

# Quantum Computers

*At the Cusp of Reality*

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# #1: Superposition



$$\frac{|0\rangle + |1\rangle}{\sqrt{2}}$$

YANNY

LAUREL

# #2: Entanglement



<http://digitalspyuk.cdnds.net/13/36/movies-harry-potter-voldemort.jpg>

# Quantum Advantage

$$\begin{pmatrix} \%|0\rangle \\ \%|1\rangle \end{pmatrix}$$

$$\begin{pmatrix} \%|00\rangle \\ \%|01\rangle \\ \%|10\rangle \\ \%|11\rangle \end{pmatrix}$$

$$\begin{pmatrix} \%|000\rangle \\ \%|001\rangle \\ \%|010\rangle \\ \%|011\rangle \\ \%|100\rangle \\ \%|101\rangle \\ \%|110\rangle \\ \%|111\rangle \end{pmatrix}$$

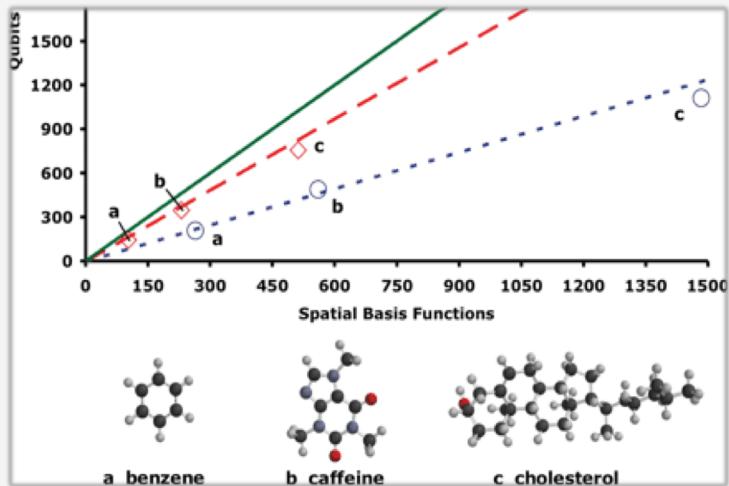
$$\begin{pmatrix} \%|0000\rangle \\ \%|0001\rangle \\ \%|0010\rangle \\ \%|0011\rangle \\ \%|0100\rangle \\ \%|0101\rangle \\ \%|0110\rangle \\ \%|0111\rangle \\ \%|1000\rangle \\ \%|1001\rangle \\ \%|1010\rangle \\ \%|1011\rangle \\ \%|1100\rangle \\ \%|1101\rangle \\ \%|1110\rangle \\ \%|1111\rangle \end{pmatrix}$$

⇒ Exponential gains: adding 1 qubit doubles power

- Quantum Advantage = when quantum surpasses classical
  - 2019? 2020?

# Applications

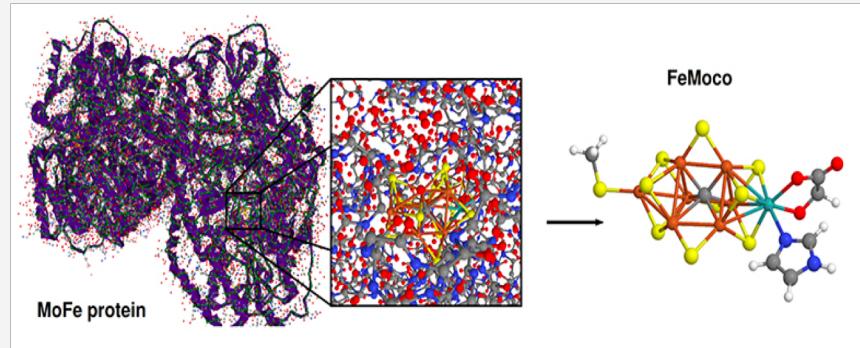
Cholesterol = 1000 Qubits



D.S. Abrams and S. Lloyd  
*Phys. Rev. Lett.* **83**, 5162 (1999).

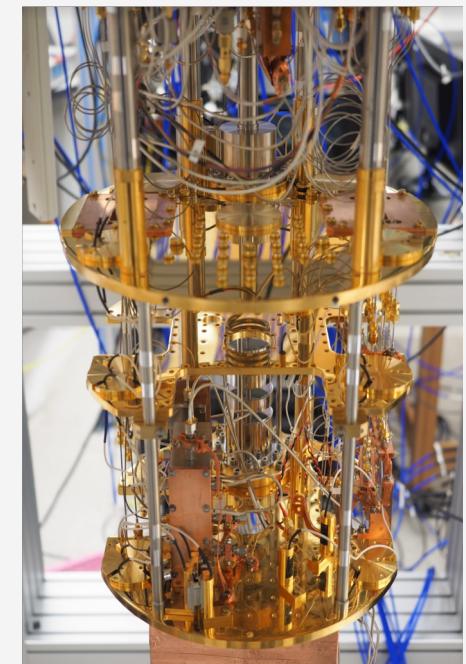
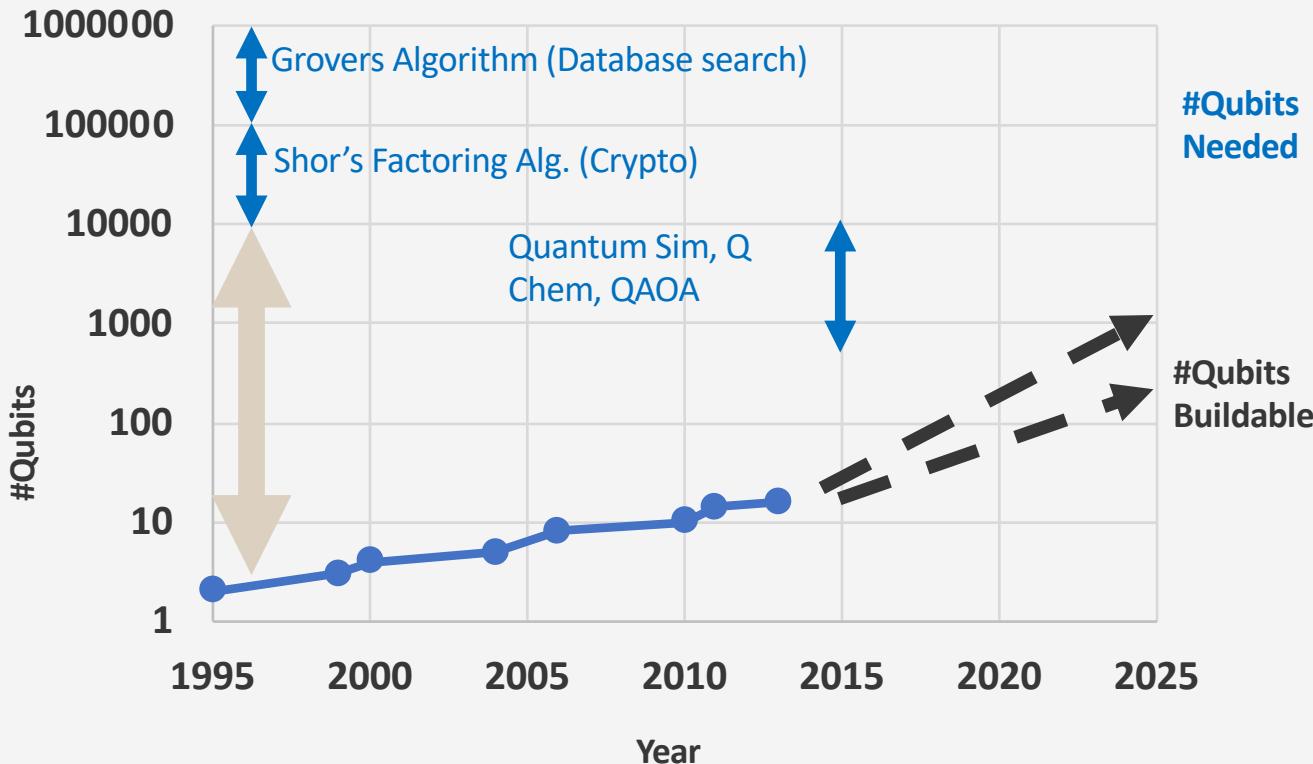
A. Aspuru-Guzik, A. Dutoi,  
P. Love, and M. Head-Gordon  
*Science* **309**, 1704 (2005).

Haber Process consumes 2% of world's energy



<https://www.microsoft.com/en-us/research/blog/problems-will-solve-quantum-computer/>

# At the Cusp of Reality



# Connections

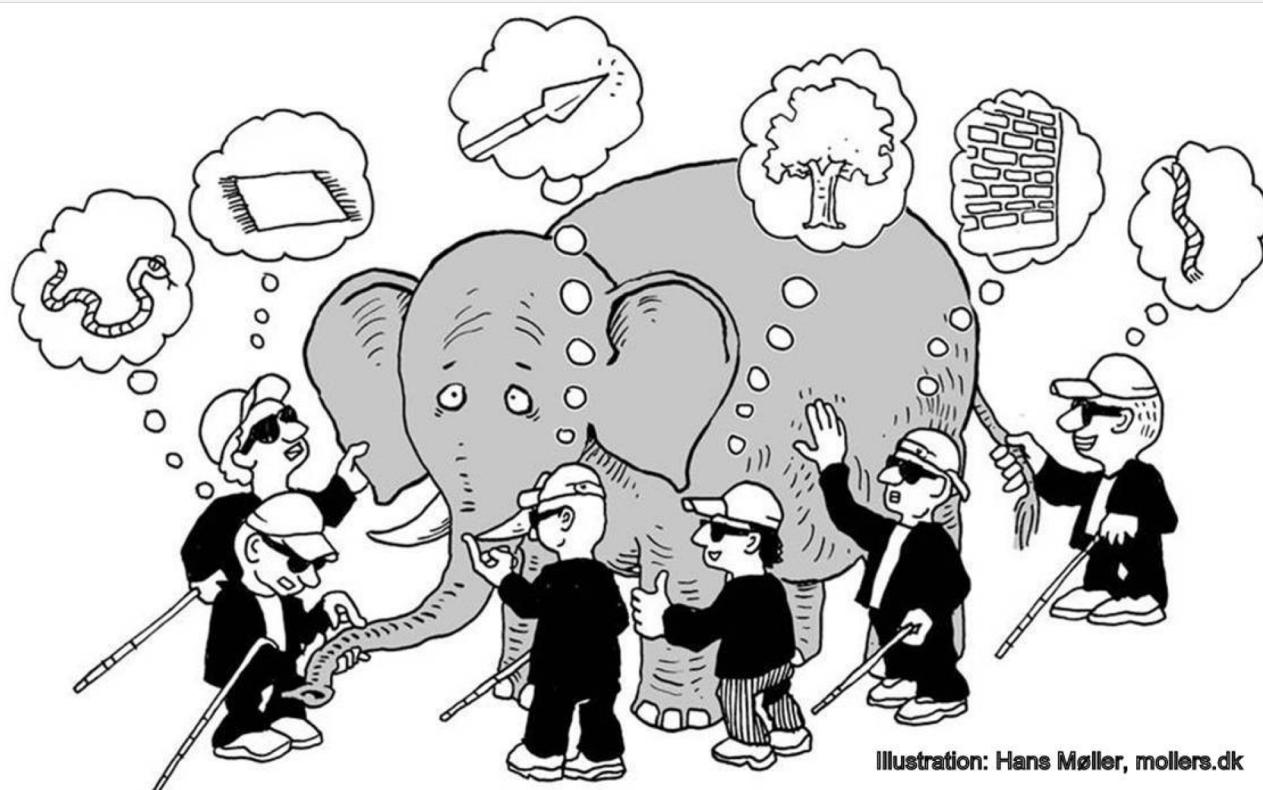
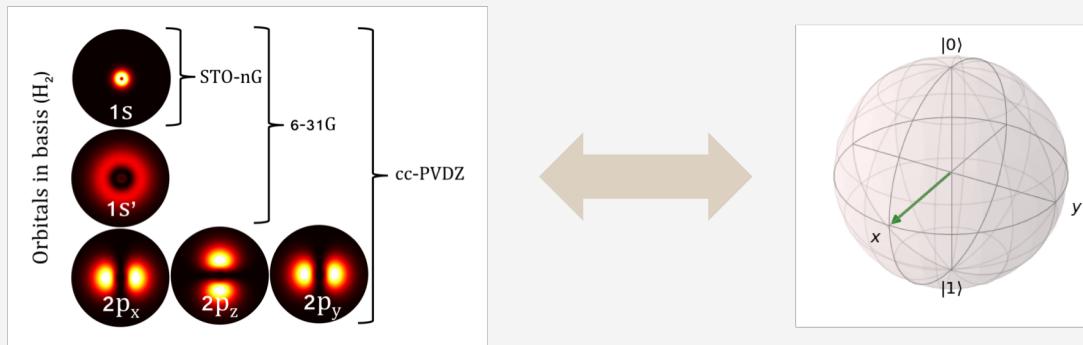


Illustration: Hans Møller, [mollers.dk](http://mollers.dk)

# Connections: OpenFermion



**Chemistry**  
Fermionic Hamiltonians  
Orbitals

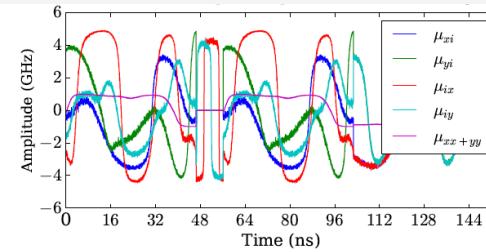
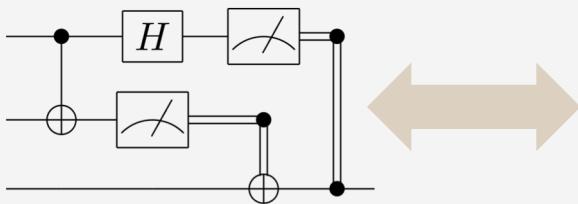


McArdle et al. 2018

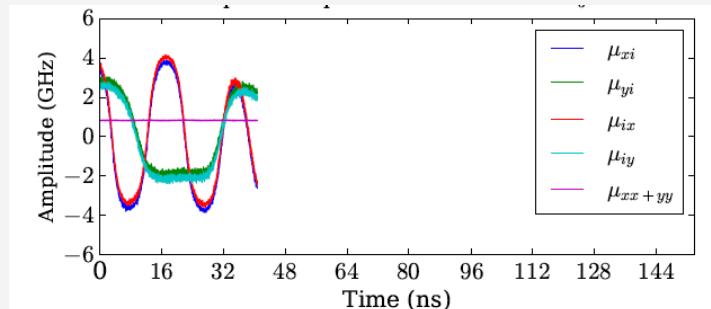
**CS**  
Bitstrings  
Operation gates

# Connections: Optimal Control

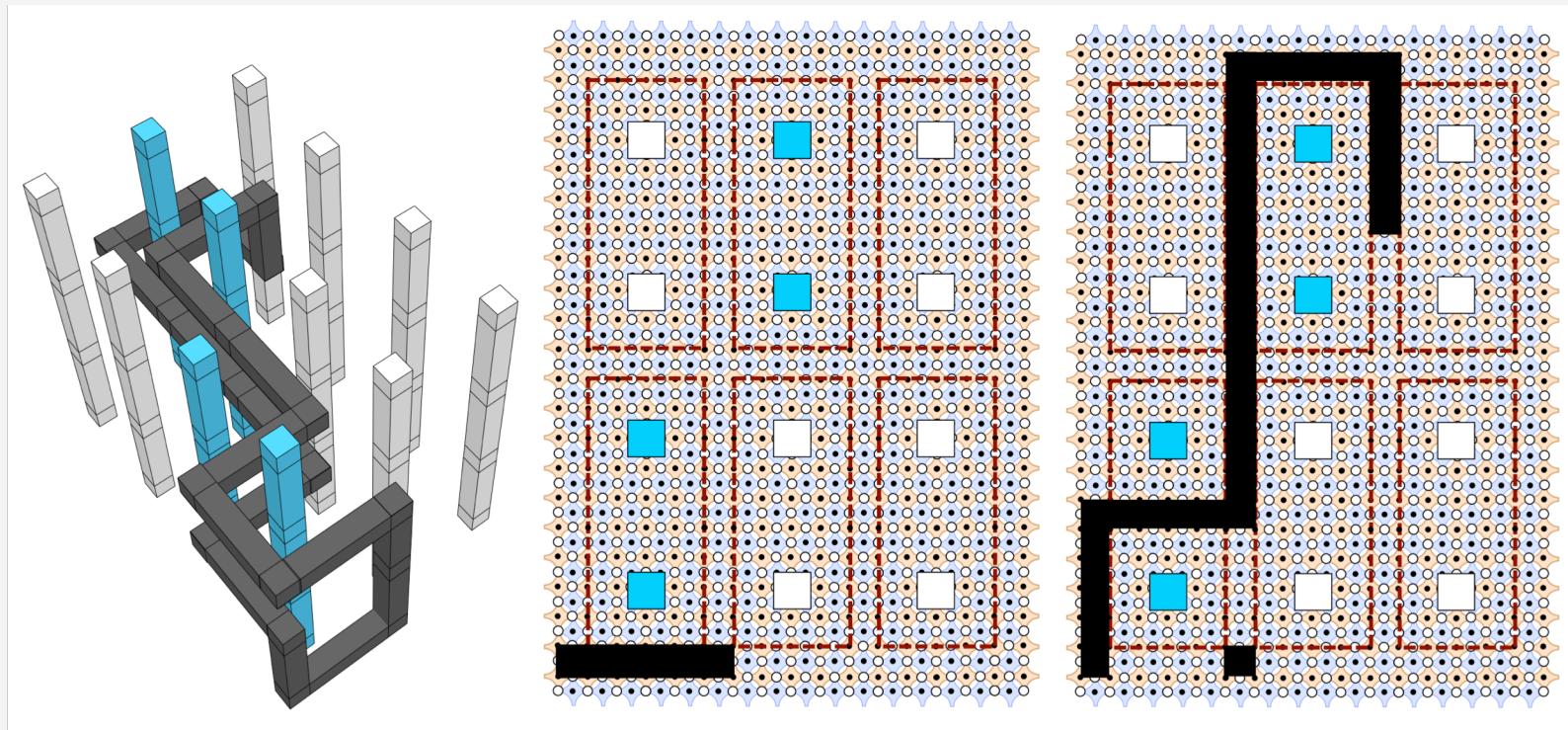
**CS**  
Circuits  
Instruction Set  
Digital/discrete



**Physics**  
Control Hamiltonians  
Pulses  
Analog/continuous



# Connections: Surface Code Routing



Optimized Surface Code Communication in Superconducting Quantum Computers

# Connections

- Educators
  - STEM education, tutorials
- Govt & Policymakers
  - National Quantum Initiative
- Industry
  - Quantum preparedness



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