

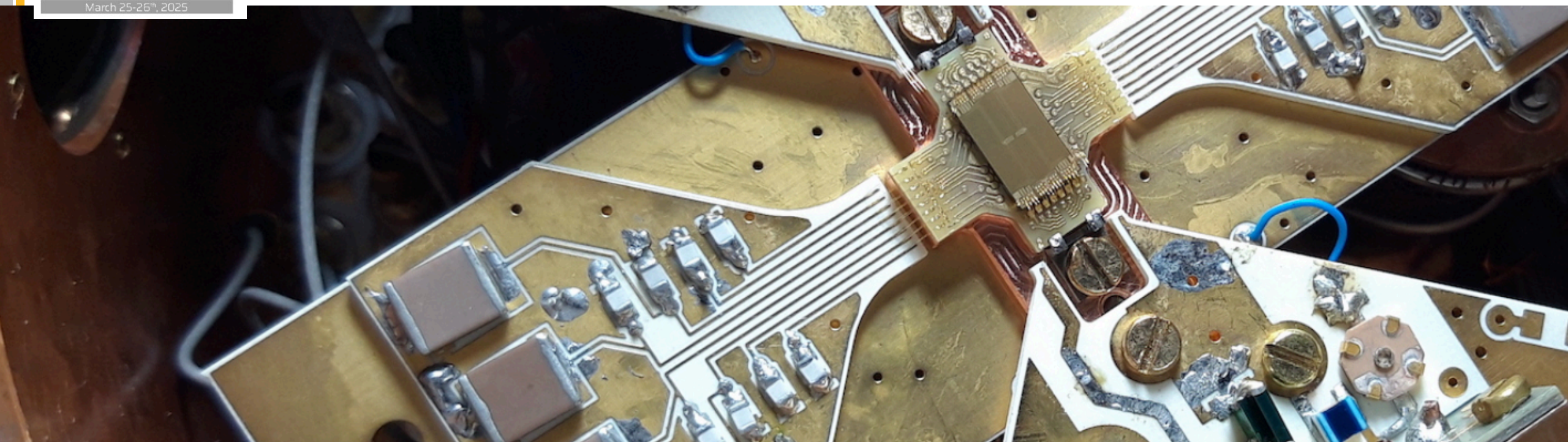


FAPESP
WEEK
GERMANY

March 25-26th, 2025



DFG Deutsche
Forschungsgemeinschaft



POTENTIAL OF COLLABORATING WITH BRASIL ON NOTIONS OF QUANTUM COMPUTING

JENS EISERT

FREIE UNIVERSITÄT BERLIN



QUANTUM COMPUTERS

- **Quantum computers:** New kind of supercomputer that can solve some structured problems efficiently intractable on classical ones



Feynman



Benioff, Deutsch



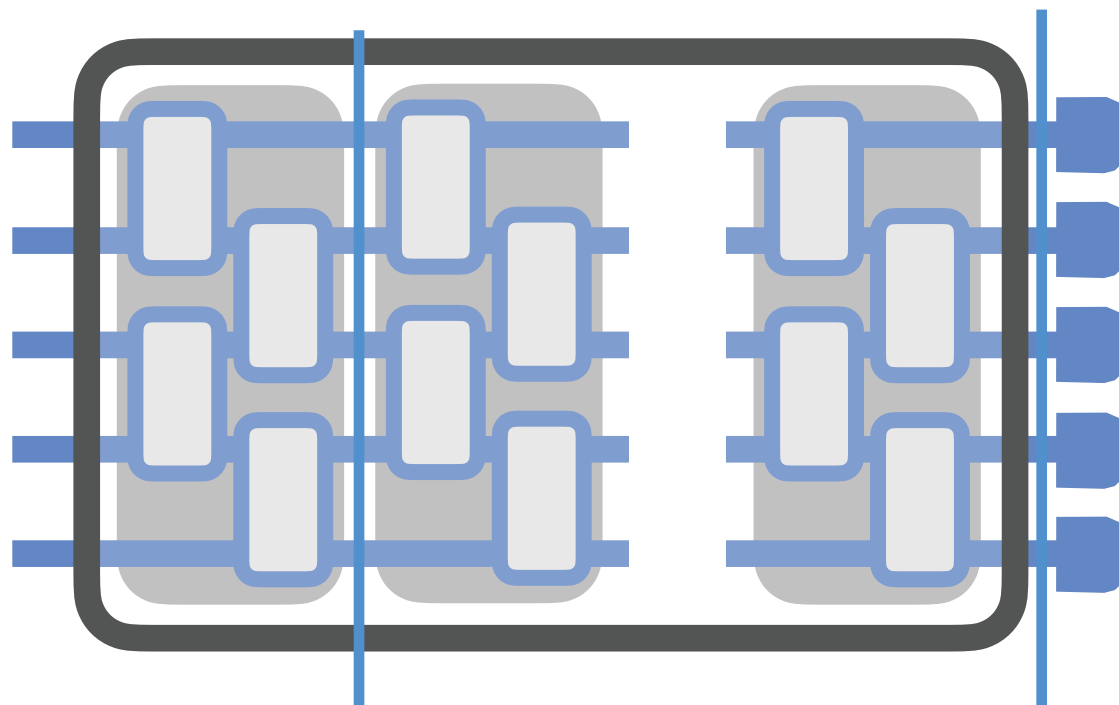
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Strongly en
quantum st



QUANTUM COMPUTERS

Classical
input



Strongly entangled
quantum state

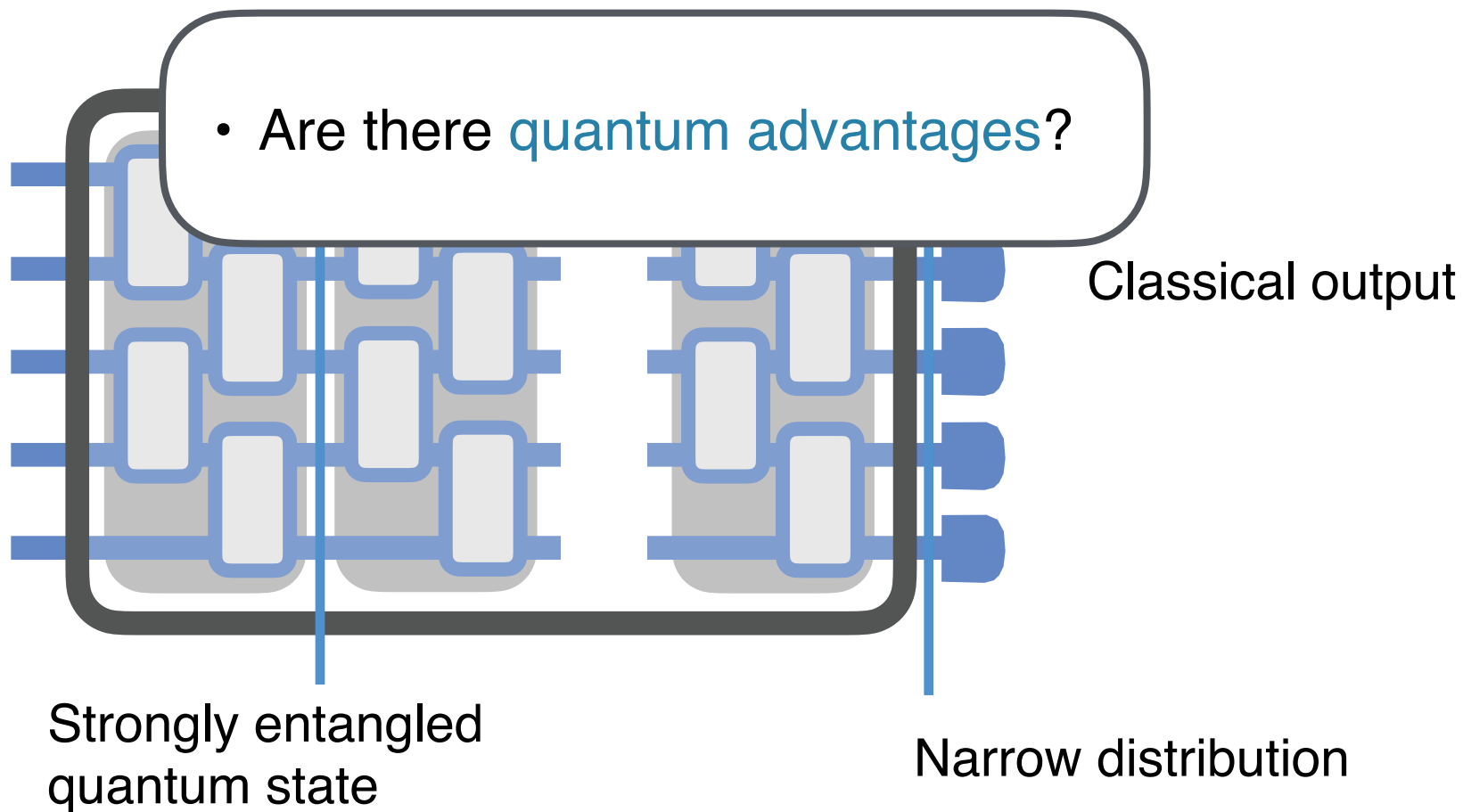
Classical output

Narrow distribution



QUANTUM COMPUTERS

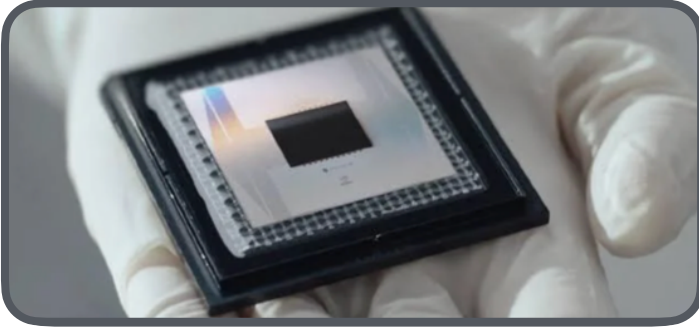
Classical
input



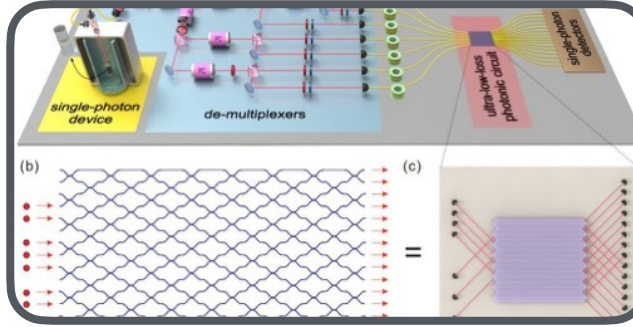


Marc

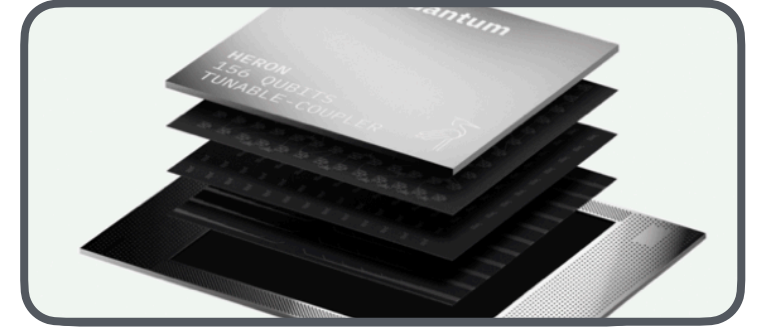
nschaft



Google Willow, 105 qubit quantum computer (2024)



20 photons in 60 modes in optical systems (2023)



IBM Heron r2, 156 superconducting qubits (2025)

Classical input

Classical output

Strongly entangled quantum state

Narrow distribution

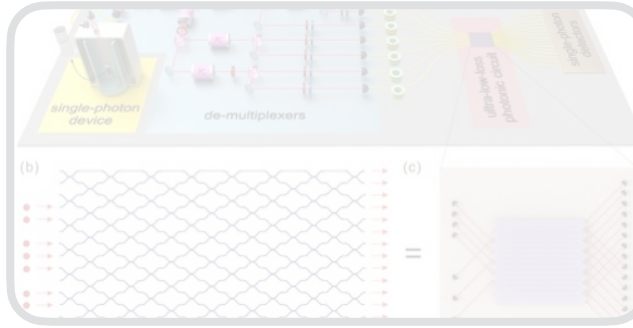


Marc

nschaft



Google Willow, 105 qubit
quantum computer (2024)



20 photons in 60 modes
in optical systems (2023)



IBM Heron r2, 156 super-
conducting qubits (2025)

- What can we achieve with
realistic quantum computers?

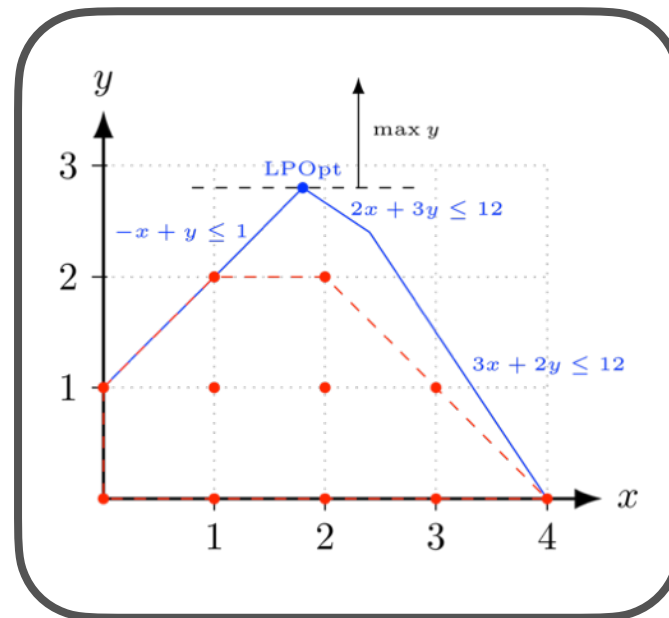
Strongly entangled
quantum state

Narrow distribution

Classical output

- Ubiquitous in industrial applications

maximize $\mathbf{c}^T \mathbf{x}$
subject to $A\mathbf{x} \leq \mathbf{b}$,
and $\mathbf{x} \geq \mathbf{0}$,
 $\mathbf{x} \in \mathbb{Z}^n$



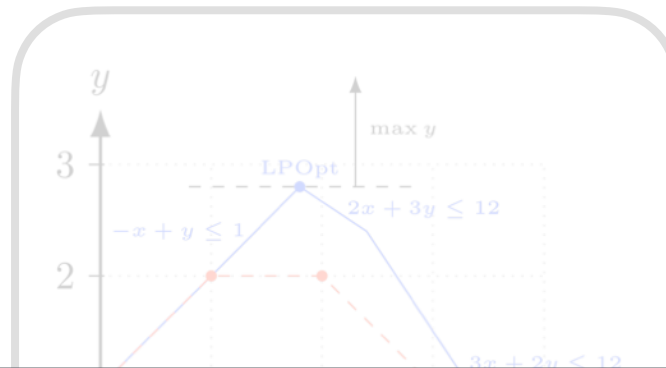
- Are usually NP-hard, do not have an efficient solution



COMBINATORIAL OPTIMIZATION

- Ubiquitous in industrial applications

maximize $\mathbf{c}^T \mathbf{x}$
subject to $A\mathbf{x} \leq \mathbf{b}$,
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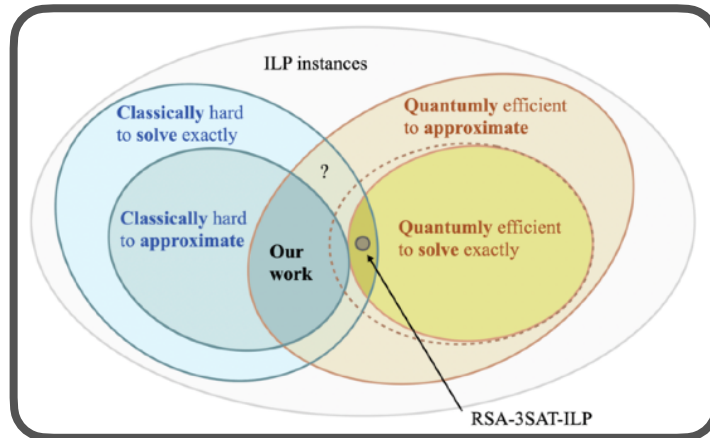


- Can we hope to see quantum advantages?

- Are usually NP-hard, do not have an efficient solution

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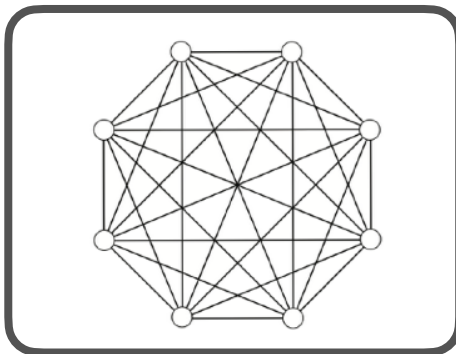
- In principle yes!



- Quantum computers can efficiently approximate classically hard instances of integer programming

Pirnay, Ulitzsch, Wilde, Eisert, Seifert, Science Advances 10, adj5170 (2024)

- “Quantum approximate optimization algorithm”



- Heuristically interesting, proven separations?

Farhi, Goldstone, Gutmann, Zhou, Quantum 6, 759 (2022)

Zhou, Wang, Choi, Pichler, Lukin, Phys Rev X 10, 021067 (2020)



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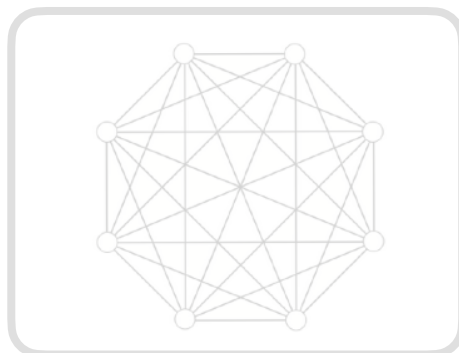


Pirnay, Ulitzsch

- Quantum computers can efficiently approximate classically hard instances of integer programming

- Yes, there are quantum advantages! But variationally? Scope for collaboration in mathematics, physics, computer science

- “Quantum approximate optimization algorithm”



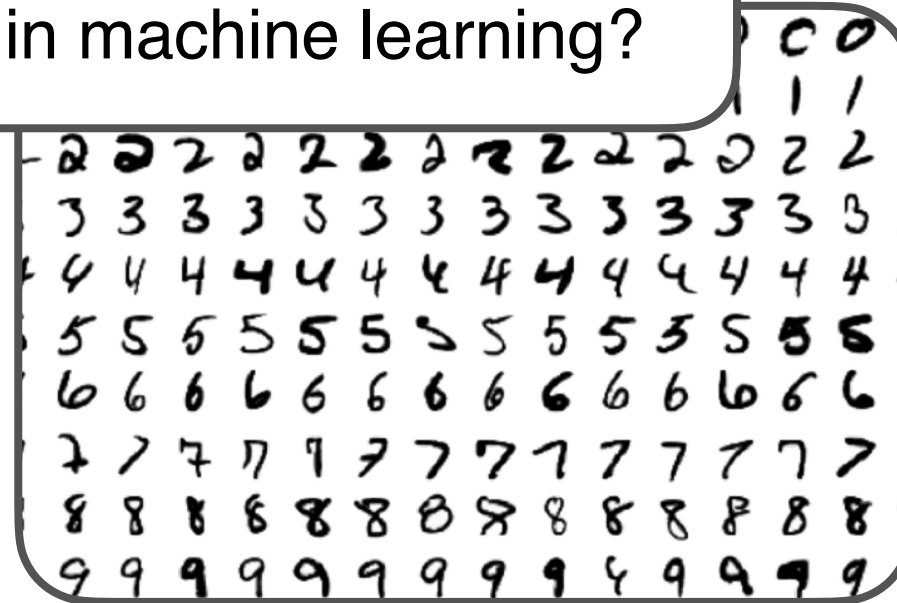
- Heuristically interesting, proven separations?

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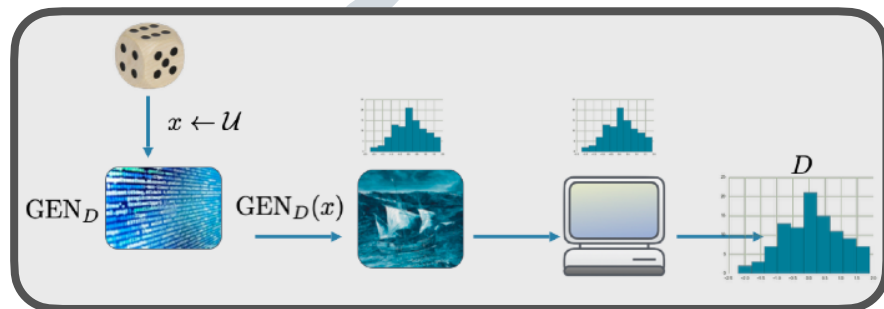


- Can **quantum computers** solve problems in machine learning?





- In principle, yes!



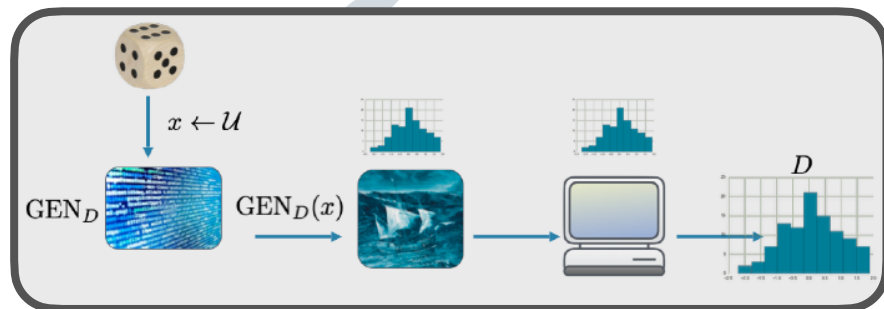
- Fault tolerant quantum computers can learn structured probability distributions superpolynomially faster

Pirnay, Sweke, Eisert, Seifert, Phys Rev A 107, 042416 (2023)

Liu, Arunachalam, Temme, Nature Phys 17, 1013 (2021)

Sweke, Seifert, Hangleiter, Eisert, Quantum 5, 417 (2021)

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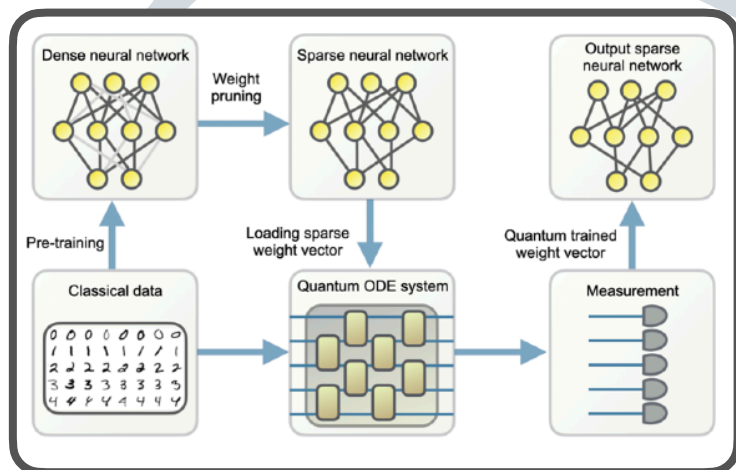


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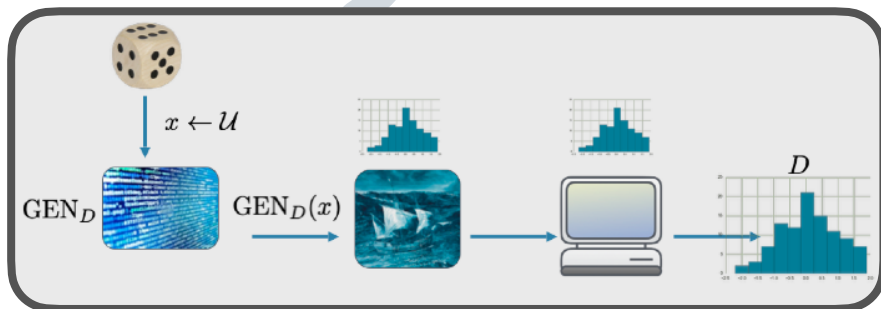


- Fault tolerant quantum computer can train industrially relevant classical sparse pruned networks better
- Benchmarks with 7 to 103 million parameters

Liu, Liu, Liu, Ye, Wang, Alexeev, Eisert, Jiang, Nature Comm 15, 434 (2024)



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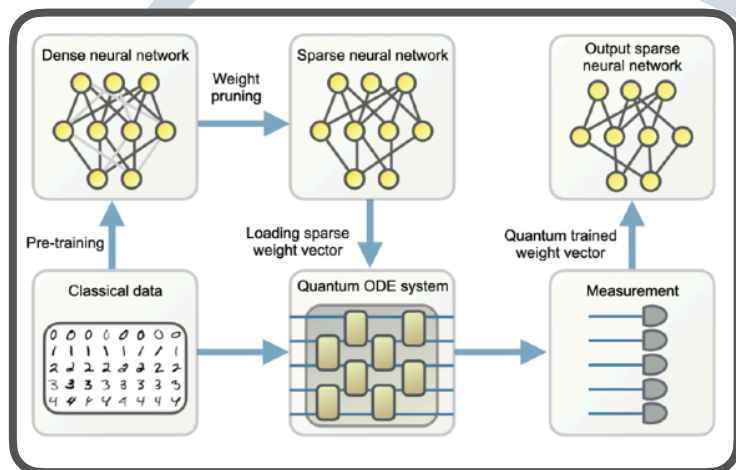


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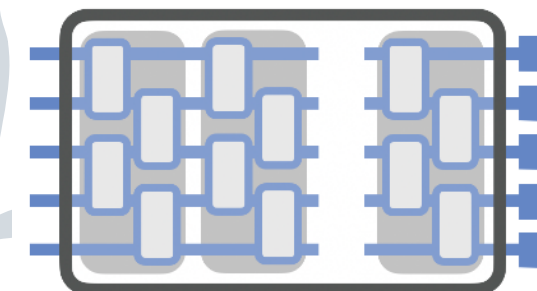
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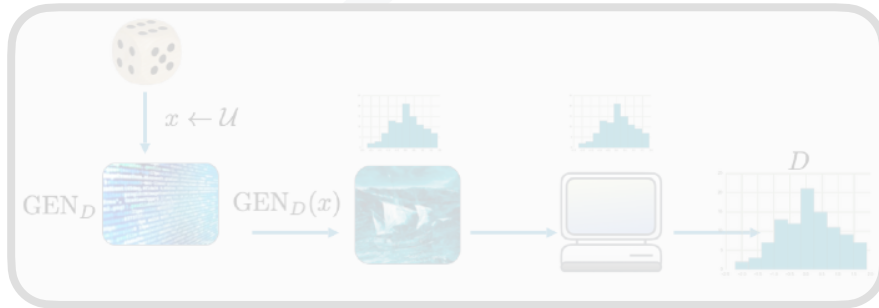


- Short circuits have paradigmatic advantages

Pirnay, Seifert, Eisert, Jerbi, arXiv:2411.15548 (2024)



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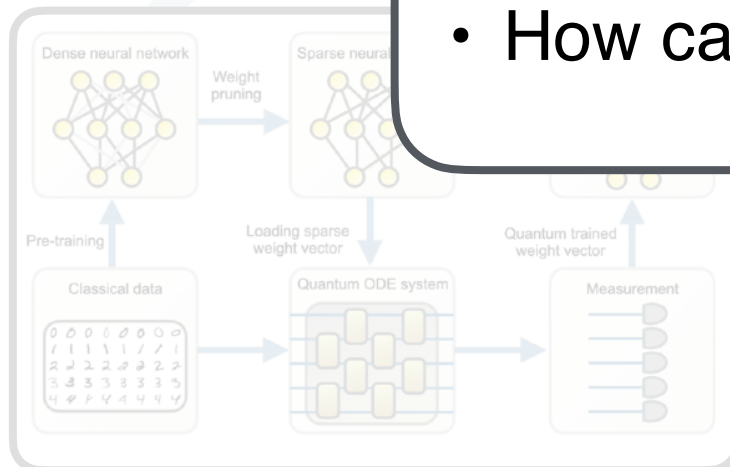
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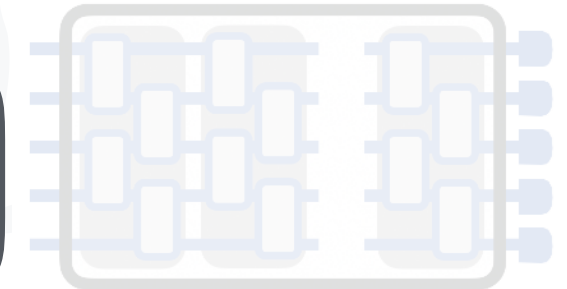
- How can this be made more practical?



sparse pruned networks better

- Benchmarks with 7 to 103 million parameters

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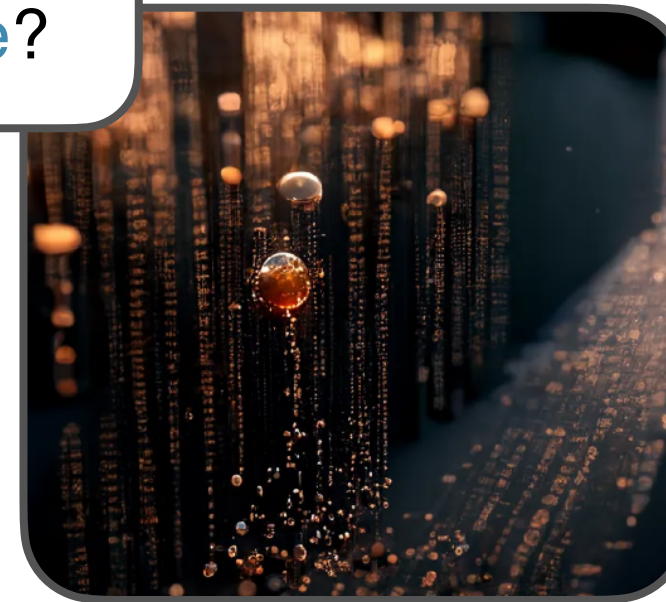
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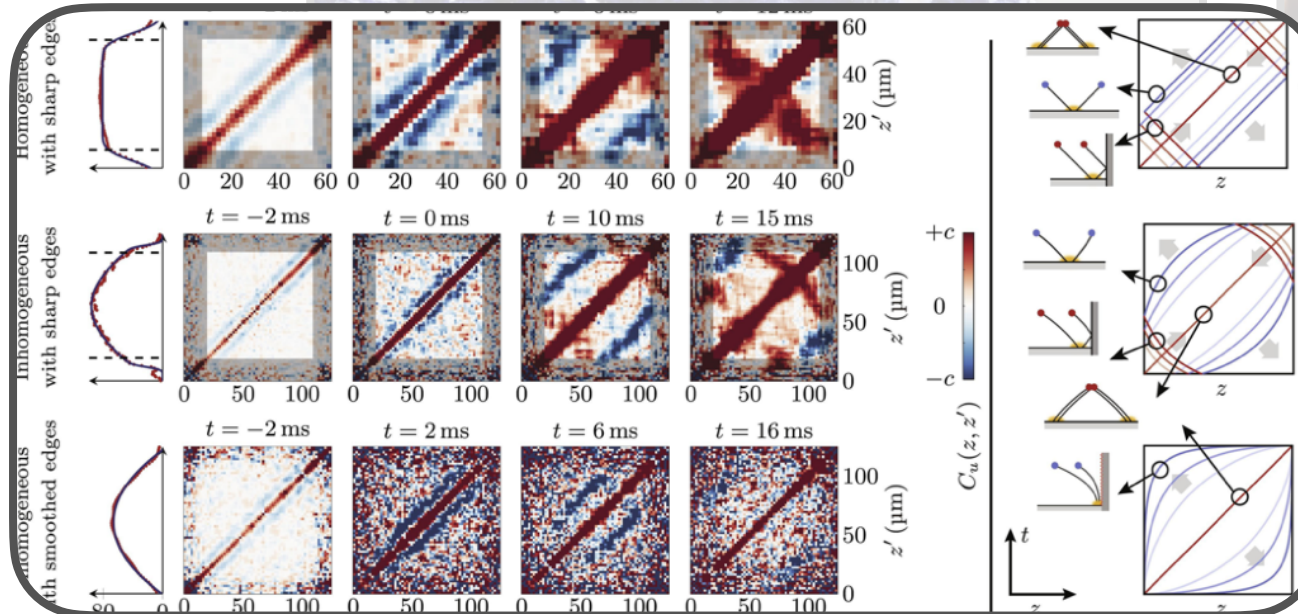
QUANTUM SIMULATION

- Do quantum computers have applications in quantum chemistry and materials science?



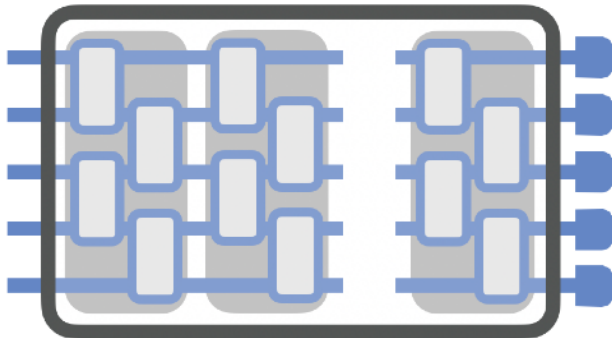
QUANTUM SIMULATION

- Yes, and their error scaling is better, but variational separations unknown



Schweigler, Gluza, Tajik, Sotiriadis, Cataldini, Ji, Møller, Sabino, Rauer, Eisert, Schmiedmayer, Nature Phys 17, 559 (2021)
Trivedi, Rubio, Cirac, arXiv:2212.04924 (2022)

- Without error correction, there are limitations

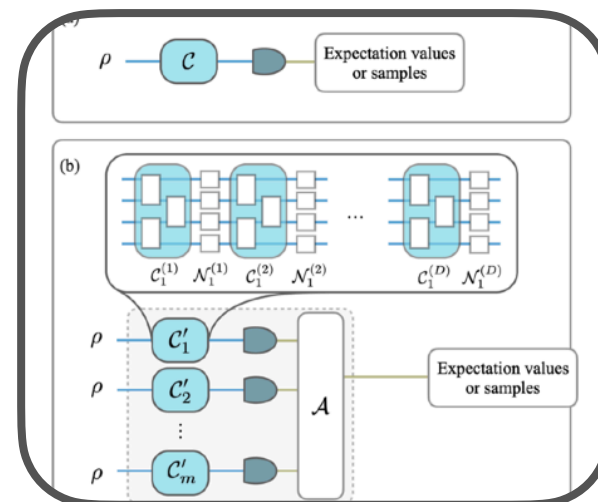


- Only-logarithmically deep quantum circuits

Stilck Franca, Garcia-Patron, Nature Phys 17, 1221 (2021)

Deshpande, Niroula, Shtanko, Gorshkov, Fefferman, Gullans, PRX Quantum 3, 040329 (2022)

Mele, Angrisani, Ghosh, Khatri, Eisert, Stilck Franca, Quek, arXiv:2403.13927 (2024)



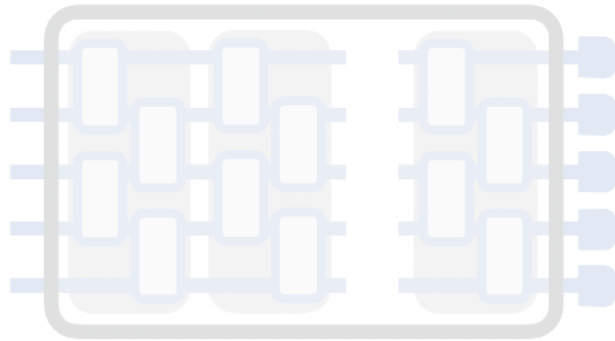
- Error mitigation only until **log-log depth**

Quek, Stilck França, Khatri, Meyer, Eisert, Nature Phys 20, 1648 (2024)



BUT, THERE ARE LIMITATIONS

- How can they be overcome?

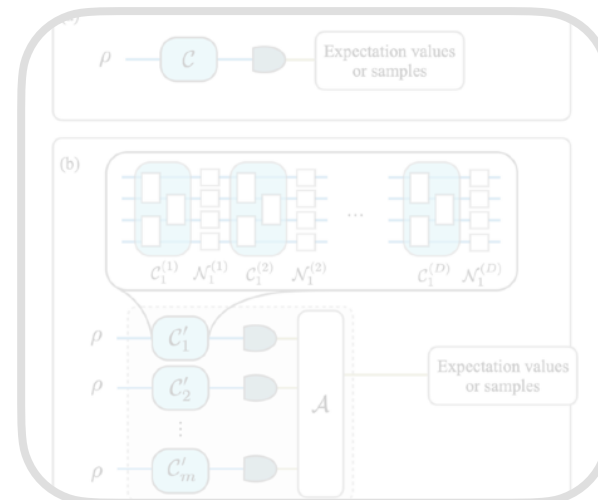


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- Error mitigation only until log-log depth

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GREAT PLACE FOR COLLABORATIONS

- Established connections





THANKS

