Qubits & Neurons

Carl Anderson
June 2026



"I believe that at the end of the century, the use of words and general educated opinion will have altered so much that one will be able to speak of machine thinking without expecting to be contradicted."

— **Alan Turing, *Computing Machinery and Intelligence* (1950)**

ARTIFICIAL INTELLIGENCE (AI)

The broadest field. AI refers to machines or systems that can perform tasks that typically require human intelligence.

Includes capabilities such as:

- Reasoning
- Problem solving
- Planning
- Perception
- Language understanding

EXAMPLES

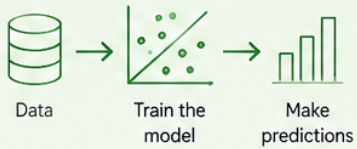
Chess engines · Robotic navigation · Virtual assistants · Search engines

MACHINE LEARNING (ML)

A subset of AI. ML enables systems to learn patterns from data and make decisions or predictions without being explicitly programmed.

How it works:

Uses algorithms to learn from historical data and improve performance on a task.



EXAMPLES

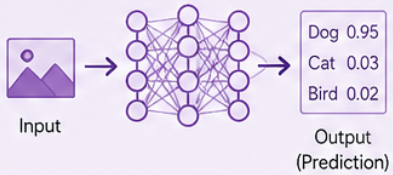
Spam filter · Product recommendations · Fraud detection · Demand forecasting

DEEP LEARNING (DL)

A subset of ML. DL uses artificial neural networks with many layers (neural networks) to learn complex patterns from large amounts of data.

How it works:

Uses multi-layer neural networks to automatically learn hierarchical representations of data.



EXAMPLES

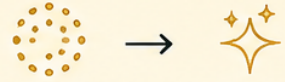
Image recognition · Speech recognition · Machine translation · Autonomous vehicles

GENERATIVE AI (GEN AI)

A subset of DL. Gen AI models learn the underlying patterns of data and generate new, original content that resembles the data they were trained on.

How it works:

Uses deep learning models (e.g., transformers, diffusion models, GANs, VAEs) to generate new content such as text, images, audio, video, or code.



EXAMPLES

Text generation (ChatGPT) · Image generation (DALL·E) · Music composition · Code generation (GitHub Copilot)

THE EARLY FOUNDATIONS (1940s–1950s)



1943 Warren McCulloch and Walter Pitts publish a mathematical model for artificial neural networks.



1950 Alan Turing publishes *Computing Machinery and Intelligence* and proposes the Turing Test as a benchmark for machine intelligence.



1956 The term "Artificial Intelligence" is coined by John McCarthy at the Dartmouth Conference, widely considered the field's official birthdate.



1957 Frank Rosenblatt develops the Perceptron, an early neural network that could learn from data.



SYMBOLIC AI AND THE FIRST "AI WINTER" (1960s–1980s)



1966 MIT's Joseph Weizenbaum creates ELIZA, one of the earliest conversational chatbots.



1970s–1980s Optimism fades as early computers struggle with real-world complexity. This leads to the first "AI Winter," a period of reduced funding and slashed research.



1980s AI gains a brief revival through commercial Expert Systems designed to mimic human reasoning in specific fields, but they are too brittle to scale.



THE RISE OF MACHINE LEARNING (1990s–2000s)



1997 IBM's Deep Blue defeats world chess champion Garry Kasparov, showcasing AI's prowess in complex decision-making.



2006 Geoffrey Hinton publishes work on "deep belief networks," laying the groundwork for the modern deep learning boom.



2011 IBM's Watson wins the Jeopardy! game show, demonstrating an advanced understanding of natural language.



1956 Dartmouth Conference: The Founding Fathers of AI



Founding fathers of AI. Courtesy of [scienceabc.com]

THE DEEP LEARNING BOOM (2010s)



2012 AlexNet, a deep convolutional neural network (CNN), dramatically wins the ImageNet competition, sparking massive interest in computer vision.



2014 Ian Goodfellow invents GANs (Generative Adversarial Networks), a breakthrough that enabled AI to generate realistic images and video.



2016 Google DeepMind's AlphaGo defeats a world champion Go player, a major milestone for heuristic reasoning in games.



2017 Google researchers publish Attention Is All You Need, introducing the Transformer architecture, which serves as the foundation for modern AI models.



FOUNDATION MODELS AND GENERATIVE AI (2020–PRESENT)



2020 OpenAI releases GPT-3, representing a massive leap in large language models (LLMs).

2021 GitHub Copilot launches in June 2021 as a technical preview. Built in collaboration with OpenAI and powered by the Codex model, it introduces the era of AI-powered "inline" code autocomplete.

2021 Google DeepMind's AlphaFold solves the 50-year-old protein folding problem, revolutionizing biology.

2022 GitHub Copilot reaches General Availability in June, rapidly integrating into IDEs like Visual Studio Code and establishing AI pair programming as an industry standard.

2022 OpenAI launches ChatGPT, marking a global cultural tipping point for consumer generative AI.

2023 Anthropic enters the chatbot and model landscape by launching the first version of Claude in March, positioning it as a highly constitutional and safe alternative to existing models.

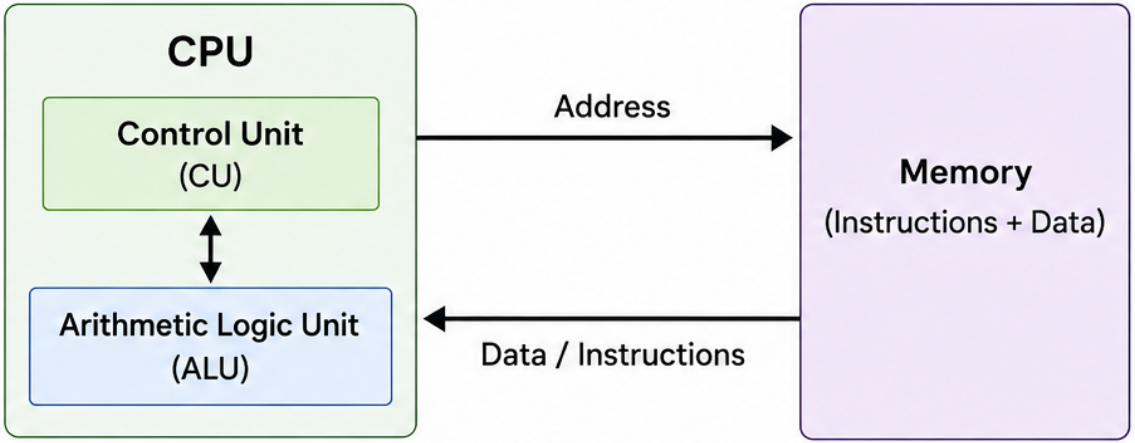
2024 GitHub Copilot transitions beyond autocomplete by heavily rolling out multi-file workspace reasoning, terminal error explanations, and an inline chat window feature.

2025 The AI race shifts toward Agentic AI capable of multi-step problem solving. OpenAI pushes reasoning capabilities with models like o3-mini, while Anthropic launches Claude 3.7 Sonnet. Alongside it, Anthropic releases Claude Code, an advanced, terminal-based AI coding agent that directly edits codebases, handles git workflows, and executes terminal debugging commands.

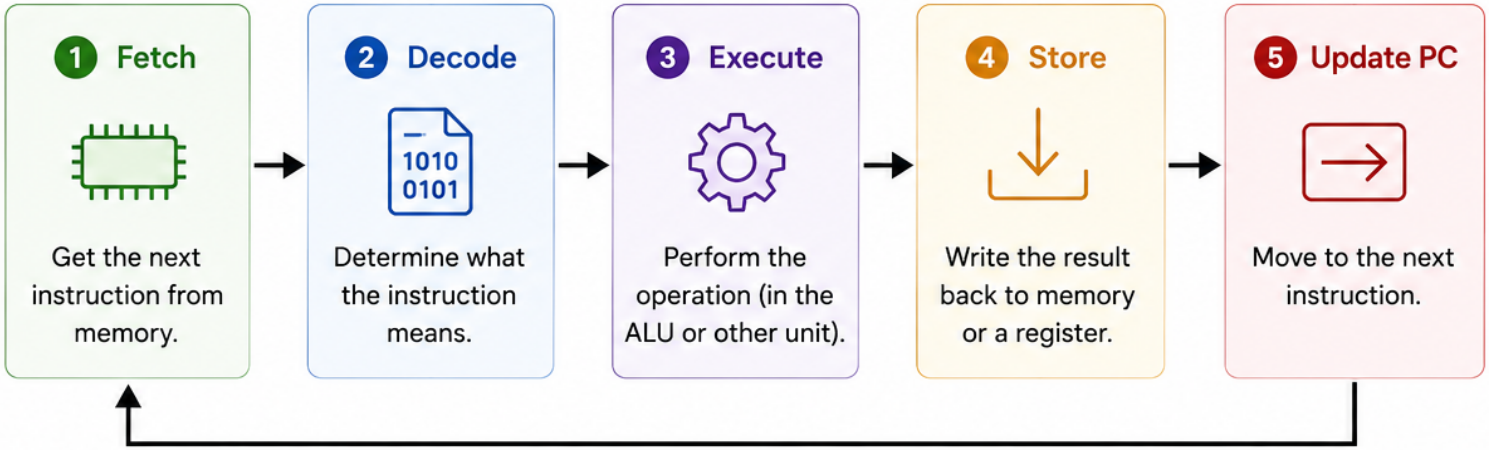
2026 AI development environments become highly agentic and collaborative. Tooling evolves with platforms like GitHub Copilot introducing automated multi-step "Agent Modes" and customizable system instructions, while Claude Code expands with autonomous capabilities including desktop UI orchestration, scheduled cloud tasks, and local project-wide memory syncs.

"...Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical."

— **Richard Feynman (1981)**



The Instruction Cycle (Repeat)



The Knapsack Problem

“Given a set of items, each with a weight and value, determine which items to put into the knapsack so the total weight is less than or equal to a carry limit and the total value of the items is as large as possible”



A “Solution”

Try all possible combinations

- Number of combinations is 2^n, where n is the number of items
- Each item has two possibilities: 1-we bring it, 0-we leave it
- For each case we calculate the total value and the total weight
- Select the case that has the highest value and less than or equal to the maximum weight
- (Profit!)

3 items = 8 possible combinations (2^3 = 8)

5 items = 32 possible combinations (2^5 = 32)

…



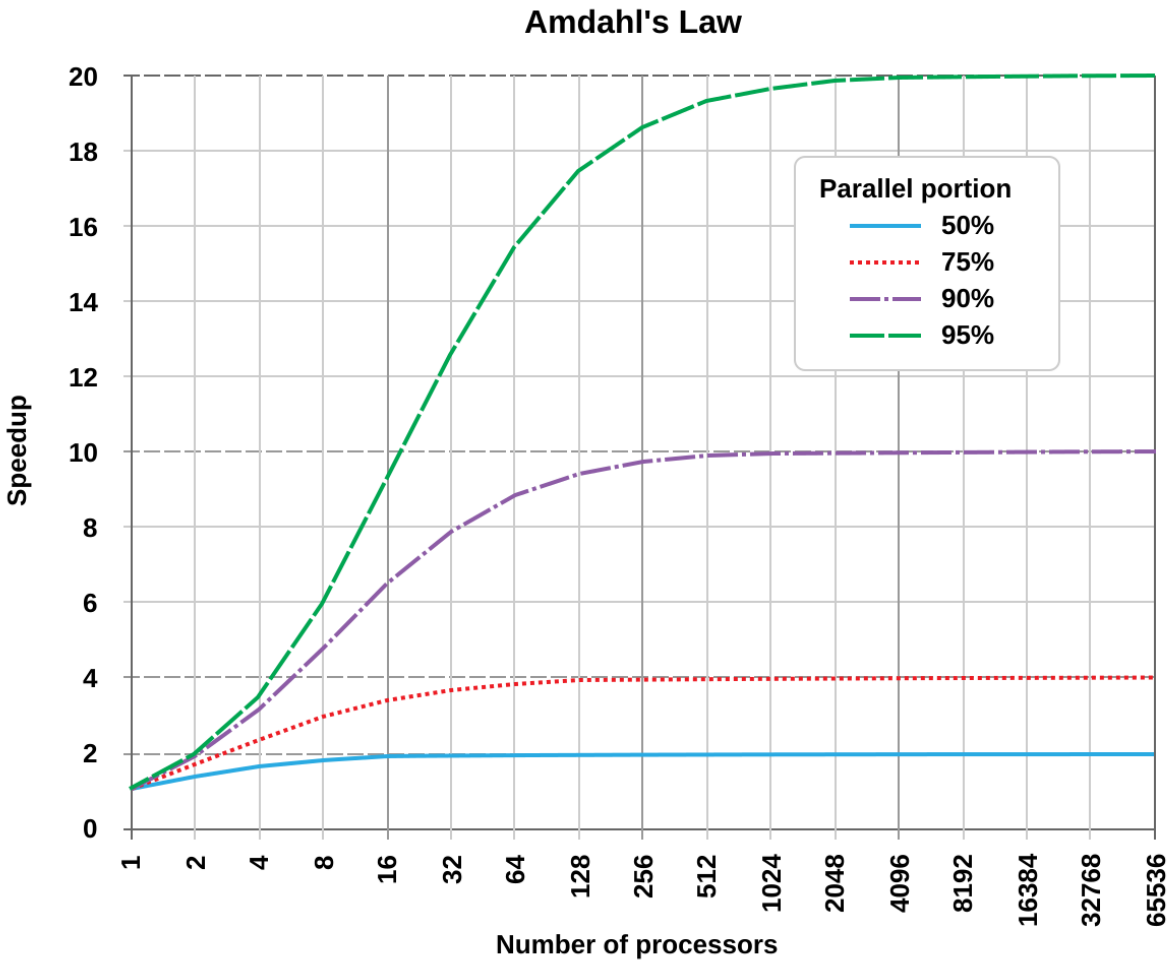
How does it scale?

Assume each iteration takes half a nanosecond on a single processor

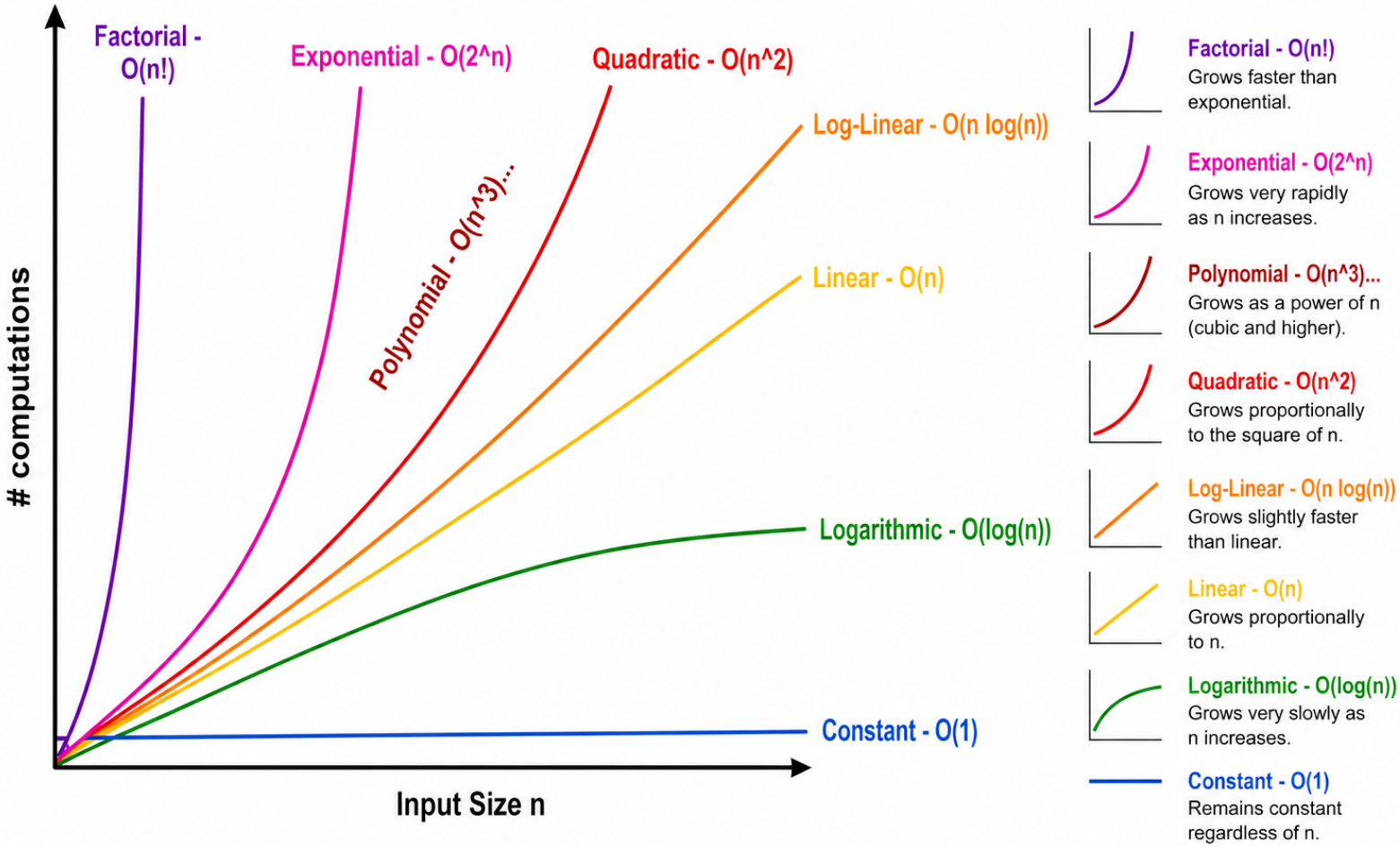
- 10 items (2^10) … no problem
- 50 items (2^50) … 7 days
- 100 items (2^100) … 20,098,468,420,666 years (20 trillion)

The age of the universe is 13.8 billion years (one less comma)





https://en.wikipedia.org/wiki/Amdahl%27s_law


Factorial - O(n!)
Exponential - O(2^n)
Quadratic - O(n^2)
Polynomial - O(n^3)...
Log-Linear - O(n log(n))
Linear - O(n)
Logarithmic - O(log(n))
Constant - O(1)
computations
Input Size n
Factorial - O(n!)
Grows faster than exponential.
Exponential - O(2^n)
Grows very rapidly as n increases.
Polynomial - O(n^3)...
Grows as a power of n (cubic and higher).
Quadratic - O(n^2)
Grows proportionally to the square of n.
Log-Linear - O(n log(n))
Grows slightly faster than linear.
Linear - O(n)
Grows proportionally to n.
Logarithmic - O(log(n))
Grows very slowly as n increases.
Constant - O(1)
Remains constant regardless of n.

“Quantum computation is … nothing less than a distinctly new way of harnessing nature … It will be the first technology that allows useful tasks to be performed in collaboration between parallel universes, and then sharing the results.” — **David Deutsch, The Fabric of Reality (1997)**

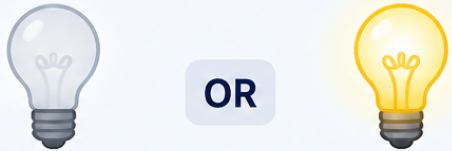
CLASSICAL BIT

Can be 0 OR 1

0 OFF

OR

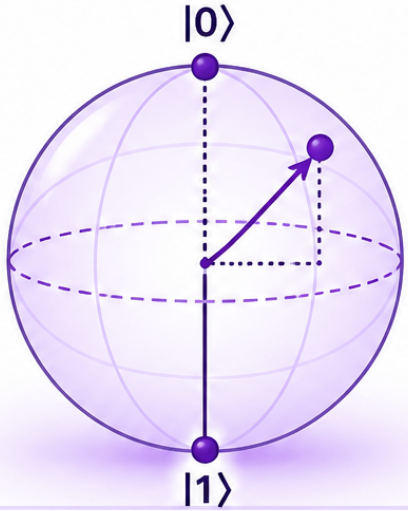
1 ON



Stores one of two states at any given time.

QUBIT

Can be 0, 1, OR both (superposition)



Any state

$\alpha|0\rangle + \beta|1\rangle$

where

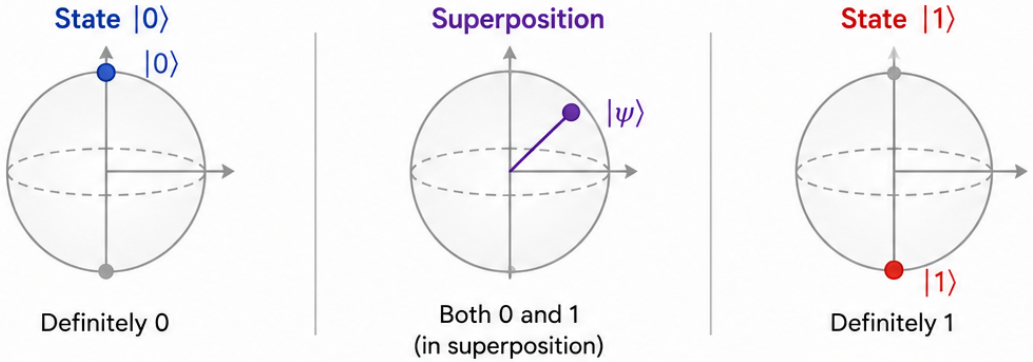
$|\alpha|^2 + |\beta|^2 = 1$



Can be in 0 and 1 simultaneously, enabling quantum parallelism.

SUPERPOSITION

A qubit can be in 0, in 1, or in both 0 and 1 at the same time.



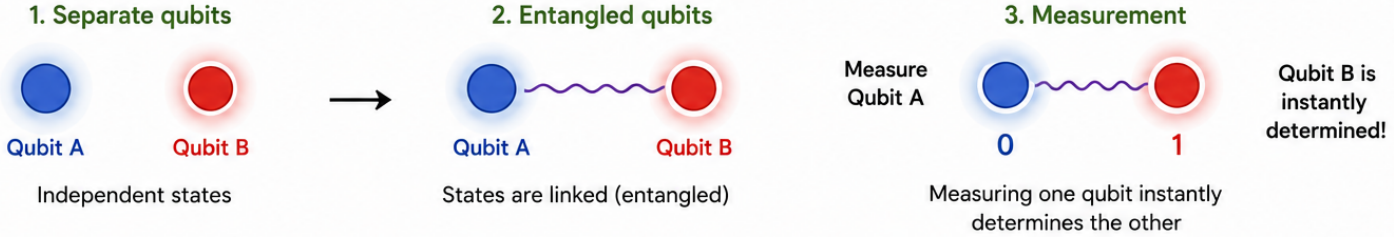
Mathematically:

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

where α and β are complex numbers such that $|\alpha|^2 + |\beta|^2 = 1$

ENTANGLEMENT

Two or more qubits become linked so that the state of one is directly related to the state of the other(s), no matter the distance.



Superposition: a single qubit is in multiple states at once.

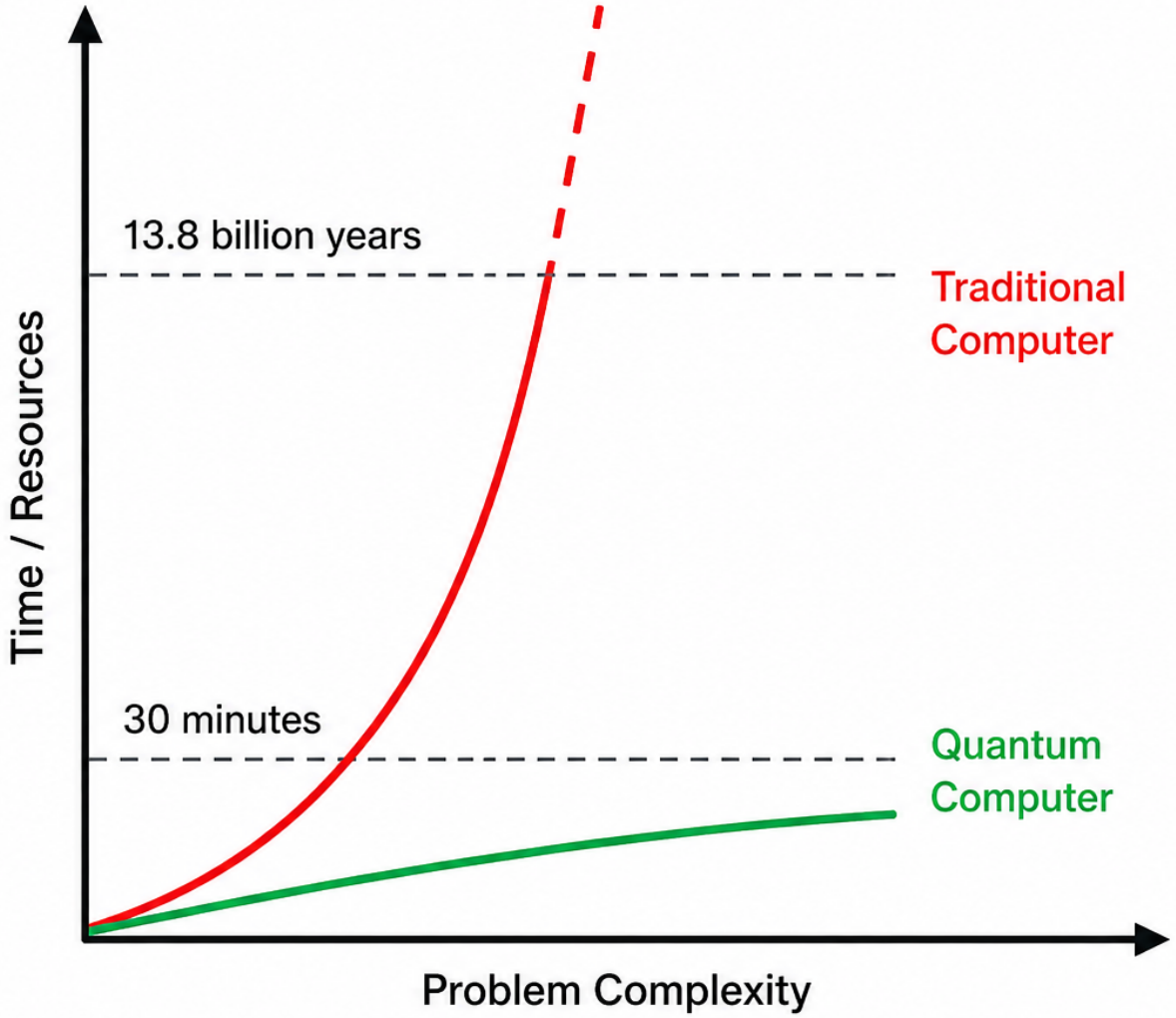
Entanglement: multiple qubits are correlated so that the state of one affects the other(s), no matter how far apart they are.

“I think that a particle must have a separate reality independent of measurements. That is, an electron has spin, location and so forth even when it is not being measured. I like to think the moon is there even if I am not looking at it.” — **Albert Einstein, (1949)**

“There is no quantum world. There is only an abstract quantum physical description. It is wrong to think that the task of physics is to find out how nature is. Physics concerns what we can say about nature.” **– Neils Bohr (1963)**

“Bohr was inconsistent, unclear, willfully obscure and right. Einstein was consistent, clear, down-to-earth and wrong.” **– John Stewart Bell, NYT (2010)**

“I think it is safe to say that no one understands quantum mechanics. Do not keep saying to yourself, if you can possibly avoid it, 'But how can it possibly be like that?' because you will go down the drain into a blind alley from which nobody has yet escaped. Nobody knows how it can be like that.” **– Richard Feynman, The Feynman Lectures on Physics, (1963)**


13.8 billion years
Traditional Computer
30 minutes
Quantum Computer
Time / Resources
Problem Complexity

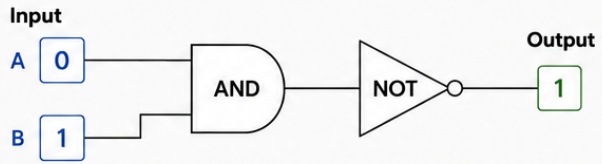
CLASSICAL COMPUTING

Uses bits (0 or 1) and logical operations.

How it works:

1. Input bits (0 or 1) are provided.
2. Logic gates (AND, OR, NOT, etc.) process the bits.
3. Output bits (0 or 1) are produced.

Example: Classical Circuit



Key points



Uses bits (0 or 1)



Logic gates process bits deterministically



Produces a single definite output

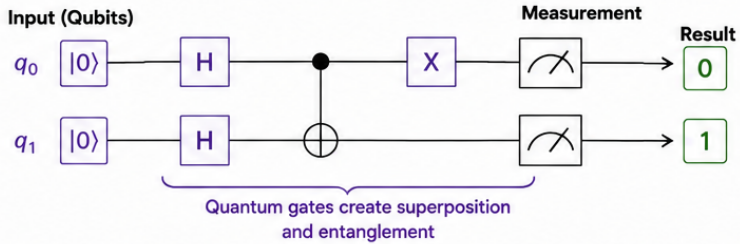
GATE-BASED QUANTUM COMPUTING

Uses qubits ($|0\rangle$ and $|1\rangle$) and quantum gates.

How it works:

1. Qubits are initialized (usually in $|0\rangle$).
2. Quantum gates change the qubits' states, creating superposition and entanglement.
3. Measurement collapses qubits to classical results (0 or 1).

Example: Quantum Circuit



Key points



Uses qubits ($|0\rangle$ and $|1\rangle$)



Quantum gates create superposition and entanglement



Measurement gives classical results (0 or 1) with probabilities

In summary:

Classical computing processes bits with deterministic logic gates to get a single output.

Gate-based quantum computing manipulates qubits with quantum gates to explore many possibilities at once, and measurement produces classical outcomes.

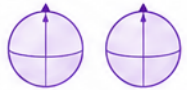
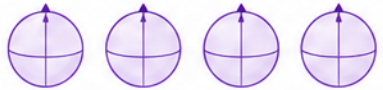
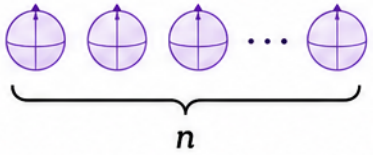
CLASSICAL BITS

Scale Linear (add more bits one by one)

Number of Bits		Possible States
1 bit	0 or 1	$2^1 = 2$
2 bits	0 0 ···	$2^2 = 4$
3 bits	0 0 0 ···	$2^3 = 8$
4 bits	0 0 0 0 ···	$2^4 = 16$
n bits	0 0 0 ··· 0 (n)	2^n (linear growth)

QUBITS

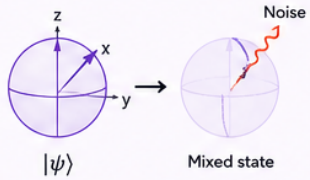
Scale Exponential (double possibilities with each additional qubit)

Number of Qubits		Possible States
1 qubit		$2^1 = 2$
2 qubits		$2^2 = 4$
3 qubits		$2^3 = 8$
4 qubits		$2^4 = 16$
n qubits	 (n)	2^n (exponential growth)

Challenges in Quantum Computing

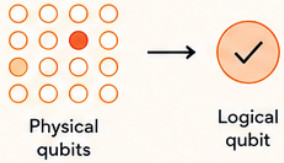
1 Decoherence

- Qubits are extremely sensitive to the environment.
- Interactions with noise cause loss of quantum information.



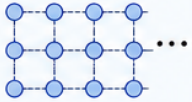
2 Error Correction

- Qubits have high error rates.
- Quantum error correction requires many physical qubits per logical qubit.
- Overhead remains a major bottleneck.



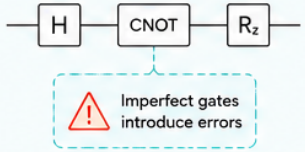
3 Scalability

- Building large-scale, fault-tolerant quantum computers is extremely hard.
- More qubits increase complexity in control, calibration, and connectivity.



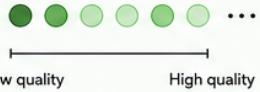
4 Gate Fidelity

- Quantum gates are not perfect.
- Errors in gates accumulate as circuits get deeper.
- High fidelity is essential for useful computations.



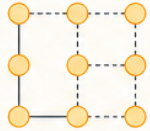
5 Qubit Quality & Uniformity

- Qubits in the same device often behave differently.
- Variability makes calibration and scaling difficult.



6 Connectivity & Architecture

- Limited qubit connectivity constrains circuit design.
- SWAP operations add overhead and increase error.



7 Control & Readout Errors

- Errors occur in qubit initialization, control pulses, and measurement.
- Readout errors limit the reliability of results.



8 Cryogenic & Hardware Requirements

- Qubits require ultra-low temperatures (millikelvin range).
- Complex, expensive, and hard-to-scale infrastructure.



9 Software & Tooling

- Quantum software stack is still immature.
- Needs better compilers, error mitigation, debugging, and benchmarking tools.



10 Cost & Accessibility

- Quantum hardware is extremely expensive.
- Limited access hinders research, education, and innovation.



THE CURRENT STATE & LANDSCAPE

Hardware maturity:
Systems are still early, but stable enough for experimentation and pilot use cases.

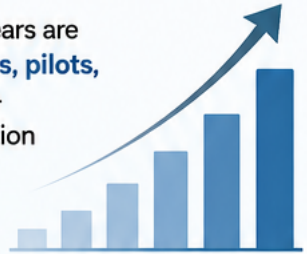
Hybrid reality:
Most value today comes from "quantum + classical + AI" workflows.

Competitive advantage window:
Early movers are shaping standards, IP, and talent pipelines.

Customer pressure:
Large enterprises want a credible roadmap, not hype.

STRATEGIC TAKEAWAY

The next 2–4 years are about **readiness, pilots, and learning**— not full production dominance.



WHICH PROBLEMS QUANTUM CAN HELP WITH

LIFE SCIENCES & HEALTHCARE

- Drug discovery and molecular simulation
- Protein folding and interaction modeling
- Clinical trial optimization

CYBERSECURITY

- Post quantum encryption
- Secure communications
- Intrusion detection

MANUFACTURING & INDUSTRIAL

- Production scheduling
- Supply chain optimization
- Materials discovery (lighter, stronger, cheaper materials)
- Predictive maintenance

FINANCIAL SERVICES

- Portfolio optimization
- Risk modeling and stress testing
- Fraud detection
- Derivatives pricing

TRANSPORTATION, LOGISTICS & AIRLINES

- Route and fleet optimization
- Real-time scheduling under uncertainty
- Fuel efficiency optimization

ENERGY & UTILITIES

- Grid optimization
- Battery chemistry simulation
- Energy trading optimization

RETAIL & CONSUMER GOODS

- Demand forecasting
- Pricing and promotion optimization
- Inventory and fulfillment optimization

WHAT QUANTUM WILL NOT DO (YET)

- Quantum will not replace cloud, AI, or HPC
- Quantum will not immediately lower IT costs
- Quantum will not solve every analytics problem
- Quantum will not make everything faster

RISKS OF NOT LOOKING AT QUANTUM

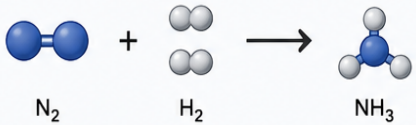
- Falling behind competitors experimenting today
- Losing influence over standards and platforms
- Post-quantum security risks
- Talent attraction challenges: quantum will be more constrained by skills & understanding than hardware.
- Customer perception of being “behind the curve”

Quantum Computing changes what is economically solvable, not just how fast something runs.

The Haber–Bosch Process

What is it?

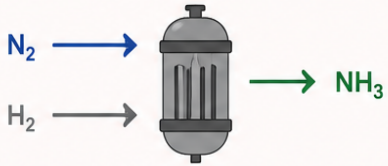
An industrial process that converts nitrogen (N_2) and hydrogen (H_2) into ammonia (NH_3).



Critical for producing fertilizers that feed billions of people worldwide.

The Process

High Temp.
400–500 °C



High Pressure
150–250 bar

Catalyst: Iron-based

Key Challenges

Extreme Conditions
Requires high temperature and pressure, leading to high energy consumption.

Catalyst Limitations
Current catalysts are not fully efficient or stable over long periods.

Sustainability
Process relies on fossil fuels and produces CO_2 emissions.

Complex Chemistry
Many elementary steps and surface interactions are not fully understood.

How Quantum Computing and AI Work Together

Quantum Computing

- Accurately models quantum behavior of electrons and atoms
- Simulates reaction mechanisms and transition states
- Identifies better catalysts and reaction pathways

Quantum + AI Synergy

Artificial Intelligence

- Analyzes large experimental datasets
- Finds patterns and predicts outcomes
- Optimizes process conditions and catalyst design

Better Understanding. Better Process.

More Efficient Catalysts | Lower Energy Consumption | Reduced CO_2 Emissions | Smarter, More Sustainable Ammonia Production

From Today's Cryptography to a Quantum-Safe Future

How Quantum Computing and AI Work Together to Advance Post-Quantum (Quantum-Proof) Cryptography

1. TODAY: Current Cryptography in Use

Widely Used Today

- Web Security (TLS/SSL)
- Digital Banking
- Secure Messaging
- Cloud & Data Storage
- VPNs & Enterprise Systems

How it Works (Example: RSA/ECC)



The Threat from Quantum Computing



Large-scale quantum computers could break RSA, ECC and other public-key cryptography using Shor's algorithm.

→ Data encrypted today could be decrypted tomorrow ("store now, decrypt later").

2. THE FUTURE: Quantum + AI for Quantum-Safe Cryptography

Quantum Computing



- Advances in quantum hardware
- Enables new hard math problems
- Powers quantum key distribution (QKD) for provable security



Artificial Intelligence



- Discovers and evaluates new cryptographic algorithms
- Optimizes parameters and performance
- Detects weaknesses and potential attacks
- Accelerates testing and standardization

Post-Quantum (Quantum-Proof) Cryptography



Based on problems quantum computers can't easily solve



Examples: Lattices, Hash-based, Code-based, Multivariate, Isogeny



Being standardized by NIST and global organizations



Protects data now and in the quantum future

How Quantum Computing and AI Work Together to Improve AI Training of Large Models

Quantum computing accelerates and optimizes AI; AI makes quantum computing smarter and more usable.

1. CURRENT CHALLENGES IN TRAINING LARGE AI MODELS

- Extremely high computational cost and training time
- Massive data and memory requirements
- High energy consumption
- Complex optimization with many parameters (local minima)
- Expensive to train frontier models

2. QUANTUM + AI SYNERGY

Quantum Computing Helps AI

- Speed up linear algebra (matrix operations)
- Optimize model parameters faster (quantum optimization)
- Handle higher-dimensional spaces more efficiently
- Improve sampling and probabilistic modeling

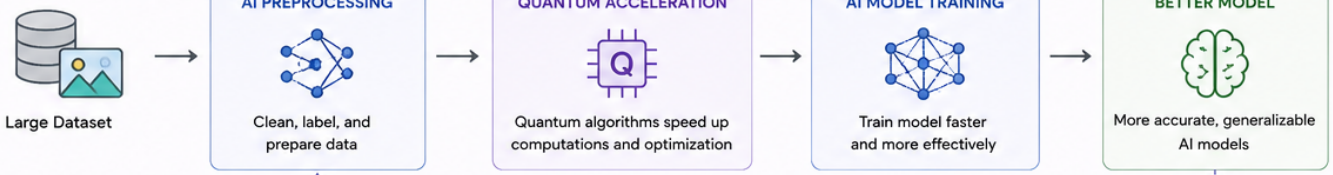
AI Helps Quantum Computing

- AI optimizes quantum circuit design and control
- AI learns error patterns to reduce quantum errors
- AI helps interpret quantum results and data
- AI automates workflows and resource allocation

3. IMPACT ON AI TRAINING

- Faster training of large models
- Better optimization and higher model accuracy
- Ability to train larger and more complex models
- Lower energy usage and computational cost
- Accelerated AI innovation and capabilities

4. HOW IT WORKS (SIMPLIFIED FLOW)



EXAMPLES OF BENEFITS

- ✓ Natural language processing
- ✓ Computer vision
- ✓ Drug discovery
- ✓ Scientific modeling
- ✓ Robotics and more