Quantum Consensus Dynamics by Entangling Maxwell Demon

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Abstract

- We introduce a Maxwell demon which generates many-body-entanglement robustly against thermal fluctuations, which allows us to obtain quantum advantage.
- Adopting the protocol of the voter model used for opinion dynamics approaching consensus, the demon randomly selects a qubit pair and performs a quantum feed back control, in continuous repetitions.
- We derive a lower bound of the entropy production rate by demon's operation, which is determined by a competition between the quantum-classical mutual information acquired by the demon and the absolute irreversibility of the feedback control.
- Our finding of the lower bound corresponds to a reformulation of the second law of thermodynamics under a stochastic and continuous quantum feedback control.

Introduction

- A modern view of a Maxwell demon is a feedback control in which the dynamics of a system uses outputs of a measurement as inputs in a smart manner.
- Recently in nano-systems, variants of the original Maxwell demon which operate stochastically or continuously have been demonstrated.
- Both achieve an enhancement of the work extraction, limited by modified second-law-like inequalities, beyond the conventional feedback control.
- Stepping further, our work proposes a new realization for a Maxwell demon, a quantum feedback control that operates both stochastically and continuously.
- Our demon adopt a protocol used in the voter model which describes the nonequilibrium human opinion dynamics, motivated by the fact that it generates classical correlation of opinions among voters.
- As a remarkable consequence, it generates robust Greenberger-Horne-Zeilinger (GHZ) entanglement among many qubits even in the presence of thermal fluctuations.

Setup

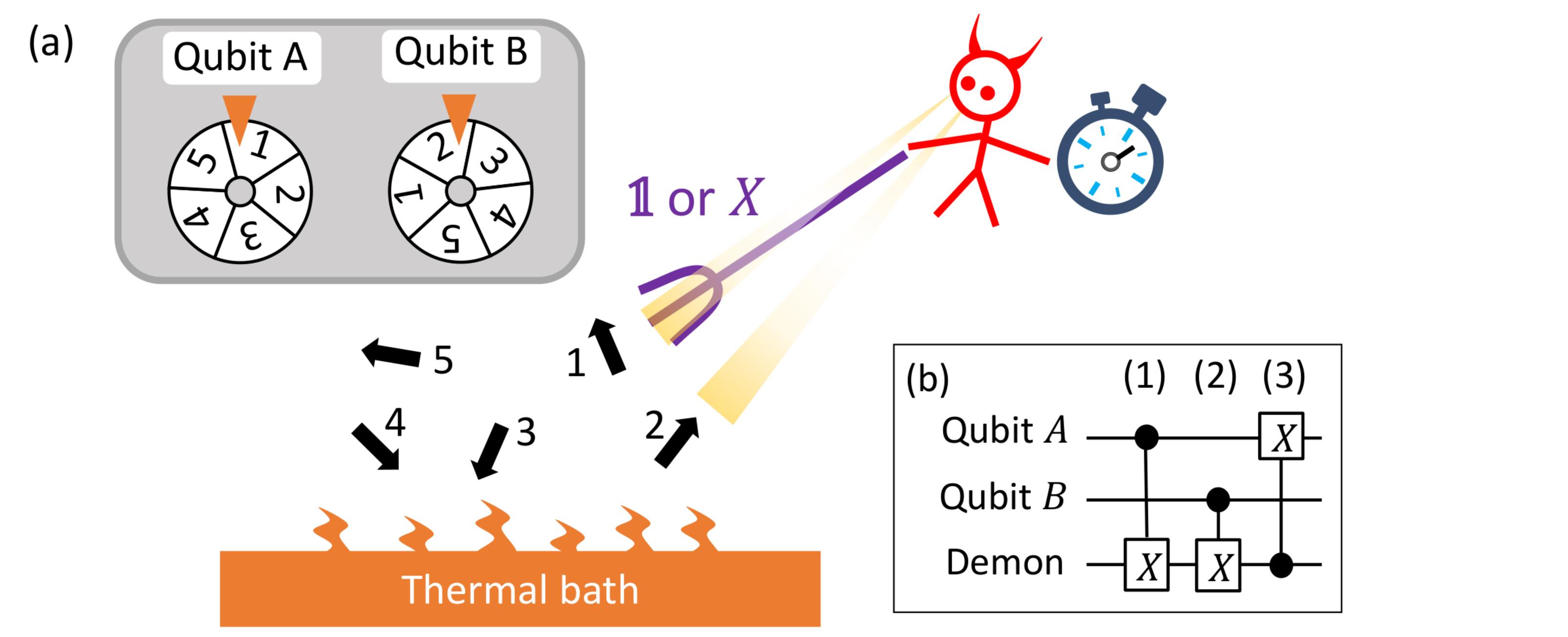

Fig. 1. **(a)** Our demon stochastically selects two qubits A and B among many, and induces a copy process in which qubit A copies the state of qubit B in certain basis states, continuously repeating the selection and copy process with frequency Γ_{copy}. A thermal bath induces spontaneous qubit flips with frequency Γ_{flip}. We focus on all-to-all connectivity for the copy processes. **(b)** Quantum circuit realizing the copy proceess.

Entanglement generation

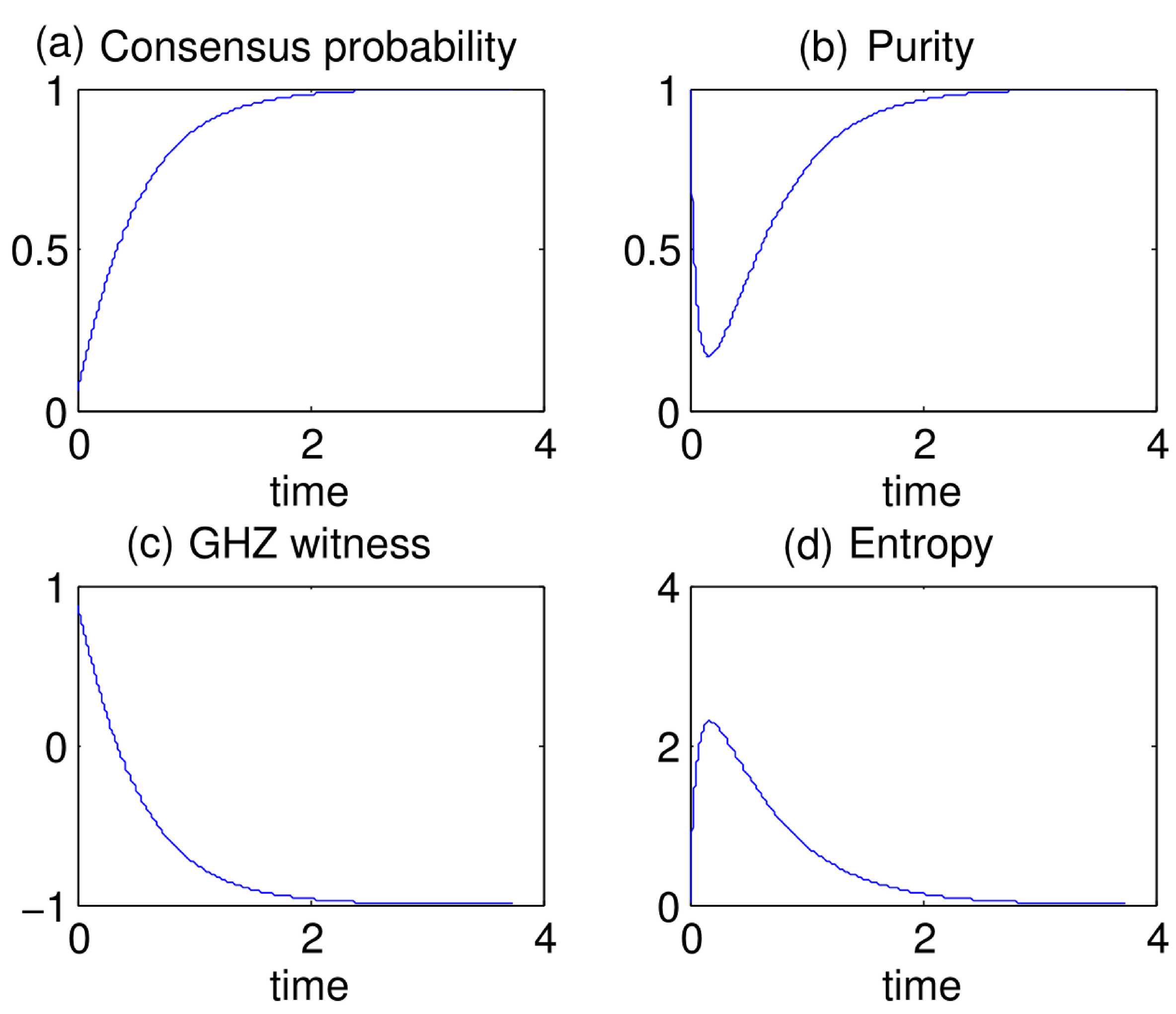

Fig. 2. Entanglement generation by the consensus dynamics in the absence of thermal fluctuations. The quantum feedback controls induce consensus among the qubits **(a)**, while enhancing GHZ entanglement **(c)**. They reduce [or increase] von Neumann entropy of the qubits depending on time **(d)**, accompanying the enhancement [or reduction] of coherence **(b)**. Here, 5 qubits are considered, and the initial state is symmetric superposition $\sum_{s_1,\cdots,s_N=0,1}|s_1\cdots s_N\rangle$. The time is measured in $\Gamma_{\mathrm{copy}}^{-1}$.

Entanglement protection

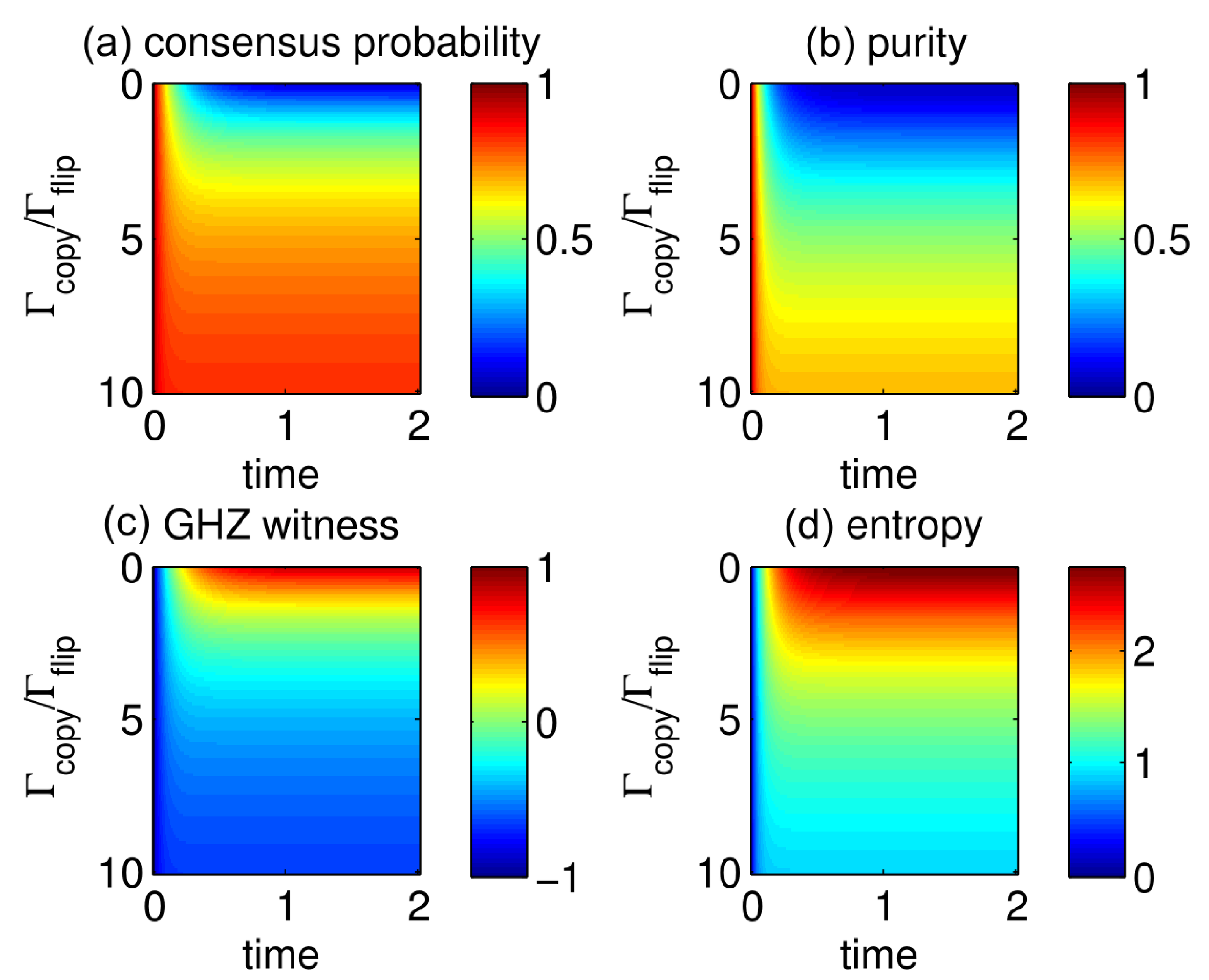

Fig. 3. Entanglement protection against thermal fluctuations. Here, the initial state is 5-qubit GHZ state, $|00000\rangle+|11111\rangle$. When $\Gamma_{\mathrm{copy}}>\Gamma_{\mathrm{flip}}$, the consensus **(a)**, entanglement **(c)**, coherence **(b)**, and entropy **(d)** is protected against the thermal fluctuations. The time is measured in $\Gamma_{\mathrm{flip}}^{-1}$.

- Combining the two properties of entanglement generation and protection, the GHZ state can be generated even in the presence of thermal fluctuations.

Entropy production by demon

- We find that the entropy production by the copy processes, $\dot{S}_{\mathrm{copy}}$, are lower bounded as

$$\dot{S}_{\mathrm{copy}} \geq N_{\mathrm{copy}}\Gamma_{\mathrm{copy}}(-\overline{I_{\mathrm{QC}}}+\overline{\lambda_{\mathrm{fb}}})$$

N_{copy}: number of possible copy pairs.

$\overline{I_{\mathrm{QC}}}$: mutual information for quantum system and classical measurement outcomes

$\overline{\lambda_{\mathrm{fb}}}$: absolute irreversibility ≡ sum of probability of backward trajectories which does not have a corresponding forward trajectory.

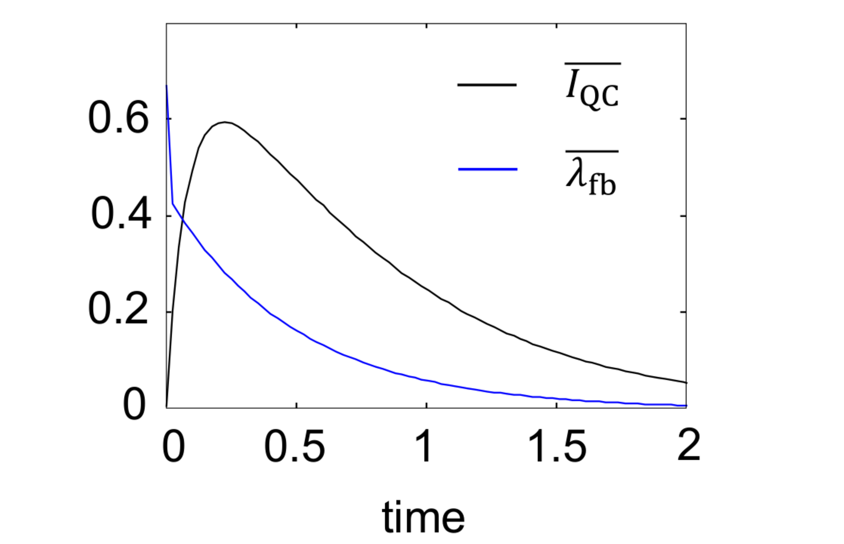

Fig. 4. Competition of $\overline{I_{\mathrm{QC}}}$ and $\overline{\lambda_{\mathrm{fb}}}$, responsible for the entropy in Fig. 2(d).

Conclusion

- Inspired by the voter model and realized by stochastic and continuous quantum feedback controls, we have introduced a quantum coherent consensus dynamics and we have shown that it is able to generate GHZ-entanglement robustly against thermal fluctuations.
- We have also formulated the second law of thermodynamics under this new class of feedback control and obtained that the lower bound of the entropy production rate is determined by a competition between the quantum-classical information and the absolute irreversibility of the feedback control.
- As demonstrated by our entangling demon, the stochastic and continuous quantum feedback control provide a new class of quantum Maxwell demon which will bring further impacts in quantum computations and quantum thermodynamic machines.

Reference: Sungguen Ryu, Rosa López and Raúl Toral. arXiv:2102.00777