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Quantum Control in the Era of Quantum Computing

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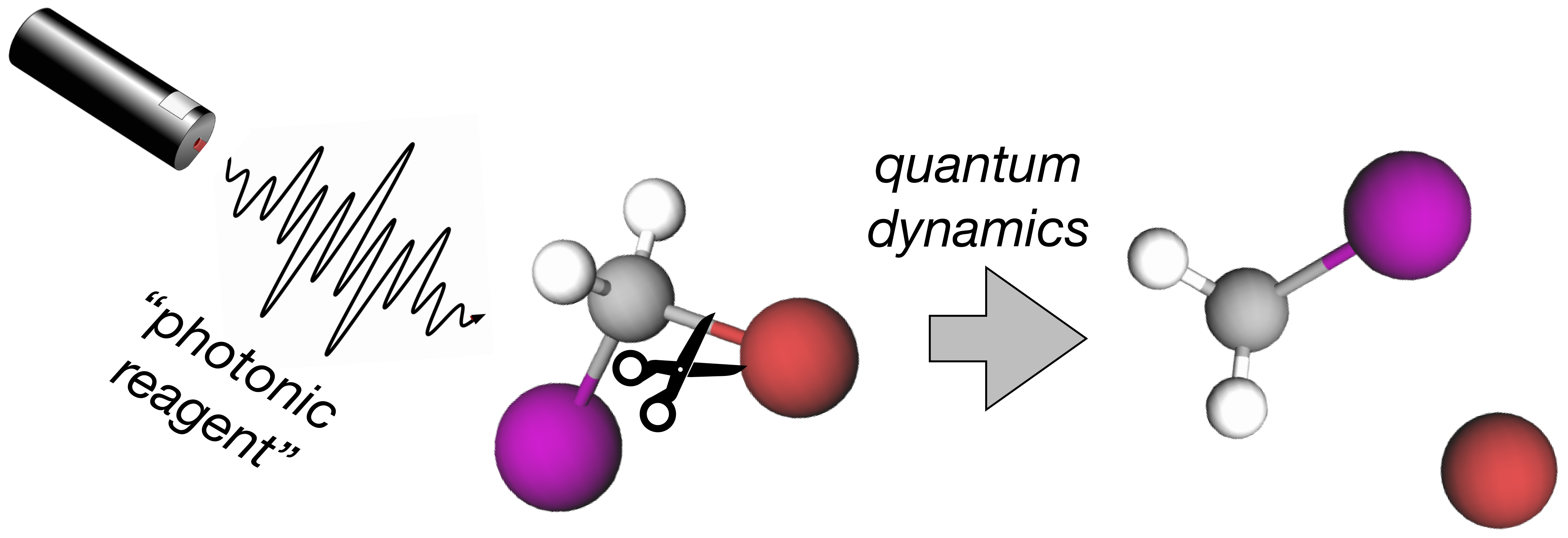
Controlling chemistry with light

Lasers can create tailored light to coherently control chemical transformations that may not otherwise be possible

- selective bond-breaking
- molecular rearrangement
- molecular orientation
- isotope selective processes
- charge and energy transfer
- etc…



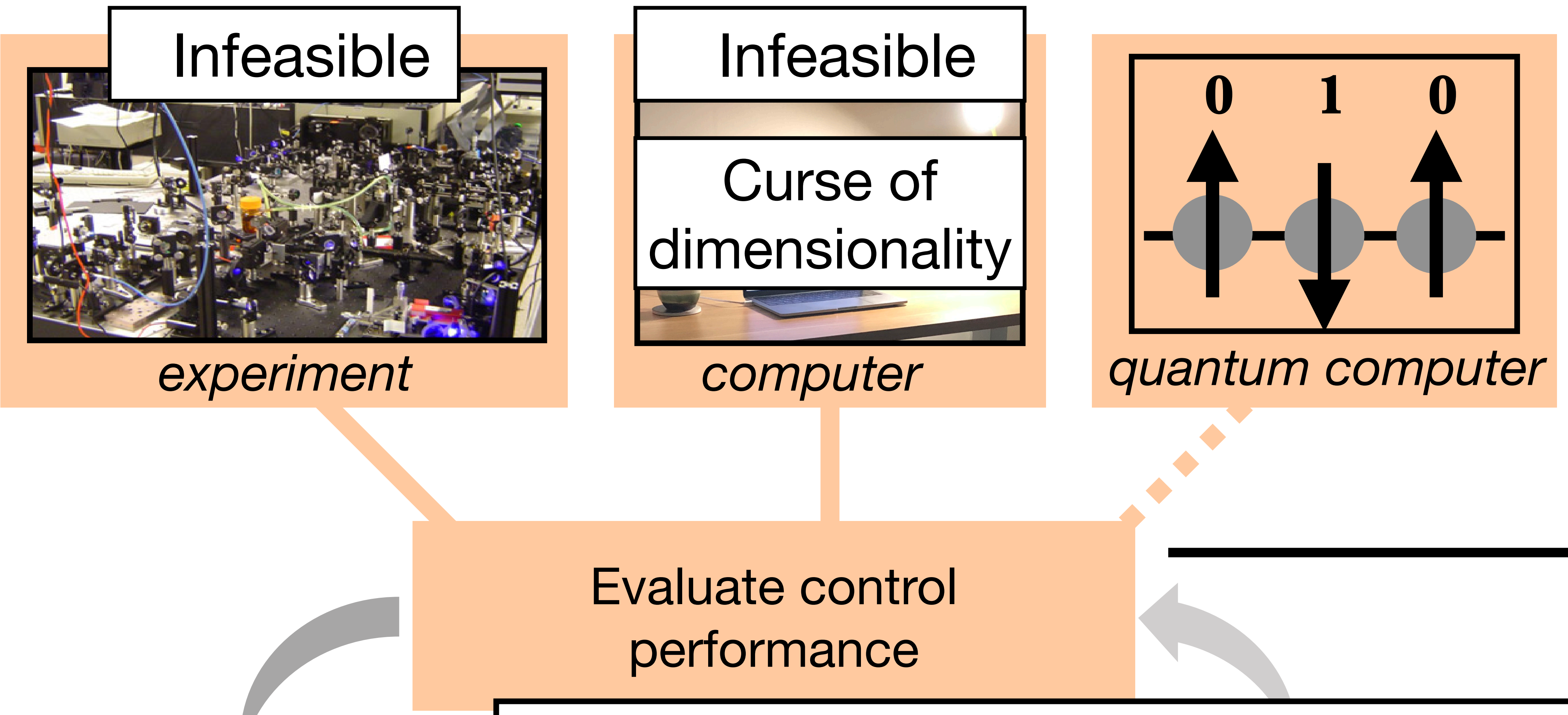
Initial ideas about this date back to the invention of the laser in 1960

So far, proof-of-principle experiments

Widespread adoption in scientific & engineering applications hasn't happened

Designing photonic reagents is hard

Quantum control challenges



Goal: design a laser pulse $f(t, \{\theta_i\})$, to steer a quantum system towards a desired control target. This is posed as

$$\min_{\{\theta_i\}} J(\{\theta_i\}).$$

How well is desired control target reached?

Involves simulating the dynamics of the quantum system induced by $f(t, \{\theta_i\})$ to evaluate $J(\{\theta_i\})$

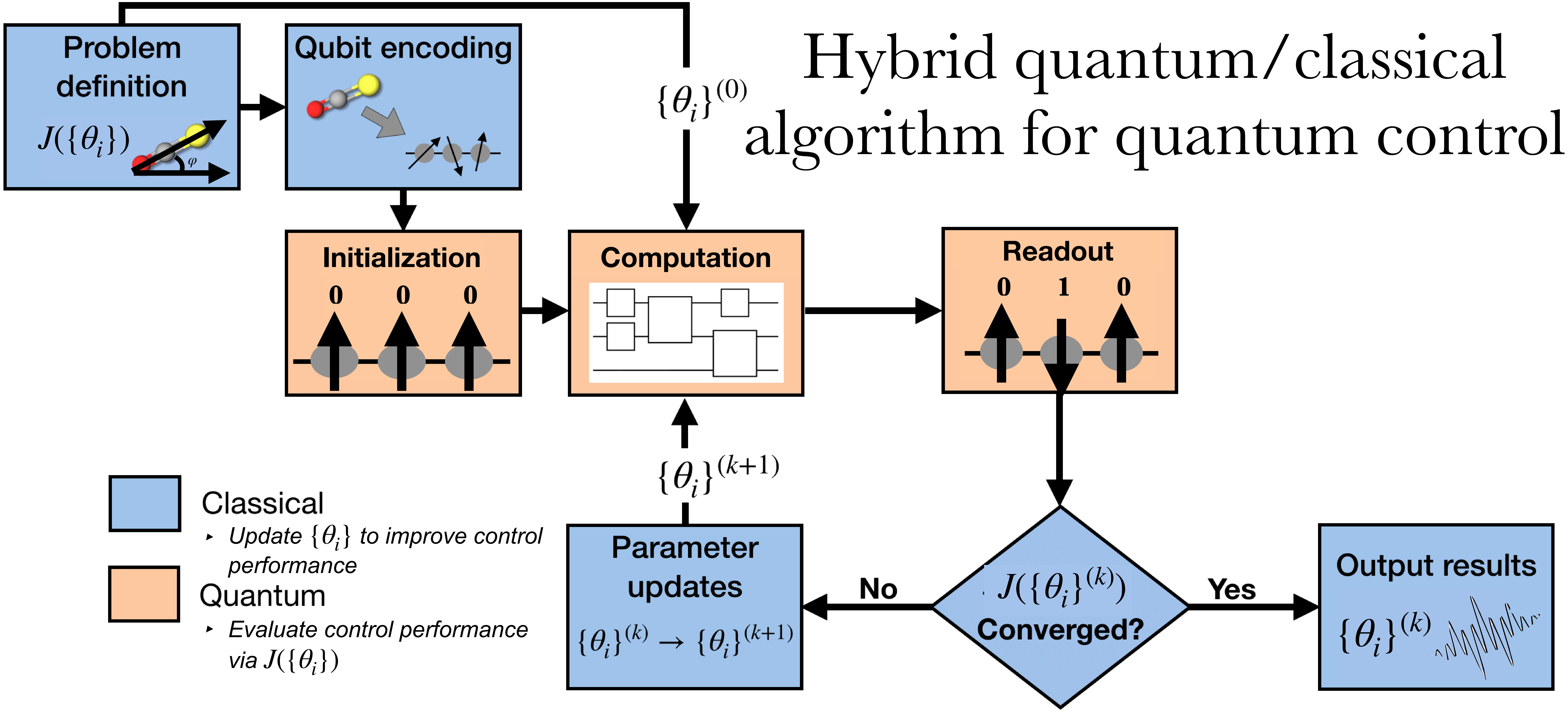
"Nature isn't classical… if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy."

Richard Feynman
"Simulating Physics with Computers" (1982)

Challenge: computer memory/time costs scale exponentially in the # quantum degrees of freedom

…not on a quantum computer!

Hybrid quantum/classical algorithm for quantum control



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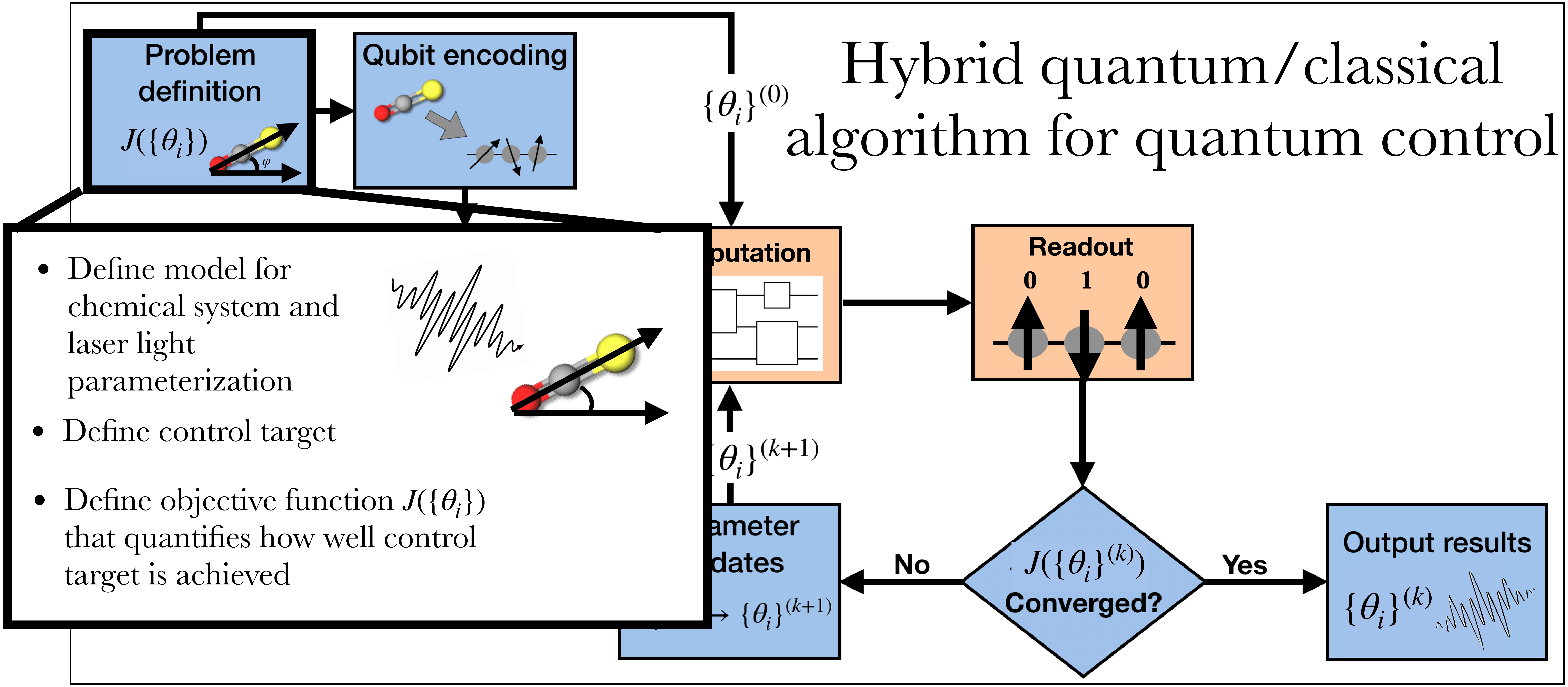

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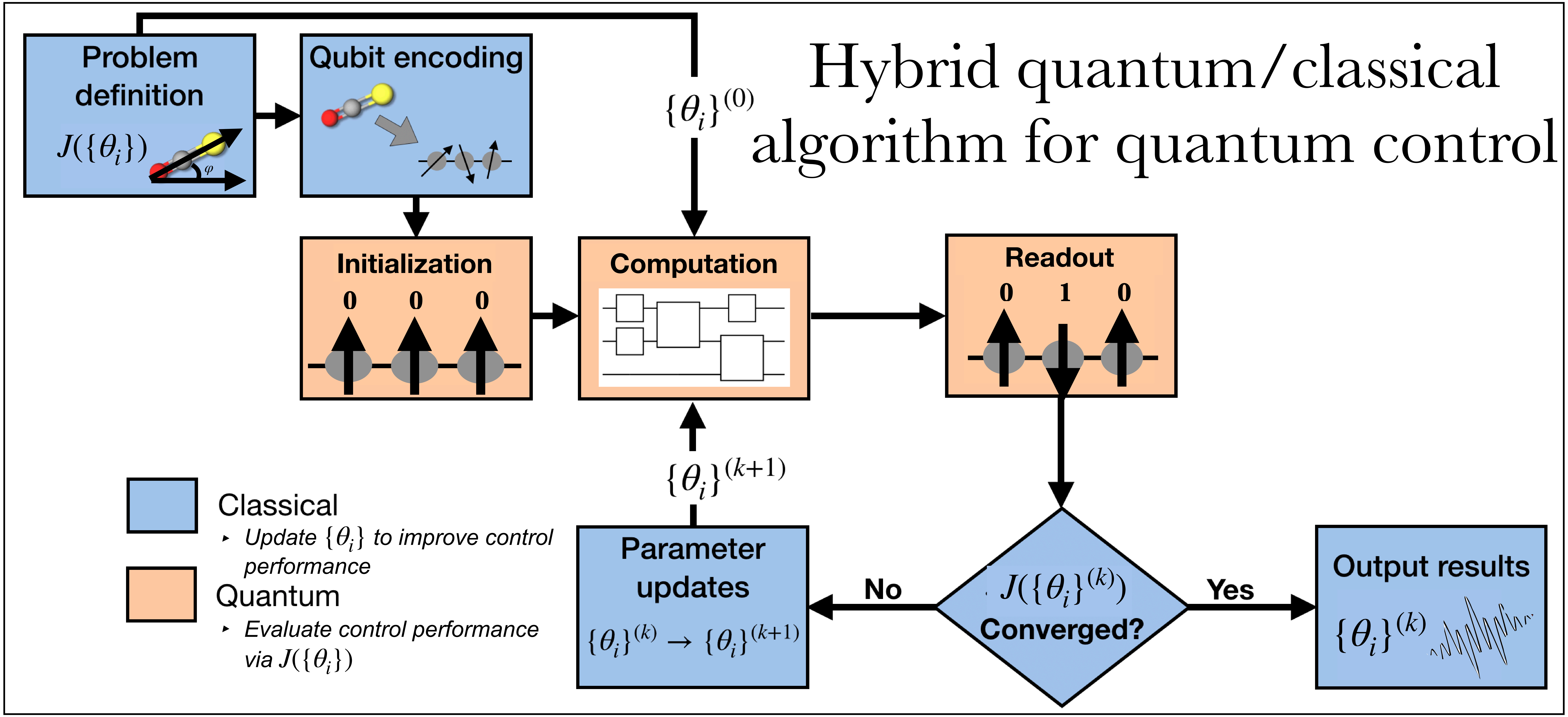

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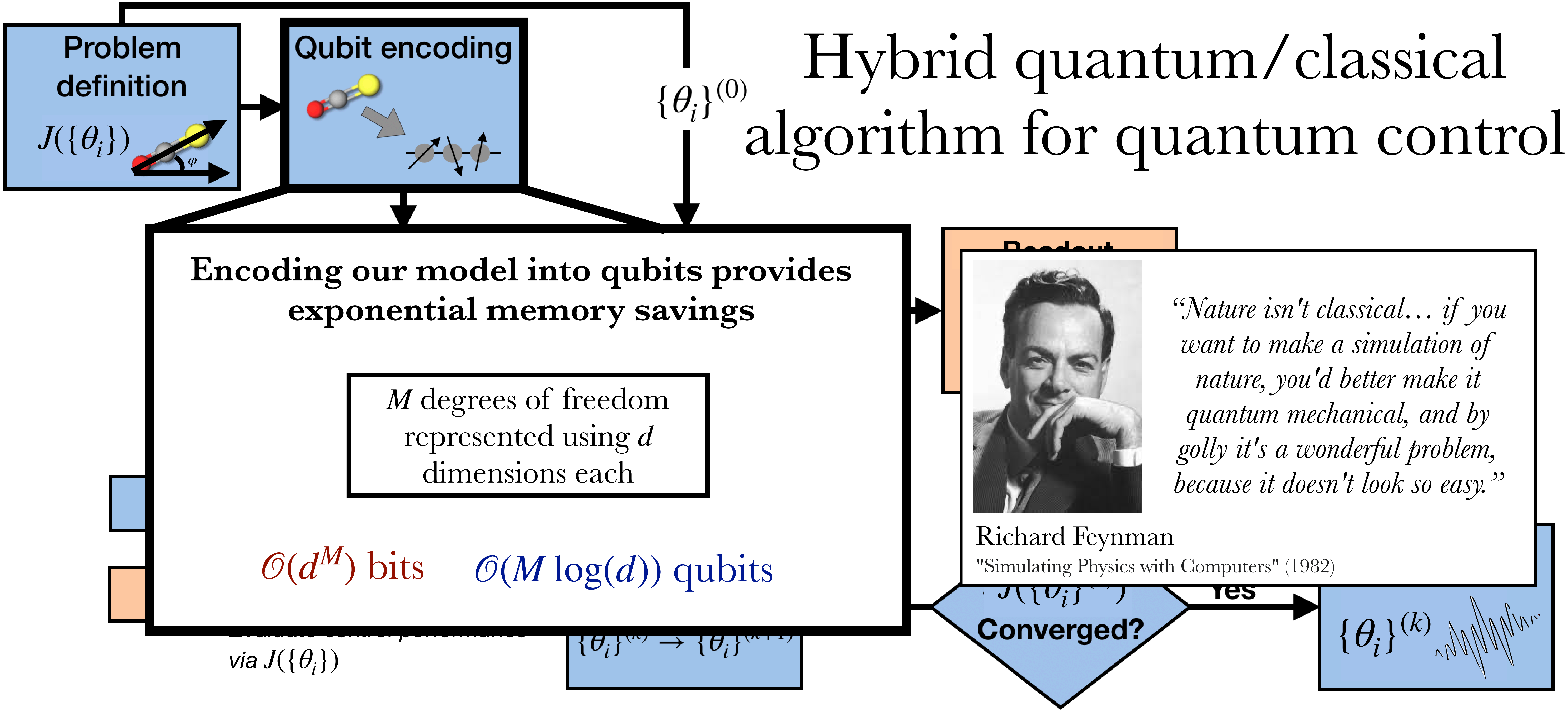

Encoding our model into qubits provides exponential memory savings

M degrees of freedom represented using d dimensions each

$\mathcal{O}(d^M)$ bits $\mathcal{O}(M \log(d))$ qubits

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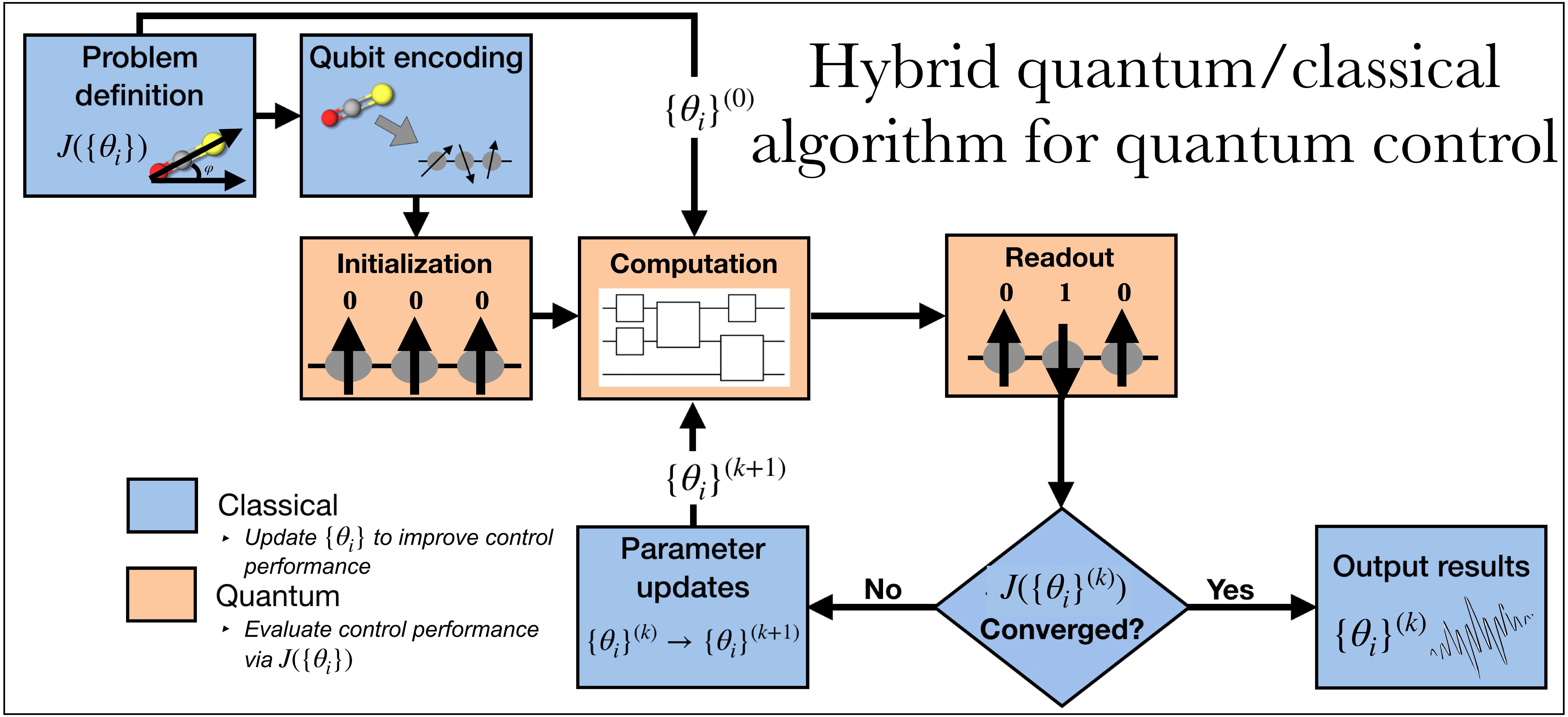

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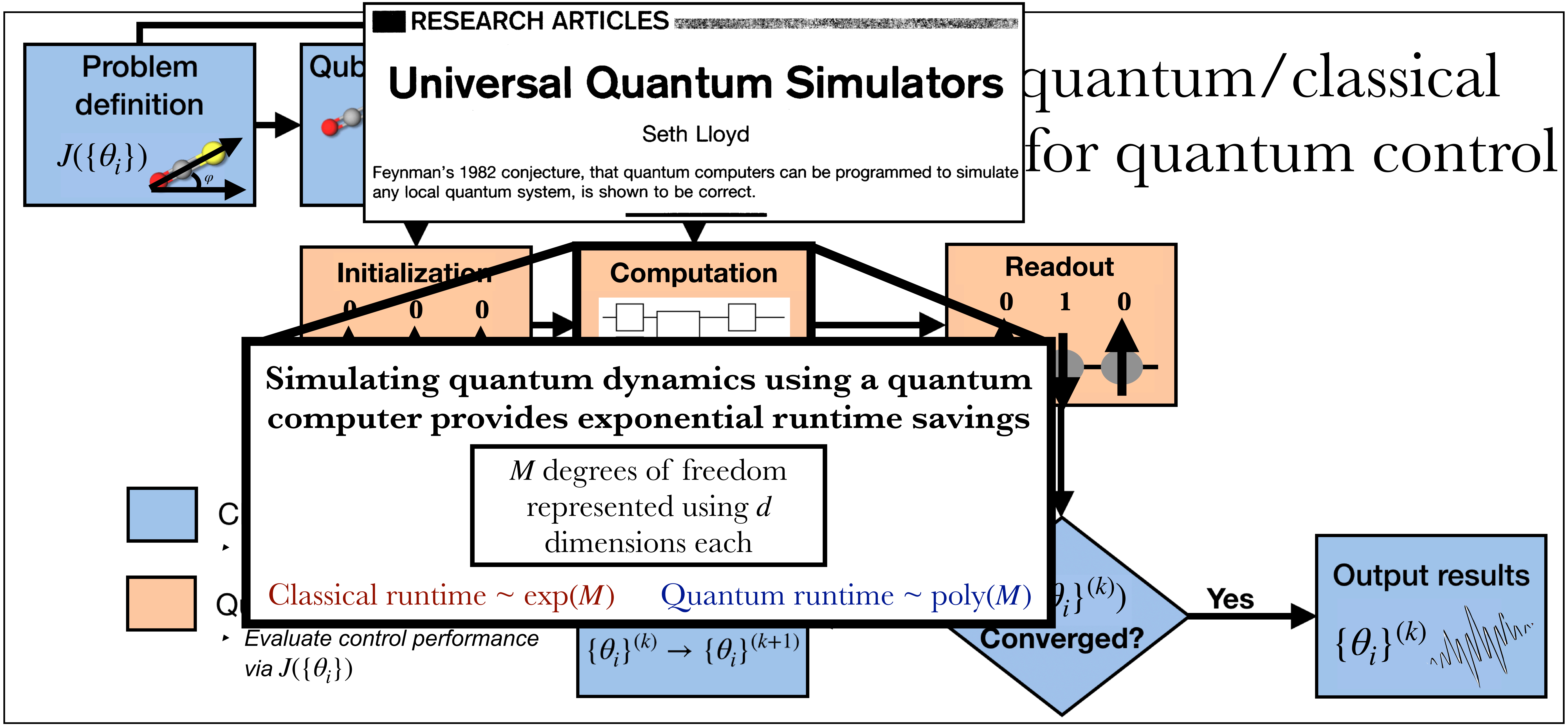
S Lloyd, Science 273, (1996).



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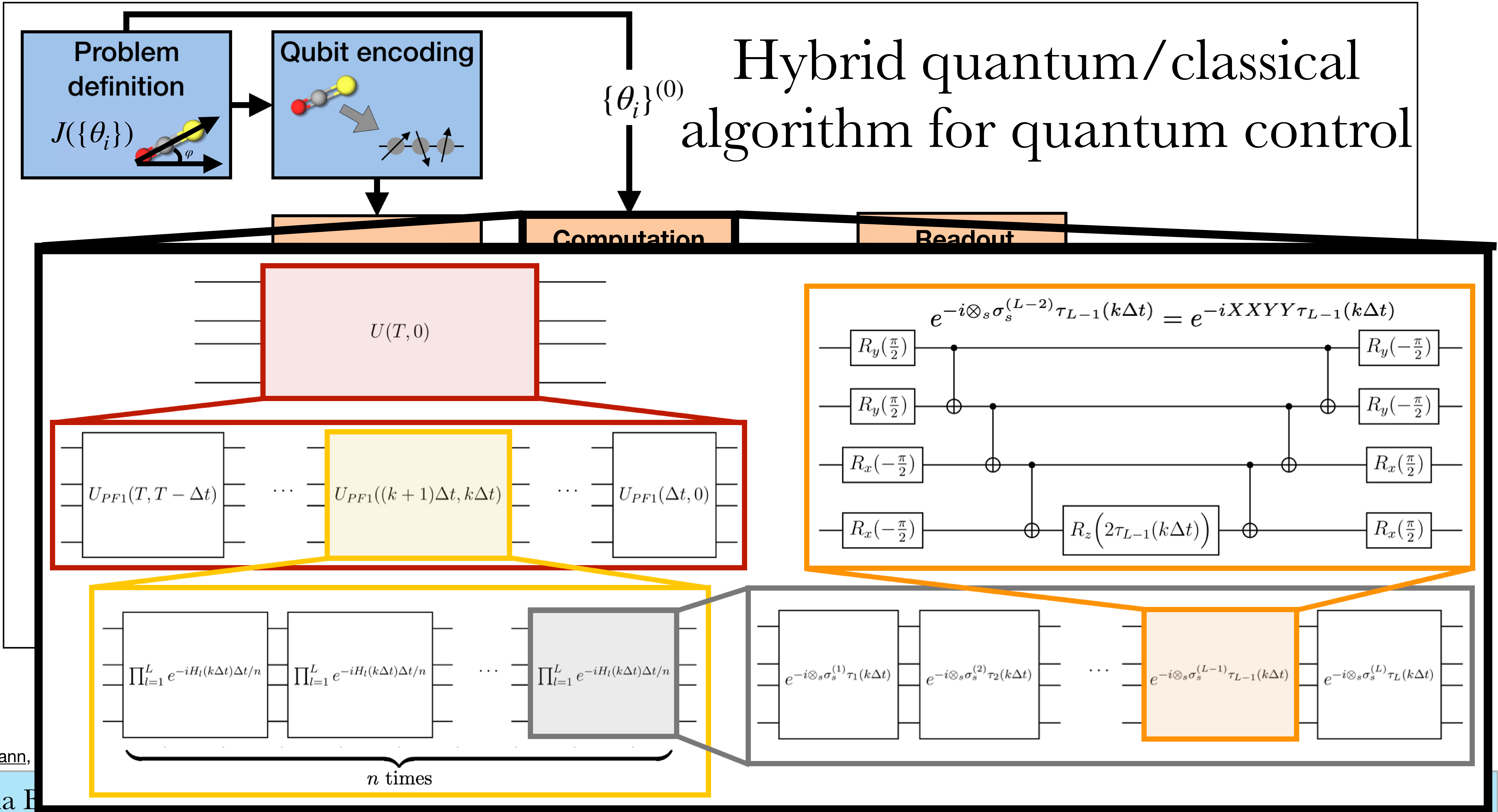

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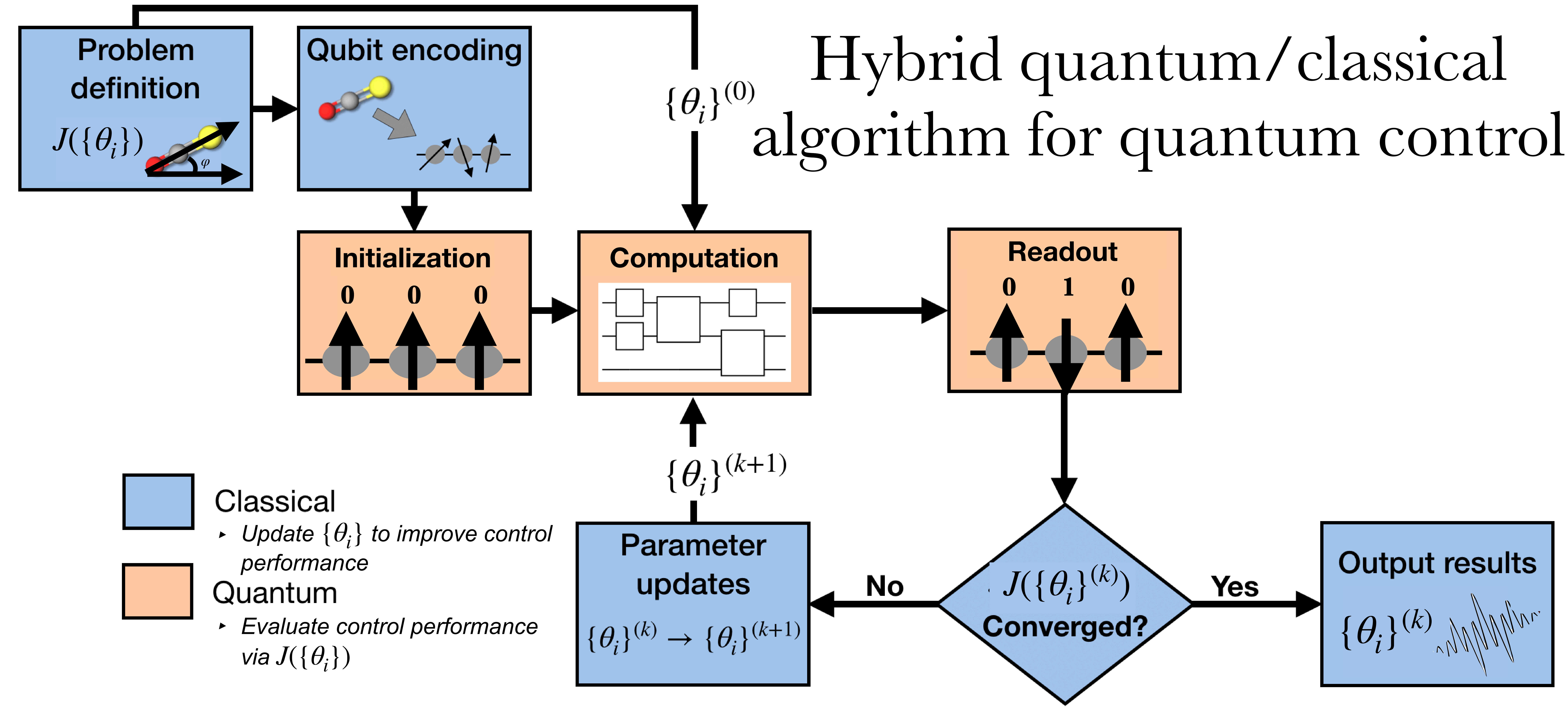
Hybrid quantum/classical algorithm for quantum control



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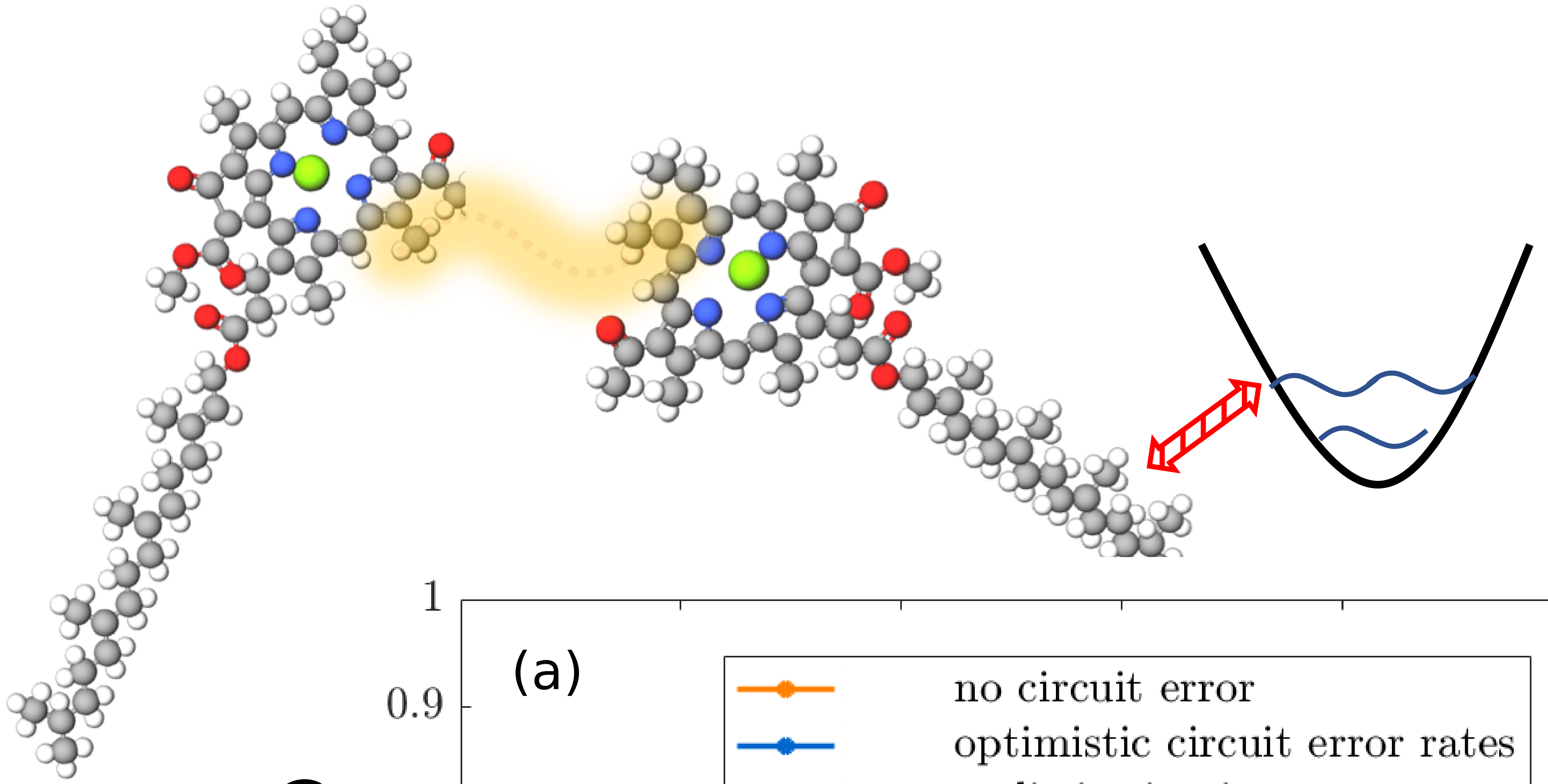
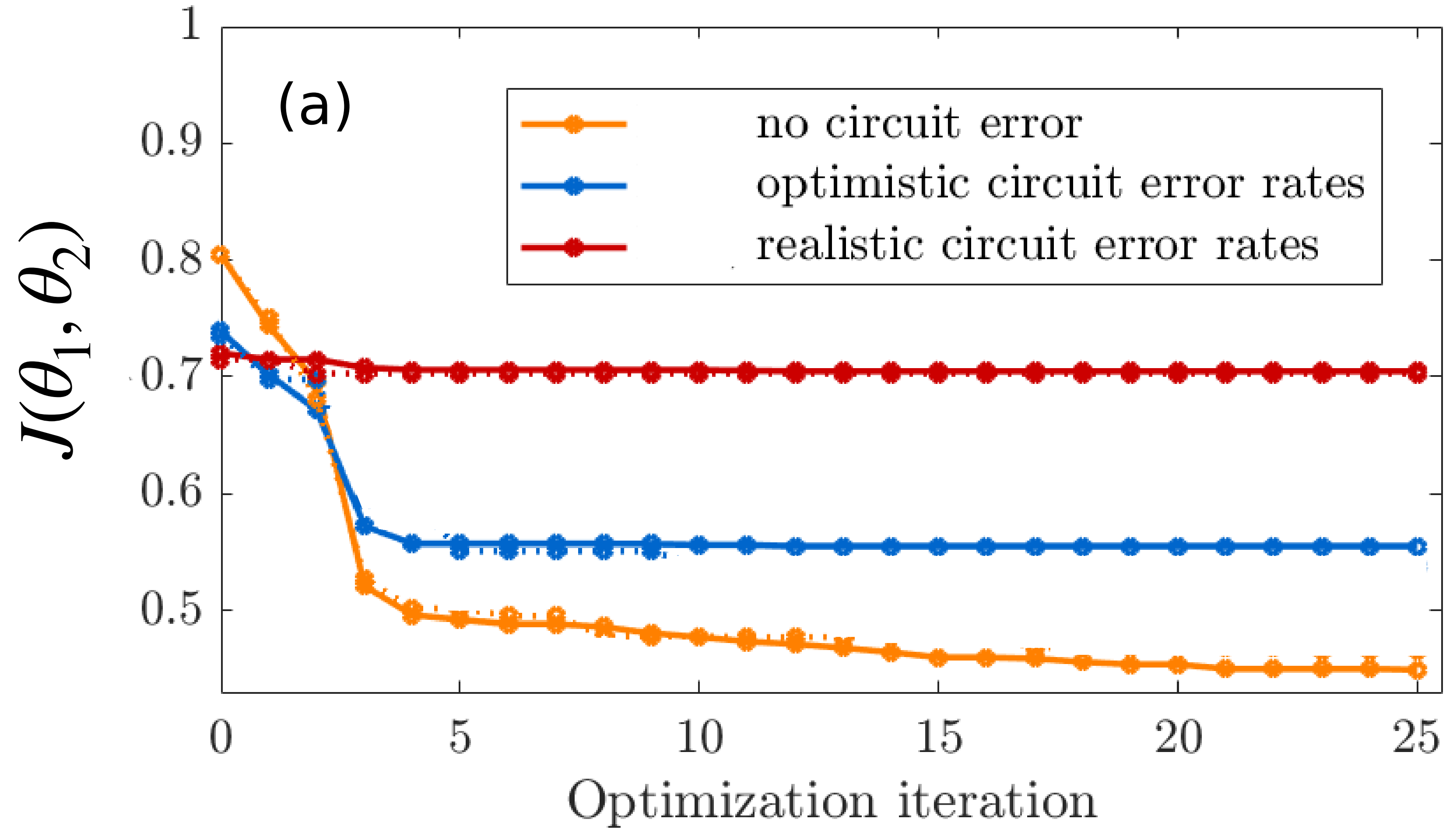
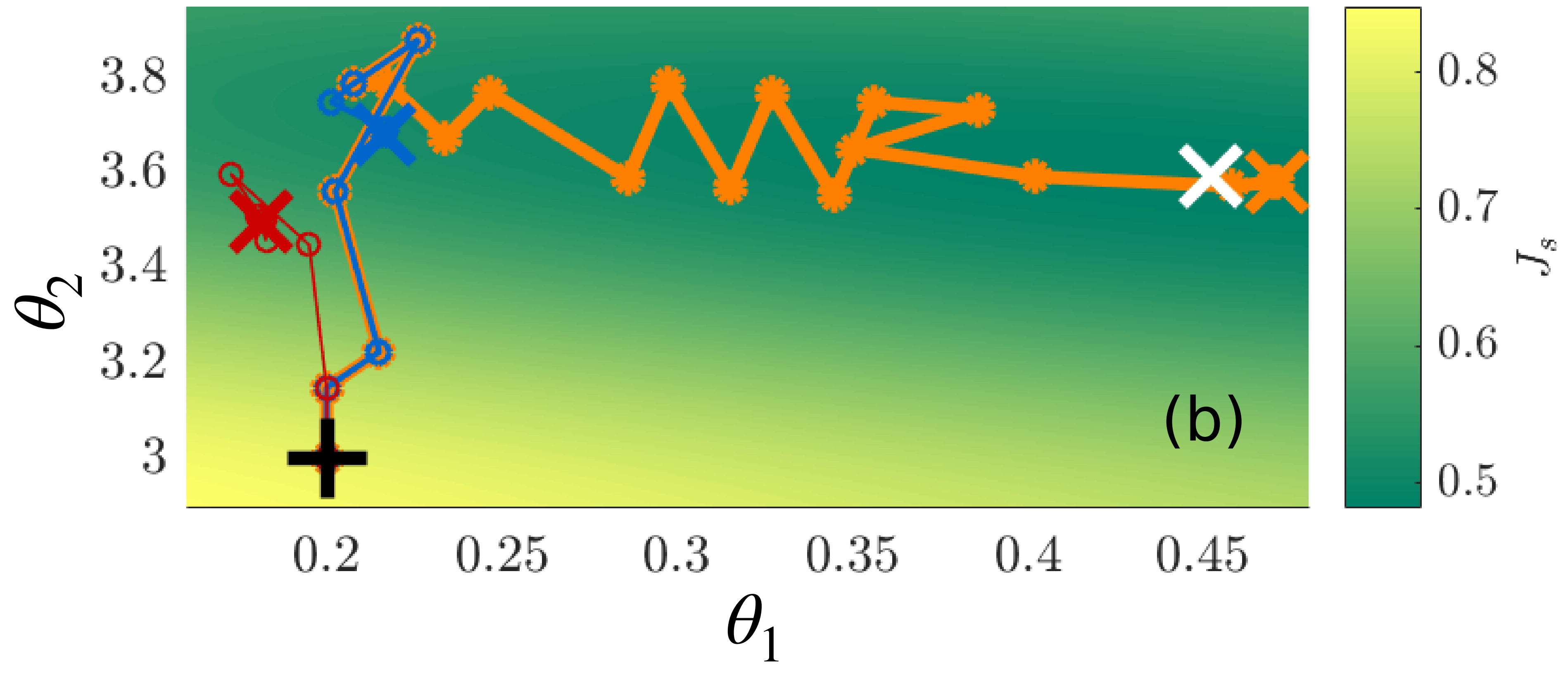
Controlled excitonic state preparation in light harvesting complex





We numerically explored the feasibility of meaningful implementation on error-prone trapped ion quantum hardware

Trout, Colin J., et al. *New Journal of Physics* 20.4 (2018): 043038.



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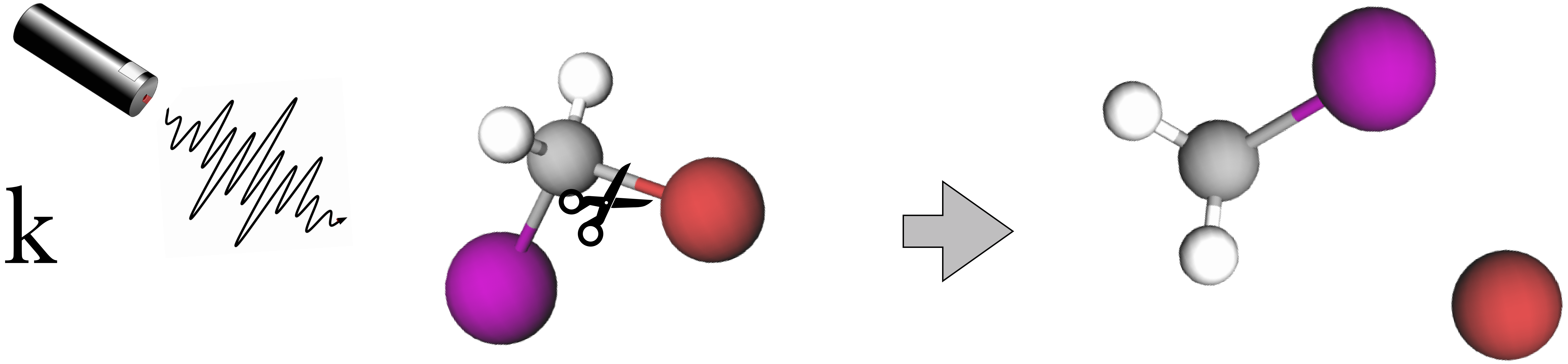
Summary & outlook



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Simulating quantum-mechanical systems is notoriously challenging
"curse of dimensionality"

In the 80's, Feynman imagined quantum computers could be powerful tools for **simulating the behavior of quantum systems**

In this talk, we explored how quantum computers could also be used as tools to determine how to **control this behavior**

Difficult to estimate when quantum computers will be mature enough to carry out meaningful calculations at-scale

Improving their performance is a quantum control problem itself!

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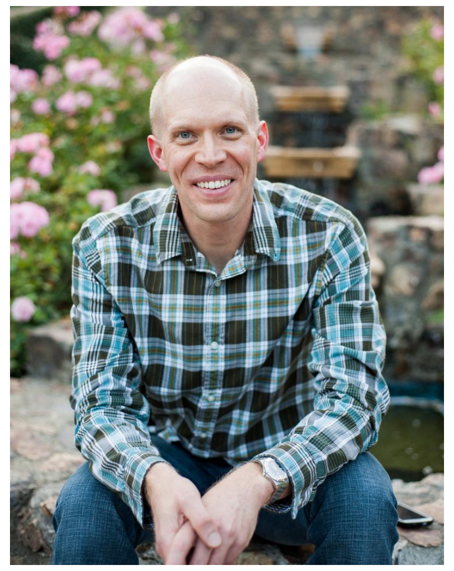
Thank you



Matthew Grace

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