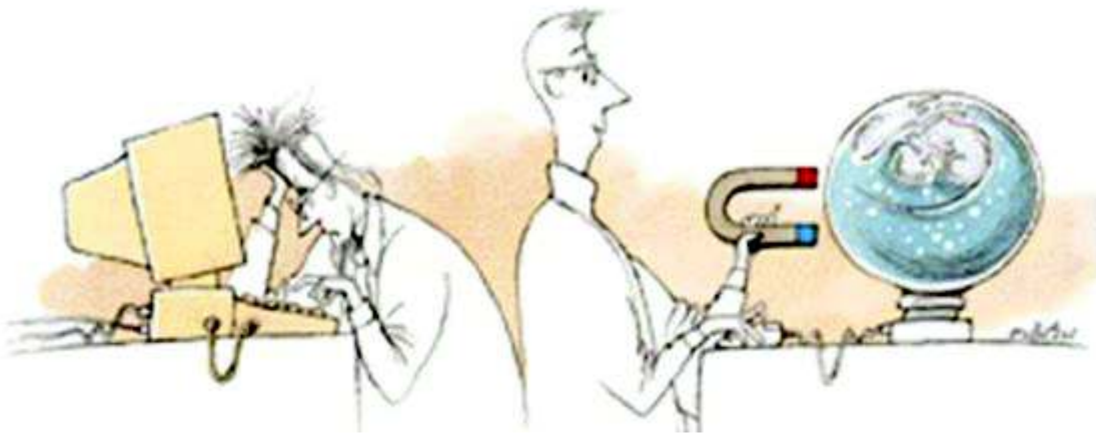
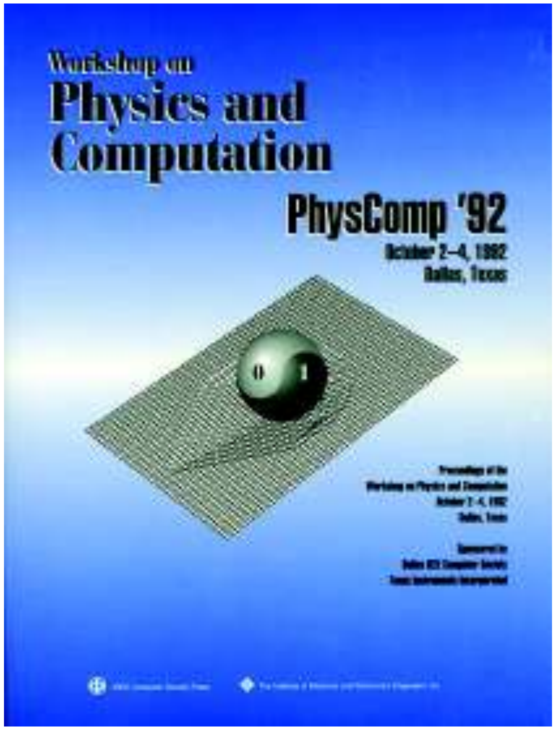


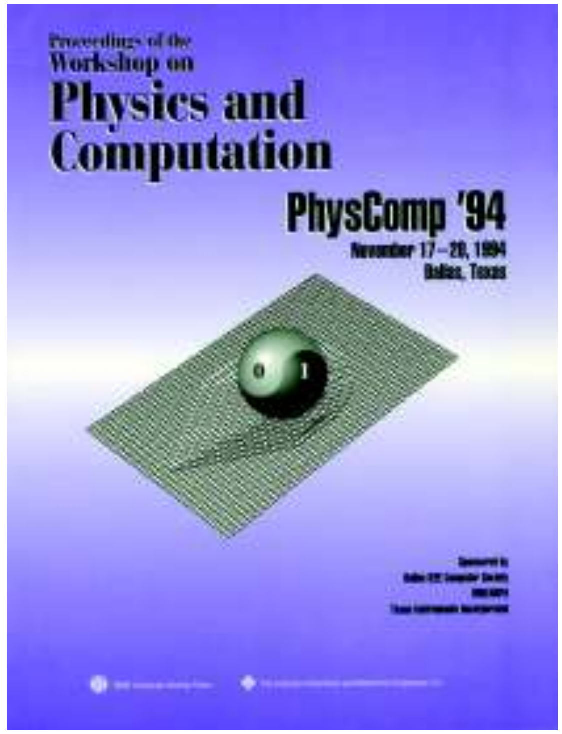
Primer on Quantum Machine Learning and AI

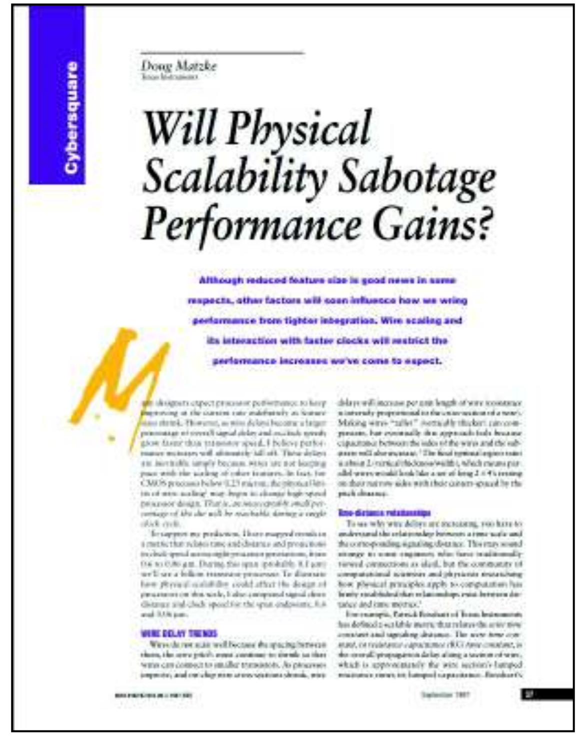
by Doug Matzke. Ph.D.
doug@quantumdoug.com

Presented at Dallas AI Meetup
Wed Jan 23, 2019

My Background in PhysComp/AI






Cybersquare

Doug Matzke

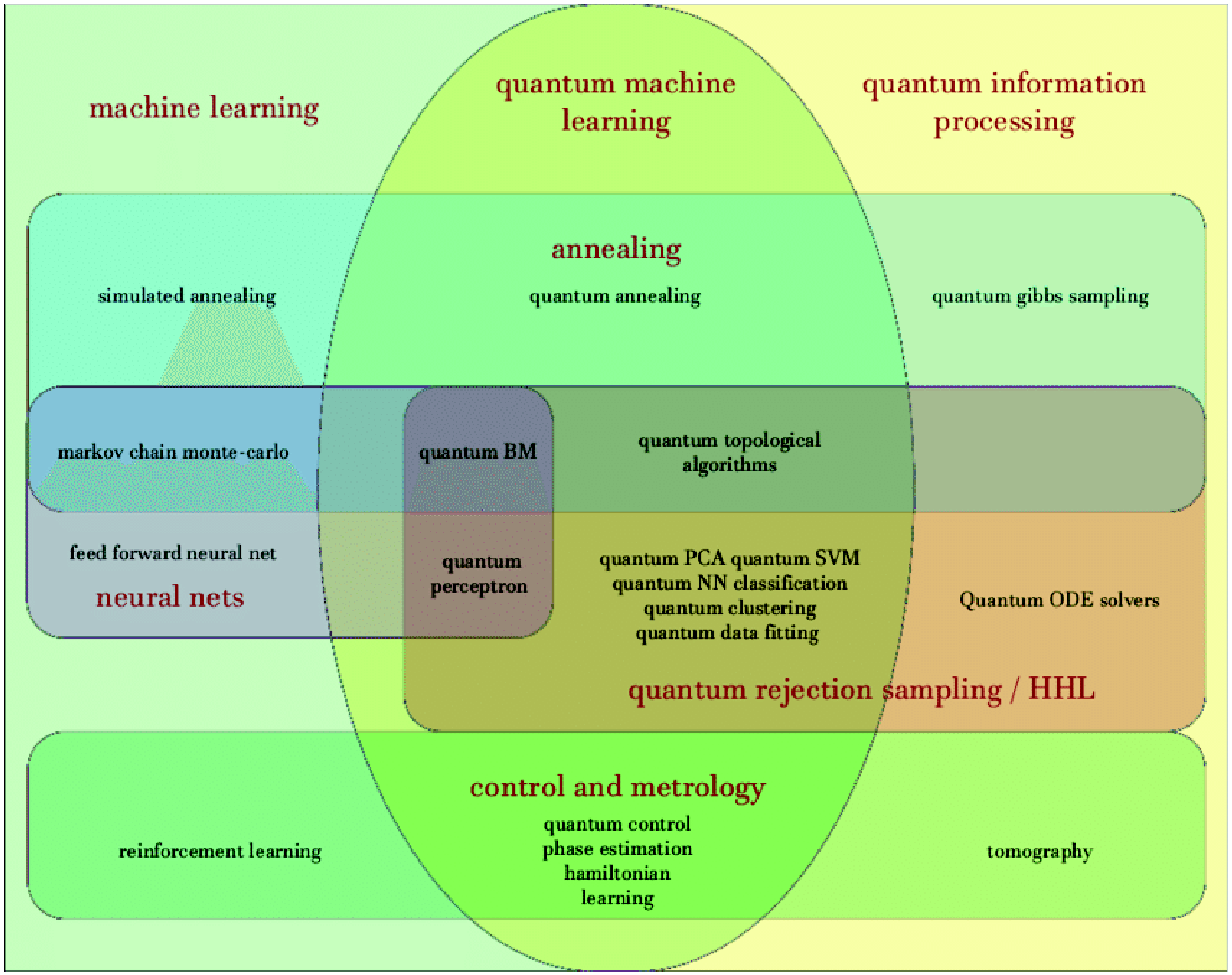
Will Physical Scalability Sabotage Performance Gains?

Although reduced feature size is good news in some respects, other factors will soon influence how we wring performance from tighter integration. Wire scaling and its interaction with faster clocks will restrict the performance increases we've come to expect.

Chairman of two PhysComp workshops on Physics and Computation
Lead off article in Computer Magazine Sept 1997 “Billion Transistor Computers”
Ph.D. at UTD in Quantum Computing using Geometric Algebra in 2002
Principle Investigator SBIR Grants for Quantum/Neural Computing 2003-2005
Created 13 patents issued or filed

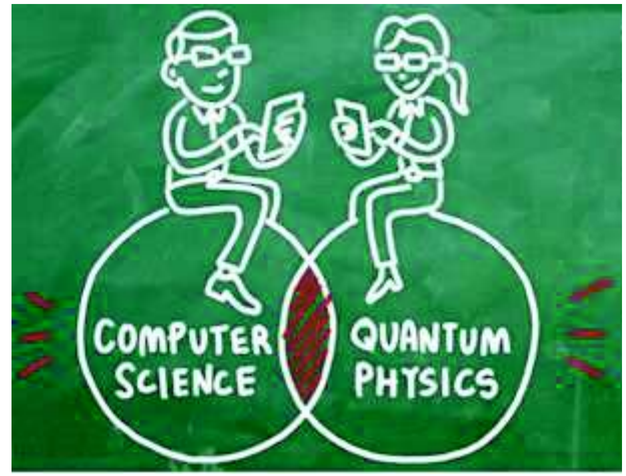
Quantum Machine Learning

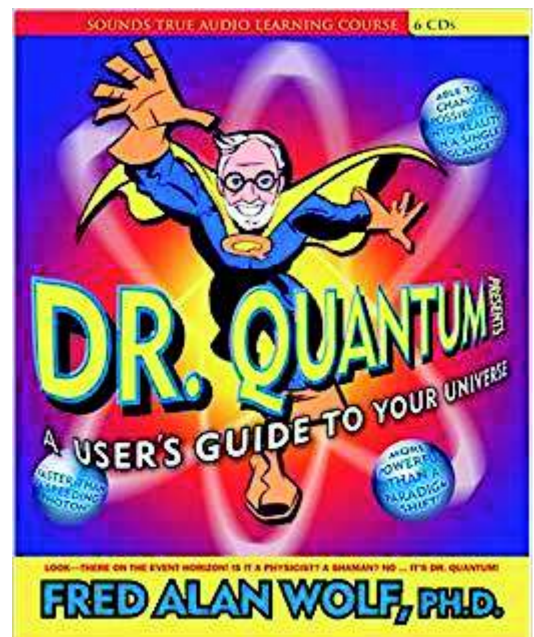
See paper: "Quantum Machine Learning", May 14, 2018,
J. Biamonte, P. Wittek, N. Pancotti, P. Rebentrost, N. Wiebe, and Seth Lloyd



Quantum Computing from Physics

- Particle wave duality
- Schrodinger's Cat
- Quantum States
- Quantum Probabilities
- Quantum Tunneling
- Quantum Noise
- Quantum Measurement
- Coherence/decoherence
- Heisenberg Uncertainty
- Reversible Phase Computing
- Dr. Quantum on YouTube
- PBS Spacetime on YouTube



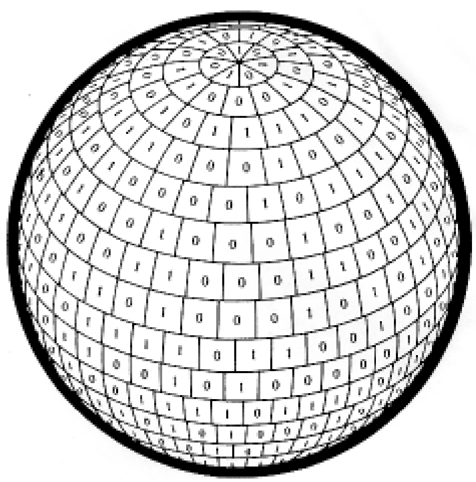


Information is Physical

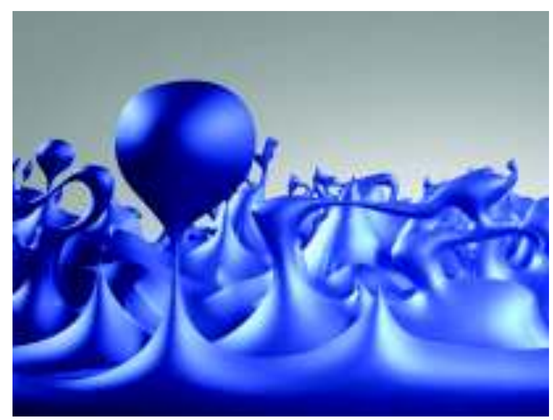
Bits are part of physics, not just computer science

- ➢Rolf Landauer: Information is Physical (bit = $kT \ln 2$)
- ➢Erasing of information effects thermodynamics
- ➢Reversible computing is essential to QuComputing
- ➢Bit is smallest increment to Black Hole (Planck area)
- ➢John Wheeler: “It from Bit” (quantum matrix)
- ➢Particle/Wave duality and Uncertainty Principle

“Quantum Matrix”

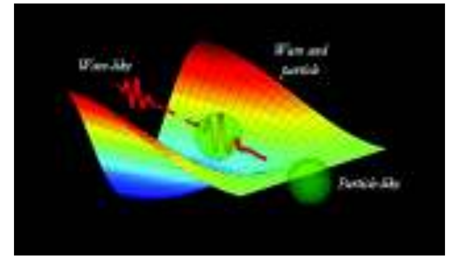


“It from Bit”

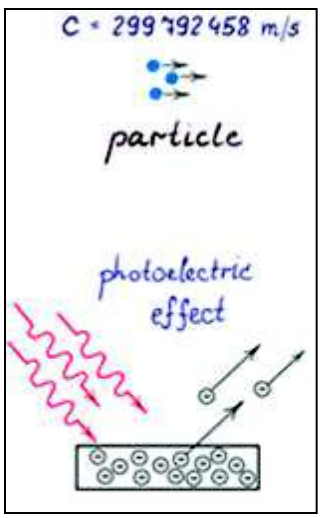


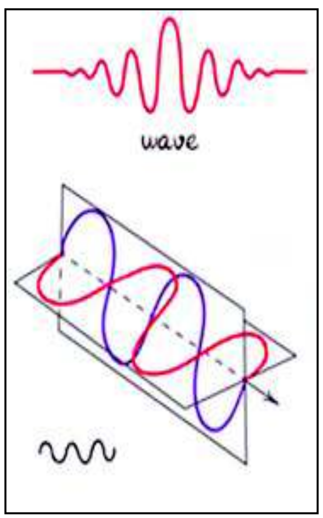
“Quantum Foam”

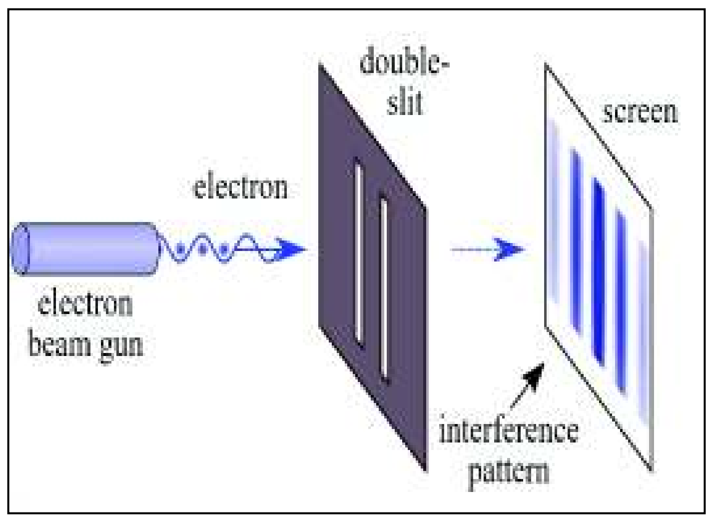
Quantized Waves

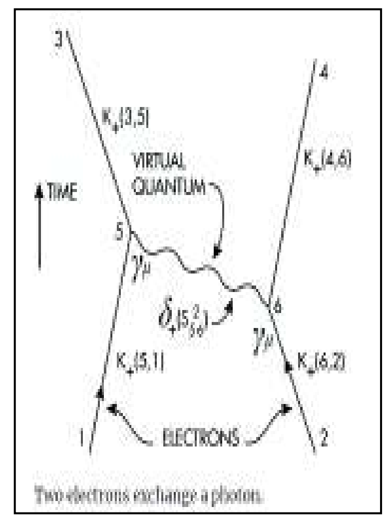


- Quantum states are distributed probability waves
- Photons/particles are quantized
- Waves/particles depending on measurement
- Waves construct even Planck Scale spacetime
- Self Consistent over all paths (Feynman diagrams)



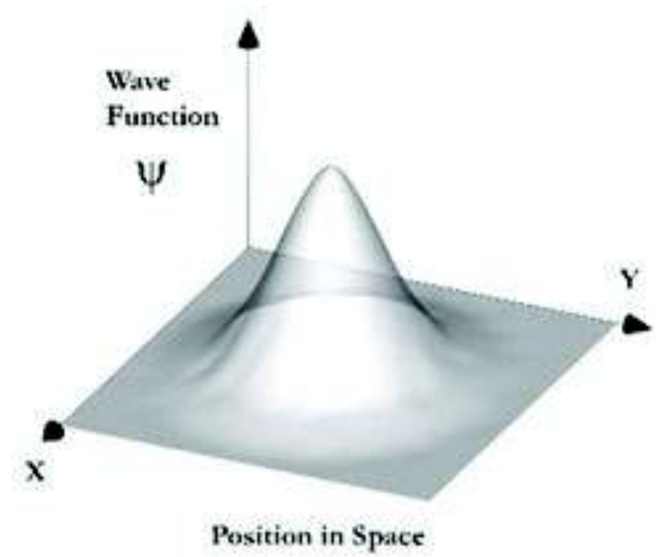


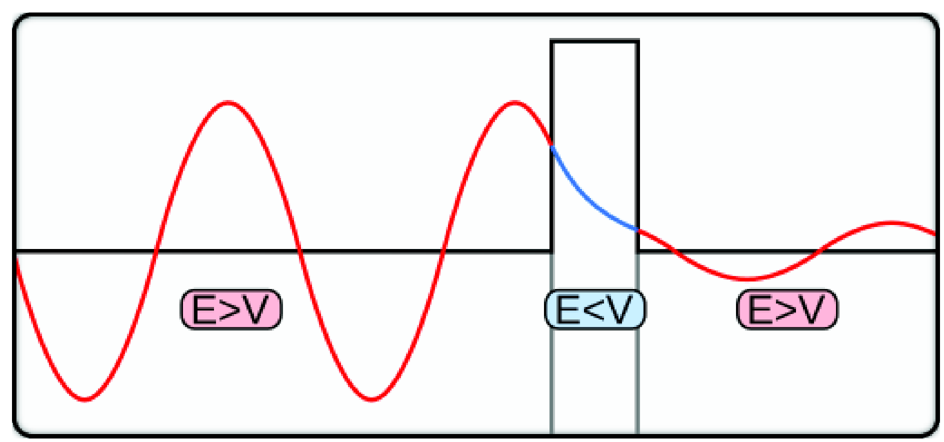




Quantum Tunneling

- Particle position is also a probability amplitude
- Probability amplitude is non-zero thru barrier (p>0)
- Probability the particle escapes energy barrier
- Superposition of position at atom/molecular level

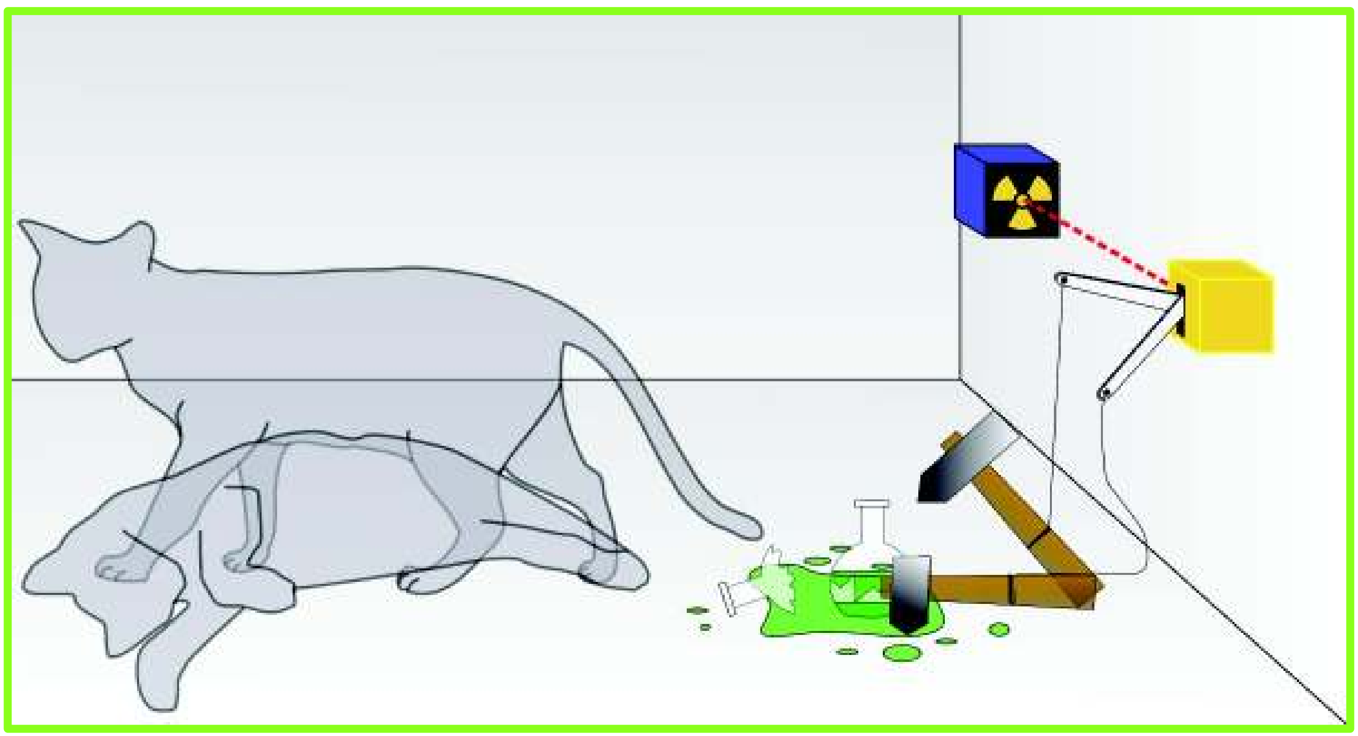




Schrodinger's Cat

Thought experiment about extent of probabilities:

- Quantum Probabilities at the Macro Scale?
- Cat Dead and/or Alive due to quantum prob



Heisenberg Uncertainty Principle

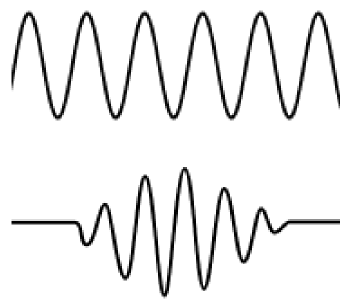
The position and the velocity of an object cannot both be simultaneously measured exactly, even in theory. This duality is due to non-commutative properties and is similar to how Fourier series frequency vs time conjugate information. So quantum mechanical systems have intrinsic uncertainty.

Uncertainty in momentum → Δp; Uncertainty in position → Δx

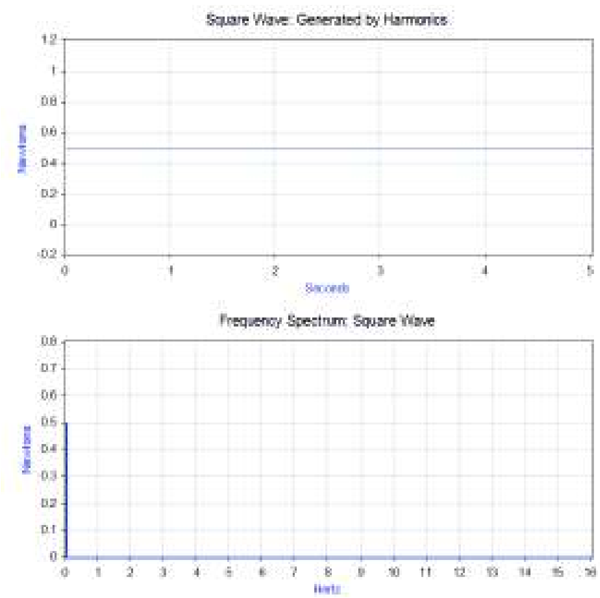
$$\Delta p \, \Delta x \geq \frac{1}{2} \hbar$$

$$\Delta E \, \Delta t \geq \frac{1}{2} \hbar$$

Uncertainty in energy → ΔE; Uncertainty in time → Δt



Wave packets



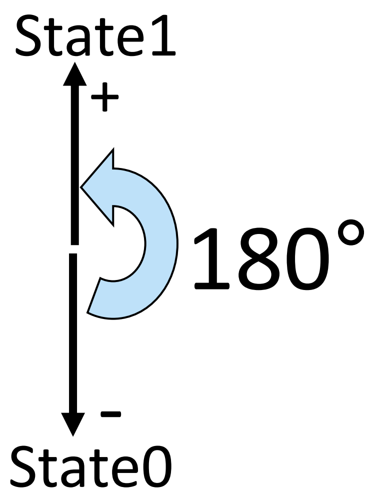
Affects our spacetime models

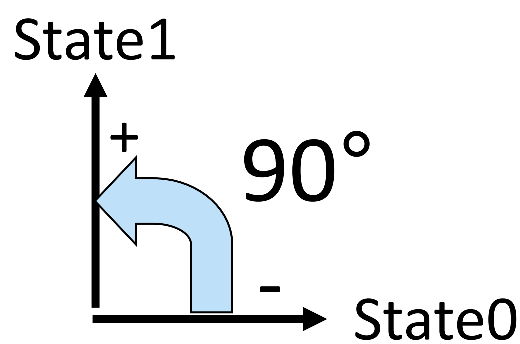
Qubit: two bits in Superposition

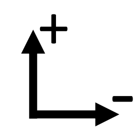
Superposition is a quantum property:

- ➢ Phase computing is source of all probabilities
- ➢ All states are simultaneous/concurrently present

Classical bit states: Mutually Exclusive	Quantum bit states: Orthogonal



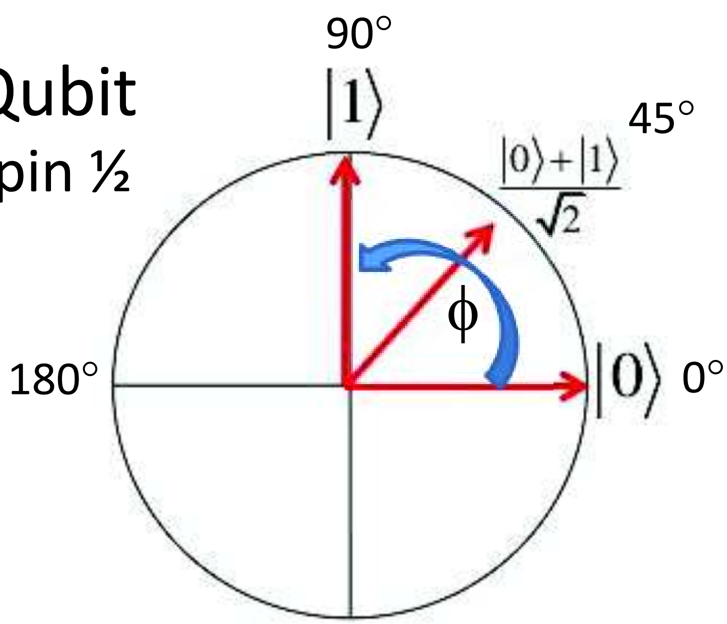




Probabilities from Qubits

- Bra-ket notation for matrices (Hilbert Spaces)
- Coefficients c_x are complex probability amplitudes
- Amplitudes squared c_x^2 are probabilities
- Unitarity: $c_0^2 + c_1^2 = 1$ (sum of probabilities is 1)
- Reversible phase based computing
- No-Cloning Theorem

Qubit
spin ½



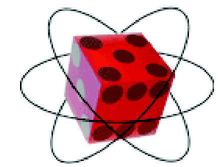
Superposition

$$c_0 |0\rangle + c_1 |1\rangle$$

$$state0_0 = |0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

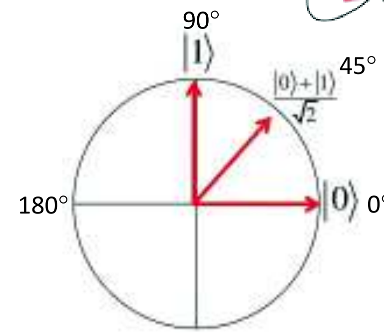
$$state1_0 = |1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

Operators for a Qubit



Reversible operations on a qubit

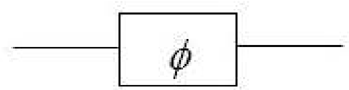
- Unitary Gate (no phase change)
- Phase Gate (rotate by some phase angle)
- Hadamard Gate (rotate by 45 degrees)
- Not Gate (rotate by 90 degrees)
- Invert Gate (rotate by 180 degrees)



$H|0\rangle \rightarrow \frac{|0\rangle+|1\rangle}{\sqrt{2}}$

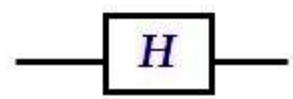
$X|0\rangle \rightarrow |1\rangle$

Phase Shift gate $\begin{pmatrix} 1 & 0 \\ 0 & e^{i\phi} \end{pmatrix}$



Hadamard gate
$\sqrt{NOT}$

$$H = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$



Pauli Noise gates
X=Not gate

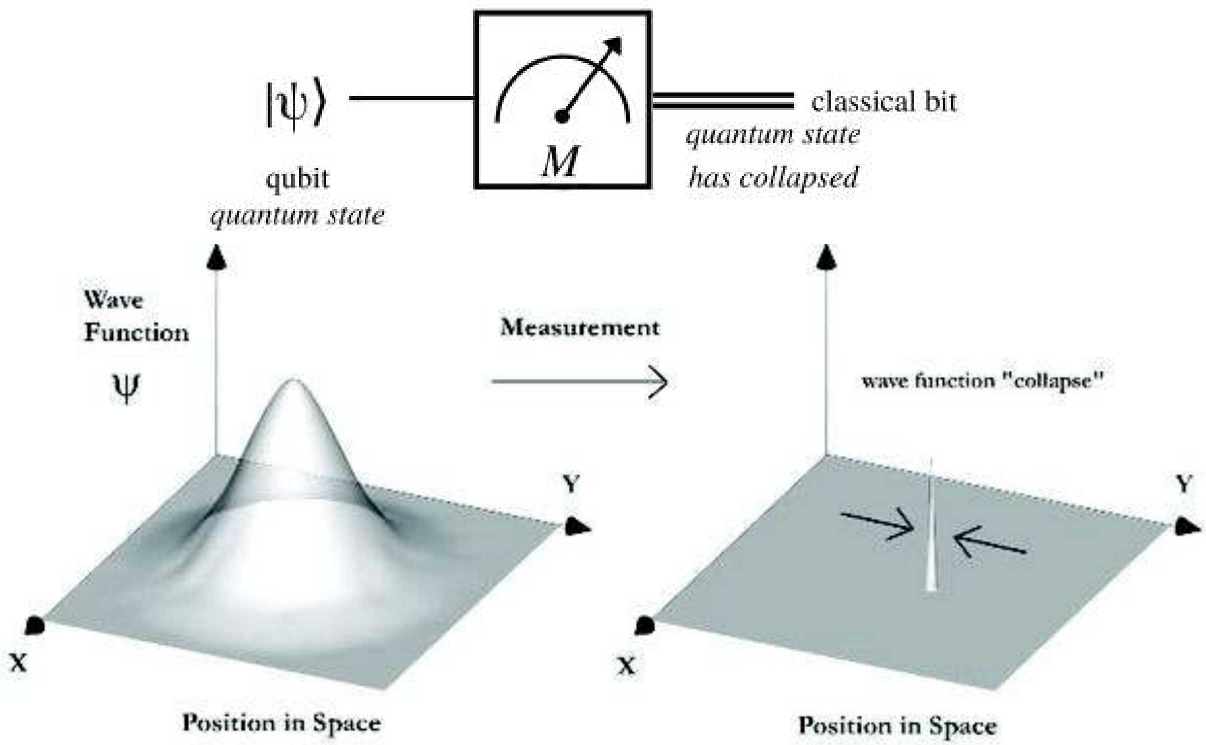
$$X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}; \quad Y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}; \quad Z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

See my other talk for 2-qubit and 3-qubit operators

Measurement on a Qubit

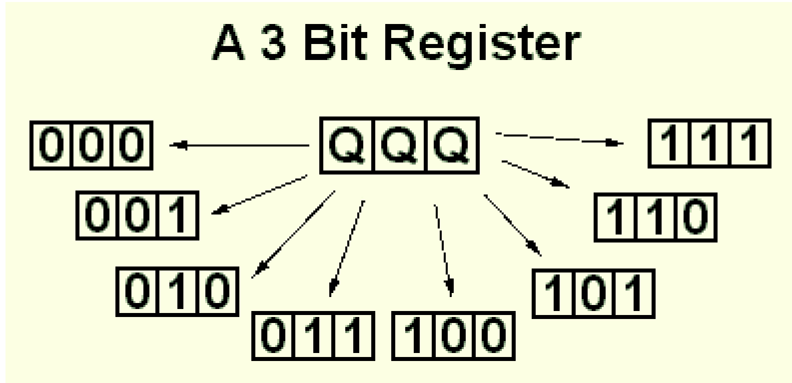
Irreversible operation on a qubit

- Measurement gives probabilistic result
- Probability is based on relative phase angle
- Collapse the wave function (Copenhagen Interpretation)



QuReg Amplifies Phase Computing

Q=R=S=($c_0|0\rangle$ + $c_1|1\rangle$)



$Q \otimes R \otimes S$

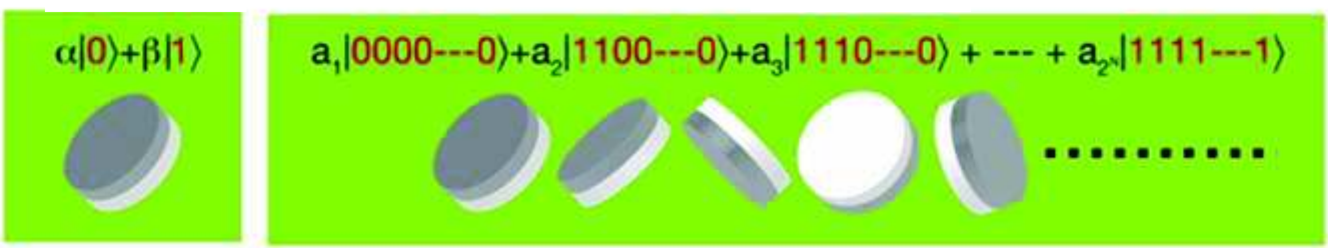
$$+c_0|000\rangle$$
$$+c_1|001\rangle$$
$$+c_2|010\rangle$$
$$+c_3|011\rangle$$
$$+c_4|100\rangle$$
$$+c_5|101\rangle$$
$$+c_6|110\rangle$$
$$+c_7|111\rangle$$

1 Bit *N Bits*

Either 0 or 1 **One out of 2^N possible permutations**

$$\sum c_i^2=1$$

1 Qubit *N Qubits*



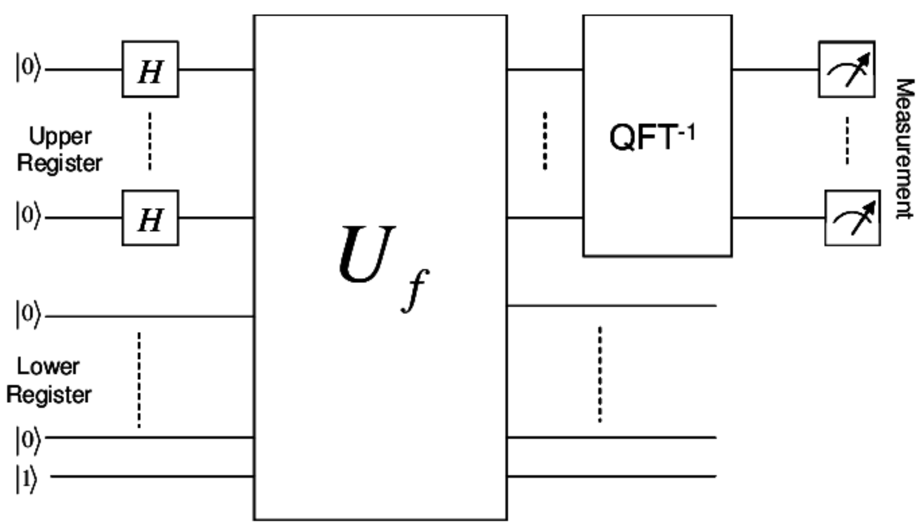
Both 0 and 1 **All of 2^N possible permutations**

for q=300 qubits,
2^{300} > # particles
in known universe

1994 Peter Shor's algorithm

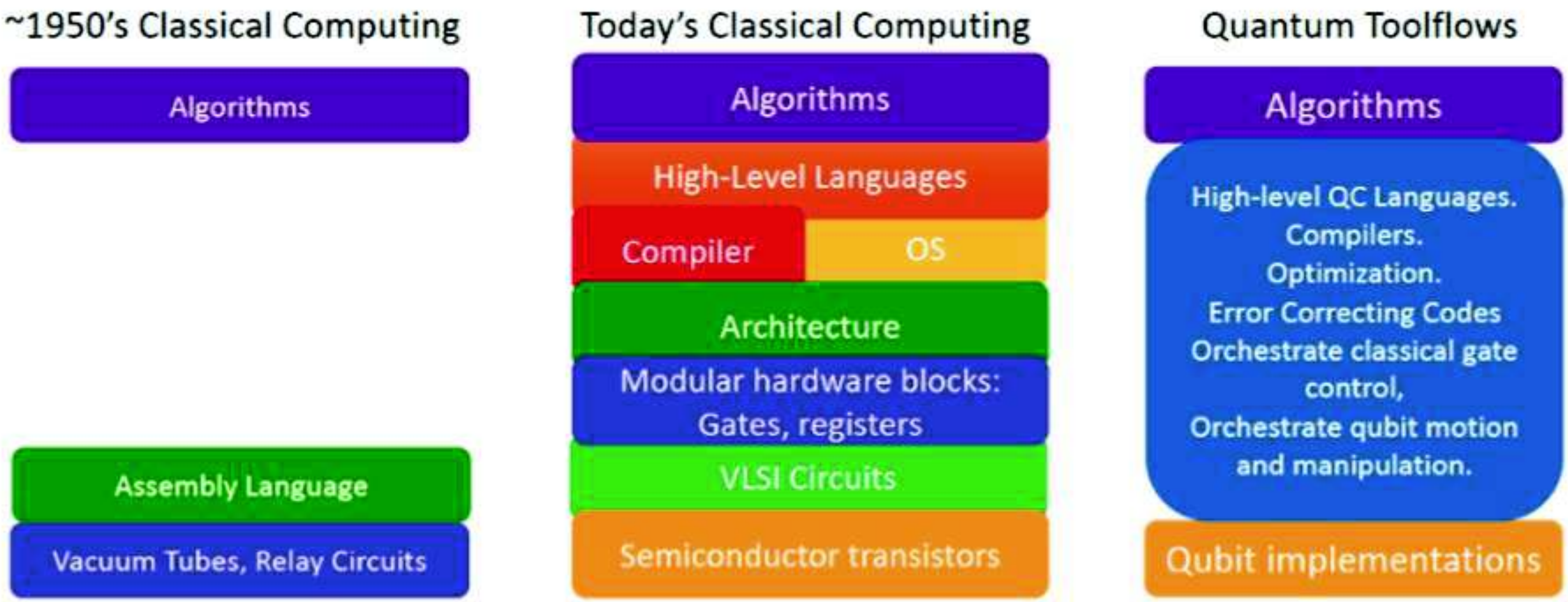
Shor's algorithm is a quantum algorithm:

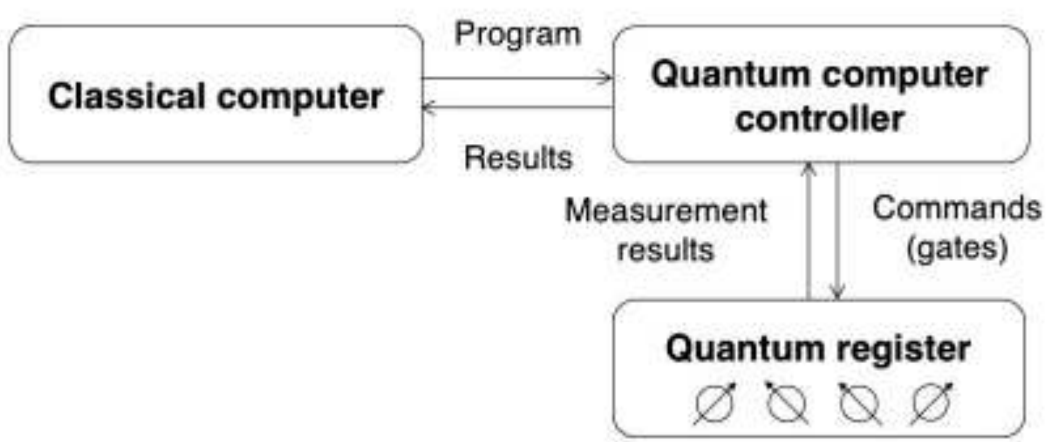
- Uses all 2^q simultaneous states to solve problem (QFT)
- Efficiently solves factoring, impossible by classical computers
- Killer application for Quantum Computers
- Defined new complexity class: Quantum Polynomial time



Spurred the development of quantum computing, quantum encryption technology and other quantum algorithms.

Quantum Software Flows

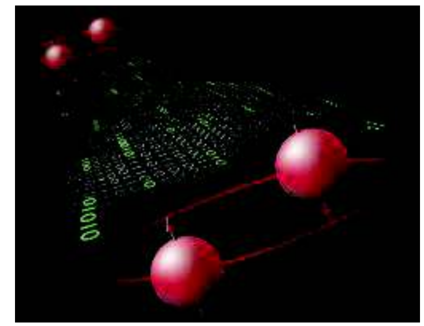


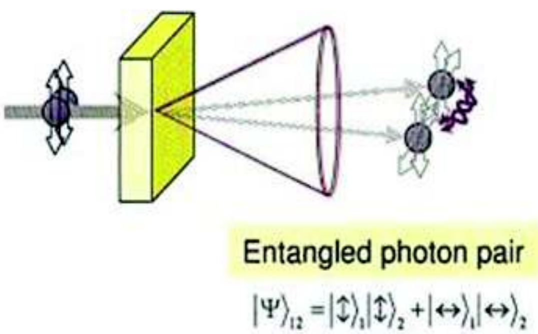


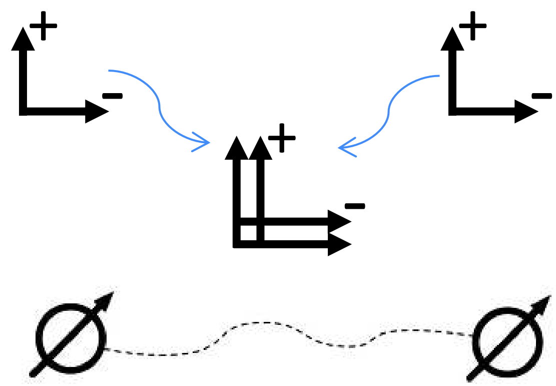
Ebits: Entangled Qubits

Entanglement is a quantum property:

- ➢Multiple things (2 Qubits) acting as one
- ➢Contains *inseparable* quantum states
- ➢Non-locality due to >3 dimensions
- ➢Einstein's "Spooky action at a distance"
- ➢EPR and Bell/Magic states/operators are well defined







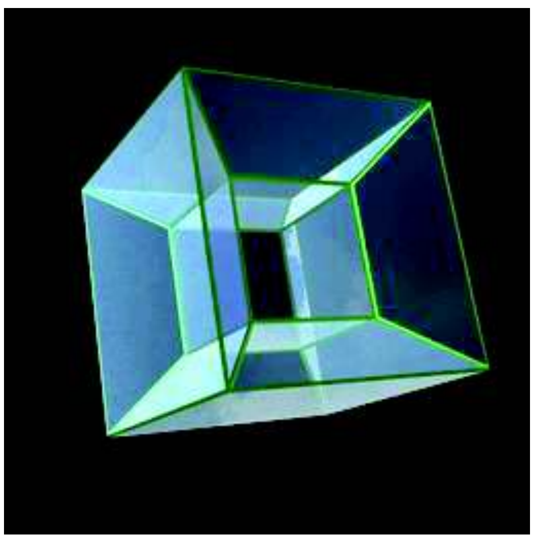
$$\Phi^{\pm} = |00\rangle \pm |11\rangle$$

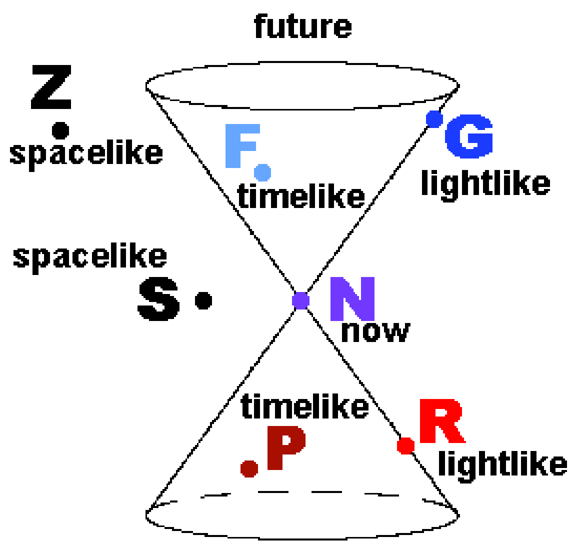
$$\Psi^{\pm} = |01\rangle \pm |10\rangle$$

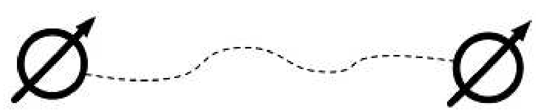
Entanglement is Space-like

Non-local connection due to 4 dimensional states

- Every ebit contains 4 private dimensions (beyond 3d+1t)
- Self consistency even though space-like states
- Ebits useful for secure communication Quantum Key Distribution
- My research shows space-time itself is entangled (tauquernions)
- My research shows dark-matter/energy is entangled







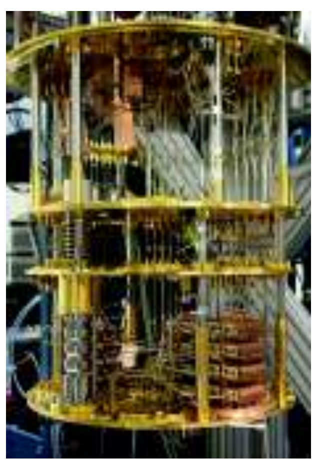
Quantum Speedup and Supremacy

A universal quantum computer >50 Qubits will quickly solve problems no classical computer can solve!!

Killer app is Shor's algorithm.

D-Wave

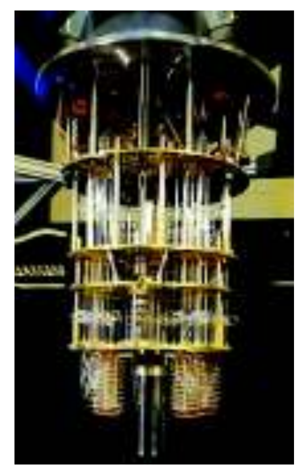
IBM



Google

Microsoft

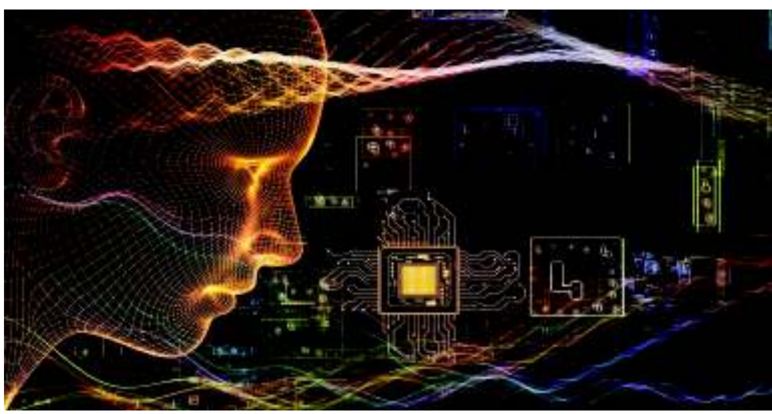
Intel



Quantum and Neural Computing

Both quantum and neural computing use hyperdimensional math models

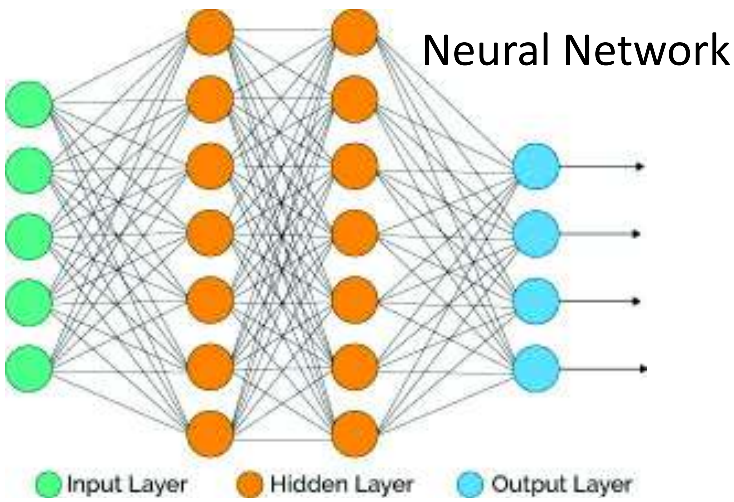
Company	Qubits	Quantum Computing	AI Computing Technology
IBM	50 qubits	Longest Time: Online IBM Q	Deep Blue & IBM Watson
Google	72 qubits	D-Wave and Bristlecone chip	TensorFlow & AlphaGo Chip
Intel	49 qubits	Tangle-Lake chip	neuromorphic chip “Loihi”
Microsoft	unknown	Topological qubits (anyons)	FPGA computing and Augmented Reality
D-Wave	2000 qubits	Adiabatic Computing	Optimization algorithms
many		Computers & Communications	deep learning neural nets

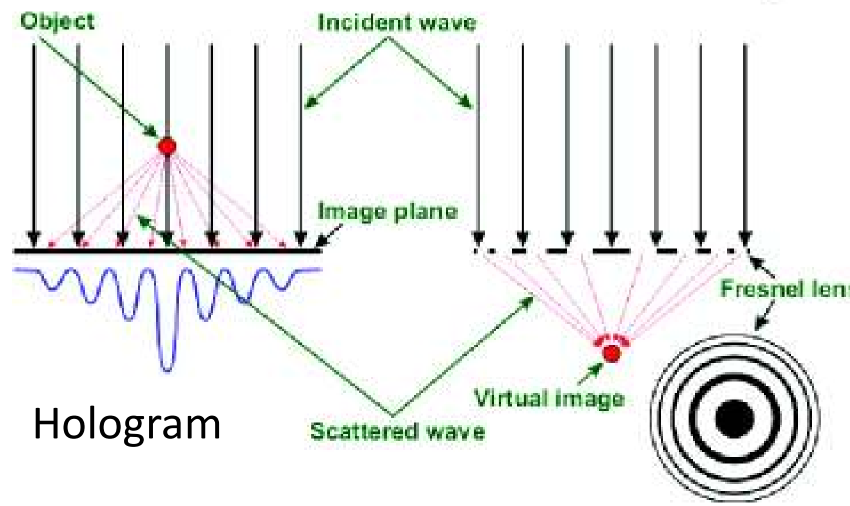


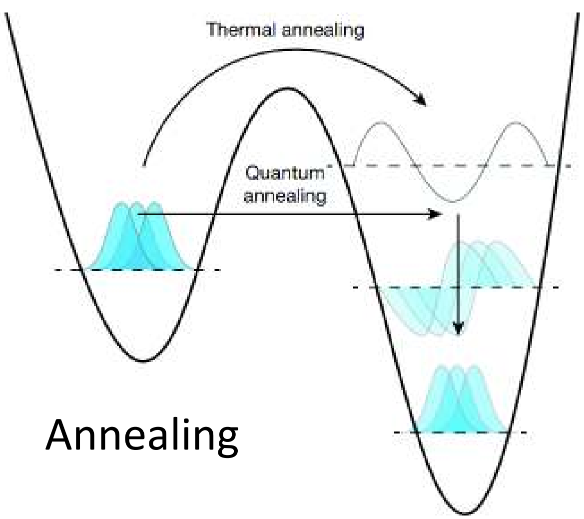
Hyperdimensional Landscapes

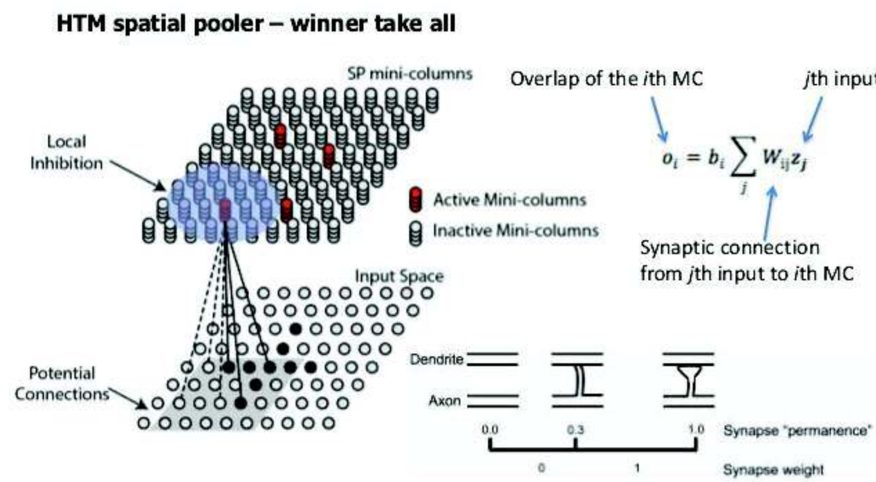
Quantum and AI share hypermath sums

$$o_i = b_i \sum_j W_{ij} z_j$$





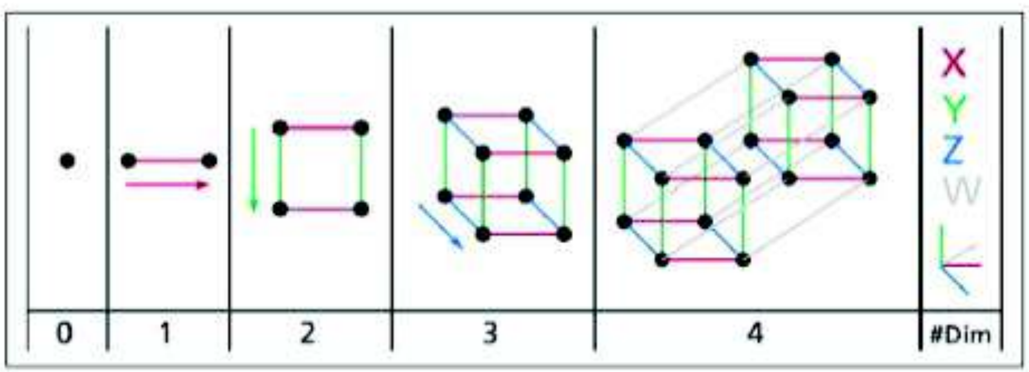


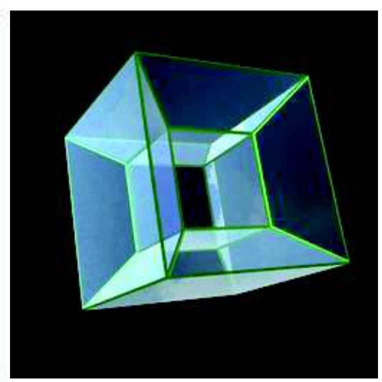


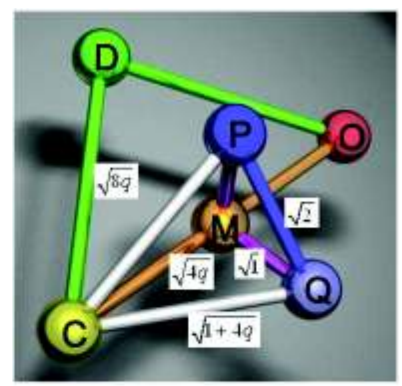
Curse of Dimensionality (it's a thing)

As the number of D features/dimensions grows:

- The possible subsets grows exponentially as 2^D
- Clustering requires knowing dims to include/exclude
- No efficient hyperdimensional radar/sonar algorithm
- Non-intuitive geometry and probabilistic geometry
- Points spread-out to the hyper-volume surface/corners
- Similarity measures looks like distance measures.
- Searching for "answers" requires massive parallelism

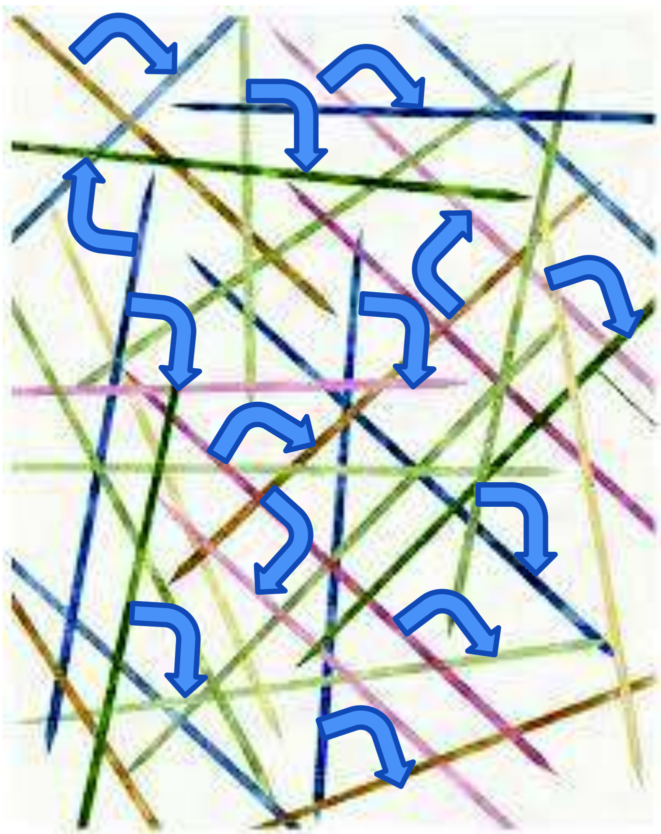




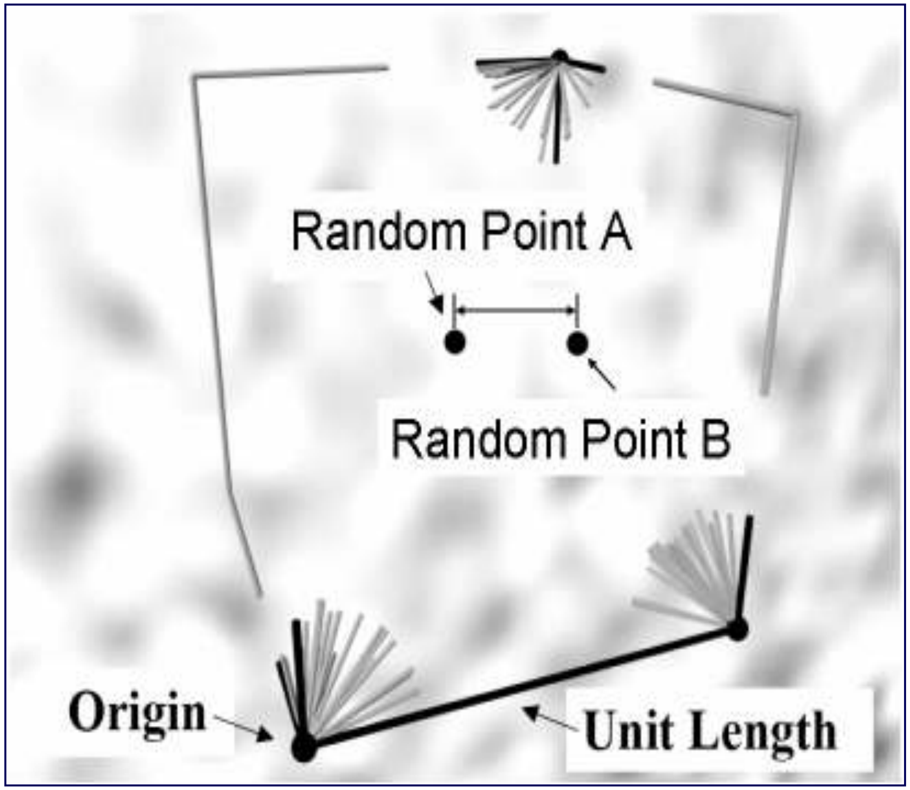


Visualizing hyperdimensions

Orthogonal dimensions



Points in hyperdimensions

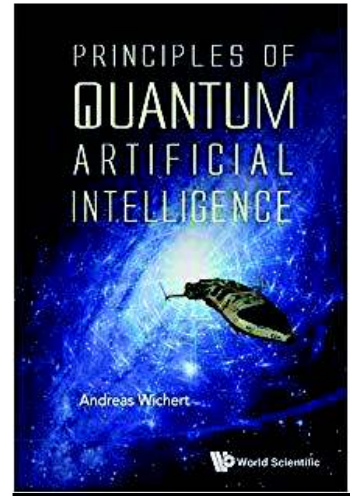


Cannot be embedded in three dimensions or 2D hologram!!

Is Quantum useful for AI?

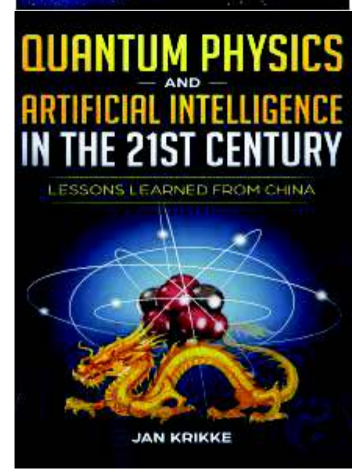
Quantum Advantages:

- Quantum Dimensions are real vs simulated (supremacy)
- Quantum superposition, entanglement and probabilities
- Quantum speedup over classical algorithms
- Quantum parallelism (QFFT, search, annealing, etc.)
- Quantum self-consistency across space/time
- Quantum enables different quantum complexity classes



Quantum Disadvantages:

- No Cloning, uncertainty and measurement bias
- Extremely exotic hardware with limited access
- No long term state storage (fragile and transient)
- Need for quantum error correction?
- Not clear how to build “universal” quantum computer
- Steep learning curve for Quantum Algorithms Math
- Choreograph quantum interference patterns to AI algorithms
- All applications might not be possible in quantum computers
- Not clear what are key applications to work on first.



Elephant in the room: Myth of AI?

"In the next 10 years we will have GAI using techology X!"

- AI researchers have been predicting this for 60 years
- AI assumes Real Intelligence is due to classical brain
- Deep Learning appears useful and effective (AlphaGo)
- Deep Neural Nets work but not sure how
- AI does not have any meaning (The Chinese Room)
- Quantum and correlithms and are both hyperdimensional
- Are real dimensions required for AI efficiency/scalability?
- Probabilistic cloud states at all levels of hierarchy
- Space-like states cannot be harnessed inside 3D
- Quantum based AI may have evolutionary advantages

Is Real Intelligence Classical or Quantum?

Conclusions: AI and the Quantum

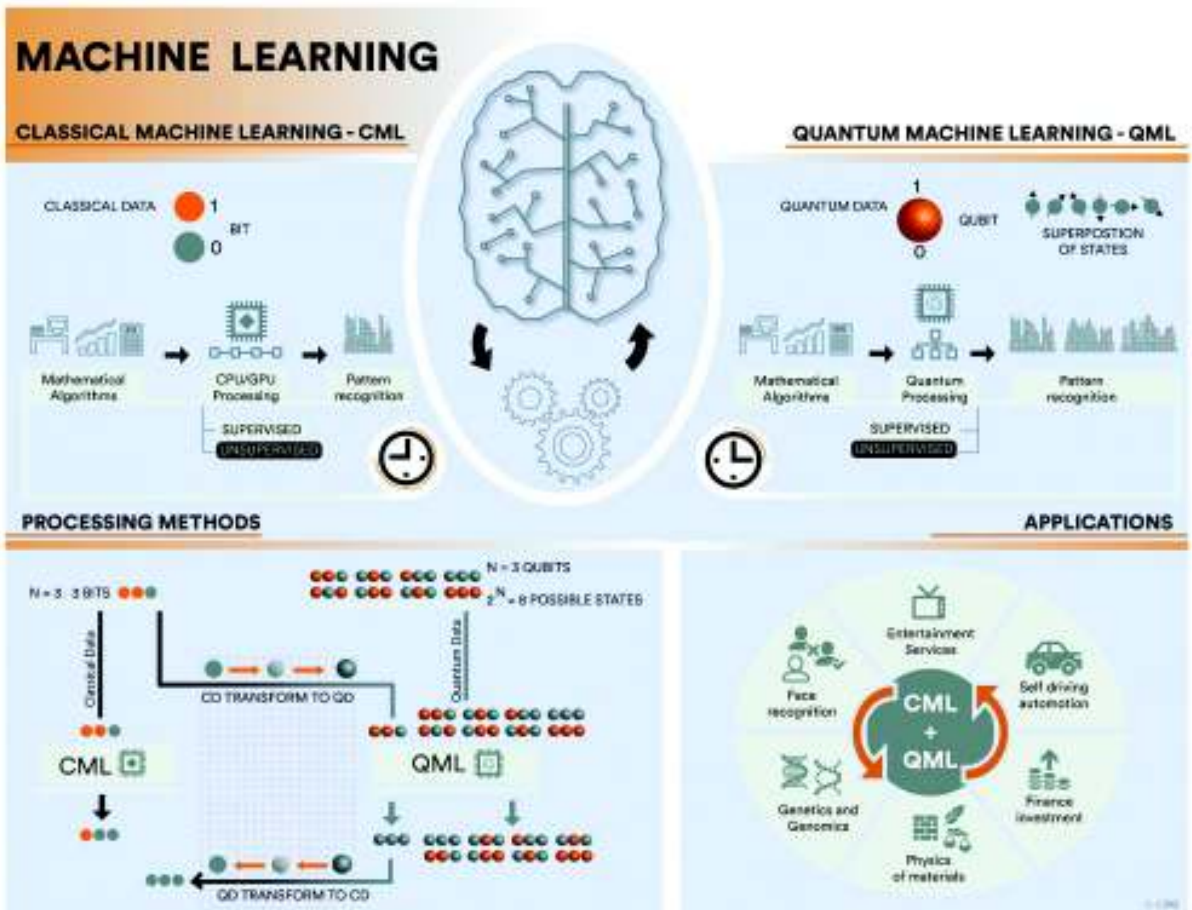
AI and quantum both challenge Computer Science:

- Both use hyperdimensional mathematics
- Both are trying to efficiently solve complex algorithms
- Both have exponential growth of algorithms
- Both rely on extremely concurrent infrastructure
- Both rely on probabilistic solutions
- Both exhibit quantum-like properties (tunneling, phase)
- Quantum and AI force us to ask the hard questions
- Quantum and AI force us to rethink spacetime itself

Researchers are just beginning to find the connections!

Question and Answers

- How does meaning emerge from brain randomness?
- How does spacetime emerge from quantum
- How does consciousness emerge from brain?



End of Presentation