Course Project, Spring 2016

# Cluster-State Quantum Computing

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**CIS410/510 Introduction to Quantum Information Theory**
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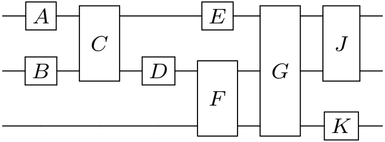



Arbitrary quantum circuit involving unitary operations on 3 qubits.

A new model, proposed by Briegel and Raussendorf [Raussendorf and Briegel, 2000], demonstrates that quantum computation can be achieved by using single qubit measurements as computational steps.

This so-called cluster model or *one-way quantum computer (1WQC)* relies on an entangled state of a large number of qubits or *cluster state* as the resource.

Interestingly, 1WQC's have no classical analogues and probe into new territory in regards to entanglement and measurements.

Basic teleporation

*Cluster states* form a class of multiparty entangled quantum states which belong to the larger set of so-called graph states.

*Examples of graph states:*

- *Bell states*
- *Greenberger-Horne-Zeilinger (GHZ) states*
- *states that appear in quantum error correction*

Intuitively, graph states can be thought of as multi-qubit states that can be represented by a graph.

- Each qubit is represented by a vertex of the graph
- An edge between vertices represents an interacting pair of qubits

A method to prepare cluster states is given in [Jorrand and Perdrix, 2005], consisting of “cascading” $C_z$ gates on $n$ qubits.

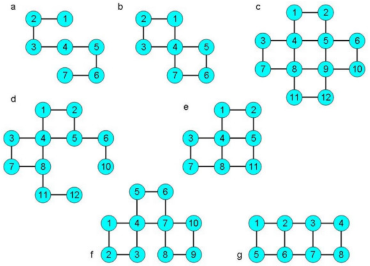
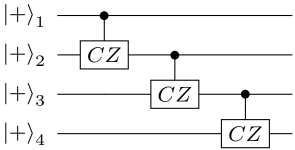
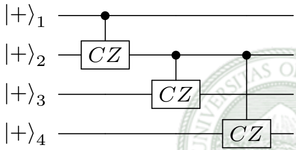



Figure: Figure showing representative 2-D cluster shapes. The vertices are qubits with integer indices, and the edges indicate entanglement connectivity between select neighbors.




A circuit to prepare a linear cluster state

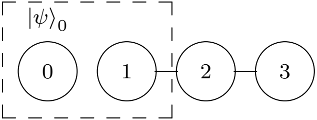



A circuit to prepare a non-linear cluster state

The spacial layout of the graph representation of the cluster state plays a role in the computational power of that state.

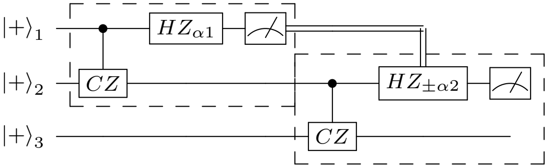
Operations on a linearly prepared cluster state can be efficiently simulated on a classical computer in $O(n \log^c(1/n))$, where $n$ is the initial number of qubits, and $c$ is the cost of floating point multiplication [Nielsen, 2006].

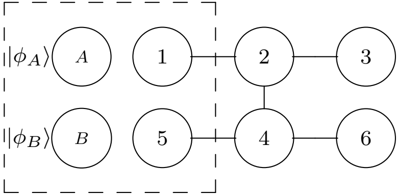
In general, measurement based models can be polynomial time reduced to the gate array model, and thus have the same power, but they are more easily parallelizable [Jozsa, 2006].



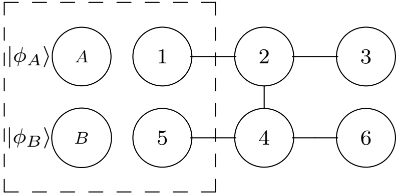

Gate $C_z^{(0,1)}$, followed by measurements $M_X^{(0)}$, $M_X^{(1)}$, & $M_X^{(2)}$.

Callback to teleportation discussion






Apply $C_z^{(A,1)}$ and $C_z^{(B,5)}$ to input quantum information into cluster state.

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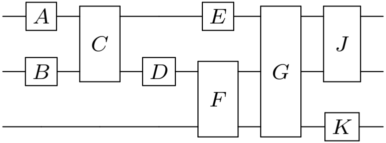
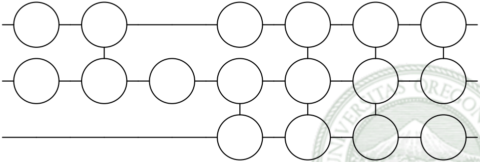
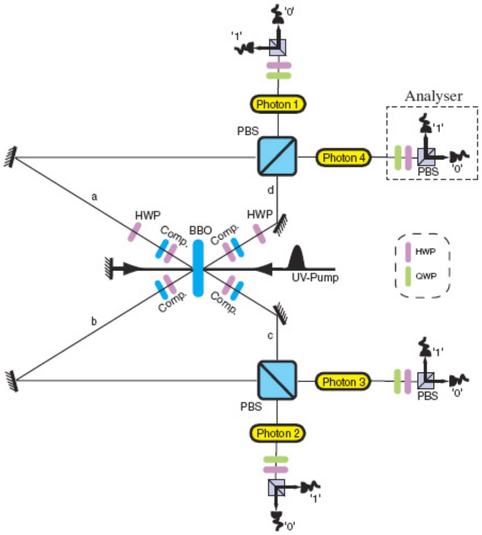
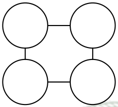


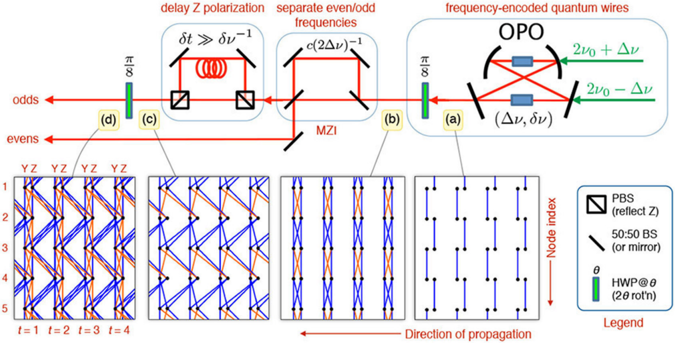
## Four Optical Qubit Cluster State




This generates a square cluster state. Two pairs of entangle photons are created and then separate pairs are entangled.



## Cluster States in Optical Frequency Combs



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Quantum computing via measurements only.

*eprint arXiv:quant-ph/0010033*.