Dogma and Heresy in Quantum Computing

DoRon Motter

February 18, 2002

Introduction

- **dog·ma** (dog-m&, 'däg-)
  - something held as an established opinion
  - a point of view or tenet put forth as authoritative without adequate grounds
- **her·e·sy** (her-&-sE)
  - an opinion or doctrine contrary to dogma
  - dissent or deviation from a dominant theory, opinion, or practice

Physical Implementation

- Scalable system with well characterized qubits
- Ability to initialize the state to a 'simple' state
- 'Long' decoherence times
- A "universal" set of quantum gates
- Qubit-specific measurement capability
- Ability to interconvert stationary and flying qubits
- Ability to faithfully transmit flying qubits between locations

Heresy

- Tenets have been laid out for physical implementation of quantum computation
  - Recognize these rules as simply a start
  - Attempt to explore their validity and reinterpret them
- Remainder of talk:
  - Implementations which sidestep some accepted notions

Universal Gates

- What set of gates is "universal?"

Universal Gates

- What set of gates is "universal?"
- CNOT + {one-bit gates}?

Universal Gates

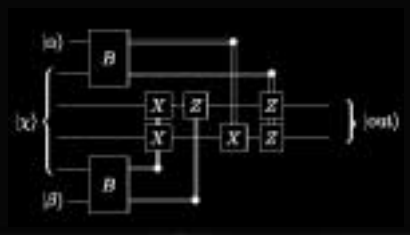
- What set of gates is "universal?"
- CNOT + {one-bit gates}?
- CNOT might be difficult to realize physically

Universal Gates

- [Gottesman Chuang 99] No two-qubit interactions need take place after the start of computation.
- Ideas
  - Use quantum teleportation as a primitive
  - Use measurement as a primitive
    - Use of measurement in gates was also explored ("programmable gates").

Universal Gates

- [Gottesman Chuang 99] CNOT can be performed using classically controlled single qubit operations, prior entanglement, and Bell basis measurements.



Universal Gates

- We have replaced CNOT with Bell basis measurements
- Some form of two-qubit interaction is necessary during execution of a quantum computer

Universal Gates

- We have replaced CNOT with Bell basis measurements

Universal Gates

- We have replaced CNOT with Bell basis measurements
- [Raussendorf Briegel] cluster-state entanglement

Cluster-State Entanglement

- Entire resource for computation is provided initially in the form of a cluster state
- Information is processed using one particle measurements only
- A physical realization of cluster states is outlined

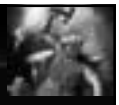
Exchange-Only QC

- Heisenburg interaction known to be "nice" for implementation
  - Accurate functional form
  - Strong interaction (fast gates
- Not universal
  - Cannot generate an arbitrary Unitary over spin-1/2 qubits

Exchange-Only QC

- Can encode qubits into states for which the spin number remains the same
- In principle a solved problem
- In practice, constant factor overhead

Precision in Gates



- Relatively many schemes have been introduced which add new perspective on computation
- However, each "gate" as the result of some Hamiltonian action must be done in a highly precise manner

Precision in Gates

- Relatively many schemes have been introduced which add new perspective on computation

Geometric Phases

- Even if gates are the result of interaction, it need not depend sensitively on H(t)
  - Sensitive effects are those that depend on dynamical phase
    - Change of state is linked to a change of energy as a function of time
  - Transformations based on geometric phase are insensitive to time profile of H(t)

Conclusions

- Theoretical and experimental work must progress for realization of QC
- From a Computer Science perspective
  - Accept quantum circuits as a model of computation
  - This stems from it being close to what a physical realization of QC might be
  - Other equivalent models of computation (QTM) are more abstract (and have few other advantages)
- Changes in the way quantum computers will be realized may have an effect on the model of computation used to describe them