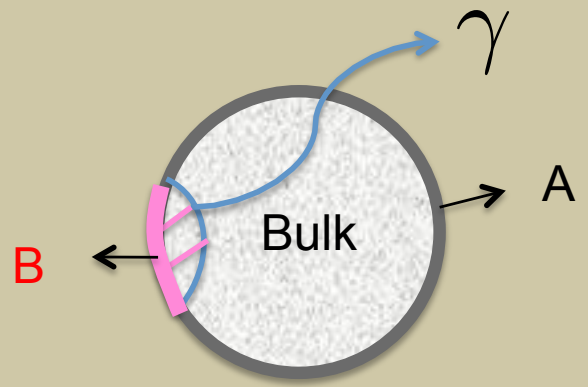
- Statistical Entropy $S_{stat} = -\mathrm{Tr}\ \rho_{tot} \ln \rho_{tot}$



- Entanglement Entropy
  1. Total = A + B
  2. Reduced density matrix: $\rho_A \equiv \mathrm{Tr}_B\ \rho_{tot}$
  3. Entanglement entropy: $S^A_{E.E.} \equiv -\mathrm{Tr}_A\ \rho_A \ln \rho_A$

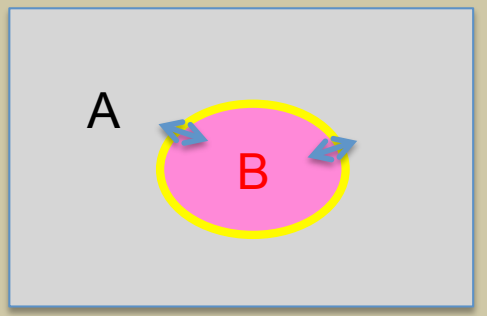
- A has no access to B $\Longrightarrow$ Holographically $S^A_{E.E.} = \frac{Area(\gamma)}{4G_N}$





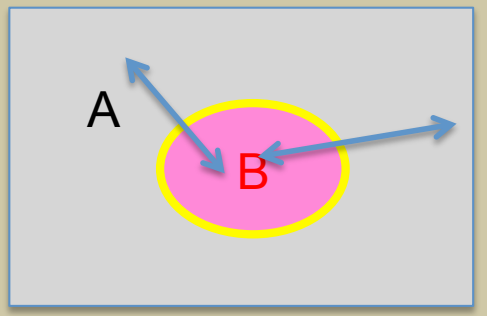
Volume Law & Non-locality

- Entanglement entropy measures *correlation between A and B.*
  - For ground state in local theory: $S^A_{E.E.} \sim Area(\partial A)$
  - Boundary theory of AdS: Local!



- Boundary theory of Flat space: $S^A_{E.E.} \sim Vol(A)$
  - boundary theory is non-local!
- Example of non-local theory

$$S_{boundary} = \int d\Omega_d \left[\phi \cdot e^{\sqrt{-\Delta}} \cdot \phi\right]$$



Correlation functions

- After adding counter terms, $\langle \hat{O}(x_1) \dots \hat{O}(x_n) \rangle = 0$

- It does not mean the boundary theory is empty!!!

  It means that it is non-local and highly-entangled!

- Use Entanglement Entropy to reproduce bulk physics!!

Summary & Outlook

Summary:

- The boundary theory of the gravity in asymptotically flat space is a non-local and highly-entangled quantum field theory.
- The boundary correlation functions are all trivial and one should use instead the entanglement entropies to reproduce the bulk physics.

Outlook:

- Concrete field theory realization.
- Schwarzschild black hole entropy.
- ...

ありがとうございます!