Feedback-based quantum algorithm inspired by Counterdiabatic Driving

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Scientific background

- The feedback-based quantum algorithm is a “fully quantum” algorithm that uses a quantum control method to design quantum circuits to prepare the ground state of a quantum many-body system as well as solve combinatorial optimization problems.
- The equation of motion: $i\frac{d|\psi(t)\rangle}{dt} = (H_P + H_C(t))\,|\psi(t)\rangle,$

$$H_C(t) = \sum_{m=1}^{M} \beta_m(t) H_m$$

H_m are the time-independent Hermitian operators
$\beta_m(t)$ are control parameters

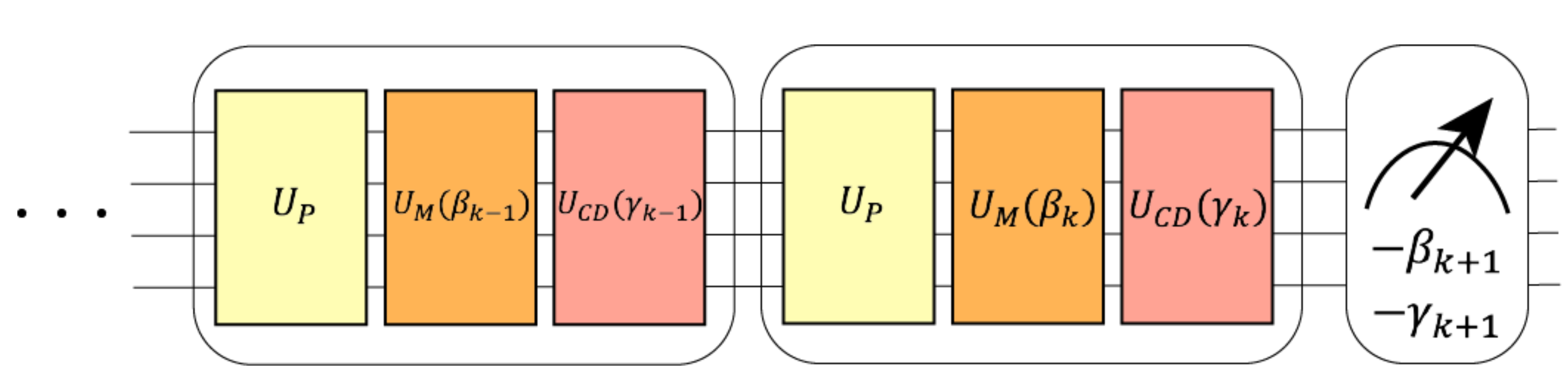
- The goal is to find a time-evolution that ensures that the average energy decreases with increasing time

$$\frac{dE(t)}{dt} = i\langle\psi(t)|[H_C, H_P]|\psi(t)\rangle \leq 0$$

- By assigning $\beta_m(t) = -i < \psi(t)|[H_m, H_P]|\psi(t) >$, one can ensure that the energy decreases.
- In Ref. [1], it was demonstrated for combinatorial optimization problem with a single control Hamiltonian.

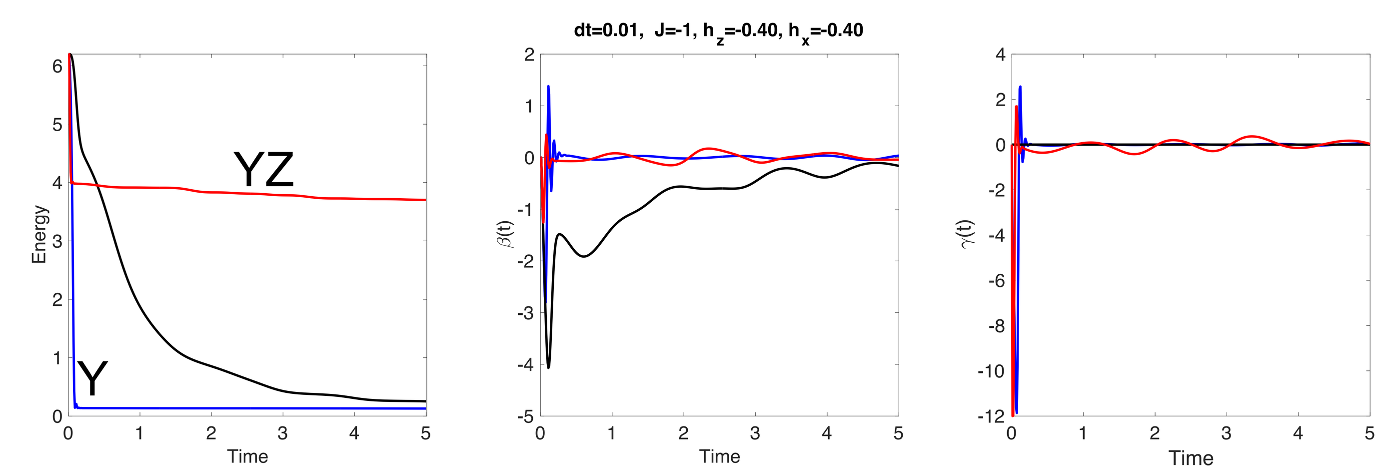
Motivation and the algorithm

- The feedback-based algorithm is slow and requires a deep quantum circuit to implement.
- Here, we argue that the feedback-based algorithm can be accelerated by adding another control parameter inspired from counterdiabatic drive.
- We choose a single operator heuristically from an operator pool to demonstrate that such an addition can indeed accelerate the algorithm.
- The quantum circuit for such an algorithm is built iteratively by computing expectation value via measurement after k-th layer and assigning the measurement results to construct the k+1-th layer

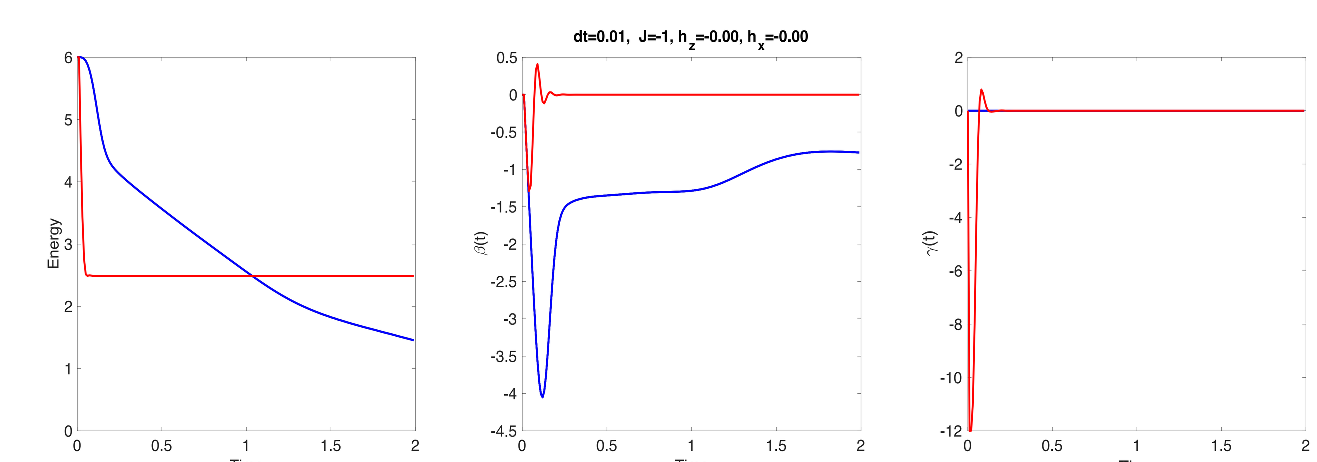


Results

- Hamiltonian: $H_{\text{prob}}(\sigma) = -\sum_{\langle i,j\rangle} J_{ij}\sigma_i^z\sigma_j^z - \sum_i h_i\sigma_i^z - \sum_i k_i\sigma_i^x$
- For simplicity we choose $J_{ij} = J, h_i = h_z, k_i = h_x$, and periodic boundary condition
- Mixed field Ising model



- GHZ state



Conclusions

- We observe that indeed adding an additional control parameter inspired by the counterdiabatic drive can accelerate the feedback-based algorithm.
- However, for certain Hamiltonian this comes at a cost of not reaching the ground state.
- However, for small enough system size the CD acts much better in increasing the ground state probability.

References

A. B. Magann, K. M. Rudinger, M. D. Grace, and M. Sarovar, Phys. Rev. Lett. **129**, 250502 (2022).