Error suppression in continuous-time quantum computing

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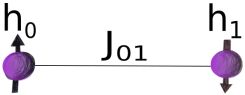
Outline

- **Aim:** Improve error suppression capabilities of continuous-time quantum computing.
- Connecting multiple copies of an Ising model by (anti-) ferromagnetic couplings: may improve robustness to error.

1.1 Ising model problem

- Aim: Protect an **Ising model** which has the solution to a problem encoded in it's ground state, from errors due to **lack of precision**.
- Examples of problems that can be encoded in this way include: MIS, Max2SAT.
- The Ising Hamiltonian is of the form,

$$\hat{H} = \sum_{j=0}^{n-1} h_j \hat{Z}_j + \sum_{j \neq k=0}^{n-1} J_{jk} \hat{Z}_j \hat{Z}_k$$



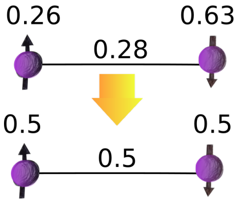
- Use **continuous-time techniques** to find ground state such as Quantum Walks or AQC. (more info see [Morley, J. G. et al, (2017). Phys. Rev. A.])

1.2 Precision

- Errors on Ising model, modelled as a **lack of precision** p on the fields h_i and couplings J_{ij}
- Define the number of values a parameter can take n_v as,

$$n_v = 2^p + 1$$

- **E.g.** If $p = 2$! $n_v = 5$
  ! possible values [1; 0:5; 0; 0:5; 1].
- An Ising model with true precision:
- Will be represented as: (On a quantum computer with $p = 2$)



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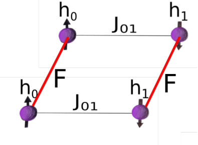
1.3 Protection

- In order to give the Ising model more resistance to errors , or lack of precision *p*, **we add a copy**. (First introduced in [Young, K. C. et al, (2013) Phys. Rev. A.])



- *F*'s provide ferro- or **anti-ferromagnetic** couplings.
- Each *F* has the same value.

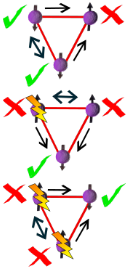
The Hamiltonian for this is,

$$\hat{H} = \sum_{i=0}^{n-1}\sum_{k=0}^{m-1}(h_i + {}^{h}_{i;k})\hat{Z}_{i;k} + \sum_{i\neq j=0}^{n-1}\sum_{k=0}^{m-1}(J_{ij} + {}^{J}_{i;j;k})\hat{Z}_{i;k}\hat{Z}_{j;k}$$

$$\sum_{i=0}^{n-1}\sum_{k\neq l=0}^{m-1} F Z_{i;k} Z_{i;l}$$

1.4 Further Protection

- To add more protection we **add another copy:**
  - Triangular structure with anti-ferromagnetic links adds **frustration** to the system.



- **No errors:** One copy is forced to be incorrect.
- **One error:** One copy is forced to be correct.
- **Two errors:** One copy is forced to be correct.

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2. Measuring success

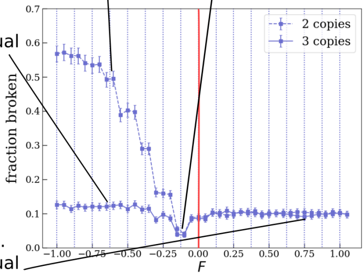
QLM QUANTUM LIGHT AND MATTER

- **One** or more copies correct ! Success!
- Fraction broken (f.b.): fraction of times **all copies** are broken.

2 copies: f.b. much greater than f.b. at F=0.

2,3 copies: f.b. less than f.b at F=0!

3 copies: f.b. greater or equal to f.b. at F=0



2,3 copies: f.b. greater or equal to f.b. at F=0.

- 10000 random 5 qubit Ising chain models
- $p = 4$ (17 allowed values [1; 1])

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3. Connected vs Separate Copies

- 10000 random examples of 5-10 qubit Ising spin glass models replicated onto 3 copies (triangle).
- Varied precision p from 1 to 10.

- Improvement increases with precision!

4. Can we do better?

- Connecting copies with anti-ferromagnetic couplings: sometimes works, sometimes doesn't.
- Fraction broken shows average effect.
- There could be further improvement!
- Developed a technique to try and harness this effect.
  - Works for small Ising spin chains.
  - Doesn't work for large Ising spin chains or spin glasses.
  - ! more work needed.

5. Conclusion

- Connecting three copies of a qubit Ising spin glass, with anti-ferromagnetic (F < 0) couplings is better for error suppression than three separate copies for all sizes tested so far.

- Inclusion of frustration in the structure of the connected copies is key to seeing this bene€cial effect.

- A technique which aims to add additional improvement to this error suppression, works on small sizes of Ising spin chains.

References

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