

Quantum Computing

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Outline of Talk

- 1 Introduction
- 2 Quantum Architecture
- 3 Google AI Quantum

Keywords I

- **quantum**

In early 1900's quantum theory developed, successfully explaining weird behavior of atoms/electrons

In late 20th century it was discovered that it can be applied to information itself

- **quantum computer**

A device capable of controlling quantum states in fashionable way (the way ordinary computer controls/manipulates bits)

- **qubit**

quantum version of bits (values: $|0\rangle$, $|1\rangle$, or both at once), superposition phenomenon ($| \rangle$ used to distinguish qubits from ordinary bits)

- **superposition**

weighted sum or difference of two or more states

- **quantum superpositions**

predicts that a computer with N qubits can exist in superposition of all 2^N (all at the same time), which is exponentially higher than ordinary/classical computer

Keywords II

- entanglement

A property of quantum superpositions

Why Quantum Computer?

- Moore's Law
- components becoming smaller - atomic scale?
- quantum effects
 - it will start to play role even before we reach transistors that are only one atom large
- build quantum computers that embrace quantum effects
 - making use of quantum physics to build different computers than traditional one

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Applications I

● Optimization

- systems design
- airline scheduling
- mission planning
- financial analysis
- web search
- cancer radiotherapy
- Volkswagen was the first car manufacturer to use a quantum computer to calculate traffic flows.
- Recruit Communications and D-Wave - collaborated to apply quantum computing to marketing, advertising and communications. (optimize the efficiency of matching advertisements to customers for web advertising.)

Applications II

● Machine Learning

- Improving forecast capability with neural network
- learn to recognize essences of objects by recognizing patterns in huge amount of data
- native capability of D-Wave Quantum Processing Unit (QPU)
- NASA scientists trained the D-Wave 2X system on image data sets in a generative unsupervised learning

Applications III

- **Biomedical Simulations**

- simulate molecular structures
- Using D-wave One quantum computer researchers from Harvard University solved the puzzle of how some proteins fold in year 2012

- **Financial Services**

- complex financial modeling and risk management within the financial industry
- new ways to model financial data
- isolate primary global risk factors

Top Quantum Computing Companies I

- **D-wave Systems**

World's first Quantum Computing Company

integrates new discoveries in physics, engineering, manufacturing and computer science into computational breakthrough approaches to solve most complex challenges.

- **IBM Quantum Computing**

Offers quantum experience on cloud-enabled quantum computing platform

allows user to run algorithms, experiments, work on qubits, simulation etc.

- **Microsoft Quantum Computing**

Conducts theoretical and experimental approaches to creating quantum computers

- **Google Research**

Quantum Artificial Intelligence Lab - joint initiative of NASA, Universities Space Research Association and Google Research

goal - how quantum computing help with machine learning and other complex problems of computer science

Lab hosted at NASA's Ames Research Center

Top Quantum Computing Companies II

- **Toshiba Quantum Information Group**

Research teams on Quantum Information, Speech Technology and Computer Vision.

Collaboration with Cavendish Laboratory and Engineering Department of the University, Cambridge and Toshiba R&D groups.

- **Intel**

10 year collaboration with institute QuTech, Netherlands formed in 2013 by Delft University of Technology for Applied Research in Quantum Computers

- **Alibaba Quantum Computing Laboratory**

goal - bring study and applications to the next level, platform for connectivity, computing and information security

- **Cambridge Quantum Computing**

independent company - expertise in Quantum Information Processing, AI, Optimization and pattern recognition

Top Quantum Computing Companies III

- And many more...

HP Lab : Quantum Information Processing, IQB Information Technologies, Lockheed Martin, Regetti, IONQ, QxBranch, Post-Quantum, ID Quantique, QuintessenceLabs, Quantum Biosystems

Types of Quantum Processor

Silicon Spin Qubits

Electrons or nuclear spins on a solid substrate

Superconducting Circuits

currents superposition around superconductor

Ion's Trap

Trap ions in electric fields

Photonic Circuits

qubits are photons driven in silicon circuits

Timeline

May, 2011	•	D-Wave One (Ranier)	128qb
2013	•	D-Wave Two	512 qb
2015	•	D-Wave 2X	1152 qb
2016	•	IBM Q Experience 5	5qb
2017	•	Google	20 qb
2017	•	D-Wave 2000Q	2000 qb
May, 2017	•	IBM Q 16	16 qb
May, 2017	•	IBM Q 17	17 qb
October, 2017	•	Intel 17-Qubit Superconducting Test Chip	17 qb
November, 2017	•	IBM Q 20	20 qb
2017	•	Rigetti 19Q	19 qb
January 2018	•	Intel Tangle Lake	49 qb
March 2018	•	Google Bristlecone	72 qb

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Google AI Quantum I

Superconducting qubit processors

Superconducting qubits with chip-based scalable architecture targeting two-qubit gate error $< 0.5\%$. Google's Bristlecone is newest 72-qubit quantum processor^a.

^aas on 2018

Qubit metrology

Reducing two-qubit loss below 0.2% is critical for error correction. Working on a quantum supremacy experiment, to approximately sample a quantum circuit beyond the capabilities of state-of-the-art classical computers and algorithms.

Google AI Quantum II

Quantum simulation

Simulation of physical systems is among the most anticipated applications of quantum computing.

quantum algorithms for modelling systems of interacting electrons with applications in chemistry and materials science.

Quantum neural networks

a framework to implement a quantum neural network on near-term processors.

understanding advantages may arise from generate massive superposition states during operation of the network.

Google AI Quantum III

Quantum assisted optimization

Developing hybrid quantum-classical solvers for approximate optimization.

Thermal jumps in classical algorithms to overcome energy barriers could be enhanced by invoking quantum updates.

Particular interested in coherent population transfer.