

Quantum Computer Talk

by Daniel Wedul

Main topics

I Brief History

II The problem with current computers

III Outline of a quantum computer

IV The fundamentals behind a quantum computer

V Some gates of interest

VI Where we stand

(if time permits)

VII Deutsch's algorithm to test for multiple universes

- 1920s Copenhagen interpretation formed
- 1936 Alan Turing - Universal Model of computation
- 1957 Many Worlds interpretation proposed by Hugh Everett III
- 1960s Rolf Landaur “Computation is Physics”
- 1973 1st Electron isolated or “captured” - Hans Dehmelt
- 1977-8 David Deutsch proposes quantum computer as a method to test the multiple universes theory
- 1979 1st published model for a computer based on quantum mechanical components - Paul Benioff
- 1981 Feynman proposes a universal simulator that could simulate any physical situation in real-time or faster
- 1984 Feynman proposes a cleaner model for a computer based on quantum mechanics
- 1985 Deutsch’s paper 77-78 paper finally published
- 1985 Deutsch writes and has published another paper proposing a Universal quantum computer
- 1993 First potentially realizable quantum computer scheme published - Seth Lloyd
- 1994 Laser cooled ion traps realized as possible quantum registers - Ignazio Cirac and Peter Zoller
- 1997 A scheme for a quantum computer made of a cup of coffee printed in Popular Science
- 1998 First computer based on quantum mechanics
- 2010 Predicted end of Moore’s law

Moore's Laws

1. "The number of transistors in silicon chips doubles every 1.5 years."
2. "The cost of a chip manufacturing plant doubles every 4 years."

It currently costs about \$2 billion to build a chip manufacturing plant

The number of electrons used in each transistor is going down.

Currently most transistors use about 500 electrons.

The single electron transistor has been built but isn't practical because of cost.

Some problems that cannot be solved on classical computers

Traveling salesman problem - find the shortest route that goes through all cities.

Factoring (of large numbers) - factor a 100 digit number

Models of physical situations - as proposed by Feynman

Random numbers aren't really random - uses algorithms to produce numbers.

P vs NP and NP complete

P problems can be solved in polynomial time (short enough to do while we're alive)

NP problems cannot be solved in polynomial time

NP complete problems are problems that might be solvable in polynomial time but no one has found a method for doing it.

David Deutsch's Idea of a Universal Quantum Computer

A Universal Quantum Computer can

1. Act as Feynman's universal simulator
2. Do everything a classical computer can do
3. Take advantage of quantum parallelism to do things a classical computer cannot

Main concepts of Quantum Computers

A. Interference

B. Superposition

C. Qubits

D. Entanglement

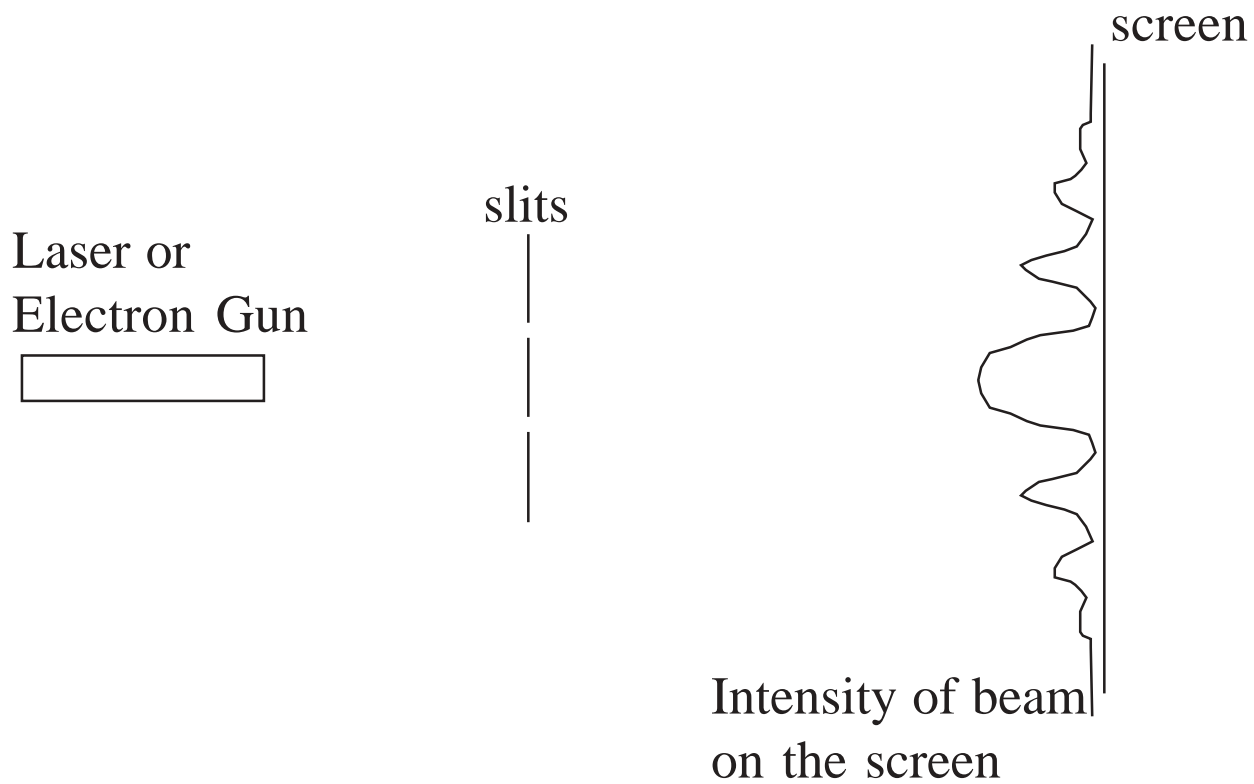
E. Decoherence and dissipation

F. Copenhagen interpretation

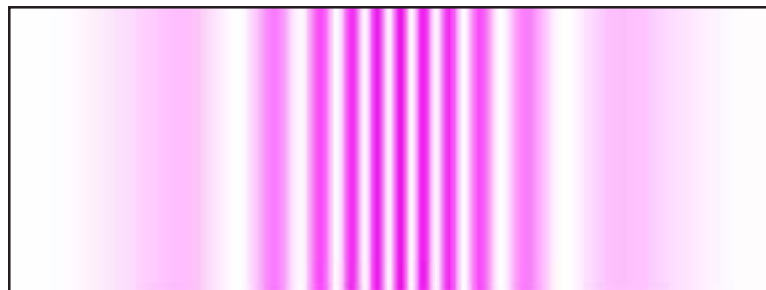
G. Many Worlds interpretation

Interference

Wavelike aspects of quantum particles can overlap one another to cause unusual and distinctive patterns



Interference pattern seen on screen.



Superposition:

The combination of two or more states

Examples

Particles with spin $+1/2$ or $-1/2$:

If something hits the particle with half the energy required to switch the spin then the particle has both spins

Polarization of photons:

If a vertically polarized photon goes through a polarizer at a 45 degree angle then the photon is both horizontally and vertically polarized.

Discrete energy levels in excited atoms:

An electron will jump to the next energy level if light is shone on it for a certain length of time. If the light is shone on the particle for $1/2$ that required time then the electron will occupy both energy levels.

Qubits:

A digital bit can have values of either 0 or 1

An analog bit can have any value from 0 to 1

A qubit (quantum bit) can have the value of both 0 and 1 at the same time. A qubit can be put in a superposition of states.

Entanglement

The ability of quantum systems to exhibit correlations between states within a superposition.

If two particles are entangled then, when measured, they will either always measure the same or always measure different.

Examples:

If an electron is excited to the second energy level and allowed to drop all the way to the ground state, it will release two entangled photons in opposite directions.

Einstein: “Spooky action at a distance”

Entanglement seems to allow information to travel faster than the speed of light because if the two particles are separated then how can they both know how to act when measured at the same time.

Decoherence and dissipation

Decoherence is when a qubit becomes entangled with its environment and no longer possesses the proper superposition

Dissipation is where a qubit loses energy to its environment (an electron naturally falling to a lower energy level)

It is extremely difficult to isolate a quantum entity from its environment

There are many different things that can disrupt a qubit; heat, cosmic rays, the structure holding the qubit, other qubits, just about anything.

Copenhagen interpretation

“There is no need to give intrinsic properties (i.e. position and velocity) to isolated quantum entities such as electrons”
Properties of quantum systems only make sense in the measurements made.

A quantum entity isn't there until it is measured.

Formed by Niels Bohr

Many Worlds interpretation

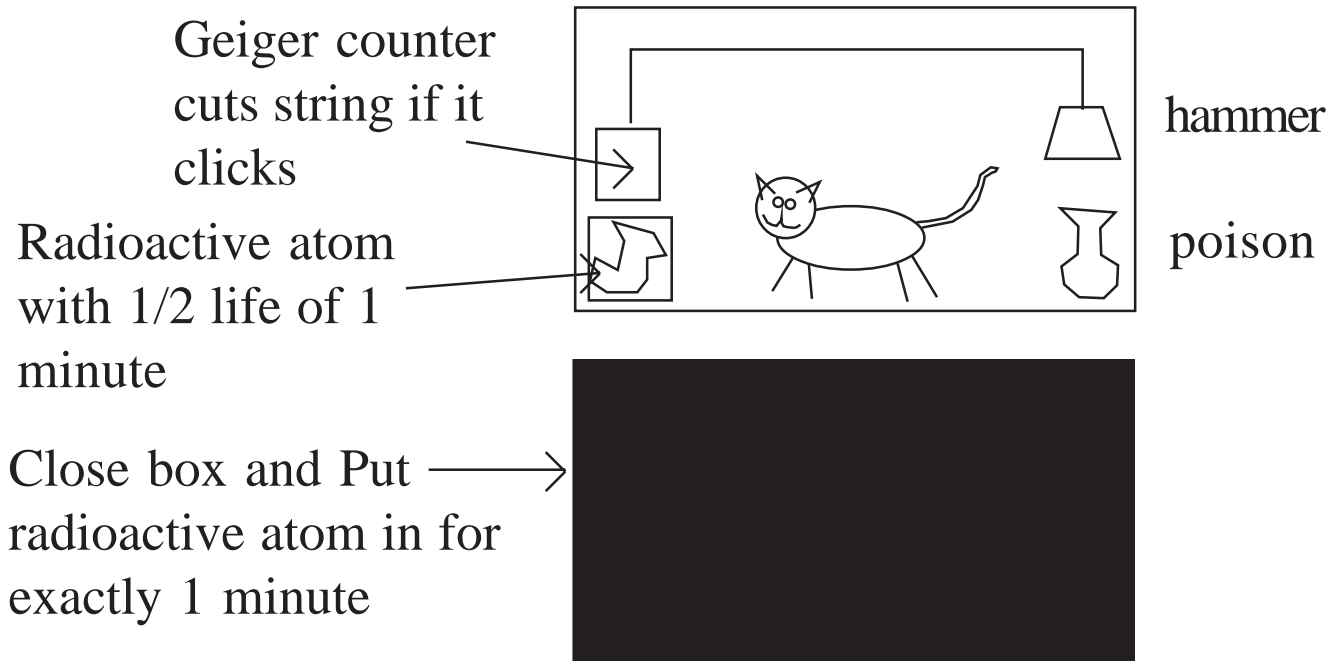
Any time a decision is made, The universe splits, In one universe one path is taken, and the other universe another path is taken.

or

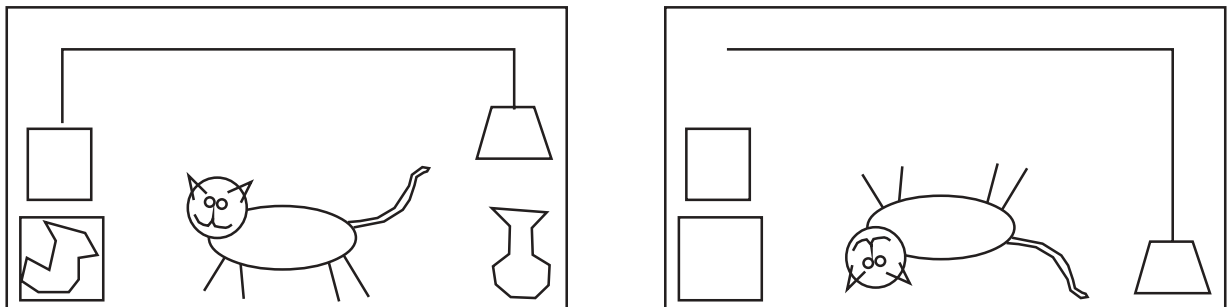
Any time we don't know what state something is in, Universes are created so that there is one universe for every state.

Formed by Hugh Everett III

Schrodinger's Cat (thought experiment only)



Possible outcomes



Copenhagen interpretation says: The idea of whether or not the cat is dead makes no sense till we open the box and look at the cat.

Many World interpretation: In one universe the cat is alive, and in another the cat is dead, by opening the box and looking at the cat we find out which universe we are in.

It Raises the question of “What counts as an observer?”

Basic concept

A quantum computer takes advantage of multiple universes by putting qubits into superpositions.

If we have 8 bits we can represent one of the numbers from 0 to 127.

If we have 8 qubits we can represent ALL of the numbers from 0 to 127 at the same time.

There will be 128 universes with a different number in each one.

By using interference between qubits we can create the “gates” required for computations.

As long as we don't look at a qubit it can retain it's superposition.

Some specific gates of interest

Square Root of Not:

Single qubit gate, one gate puts the qubit into a superposition of states. A second gate puts the qubit in the state opposite than when it started.

Hadamard gate:

Single qubit gate, one gate puts the qubit into a superposition of states, A second gate puts the qubit back to its original state.

2-qubit XOR gate: One qubit is the control qubit and remains unchanged. The second qubit is switched if the control qubit is on

In classic computing the NAND gate is used because placing NAND gates in certain orders can produce any truth table needed.

In quantum computing the 2-qubit XOR and the single qubit gates can combine to produce any outcome.

Where we stand

We have qubits galore!

“If we shine light right on anything it can be a qubit”

Qubits of special notice:

Heteropolymer (plastic)

Ion Trap

Cavity QED

NMR

Heteropolymer (plastic)

How it works:

Uses a linear array of atoms as memory cells.

Each atom can be in a grounded or excited state giving our 0 state and 1 state

Uses laser pulses to change between states

Positives:

Easy to get atoms in linear array and to access them with the laser

Both states are relatively stable

Negatives:

Difficult to get the atoms to interfere with one another

Very difficult to isolate the atoms so decoherence and dissipation are a problem

Ion Trap

How it works:

Uses electromagnetic fields to trap ions

Each atom can be in a grounded or excited state

A Beryllium ion can be used to encode two qubits

Positives:

Easy to trap the atoms and excite them.

Fairly easy to get the atoms to interfere with each other

1 atom can be used as 2 qubits

Negatives:

Only Neighboring atoms can interact so the number of qubits that are practical is small

Cavity QED (Quantum Electrodynamics)

How it works:

Uses the polarization of photons for the qubits

Positives:

XOR gate implemented and tested already

Negatives:

Only currently works on small quantum systems

It is difficult to store a photon

NMR (Nuclear Magnetic Resonance)

How it works:

Uses a test-tube-sized sample of some liquid

Each atom in the liquid is a qubit

Uses the spin of one of the nuclei of an atom in the molecules

Positives:

Uses current technology

Almost any liquid can be used

Negatives:

Decoheres very quickly because the system isn't isolated well (it's a liquid...)

Amount of liquid needed grows exponentially with the size of the problem.

Summary:

What we have

All the theory to drive the computers.

Several actual methods of implementing qubits

Many operations needed to do calculations

What we need to work on

#1: Decoherence - We need to be able to keep the qubits in superposition longer

#2: Systems that contain enough qubits to do interesting calculations. The current limit is about 50 qubits.

Deutsch's Method for testing the Multiple Universes Theory

1. Assume we have a fully functional quantum computer
2. Take one qubit and set it to 0
3. Apply a square root of NOT to that qubit
4. Have the computer look at the value of the qubit
 - In one Universe there will be a 0 and in another a 1
5. The computer announces that it has made the measurement.
6. The computer then "forgets" all knowledge of the value observed
 - This allows the Universes to still produce interference
7. Perform another square root of NOT operation on the qubit

Results:

If the Many Universes Theory is correct the measured value will always be 1. Otherwise it will randomly be 0 or 1