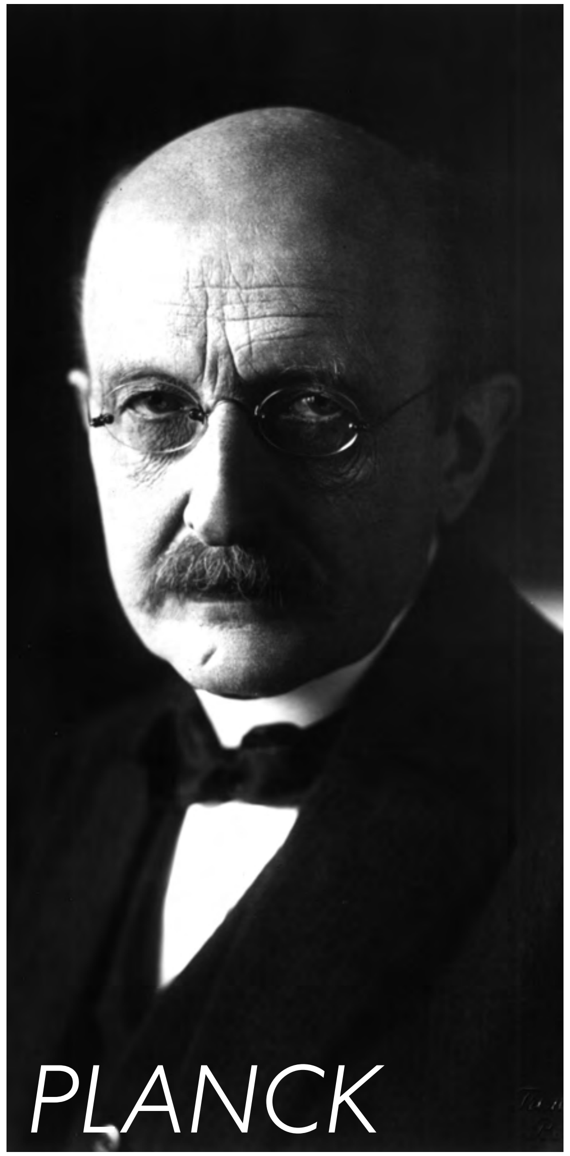
Quantum Supremacy and You

An Architect's Guide to Quantum Computing

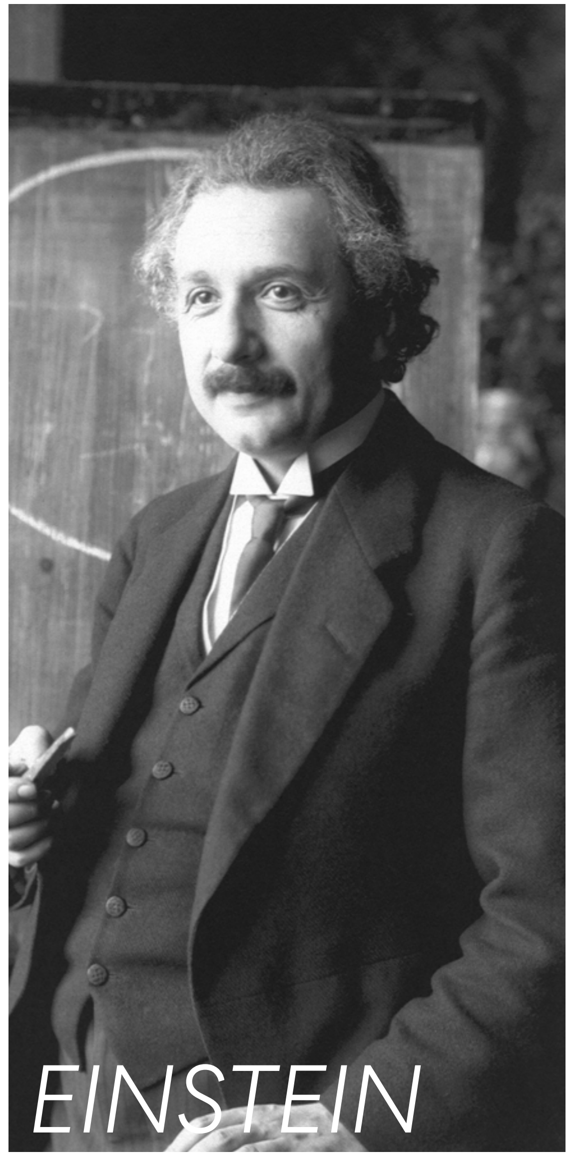
By Chris Hague



Nobel Laureate 1919

Fundamental hypothesis of quantum energy

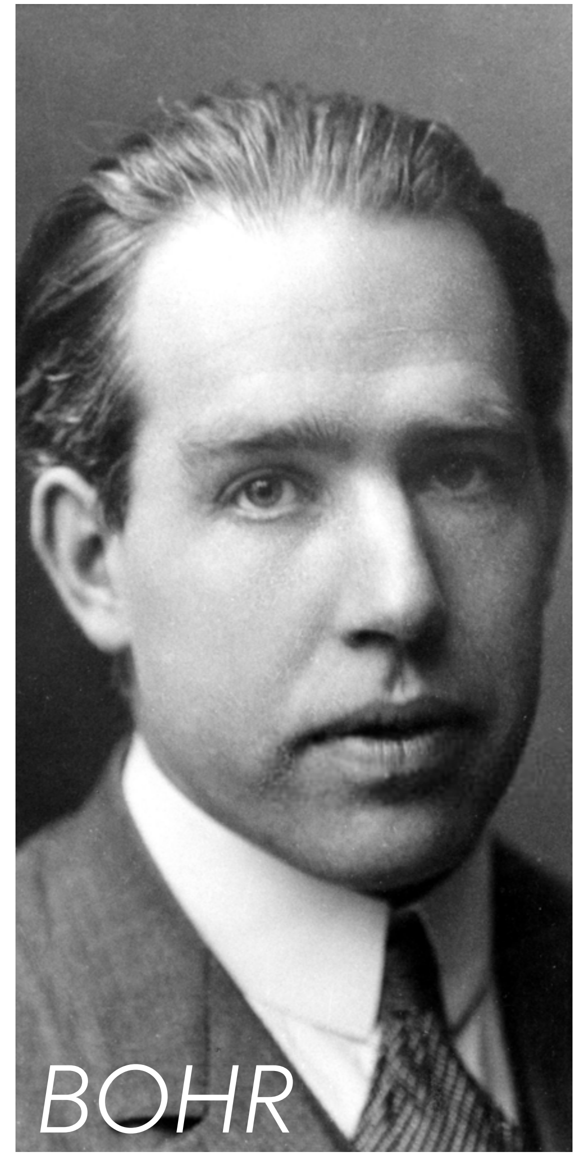
1900



Nobel Laureate 1921

Photoelectric Effect, wave particle duality, & Quantum Entanglement

1905



Nobel Laureate 1922

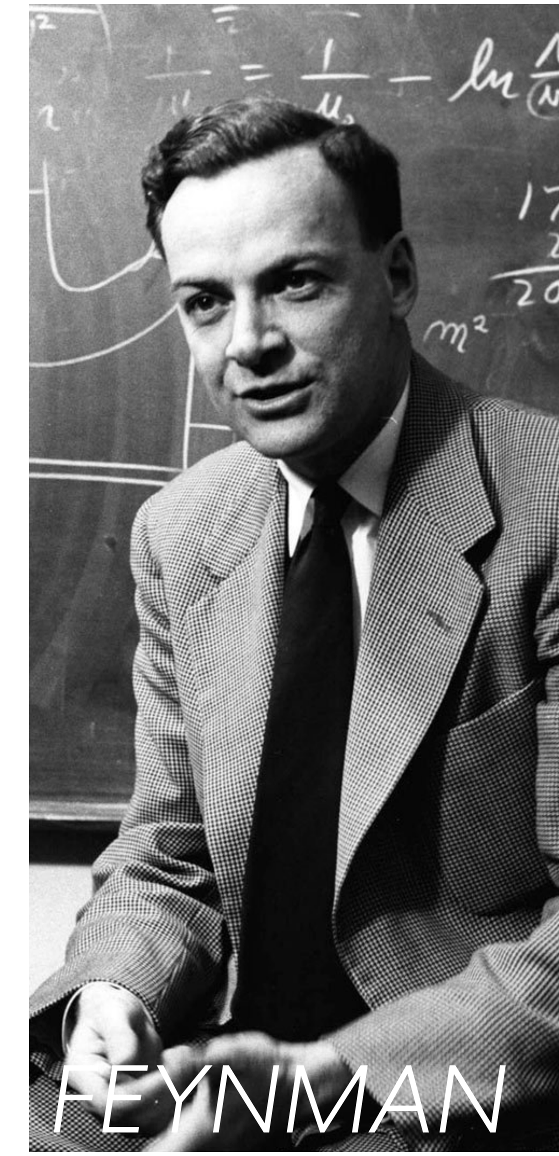
Discrete electron energy fields

~1920

Nobel Laureate 1933

Uncertainty Principle

1927



Nobel Laureate 1965

Proposing Quantum Computers could simulate systems classical computers could not

1980

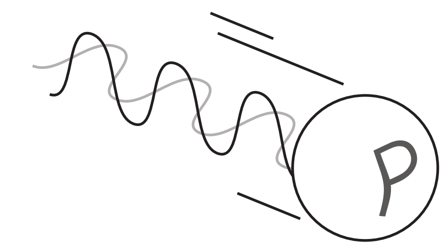
Quantum Mechanics

A branch of physical mechanics of mathematic descriptions of the motion and interaction of subatomic particles.

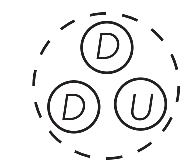
Subatomic particles are the constituents of atoms, including electrons, protons, and neutrons that are made of specific arrangements of smaller particles called Quarks.

Heisenberg Uncertainty Principle: the more the position of a particle is observed, to less can be derived about its momentum, and vice versa.

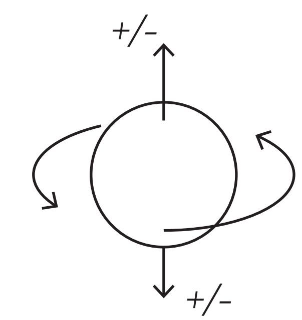
Quantum Entanglement: Spooky action at a distance; the connection of physical properties of quantum particles that are not physically interacting.



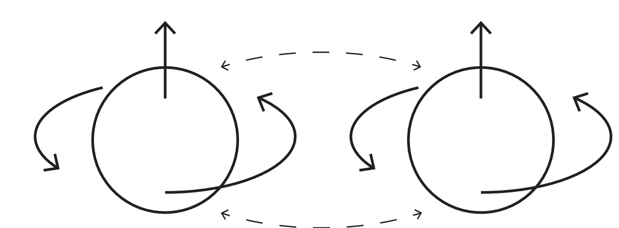
Photon Wave-Particle Duality



Quarks in a Neutron



Particle Polarity Superposition



Entangled Particles

Classical Computing 101

Classical computers utilize chips or processing units that contain modules containing Logic Gates of arranged transistors to control the flow of electricity.

Transistors are controlled by Binary Digits or “Bits” that use either 1’s or 0’s to denote high or low energy states of electric flow.

Transistors are arranged in specific ways to create Logic Gates that produce specific outputs for correlated inputs through Boolean Logic processes.

Logic Gates are arranged in modules that perform mathematic functions such as addition, subtraction, and multiplication. All computer processes are based on this fundamental base.

0 1

Classical Binary Digits

01010000 = P
01010111 = W

Bit Strings to Letters

Classical Computing 101

One Operation

Four Bits

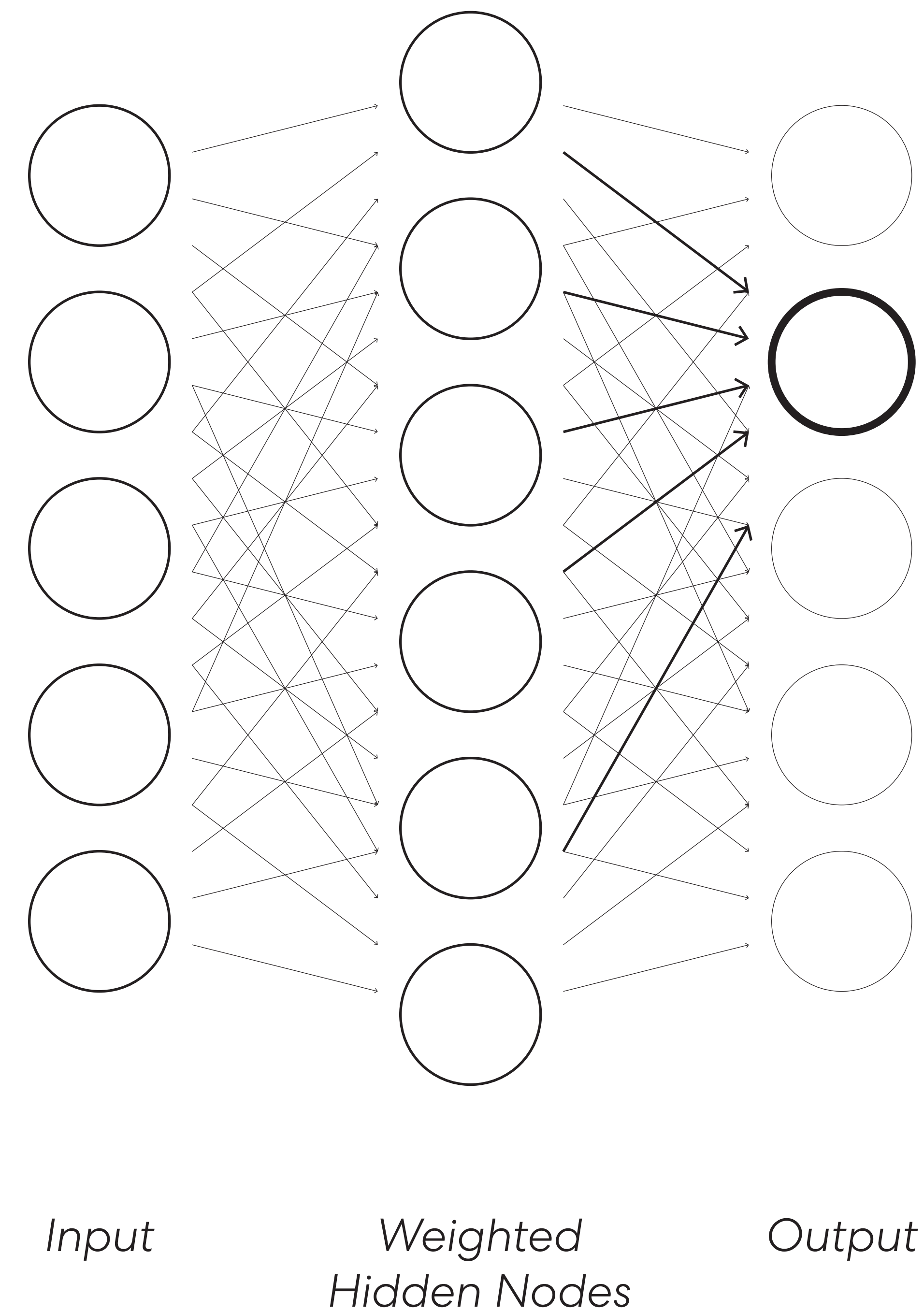
0000	0001	0010	0011
0100	0101	0110	0111
1000	1001	1010	1011
1100	1101	1110	1111

Classical Machine Learning

Machine Learning or colloquially known as Artifical Intelligence, is a classical computing technique of systematic training of a networked series of nodes that each perform simple tasks and can statistically produce an answer by concensus through mathematic weighting of each node's answer.

When being trained, a 'neural' network is given many pieces of data that are linked to a particular outcome based on a pattern, such as many images of the same item. The neural net finds patterns by correlation.

An extremely sophisticated system of this type was tasked with learning the statistically intensive board game Go, and then proceeded to beat the 18-time human Go champion, 4 to 1 in 2016.



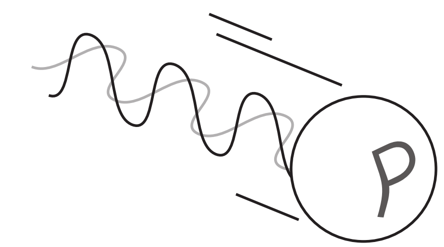
Quantum Computing Basics

Quantum Computers use physical devices such as a photons or an atoms called a Quantum Bits or Qubits that exist in quantum state of Superposition,

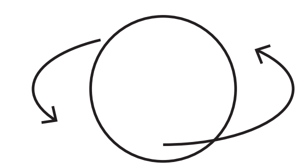
Superposition is the physical state in which the devices exists in both orientations at once, analogous to representing a 0 and 1 simultaneously.

Separate Qubits can be quantumly entangled to create quantum gates; gates can be arranged into modules or programs to statistically perform mathematic functions.

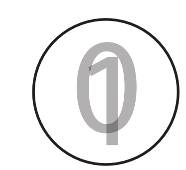
Although, in a quantum program every possible operation is performed simultaneously, and the statistically correct answer will be observed at the end.



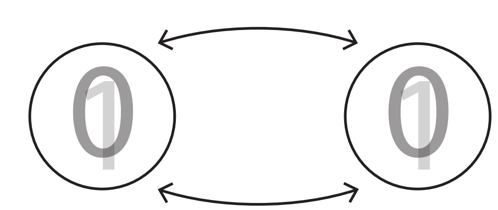
Photon Wave Polarity



Quantum Spin



Qubit in Superposition



Entangled Qubits

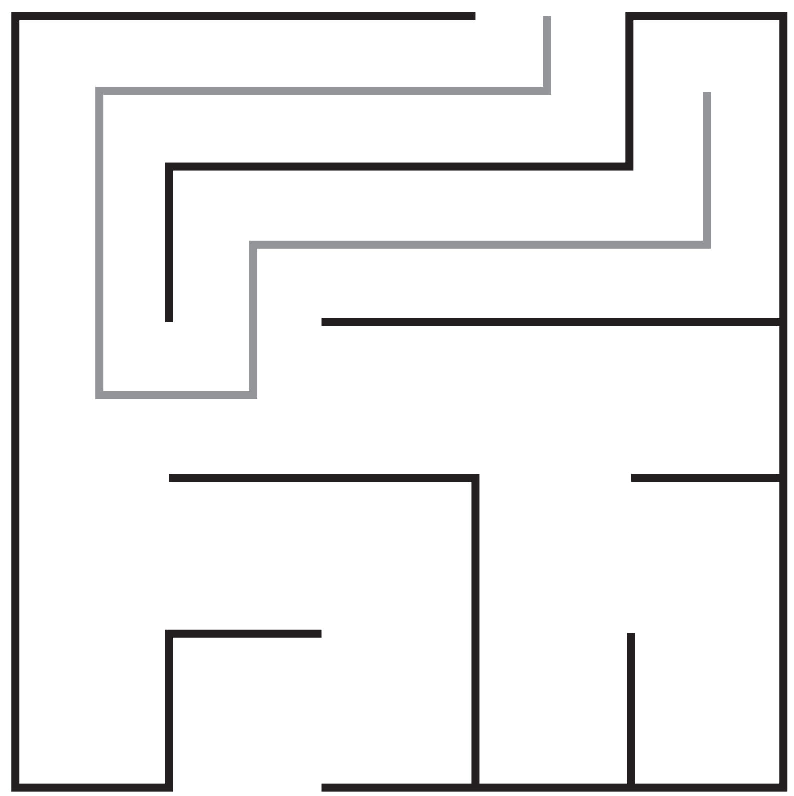
Quantum Computing Basics

One Operation

Four Qubits

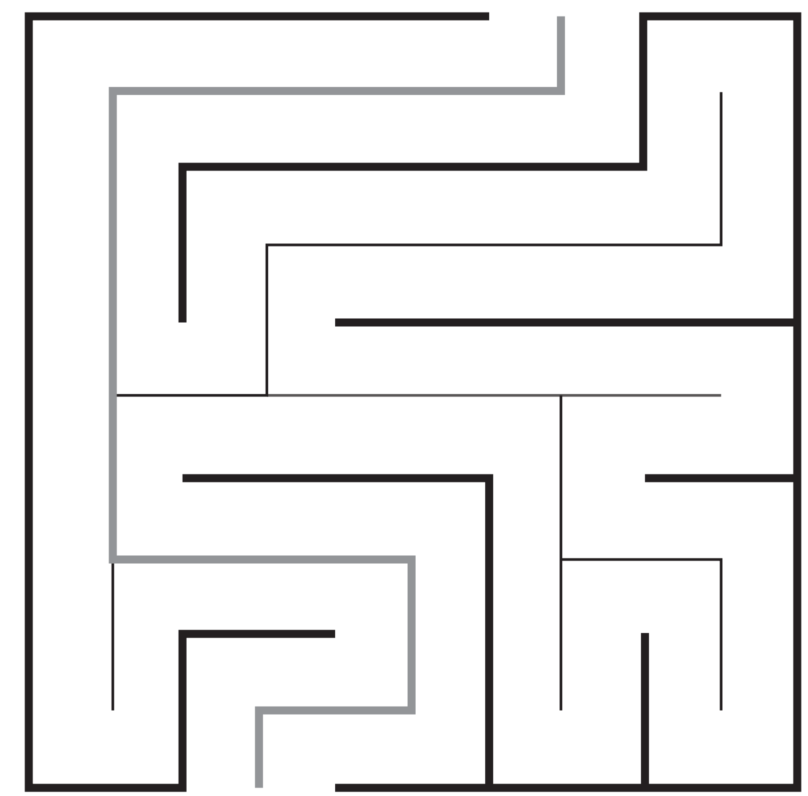
0000	0001	0010	0011
0100	0101	0110	0111
1000	1001	1010	1011
1100	1101	1110	1111

Classical Computing



One Operation

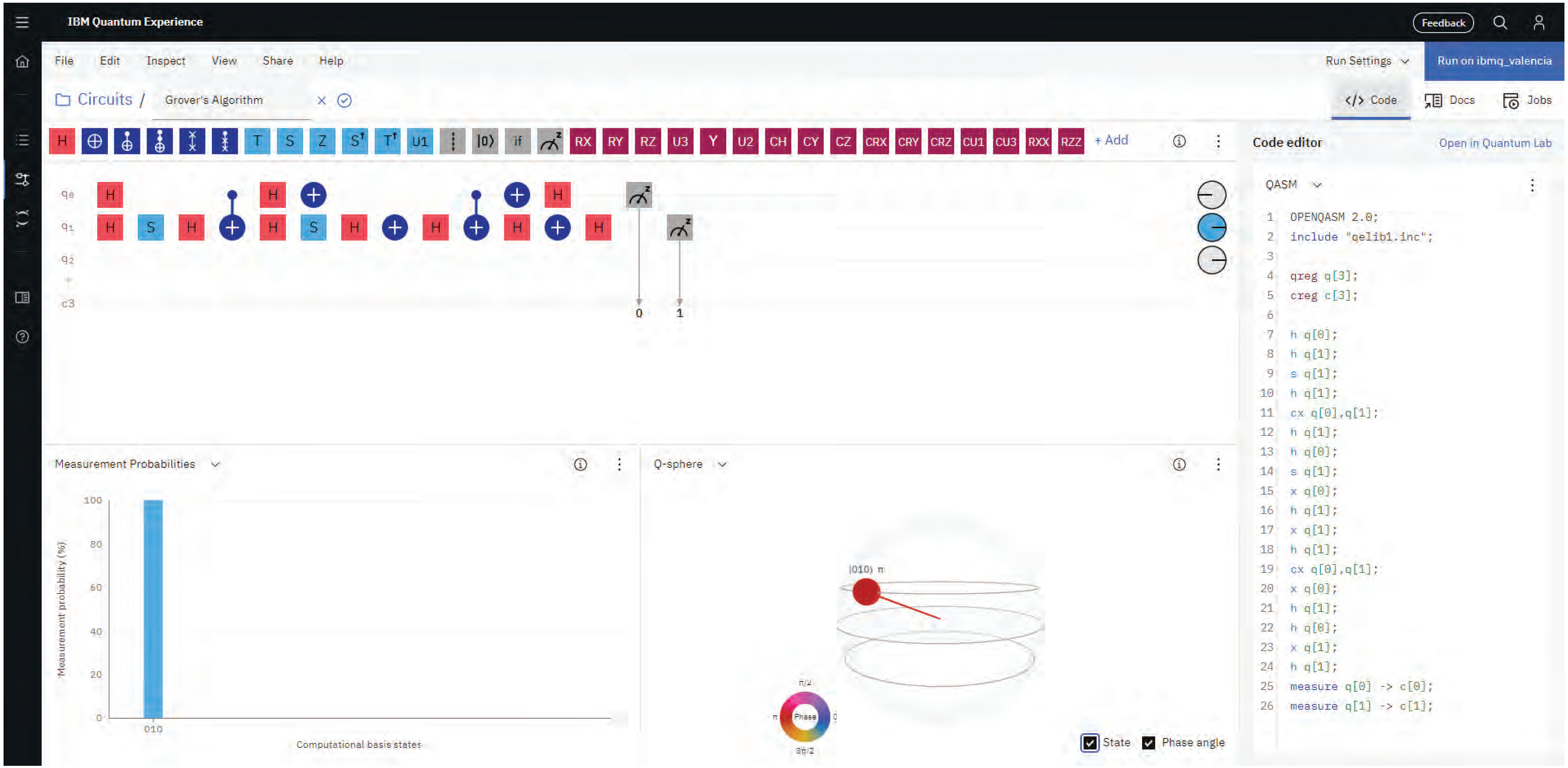
Quantum Computing



One Operation

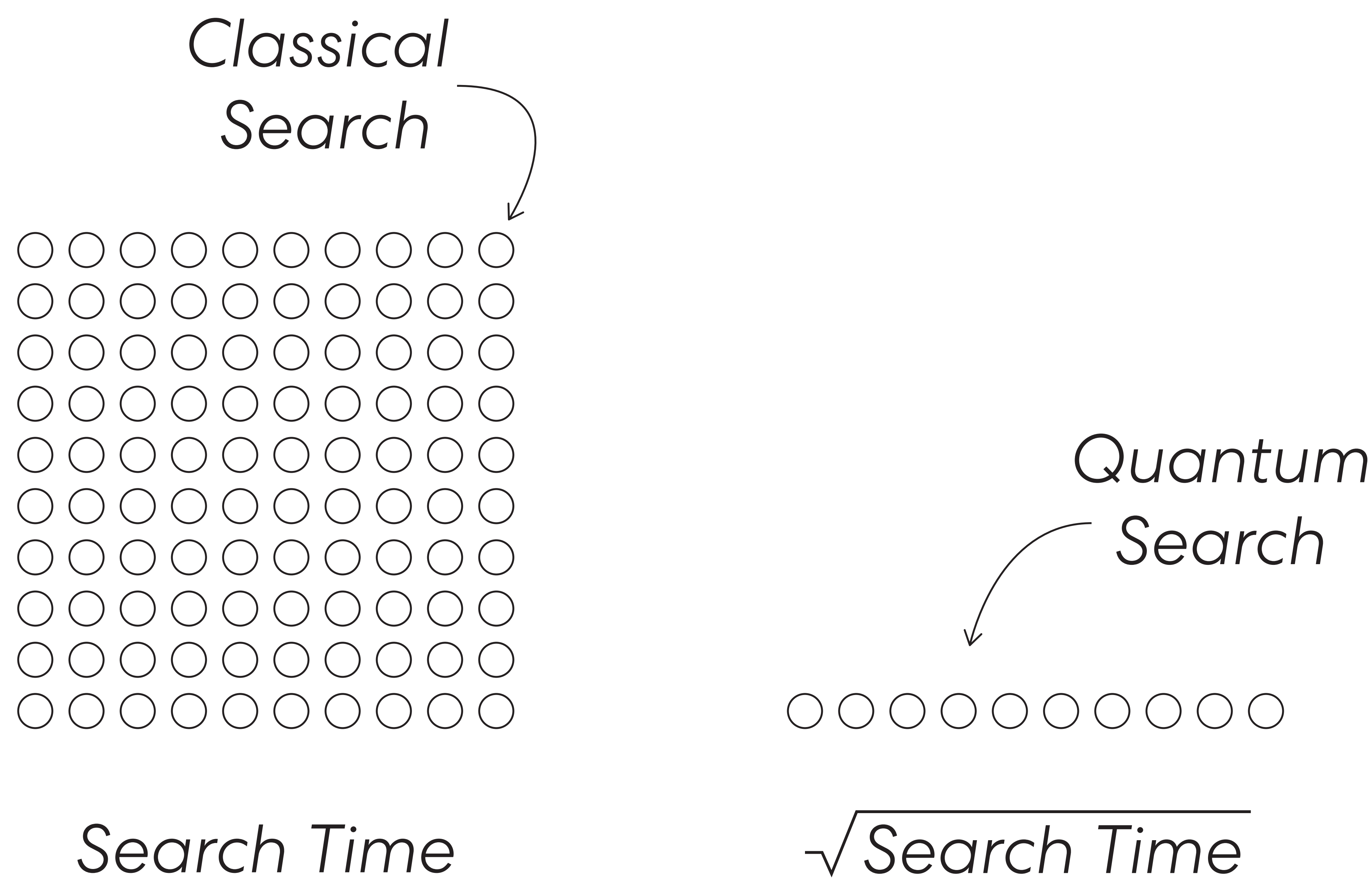
Quantum Programming

IBM Quantum Experience - Graphic Quantum Programing Interace



Grover’s Algorithm

Unstructured Search of a Database

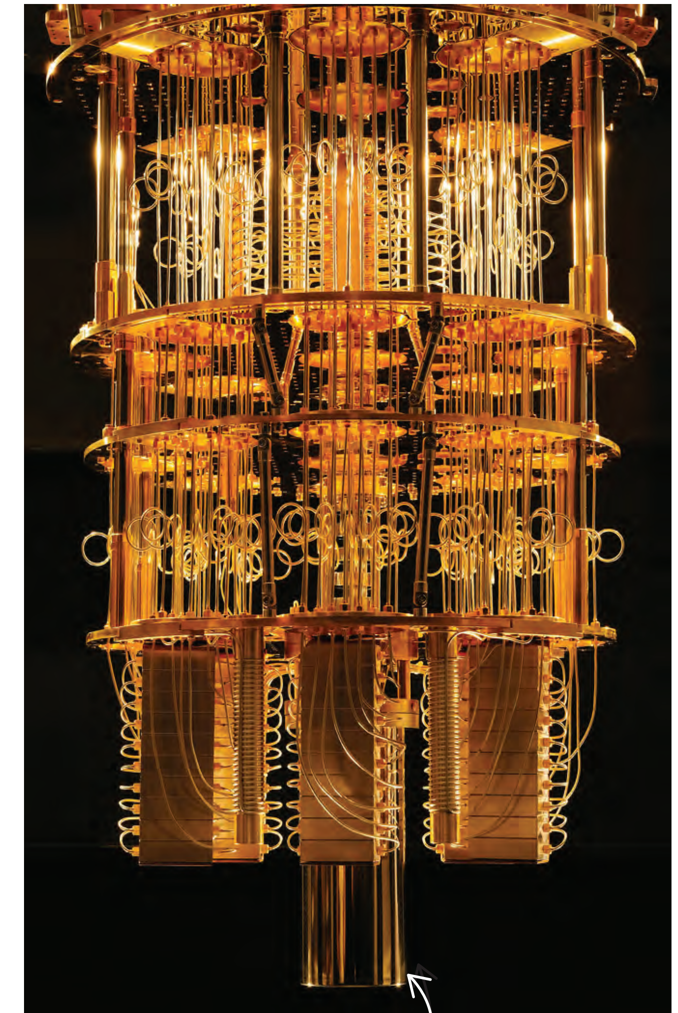


Quantum Supremacy

In October 2019, Google published a paper in Nature stating that their 53 Qubit chip completed a task significantly faster than a state-of-the-art classical computer; we have since lived in an era of "quantum supremacy."

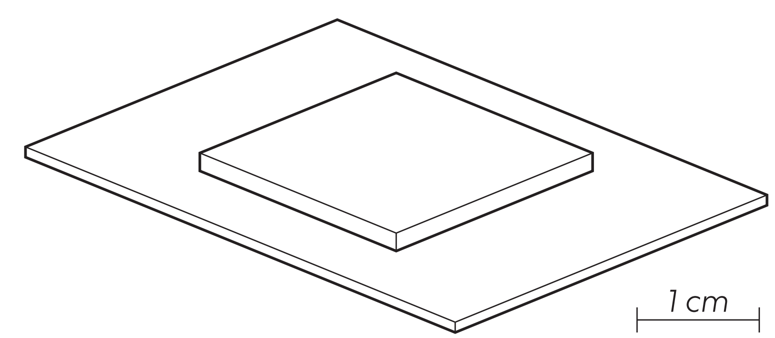
"A fundamental challenge is to build a high-fidelity processor capable of running quantum algorithms in an exponentially large computational space. Here we report the use of a processor with programmable superconducting qubits to create quantum states on 53 qubits, corresponding to a computational state-space of dimension 2^{53} (about 10^{16}). Measurements from repeated experiments sample the resulting probability distribution, which we verify using classical simulations. Our Sycamore processor takes about 200 seconds to sample one instance of a quantum circuit a million times—our benchmarks currently indicate that the equivalent task for a state-of-the-art classical supercomputer would take approximately 10,000 years."

Quantum supremacy using a programmable superconducting processor
Frank Arute, Kunal Arya, et al. 2019. 23rd of October



~75 cm

Quantum Processor in the Condenser

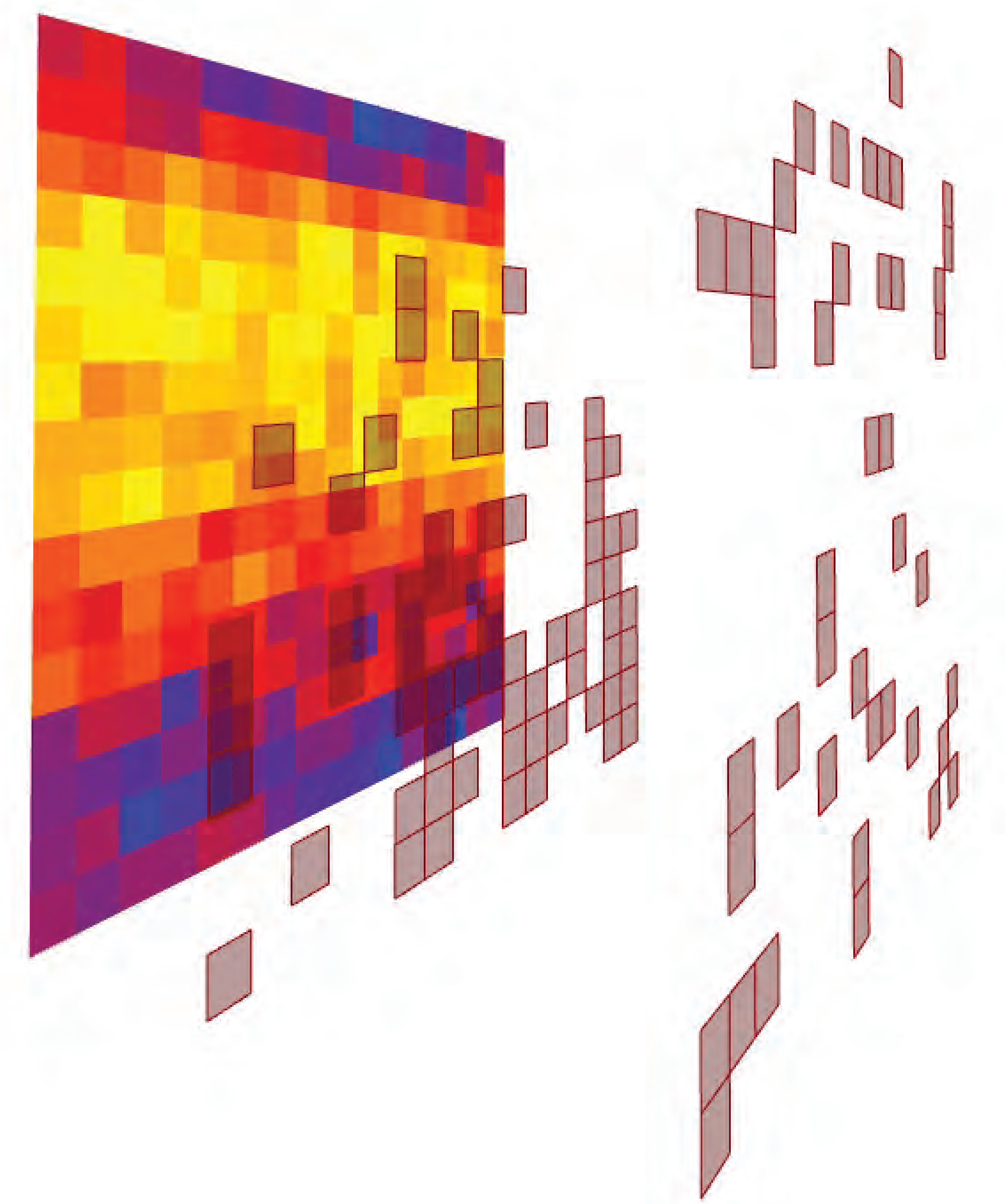


Standard Quantum Processor

Quantum Computing Use

In the Fall 2019 Innovation Incubator "Pushing the Envelope" studied a 16x16 grid multilayer frit shading device. The grid could either be populated or not by a square of frit; the solution space is therefore a 2^{256} system or 10^{76} which is approximately how many atoms are in the universe.

The quantum computer developed by Google could deterministically solve this in less than a day. If a 64 Qubit system was developed, it would only take 16 cycles of the processor. If a 256-Qubit system could be implemented, it would be deterministically solved instantly.

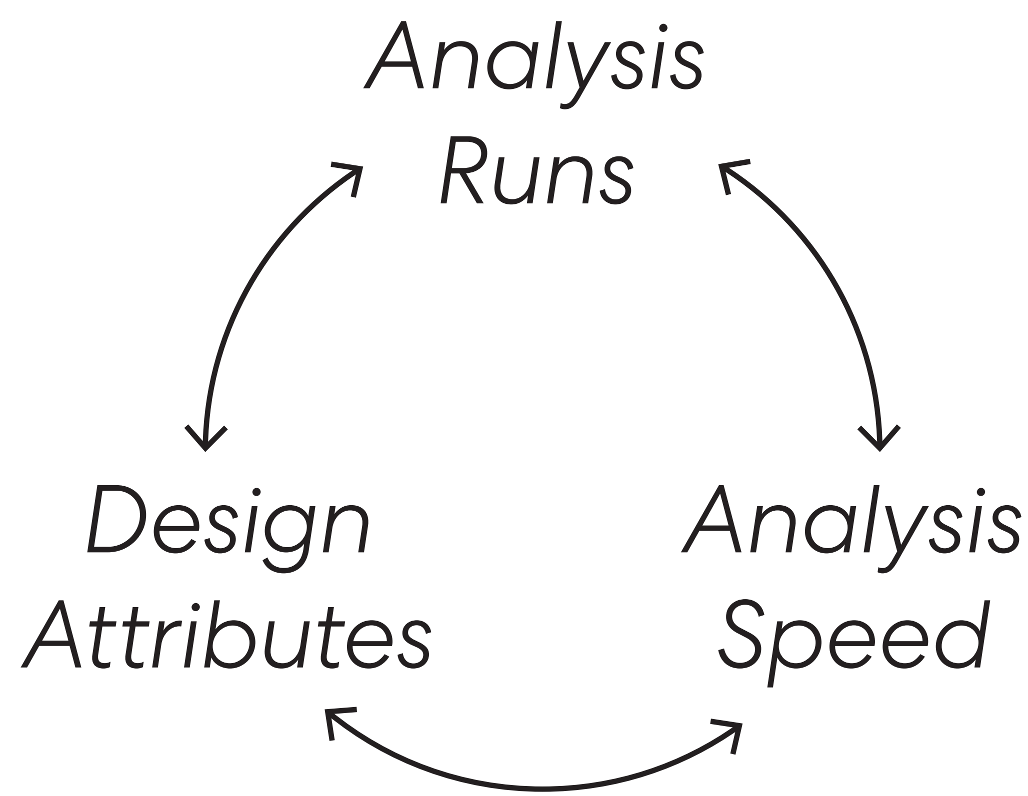


Quantum Design Space Construction

In the Design Space Construction workflow developed by Perkins & Will's Process Lab, projects are distilled down to the simplest possible models, and utilize sophisticated statistical analysis procedures to extract the most useful data out of the least amount of performance analysis runs.

Quantum Acceleration theorized in Grover's Algorithm and proved by Google could speed the process exponentially, increase granular analysis, or most importantly inculde more simultaneous metrics ond design attributes.

Analysis scope could increase other fields and design criterion, such as speculative development, urban environments, cost analysis, integrated structural systems, high-fidelity shading strategies.

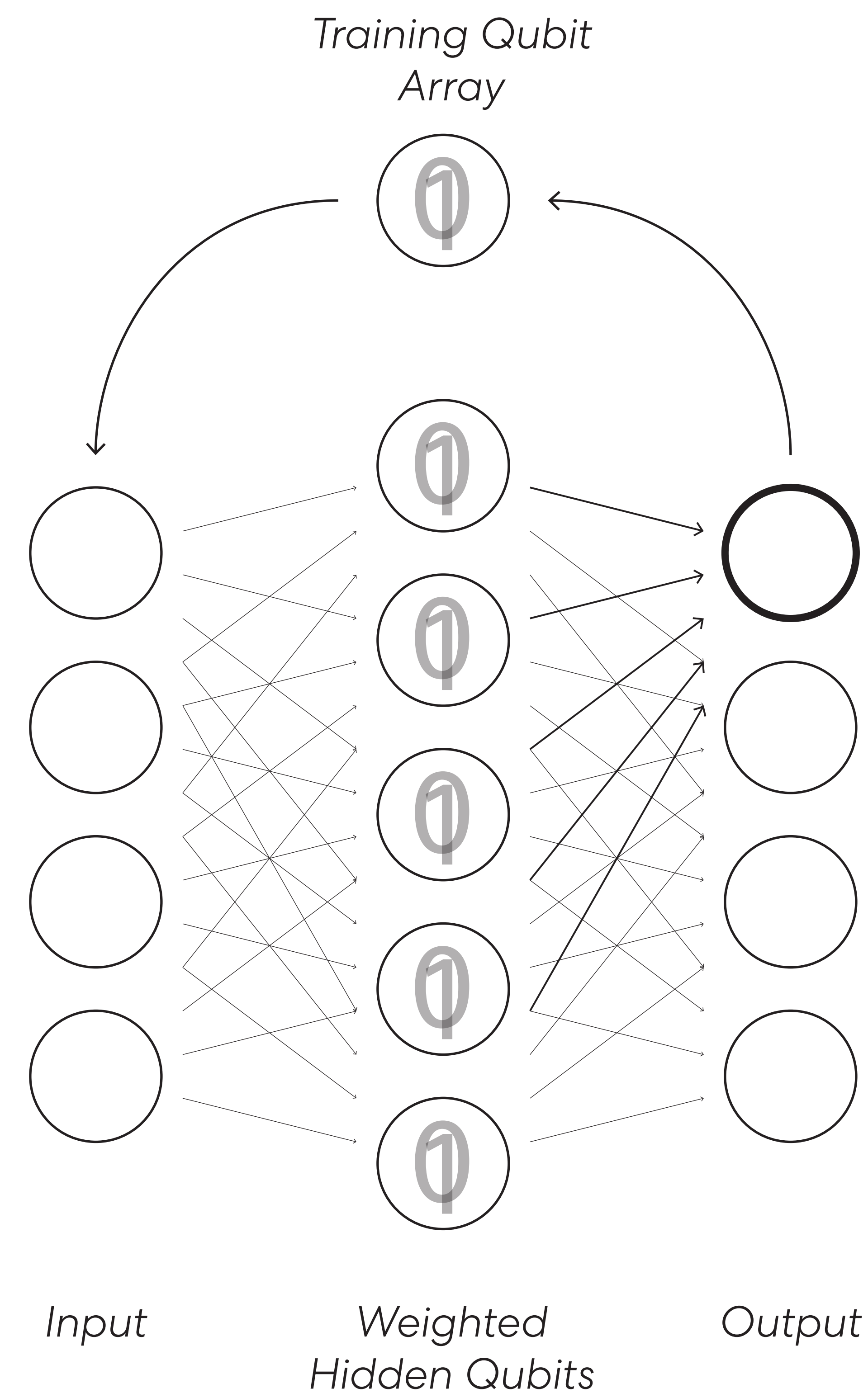


Quantum Machine Learning

Another speculative use for Quantum Acceleration is in parallel with Machine Learning. Training and running the neural networks could benefit from mass single-cycle solutions.

This could have a similar synergetic balancing of increase fidelity of training environments, increased speed, or increased number of nodes for more complex tasks to be performed by the neural network.

Accelerated Neural Networks could fill in gaps of data sets to create more robust analytical models at all scales, from Urban and Ecological Environment to a repository of successful details and building techniques. Accelerated Neural Nets could also be stacked on other processes, such as Design Space Construction and other multi-variable analyses.



Q&A

Thank you

Citations

Portrait of Max Planck. Photograph by Transocean (Photographic company, Berlin). Courtesy of the Smithsonian Libraries. No copyright. https://library.si.edu/image-gallery/73553

Portrait of Albert Einstein. Photograph by ferdinand Schmutzer. Courtesy of the National Library of Austria. Public Domain. https://en.wikipedia.org/wiki/File:Einstein_1921_by_F_Schmutzer_-_restoration.jpg

Portrait of Neils Bohr. Photograph by AB Lagrelius & Westphal (Photographic company, Sweden). Public Domain. https://commons.wikimedia.org/wiki/File:Niels_Bohr.jpg

Portrait of Werner Heisenberg. Unknown Author. Bundesarchiv, Bild 183-R57262 / Unknown author / CC-BY-SA 3.0. Courtesy of German Federal Archives. https://commons.wikimedia.org/wiki/File:Bundesarchiv_Bild183-R57262,_Werner_Heisenberg.jpg

Portrait of Richard Feynman. Courtesy of Caltech Archives. https://www.caltech.edu/about/news/remembering-richard-feynman-81875

Image from IBM Quantum Experience interface, 2020. https://quantum-computing.ibm.com/composer/1a84aa4950a418301eb0f98a22d7cbdc

Arute, F., Arya, K., Babbush, R. et al. Quantum supremacy using a programmable superconducting processor. Nature 574, 505–510 (2019).

"IBM quantum computer" by IBM Research is licensed with CC BY-ND 2.0. To view a copy of this license, visit https://creativecommons.org/licenses/by-nd/2.0/https://doi.org/10.1038/s41586-019-1666-5