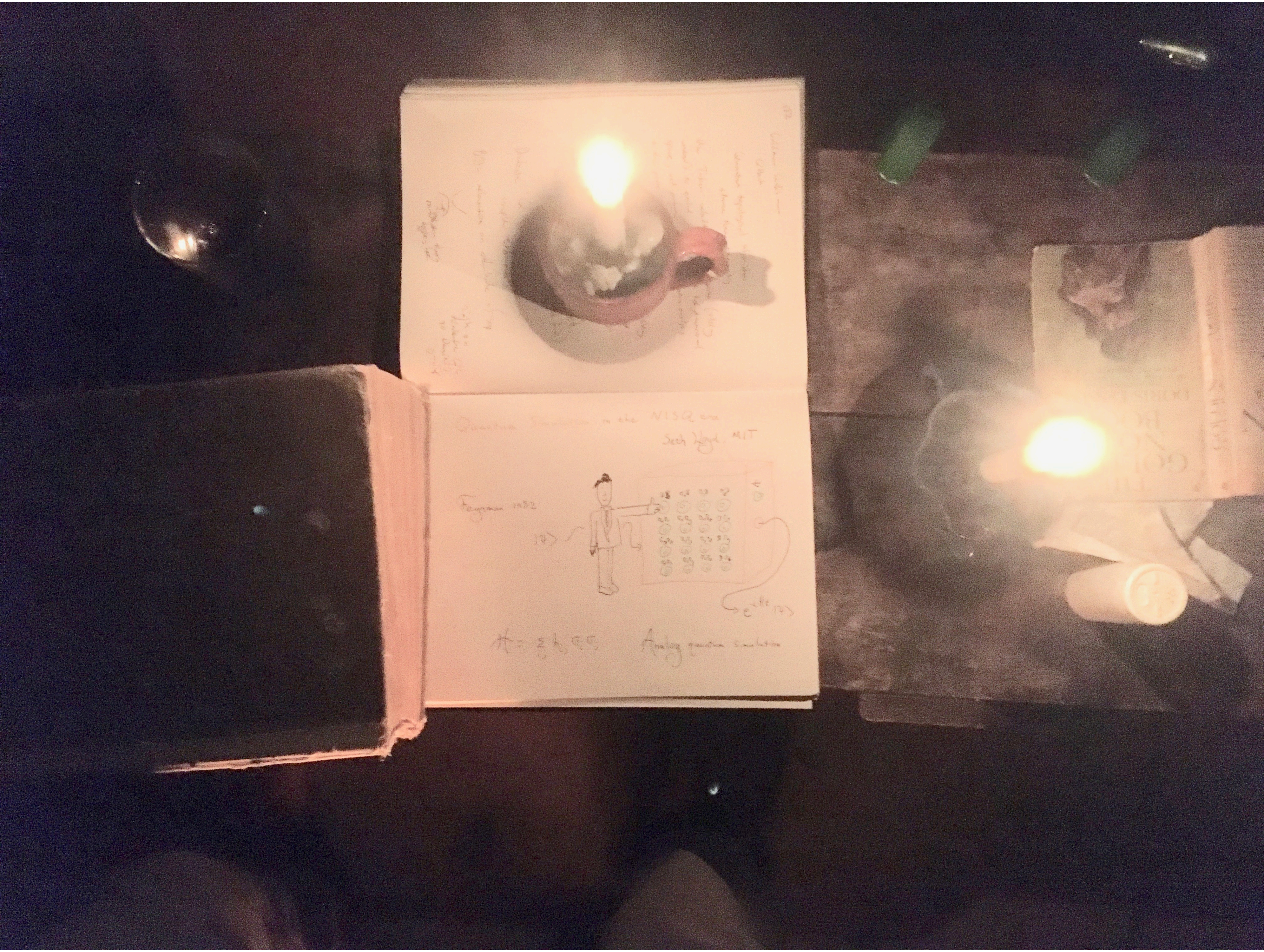
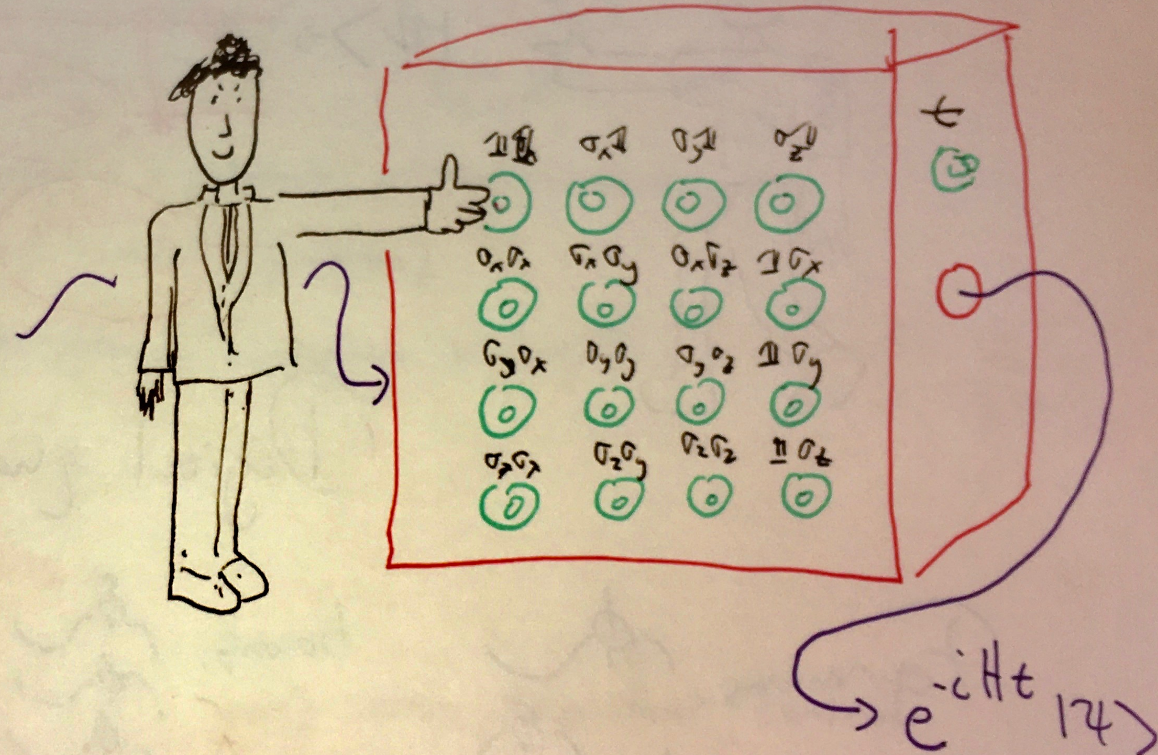

Quantum Simulation in the NISQ era
Seth Lloyd, MIT
Feynman 1982
Analog quantum simulation

Quantum Simulation in the NISQ era

Seth Lloyd, MIT

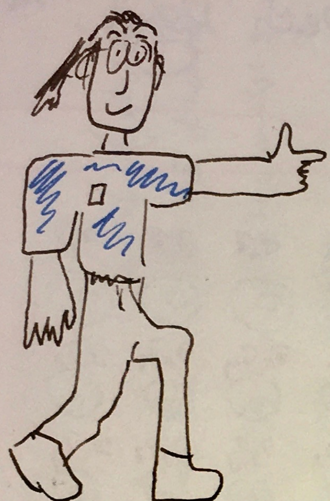
Feynman 1982

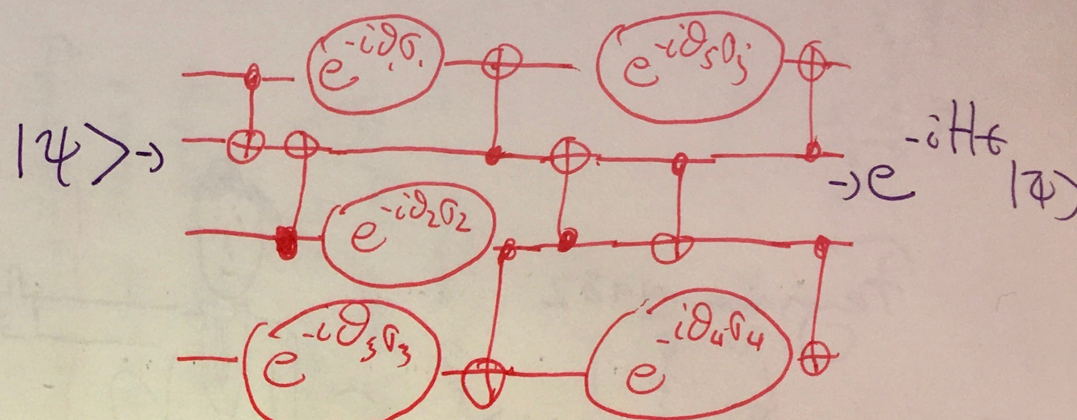


$$\mathcal{H} = \sum_{ij} h_{ij} \sigma_i \sigma_j$$

Analog quantum simulation

Lloyd 1995





Digital quantum simulation

Fermions

bosons

$\mathcal{H} = \sum_{j \text{ local}} \mathcal{H}_j$

Trotterization

¡Noise!

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

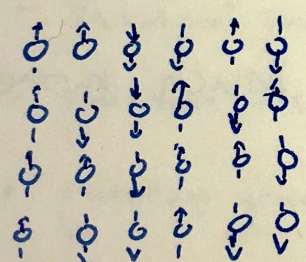
Chemical structure
+ finding ground states

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

to understand complex molecules

(Abrams, Lloyd 1997
-> cf. VQE)

Quantum many body dynamics



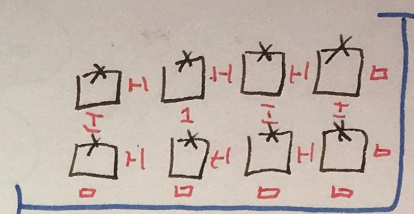
-> time dependent control
of natural Hamiltonian to induce
effective Hamiltonian

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

(Cory 1998)

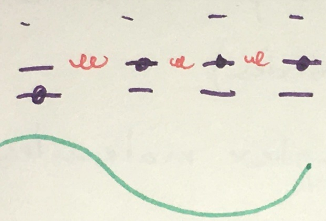
Noisy Intermediate Scale Quantum devices

superconducting qubits



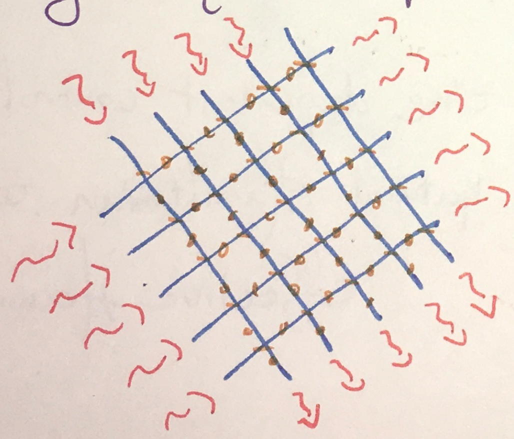
nonlinear oscillators coupled with harmonic oscillators

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 designer architectures and precisely tunable controls
will become an integral tool of quantum physics

— ¡As long as we can deal with the noise!