Entanglement membrane in generalized dual-unitary circuits

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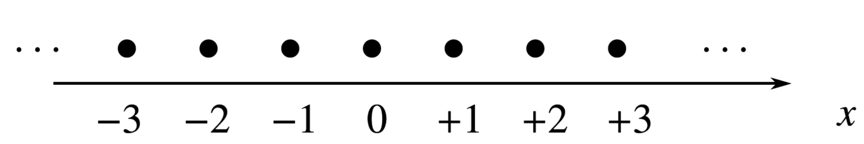
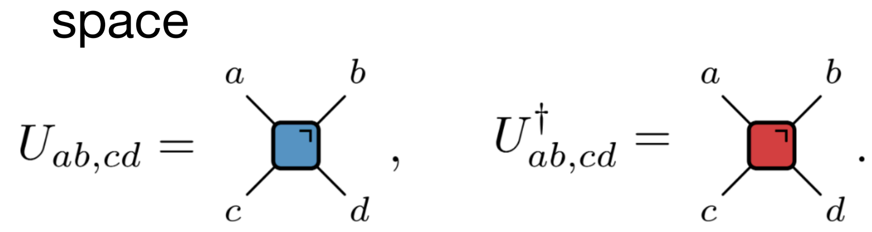
We investigate the entanglement and information dynamics in recently introduced [1] generalized dual-unitary circuits. We show that generalized dual-unitary circuits display sub-maximal entanglement growth, thus establishing them as exactly solvable models with a more generic phenomenology than dual-unitary circuits.

1. Unitary circuits

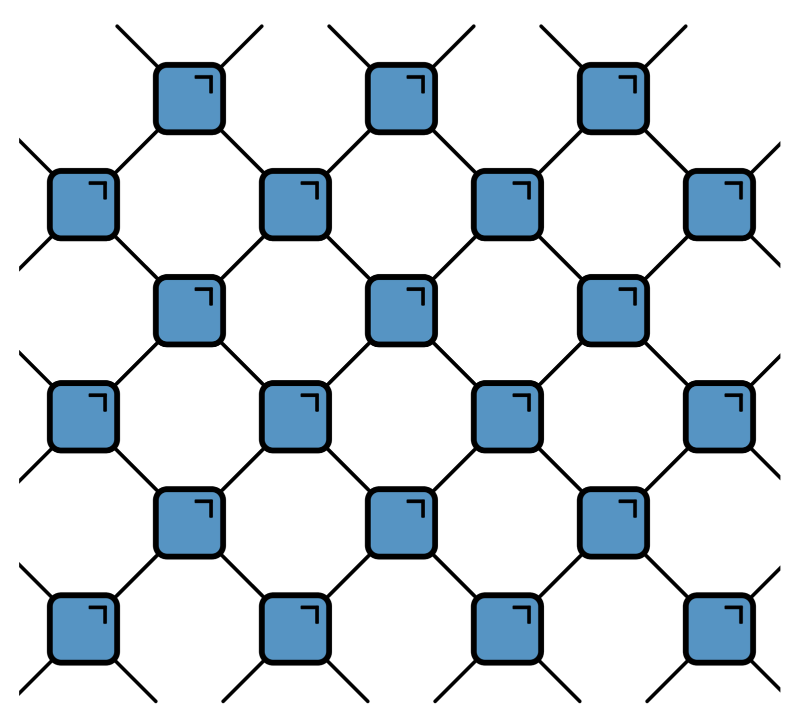
- Chain of qudits (dimension q)



- Two-site gates act on local Hilbert space

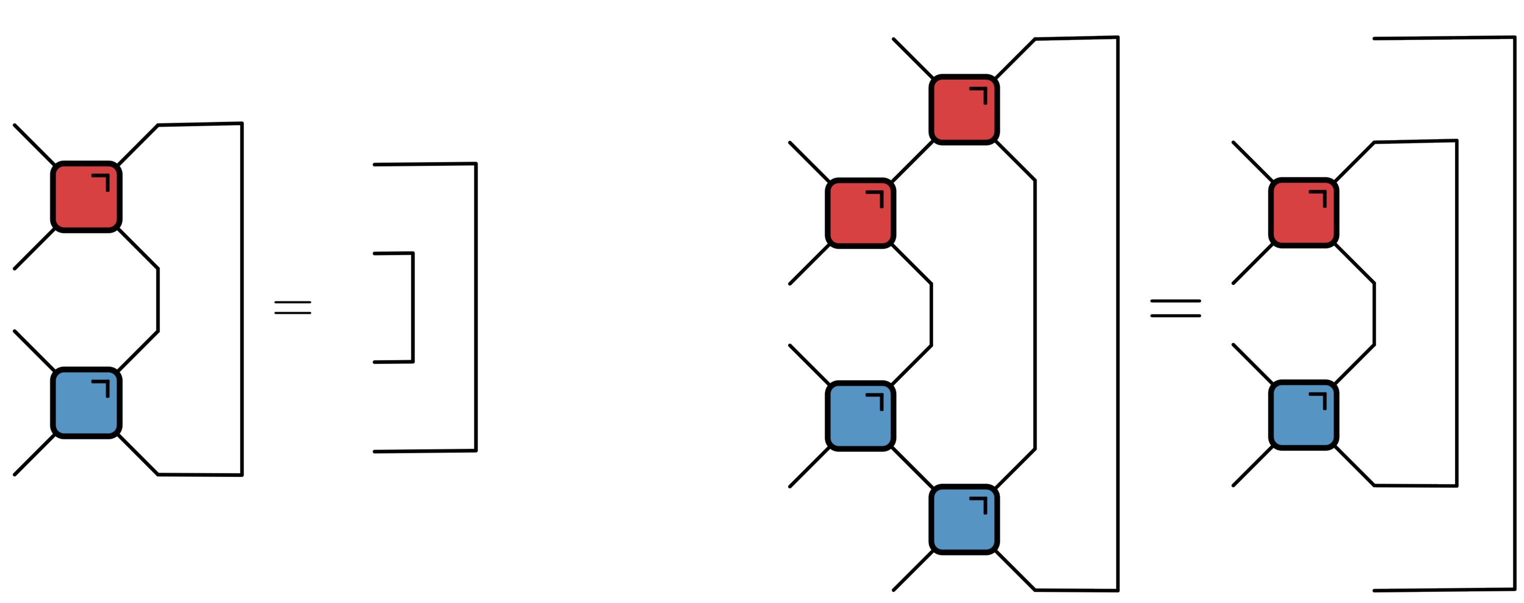


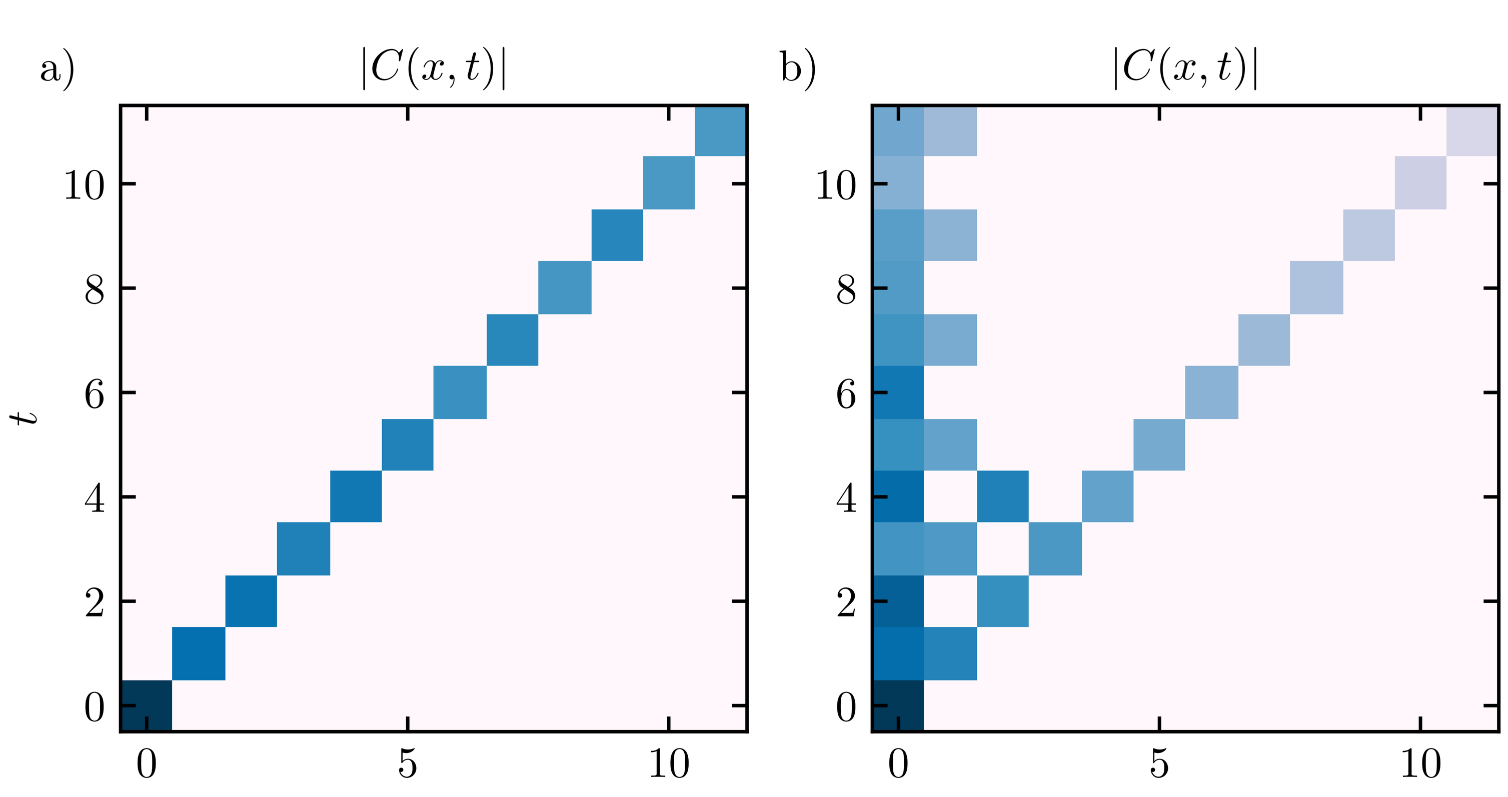
- Minimal model for local and unitary dynamics



2. Generalized dual unitarity

Dual unitarity → DU2

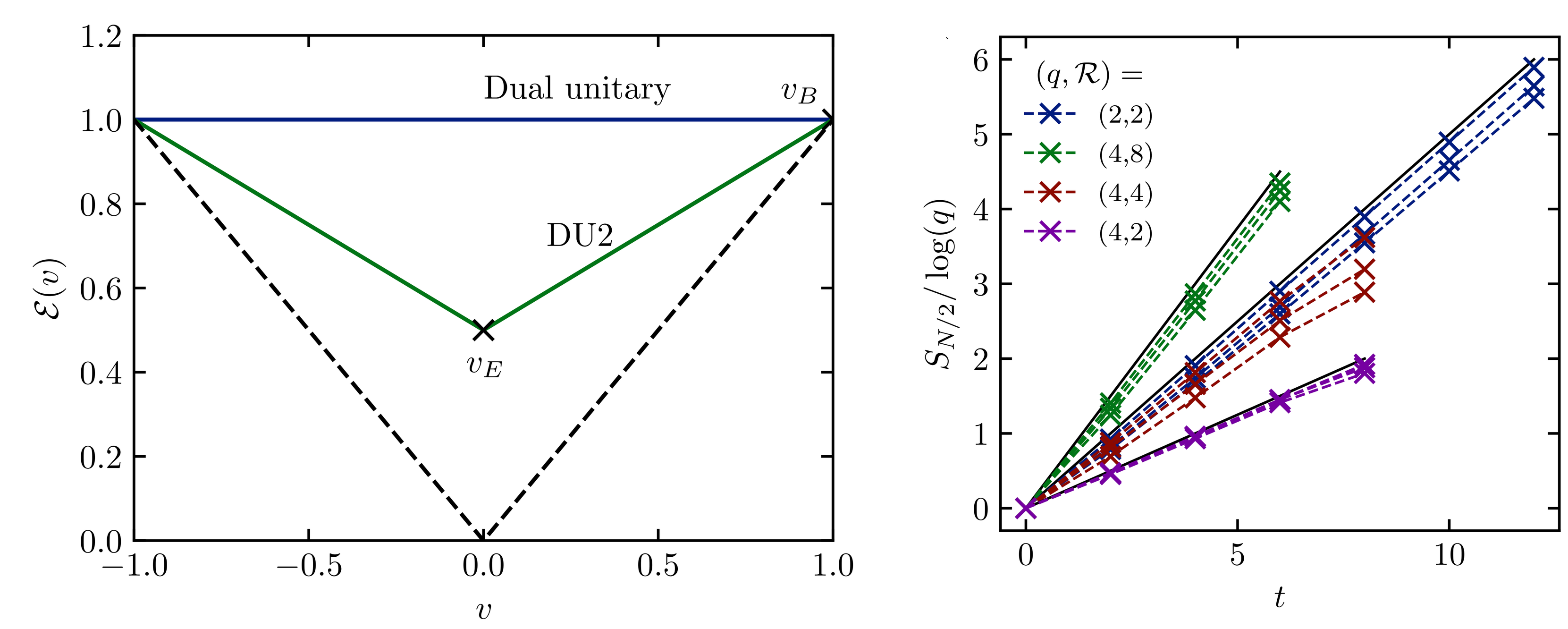




- Dual-unitary circuits [2]: exactly solvable yet chaotic dynamics
- But: special features, for ex. maximal entanglement growth
- DU2 circuits preserve exact solvability
- Connections to kinetically constrained models

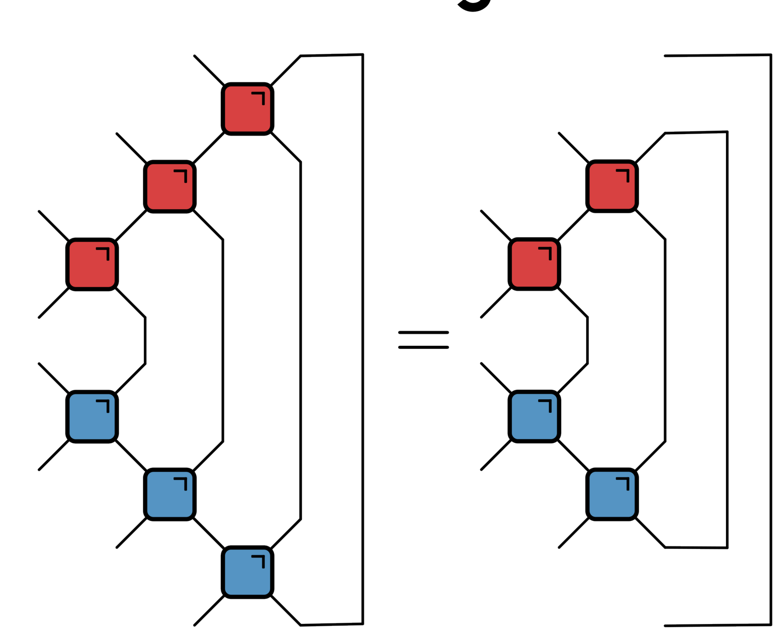
3. Entanglement line tension in DU2 circuits

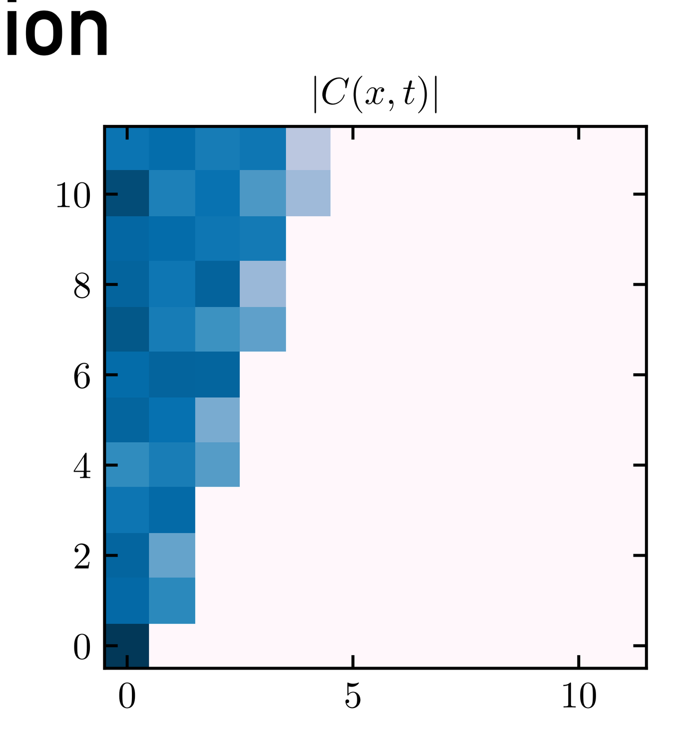
- Use entanglement line tension [4] to extract v_E and v_B
- Result: linear form $\mathscr{E}(v) = v_E + (1 - v_E)|v|$
- Entanglement velocity is reduced by immobile operators
- Entanglement velocity is quantized



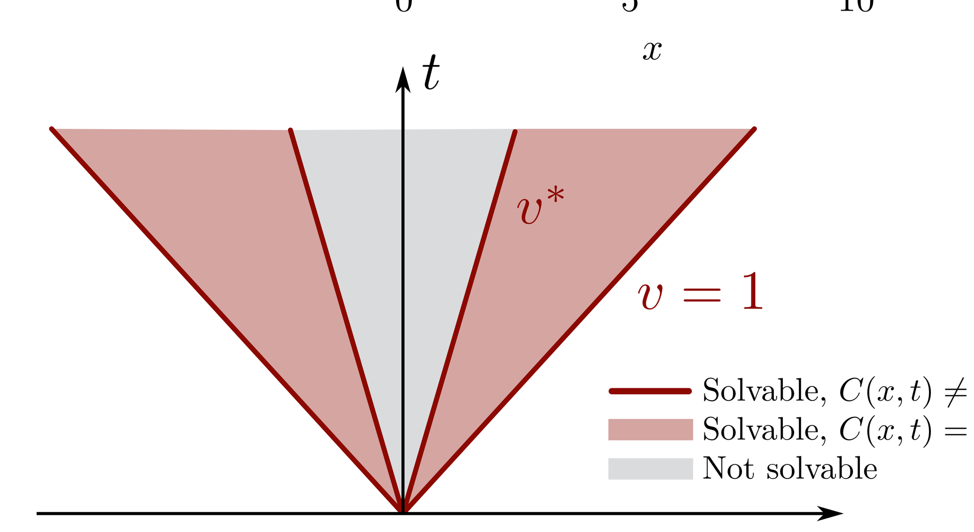
4. Higher levels of generalization

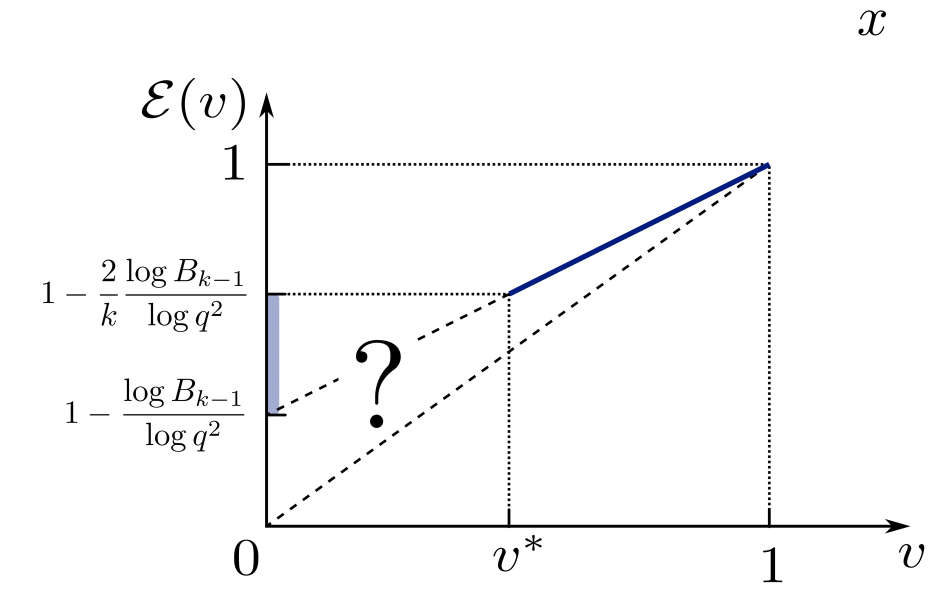
DU3





- Looks a lot like typical many-body dynamics
- But: no longer exactly solvable everywhere
- Inner light cone not accessible, but give bounds on v_E
  - Always:
  $$v_E \geq 1 - \frac{\log B_{k-1}}{\log q^2}$$
  - With parity:
  $$v_E \leq 1 - \frac{2}{k}\frac{\log B_{k-1}}{\log q^2}$$
- Intuition: DoF of all velocities contribute to entanglement. Use knowledge about fast DoF to place bounds





5. Key Findings

- Generalized dual-unitary circuits have more generic entanglement dynamics compared to dual unitaries
- DU2: entanglement growth is slowed down by immobile operators
- Higher levels: more general behavior possible, bound on entanglement velocity

References

[1] Yu, Wang, Kos. *Quantum* 8, 1260 (2024)
[2] Bertini, Kos, Prosen. *Physical Review Letters* 123.21 (2019)
[3] Fisher et al. *Annual Review of Condensed Matter Physics* 14 (2023)
[4] Jonay, Huse, Nahum. *arXiv:1803.00089* (2018)
[5] Rampp, Rather, Claeys. *Physical Review Research* 6, 033271 (2024)
[6] Foligno, Kos, Bertini. *Physical Review Letters* 132, 250402 (2024)