Spin-Coherent State for Quantum Annealing with Antiferromagnetic fluctuation

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Ferromagnetic p-spin model

$$\hat{H}(s,\lambda) = s\hat{H}_0 + (1-s)\hat{V}_{\mathrm{TF}}, \quad (0 \leq s \leq 1)$$

where $\hat{H}_0 = -N\left(\frac{1}{N}\sum_{i=1}^{N}\hat{\sigma}_i^z\right)^p, \ \hat{V}_{\mathrm{TF}} = -\sum_{i=1}^{N}\hat{\sigma}_i^x.$

The Glover Problem for $p \to \infty$

However, with this Hamiltonian , 1st-order phase transition disturbs the QA for efficiently finding the ground state .

Ref.) T. Jörg et al., EPL 89, 40004 (2010).

The antiferromagnetic fluctuation was proposed to avoid 1st-order phase transition .

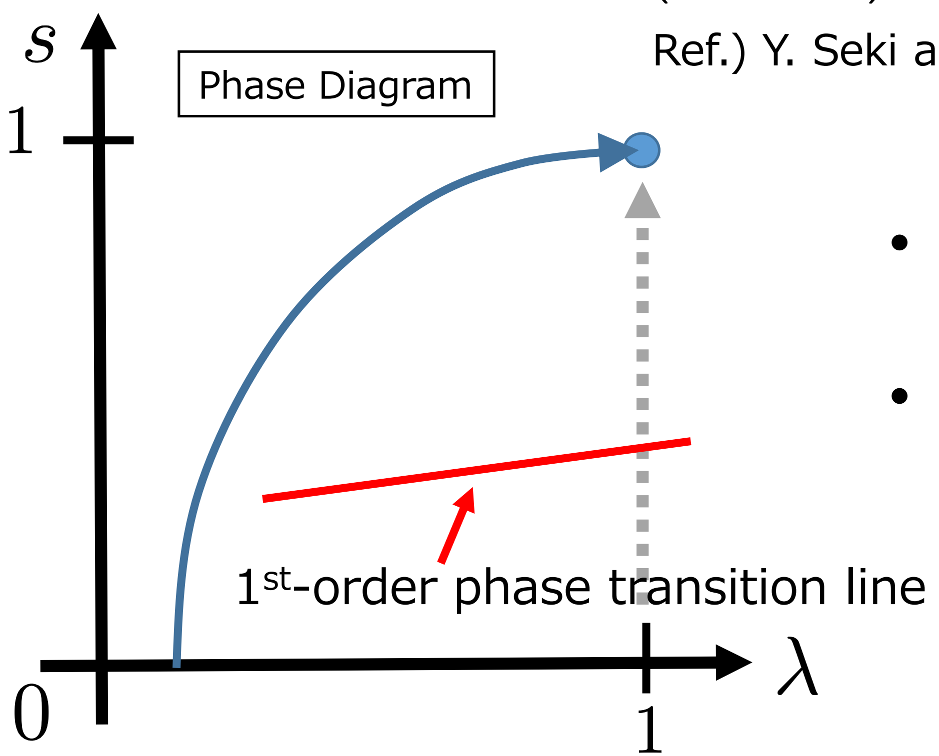
Antiferromagnetic fluctuation (AFF)

Our Hamiltonian:

$$\hat{H}(s,\lambda) = s\left\{\lambda \hat{H}_0 + \underline{(1-\lambda)\hat{V}_{\mathrm{AFF}}}\right\} + (1-s)\hat{V}_{\mathrm{TF}},$$

where $\hat{V}_{\mathrm{AFF}} = +N\left(\frac{1}{N}\sum_{i=1}^{N}\hat{\sigma}_i^x\right)^2$, λ : initial: an arbitrary value
final : 1

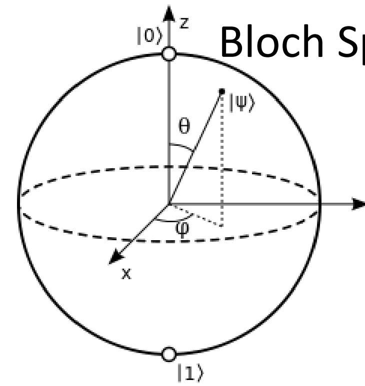
Ref.) Y. Seki and H. Nishimori, PRE **85**, 051112 (2012).



- In present study, we investigate the physical background of AFF.
- Especially, **Quantum effect of the AFF.**

The Spin-Coherent State

$$|\theta, \phi\rangle = \bigotimes_{i=1}^{N} \cos\left(\frac{\theta}{2}\right)|0\rangle_i + \sin\left(\frac{\theta}{2}\right) e^{i\phi}|1\rangle_i$$



Bloch Sphere

and $N \gg 1$

Semi-Classical approximation

Ref.) S. Muthukrishnan, T. Albash, and D. A. Lidar, Phys. Rev. X **6**, 031010 (2016).

- If the approximation breaks down,
  we cannot interpret the QA process in classical.
- We investigate the validity of the semi-classical approximation for our Hamiltonian.

Concurrence

- A measure of Entanglement between two spins

Quantum Effect

$$C(\rho) = \max(0, \lambda_1 - \lambda_2 - \lambda_3 - \lambda_4)$$

λ_i are the eigenvalues of the Hermitian operator $R = \sqrt{\sqrt{\rho}\tilde{\rho}\sqrt{\rho}}$

with $\tilde{\rho} = (\sigma_y \otimes \sigma_y)\rho^*(\sigma_y \otimes \sigma_y)$.

- If the concurrence is non-zero, there is the entanglement.
- We find that the concurrence becomes a large value by the AFF.