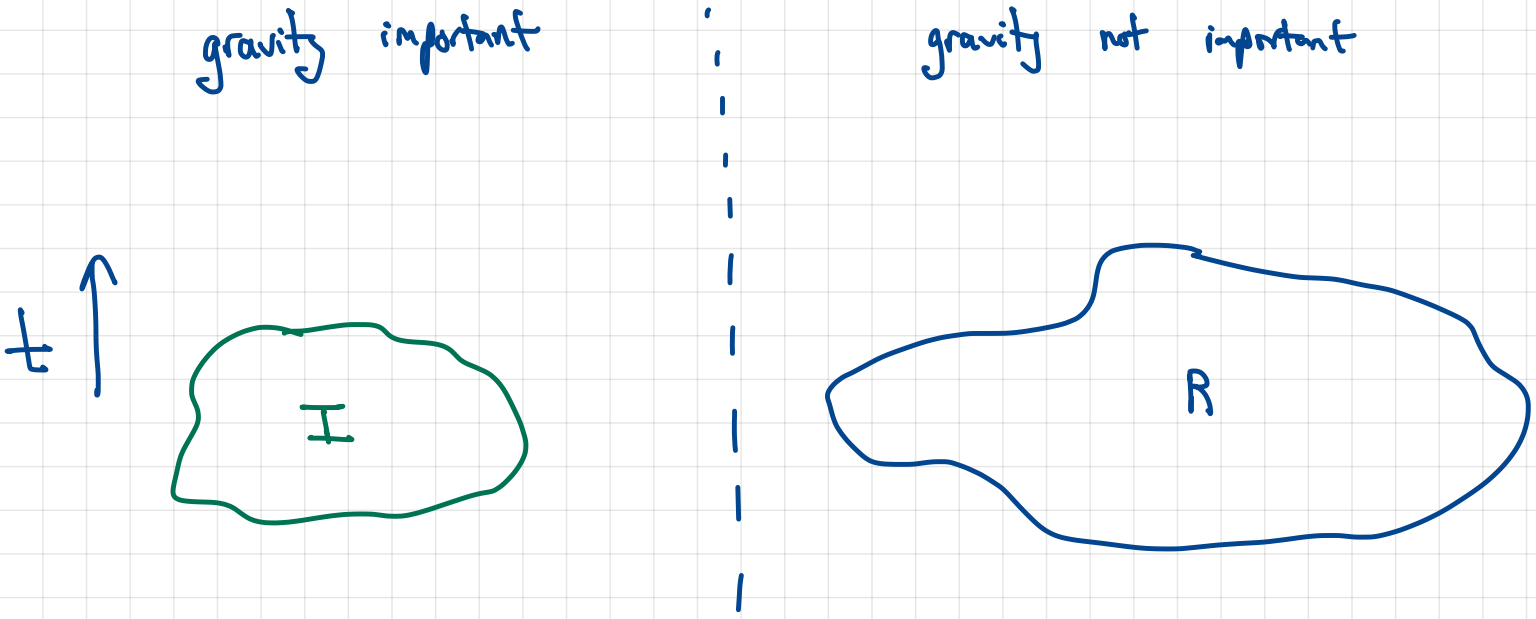
19.

The Island Effect

Read: The review paper "The entropy of Hawking Radiation"
2006.06872

Recently it has been understood that the HEE formula does not require or rely on holography or AdS.

The Island Formula



Conjecture:

$$S(\rho_R) = \min_I \text{ext}_I \, S_{gen}(I \cup R)$$

$$S_{gen}(I \cup R) = \frac{1}{4}\text{Area}(\partial I) + S(\tilde{\rho}_{I \cup R})$$

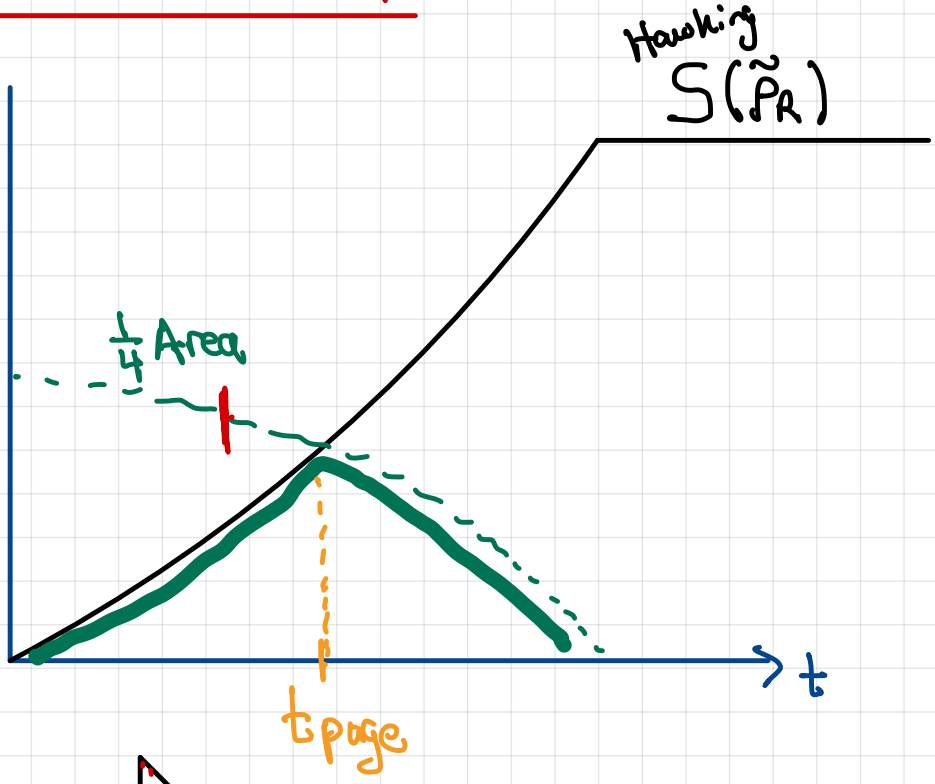
ρ = purported exact state

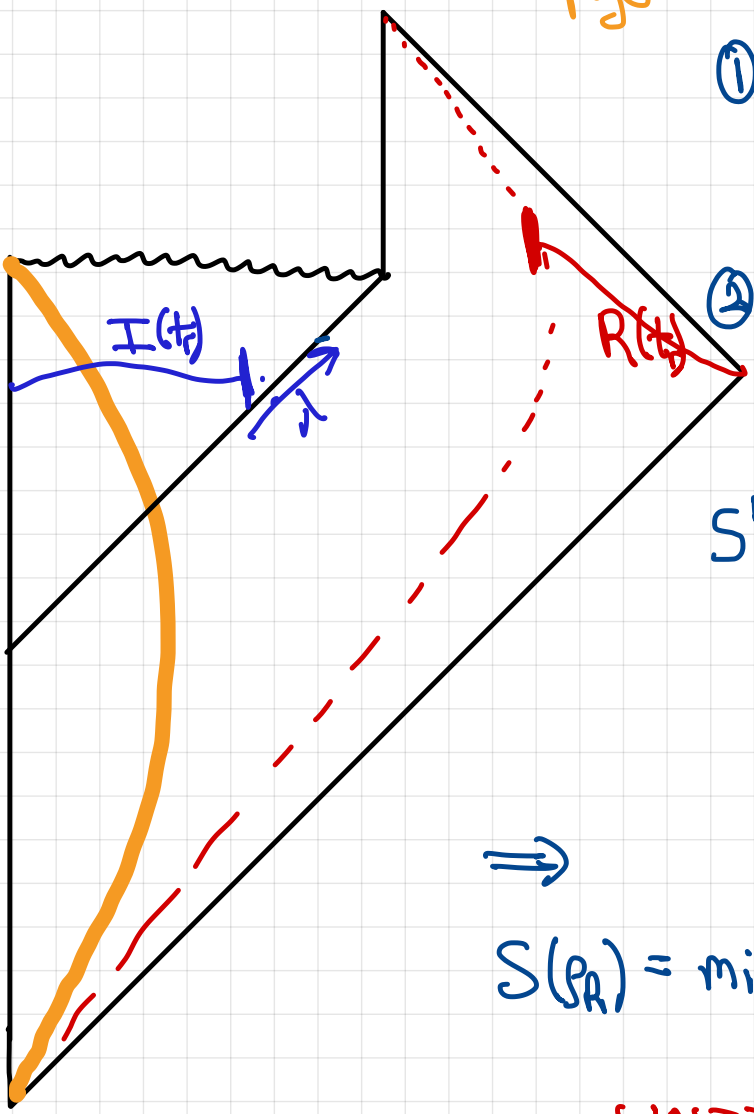
$\tilde{\rho}$ = state calc'd by ordinary methods of QFT in curved space

Conjecture'

Physics in I can be reconstructed from ρ_R, similar to AdS/CFT.

Page Curve Revisited





① I = nothing is always extremal

$$S^{(1)}(\rho_R) = S(\tilde{\rho}_R) = S_{Hawking}$$

② For $t > t_c$, a new QES appears ~ horizon, $\lambda(t_r)$

$$S^{(2)}(\rho_R) = \frac{1}{4}\,\text{Area}\left(\lambda(t_r)\right) + S(\tilde{\rho}_{EUR}) \approx 0$$

(draw picture)

$$\Rightarrow$$

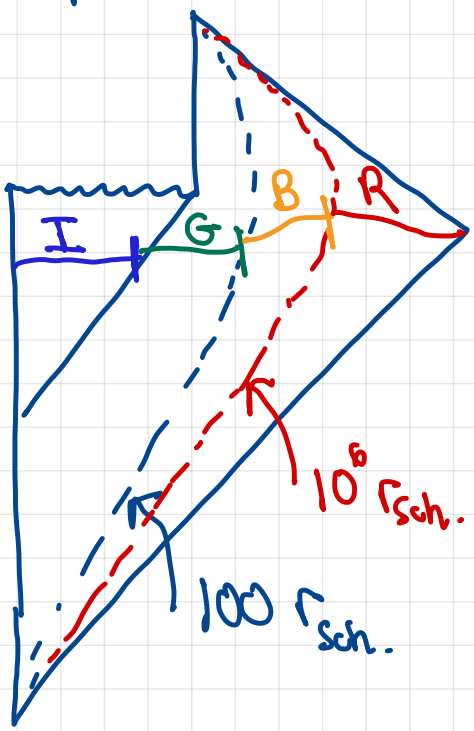
$$S(\rho_R) = \min\left[S_{Hawking}, \frac{1}{4}\,\text{Area}\left(\lambda(t_r)\right)\right]$$

UNITARY

Interpretation

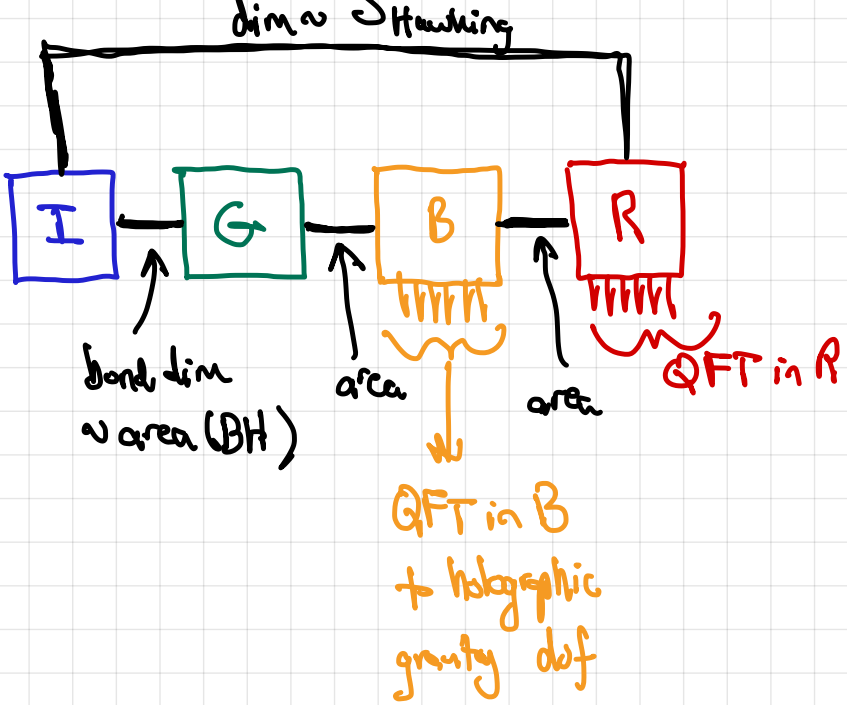
QFT in island can in principle be reconstructed from ρ_R

Toy tensor net / code:



Quantum state of QG

$|\Psi\rangle \approx$

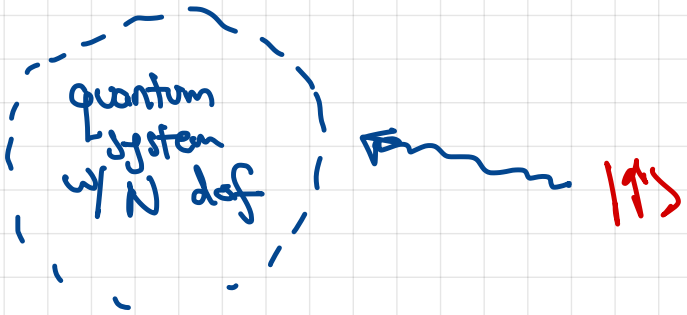


(explain min cuts)

Claim: this tensor net accurately captures qualitatively and quantitatively the underlying error-correcting code.

Scrambling

Hayden-Preskill; Sekino-Susskind



How long before qubit info "thermalizes" into system?

Fast scrambling conjecture: (Sekino-Susskind)

(I) $t \gtrsim \log N$ in any quantum system w/ pairwise interactions

(II) BH saturate bound

BH as mirrors (Hayden-Preskill)

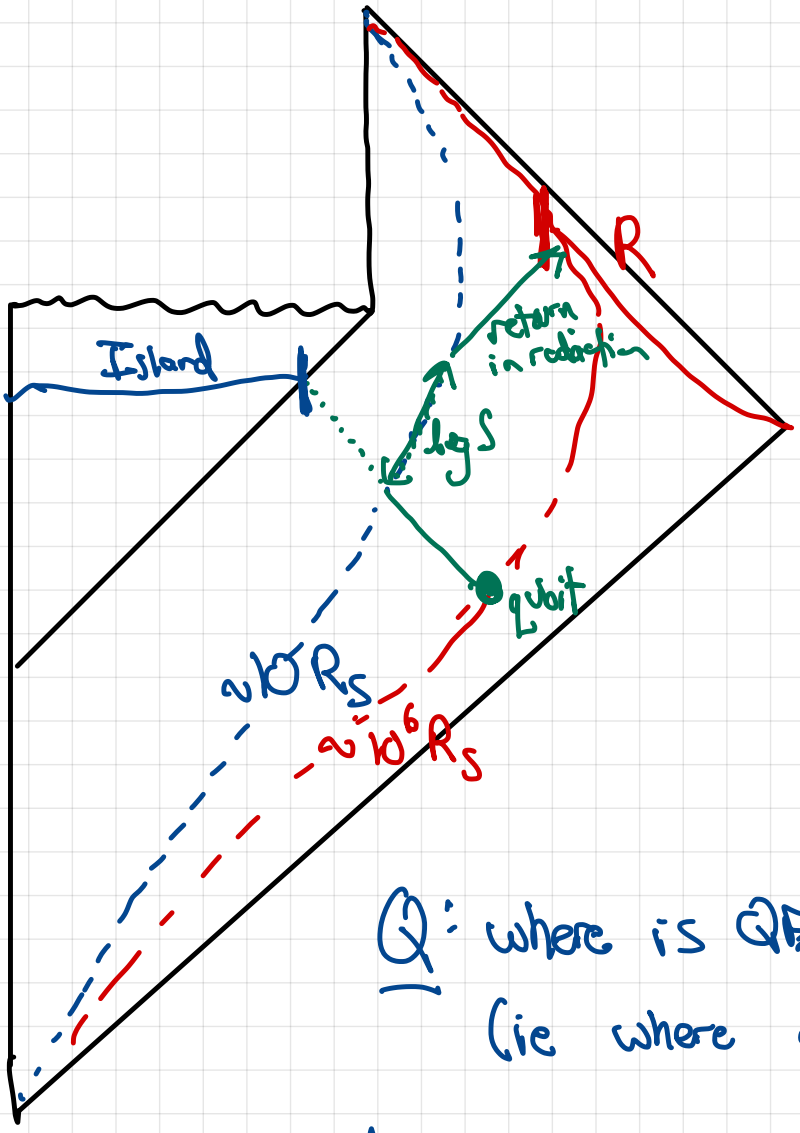
1. Form BH in pure state
2. Collect Rad. until $t > t_{page}$
3. Throw in one more qubit $|0\rangle$
4. How long before Rad. "knows" the qubit?

No-cloning $\Rightarrow$

$t \gtrsim \log S_{BH}$ (explain)

Conjecture: $t = \frac{\beta}{2\pi} \log S_{BH}$ (Model as random, local quantum circuit)

How does this all relate to island effect?



Q: where is QES?
(ie where along horizon)

Ans: time predicted by Hayden-Preskill

Lesson

BH ~ quantum system w/ $\frac{1}{4}A$ d.o.f.

B "belongs to BH"

I "belongs to radiation"