Experimental one-way quantum computing

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Introduction

- Quantum circuits are arranged similar to classical computers
- However, a circuit can be implemented in many ways (i.e. topological computer, KLM model, one-way)

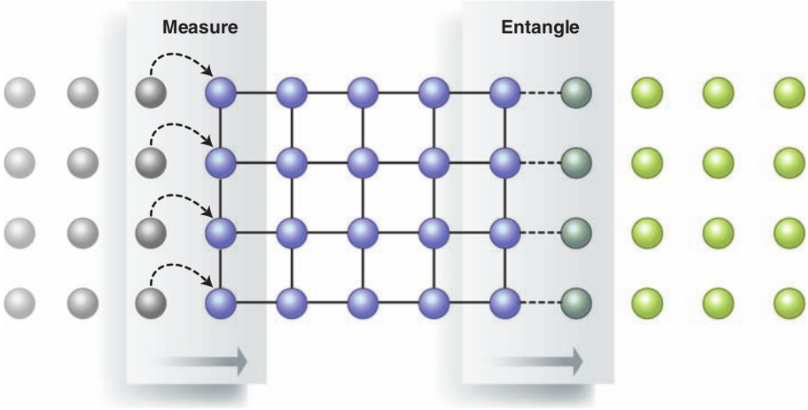
Why pursue such models?

- Original proposals were competing for scalability
- Ease of implementation

One-way quantum Computer

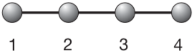
- Measurements do all the computation
- Special entangled state is the entire resource for the quantum computing
  - called a cluster state
- Different arrangements of single qubit measurements create different algorithms
  - ordering
  - measurement bases (feedforward)
- Not time reversible, i.e. it is one-way

Cluster States

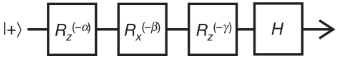


Cluster States

$$\begin{aligned}&|0\rangle_1|+\rangle_2|0\rangle_3|+\rangle_4\\+&|0\rangle_1|-\rangle_2|1\rangle_3|-\rangle_4\\+&|1\rangle_1|-\rangle_2|0\rangle_3|+\rangle_4\\+&|1\rangle_1|+\rangle_2|1\rangle_3|-\rangle_4\end{aligned}$$



Linear$^{(4)}$ cluster



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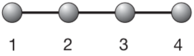
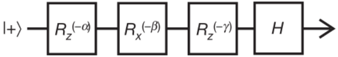


Linear(4) cluster



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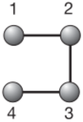
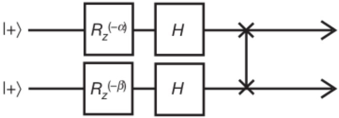
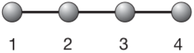


Horseshoe(4) cluster (rotated180º)

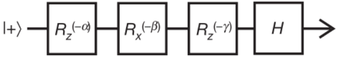


Cluster States

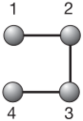
$$|0\rangle_1 |+\rangle_2 |0\rangle_3 |+\rangle_4 + |0\rangle_1 |-\rangle_2 |1\rangle_3 |-\rangle_4 + |1\rangle_1 |-\rangle_2 |0\rangle_3 |+\rangle_4 + |1\rangle_1 |+\rangle_2 |1\rangle_3 |-\rangle_4$$



Linear(4) cluster



$$|0\rangle_1 |+\rangle_2 |0\rangle_3 |+\rangle_4 + |0\rangle_1 |-\rangle_2 |1\rangle_3 |-\rangle_4 + |1\rangle_1 |-\rangle_2 |0\rangle_3 |+\rangle_4 + |1\rangle_1 |+\rangle_2 |1\rangle_3 |-\rangle_4$$



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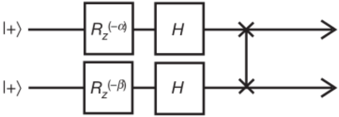
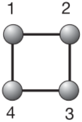
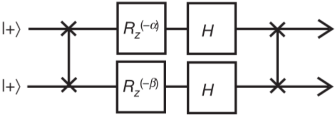


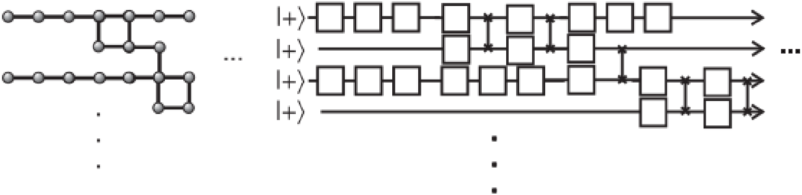
$$|0\rangle_1 |+\rangle_2 |0\rangle_3 |+\rangle_4 + |0\rangle_1 |-\rangle_2 |1\rangle_3 |-\rangle_4 + |1\rangle_1 |-\rangle_2 |0\rangle_3 |-\rangle_4 + |1\rangle_1 |+\rangle_2 |1\rangle_3 |+\rangle_4$$



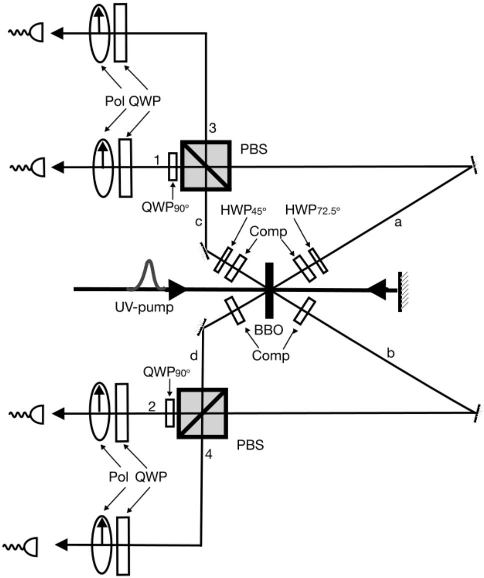
Box(4) cluster



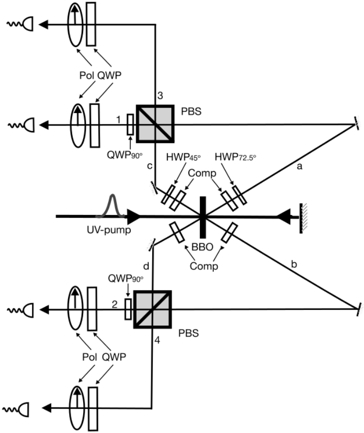
Cluster States



Cluster States



Cluster States



$$|\Phi_{\text{cluster}}\rangle = \frac{1}{2}\left(|HHHH\rangle + |HHVV\rangle + |VVHH\rangle - |VVVV\rangle\right)$$

Experiment

- Creation of the cluster state
  - Fidelity 0.63 ± 0.02 (above the threshold 0.5 for bi-separable four-qubit states)
- Implemented single qubit rotations
  - Fidelities from 0.58 ± 0.08 to $0.99^{+0.01}_{-0.02}$
- Implemented two qubit gates
  - Fidelities from 0.64 ± 0.05 to 0.94 ± 0.01
- Grover's search algorithm
  - Measurement in this specific application only introduce σ_z-errors, which can completely be corrected by post-processing
  - Probability of correct outcome around 90%

Conclusions

- First demonstration of a quantum algorithm in a cluster state computer
- Generated four qubit cluster states with optics
- Demonstrated a universal set of gate (single and two qubit)

Challenges

- Creation of cluster state can be improved (more qubits)
- Implement fast feedforward to change measurements in real time

Further reading

- R. Prevedel, P. Walther, F. Tiefenbacher, P. Bohi, R. Kaltenbaek, T. Jennewein, and A. Zeilinger.
  High-speed linear optics quantum computing using active feed-forward.
  Nature, 445(7123):65–69, Jan 2007.
- R. Raussendorf and H. J. Briegel.
  A One-Way Quantum Computer.
  Phys. Rev. Lett., 86:5188–5191, May 2001.
- P. Walther, K. J. Resch, T. Rudolph, E. Schenck, H. Weinfurter, V. Vedral, M. Aspelmeyer, and A. Zeilinger.
  Experimental one-way quantum computing.
  Nature, 434(7030):169–176, Mar 2005.

Thank you

Feedforward