Equivalence between AQC and CBQC
and
Looking at the actual quantum hardware

Lecture 4

Nike Dattani

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HPQC Labs

2022 11 28

1996

Grover's algorithm:

- Circuit-based algorithm
- Searches an unstructured database
- Uses $O(\sqrt{N})$ steps. Classical requires $O(N)$

A fast quantum mechanical algorithm for database search

Lov K. Grover • Published in Symposium on the Theory of… 29 May 1996 • Computer Science

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Lov K. Grover • Published in Symposium on the Theory of… 29 May 1996 • Computer Science

1997

Grover's algorithm can't be improved:

- Needs $\Omega(\sqrt{N})$ steps.

Strengths and Weaknesses of Quantum Computing

Charles H. Bennett, Ethan Bernstein, Gilles Brassard, and Umesh Vazirani

1997

Circuit-based QC isn't the only way to search a database with $\Theta(\sqrt{N})$ vs $\Theta(N)$

- Completely different method of quantum computation
- Searches a structured database

[Submitted on 18 Nov 1997]

Quantum Mechanical Square Root Speedup in a Structured Search Problem

Edward Farhi, Sam Gutmann

An unstructured search for one item out of N can be performed quantum mechanically in time of order square root of N whereas classically this requires of order N steps. This raises the question of whether square root speedup persists in problems with more structure. In this note we focus on one example of a structured problem and find a quantum algorithm which takes time of order the square root of the classical time.

2001

Searching an unstructured database with AQC costs $\Theta(\sqrt{N})$

AQC and circuit-based QC are equivalent for searching databases!

How powerful is adiabatic quantum computation?

W. V. Dam, M. Mosca, U. Vazirani • Published 8 October 2001 • Physics, Computer Science • Proceedings 2001 IEEE International Conference on Cluster Computing

2007

AQC and circuit-based QC are equivalent for
all problems!

Adiabatic Quantum Computation is Equivalent to Standard Quantum Computation

Dorit Aharonov, Wim van Dam, Julia Kempe, Zeph Landau, Seth Lloyd, and Oded Regev

AQC can simulate circuit-based quantum computing with overhead that scales only polynomially with the problem size

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CBQC can simulate AQC with overhead that scales only polynomially with the problem size

Many people still think AQC is fake (1985 vs 2007)

D-Wave One (2011) – 128 qubits

- World's first commercial quantum computer
- sold for $10 million to Lockheed Martin

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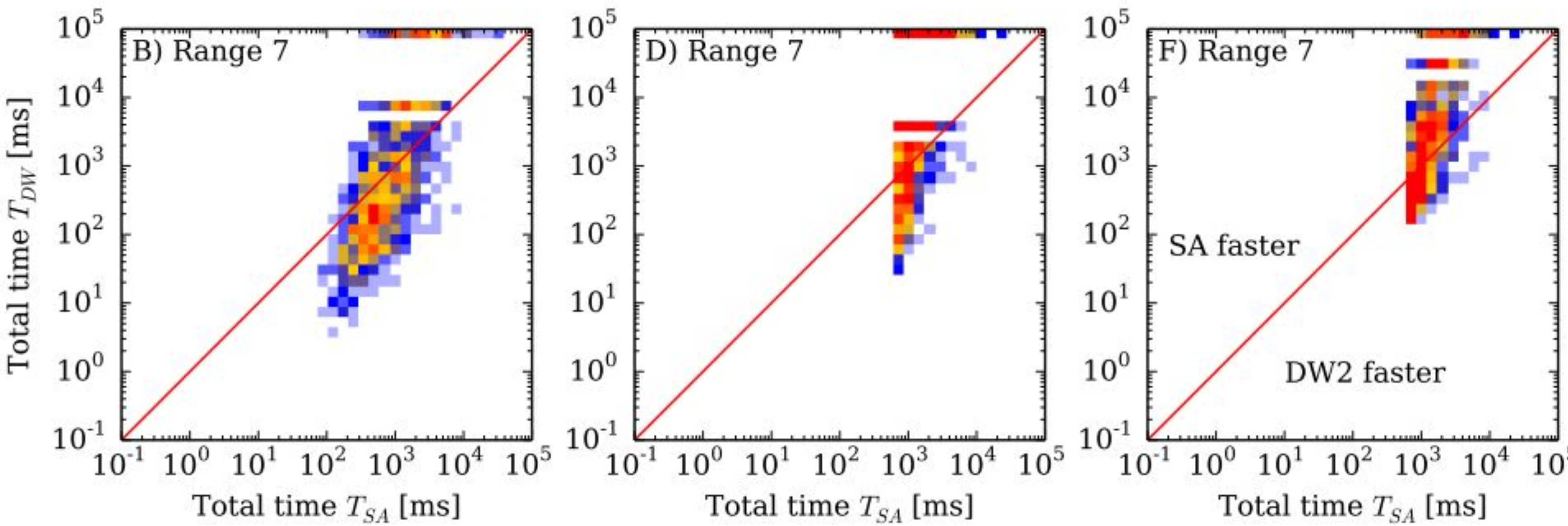
D-Wave Two (2012) – 512 qubits

- sold for $10 million to NASA and Google
  Quantum Artificial Intelligence lab

Ronnow *et al.* (Science 2014)



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- Customers: Volkswagen, Temporal Defense Systems Inc, Virginia Tech, Denso Corp, Oak R National Lab, USC, etc.

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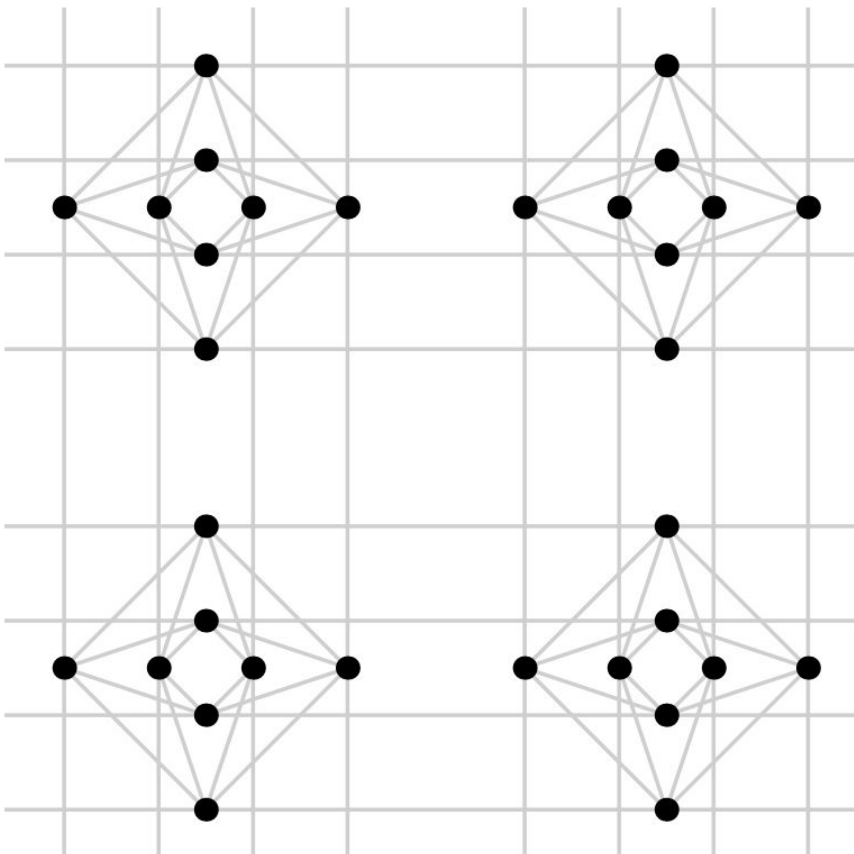
D-Wave Five (2021) – 5640 qubits

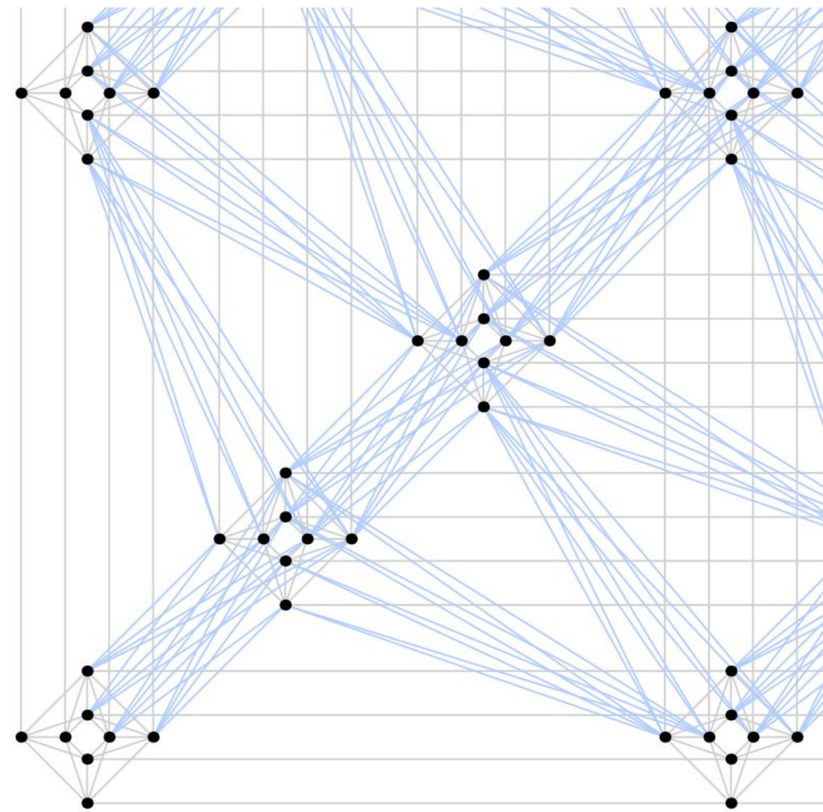
Pegasus: The second connectivity graph for large-scale quantum annealing hardware

Nike Dattani[*]
Harvard-Smithsonian Center for Astrophysics and

Szilard Szalay[†]
Wigner Research Centre for Physics

Nicholas Chancellor[‡]
Joint Quantum Centre, Durham University





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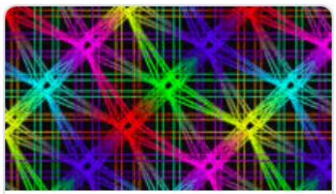
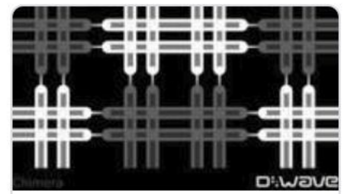


D-Wave Previews Next-Gen Platform; Debuts Pegasus Topology; Targets 5000 Qubits
HPCwire
14 hours ago

D-Wave previews quantum computing platform with over 5,000 qubits
VentureBeat
19 hours ago



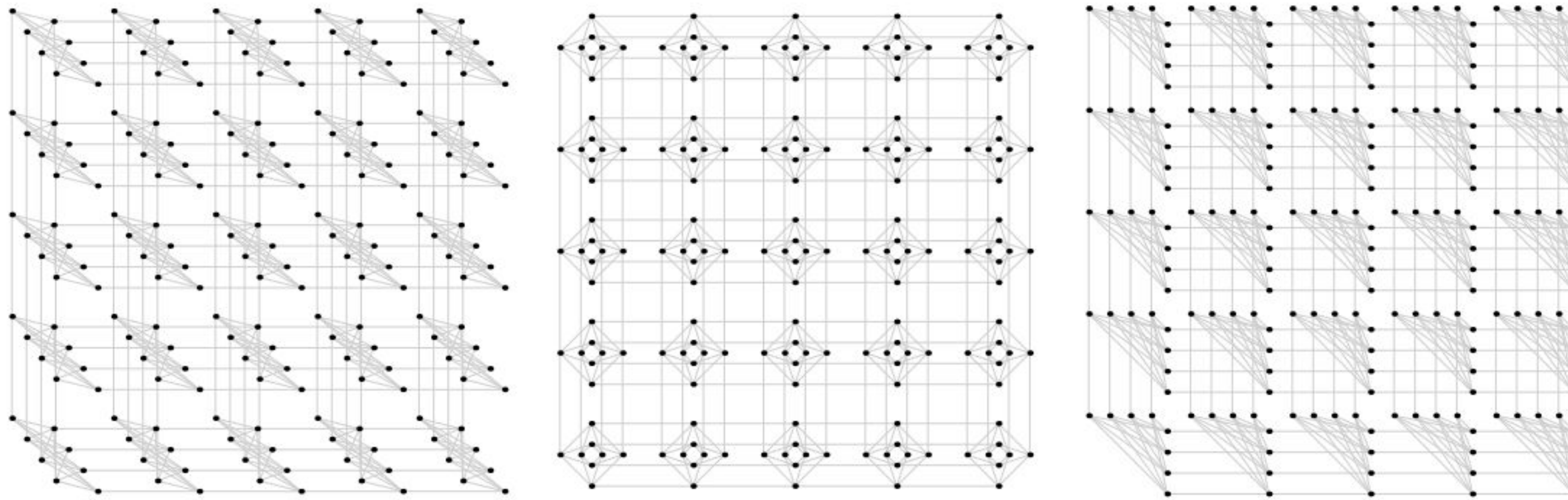
D-Wave announces next generation platform with 5000 qubits, due mid-2020
Neowin
16 hours ago

→ More for pegasus d-wave

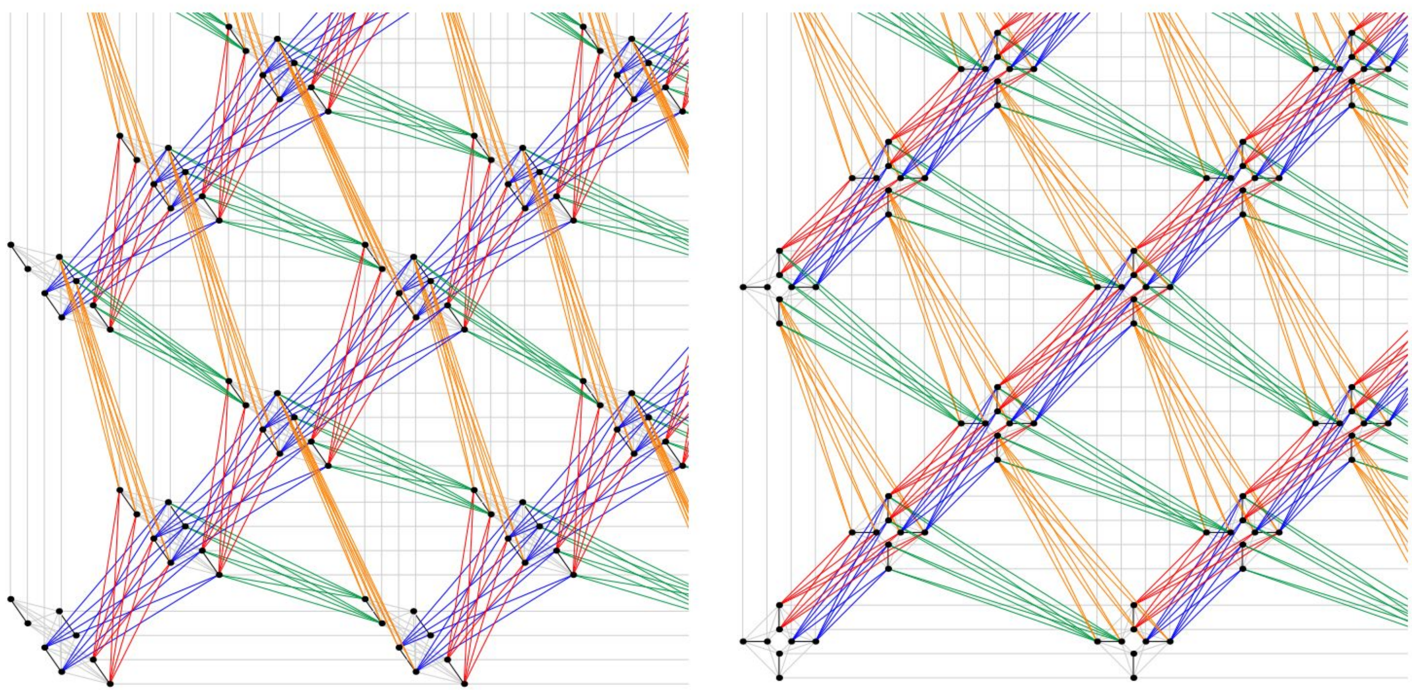
D-Wave Previews Next-Generation Quantum Computing Platform | D ...
https://www.dwavesys.com/.../d-wave-previews-next-generation-quantum-computing-... ▾
18 hours ago - New Topology: The **Pegasus**™ topology is the most connected of any commercial quantum system in the world. Currently, each qubit in the ...

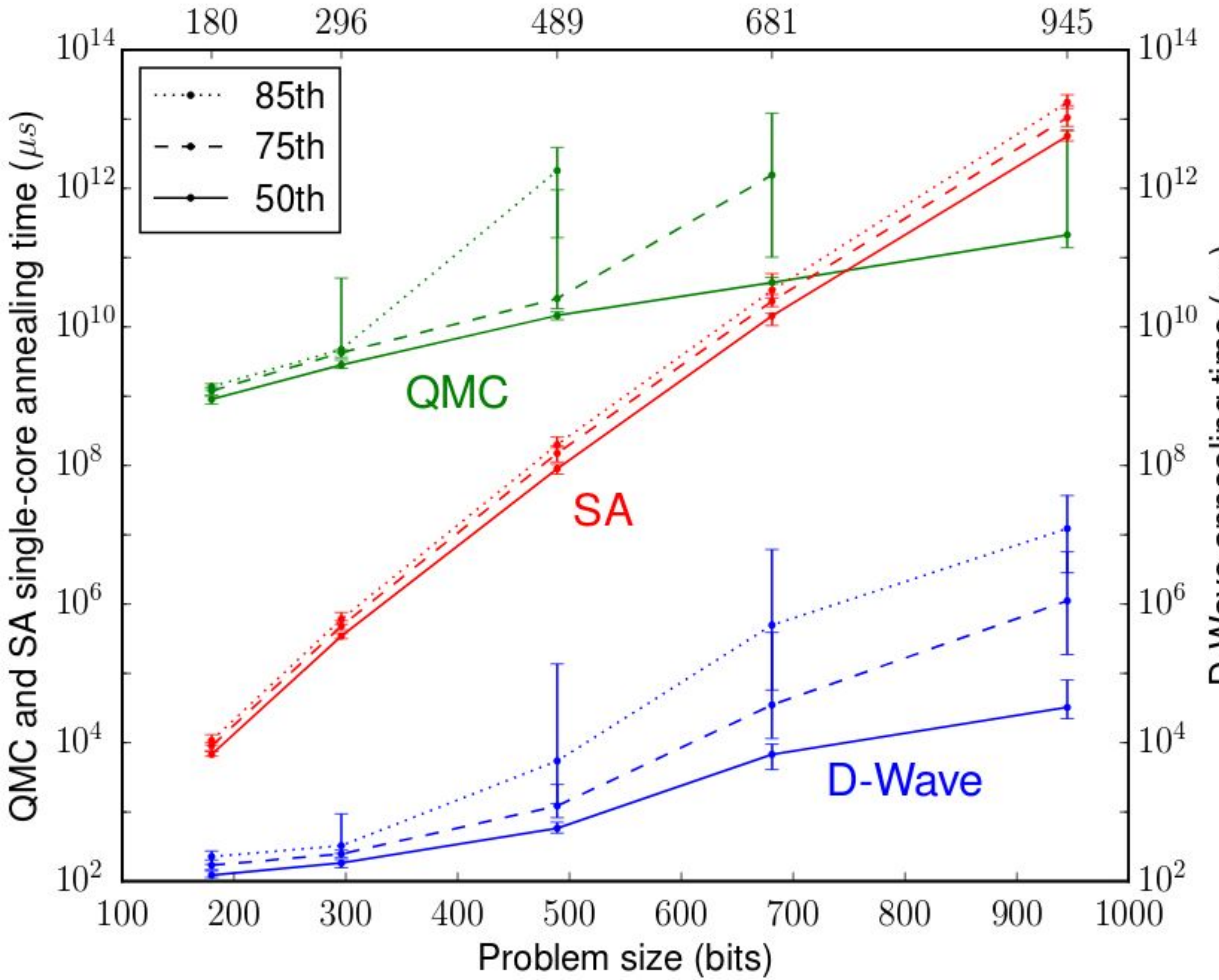
D-Wave Previews Next-Gen Platform; Debuts Pegasus Topology ...
https://www.hpcwire.com/.../d-wave-previews-next-gen-platform-debuts-pegasus-topo... ▾
14 hours ago - Quantum computing pioneer **D-Wave** Systems today “previewed” plans for ... One

(a) Tilted classic (b) Diamond (c) Triangle



(a) Tilted classic (b) Diamond

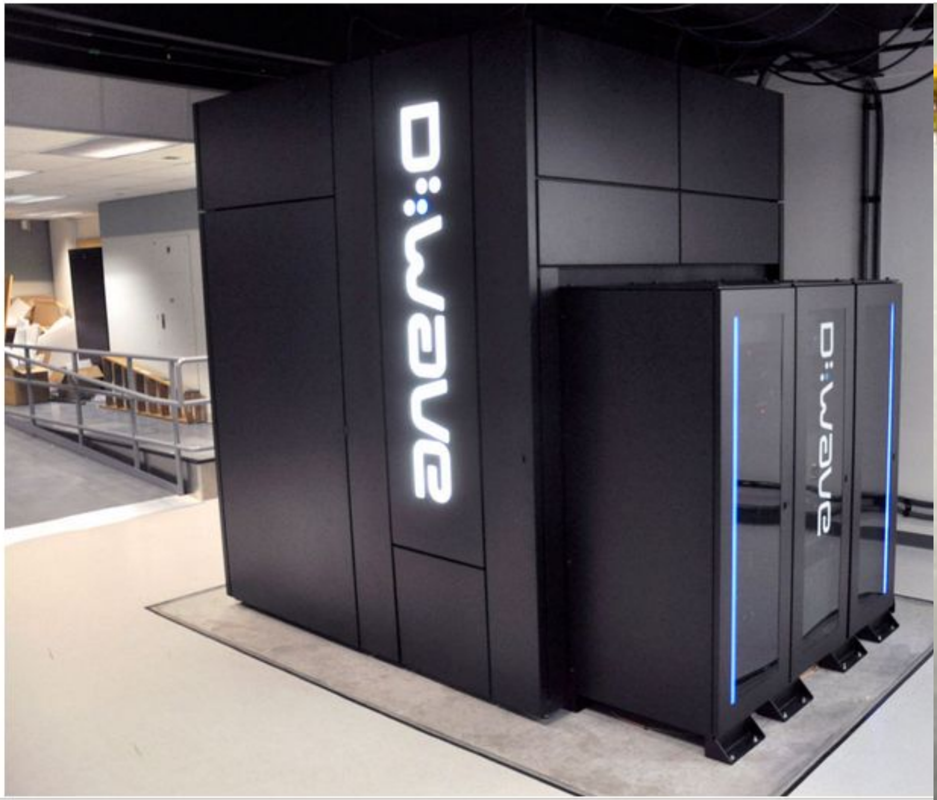


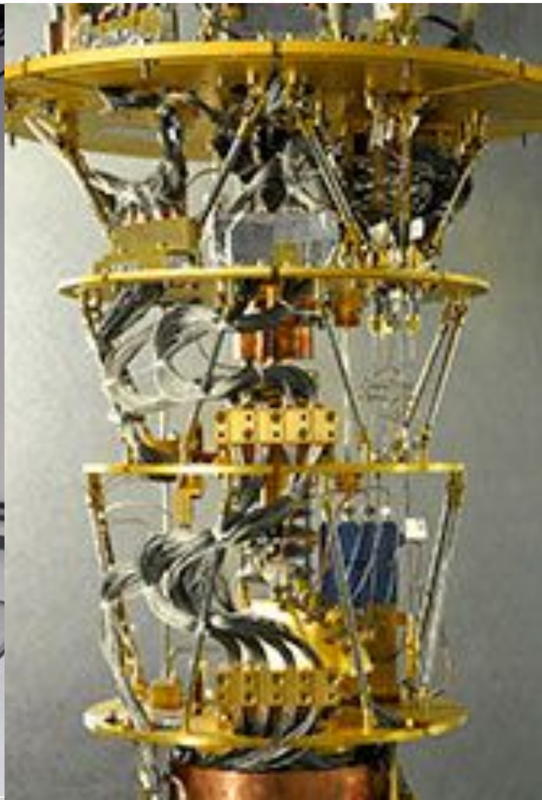


180
296
489
681
945
85th
75th
50th
QMC
SA
D-Wave
QMC and SA single-core annealing time (μs)
D-Wave annealing time (μs)
Problem size (bits)
10^{14}
10^{12}
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
100
200
300
400
500
600
700
800
900
1000

D-Wave Two™ Computer

- Manufacturer: D-Wave Systems Inc.
- Uses a 1,097-qubit Washington processor
- Niobium superconducting loop encodes 2 states as tiny magnetic fields
- Processor cooled with liquid helium to 20 millikelvin (near absolute zero)
- Uses 12 kilowatts of power

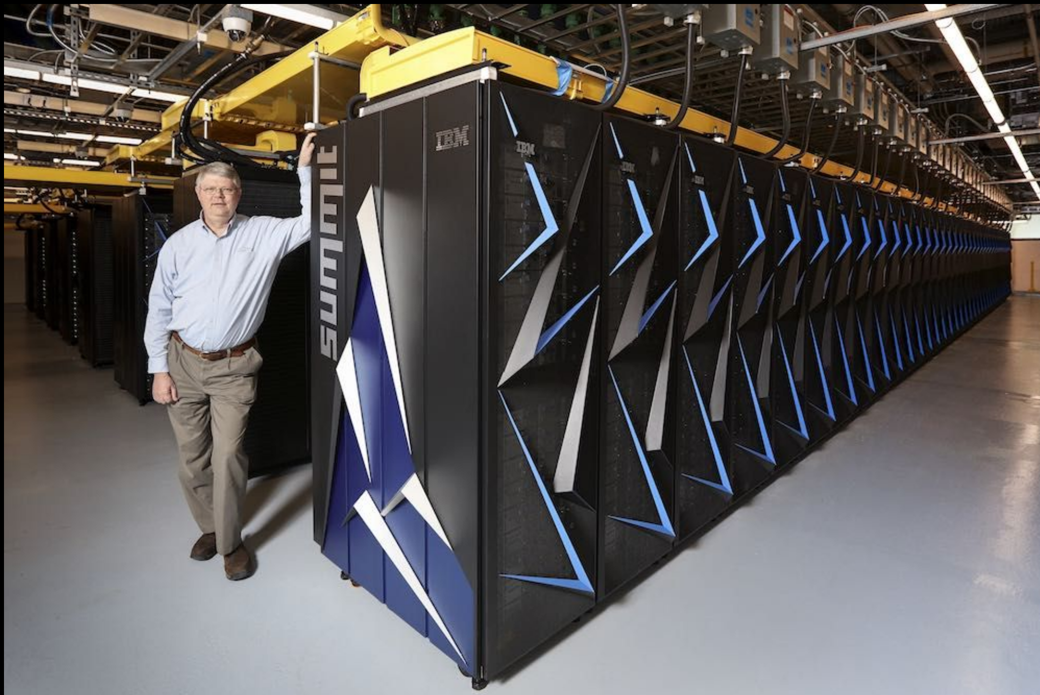


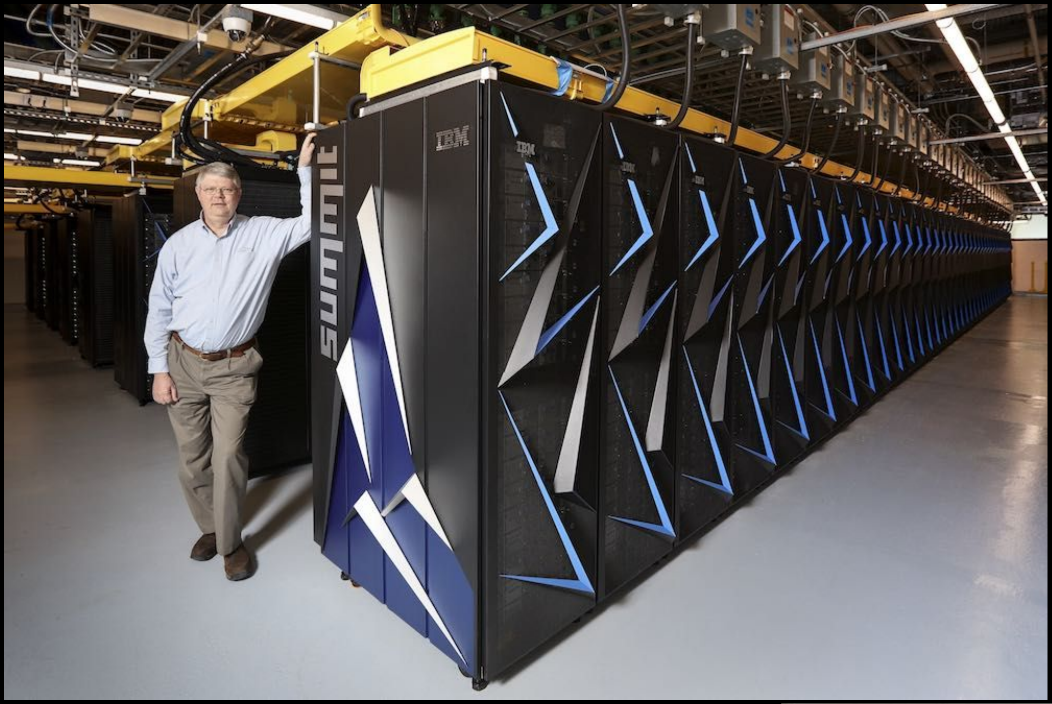


Green500 List

Note: Shaded entries in the table below mean the power data is derived and not meassured.

Rank	TOP500 Rank	System	Cores	Rmax (TFlop/s)	Power (kW)	Power Efficiency (GFlops/watts)
1	259	**Shoubu system B** - ZettaScaler-2.2, Xeon D-1571 16C 1.3GHz, Infiniband EDR, PEZY-SC2 , PEZY Computing / Exascaler Inc. Advanced Center for Computing and Communication, RIKEN Japan	794,400	842.0	50	17.009
2	307	**Suiren2** - ZettaScaler-2.2, Xeon D-1571 16C 1.3GHz, Infiniband EDR, PEZY-SC2 , PEZY Computing / Exascaler Inc. High Energy Accelerator Research Organization /KEK Japan	762,624	788.2	47	16.759
3	276	**Sakura** - ZettaScaler-2.2, Xeon E5-2618Lv3 8C 2.3GHz, Infiniband EDR, PEZY-SC2 , PEZY Computing / Exascaler Inc. PEZY Computing K.K. Japan	794,400	824.7	50	16.657
4	149	**DGX SaturnV Volta** - NVIDIA DGX-1 Volta36, Xeon E5-2698v4 20C 2.2GHz, Infiniband EDR, NVIDIA Tesla V100 , Nvidia NVIDIA Corporation United States	22,440	1,070.0	97	15.113
5	4	**Gyoukou** - ZettaScaler-2.2 HPC system, Xeon D-1571 16C 1.3GHz, Infiniband EDR, PEZY-SC2 700Mhz , ExaScaler Japan Agency for Marine-Earth Science and Technology Japan	19,860,000	19,135.8	1,350	14.173


IBM
summit


summit
IBM

- D-Wave device uses SQUIDs
- needs liquid helium
- temperature 80 mK

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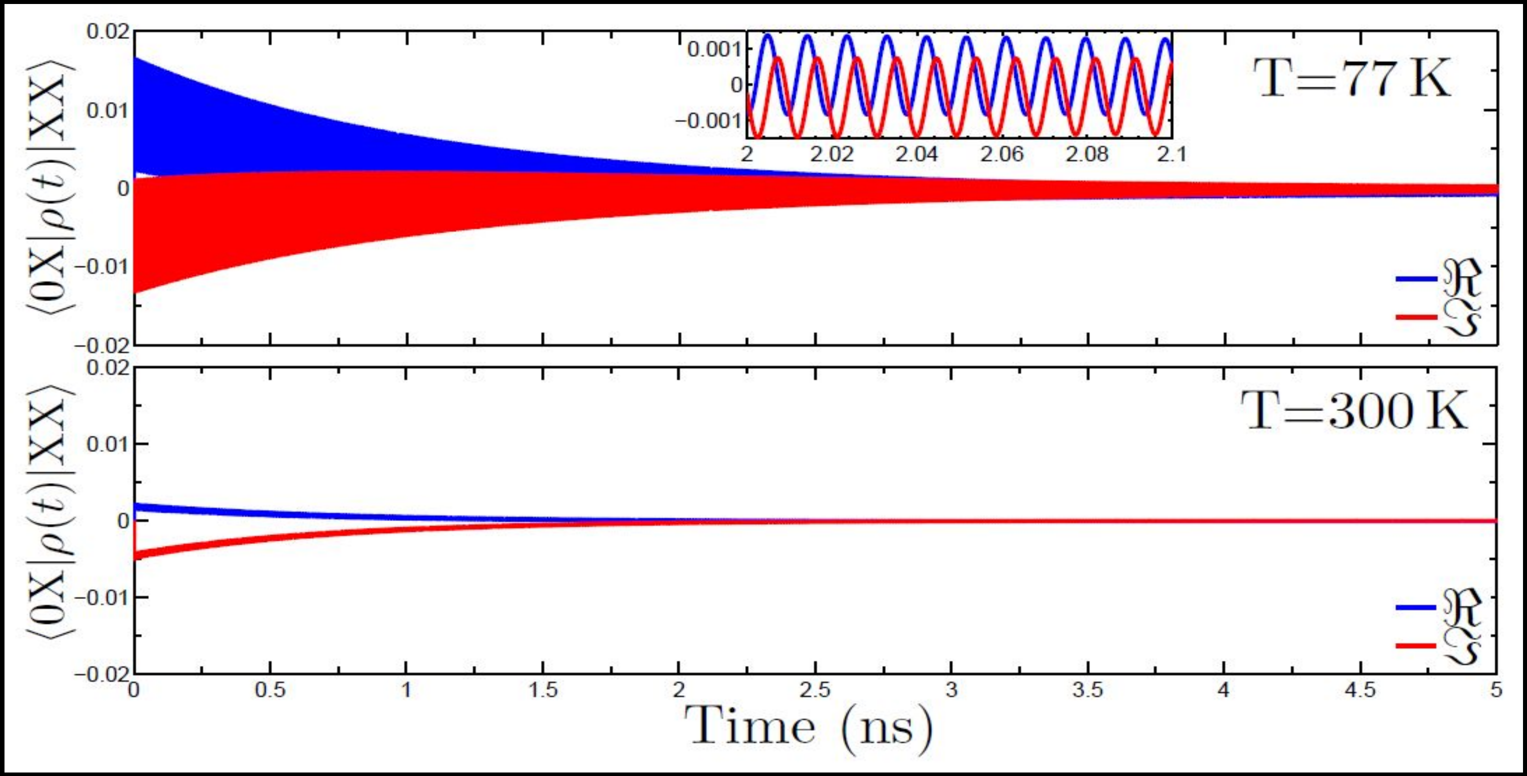


With quantum dots, coherence lasts at 77K

Towards a feasible implementation of quantum neural networks using quantum dots

M. V. Altaisky and N. N. Zolnikova
*Space Research Institute RAS, Profsoyuznaya 84/32, Moscow, 117997, Russia**

N. E. Kaputkina
National Technological University "MISiS", Leninsky prospect 4, Moscow, 119049, Russia†

V. A. Krylov
Joint Institute for Nuclear Research, Joliot Curie 6, Dubna, 141980, Russia‡

Yu. E. Lozovik
Institute of Spectroscopy, Troitsk, Moscow, 142190, Russia§

Nikesh S. Dattani
Quantum Chemistry Laboratory, Kyoto University, Kyoto, 606-8502, Japan and
School of Materials Science and Engineering, Nanyang Technological University, 639798, Singapore¶

(Dated: Mar 17, 2015)

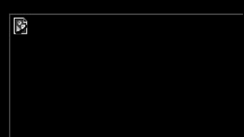
Quantum Chemistry on a Quantum Computer

$$H = \sum_{p,q} h_{pq} a_p^\dagger a_q + \frac{1}{2} \sum_{p,q,r,s} h_{pqrs} a_p^\dagger a_q^\dagger a_r a_s$$

Jordan-Wigner Transform

$$a_j \Leftrightarrow \mathbf{1}^{\otimes j-1} \otimes \sigma^+ \otimes \sigma^{z \otimes N-j-1}$$

$$a_j^\dagger \Leftrightarrow \mathbf{1}^{\otimes j-1} \otimes \sigma^- \otimes \sigma^{z \otimes N-j-1}$$



$$\sigma^y = \begin{bmatrix} 0 & -i \\ i & 0 \end{bmatrix} \quad \sigma^x = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

$$\sigma^+ \equiv \frac{\sigma^x + i\sigma^y}{2} \quad \sigma^- \equiv \frac{\sigma^x - i\sigma^y}{2}$$

H_2 molecule

$$
\begin{aligned}
H &= -0.812611\mathbf{1} + 0.171201 Z_0 + 0.171201 Z_1 - 0.2227965 Z_2 - 0.2227965 Z_3 \\
&= +0.16862325 Z_1 Z_0 + 0.12054625 Z_2 Z_0 + 0.165868 Z_2 Z_1 + 0.165868 Z_3 Z_0 \\
&= +0.12054625 Z_3 Z_1 + 0.17434925 Z_3 Z_2 - 0.04532175 X_3 X_2 Y_1 Y_0 \\
&= +0.04532175 X_3 Y_2 Y_1 X_0 + 0.04532175 Y_3 X_2 X_1 Y_0 - 0.04532175 Y_3 Y_2 X_1 X_0
\end{aligned}
$$

Elucidating Reaction Mechanisms on Quantum Computers

Markus Reiher,[1] Nathan Wiebe,[2] Krysta M. Svore,[2] Dave Wecker,[2] and Matthias Troyer[3,2,4]

[1] *Laboratorium für Physikalische Chemie, ETH Zurich, Valdimir-Prelog-Weg 2, 8093 Zurich, Switzerland*

[2] *Quantum Architectures and Computation Group, Microsoft Research, Redmond, WA 98052, USA*

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[4] *Station Q, Microsoft Research, Santa Barbara, CA 93106-6105, USA*

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$$N_2 + 3H_2 \rightarrow 2NH_3$$

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Haber-Bosch process:

- Makes fertilizers that feed about 40% of the world's population.
- T = **427°C** , P = 150 atm
- Consumes 2% of the world’s annual energy supply

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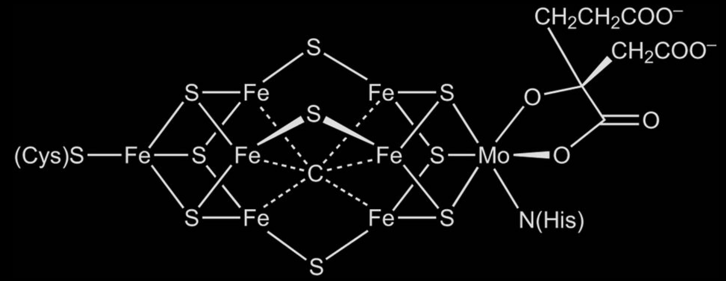

FeMoco

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Struct. 1	T-Gates	Clifford Gates	Time	Log. Qubits
Serial	1.1×10^{15}	1.7×10^{15}	130 days	$\boxed{111}$

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	Serial rotations		
Error Rate	$\mathbf{10^{-3}}$	$\mathbf{10^{-6}}$	$\mathbf{10^{-9}}$
Required code distance	35,17	9	5
Logical qubits	111		
Physical qubits per logical qubit	15313	1013	313
Total physical qubits for processor	1.7×10^6	1.1×10^5	3.5×10^4

The electronic complexity of the ground-state of the FeMo cofactor of nitrogenase as relevant to quantum simulations

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Postponing the orthogonality catastrophe: efficient state preparation for electronic structure simulations on quantum devices

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(Dated: September 17, 2018)

Quantum computers have the potential to be powerful, but we need more qubits and less noise!

Thank you!

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