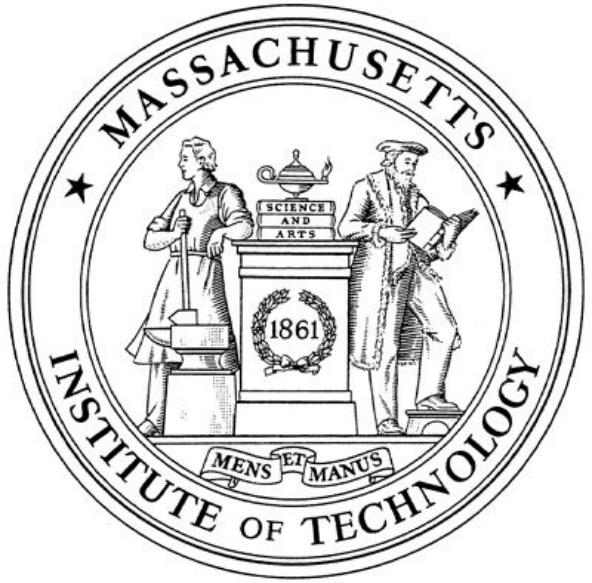
Emergence of bulk locality and causality

Hong Liu



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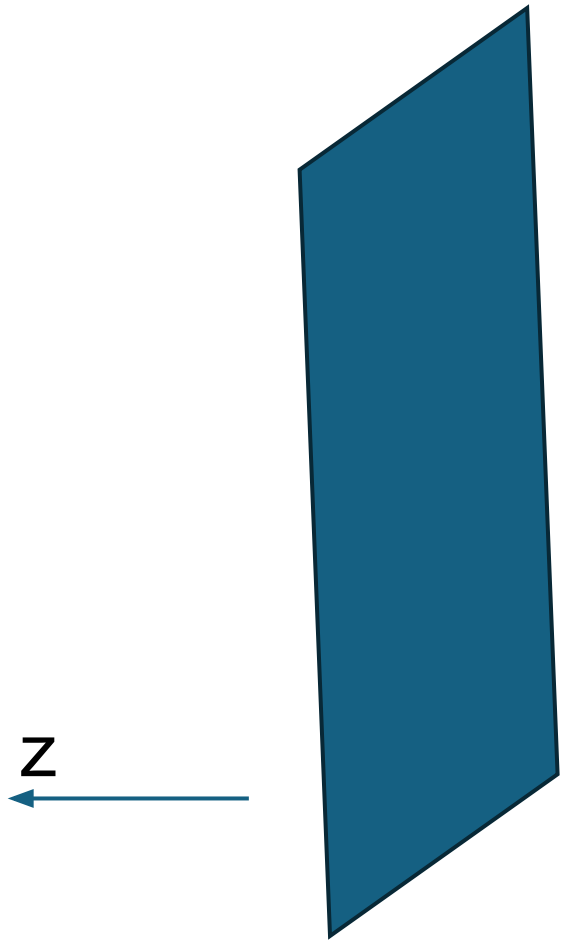
We now have two ways of understanding emergence of bulk spacetime from boundary (in the large N, strong coupling limit).

Bulk spacetime from RG



scale ⟺ radial direction z

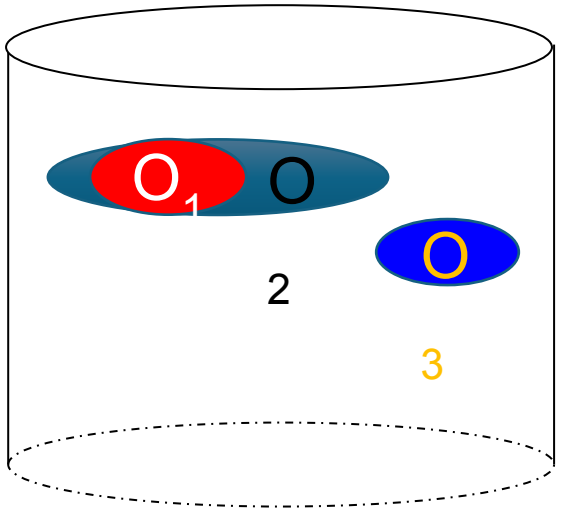
Wilsonian RG flow ⟺ radial evolution

can in principle reconstruct from RG :

bulk geometry + Einstein and matter actions

However, in this approach, local physics, causal structure,
entanglement structure not manifest

These concepts have to do with subsystems



Emergence of spacetime ⟺ emergence of all bulk subsystems

Emergence of bulk locality and causality

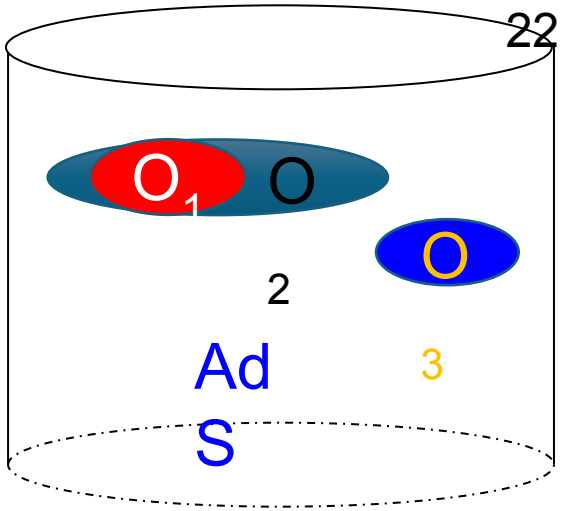
Subregion-Subalgebra duality:

(Leutheusser, HL, 2212.13266)

bulk subregion ⟺ **Emergent** boundary type III_1 von Neumann subalgebra

O_1 ⟺ $\mathcal{A}_1$ (capture all physical operations in O_1)

$O_1 \subset O_2$ ⟺ $\mathcal{A}_1 \subset \mathcal{A}_2$



O_1 and O_3 are spacelike separated (causal structure) ⟺ $[\mathcal{A}_1, \mathcal{A}_3] = 0$

(time-like separated operators can commute!)

sharply defined O_1 ⟺ type III_1 structure of $\mathcal{A}_1$

(specific bulk entanglement structure)

(from infinite entanglement in the $N \to \infty$ limit)

Subregion-subalgebra duality is reminiscent of Gelfand duality, which provides a description of a topological space in terms of algebras of functions on the space.

Gelfand duality is the starting point of formulating the concept of
noncommutative geometry (Connes).
The algebraic description of bulk spacetime is powerful and flexible language to talk about bulk spacetime and physics in it,
potentially including in the stringy and quantum gravitational regimes.

The algebraic description is powerful and flexible: can potentially provide a language for describing stringy and quantum gravitational regimes.