On the Entanglement of Multiple CFTs via Rotating Black Hole Interior

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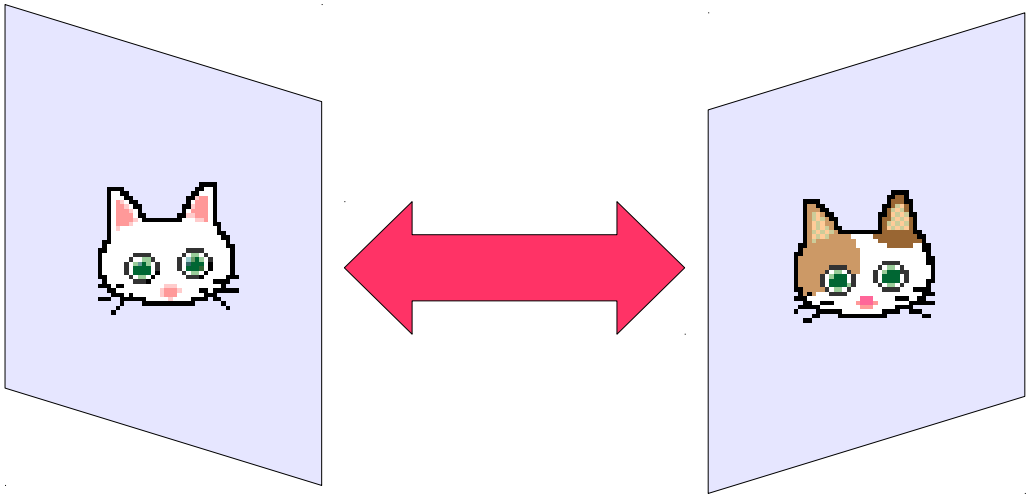


Entanglement between decoupled worlds

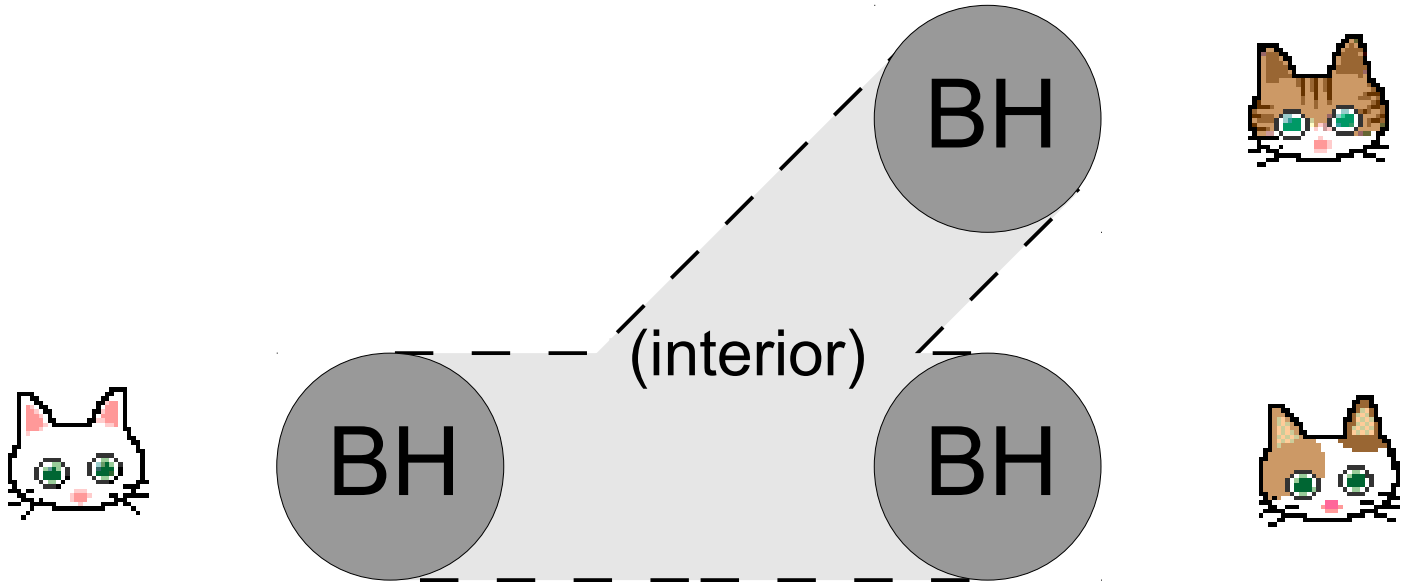
Black Hole geometry connecting different universes

(Wormhole)

Black Hole geometry connecting different universes

(Wormhole)

Rotation produces yet other patterns



Plan to Talk

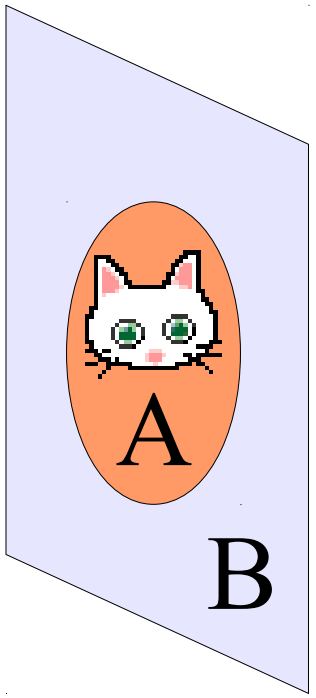
1. Quantum Entanglement
   and AdS/CFT Correspondence

2. Entanglement between CFTs
   via Black Hole Interior

3. Multiple Classes of Entanglement
   via Rotating Black Hole Interior

1. Quantum Entanglement and AdS/CFT Correspondence

Quantum Entanglement



"EPR correlation"

between A & B

Quantum Entanglement

Example in 2-qubit system

$$|\psi>=\frac{1}{\sqrt{2}}(|0>_A\otimes|1>_B+|1>_A\otimes|0>_B)$$

cf.) $|\psi>=|0>_A\otimes|1>_B$

- Correlation between A and B

$$<\mathcal{O}_A\mathcal{O}_B>\neq<\mathcal{O}_A><\mathcal{O}_B>$$

- Subsystems become mixed states

$$\rho_A=\mathrm{Tr}_B[\rho_\psi] \quad =\frac{1}{2}(|0>_A<0|_A+|1>_A<1|_A)$$

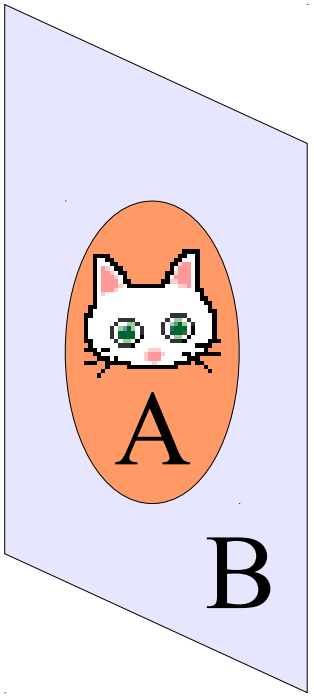
$$\rho_B=\mathrm{Tr}_A[\rho_\psi] \quad =\frac{1}{2}(|0>_B<0|_B+|1>_B<1|_B)$$

- "Entanglement Entropy" (EE)

$$S_A=-\mathrm{Tr}\rho_A\log\rho_A \quad =\log 2$$

Quantum Entanglement

Quantum Field Theory



- Correlation between A and B

$$< \mathcal{O}(\vec{x}_A)\mathcal{O}(\vec{x}_B) > \neq < \mathcal{O}(\vec{x}_A) >< \mathcal{O}(\vec{x}_B) >$$

- Subsystems become mixed states

$$\rho_A = \mathrm{Tr}_B[\rho_{total}]$$

- Entanglement Entropy

$$S_A = -\mathrm{Tr}\rho_A \log \rho_A$$

Quantum Entanglement

! Caution ! 

- (ρ_A , ρ_B) pair cannot reproduce $|\psi>$.

$$\rho_A = \frac{1}{2}(|0>_A<0|_A + |1>_A<1|_A)$$

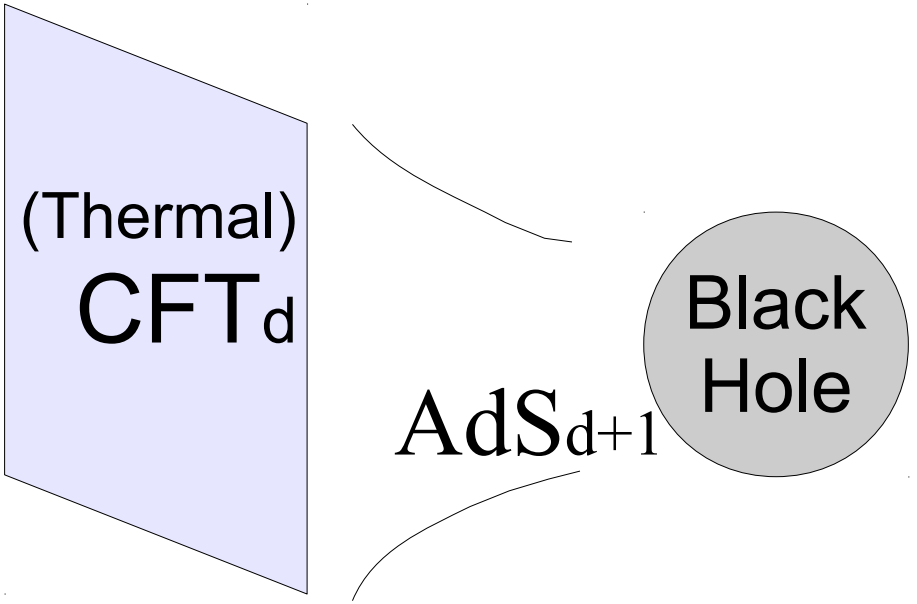
$$\rho_B = \frac{1}{2}(|0>_B<0|_B + |1>_B<1|_B)$$

$$|\psi>= \frac{1}{\sqrt{2}}(|0>_A \otimes |1>_B + e^{i\theta}|1>_A \otimes |0>_B)$$

$$|\psi>= \frac{1}{\sqrt{2}}(|0>_A \otimes |0>_B + e^{i\theta}|1>_A \otimes |1>_B)$$

$|\psi>$ includes “Way of Entanglement”.

AdS/CFT Correspondence

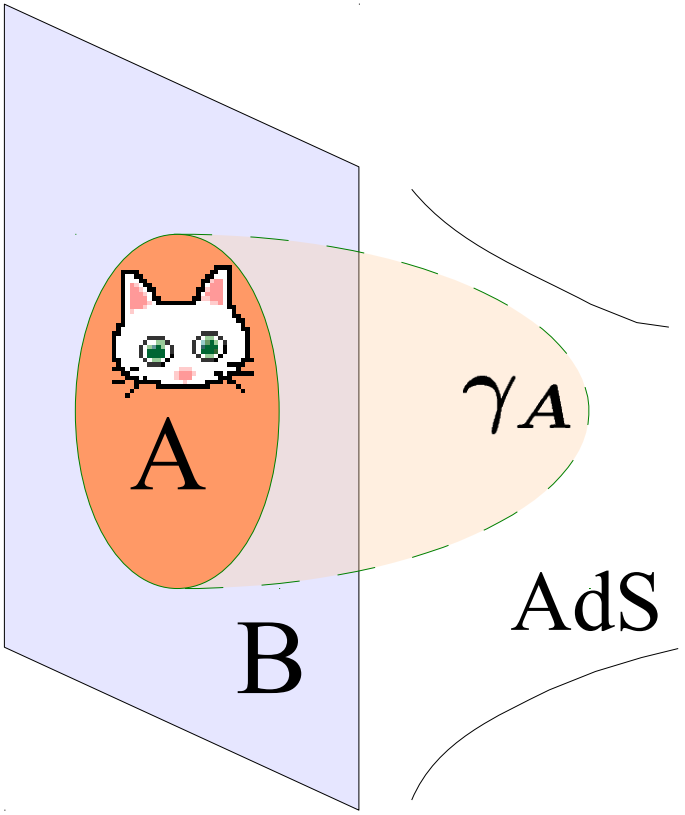


d-dim CFT ⟺ Gravity on (d+1)-dim Anti-de-Sitter

Conformal symmetry	Specetime isometry
Energy	Black Hole mass (M_{ADM})
Temperature	Surface gravity (T_H)
Entropy	Black Hole horizon area (S_{BH})

Holographic Entanglement Entropy

[Ryu-Takayanagi, 2006]

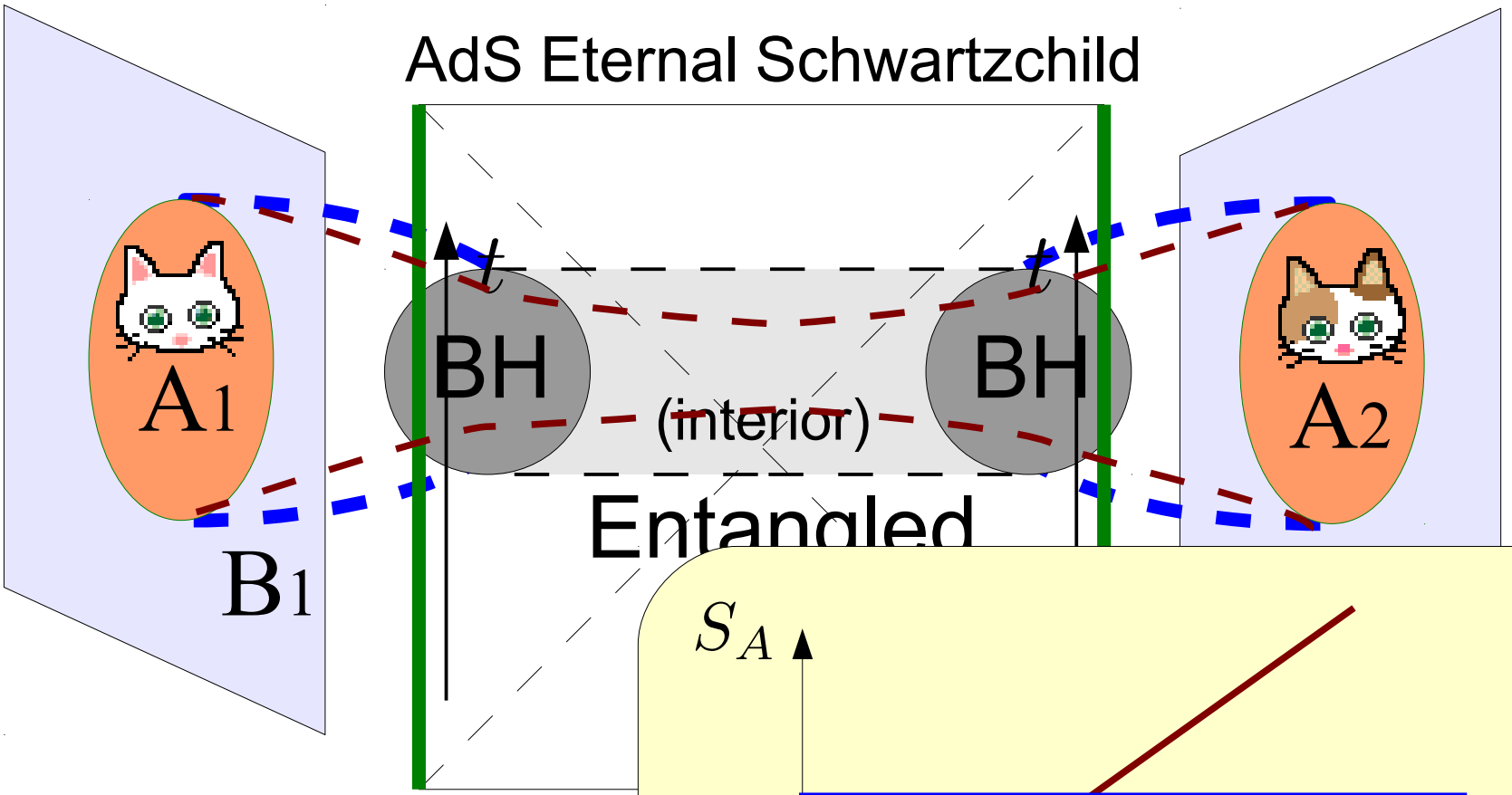


$$S_A = \frac{\min \text{Area}(\gamma_A)}{4G_N}$$

Entanglement ⟺ Spacetime Structure

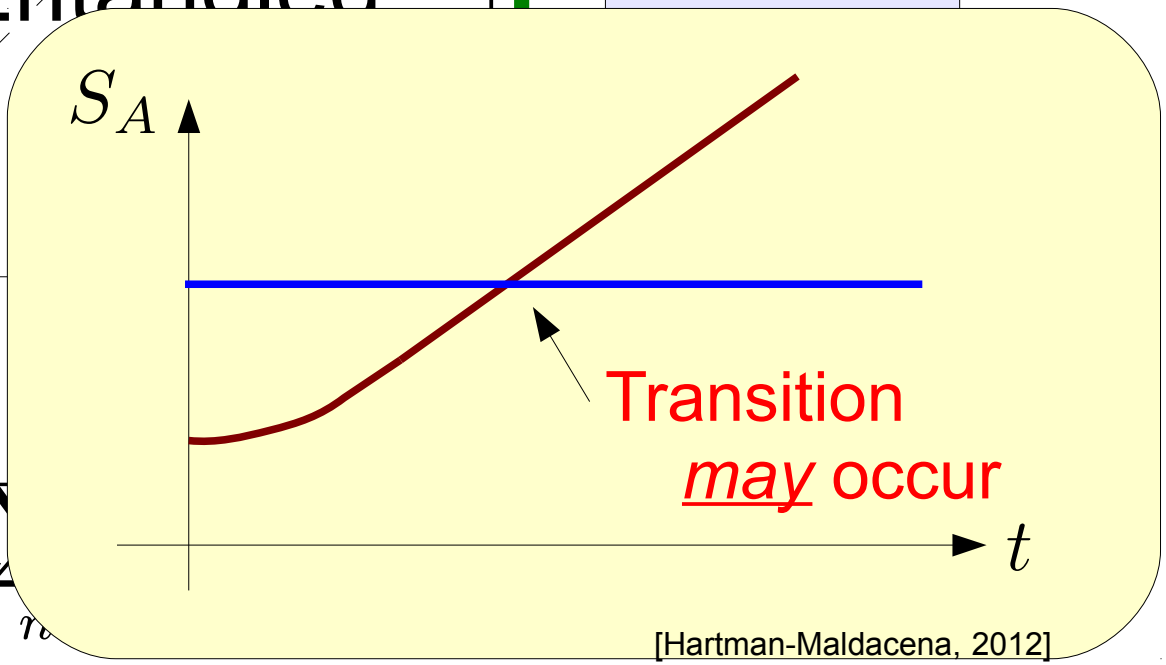
2. Entanglement between CFTs via Black Hole Interior

Entanglement between Two CFTs



$$\rho_L = \sum_n e^{-\beta E_n} |n\rangle_L \langle n|_L$$

$$|\Psi(t)\rangle = \sum_n$$



[Hartman-Maldacena, 2012]

3. Multiple Classes of Entanglement via Rotating Black Hole Interior

Yet Other Ways of Entanglement

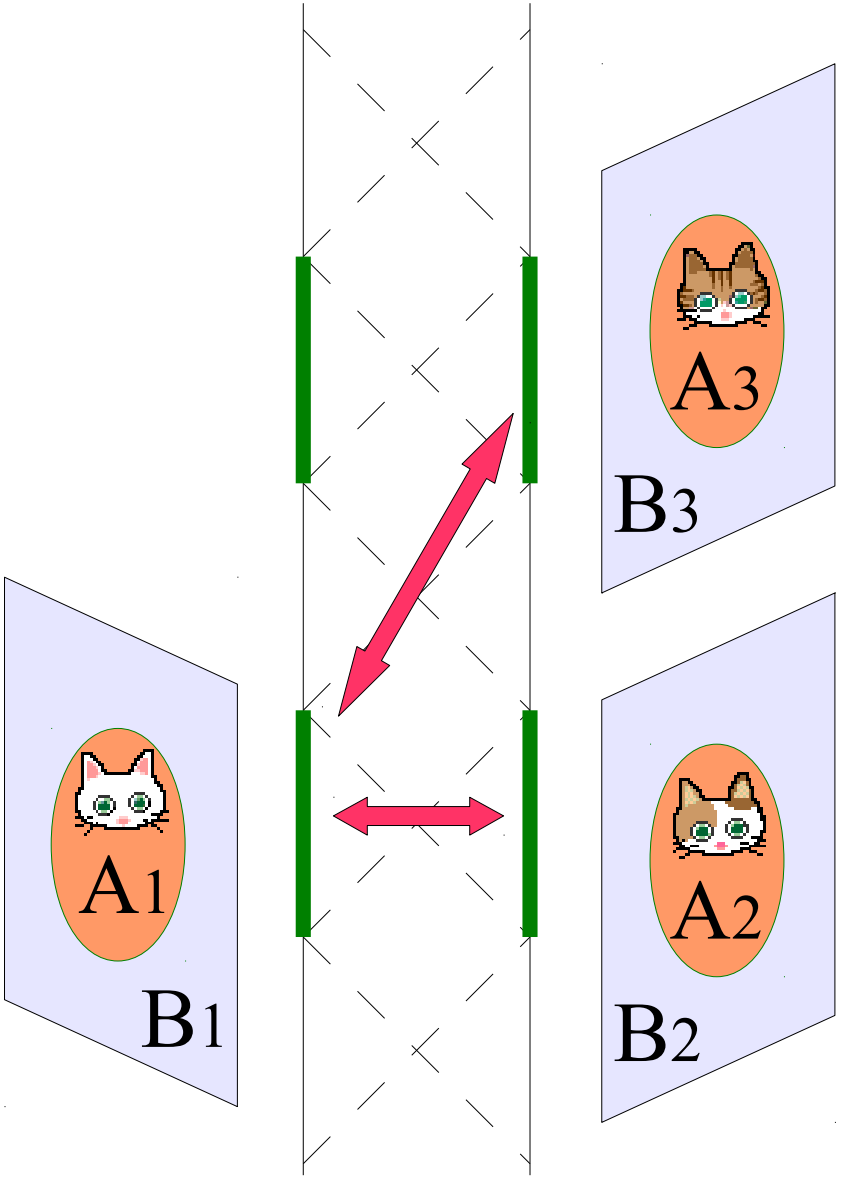
Rotating (or Charged) BH

→ many boundaries

New  -entanglement

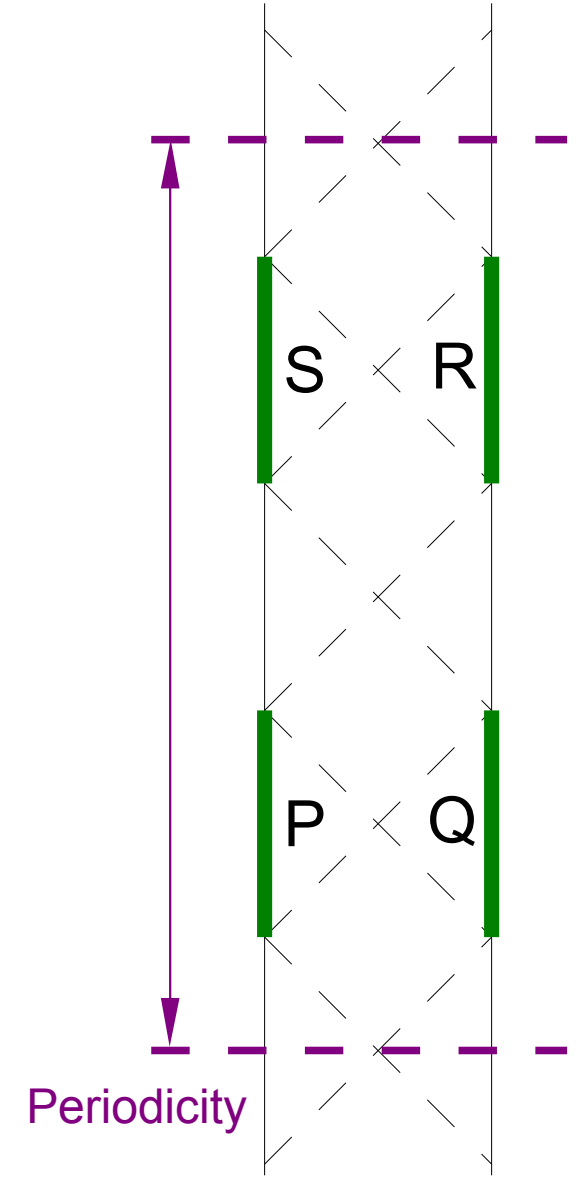
How different from

 -entanglement ?



Model: Extended Rotating BTZ

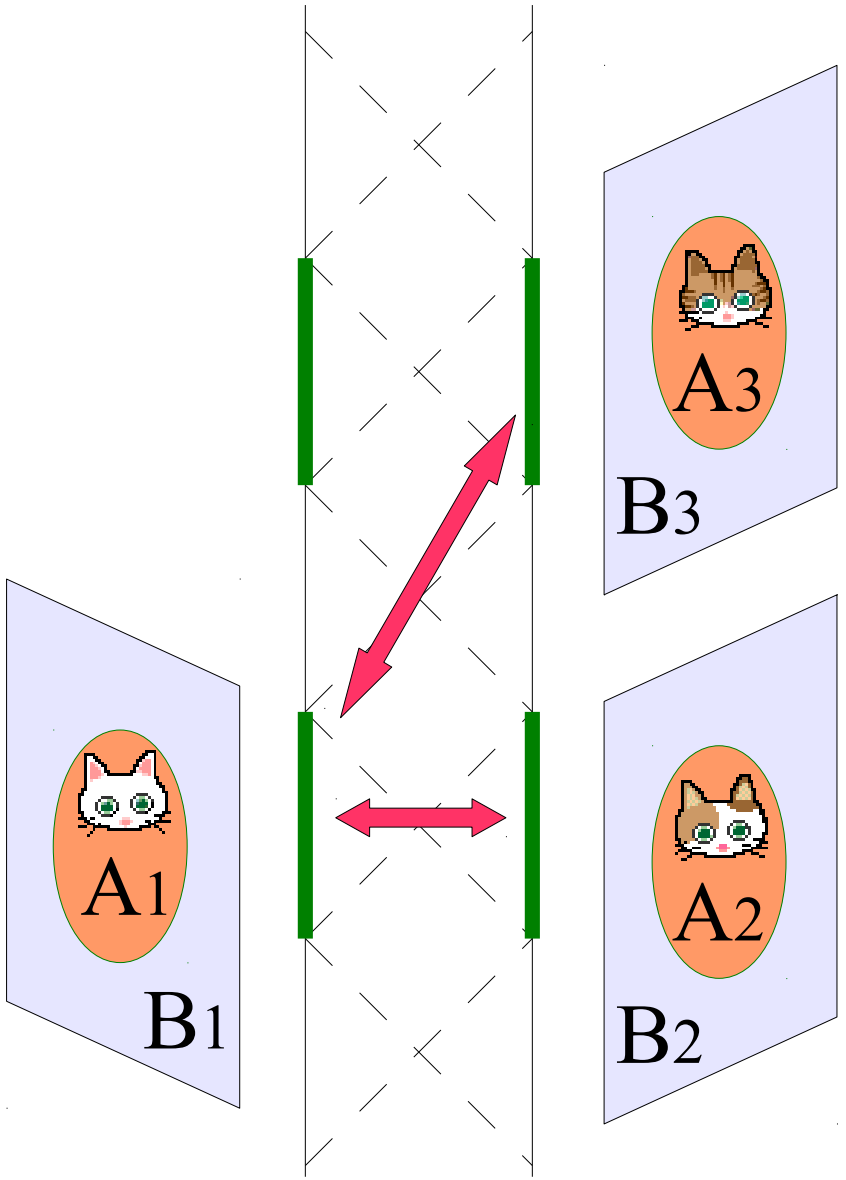
[Hemming, Keski-Vakkuri, Kraus, 2002]

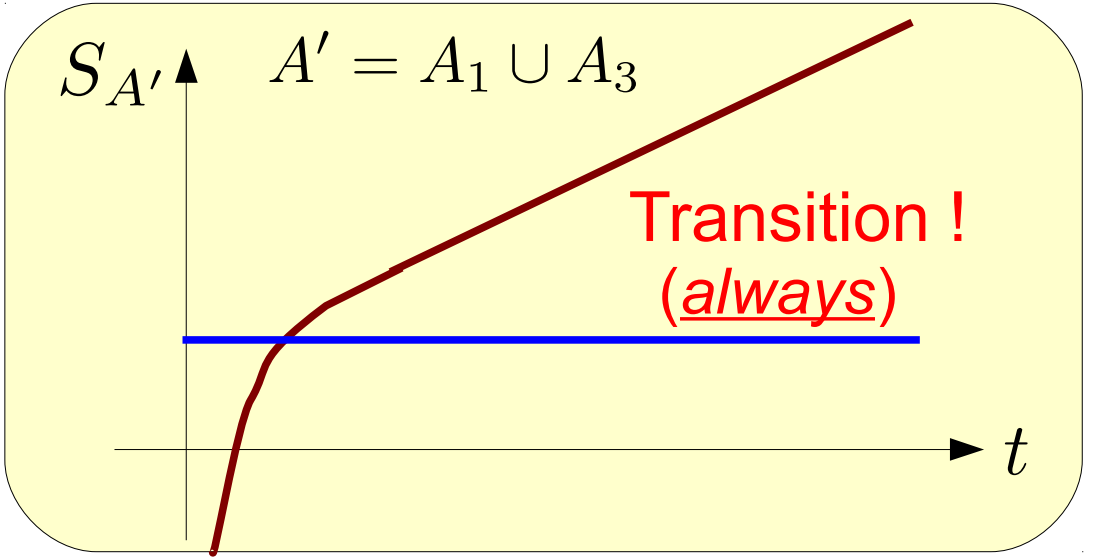


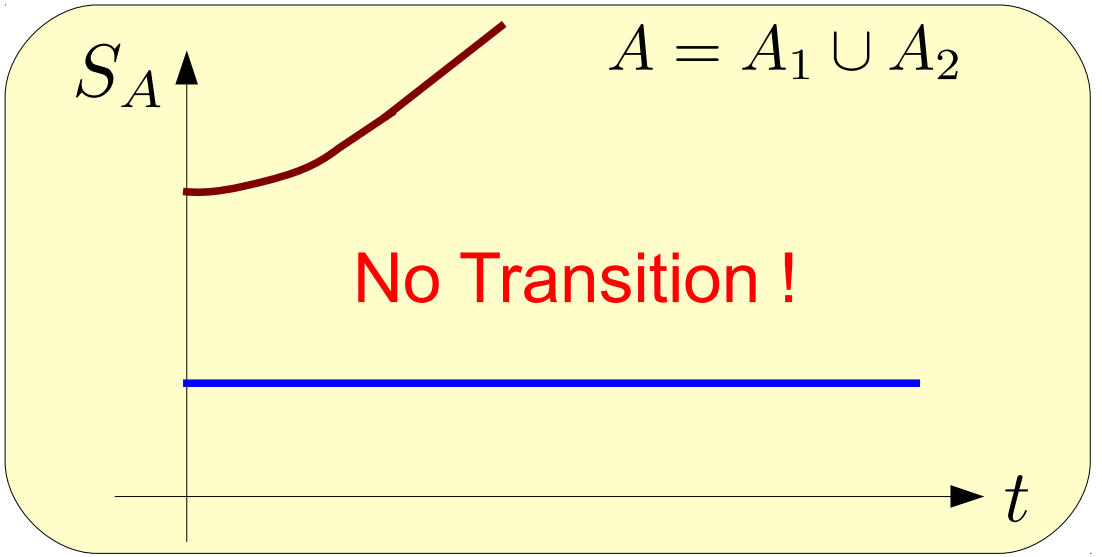
- 4 outside regions
- Locally AdS_3 everywhere
- Globally parameterized by hyperboloid embedding coordinate

Inter-boundary minimal geodesics by analytic continuation from P

Time Evolutions of Entanglement

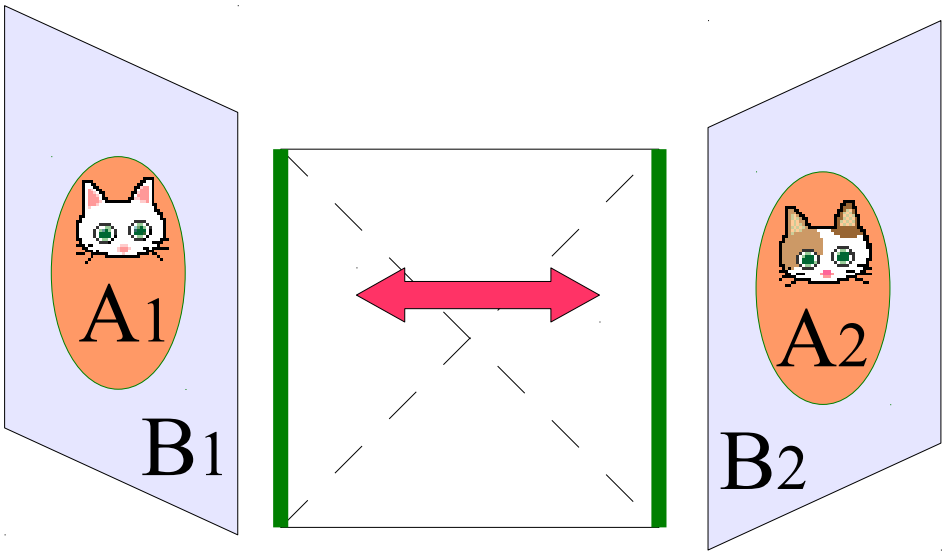


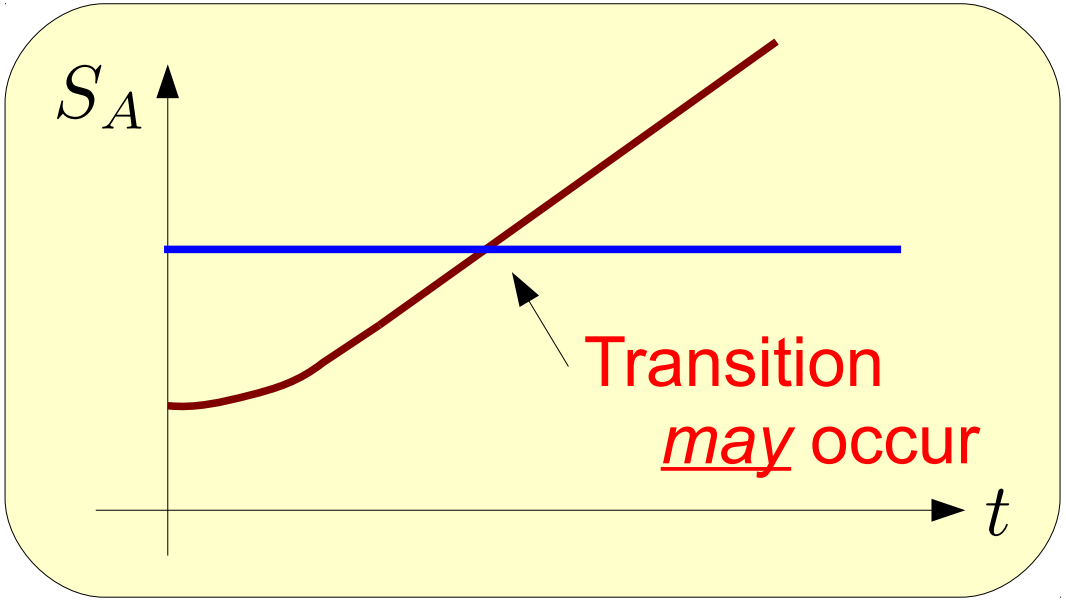




Rotating Black Hole (near-extremal)

Schwartzchild Case Again





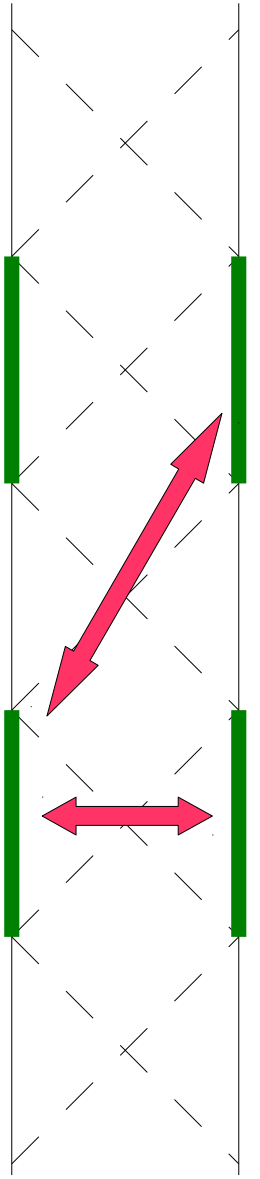
Discussions & Future work

•Our calc is AdS_3/CFT_2
→ how about higher dimensions?

• Two classes of "natural" ways of "maximal entanglement"
→ counterpart on CFT side?

• Instability around inner horizon
→ our calc reliable? Can EE detect it?

• Any implication for spacetime emergence out of entanglement?



図画等の出典・著作権

- 猫 

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- ミッフィー (c) Dick Bruna