Quantum Simulation

- Motivation
- Pipeline
- Matter -> Hamiltonian
- Awful Scaling
- Demo of my research!

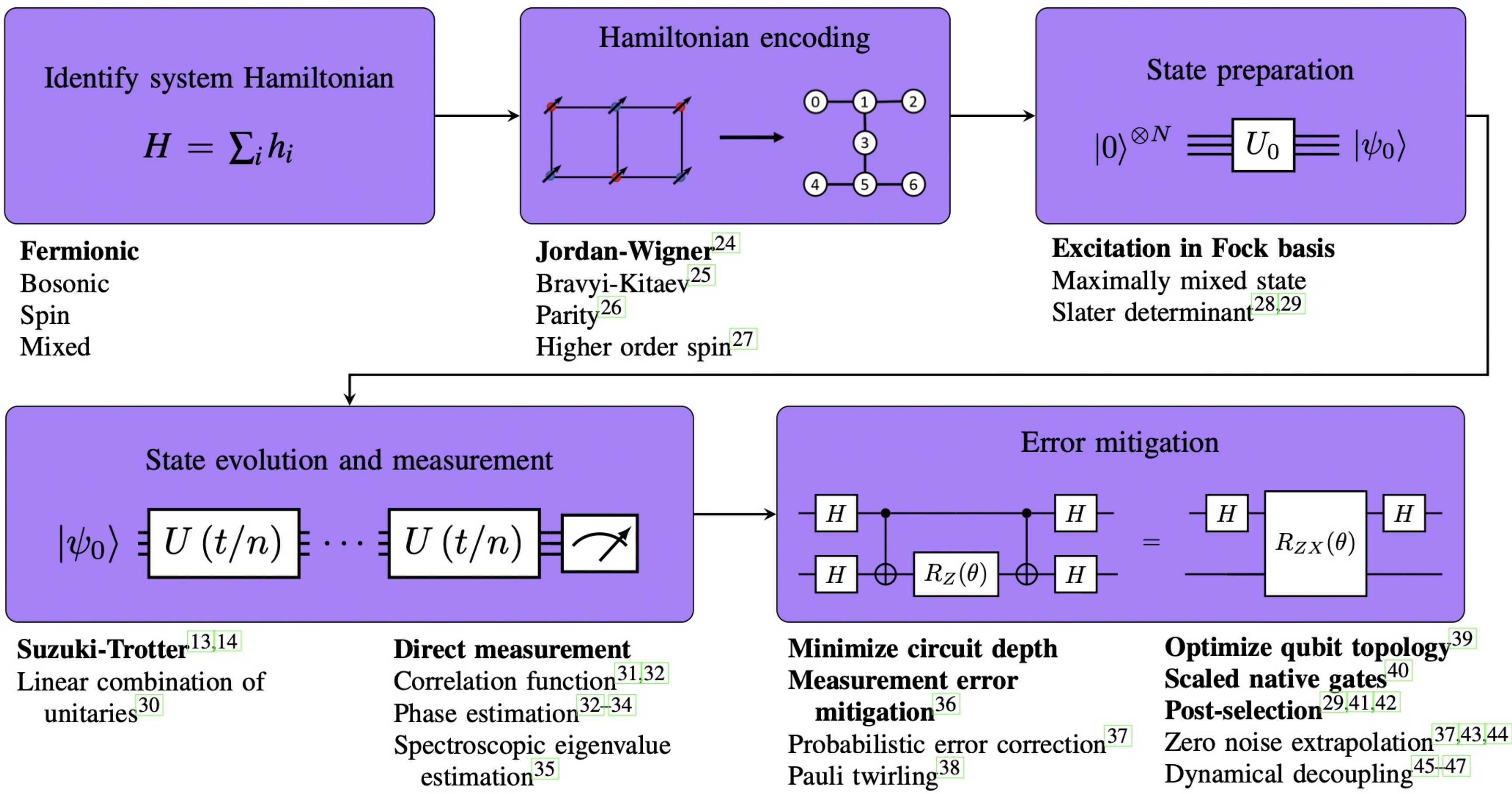
Quantum simulation

"The underlying physical laws necessary for the mathematical theory of a large part of physics and the whole of chemistry are thus completely known, and the difficulty is only that the exact application of these laws leads to equations much too complicated to be soluble. "

— Dirac

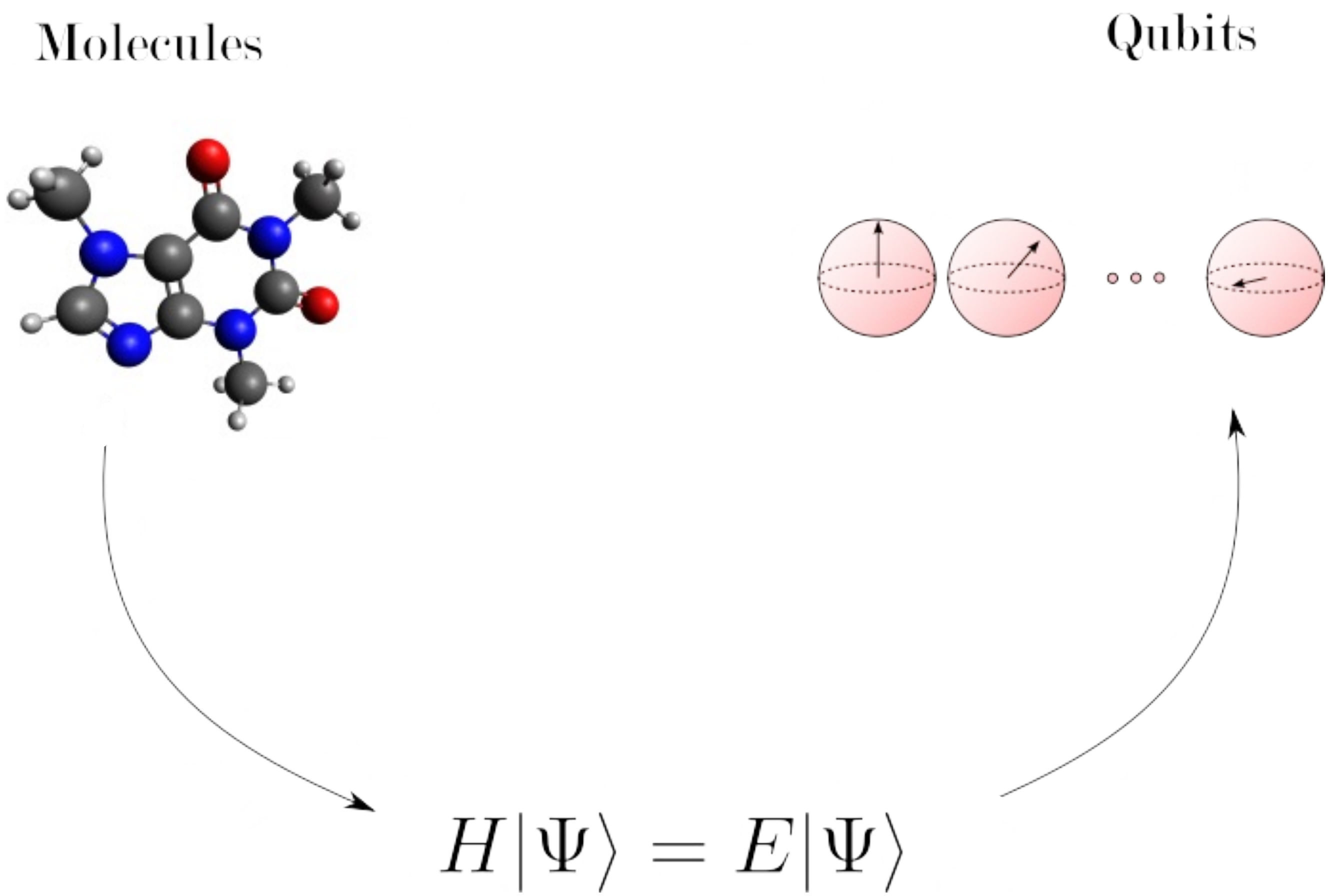
Potential Applications

Pipeline



Quantum Simulation on Noisy Superconducting Quantum Computers

Translating Matter into Qubits



Jarrod R. McClean

Hydrogen Gas Hamiltonian

H_2

$$-1.05\, II + 0.397\, IZ - 0.397\, ZI + 0.011\, ZZ + 0.181\, XX$$

Sum

=

$$\begin{bmatrix} -1.06365335002909 & 0 & 0 & 0.180931199784232 \\ 0 & -1.83696799120298 & 0.180931199784232 & 0 \\ 0 & 0.180931199784232 & -0.245218291830263 & 0 \\ 0.180931199784232 & 0 & 0 & -1.06365335002909 \end{bmatrix}$$

Want to Know Eigenvalues

$$H = \begin{bmatrix} -1.06365335002909 & 0 & 0 & 0.180931199784232 \\ 0 & -1.83696799120298 & 0.180931199784232 & 0 \\ 0 & 0.180931199784232 & -0.245218291830263 & 0 \\ 0.180931199784232 & 0 & 0 & -1.06365335002909 \end{bmatrix}$$

Hamiltonian → Energy Function

Eigenvalues → Energy

lowest Eigenvalue → Groundstate

Math Physics

Horrible Scaling

Schwinger model

QED

1 spacial +1 time

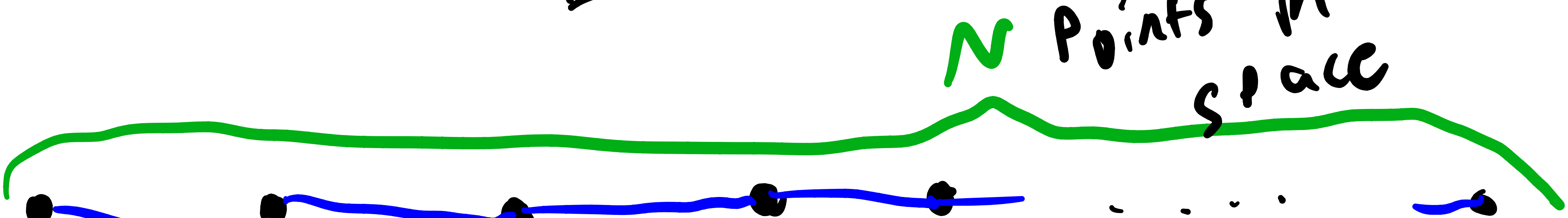
Toy Model

$$H_E = \frac{g^2 a}{2} \sum_{i=1}^{N-1} \left(\sum_{j<i} \frac{Z_j + (-1)^j}{2} + \frac{\theta}{2\pi} \right)^2$$

$$H_M = \frac{m}{2} \sum_{i=1}^{N} (-1)^i Z_i$$

$$H_I = \frac{1}{4a} \sum_{i=1}^{N-1} X_i X_{i+1} + Y_i Y_{i+1} \,.$$

$$H = H_E + H_m + H_I$$



Hilbert Space is a BIG Place

$N \rightarrow 2^N \cdot 2^N = 2^{2N}$ Numbers in Ham.

$2 \rightarrow 16$

⋮

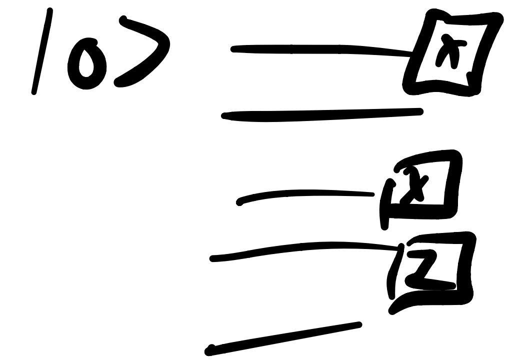
XXIIYY $6 \rightarrow 4096$

⋮

$134 \rightarrow 4.7\times10^{80} > 3.28\times10^{80}$ particles in universe

= ☹

Luckily

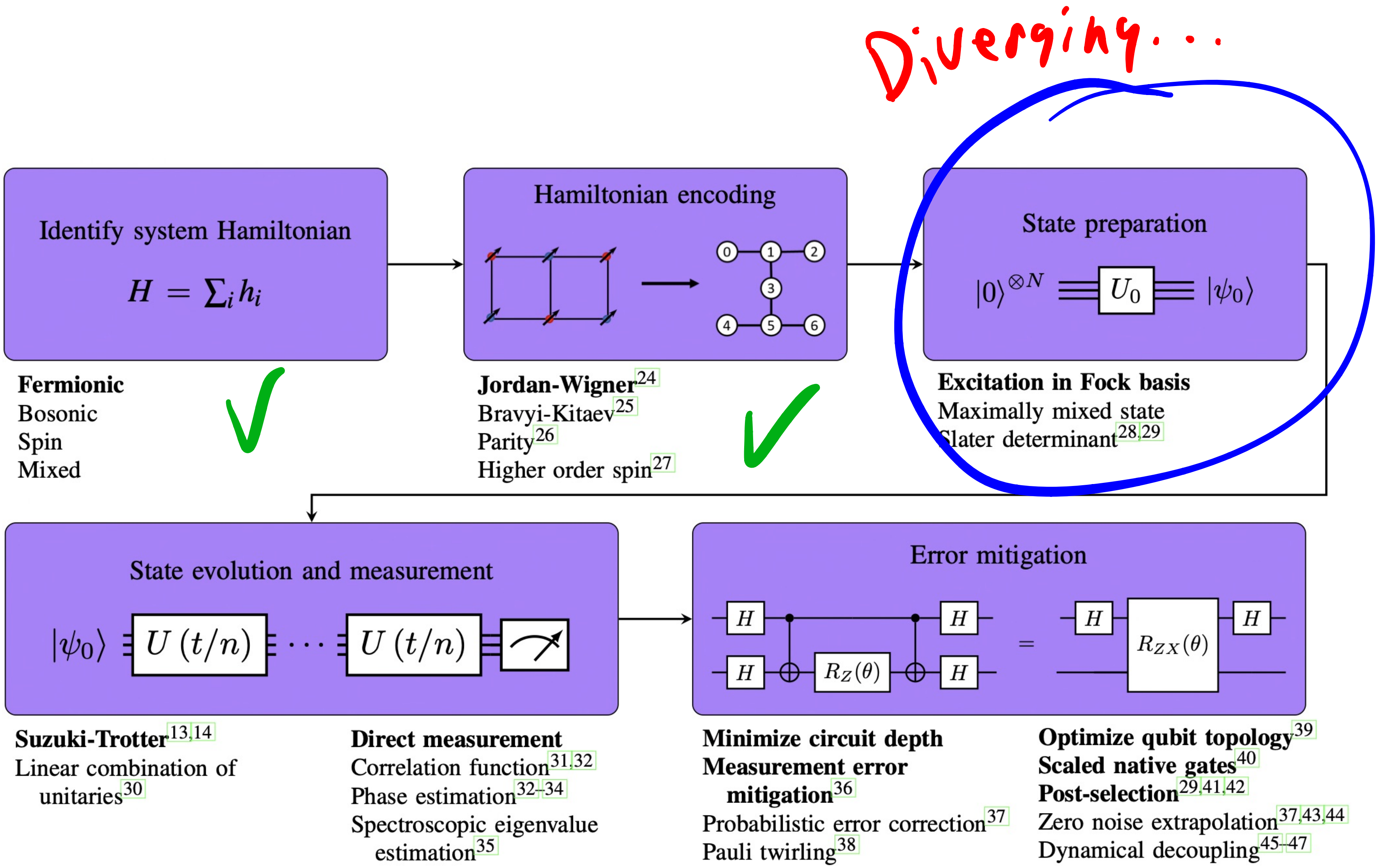


$N \sim N$ qubits!

Quantum Computers have polynomial complexity btwn points and Qubits

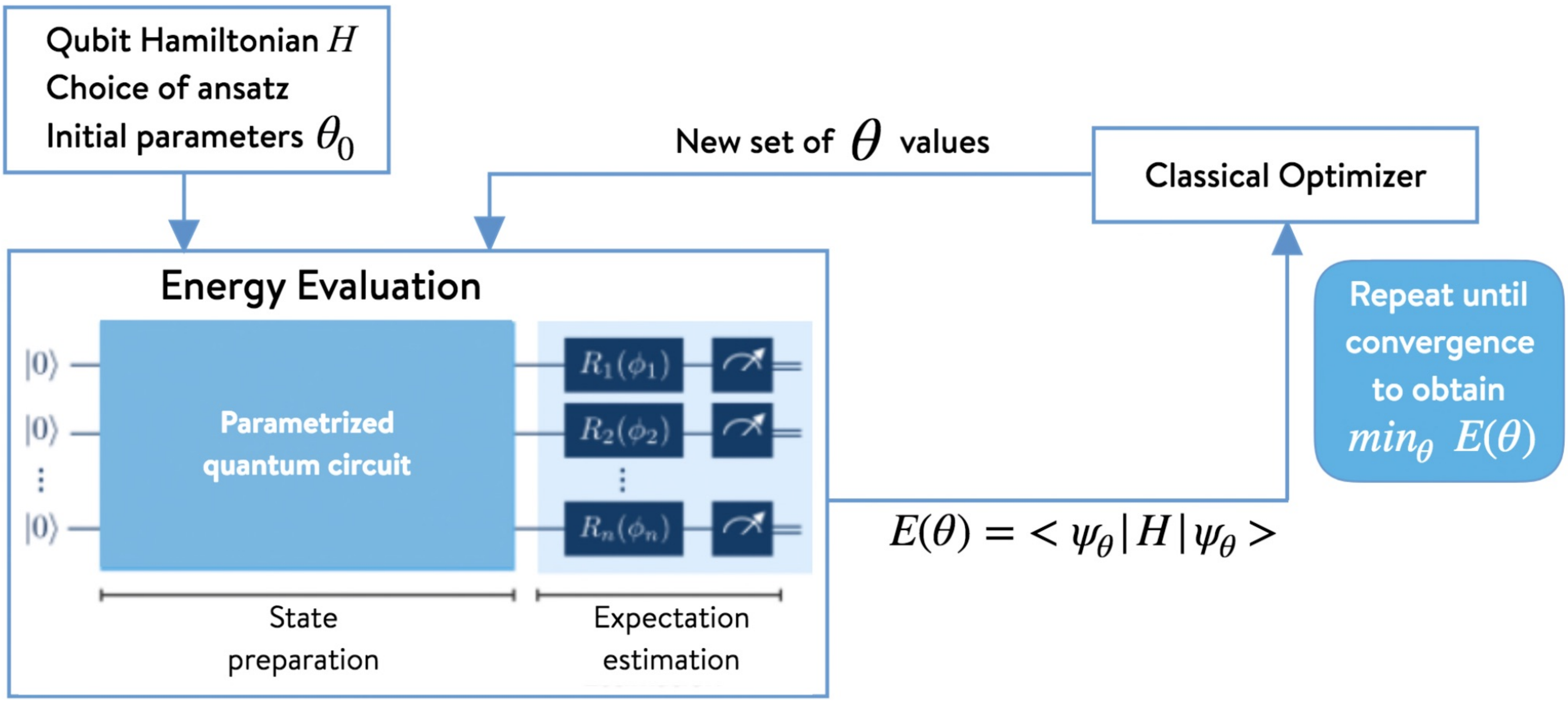
(at least for Schwinger model)

Prepping the state



Burning

VQE – The Noisy State Preperation



ansatz = $|\psi_\theta\rangle$ = state prep.

Example QAOA

Ansatz for H_2

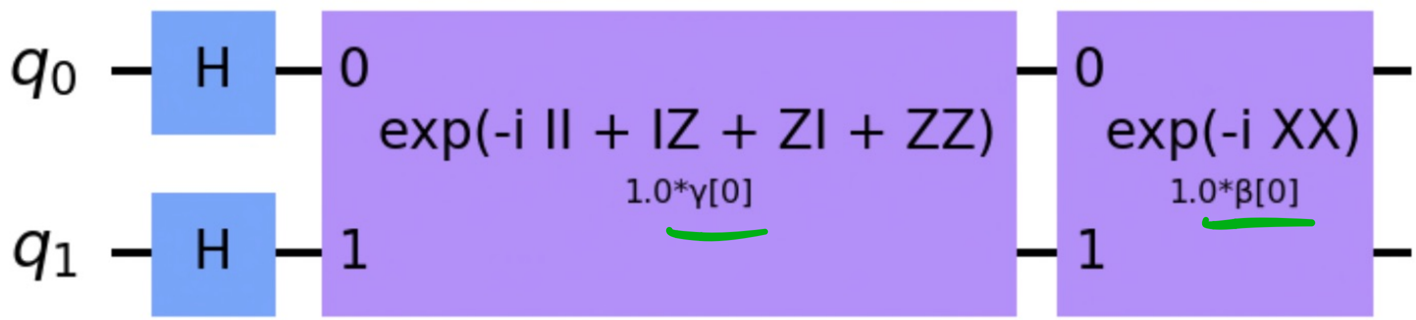
$H =$

$$\begin{bmatrix} -1.06365335002909 & 0 & 0 & 0.180931199784232 \\ 0 & -1.83696799120298 & 0.180931199784232 & 0 \\ 0 & 0.180931199784232 & -0.245218291830263 & 0 \\ 0.180931199784232 & 0 & 0 & -1.06365335002909 \end{bmatrix}$$

Driver

Mixer

$|\psi_\theta\rangle =$



$e^{iH\text{amiltonian}} = U\text{nitary}$

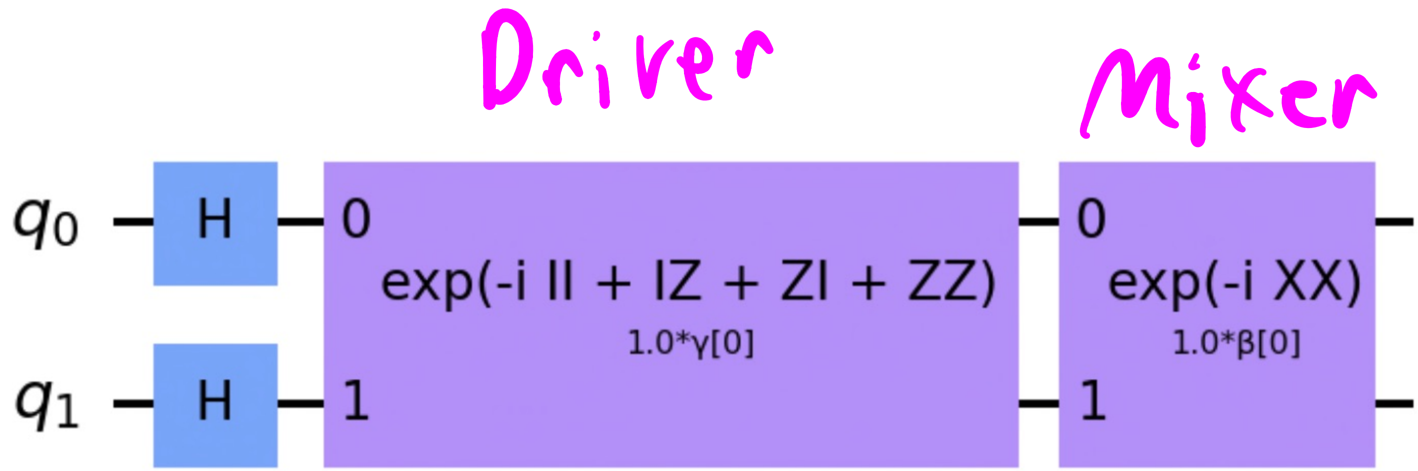
Parameters

$\vec{\theta} = \begin{bmatrix} \gamma \\ \beta \end{bmatrix}$

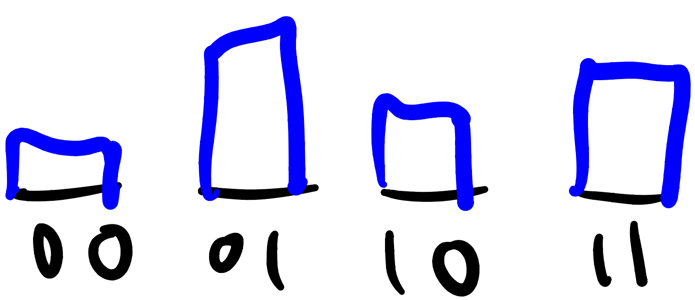
eval $= \langle \psi_0 | H | \psi_0 \rangle$

Noisy!

$|\psi_\theta\rangle =$



You measure this circuit a bunch of times, getting some distribution that is the wave function



$\sim |\psi_\theta\rangle = \begin{bmatrix} 0.375 \\ 0.6 \\ 0.375 \\ 0.6 \end{bmatrix}$