

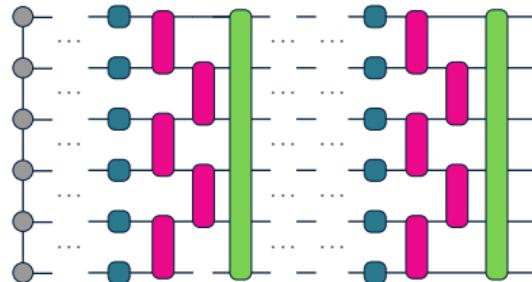
What Are (and Aren't) Quantum Computers?

Matthew Duschenes

University of Waterloo, Institute for Quantum Computing, & Perimeter Institute

January 15, 2025

Perimeter Institute Outreach



How Does Someone End Up In Theoretical Physics?

About Me

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Lots of
Things

Go Renegades
2009-2013

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Engineering
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Theoretical
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Applied
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Quantum
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Go Warriors
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- Derive (*pen and paper*), simulate (*coding*), or experiment (*labs*)
- Try and find *most-general* explanations for observations

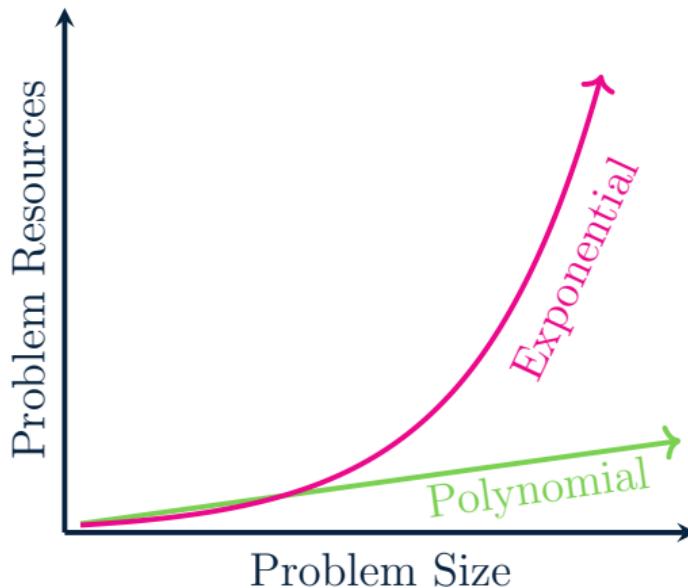
Why Might We Need Quantum Computers?

What Makes Problems *Hard*?

- What makes problems *technologically* hard to solve?

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i.e) How do required *resources* increase as problems get harder?

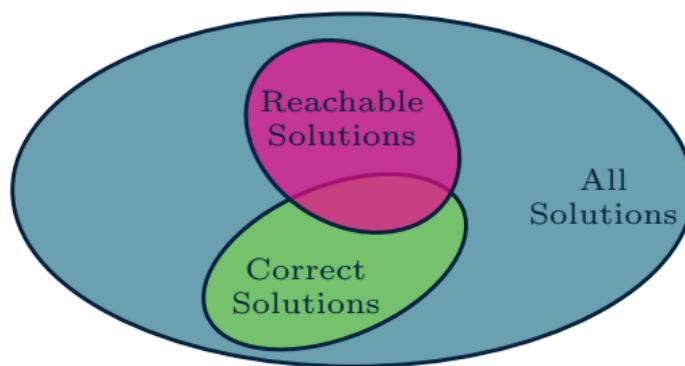


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$$|x\rangle \longrightarrow ??$$

Quantum Hype!

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The screenshot shows the official Canadian government website for the National Quantum Strategy. The header includes the Canadian flag and links for "Government of Canada" and "Government du Canada". A search bar is at the top right. Below the header, a navigation menu has "MENU" expanded. The main content area features a breadcrumb trail: "Canada.ca > Innovation, Science and Economic Development Canada > Public consultations > Overview of Canada's National Quantum Strategy". The title "Overview of Canada's National Quantum Strategy" is displayed, along with a subtitle "From: Innovation, Science and Economic Development Canada". A large image of a quantum sphere with glowing particles serves as the background for the section. Below the image, a paragraph discusses the opportunities in quantum science.

Quantum science is at the leading edge of research and innovation. This emerging field will transform how we develop and design everything from life-saving drugs to next-generation batteries, and Canadian scientists and entrepreneurs are well-positioned to take advantage of these opportunities.

(a) Canadian Quantum Strategy
(*sed-isde.canada.ca*, 2024)



The screenshot shows a news article from the University of Waterloo's Institute for Quantum Computing. The header features the university's logo and the "INSTITUTE FOR QUANTUM COMPUTING". The main headline reads "New funding from Canada's Strategic Science Fund awarded to IQC Canada Inc., in support of IQC research". Below the headline is a yellow banner with the date "MONDAY, MAY 27, 2024". A small "See full story" link is visible. At the bottom, a note credits the funding source: "The Institute for Quantum Computing (IQC) at the University of Waterloo is pleased to congratulate IQC Canada Inc., for receiving \$18.4 M in funding from Innovation, Science and Economic Development Canada's Strategic Science Fund (SSF). The fund aims to mobilize the expertise and resources of independent, third-party science and research organizations to enhance Canada's science technology and innovative excellence."

(b) IQC Quantum Funding
(*uwaterloo.ca*, 2024)



The screenshot shows a news article from Xanadu. The header includes the Xanadu logo and navigation links for "Products", "Partners", "Community", and "Company". The main headline is "Government of Canada supports Xanadu to accelerate quantum computing research and education". Below the headline is a small note: "Xanadu receives \$3.75M CAD through the Regional Quantum Initiative to accelerate the development of quantum software for practical applications". The date "February 22, 2024" is at the bottom.

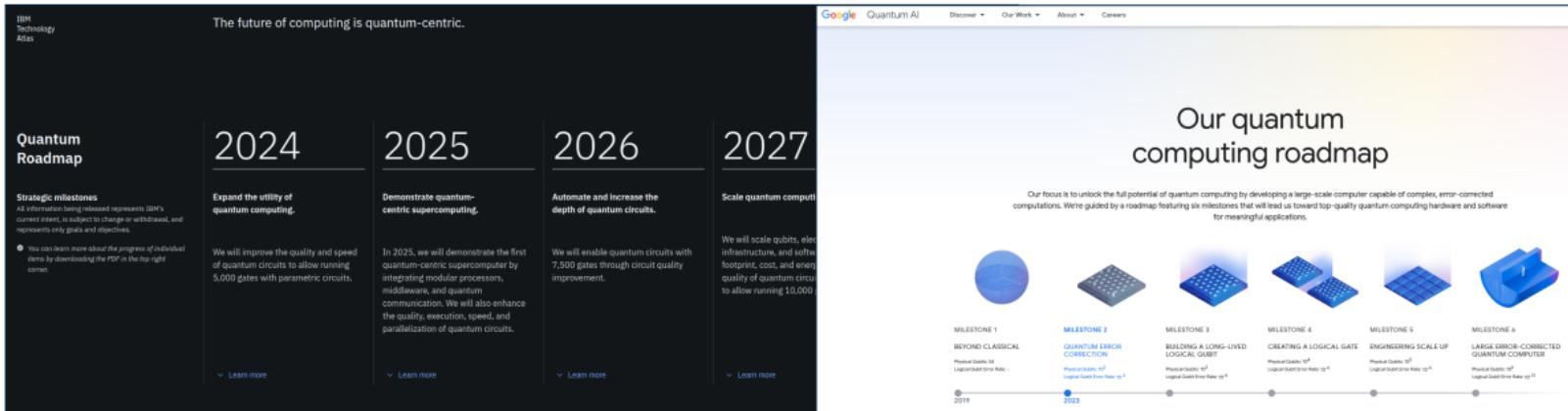
(c) Xanadu Quantum Funding
(*xanadu.ai*, 2024)

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(d) IBM Quantum Roadmap
(ibm.com, 2024)

(e) Google Quantum Roadmap
(quantumai.google, 2024)

Quantum Hype!

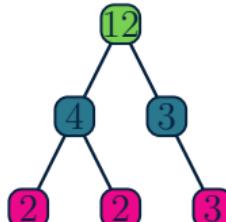
- Serious commitment from *government, universities, and companies*
- When will we have a *useful* quantum computer?
- How will quantum computers be *used*?

What May Quantum Computers Be Useful For?

- Ultimately, we want to do something *useful* with these quantum devices

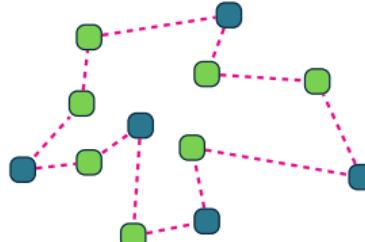
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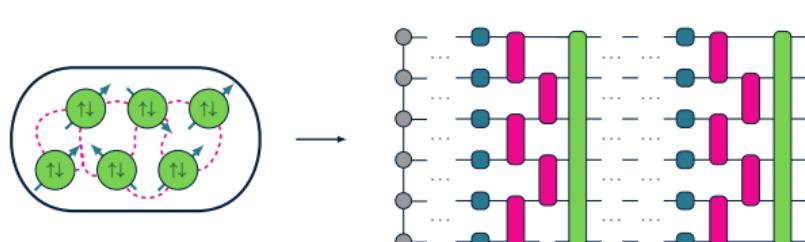
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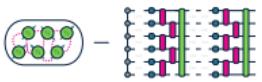


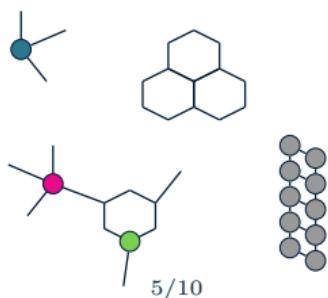
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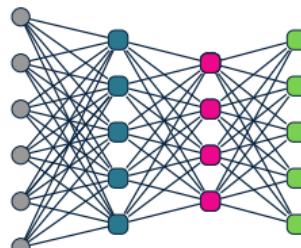
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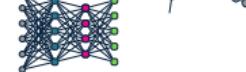
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- *Machine learning* functions i.e) Classify images and infer functions

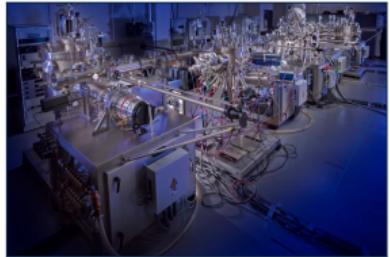


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- What makes quantum systems *potentially better* than classical systems?

What Are Quantum Computers?

Quantum Computing Experiments



(d) IQC Trapped Ions

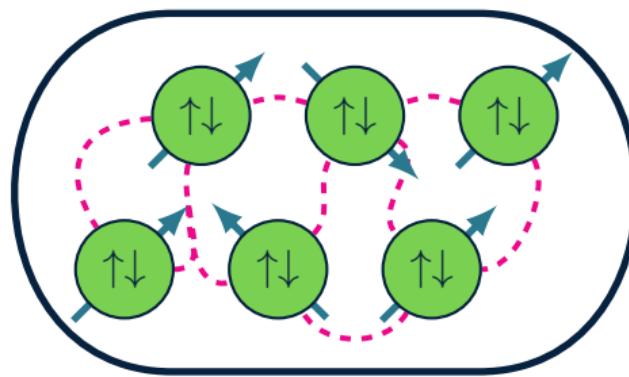


(e) Xanadu Quantum Optics



(f) Google Superconducting Circuits

Quantum Computing Experiments



Qubits

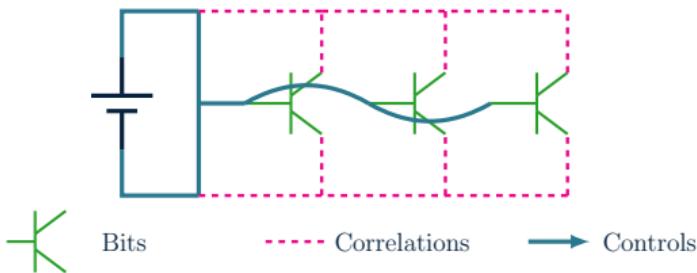
Correlations

Controls

Classical Versus Quantum Information

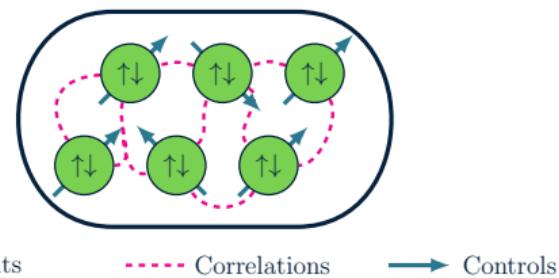
Classical

- Information as *bits 0 or 1*
 - Correlations as *statistical covariance*
 - *Multiple* measurements
 - *Many possible* dynamics
- i.e) Voltage levels of *transistors*

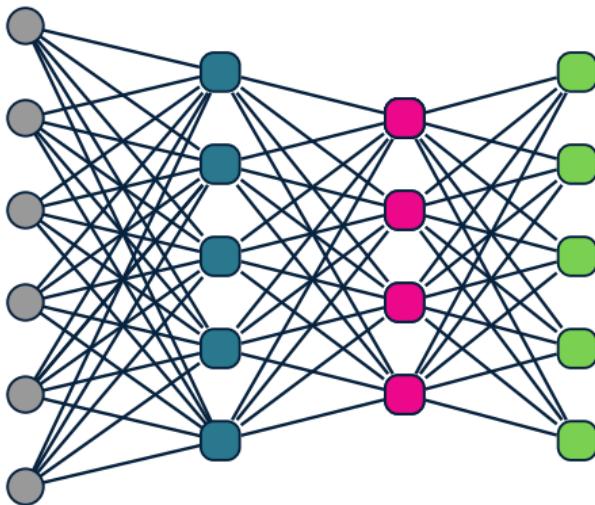


Quantum

- Information as *qubits $|0\rangle$ and/or $|1\rangle$*
 - Correlations as *entanglement*
 - *Only one-time* measurements
 - *Specific* dynamics
- i.e) Energy levels of *electrons*

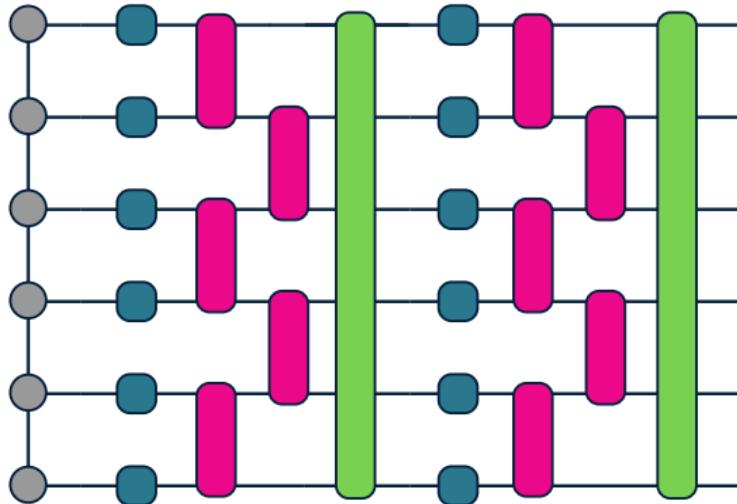


Classical Versus Quantum Algorithms



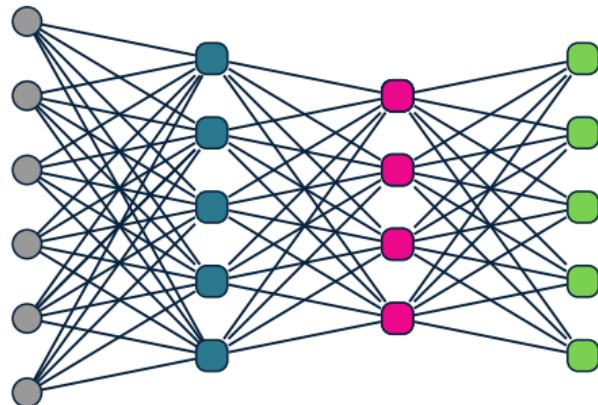
Classical Neural Network

Classical Versus Quantum Algorithms

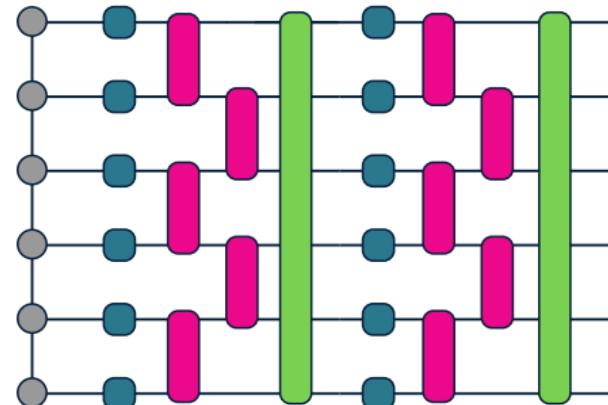


Quantum Unitary Circuit

Classical Versus Quantum Algorithms

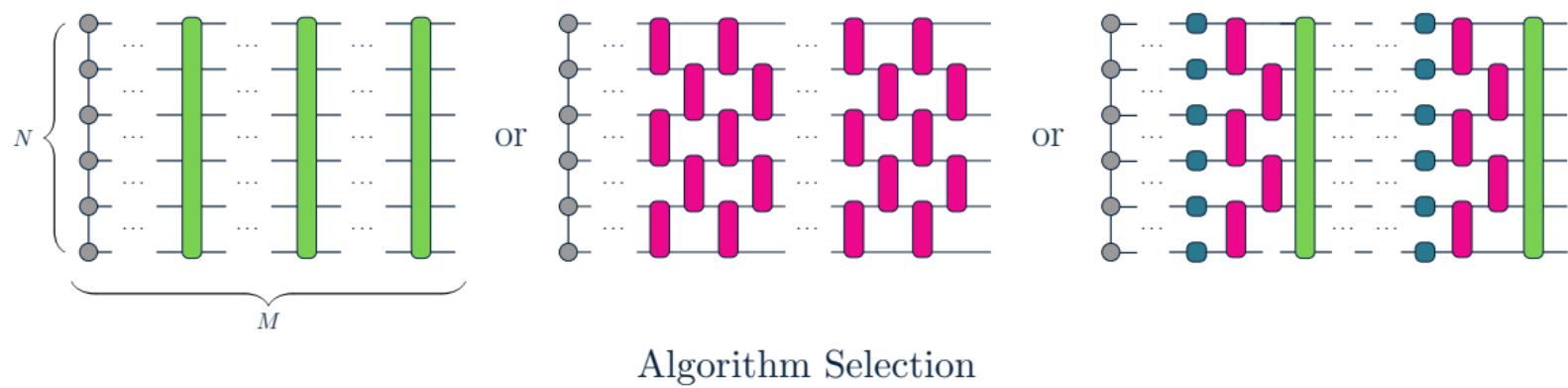


Classical Neural Network
 $f_{\theta}(x)$



Quantum Unitary Circuit
 $U_{\theta} |\psi(x)\rangle$

Classical Versus Quantum Algorithms



What Aren't Quantum Computers?

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→ Likely No Quantum Laptops!

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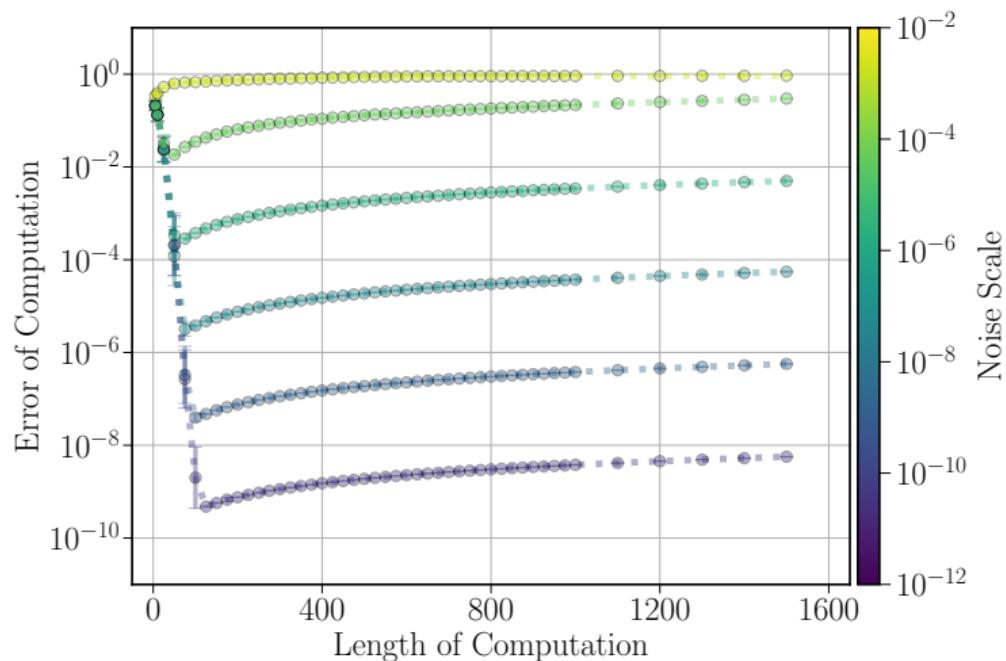
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→ Likely No Quantum Laptops!
- Back and forth between *state-of-the-art* classical and quantum methods

What Is Quantum Advantage?

What if we are only able to *experimentally* implement *noisy* computations?



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- Useful Reviews:
 1. Fedorov, A. *et al.* , Quantum computing at the quantum advantage threshold: a down-to-business review. arXiv:2203.17181 [quant-ph] (2022).
 2. Schuld, M. *et al.* , An introduction to quantum machine learning. Contemporary Physics, 56(2), 172–185. (2015).
 3. Schuld, M. *et al.* , Is Quantum Advantage the Right Goal for Quantum Machine Learning? PRX Quantum, 3(3), 030101. (2022).
 4. Bharti, K. *et al.* , Noisy intermediate-scale quantum algorithms. Reviews of Modern Physics, 94(1), 015004. (2022).