The Future is Quantum Computing ?

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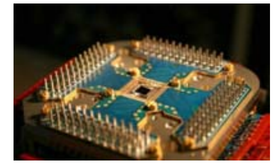
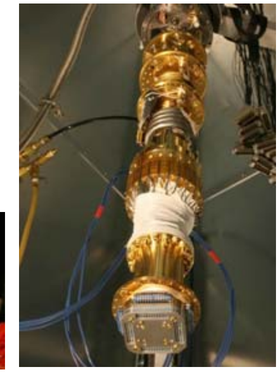
HotChips Panel
August 2007

Do quantum computers exist?

- Engadget headline: "World's first 'commercial' quantum computer solves Sudoku" (Feb 14th 2007)
  - "As expected, Canada's D-Wave Systems has announced 'the world's first commercially viable quantum computer,' and they seem to be pretty stoked about it. The achievement is notable, since they've managed to build a whole 16 qubit computer that actually does some simple computations, even if it's far less powerful than even the most basic of home computers."

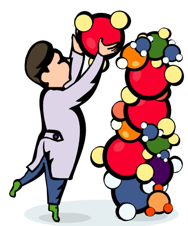




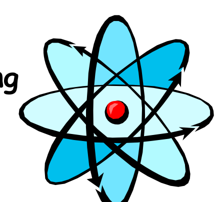
  - Clearly an important first problem to solve!
    - » Not clear that this machine actually works, however. A fair amount of suspicion that it is simply hype.
    - » Purports to use "Adiabatic Quantum Computing"

Ok, but why would you want a Quantum Computer?

- Suppose you want to:
  - Compute quantum properties of new materials in polynomial time
    - » So called "Quantum Simulation"
    - » This was the application that Richard Feynman proposed originally
  - Factor large numbers in polynomial time
    - » Shor's Algorithm
  - Find items in unsorted database in time proportional to square-root of n
    - » Grover's Algorithm



- Also: Its cool!
  - Quantum Computers would be interesting from a theoretical standpoint
  - Use properties of quantum mechanics to compute



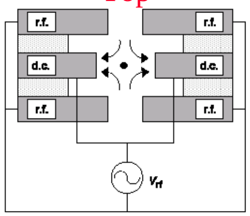
What are Quantum Computers?

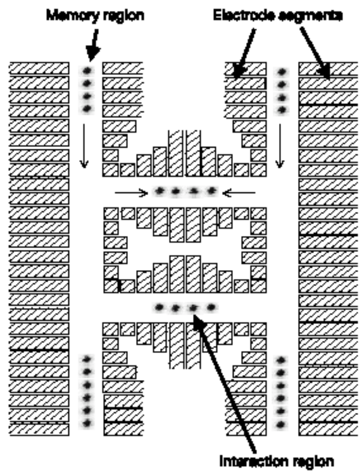
- Use of Quantization and Superposition to compute:
  - Quantization: Only certain values or orbits are good
  - Superposition: Schizophrenic physical elements don't quite know whether they are one thing or another
- Bits can be in a combination of "1" and "0":
  - Written as: $\Psi = C_0|0\rangle + C_1|1\rangle$, called a "qubit"
  - The C's are *complex numbers!*
    - » Important Constraint: $|C_0|^2 + |C_1|^2 = 1$ *[think probability]*
- Measurement (looking at bit) forces bit to be 0 or 1
- n-bit register can hold 2^n values *simultaneously!*
  - Called "Entanglement" between bits
  - 3-bit example:

$$\Psi = C_{000}|000\rangle + C_{001}|001\rangle + C_{010}|010\rangle + C_{011}|011\rangle + C_{100}|100\rangle + C_{101}|101\rangle + C_{110}|110\rangle + C_{111}|111\rangle$$

  - Multi-bit gates work on coefficients between bits.
    - » Universal set of gates required for arbitrary computation
- Fundamental Issue: Arbitrary Entanglement fragile!
  - Requires all information to be coded in QECC codes

ION Trap Quantum Computer: Promising technology



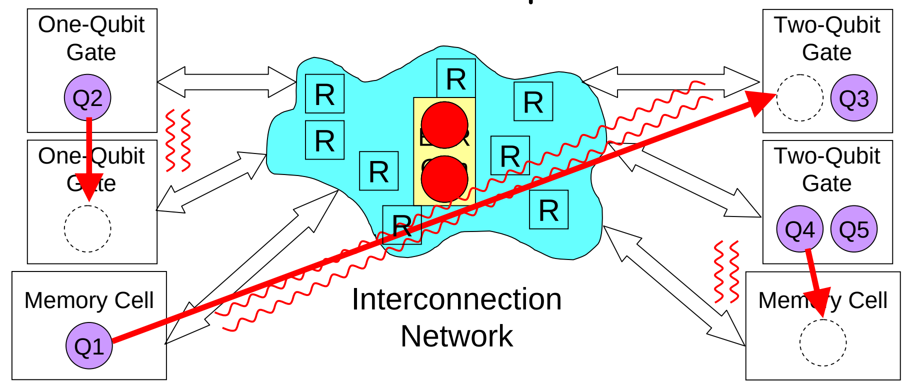


Top View
Proposal: NIST Group

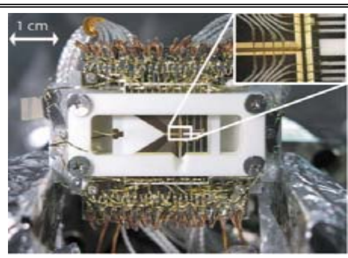
- IONS of Be^+ trapped in oscillating quadrature field
  - Internal electronic modes of IONS used for quantum bits
  - MEMs technology
  - Target? 50,000 ions
  - ROOM Temperature!
- Ions moved to interaction regions
  - Ions interactions with one another moderated by lasers

Interesting fact #314159: Use of Teleportation for cross-chip communication

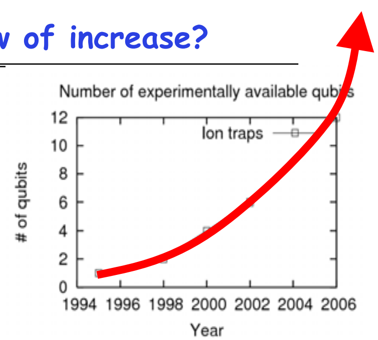
- Short-range communication is ballistic (movement)
- Errors accumulate with distance ⇒ Long-range communication via "Teleportation"
  - Teleportation uses EPR ("Einstein, Podolsky, Rosen") pairs of qubits at source and destination
  - EPR distribution network takes place of wires



Following a Moore's law of increase?



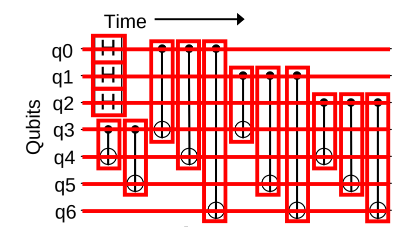
Courtesy of Monroe group at U. Mich.

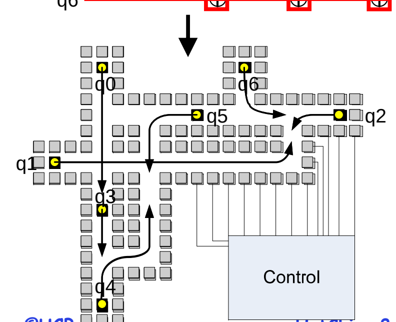


- DARPA Roadmap predicts 50 qubits by 2012
  - Ion traps: 30 qubits by 2008
- Quantum circuit design done by hand so far
- However:
  - Potential Complexity of layout and control
  - Verification of fault-tolerant properties
  - ⇒ Automation (CAD) desirable?

Use of CAD for Ion Trap Physical Layout

- Input: Gate level quantum circuit
  - Bit lines
  - 1-qubit gates
  - 2-qubit gates
- Output:
  - Layout of channels
  - Gate locations
  - Initial locations of qubit ions
  - Movement/gate schedule
  - Control for schedule





Closing Thoughts

- Quantum Computing is a "meta technology"
  - Any technology can be used if it:
    - » exhibits entanglement and is sufficiently insulated from environment
    - » Supports a basic set of operations between qubits
  - Ion traps are fairly promising technology
- Architecture of Quantum Computers actually an interesting topic with interesting challenges
  - Errors, Control, Communications
  - Not too early to be working on it
    - » Might be able to help with building first *real* quantum computer
- Quantum Entanglement very interesting property
  - Called "spooky action at a distance" by Einstein
  - Bits widely separated still "communicate" with each other
- Some papers:
  - http://qarc.cs.berkeley.edu/publications