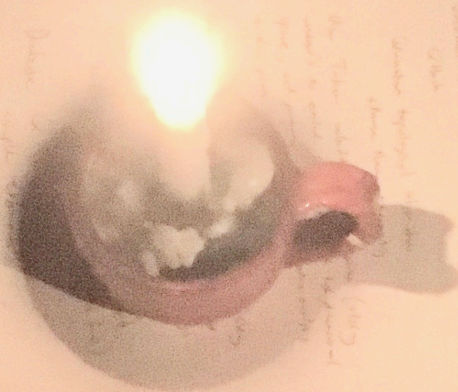


Quantum Simulation in the NISQ era
 Seth Lloyd, MIT

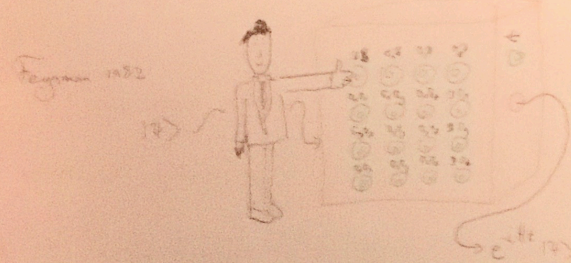
Quantum simulation is a natural application of quantum computers. The idea is to use a quantum circuit to simulate the evolution of a quantum system. This is done by decomposing the system's Hamiltonian into a sequence of gates that can be implemented on a quantum circuit. The resulting circuit can then be executed on a quantum device to simulate the system's behavior.

The main challenge in quantum simulation is the need for a large number of qubits and high gate fidelity. This is because the number of qubits required to simulate a system grows exponentially with the system's size. Additionally, the gates used to implement the simulation must be highly accurate to avoid errors in the results.

Despite these challenges, quantum simulation is a promising area of research. It has the potential to revolutionize our understanding of quantum systems and to enable the development of new materials and drugs.



Quantum Simulation in the NISQ era
 Seth Lloyd, MIT



$H = \sum_{i,j} c_{ij} \sigma_i^x \sigma_j^x$ Analog quantum simulation

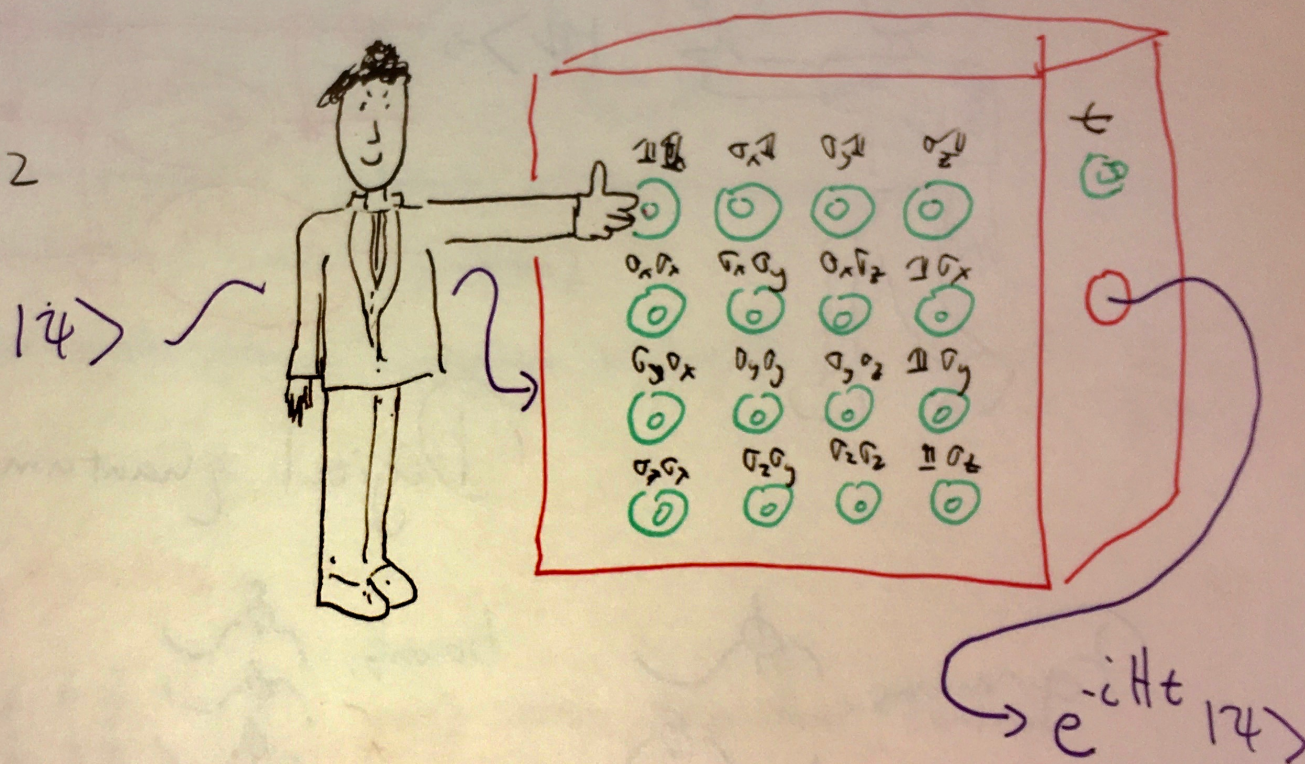
The image shows the back cover of a book titled 'The Golden Rule' by John Galsworthy. The cover features a portrait of a man in a suit. The book is resting on a dark surface.



Quantum Simulation in the NISQ era

Seth Lloyd, MIT

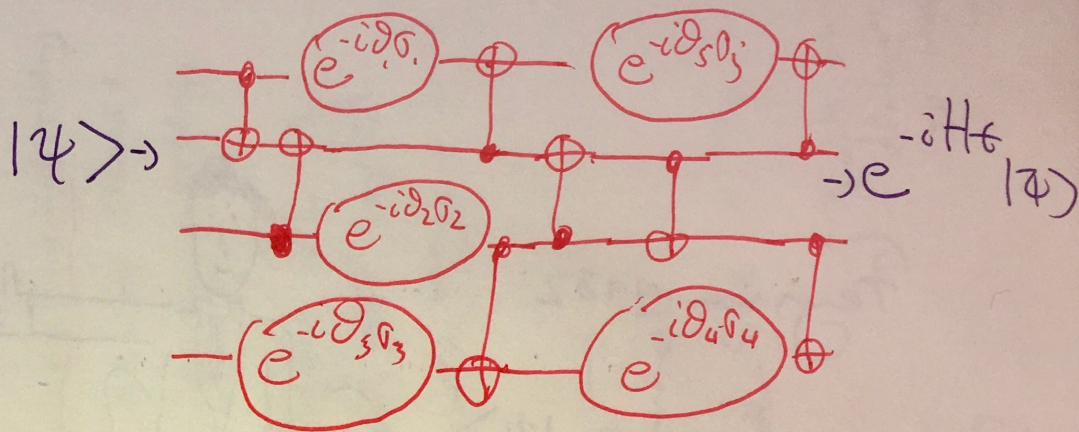
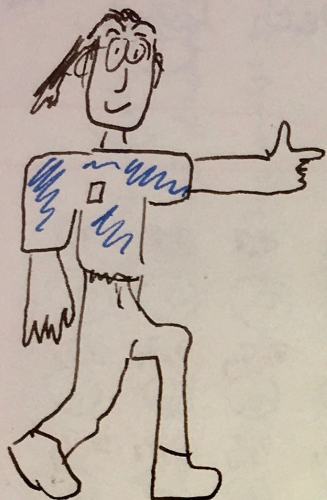
Feynman 1982



$$H = \sum_{i,j} h_{ij} \sigma_i \sigma_j$$

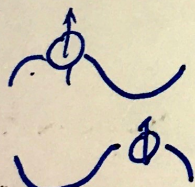
Analog quantum simulation

Lloyd 1995



Digital quantum simulation

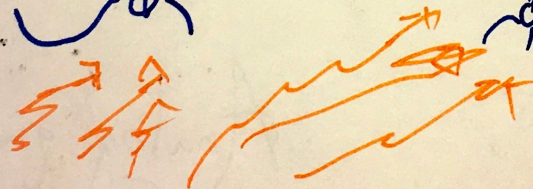
Fermions



bosons



! Noise !

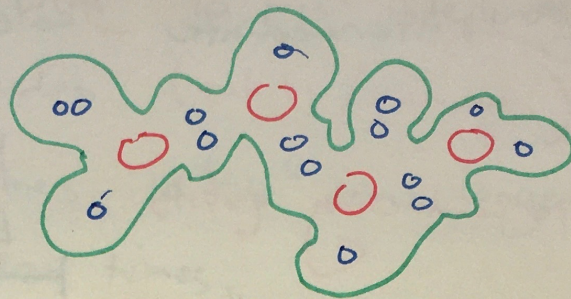


$$H = \sum_{j \text{ local}} H_j$$

Trotterization

Early results: What can you simulate with 100 qubits, 10,000 ops?

Chemical structure
+ finding ground states

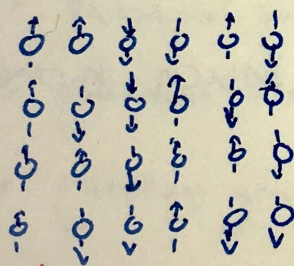


→ apply fermionic simulation + quantum phase estimation
(find eigenvalues + reveal eigenstates)

to understand complex molecules

(Abrams, Lloyd 1997)
→ cf. VQE)

Quantum many body dynamics



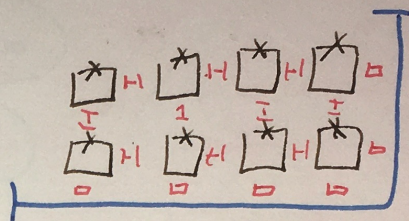
$$H(t) = H_{\text{dipole}} + \gamma(t) \sum_j \sigma_j^x$$

→ time dependent control
of natural Hamiltonian to induce
effective Hamiltonian

(Cory 1998)

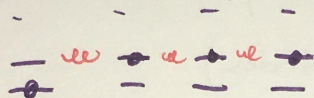
Noisy Intermediate Scale Quantum devices

superconducting qubits



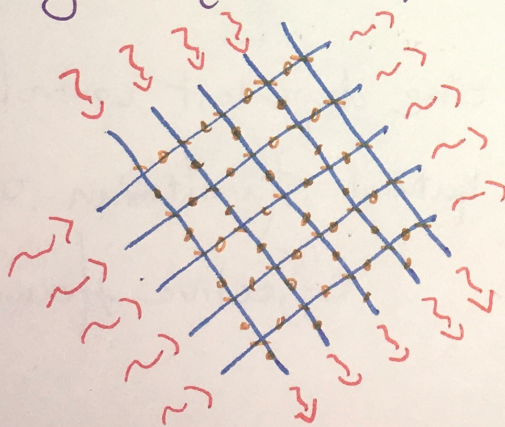
nonlinear oscillators coupled with harmonic oscillators

ion traps



atoms coupled with vibrational modes

integrated quantum optics



+ much more!

We now have systems with $10^2 - 10^4$ independently controllable quantum degrees of freedom (qubits/qumodes) with coherence times $10^4 - 10^6$ times longer than interaction times.

$\Rightarrow$ Tremendous opportunity for quantum simulation!

- multiparticle dynamics, many body localization
- quantum field theory, strong interactions
- Variational quantum eigensolver, chemical structure
- quantum chemical dynamics, excitonics
- quantum gravity, black hole scrambling (aspirational ;-)

And yet the same issues remain two decades later!

- noise in simulator becomes noise in simulation
- quantum error correction/suppression for quantum simulators
- imperfections/nonreproducibility of control signals.
- how do you read out the results?

Prediction: Analog quantum simulators a la Feynman
— with designed architectures and precisely tunable controls
will become an integral tool of quantum physics

— As long as we can deal with the noise!

