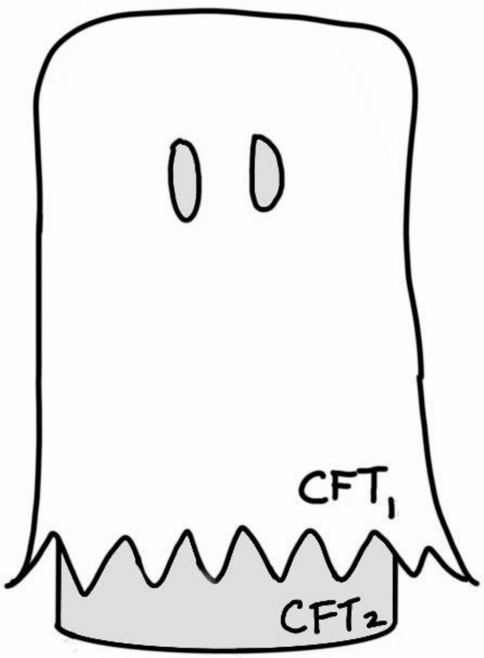
HOLO-WEEN



Mark Van Raamsdonk, U.B.C.

Toronto HEP Theory Seminar

based on work w. Petar Simidzija

2006.13943

MOTIVATION:

Deep connection between entanglement structure of holographic states + dual spacetime geometries.

How much info about dual spacetime is captured by "universal" properties of state?

matter fields?

internal space geometry?

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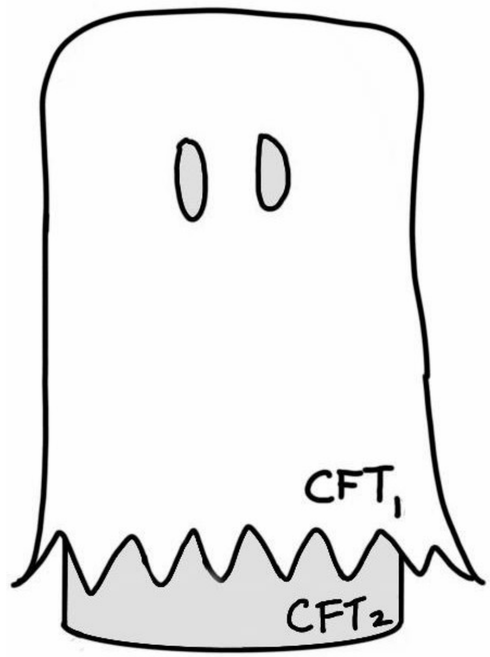
matter fields?

internal space geometry?

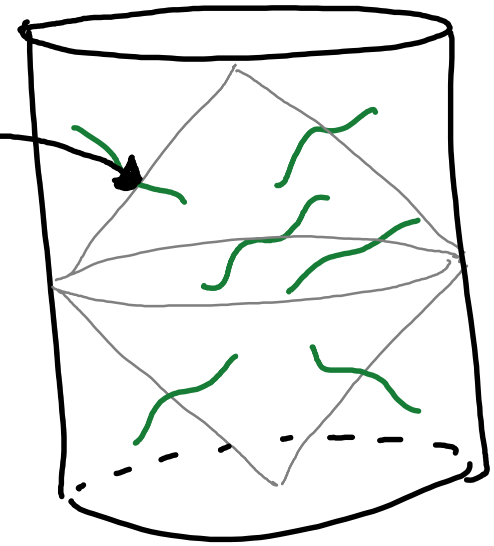
extreme possibility: precise microscopic d.o.f. + Hamiltonian unimportant

- Can a suitably chosen state of one holographic CFT faithfully encode spacetime dual to state of a completely different holographic CFT?

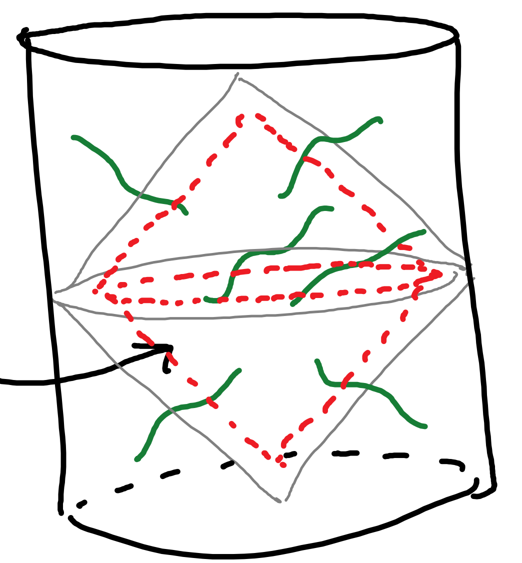


Can we "dress up" CFT$_2$ to look like a state of CFT$_1$?

$|\Psi\rangle^{t=0}_{CFT_1}$ dual to

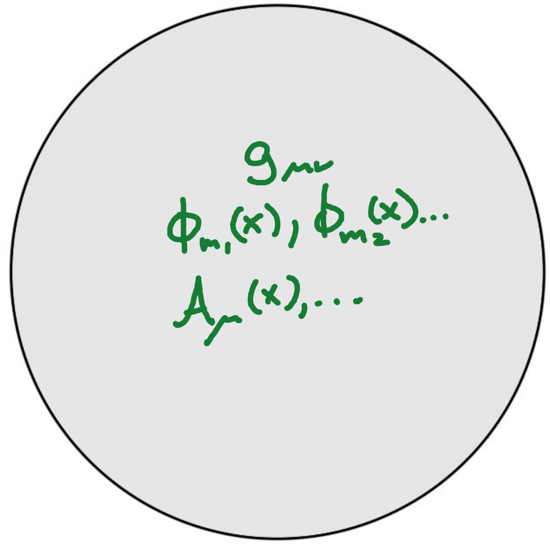


Can we find $|\Psi\rangle_{CFT_2}$ whose dual spacetime includes



obvious objection:

$$|\Psi\rangle_{CFT_1} \longrightarrow$$



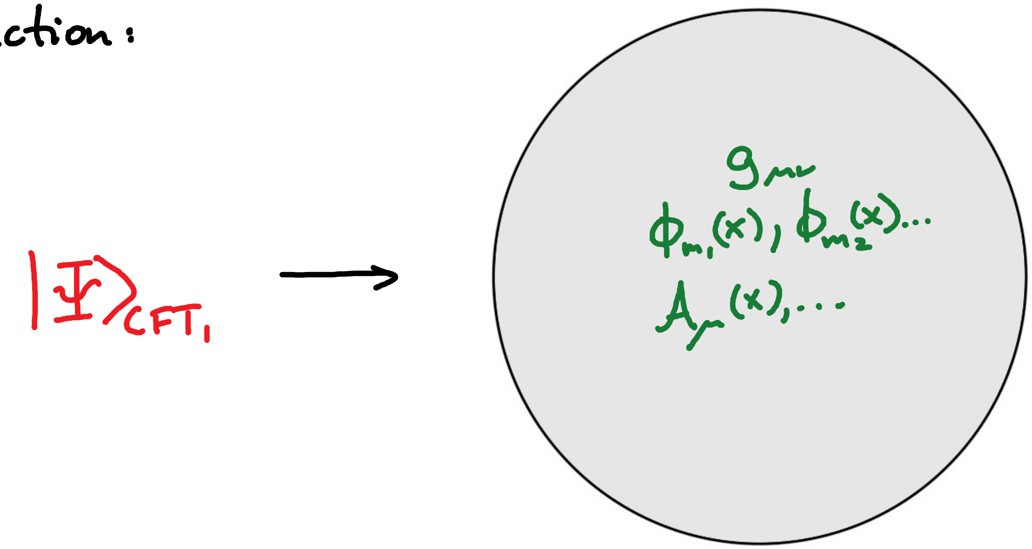
specific fields (incl. KK modes) associated w. specific CFT ops.

$$\phi_{m_1} \longleftrightarrow \mathcal{O}_{\Delta_1}$$

$$\phi_{m_2} \longleftrightarrow \mathcal{O}_{\Delta_2}$$

$$\vdots$$

asymptotic behavior of spacetime related to short-distance correlators of these operators obvious objection:



specific fields (incl. KK modes) associated w. specific CFT ops.

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$$\phi_{m_2} \longleftrightarrow \mathcal{O}_{\Delta_2}$$

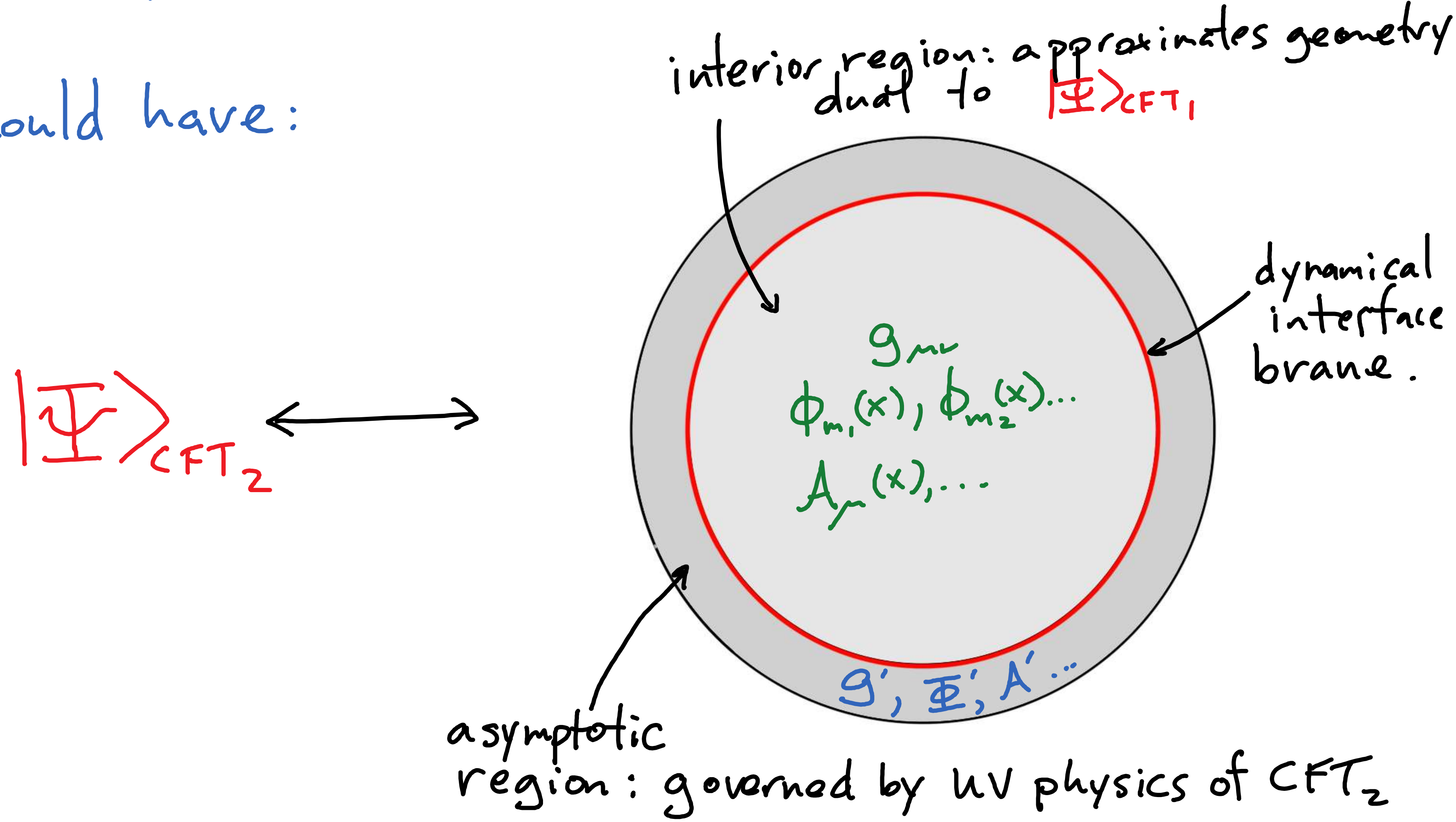
$$\vdots$$

asymptotic behavior of spacetime related to short-distance correlators of these operators

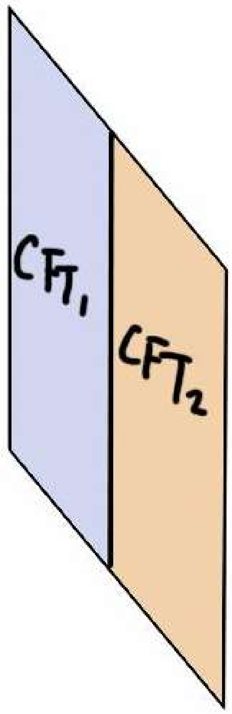
How can we hope to describe same spacetime using CFT_2 w. completely different operator spectrum?

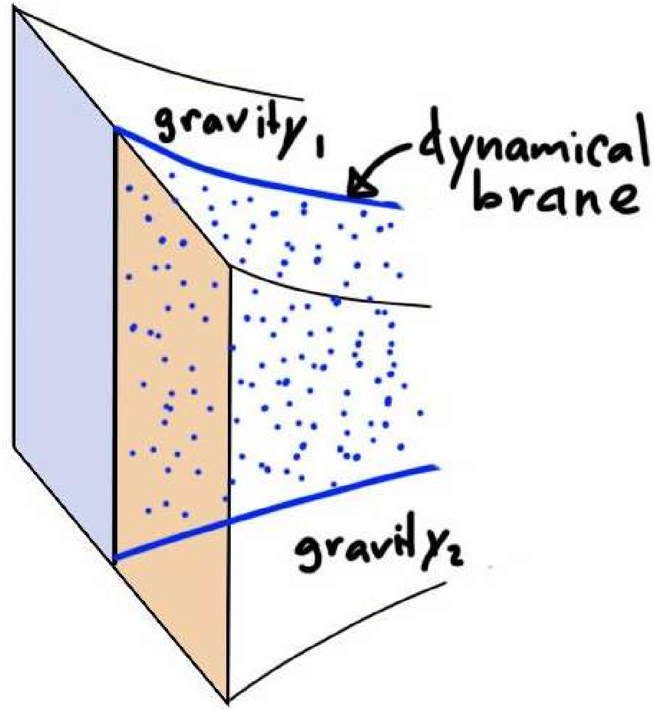
Key point: different semiclassical theories of gravity can be part of same non-perturbative theory.

Could have:



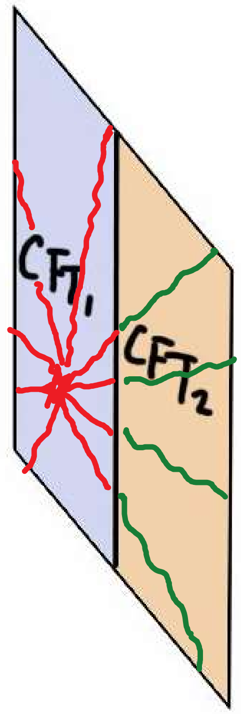
Which holographic CFTs / semiclassical gravity theories can be connected in this way?

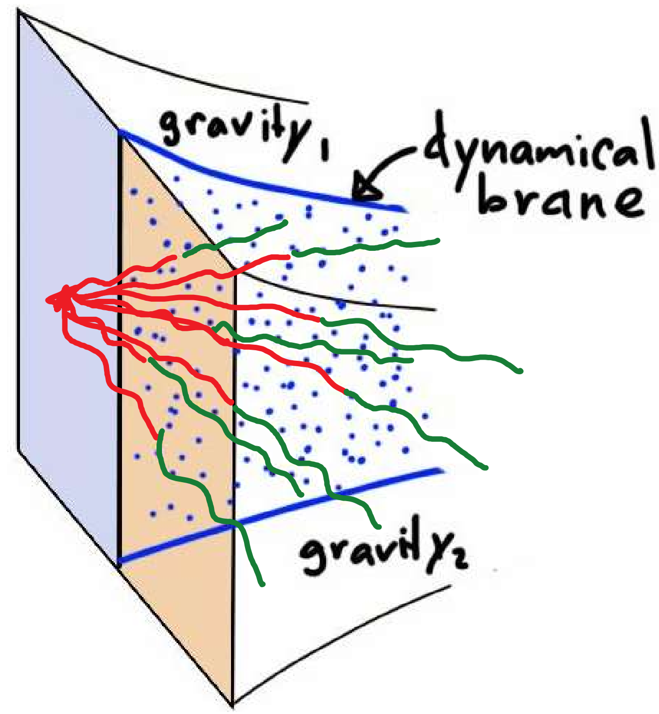




Suggestion:

Theories of gravity dual to different CFTs must be part of the same theory (with non-perturbative interface brane) provided the CFTs can be coupled non-trivially at an interface.





Suggestion:

Theories of gravity dual to different CFTs must be part of the same theory (with non-perturbative interface brane) provided the CFTs can be coupled non-trivially at an interface.

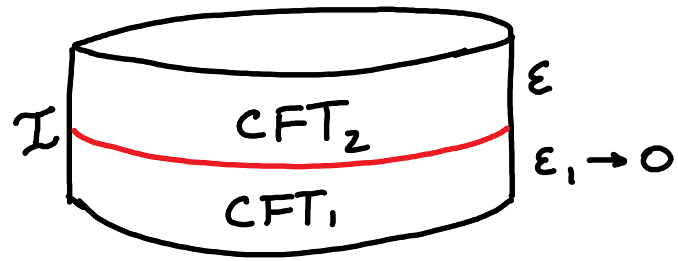
THIS TALK: assume CFT_1 and CFT_2 can be coupled in this way

→ Construct specific states of CFT_2 that approximate CFT_1 states

→ Explore gravity dual. Do we realize the bubble picture?

A map from $\mathcal{H}_{CFT_1}$ to $\mathcal{H}_{CFT_2}$

$$M_{\mathcal{I},\varepsilon} \equiv$$



$$= \lim_{\varepsilon_1 \to 0} e^{-\varepsilon H_2}\, \hat{Q}_{\mathcal{I}}\, e^{-\varepsilon_1 H_1}$$

Euclidean evolution w.r.t. H_{CFT_2} : results in finite energy state

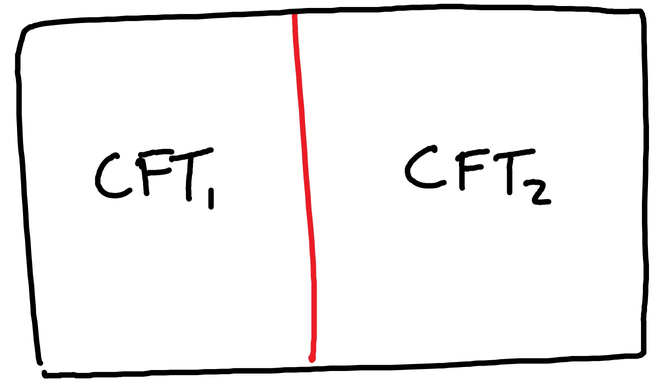
Quench operator (switches from H_{CFT_1} to H_{CFT_2})

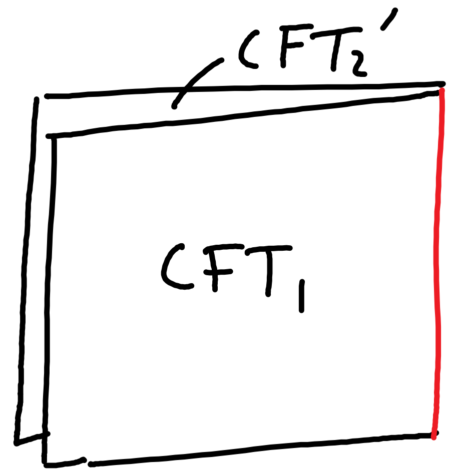
defined by choice of interface

Interface between CFT_1 and CFT_2

||

Boundary for $CFT_1 \otimes CFT_2'$





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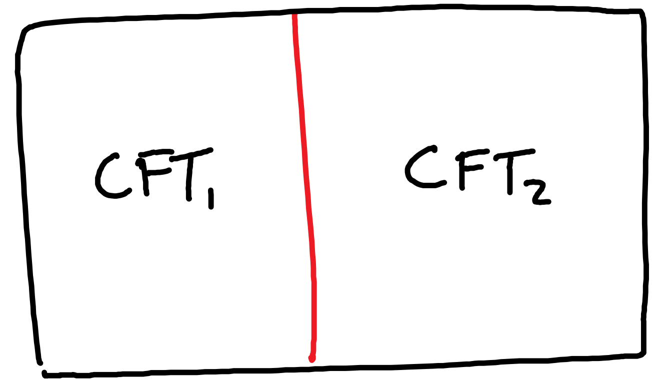
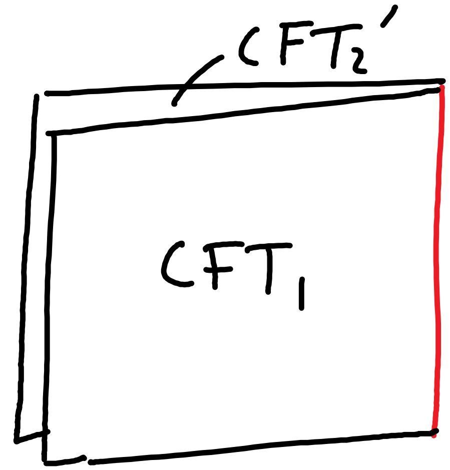
Usually, many possible choices (determined in principle by boundary bootstrap)

Interface between CFT_1 and CFT_2

||

Boundary for $\mathrm{CFT}_1 \otimes \mathrm{CFT}_2'$





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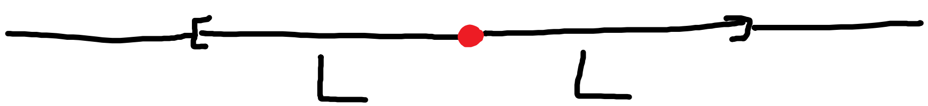
Usually, many possible choices (determined in principle by boundary bootstrap)

Useful parameter: interface entropy

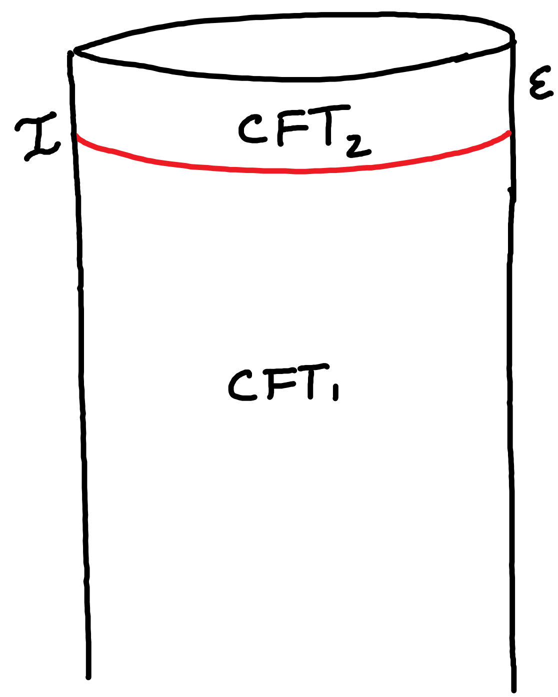


$$S = \frac{c_1 + c_2}{6} \log\left(\frac{2L}{\varepsilon}\right) + \log(g)$$

Focus on CFT_1 vacuum

Take: $|\Psi_2\rangle = M_{\mathcal{I},\varepsilon} |vac\rangle_{CFT_1}$

$=$



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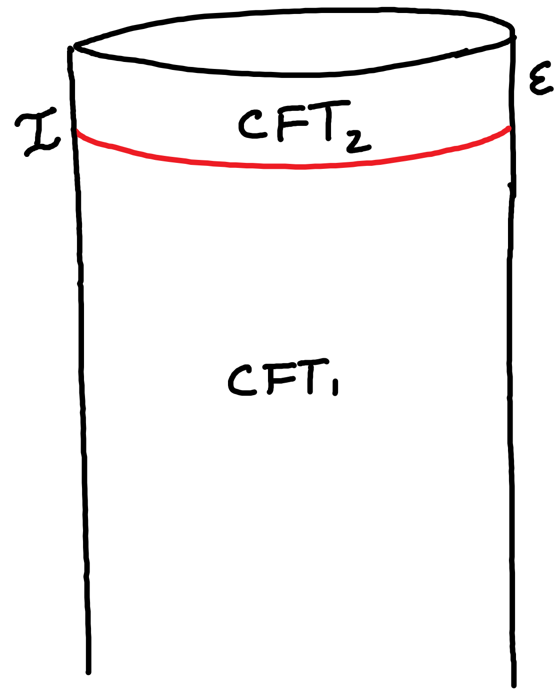
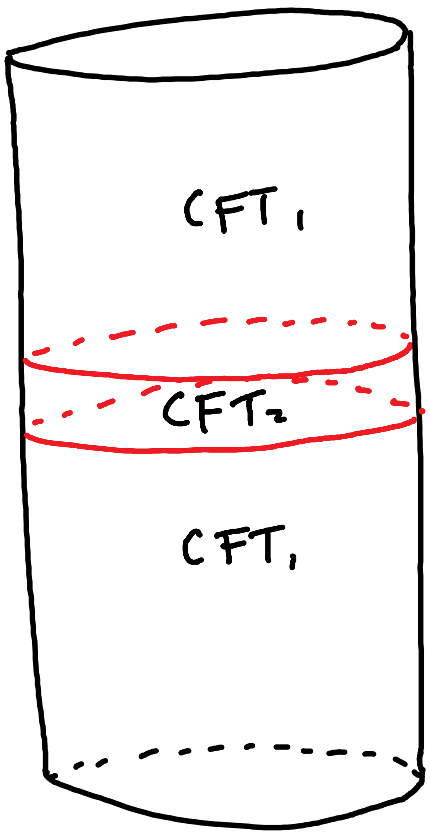
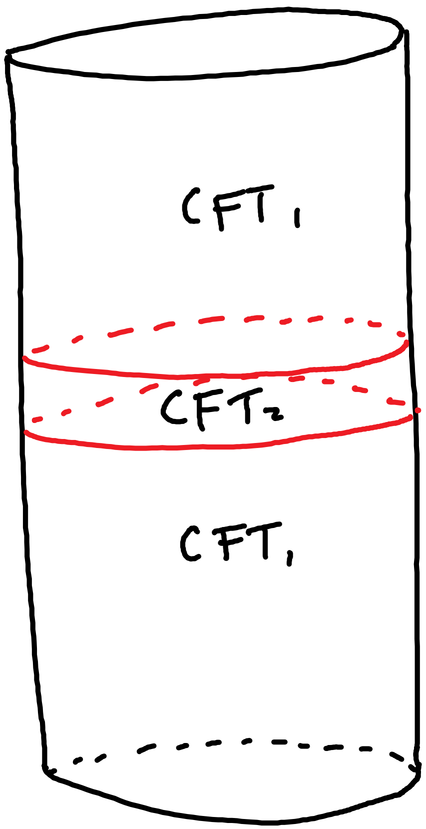
$=$ 

What is the dual geometry?

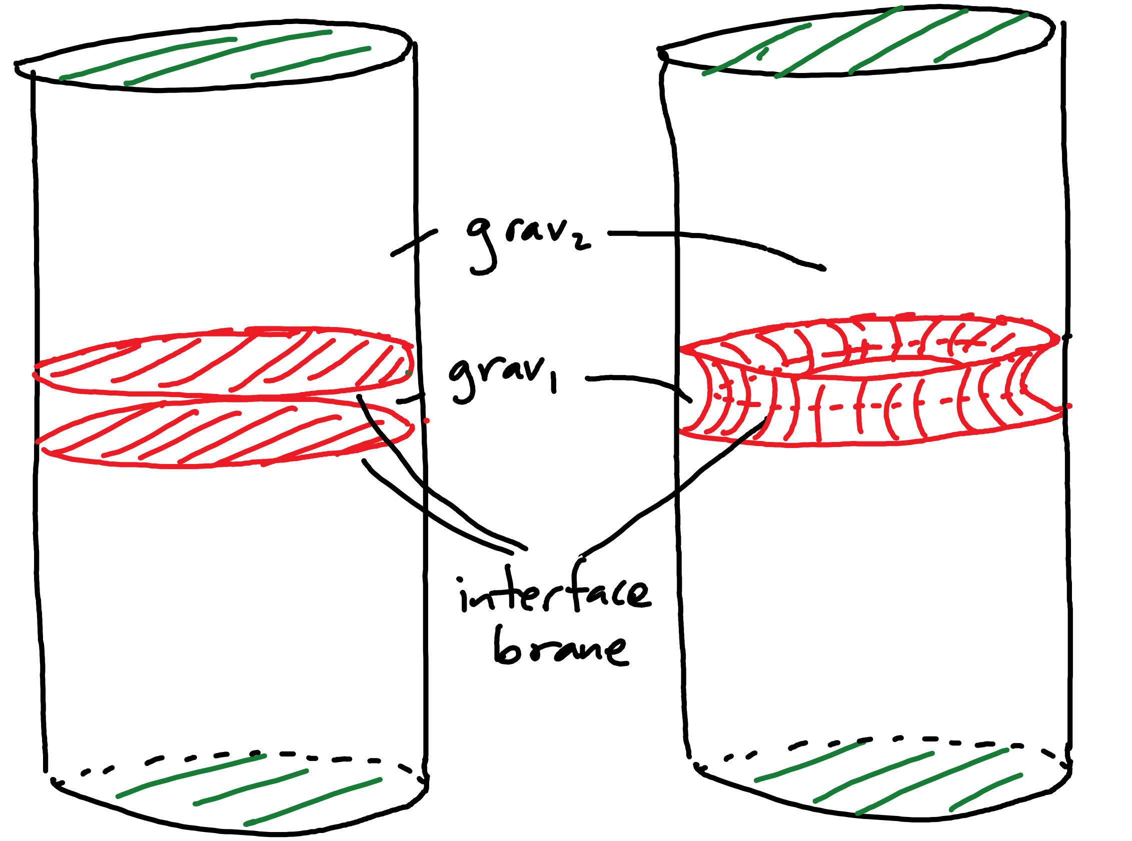
Path integral for $\langle \Psi_2 | \cdots | \Psi_2 \rangle$



Path integral for $\langle \Psi_2 | \cdots | \Psi_2 \rangle$

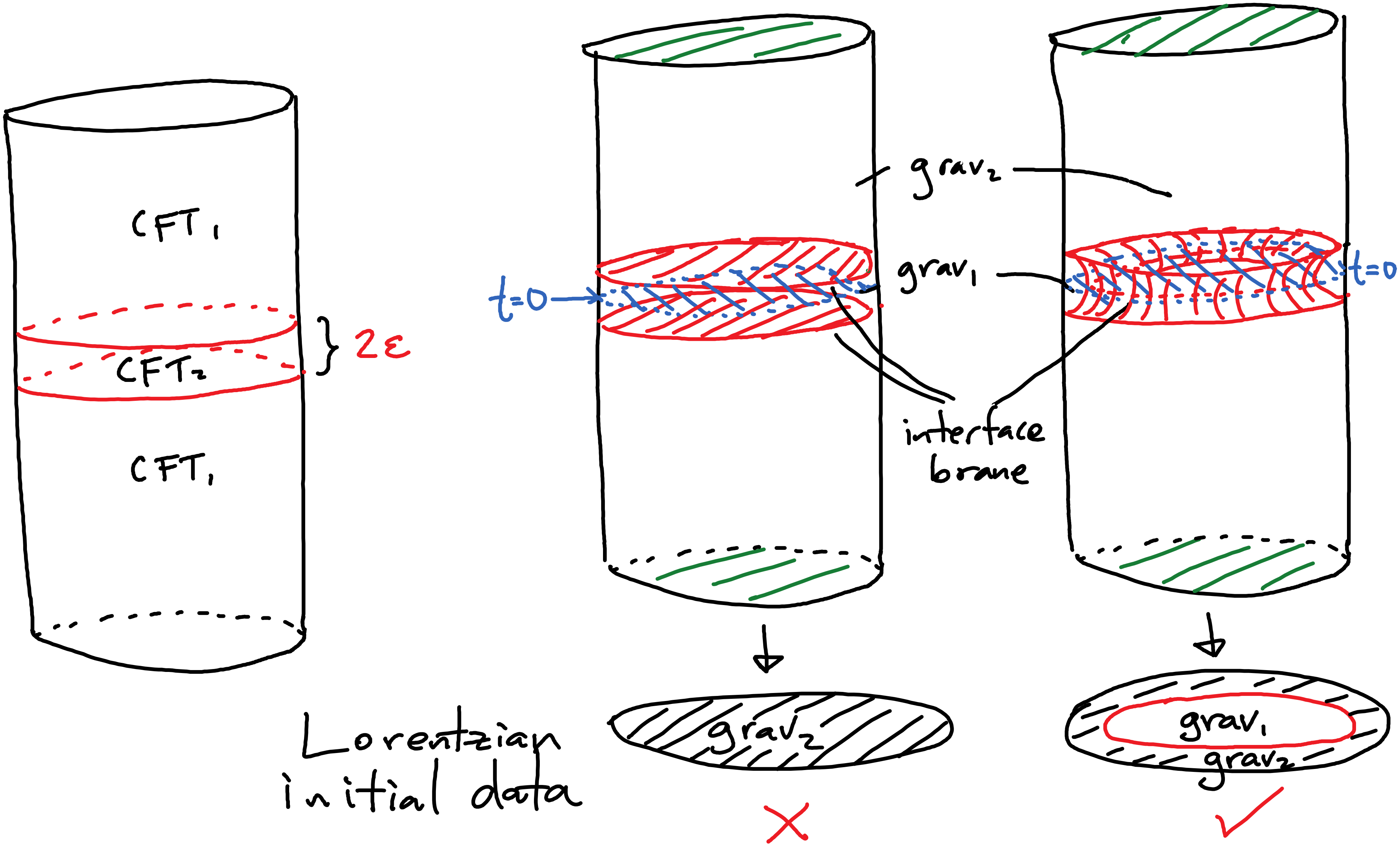


Possible dual Euclidean geometries:



Path integral for $\langle \Psi_2 | \cdots | \Psi_2 \rangle$

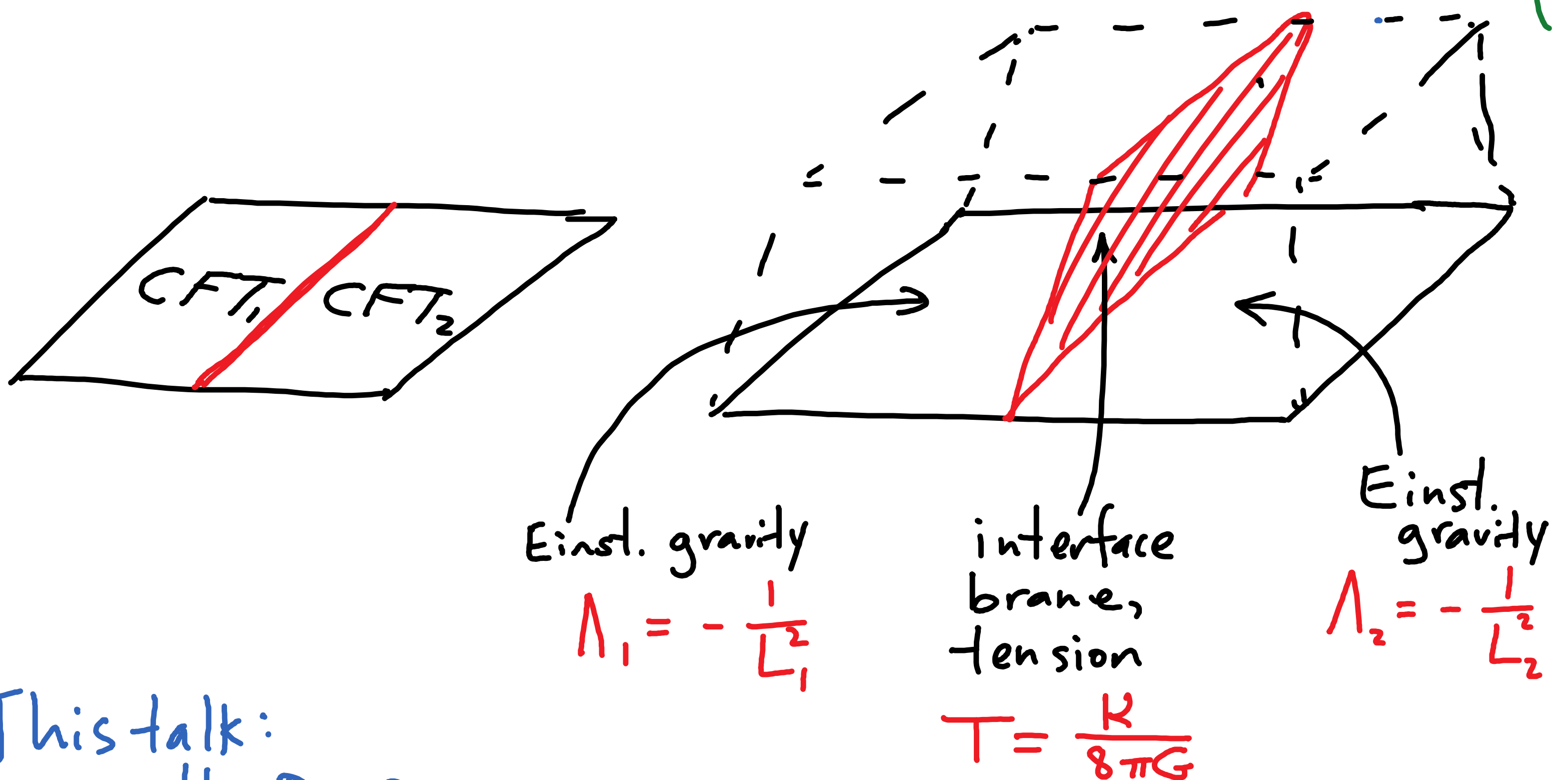
Possible dual Euclidean geometries:



Does the "bubble" geometry have lower action when $\varepsilon \to 0$?

Investigate in context of a simple model.

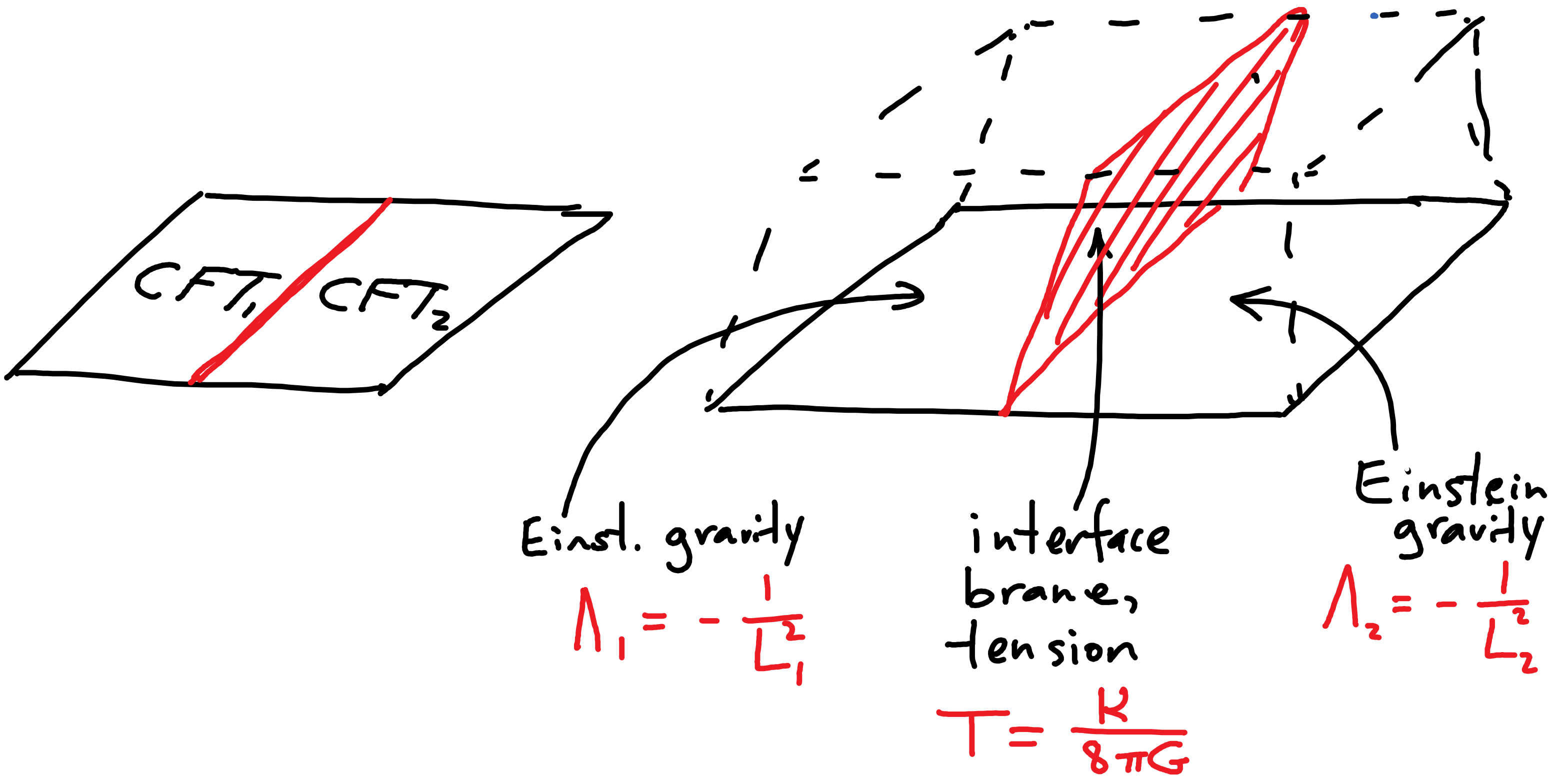
(similar to BCFT model of Karch/Randall, Takayanagi)



This talk: mostly $D=3$

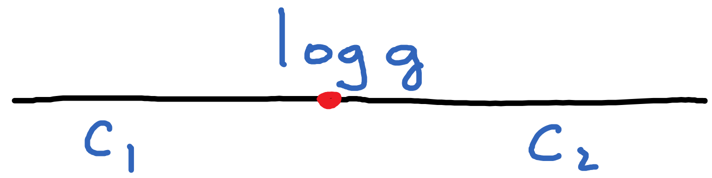
Does the "bubble" geometry have lower action when $\varepsilon \to 0$?

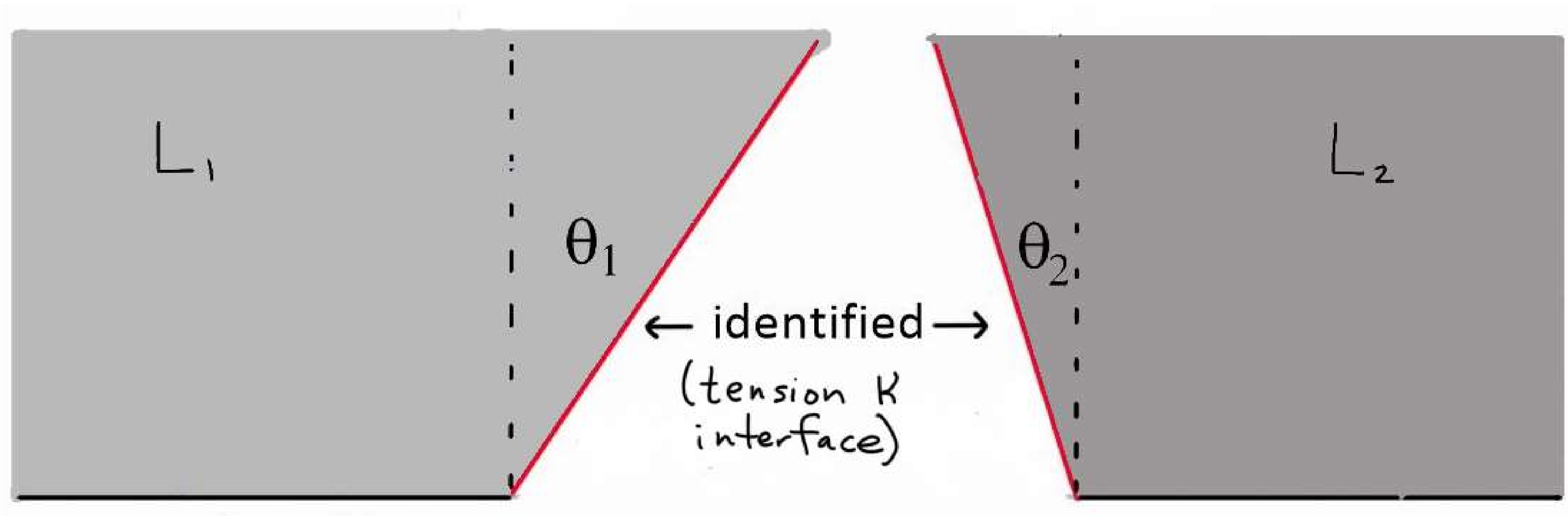
Investigate in context of a simple model.



Microscopically: interface brane could represent region of 10D geometry where internal space has transition

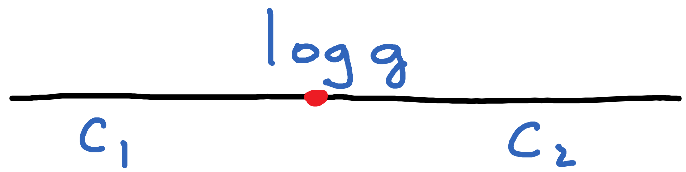
Single Interface



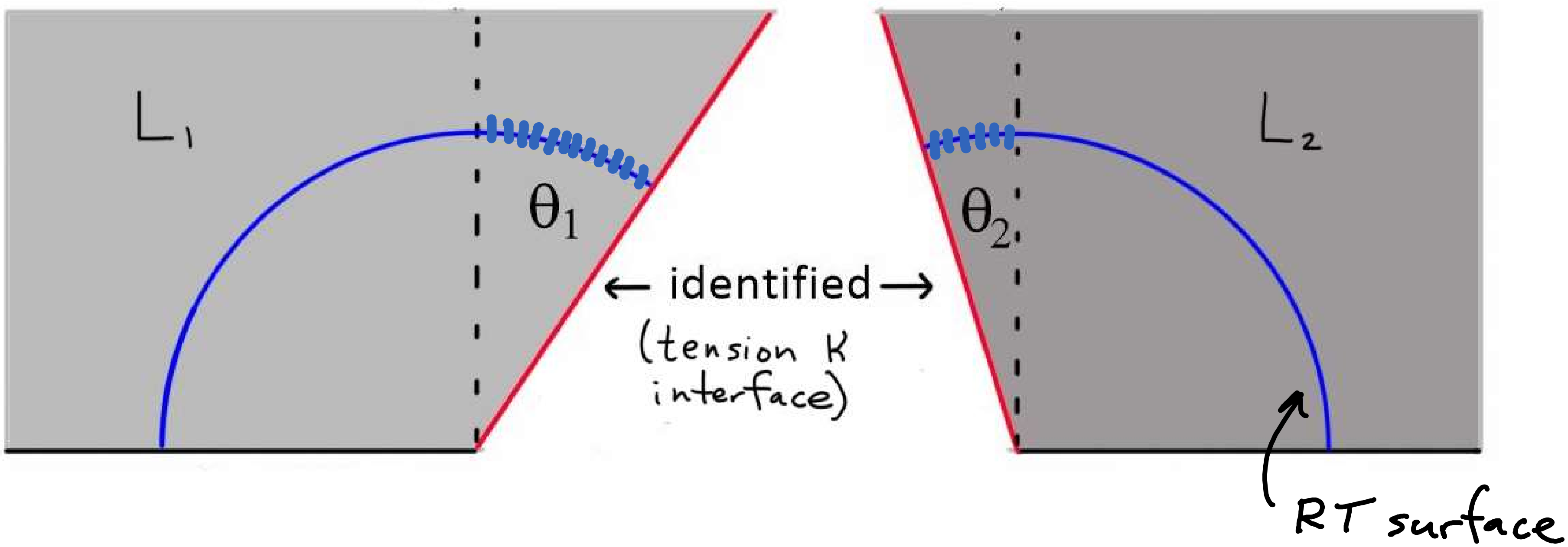


interface brane trajectory determined via junction conditions → fixed angle in Poincaré coords.

Single Interface

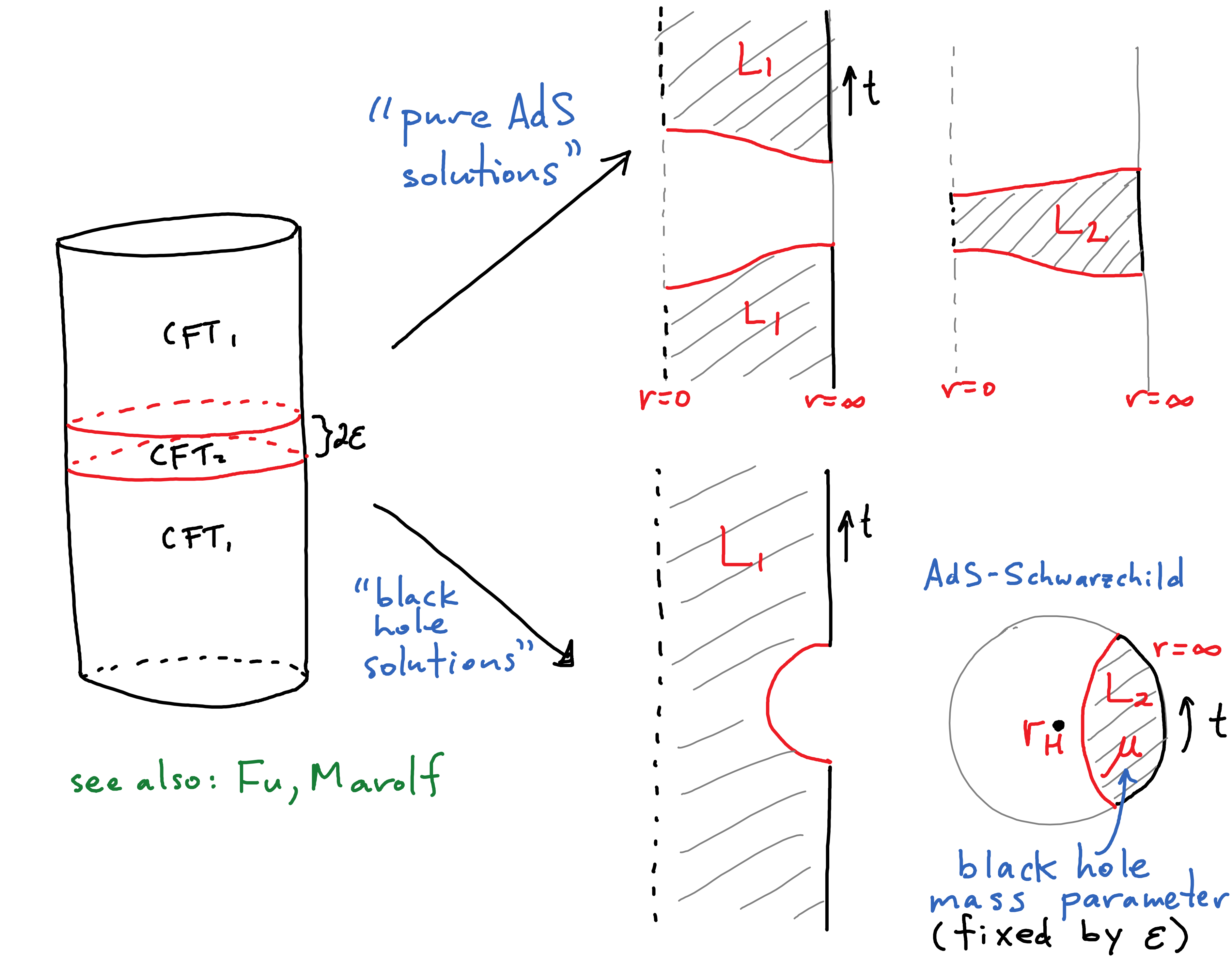


$$\log g = \frac{1}{4G}\left(\text{area of}\right.$$  $)$



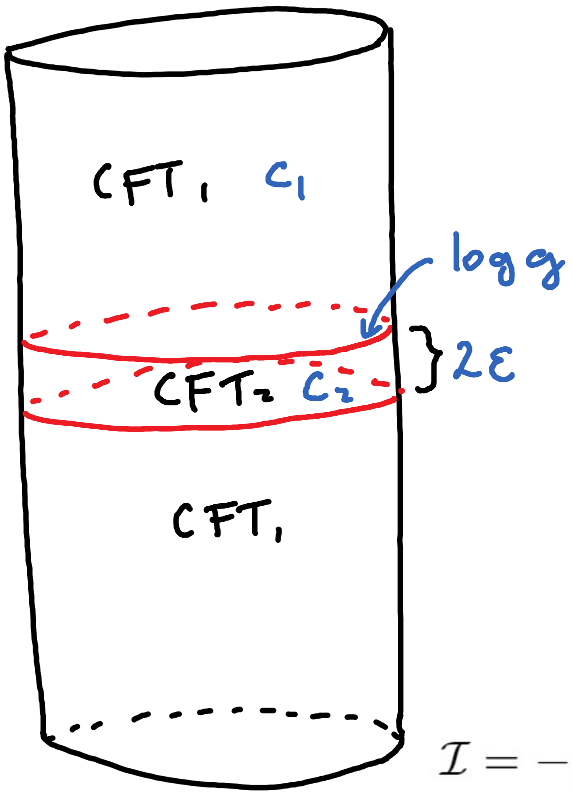
Brane tension related to interface entropy:

$$\kappa \in \left(\left|\frac{1}{L_1}-\frac{1}{L_2}\right|, \frac{1}{L_1}+\frac{1}{L_2}\right) \longleftrightarrow \log(g) \in (-\infty, \infty)$$



CFT1
CFT2
CFT1
}2ε
"pure AdS solutions"
L1
t
L1
r=0
r=∞
L2
r=0
r=∞
"black hole solutions"
L1
t
AdS-Schwarzchild
r=∞
L2
rH
μ
t
black hole mass parameter
(fixed by ε)
see also: Fu, Marolf

For CFT parameters $c_1, c_2, \log g, \varepsilon$:



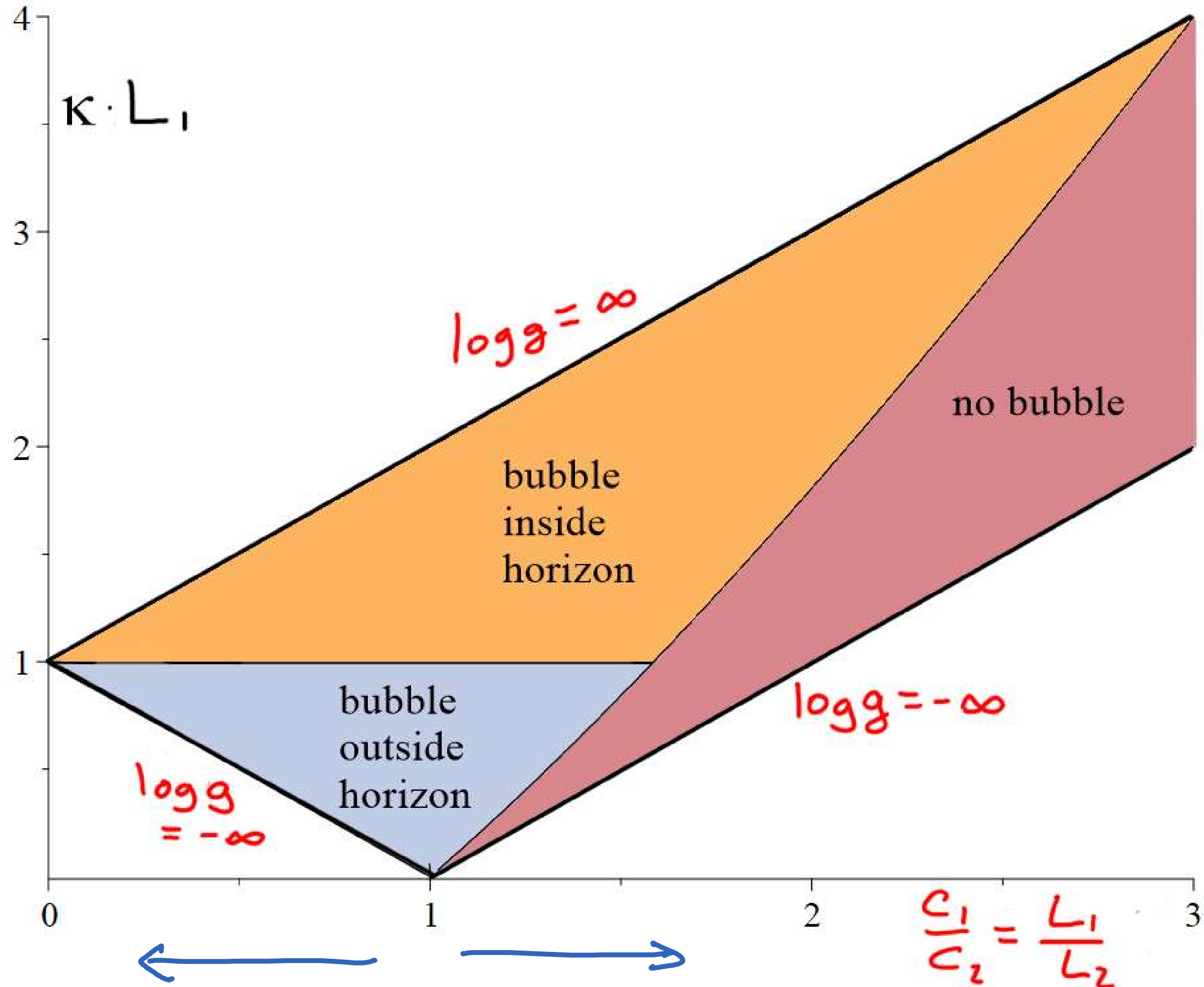
- find allowed solutions with gravity parameters $\frac{L_i}{G} = \frac{2}{3} c_i$, $\kappa(\log g)$

$$\varepsilon_{grav}(\mu) = \varepsilon_{CFT}$$

- compare actions to find least action solution

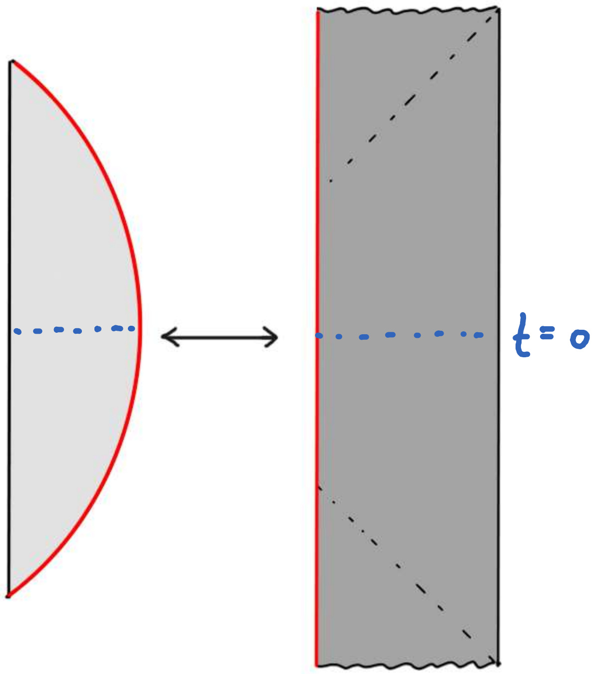
$$\mathcal{I} = -\frac{1}{16\pi G_D}\left[\int_{\mathcal{M}_1} \mathrm{d}^D x\,\sqrt{g_1}\,(R_1 - 2\Lambda_1) + \int_{\mathcal{M}_2} \mathrm{d}^D x\,\sqrt{g_2}\,(R_2 - 2\Lambda_2) + 2\int_{\mathcal{S}} \mathrm{d}^{D-1} y\,\sqrt{h}(K_1 - K_2) - 2(D-2)\int_{\mathcal{S}} \mathrm{d}^{D-1} y\,\sqrt{h}\kappa\right],$$

Results for small ε:



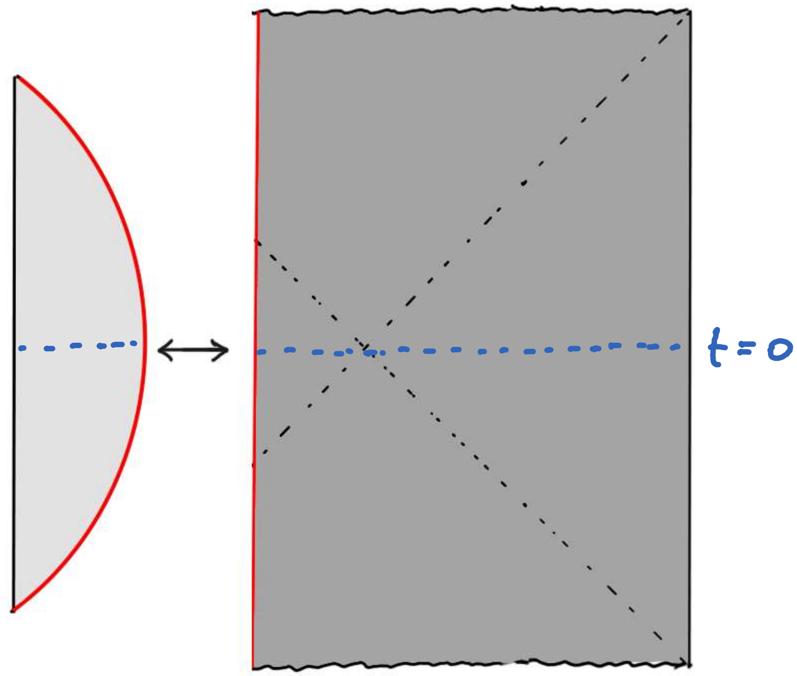
$\leftarrow$ CFT₂ has more d.o.f. $\qquad$ CFT₂ has less d.o.f. $\rightarrow$

Lorentzian Solutions:



bubble outside horizon:

$c_2 > \frac{1}{3} c_1$

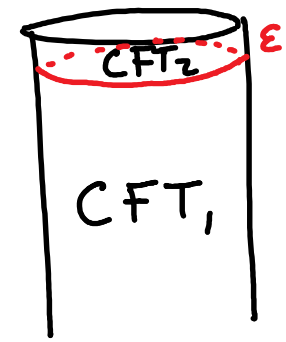


bubble behind horizon:

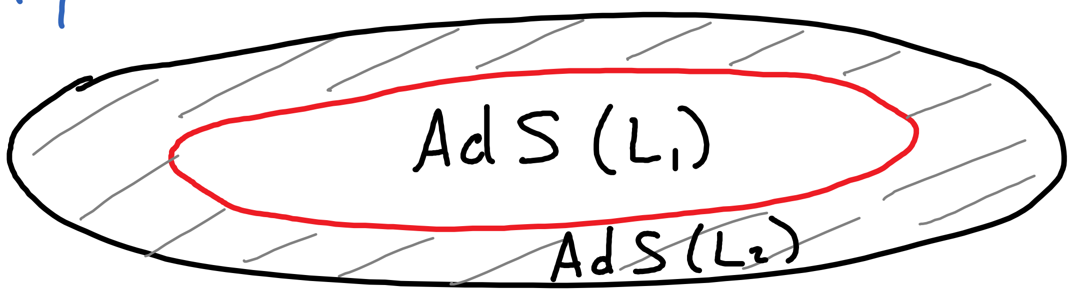
$c_2 > \frac{1}{3} c_1$, large enough $k / \log g$

Summary so far:

State $|\Psi\rangle_{CFT_2} = e^{-\varepsilon H_2} Q_I |vac\rangle_{CFT_1}$



faithfully encodes a bubble of geometry dual to CFT_1 vacuum:



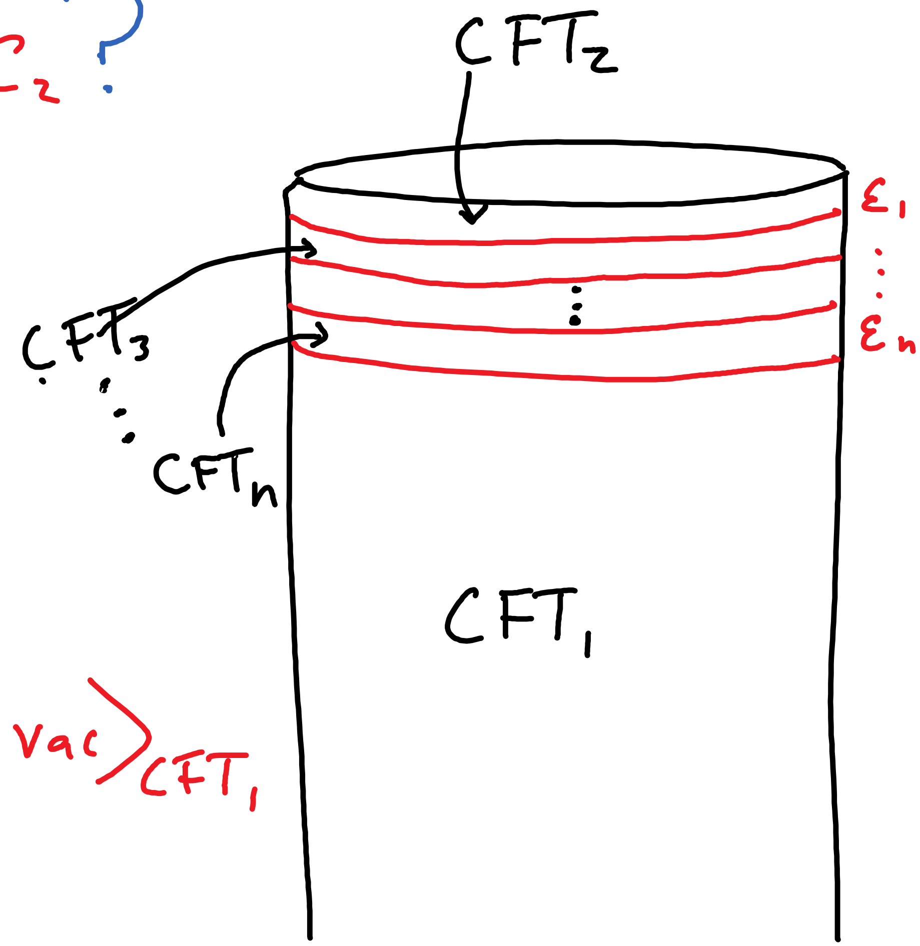
for small ε if $c_2 > c_1$

or $\frac{1}{3}c_1 < c_2 < c_1$ and $\log g$ large enough.

What about smaller c_2?

Try:

$$|\Psi_2\rangle_{CFT_2} = e^{-\epsilon H_2} Q_{I_{23}} \cdots e^{-\epsilon H_n} Q_{I_{n1}} |vac\rangle_{CFT_1}$$

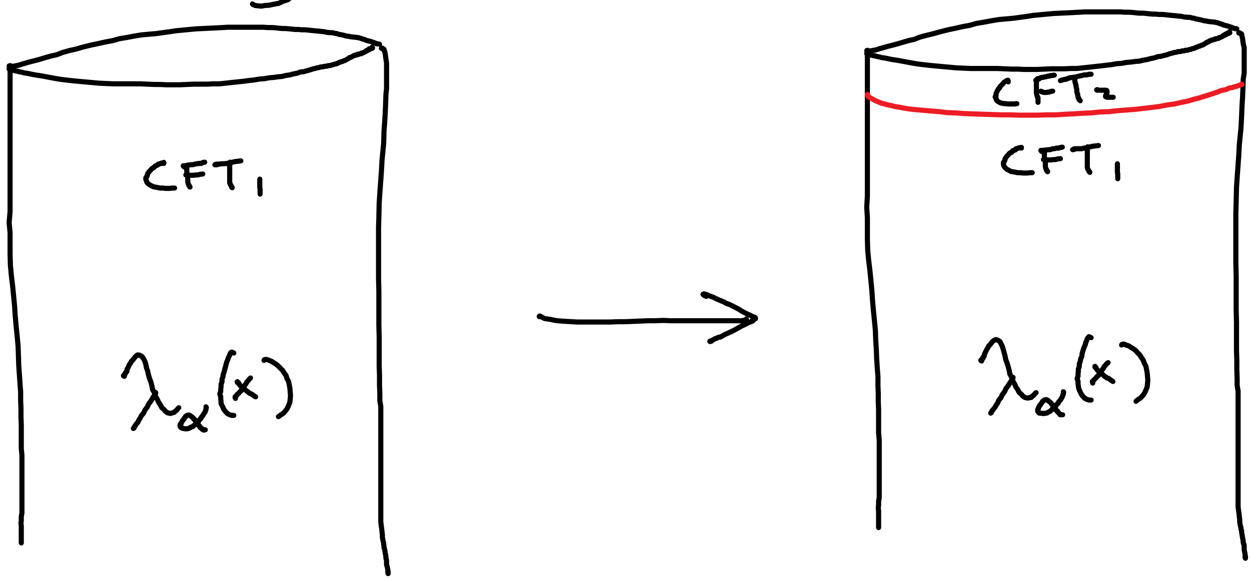


Preliminary results: for small $\left(\frac{\Delta c}{c}\right)_i$, small κ_i, nested bubble solution is preferred!

In the context of the model:

Any CFT can encode spacetime dual to vacuum of any other CFT

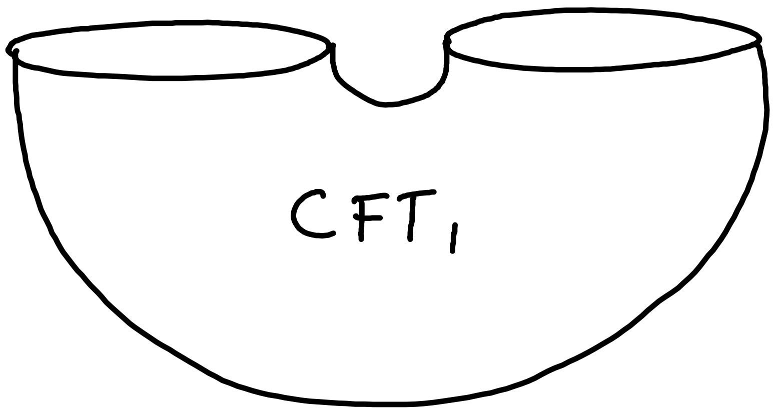
Approximating other states:

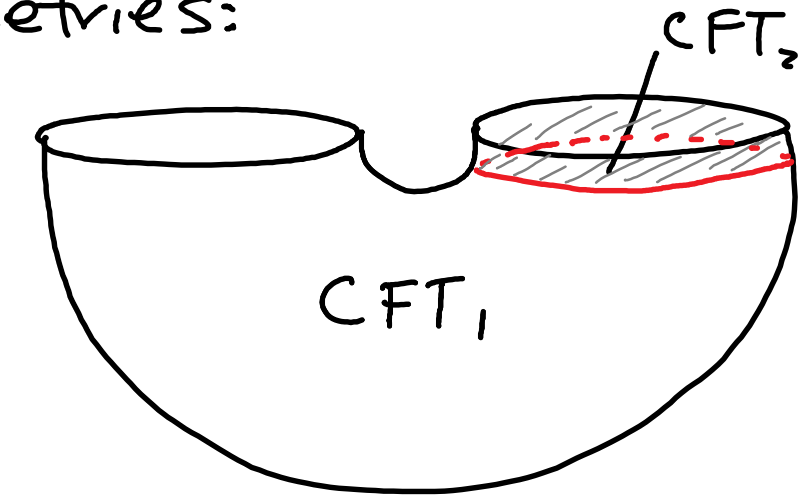


Add sources $\int \lambda_\alpha(x) \mathcal{O}_\alpha(x)$ to Euclidean action in path integral to get CFT$_1$ states dual to very general perturbations of AdS.

Same mapping should give CFT$_2$ state approximating this geometry (at least perturbatively)

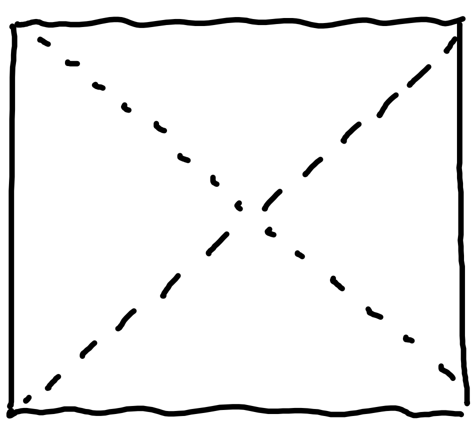
Approximating black hole geometries:

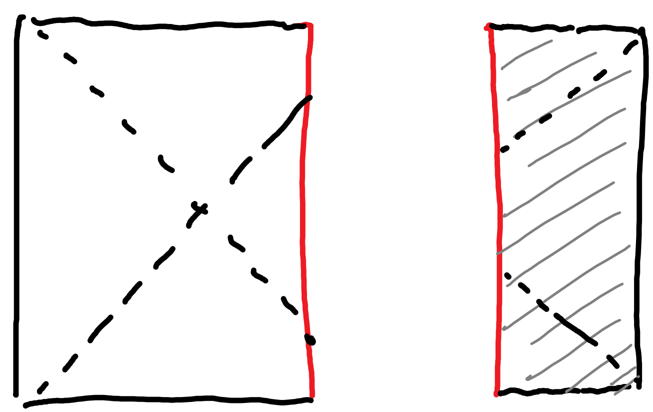




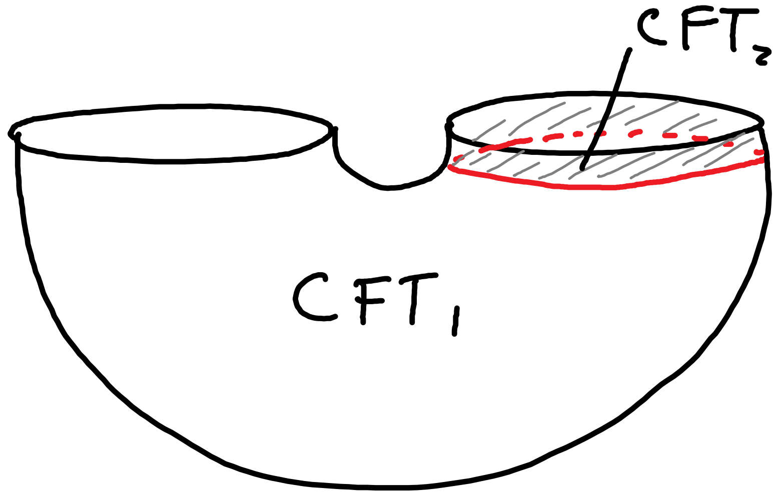
$|\Psi_{TFD}\rangle_{CFT_1 \otimes CFT_1}$

$\mathbb{1}^L \otimes M^R_{I,\epsilon} |\Psi_{TFD}\rangle \in \mathcal{H}_{CFT_1} \otimes \mathcal{H}_{CFT_2}$





CFT_2^R encoded behind-the-horizon physics of B.H. dual to CFT_1^L



Entangled states of
CFT1 + CFT2

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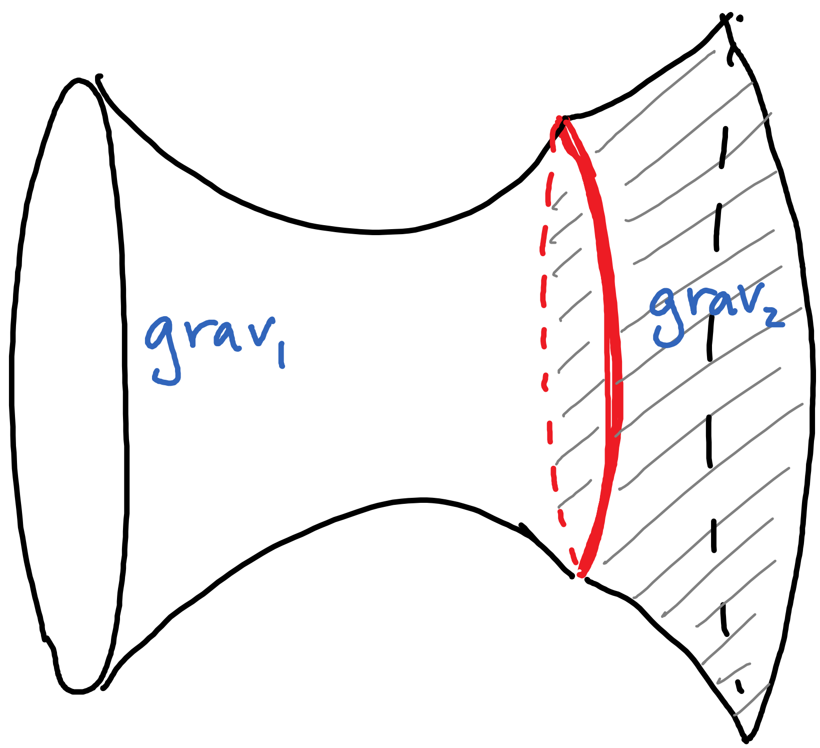
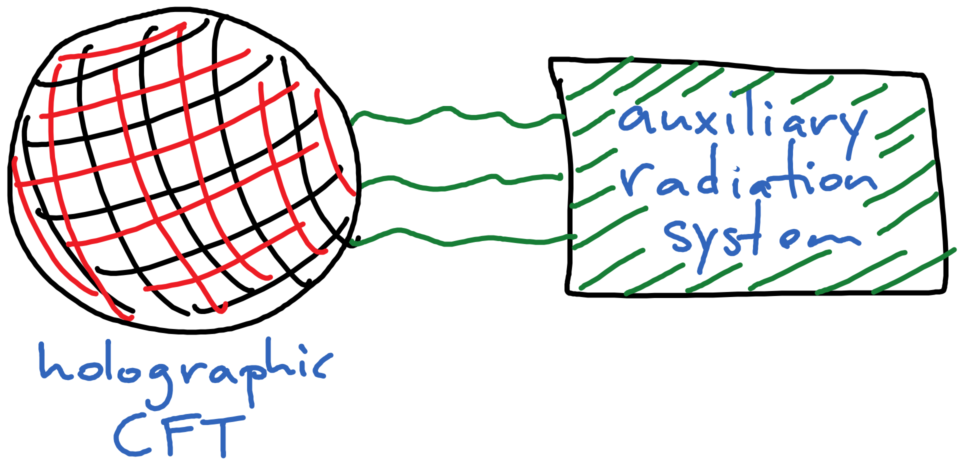


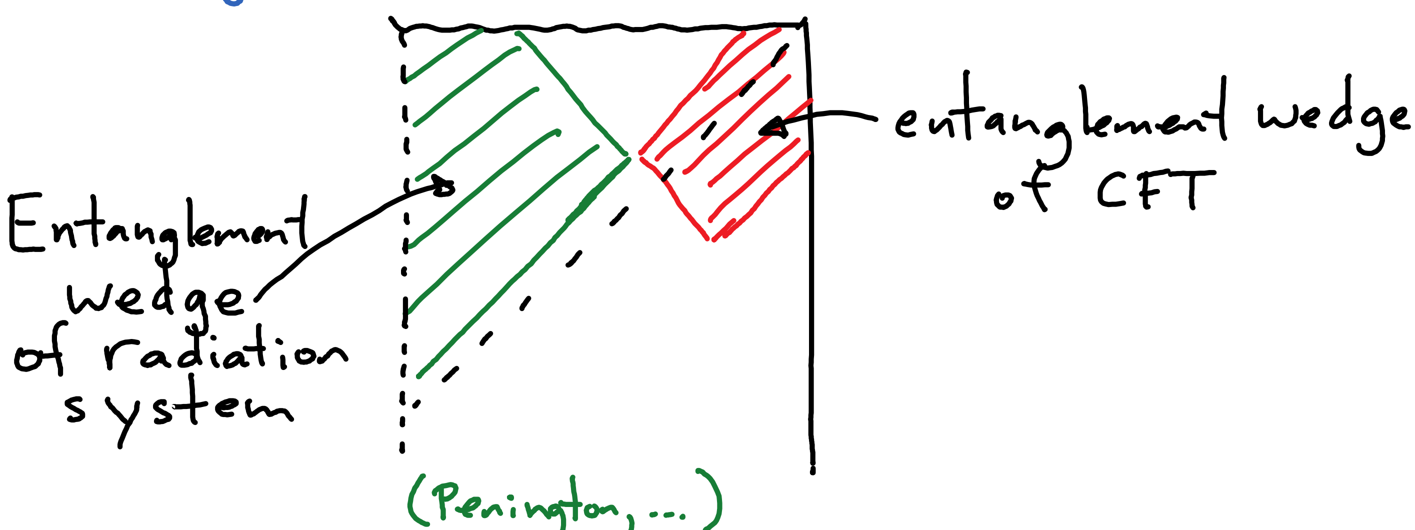
wormhole connecting asymptotic regions described by different low-energy gravity theories

Auxiliary radiation systems can encode late-time black hole interiors.

- Maldacena-Susskind
  - MVR
  - Penington
- Almheiri, Engelhardt, Marolf, Maxfield
- Almheiri, Mahajan, Maldacena, Zhao

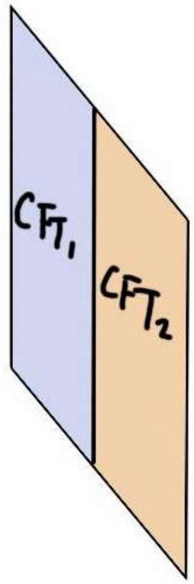


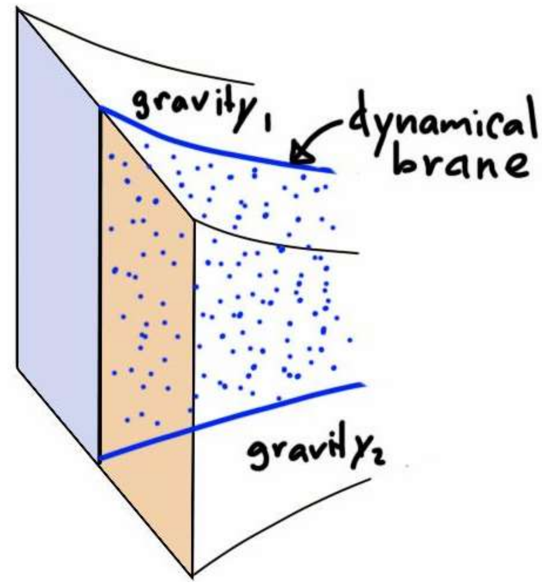
After Page time:



SUMMARY

we have suggested:

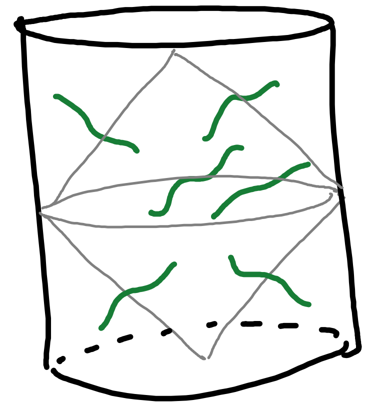




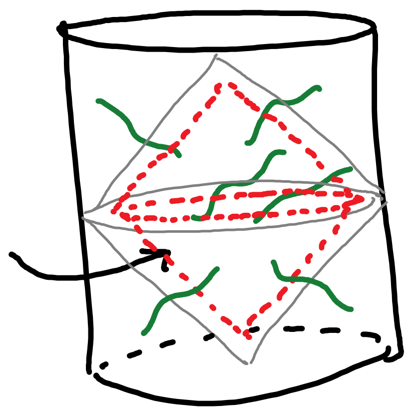
① Theories of gravity dual to CFTs that can be coupled non-trivially at an interface are part of same non-perturbative theory.

different theories ⟷ different equivalence classes of CFTs

Is there more than one class?

② Given $|\Psi\rangle_{CFT_1}$ dual to  .

For CFT_2 in same class, can find $|\Psi\rangle_{CFT_2}$

dual to spacetime containing  .

e.g. $|\Psi\rangle_{CFT_2} = e^{-\varepsilon H_2} Q_I |\Psi\rangle_{CFT_1}$

Consistent with the idea that:

holographic CFTs ⟷ allowed asymptotically AdS behaviors for quantum gravity

but:

quantum gravity ←·····?·····→ universal physics of quantum systems e.g. entanglement structure + dynamics

THANKS!

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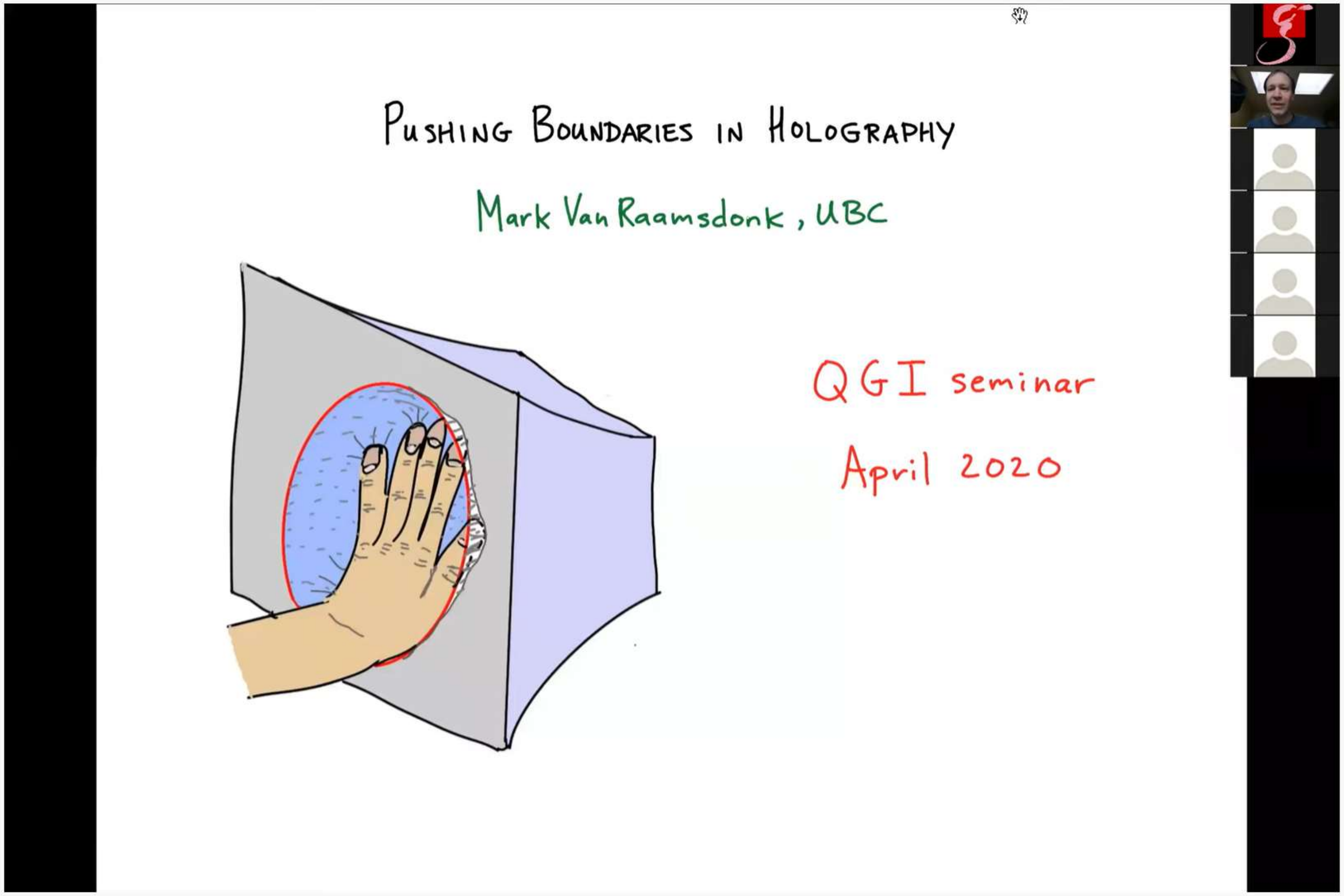

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