Quantum Computers are 5 Years Away

And they have been for a while

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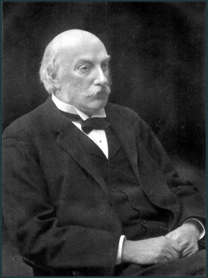
The University of Edinburgh

Content

A Brief History of Quantum Mechanics

Lord Rayleigh and James Jeans



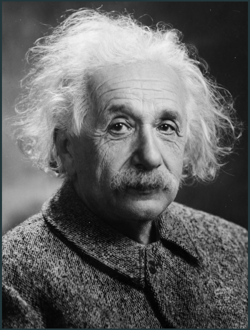
1900 - Classical prediction for blackbody radiation.

Max Planck

1900 - Suggests the quanta.

"My unavailing attempts to somehow reintegrate the action quantum into classical theory extended over several years and caused me much trouble."

Albert Einstein



1905 - Photo electric effect.

"We cannot solve our problems with the same thinking we used when we created them."

George Paget Thomson and Clinton Davisson

1927 - Electon diffraction using thin metal film.

1927 - Electon diffraction using a crystal.

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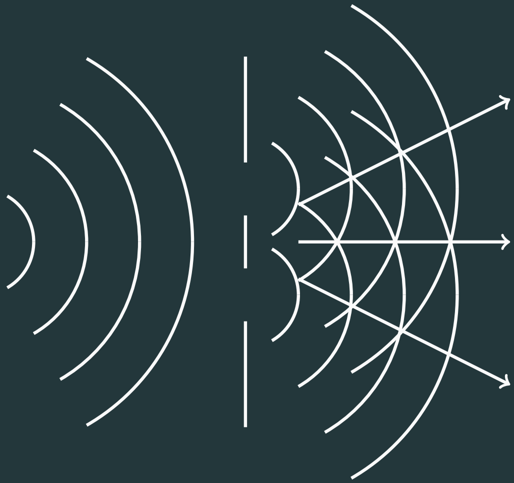

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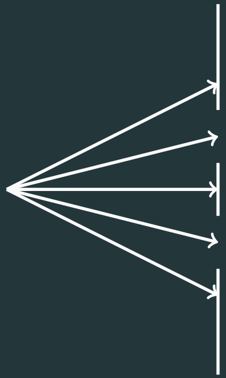

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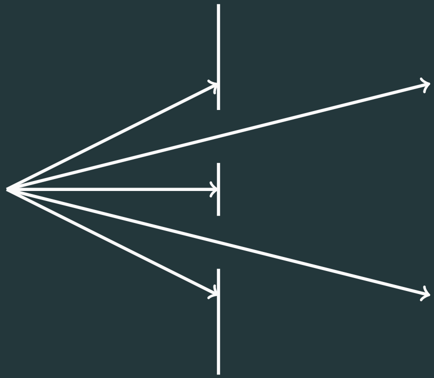


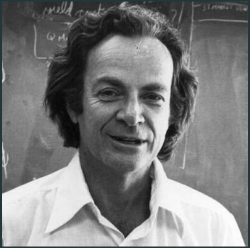
John Stewart Bell

1964 - Bell test of local hidden variables.

"Does not any analysis of measurement require concepts more fundamental than measurement? And should not the fundamental theory be about these more fundamental concepts?"

Can Quantum Mechanics be Useful?

Richard Feynman



1981 - Suggested quantum computing.

“Nature isn’t classical, dammit, and if you want to make a simulation of nature, you’d better make it quantum mechanical, and by golly it’s a wonderful problem, because it doesn’t look so easy.”

David Deutsch

1985 - Quantum Turing machine.

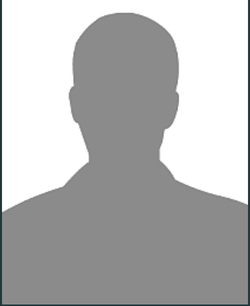
"Computing devices resembling the universal quantum computer can, in principle, be built and would have many remarkable properties not reproducible by any Turing machine."

David Deutsch & Richard Jozsa

1992 - Separation between P and EQP .

"The quantum computation solves the problem with certainty in exponentially less time than any classical deterministic computation."

Daniel Simon

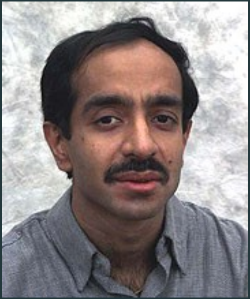


1994 - Separation between BPP and BQP .

Peter Shor

1994 - Quantum computers can factor numbers in polynomial time.

Lov Grover



1996 - Quantum computers can search unstructured databases faster than classical computers.

Can We Build Quantum Computers?

Qubit Counter

qubit counter

Timeline

1998: 2-qubit demonstration of Deusch's algorithm in Oxford. First demonstration of Grover's algorithm.

2000: 7-qubit computer demonstrated at the Los Alamos National Laboratory.

2001: First execution of Shor's algorithm by IBM. The number was 15.

2003: First linear optical quantum computer.

2005: The first quantum byte, or qubyte, is announced at the University of Innsbruck in Austria.

Timeline

2006: First 12 qubit quantum computer benchmarked by researchers in Waterloo.

2016: Google, using an array of 9 superconducting qubits, simulates a hydrogen molecule.

2017: IBM unveils 17-qubit quantum computer. Intel develops a 17-qubit chip. IBM reveals a working 50-qubit quantum computer.

2018

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"Breaking the 49-Qubit Barrier in the Simulation of Quantum Circuits"

2018

2017: IBM reveals a working 50-qubit quantum computer.

“Breaking the 49-Qubit Barrier in the Simulation of Quantum Circuits”

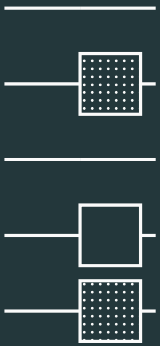
Google announced the creation of a 72-qubit quantum chip called “Bristlecone”

Quantum Superiority

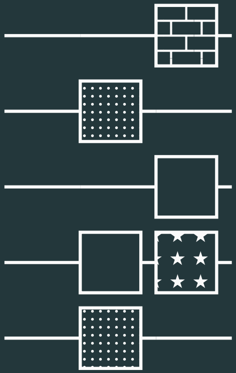
Quantum supremacy is achieved when a formal computational task is performed with an existing quantum device which cannot be performed using any known algorithm running on an existing classical supercomputer in a reasonable amount of time.

Quantum Superiority

Quantum Superiority



Quantum Superiority



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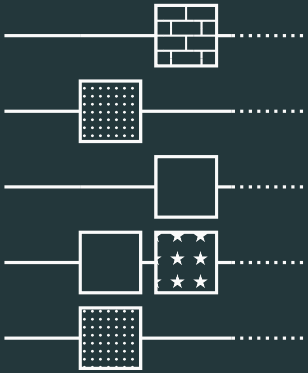

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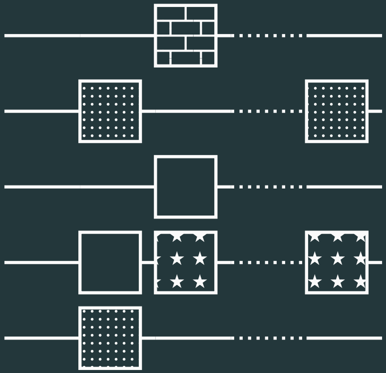
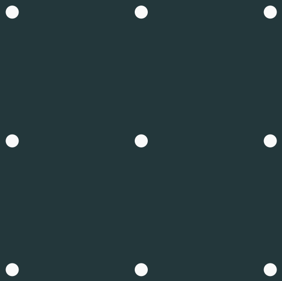
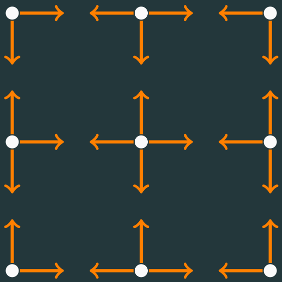


Noisy Quantum Computers and Superiority

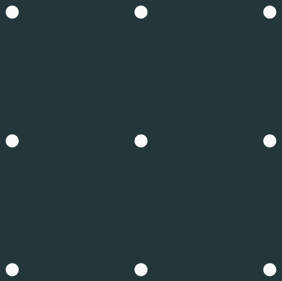
NQIT Archetecture [1]



NQIT Archetecture [1]



2D-DQS on NQIT Archetecture [2]



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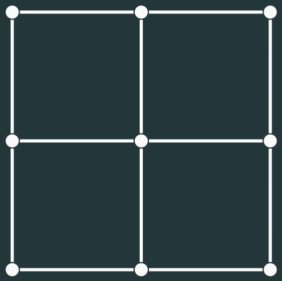

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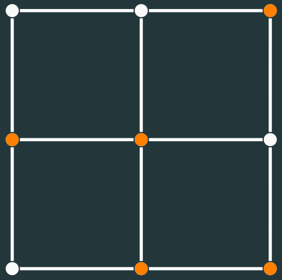

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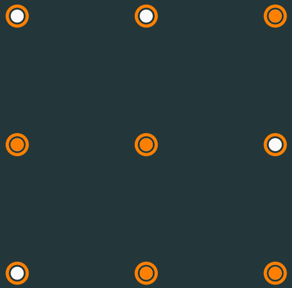

2D-DQS on NQIT Archetecture [2]

- Cannot be sampled from classically, up to relative error, assuming integrity of PH
  - Unrealistic as neither could *real world* quantum computer
- Cannot be sampled from up l_1 norm error assuming two further conjecturs
  - Average case hardness of Ising sampling
  - Anti concentration
  - Numerical and analytical evidence to support both

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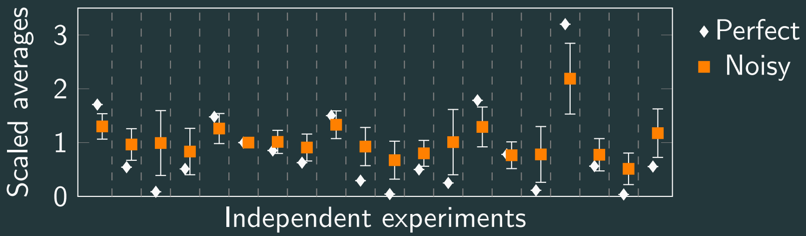
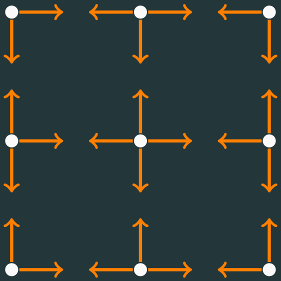
  - Average case hardness of Ising sampling
  - Anti concentration
  - Numerical and analytical evidence to support both
- Remarkable to find superiority under restrictive and implementation motivated condition

2D-DQS Perfect vs Noisy [3]



True NQIT Archetecture [1]



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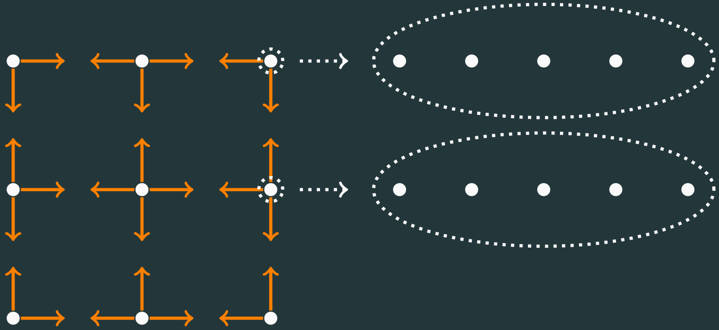

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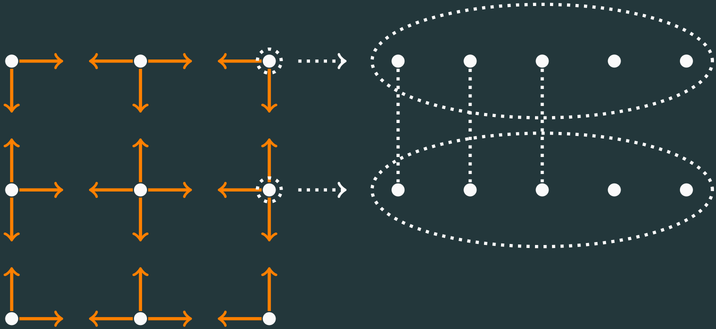

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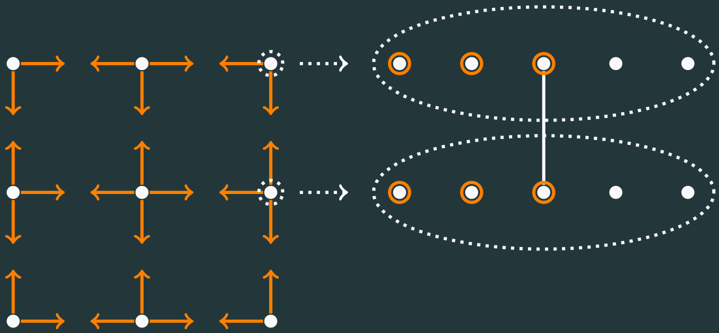

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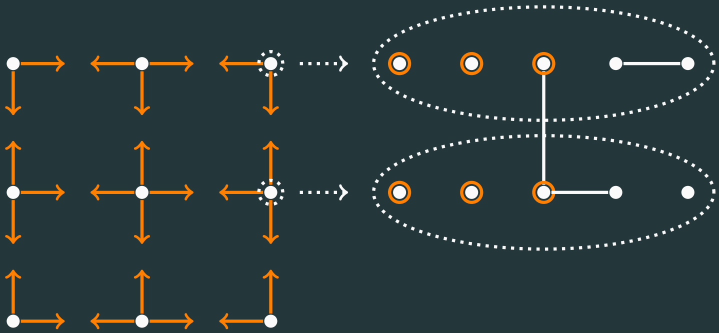

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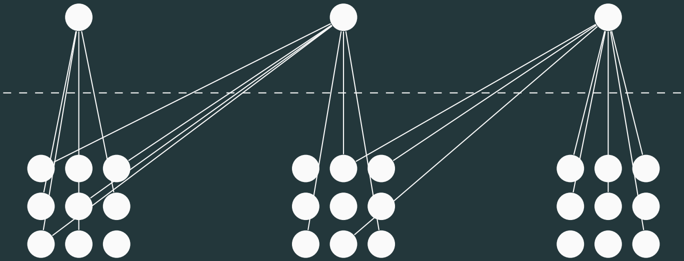

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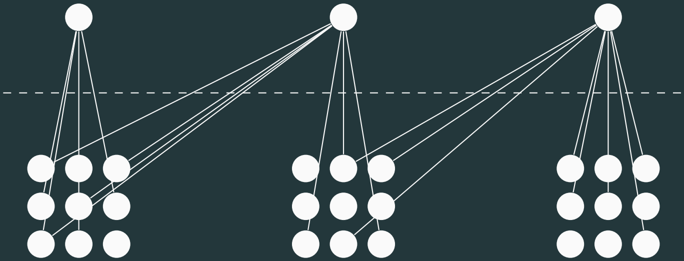


To much noise :(

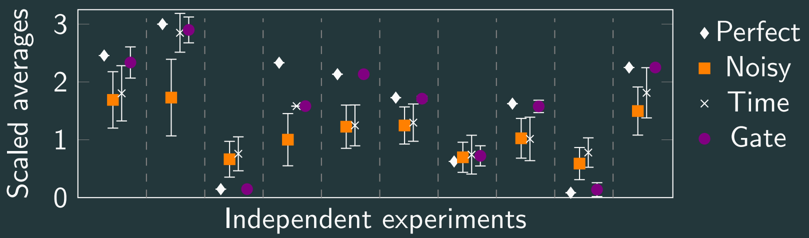
Locating Main Source of Error

Two types of error:

Time: Decay over time while in storage.

Gate: Inaccuracy in the gate being applied.

Only Gate and Only Time Based Noise[3]



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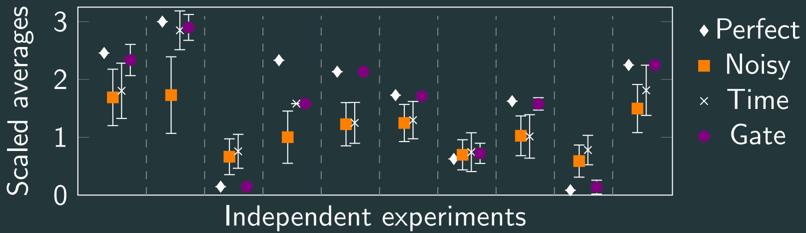


Time has the biggest impact!

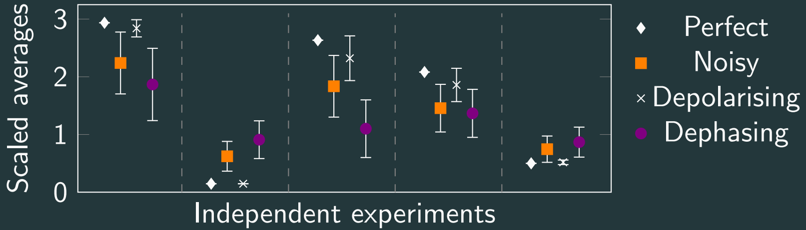
Locating Main Source of Time Error

Two types of time error:

Depolarising: Entanglement to the environment, modelled as random Pauli gate.

Dephasing: Decay of information not in computational basis, modelled by random Pauli-Z gate.

Only Dephasing and Only Depolarising Noise [3]



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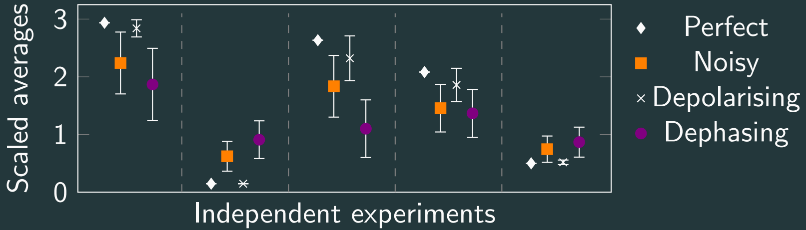

Dephasing has the biggest impact!

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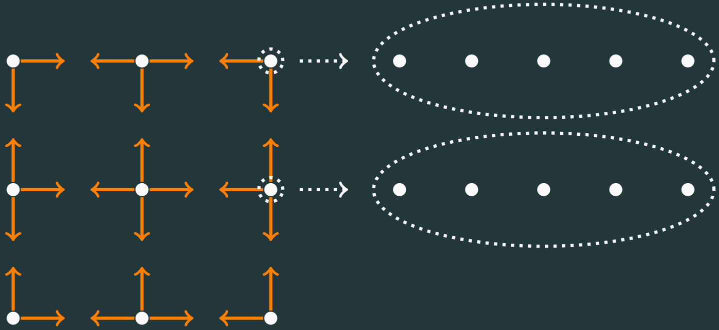
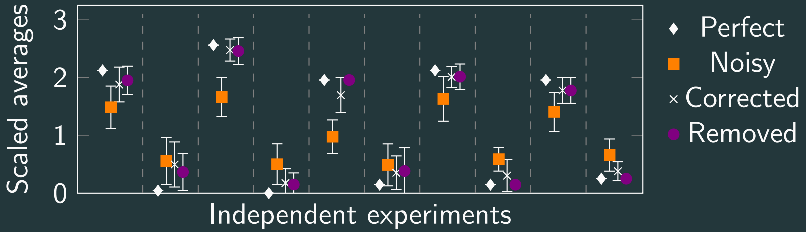


Error Corrected Dephasing [3]



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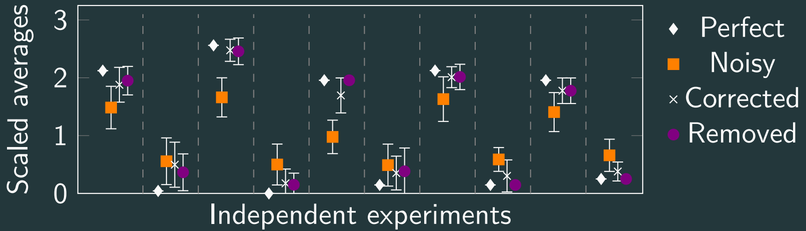

Seems to work!

Conclusion

Conclusion

- Google has a number of qubits which, if they are good enough, could give a demonstration of quantum superiority.
  - Keep your eyes pealed.
- Supremacy test on NQIT out of touch for now.
  - Isolated Dephasing as main cause.
  - Proposed relatively simple solution.

References

[1] Ramil Nigmatullin, Christopher J Ballance, Niel de Beaudrap, and Simon C Benjamin. Minimally complex ion traps as modules for quantum communication and computing. *New Journal of Physics*, 18(10):103028, 2016. URL `http://stacks.iop.org/1367-2630/18/i=10/a=103028`.

[2] Juan Bermejo-Vega, Dominik Hangleiter, Martin Schwarz, Robert Raussendorf, and Jens Eisert. Architectures for quantum simulation showing quantum supremacy. *arXiv preprint arXiv:1703.00466*, 2017.

References II

[3] Iskren Vankov, Daniel Mills, Petros Wallden, and Elham Kashefi. Methods for classically simulating noisy networked quantum architectures. *arXiv preprint arXiv:1803.04167*, 2018.