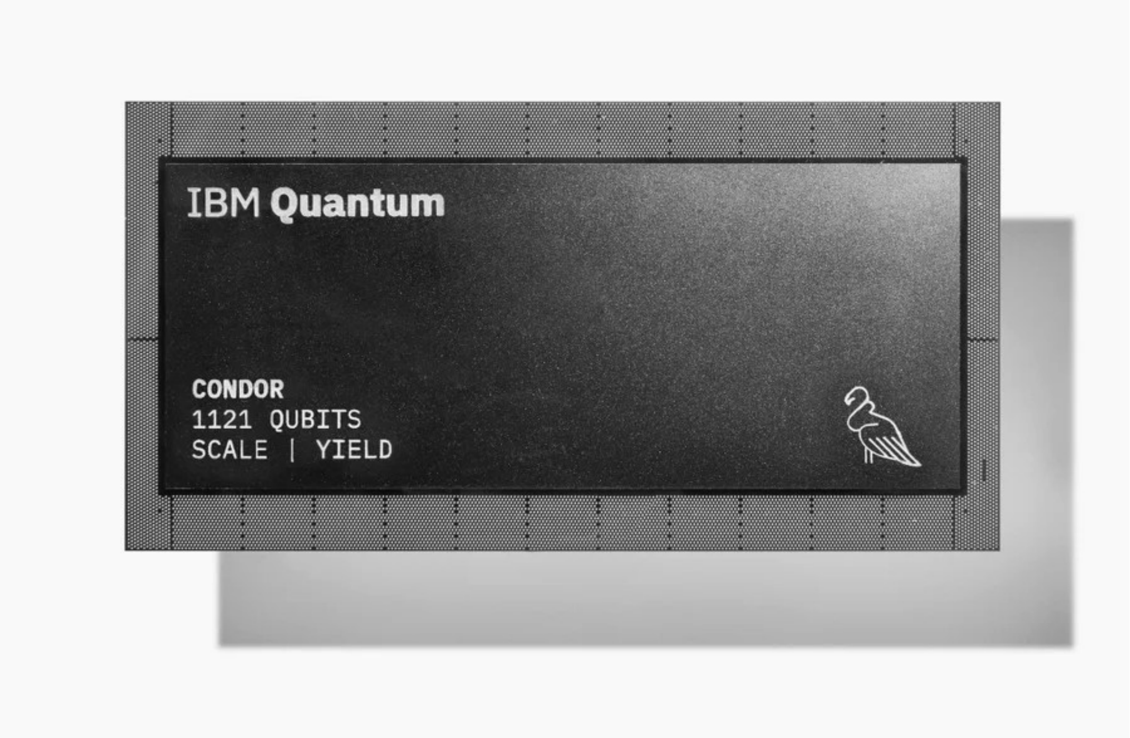
https://github.com/osbama/IntroQML_NCC/

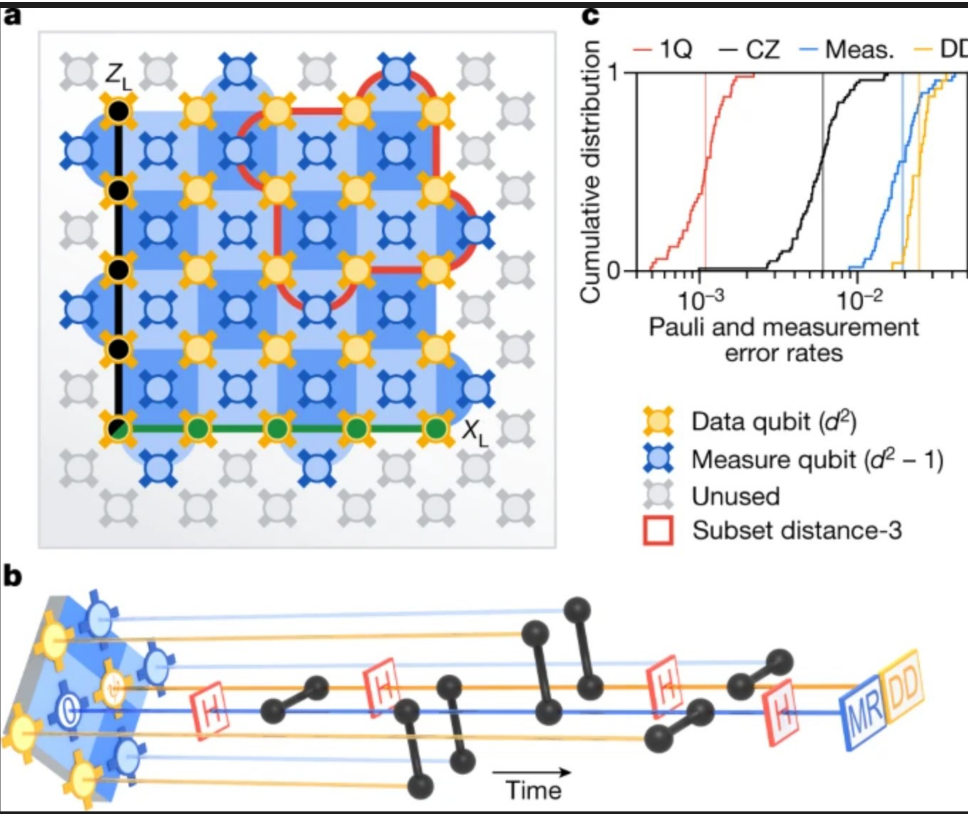
5 December 2023: IBM Releases First-Ever 1,000-Qubit Quantum Chip

https://www.scientificamerican.com/article/ibm-releases-first-ever-1-000-qubit-quantum-chip/

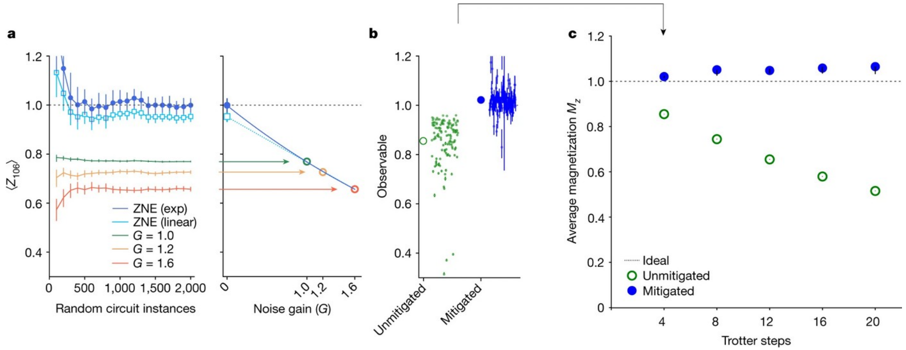


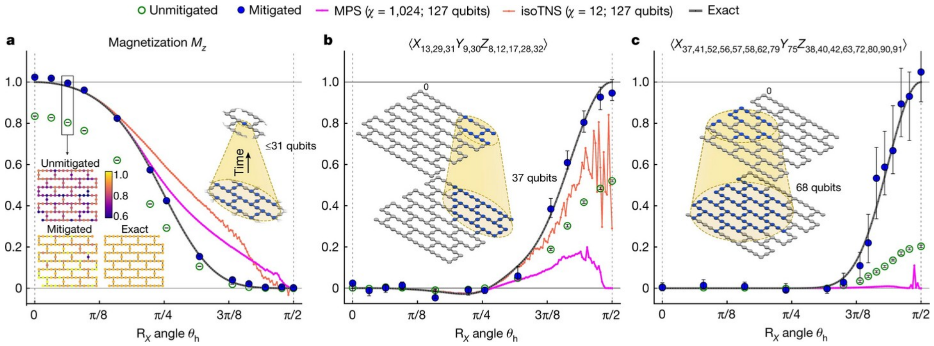
Rose's Law: Quantum computing qubits should double every two years

Error mitigation became practical in 2023



https://www.nature.com/articles/s41586-022-05434-1



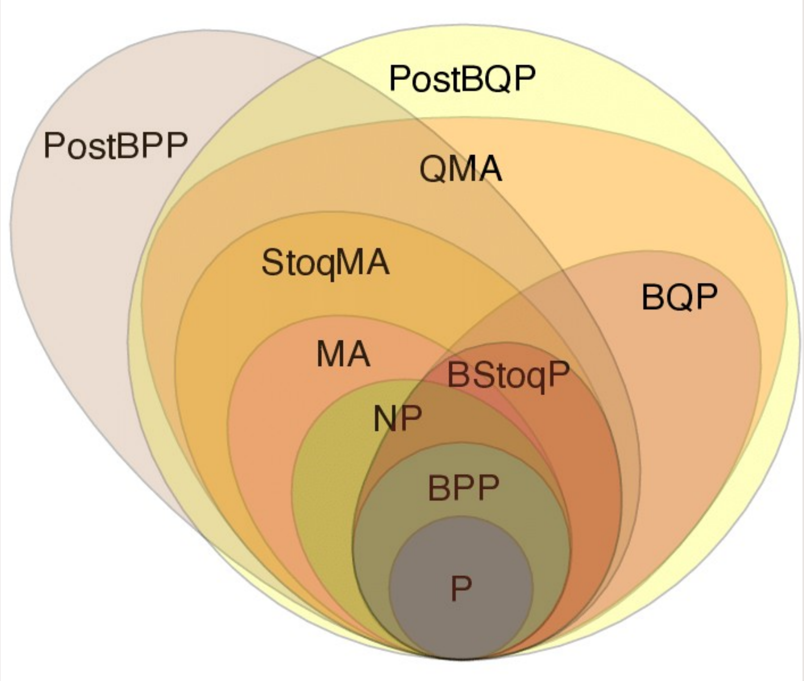


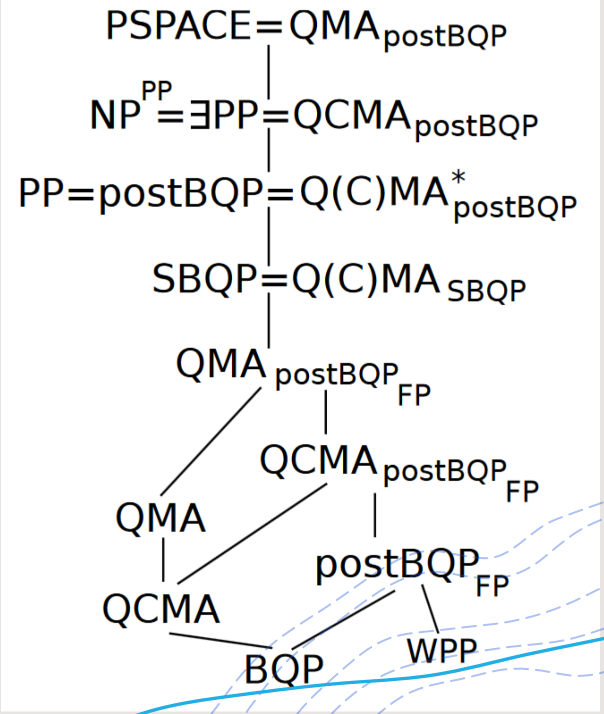
https://www.nature.com/articles/s41586-023-06096-3

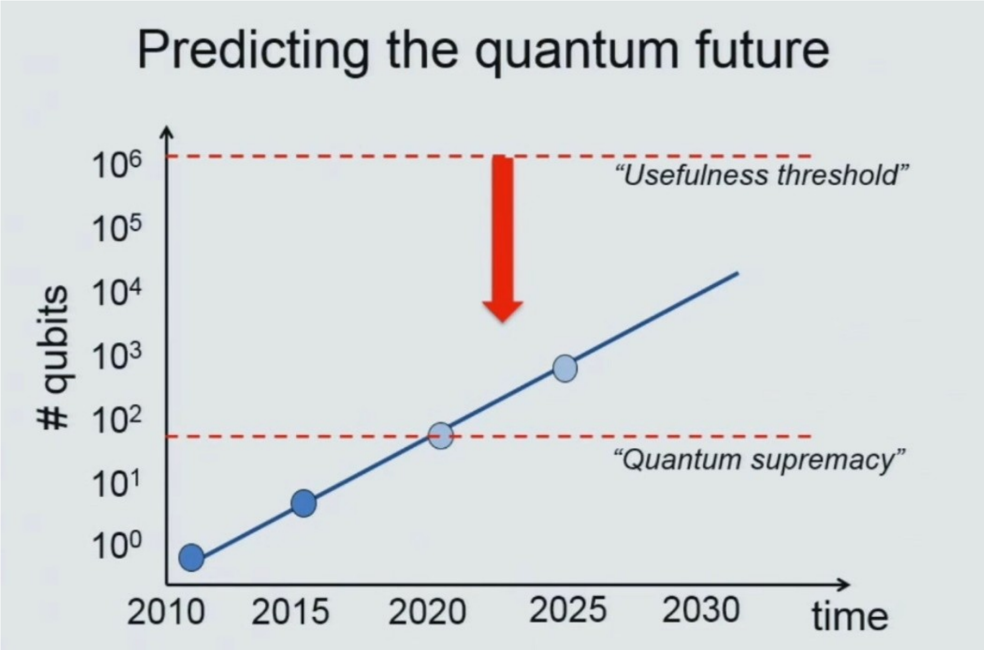
Quantum complexity classes are an active field of research, however it is widely believed that **quantum computers and traditional computers will complement each other in solving problems that are not possible in either by itself**

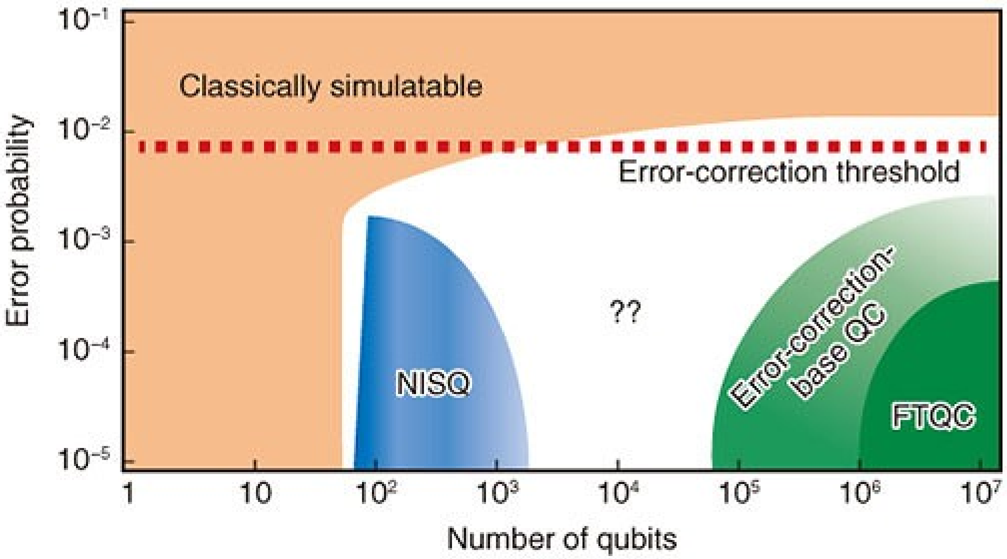
Example research:

+ https://journals.aps.org/rmp/abstract/10.1103/RevModPhys.90.015002
+ https://arxiv.org/pdf/1704.01514.pdf









https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr202105fa4.html

"There's no way to get there without a breakthrough," "It motivates us to go invest more in fusion."

AI Training Takes a Lot of Power: Training AI models is a real energy hog. For instance, the BLOOM model used up 433 MWh, GPT-3 needed a whopping 1287 MWh, Gopher 1066 MWh, and OPT 324 MWh. GPT4 training uses 40 times more 51,773 MWh and 62,319 MWh

https://www.sciencedirect.com/science/article/abs/pii/S2542435123003653#fig1

It’s the scaling!

Quantum state space becomes 2^n large in the number of qubits, this means, if you want to simulate a quantum computer with a traditional computer the scaling is not so friendly: adding one qubit actually doubles the amount of coefficients and thus resources needed to describe the system. This translates to a huge energy advantage for digital quantum computers for similar tasks.

IBM’s Condor will be ~100 times more energy efficient for comparable tasks in theory. The gap in energy efficiency will scale exponentially as the Qubit size increases

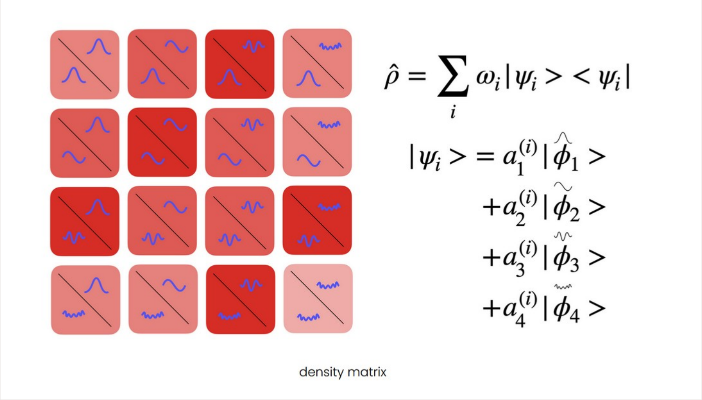
https://chicagoquantum.medium.com/quantum-computers-are-more-energy-efficient-b6ba62bcb9f2

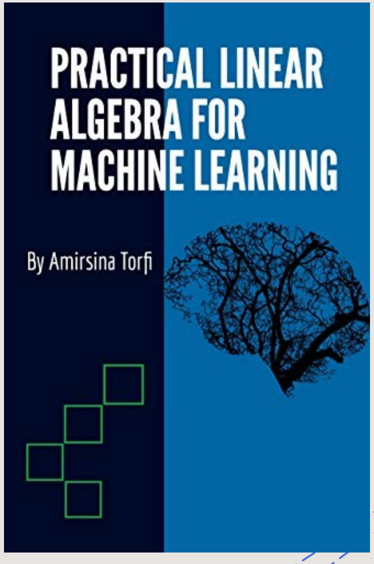
In AI development, the dominant paradigm is that the more training data, the better. OpenAI’s GPT-2 model had a data set consisting of 40 gigabytes of text. GPT-3, which ChatGPT is based on, was trained on 570 GB of data. OpenAI has not shared how big the data set for its latest model, GPT-4, is. **OpenAI has trouble with European data protection laws** following a temporary ban in Italy and a slew of investigations in other EU countries. If it fails, it could face hefty fines, be forced to delete data, or even be banned.

https://www.technologyreview.com/2023/04/19/1071789/openais-hunger-for-data-is-coming-back-to-bite-it/

For classical data analysis, QML models offer some advantage over classical models under certain circumstances. It has also been proven that QML models can provide an exponential advantage in sample complexity for analyzing quantum data.

https://www.nature.com/articles/s41467-022-32550-3





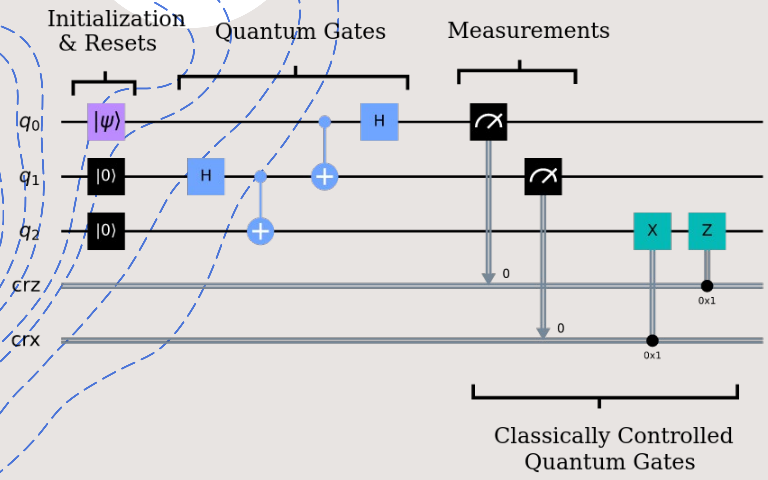
Using density matrix formalism, and machine learning methods, we can integrate quantum computers with traditional ones

Quantum Tech: Quantum computing

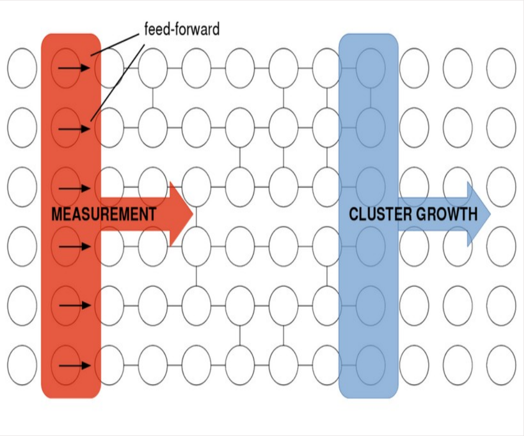
Different platforms and hardware

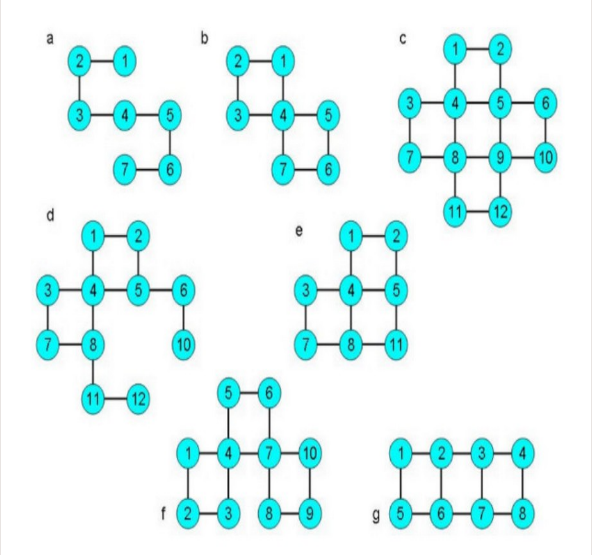
Graphics: Nathan Shammah

		Advantages	Challenges
Gate-based	Superconducting circuits	15 years of exponential improvement in extending dephasing time (x10 / 3yrs).	Artificial atoms: defects, off-resonances. Wiring leads to qubit cross-talk. Requires cooling @ micro K Temp.
	Trapped ions	‘Perfect’ qubits due to identical ions. Long coherence time even @ room Temp. Long-range interaction: Full connectivity.	Photonic link/ion shuttling needed to create entanglement between distant modules.
	Photonics	‘Flying’ qubits for quantum internet. Silicon integrated chips (CMOS industry). Very long coherence time.	Small interaction hampers two-qubit gates. Hard to have identical photons on demand. Requires interface for storing memory.
	Spins	CMOS and SiMOS integration. Long coherence time. Up to room temperature qubits.	Charge and nuclear spin noise. Weak interaction with controlling fields.
	Neutral Atoms	Atoms are identical components. Long-range interactions. Recently: two-Rydberg-atom entanglement.	Hard to trap atom and control qubit. Linear optics, low Temp required @ micro K.
Annealing	Superconducting circuits	Encode optimization problems. No error correction required.	Not a universal quantum computer. Unclear implementation of adiabatic QC. Uncertain entanglement role and scalability.



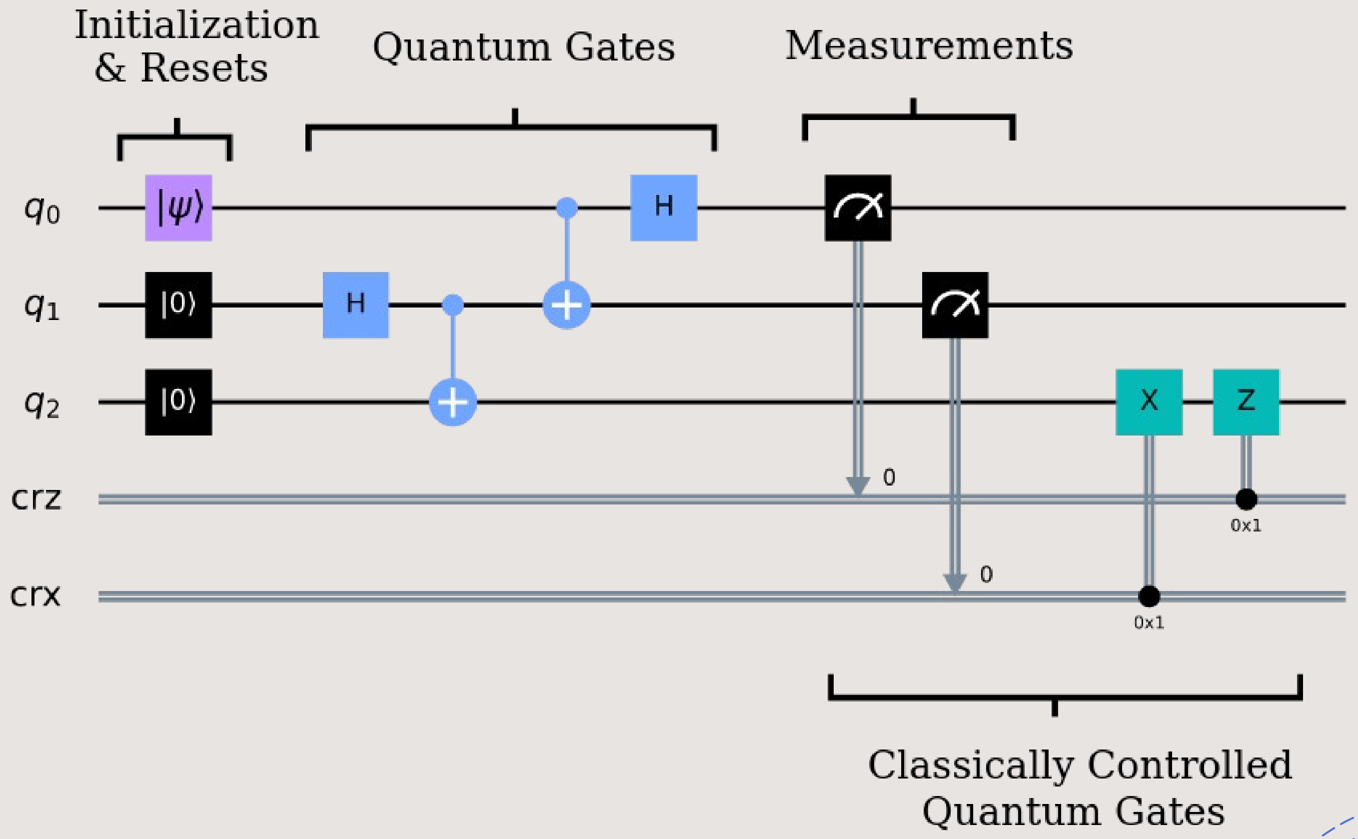
Circuit Model: D. Deutsch, Proc. R. Soc. A 425, 73 (1989).





Cluster-state quantum computation
https://doi.org/10.1016/S0034-4877(06)80014-5

Model Name	Reference
Adiabatic	Albert Messiah. Quantum Mechanics. Dover, Mineola, 1961.
Topological	Nayak, et al. arxiv:0707.1889, 2007
Quantum Walks	Childs et al. arXiv:quant-ph/0209131.
Measurement-based	Raussendorf and Briegel. PRL 86(22):5188–5191, 2001.
Quantum Turing Machines	David Deutsch. Proceedings of the Royal Society, 400:97–117,1985.



Initialization
& Resets
Quantum Gates
Measurements
q_0
q_1
q_2
crz
crx
$|\psi\rangle$
$|0\rangle$
$|0\rangle$
H
H
X
Z
0
0
0x1
0x1
Classically Controlled
Quantum Gates

Postulate 1: Associated to any isolated physical system is a complex vector space with inner product (that is, a Hilbert space) known as the *state space* of the system, The system is completely described by its *state vector*, which is a unit vector in the system's state space.

Postulate 2: The evolution of a *closed* quantum system is described by a *unitary transformation*. That is, the state $|\psi\rangle$ of the system at time t_1 is related to the state $|\psi'\rangle$ of the system at time t_2 by a unitary operator U which depends only on the times t_1 and t_2, $U|\psi\rangle = |\psi'\rangle$.

Postulate 3: Quantum measurements are described by a collection $\{M_m\}$ of *measurement operators*. These are operators acting on the state space of the system being measured. The index m refers to the measurement outcomes that may occur in the experiment. If the state of the quantum system is $|\psi\rangle$ immediately before the measurement then the probability that result m occurs is given by $p(m) = \langle\psi| M_m^\dagger M_m |\psi\rangle$, and the state of the system after the measurement is $\frac{M_m|\psi\rangle}{\sqrt{p(m)}}$.

The measurement operators satisfy the *completeness equation*, $\sum_m M_m^\dagger M_m = I$.

Postulate 4: The state space of a composite physical system is the tensor product of the state spaces of the component physical systems Moreover, if we have systems numbered 1 through n, and system number i, is prepared in the state $|\psi_i\rangle$, then the joint state of the total system is $|\psi_1\rangle \oplus |\psi_2\rangle \otimes \cdots \otimes |\psi_n\rangle$.

The postulates of quantum mechanics by Michael A. Nielsen and Isaac L. Chuang

The fundamental features of QIP are different from those of classical computing

(i)**Linear superposition.** Contrary to the classical bit, a quantum bit or qubit can take not only the two discrete values 0 and 1 but also all possible linear combinations of them. This characteristic results from a fundamental property of quantum states—it is possible to construct a linear superposition of quantum state |0〉 and quantum state |1〉.

(ii) **Quantum parallelism.** Quantum parallelism allows many operations to be performed in parallel, which is a key difference from classical computing. Namely, in classical computing, it is possible to know the internal status of the computer. On the other hand, because of the no-cloning theorem, the current state of a quantum computer cannot be known. This property has led to the development of Shor’s factorization algorithm, which can be used to crack the Rivest–Shamir–Adleman (aka RSA) encryption protocol. Other important quantum algorithms include the Grover search algorithm, which is used to search for an entry in an unstructured database; the quantum Fourier transform, which is the basis for several algorithms; and Simon's algorithm. The quantum computer can encode all input strings of length N simultaneously into a single computational step. In other words, the quantum computer can simultaneously pursue 2N classical paths, indicating that the quantum computer is significantly more powerful than the classical one.

(iii) **Entanglement.** At a quantum level, it appears that two quantum objects can form a single entity even when they are well separated from each other. Any attempt to consider this entity a combination of two independent quantum objects given by the tensor product of quantum states will fail unless signal propagation at superluminal speed is allowed. These quantum objects that cannot be decomposed into the tensor product of independent quantum objects are called entangled quantum objects. Given that arbitrary quantum states cannot be copied, which is a consequence of the no-cloning theorem, communication at superluminal speed is not possible. Therefore, entangled quantum states cannot be written as the tensor product of independent quantum states. Moreover, it can be shown that the amount of information contained in an entangled state of N qubits grows exponentially instead of linearly as it does for classical bits.

https://www.sciencedirect.com/science/article/pii/B978012822942200008X