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Modelling Black Hole Horizons via Random Spin Networks

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Based on work in collaboration with G. Chirco and D. Oriti

Loops
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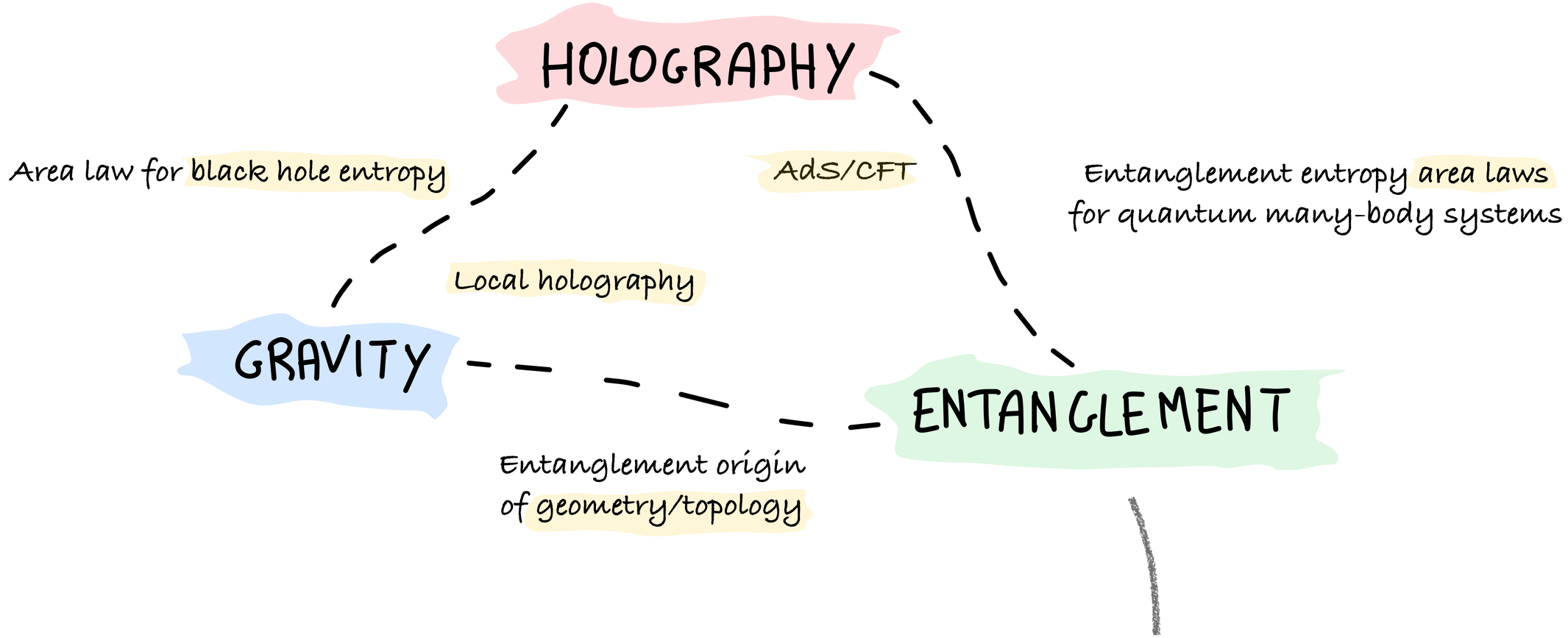
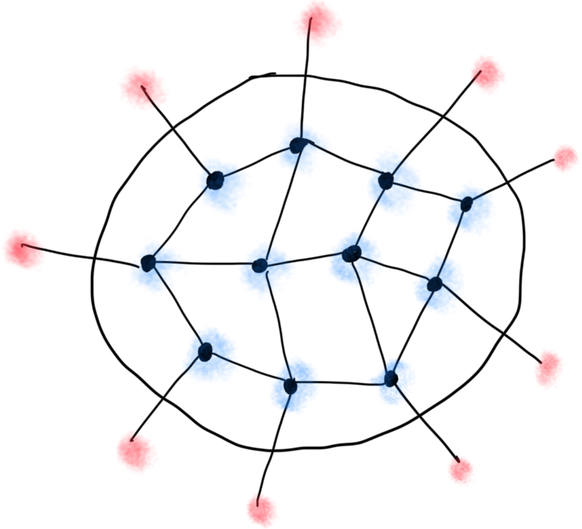
GRAVITY/HOLOGRAPHY/ENTANGLEMENT CONNECTION



➡ STUDY HOLOGRAPHY IN QUANTUM GRAVITY FROM A QUANTUM INFORMATION APPROACH

HOLOGRAPHY ON FINITE REGIONS OF SPACE MODELLED BY SPIN NETWORKS?

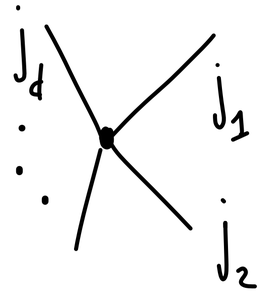
Γ = open spin network graph



$$\mathcal{H}_\Gamma = L^2\left(G^L/G^V\right) = \bigoplus_{j_\Gamma}\left(\bigotimes_v \mathcal{I}^{j_v} \otimes \bigotimes_{e\in\partial\Gamma} V^{j_e}\right)$$

intertwiner space

$$|z_v\rangle \in \mathcal{I}^{j_v} = \mathrm{Inv}_G\left(\bigotimes_{i=1}^{d} V^{j_i}\right)$$



representation space

$$|j_e n_e\rangle \in V^{j_e}$$

Spin network wavefunction at fixed spins:

$$\psi_\Gamma^{j_1 \dots j_L}(z_1 \dots z_V\, n_1 \dots n_N)$$

input: $z_1 \dots z_V$ — BULK

output: $n_1 \dots n_N$ — BOUNDARY

→ spin network as a bulk-to-boundary map

[Livine, Chen, Chirco, Oriti, E.C.]

→ properties of this map ?

information on the bulk accessible from the boundary ?

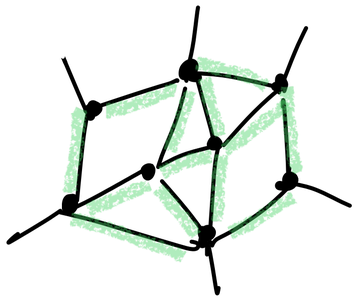
SETTING: SPIN NETWORKS AS ENTANGLEMENT GRAPHS

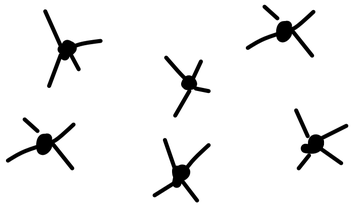
maximally entangled state of edge spins

SPIN NETWORK $|\psi_\Gamma\rangle = \left(\bigotimes_{l \in \Gamma} \langle l|\right) |\psi\rangle$ ENTANGLEMENT GRAPH

CONNECTIVITY

MANY-BODY STATE IN THE GFT FOCK SPACE





- (discrete analogue of) diffeomorphism invariance: symmetry under relabelling of vertices
- correspondence to generalised tensor networks
  - ↳ dynamical bond dimension;
    dynamical combinatorial structure;
    gauge-invariant, 2nd quantised setting

[D. Oriti, E.C., arXiv: 2012.12622]

spin network = map

output input

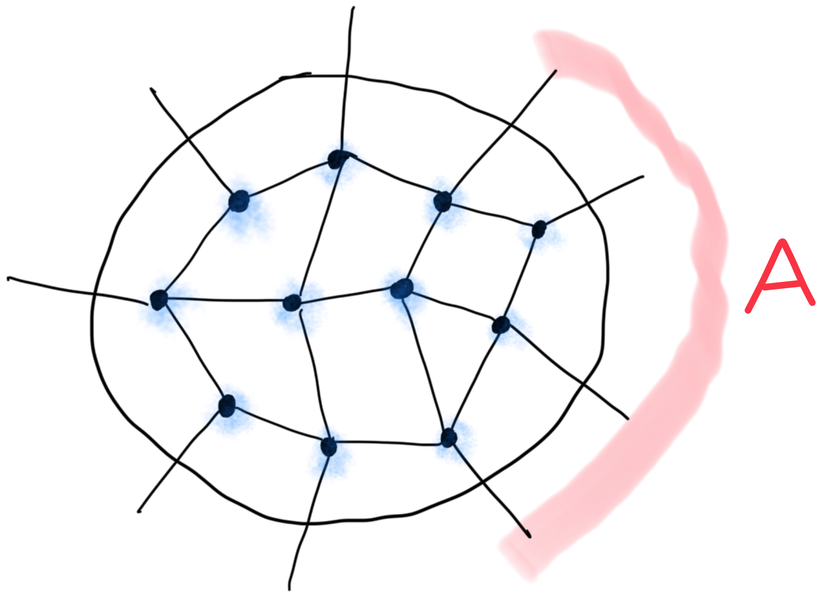
$$\rho_{\partial\Gamma} = \mathrm{Tr}\left[\rho_b \left(\bigotimes_{e\in\Gamma} |e\rangle\langle e|\right) \bigotimes_v |v\rangle\langle v|\right]$$

BOUNDARY STATE

BULK STATE

CONNECTIVITY

$$S_2(\rho^A_{\partial\Gamma}) = ?$$



spin network = map

output input

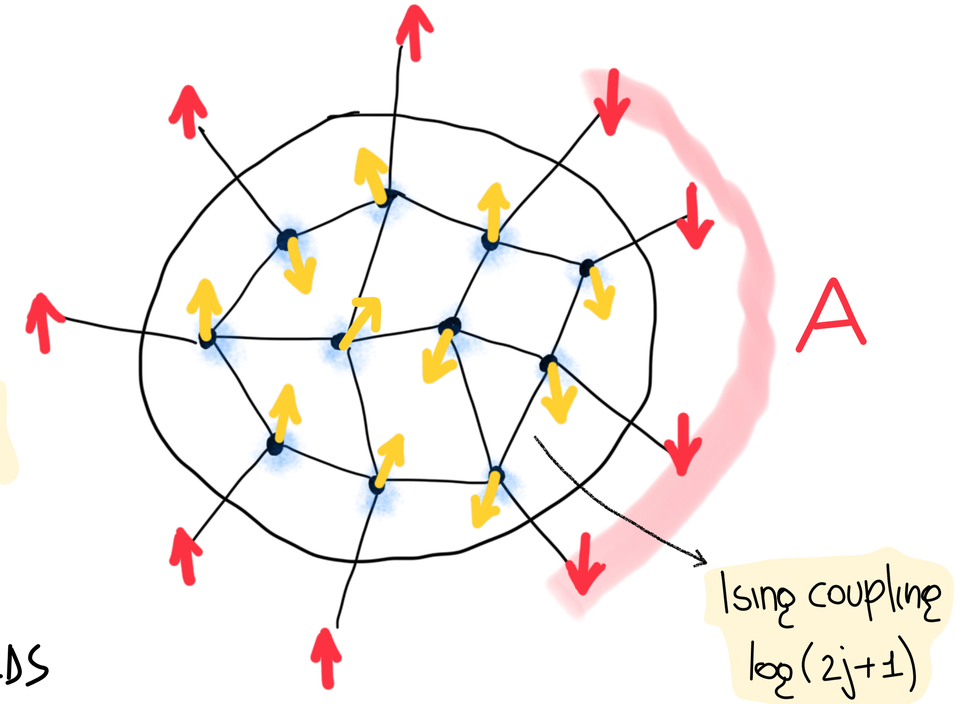
$$\rho_{\partial\Gamma} = \mathrm{Tr}\left[\rho_b \left(\bigotimes_{e\in\Gamma} |e\rangle\langle e|\right) \bigotimes_v |v\rangle\langle v|\right]$$

BOUNDARY STATE

BULK STATE

CONNECTIVITY

RANDOM (UNIFORM DISTRIBUTION)



large spins

$$S_2(\rho^A_{\partial\Gamma}) \approx \min_\sigma H(\sigma) = |\Sigma(\sigma)| + S_2(\rho_b^{\downarrow})$$

typical entropy

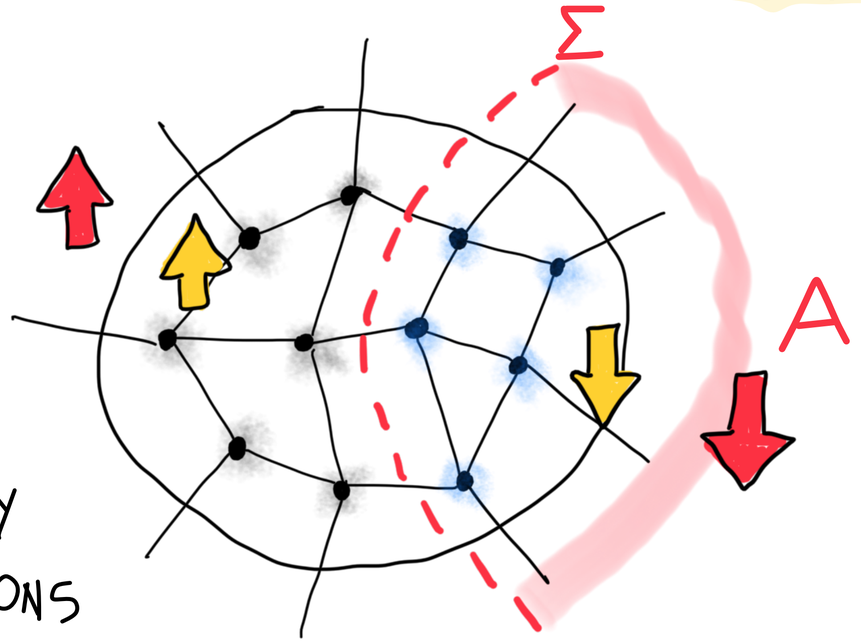
area term

volume term

ISING MODEL

WITH BOUNDARY PINNING FIELDS

$\log(2\bar{j}+1)$ ~ inverse temperature



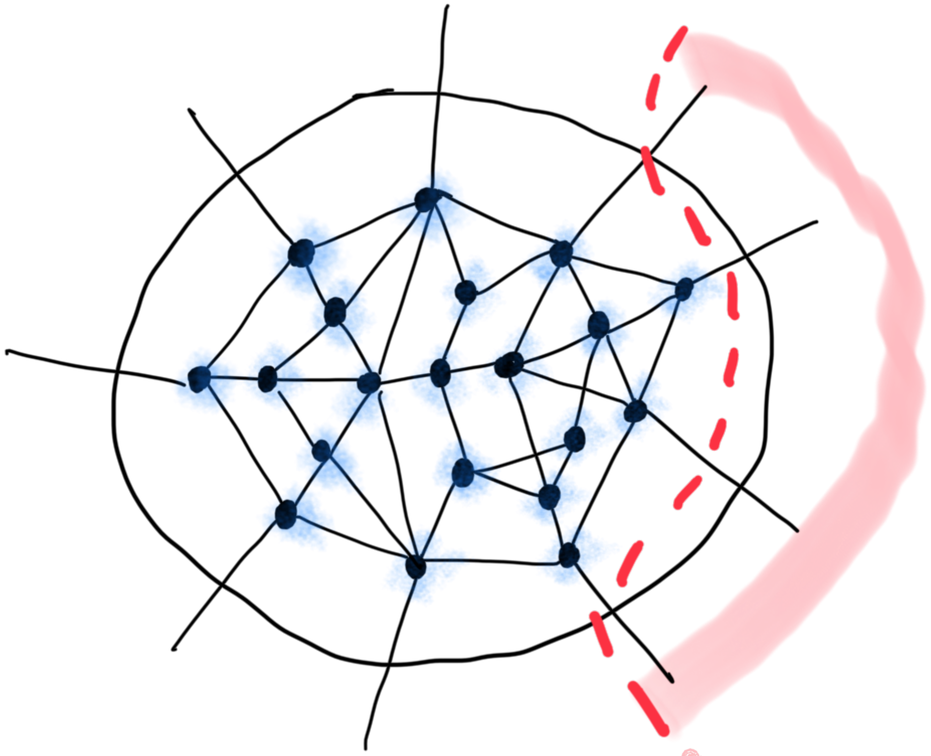
SMALL BULK ENTANGLEMENT ➡ AREA LAW FOR BOUNDARY ENTROPY WITH BULK ENTANGLEMENT CORRECTIONS

INCREASING THE BULK ENTANGLEMENT...

bulk state highly entangled

↓

no minimal surface penetrates into the bulk



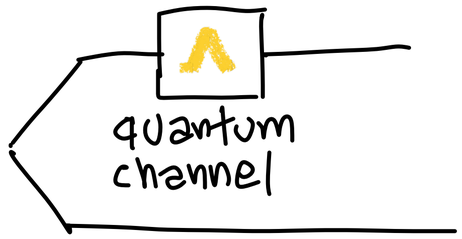
the Ising domain wall cannot enter the highly entangled bulk region

→ EMERGENCE OF A BLACK HOLE-LIKE

[C.Chirco, D.Oriti, E.C., arXiv:2110.15166]

HOLOGRAPHY VIA RANDOM SPIN NETWORKS: A BROADER PROGRAM

Study of the holographic properties of the bulk-to-boundary flow of information via the channel/state duality of quantum information theory:

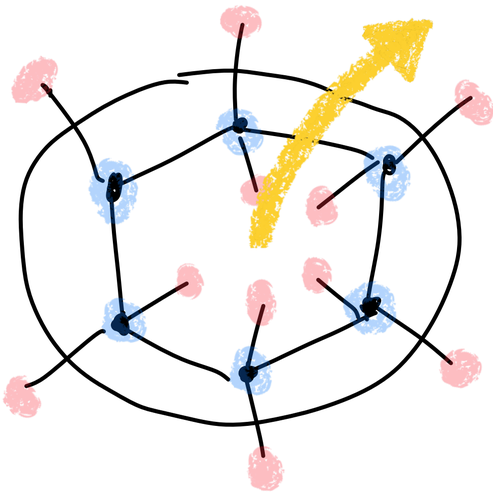


ρ_{AR}

ρ_R

$\rho_{\bar{R}} = \mathbb{I}$?

↘ entropy from Ising model



the map is an isometry iff the reduced bulk state is maximally mixed

Generalization to

- boundary-to-boundary maps
- superposition of spins

➡ TALK BY S. LANGENSCHEIDT

CONCLUSIONS

- Spin networks as entanglement graphs, correspondence with (generalized) tensor networks
- For spin network states with random vertex weights, entropy calculation mapped into Ising partition functions

✓ Bulk area law for boundary entropy for null (or small) values of the bulk entropy, with corrections due to the bulk entanglement (analogous to the Ryu-Takayanagi formula of AdS/CFT)

✓ Emergence of a black hole-like region: when a bulk region with high entanglement entropy is present, the Ising domain wall cannot enter it

OUTLOOK

- Generalization of condensed states modelling spherically symmetric geometries (Oriti, Pranzetti, Sindoni ...)
- Derivation of a "threshold condition" for the emergence of horizon-like surfaces in the bulk (Chirco, Anzà)
- Promotion to the dynamic level

↳ preliminary step: generalization to superposition of different graphs

↳ inspiration from previous results:

  - derivation, from general arguments (energy conservation, gravitational energy as boundary term), of guidelines on the holographic encoding of information in gravitational physics (Marolf, Raju ...)
  - quasi-local holographic dualities in 3d quantum gravity: bulk quantum geometrodynamics (given by Ponzano-Regge state-sum model) dual to 2d statistical models (Dittrich, Goeller, Livine, Riello)
  - LQG boundary dynamics as a 2+1-dimensional SL(2,C) gauge theory (Livine)

Thanks for
the attention!