SAND2022-2451C
SAND2022-###

From pulses to circuits and back again

A quantum control perspective on variational quantum algorithms

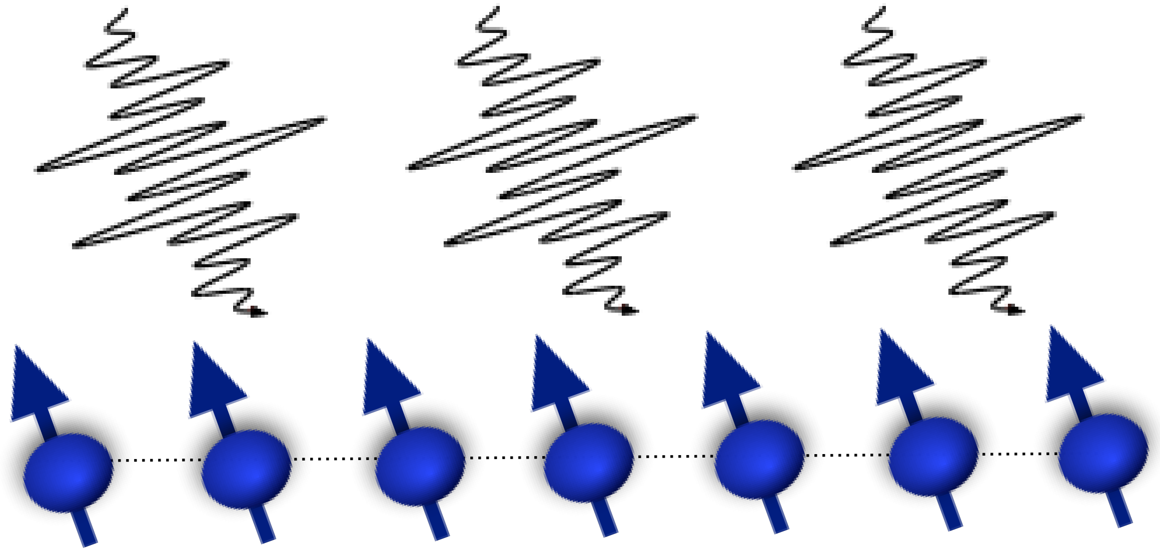
Alicia B Magann, Christian Arenz, Matthew D. Grace, Tak-San Ho, Robert L. Kosut, Jarrod R. McClean, Herschel A. Rabitz, and Mohan Sarovar

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Quantum computing

<u>Early years: pulse-level advances</u>



Published: 29 April 1999

Coherent control of macroscopic quantum states in a single-Cooper-pair box

Y. Nakamura, Yu. A. Pashkin & J. S. Tsai

Nature **398**, 786–788 (1999) | Cite this article

Published: 30 October 2003

Demonstration of conditional gate operation using superconducting charge qubits

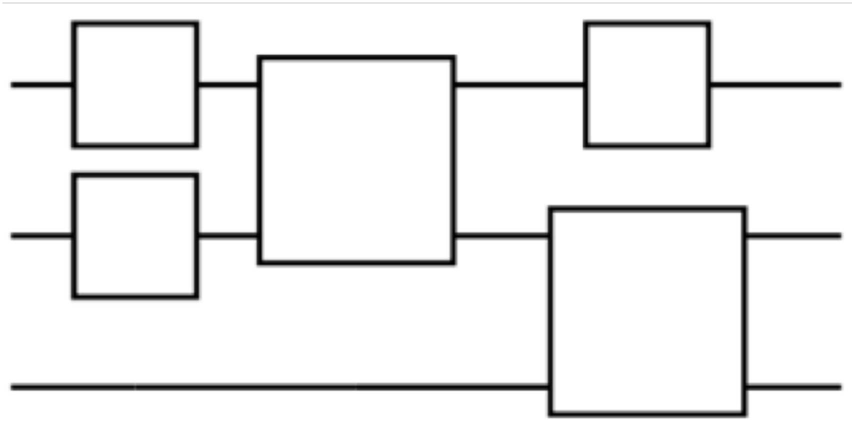
T. Yamamoto, Yu. A. Pashkin, O. Astafiev, Y. Nakamura & J. S. Tsai

Nature **425**, 941–944 (2003) | Cite this article

Quantum control

AB Magann*, C Arenz*, MD Grace, TS Ho, RL Kosut, JR McClean, HA Rabitz, M Sarovar, "From pulses to circuits and back again: A quantum optimal control perspective on variational quantum algorithms", *PRX Quantum* (2021); arXiv:2009.06702

<u>More recently: circuit-level advances</u>



Variational quantum algorithms

Open Access | Published: 23 July 2014

A variational eigenvalue solver on a photonic quantum processor

Alberto Peruzzo, Jarrod McClean, Peter Shadbolt, Man-Hong Yung, Xiao-Qi Zhou, Peter J. Love, Alán Aspuru-Guzik & Jeremy L. O'Brien

Nature Communications **5**, Article number: 4213 (2014) | Cite this article

arXiv.org > quant-ph > arXiv:1411.4028

Quantum Physics

[Submitted on 14 Nov 2014]

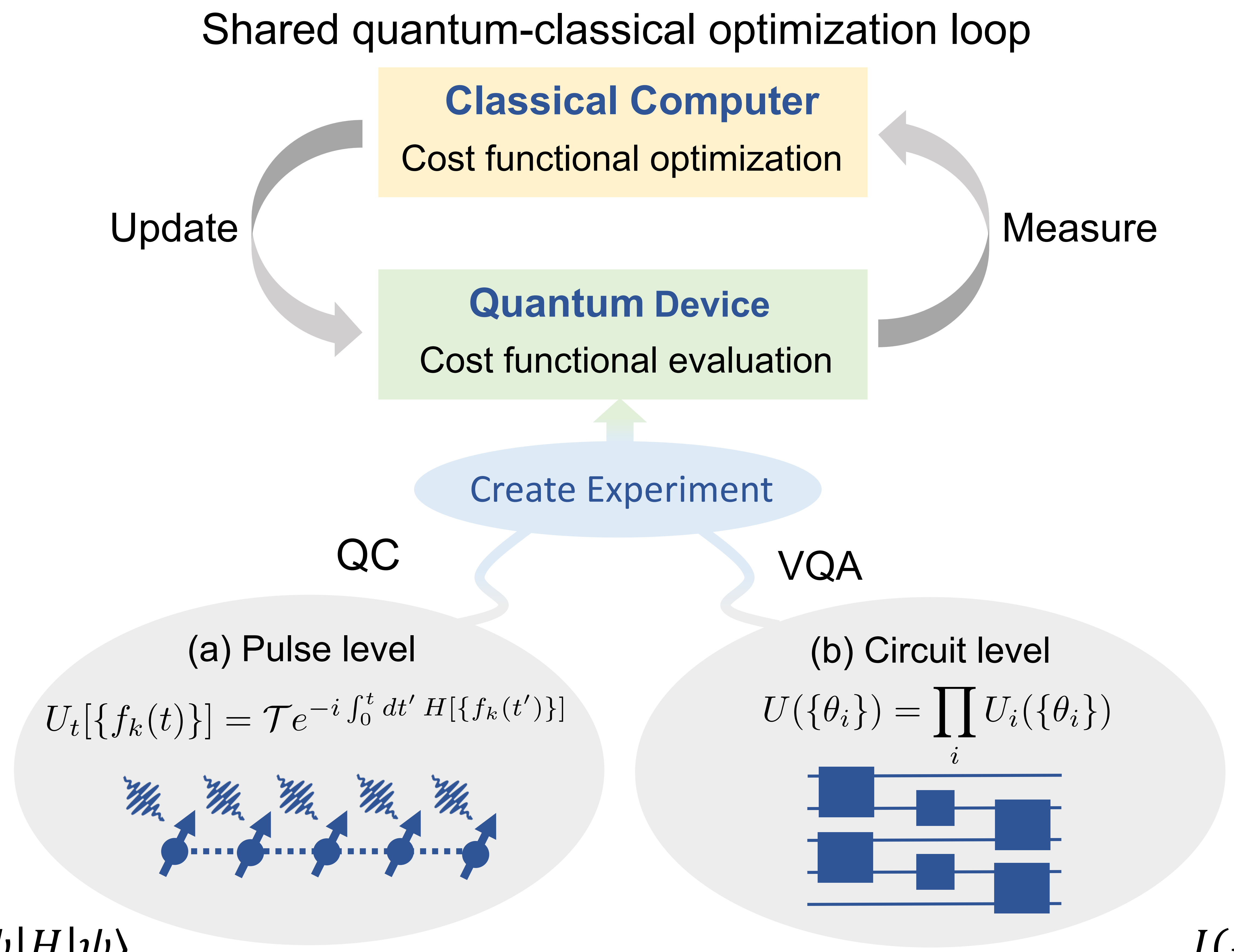
A Quantum Approximate Optimization Algorithm

Edward Farhi, Jeffrey Goldstone, Sam Gutmann

"From pulses to circuits and back again"

Connections between quantum control & variational quantum algorithms

Low-level physics description, continuous time picture



Abstracts away from underlying physics, discrete gates

$J(\{f_k(t)\}) = \langle\psi|H|\psi\rangle$

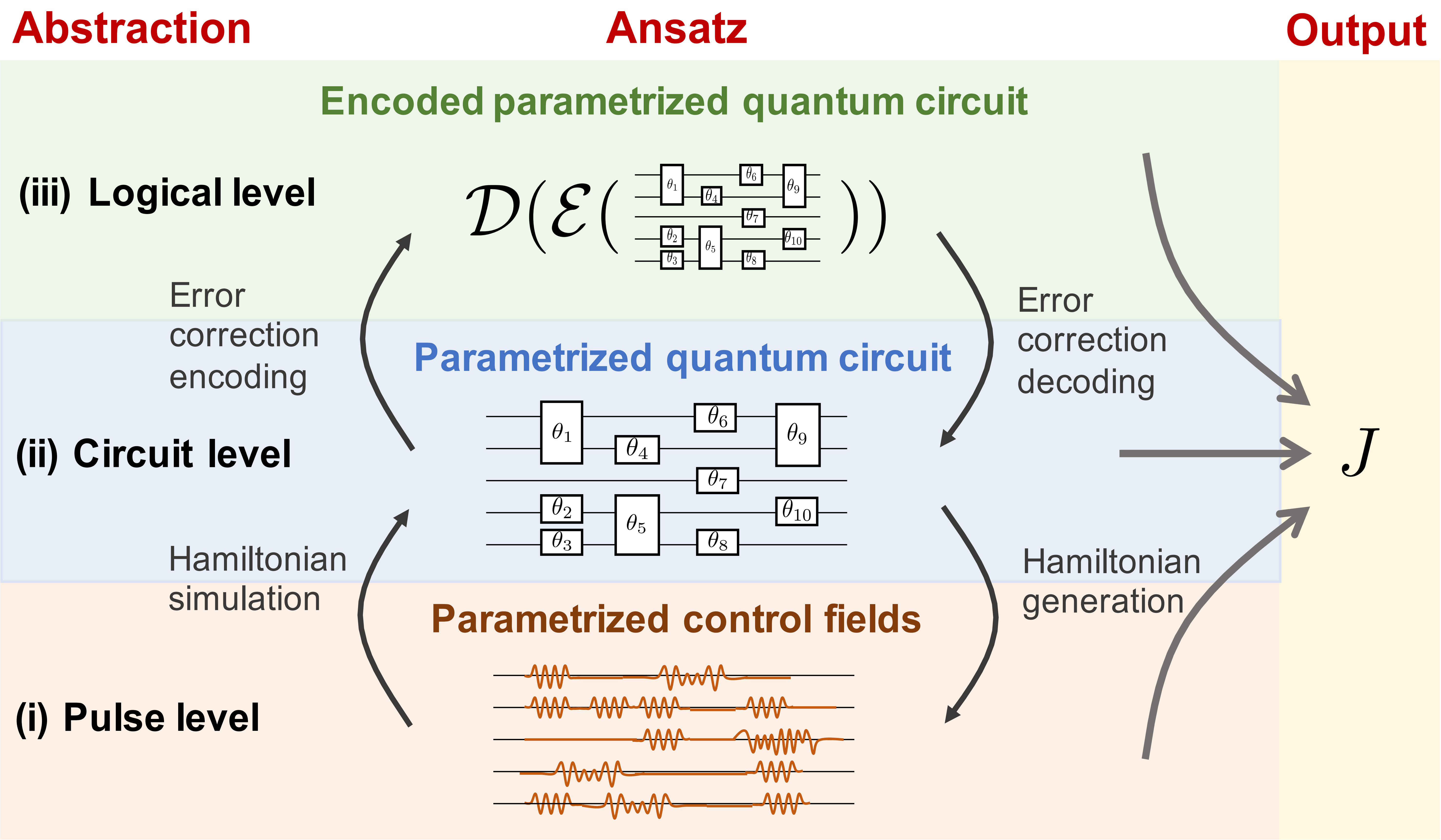
$J(\{\theta_i\}) = \langle\psi|H|\psi\rangle$

AB Magann*, C Arenz*, MD Grace, TS Ho, RL Kosut, JR McClean, HA Rabitz, M Sarovar, "From pulses to circuits and back again: A quantum optimal control perspective on variational quantum algorithms", *PRX Quantum* (2021); arXiv:2009.06702

Potential crossover areas

- ➢ Algorithm design
- ➢ Noise mitigation
- ➢ Optimization landscape analysis

Different levels in a hierarchy of abstractions

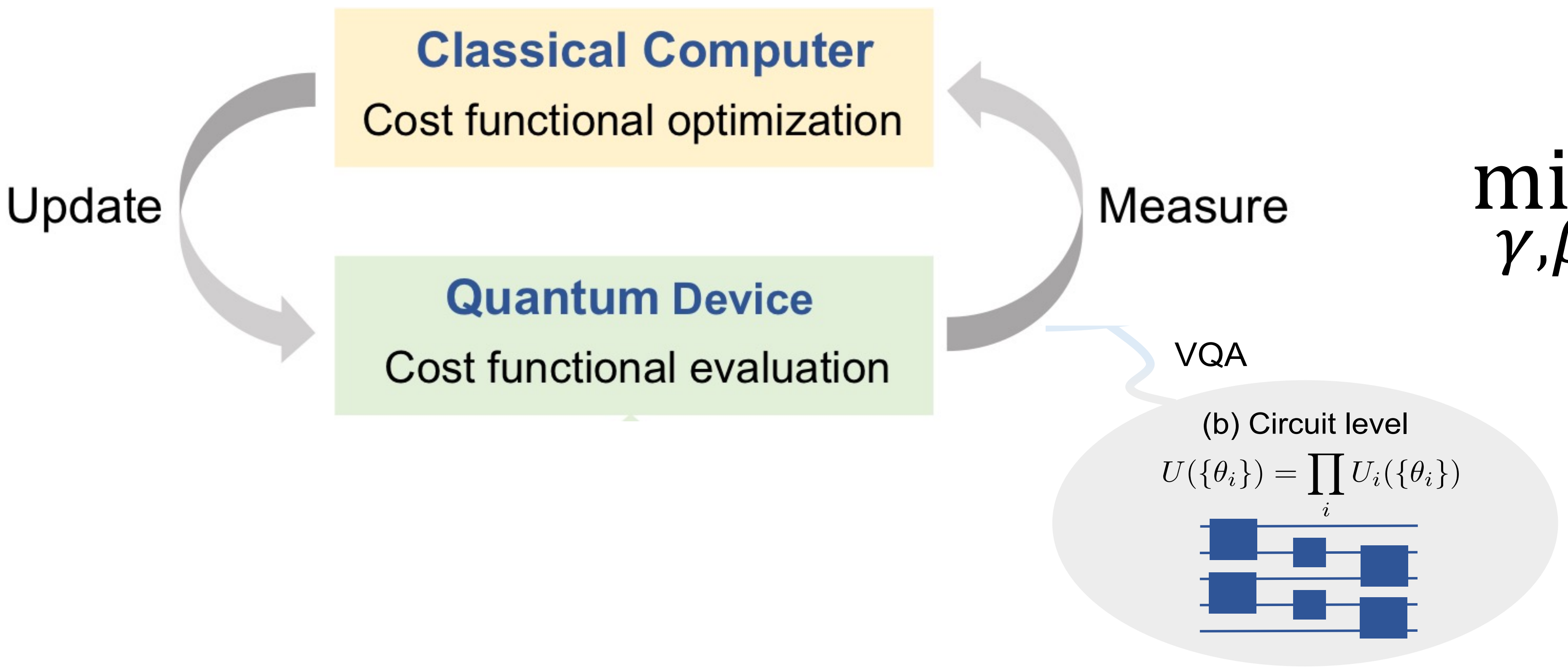


AB Magann*, C Arenz*, MD Grace, TS Ho, RL Kosut, JR McClean, HA Rabitz, M Sarovar, "From pulses to circuits and back again: A quantum optimal control perspective on variational quantum algorithms", *PRX Quantum* (2021); arXiv:2009.06702

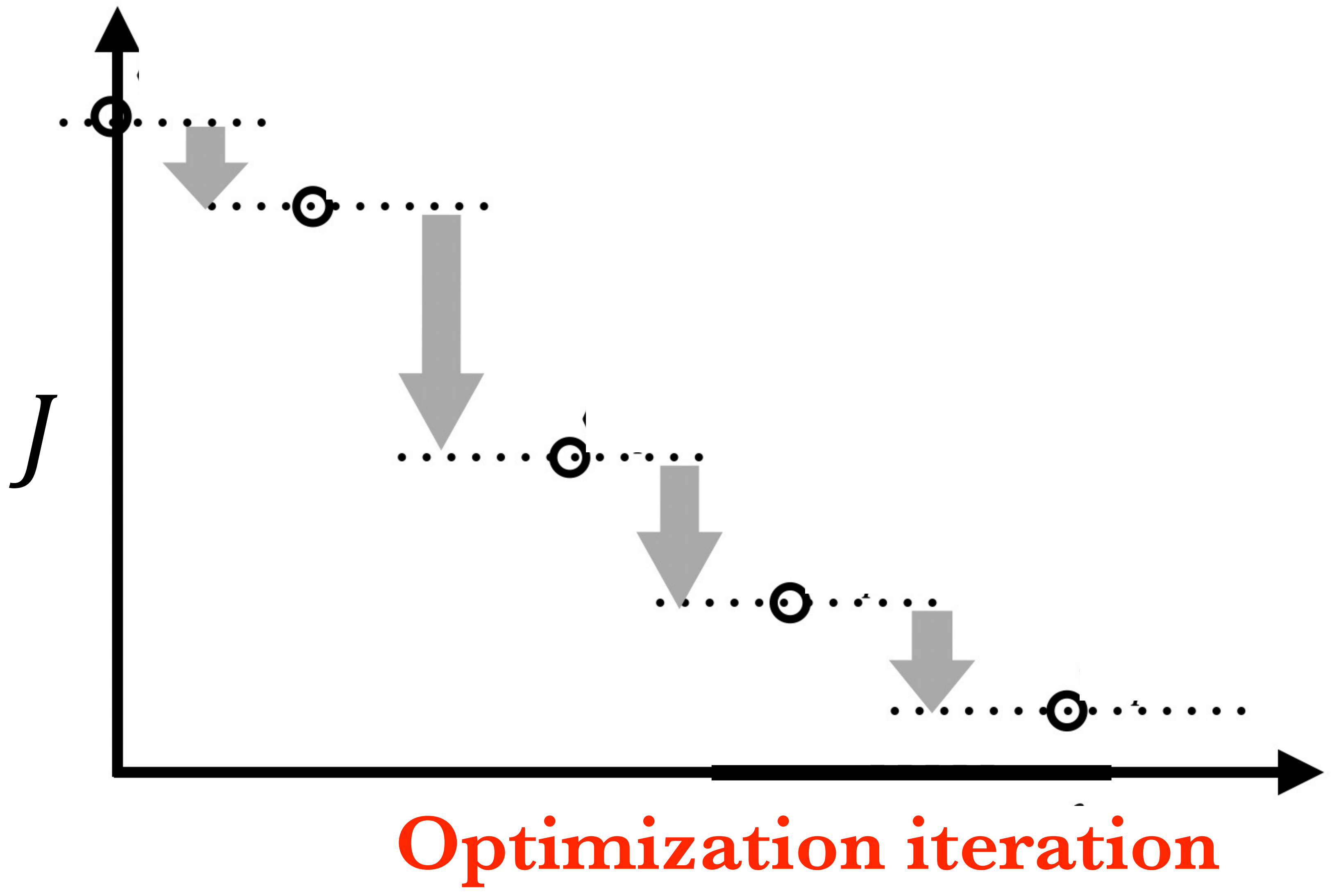
Case study:

A quantum Lyapunov control-inspired quantum algorithm for combinatorial optimization

Background: Quantum approximate optimization algorithm (QAOA)

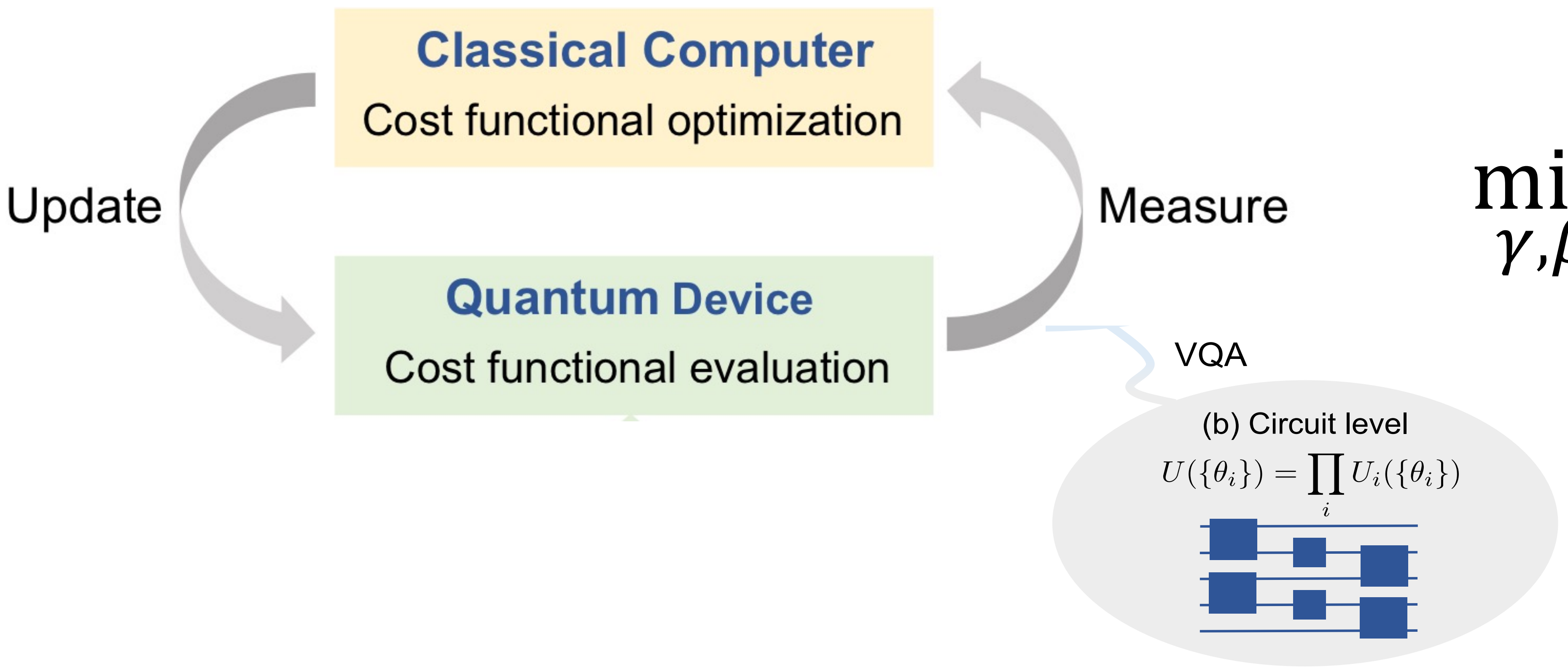


$$\min_{\gamma,\beta} \langle \psi(\gamma,\beta) | H_p | \psi(\gamma,\beta) \rangle$$

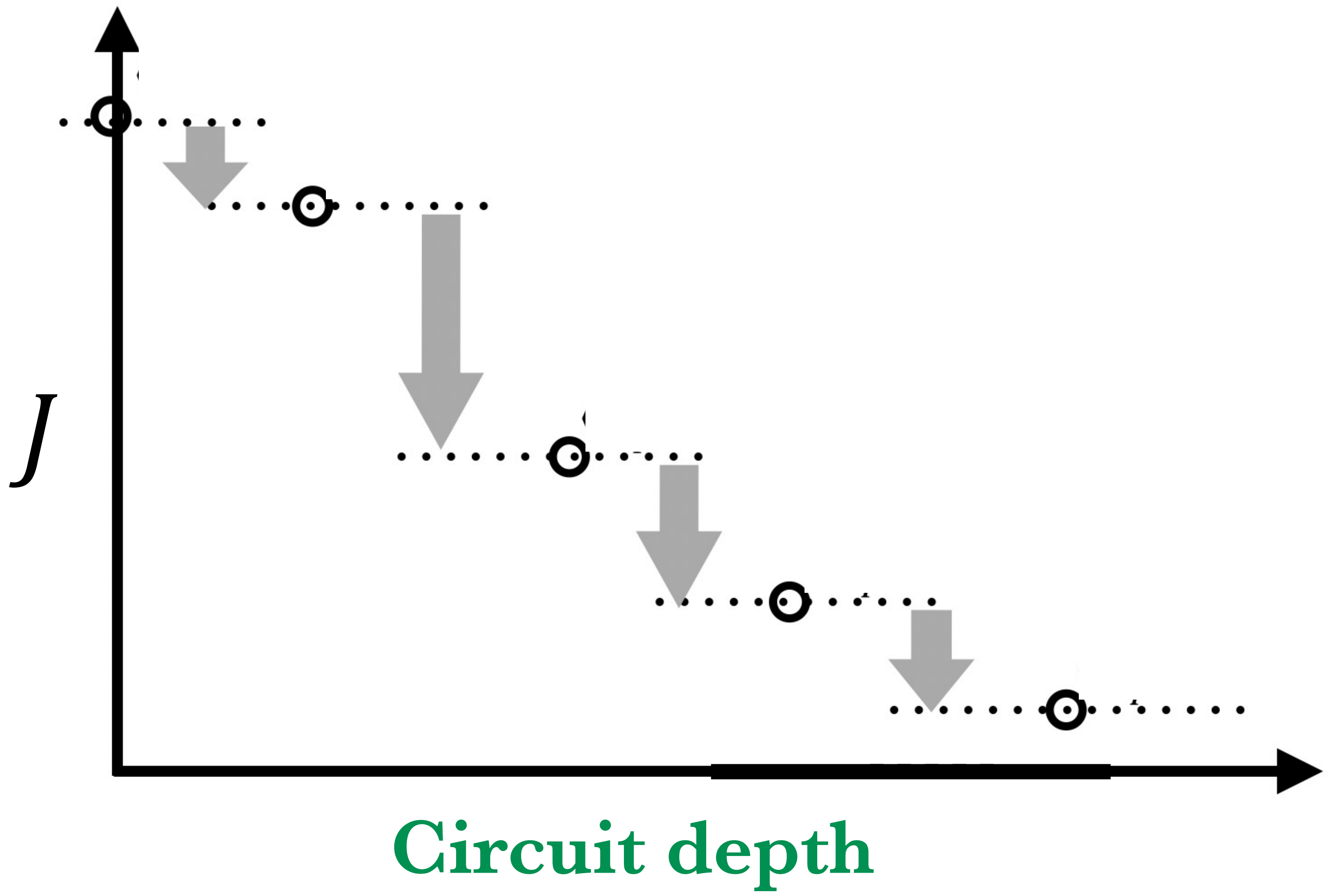


Bottleneck: searching for the optimal (γ, β) parameters

Background: Quantum approximate optimization algorithm (QAOA)



$$\min_{\gamma,\beta} \langle \psi(\gamma,\beta) | H_p | \psi(\gamma,\beta) \rangle$$



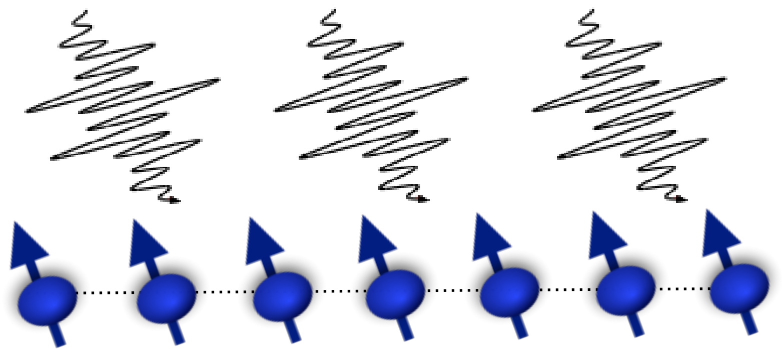
Bottleneck: searching for the optimal (γ, β) parameters

This case study: a constructive parameter setting protocol that does not require classical optimization & is inspired by quantum control theory

AB Magann, KM Rudinger, MD Grace, M Sarovar, "Feedback-based quantum optimization": arXiv:2103.08619 (2021)
AB Magann, KM Rudinger, MD Grace, M Sarovar, "Lyapunov control-inspired strategies for quantum combinatorial optimization": arXiv:2108.05945 (2021)

Lyapunov control-inspired algorithm for quantum optimization

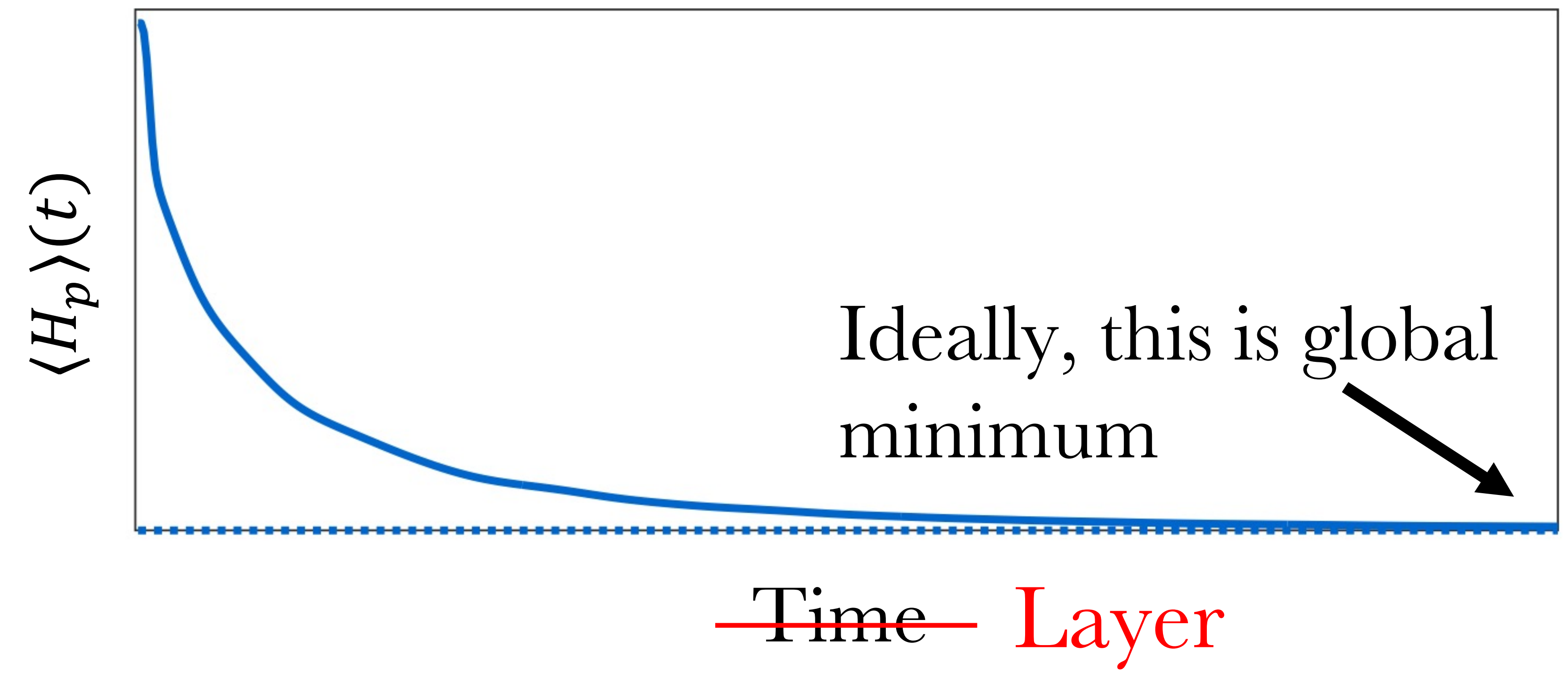
Pulse-level control perspective



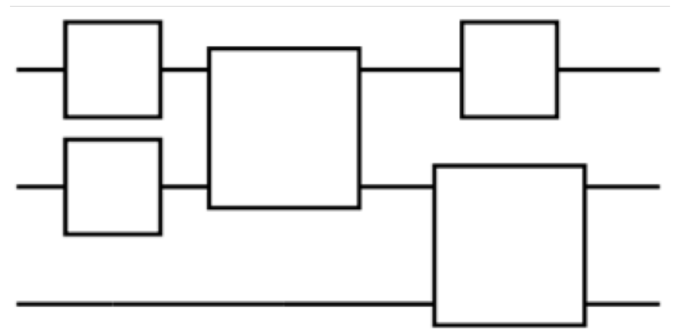
The Lyapunov control principle is to design a control function $\beta(t)$ to ensure the cost function is strictly decreasing over time by enforcing

$$\frac{d}{dt}\langle H_p\rangle(t) \leq 0, \forall t$$

Illustration of the principle



Circuit-level perspective



We define control law for $\beta(t)$, and then develop Trotterization-inspired quantum algorithm, with circuits akin to QAOA

arXiv:2103.08619 & arXiv:2108.05945

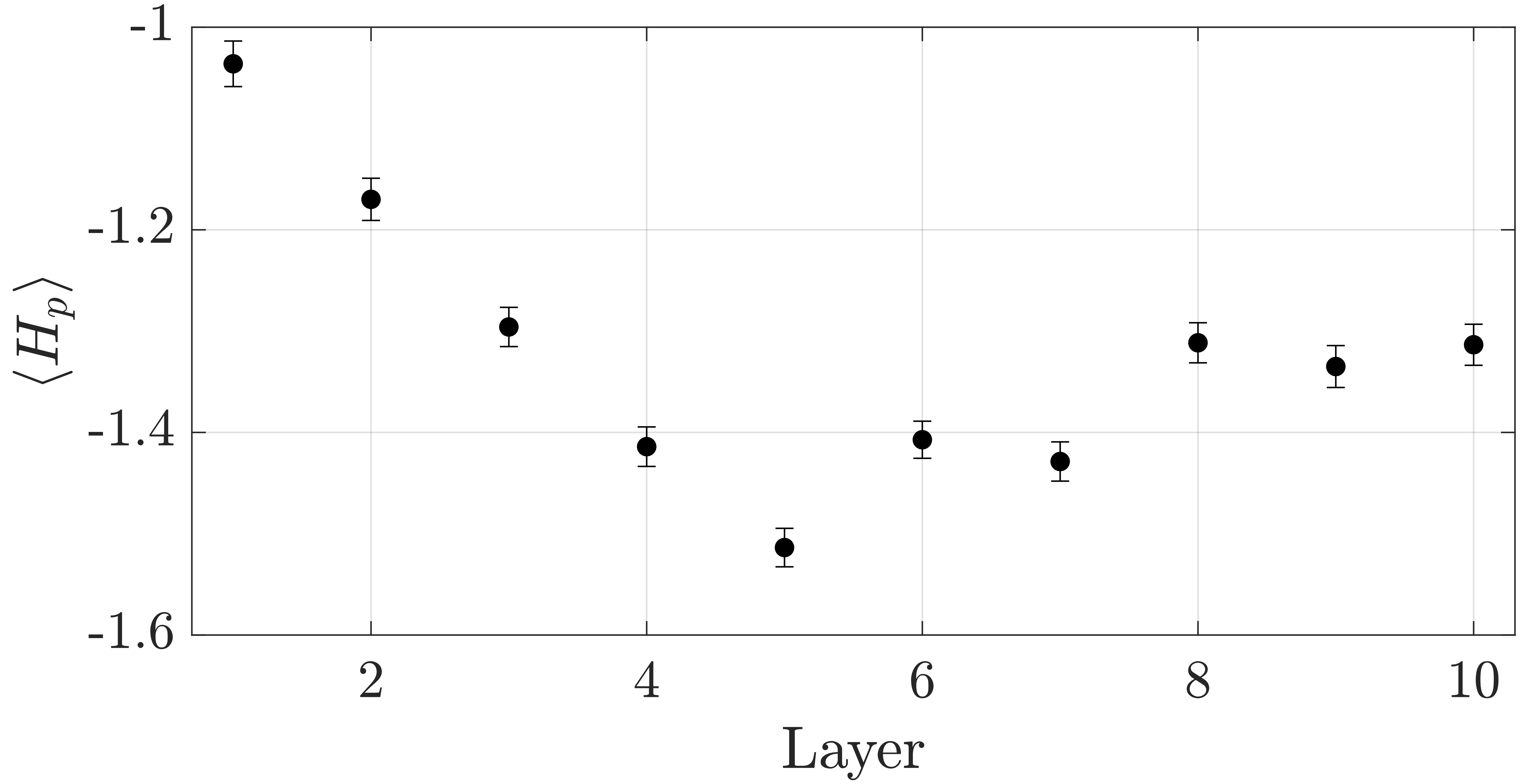
Lyapunov control-inspired algorithm for quantum optimization

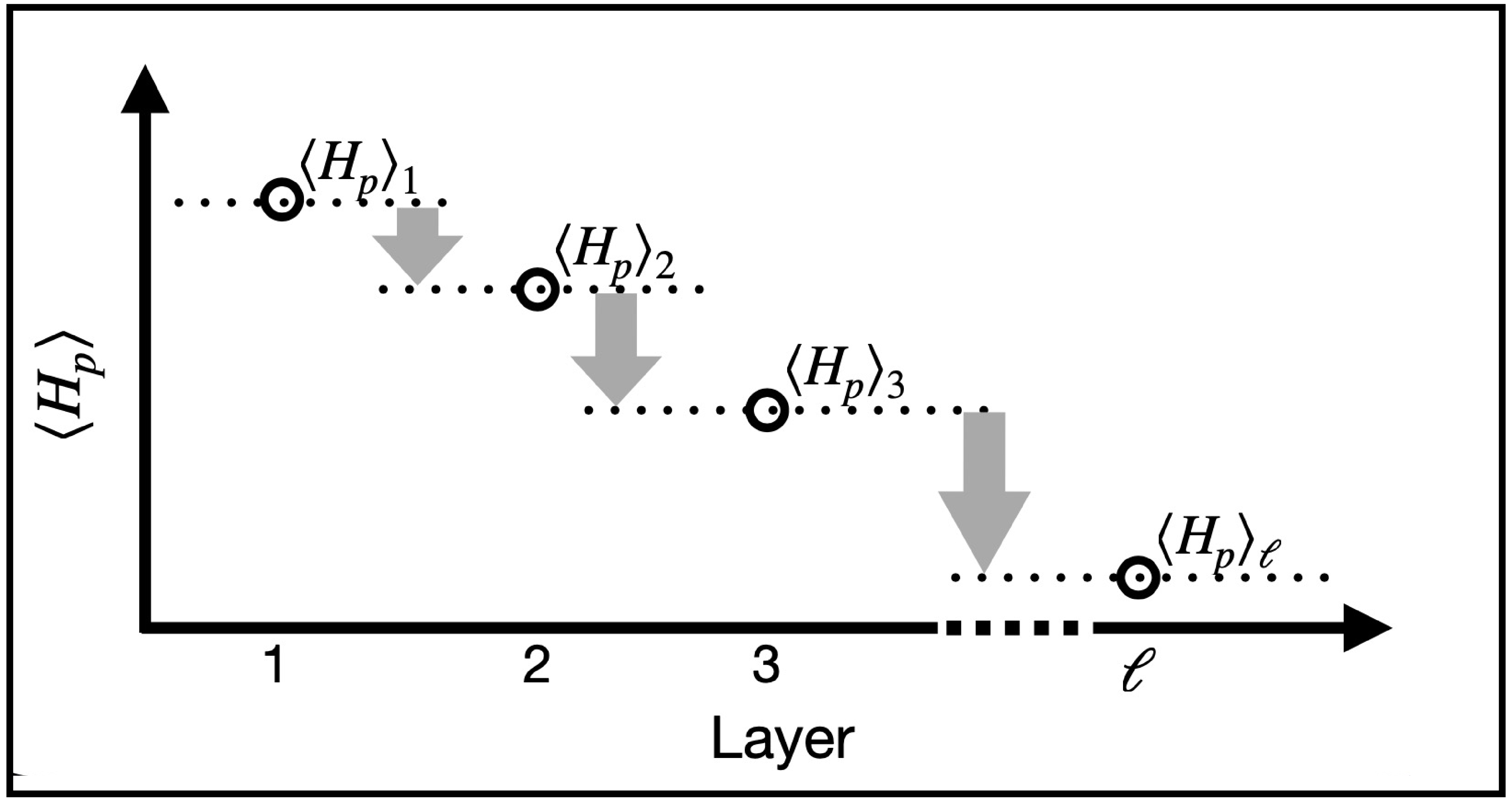
SAND2022-###

Lyapunov control-inspired algorithm for quantum optimization

Hardware demonstration

Implementation of our protocol to solve a 3 qubit instance of MaxCut on the ibmq_manila processor





Summary

- Discussed connections and analogies between (pulse-level) quantum control and (circuit-level) variational quantum algorithms
- Outlined potential crossover areas: noise, new ansätze, and optimization landscapes
- Described a Lyapunov control-based algorithm for quantum optimization as an example of quantum control/quantum algorithm crossover

SAND2022-###

Thank you

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525