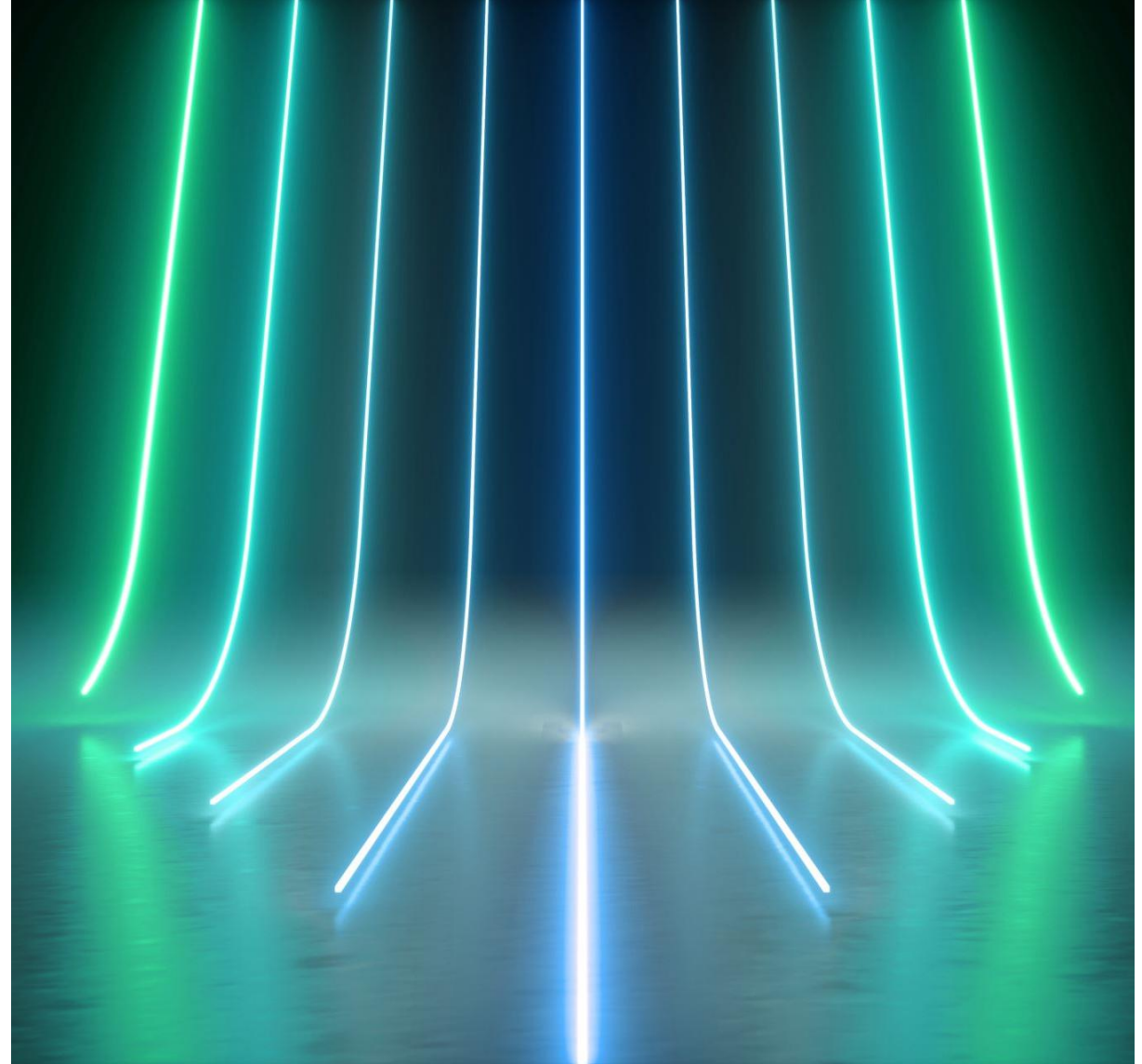


Parametric Circuits and Variational Methods

Seonggeun Park
Korea University



Qiskit Tutorial for Beginner Series at APCTP

APCTP SEMINAR
Quantum Threads: Qiskit tutorial for beginners
Fundamentals of Qiskit v1.0 and Quantum Circuit Design

Seonggeun Park
Korea University

December 9th (Mon.) 16:00
512, APCTP

This seminar series offers a comprehensive introduction to Qiskit v1.0, encompassing fundamental principles and intermediate applications in quantum computing.

The first session provides a comprehensive introduction to Qiskit and its foundational concepts, equipping participants with the skills to start designing quantum circuits. The session begins with a step-by-step guide to setting up the Qiskit development environment and an overview of the IBM Quantum platform. Participants will then learn the basics of quantum circuit construction, including how to incorporate classical feedforward mechanisms and control flow to enhance circuit functionality.

■ HOST: Junggi Yoon (junggi.yoon@apctp.org)

apctp

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APCTP SEMINAR
Quantum Threads: Qiskit tutorial for beginners
Running and Optimizing Quantum Circuits

Seonggeun Park
Korea University

December 10th (Tue.) 16:00
512, APCTP

This seminar series offers a comprehensive introduction to Qiskit v1.0, encompassing fundamental principles and intermediate applications in quantum computing.

In the second session, participants will learn how to execute quantum circuits on real quantum hardware using Qiskit. The session covers key concepts such as Qiskit primitives, which simplify interactions with quantum systems, and the basics of the Qiskit transpiler for optimizing circuit performance. Through hands-on examples, attendees will explore the process of preparing circuits for execution and optimizing them for efficient results.

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APCTP SEMINAR
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December 11th (Wed.) 16:00
512, APCTP

This seminar series offers a comprehensive introduction to Qiskit v1.0, encompassing fundamental principles and intermediate applications in quantum computing.

This advanced session focuses on designing and implementing quantum algorithms using Qiskit. Participants will explore the creation of parametric quantum circuits, which enable dynamic adjustments during execution, and learn how to implement a simple Variational Quantum Algorithm (VQA). Additionally, the session introduces the broader Qiskit ecosystem, providing practical tips for utilizing its documentation effectively.

■ HOST: Junggi Yoon (junggi.yoon@apctp.org)

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- A Quick Overview of Basic Quantum Information
- Introduction to Qiskit & IBM Quantum Platform
- Setting Up the Qiskit Development Environment
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- Implementing Classical Feedforward and Control Flow

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- Implementing Parametric Quantum Circuits & VQA
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- Implementing Parametric Quantum Circuits & VQA
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Contents

1. Implementing Parametric Quantum Circuits & VQA
2. Browsing the Qiskit Ecosystem





I. Implementing Parametric Quantum Circuits & VQA

Parametric Quantum Circuits(PQC)

- Quantum circuit that includes gates with parameters that are not yet fixed
- PQC are commonly used in Variational Quantum Algorithm (VQA) and Quantum Machine Learning (QML)

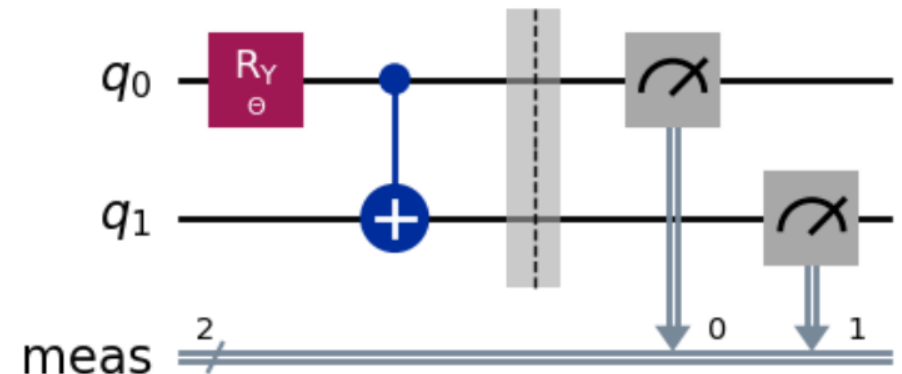
```
from qiskit.circuit import Parameter

# create the parameter
theta = Parameter('θ')
par_bell_meas = QuantumCircuit(2)

# parameterize the rotation
par_bell_meas.ry(theta, 0)
par_bell_meas.cx(0, 1)

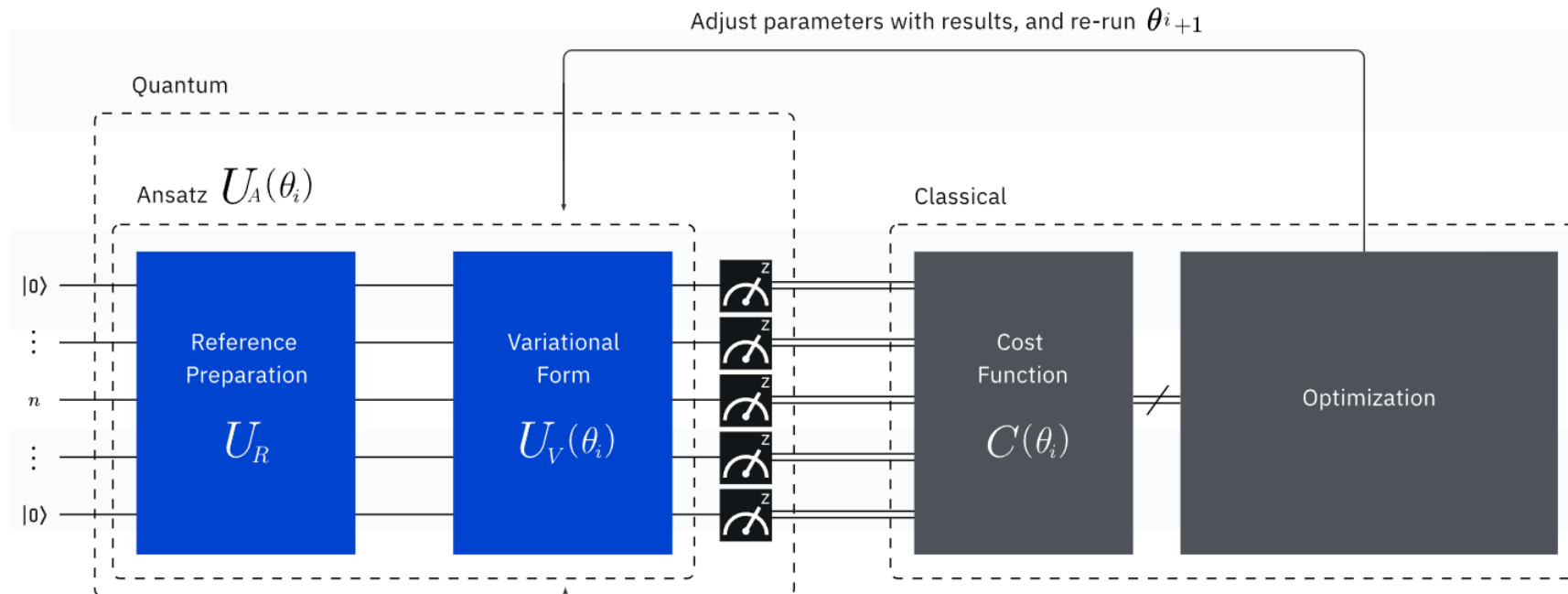
par_bell_meas.measure_all()

par_bell_meas.draw('mpl')
```



Variational Quantum Algorithm

Quantum computing approach that combines quantum circuits with classical optimization techniques to find approximate solutions to complex problems by iteratively adjusting quantum parameters to minimize a cost function.



Reference Preparation

A reference state is an initial quantum state that is chosen as a starting point for the optimization process

We initialize our system with a reference state to help our variational algorithm converge faster

The reference state can be set in

1. fixed form: $U_R|0\rangle$
2. Parameterized quantum circuit: $U_R(\vec{x})|0\rangle$

Reference Preparation

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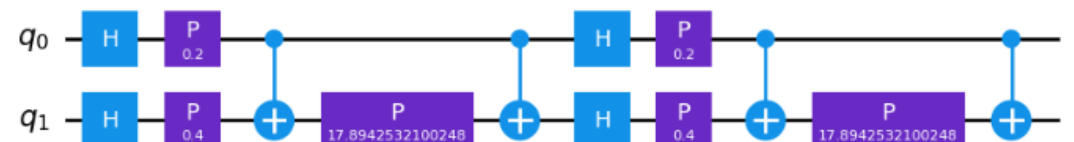
We initialize our system with a reference state to help our variational algorithm converge faster

The reference state can be set in

1. fixed form: $U_R|0\rangle$
2. Parameterized quantum circuit: $U_R(\vec{x})|0\rangle$

```
1 from qiskit.circuit.library import ZZFeatureMap
2
3 data = [0.1, 0.2]
4
5 zz_feature_map_reference = ZZFeatureMap(feature_dimension=2, reps=2)
6 zz_feature_map_reference = zz_feature_map_reference.assign_parameters(data)
7 zz_feature_map_reference.decompose().draw("mpl")
```

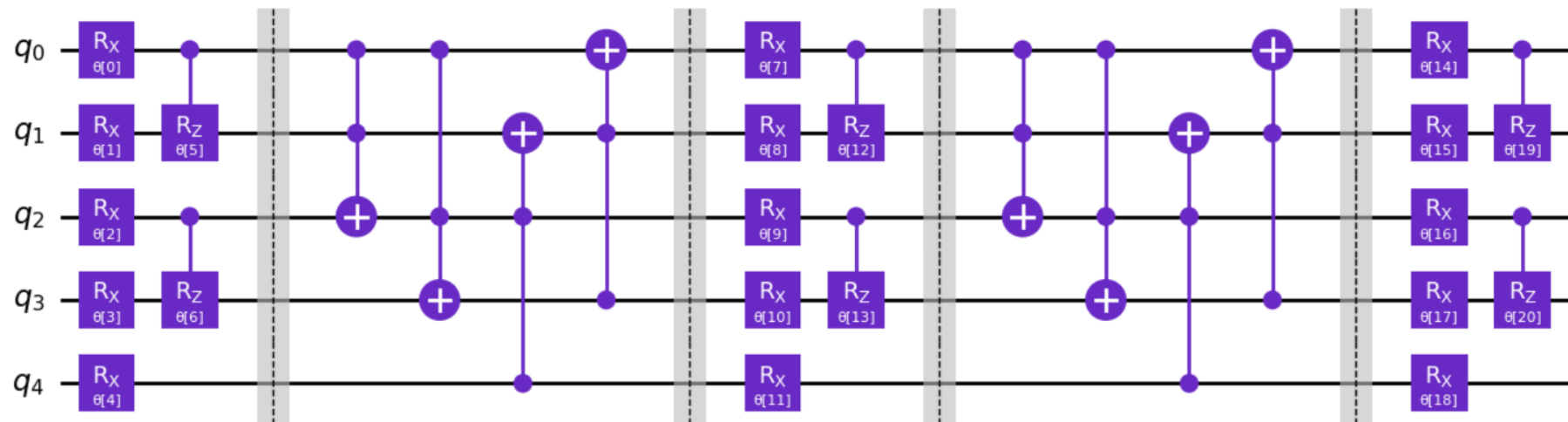
Output:



Variational Form and Ansatz

Variational algorithms operate by exploring and comparing a range of quantum states $|\psi(\vec{\theta})\rangle$, which depend on a finite set of k parameters $\vec{\theta} = (\theta^0, \dots, \theta^{k-1})$

These states can be prepared using a PQC



Variational Form and Ansatz

To iteratively optimize from a reference state $U_R|0\rangle = |\rho\rangle$ to a target state $|\psi(\vec{\theta})\rangle$, we need to define a variational form $U_V(\vec{\theta})$ that represents a collection of parameterized states for our variational algorithm to explore:

$$\begin{aligned} |0\rangle &\xrightarrow{U_R} U_R|0\rangle = |\rho\rangle \xrightarrow{U_V(\vec{\theta})} U_A(\vec{\theta})|0\rangle \\ &= U_V(\vec{\theta})U_R|0\rangle \\ &= U_V(\vec{\theta})|\rho\rangle \\ &= |\psi(\vec{\theta})\rangle \end{aligned}$$

Cost Function

In general, cost functions are used to describe the goal of a problem and how well a trial state is performing with respect to that goal.

This definition can be applied to various examples in chemistry, machine learning, finance, optimization, and so on.

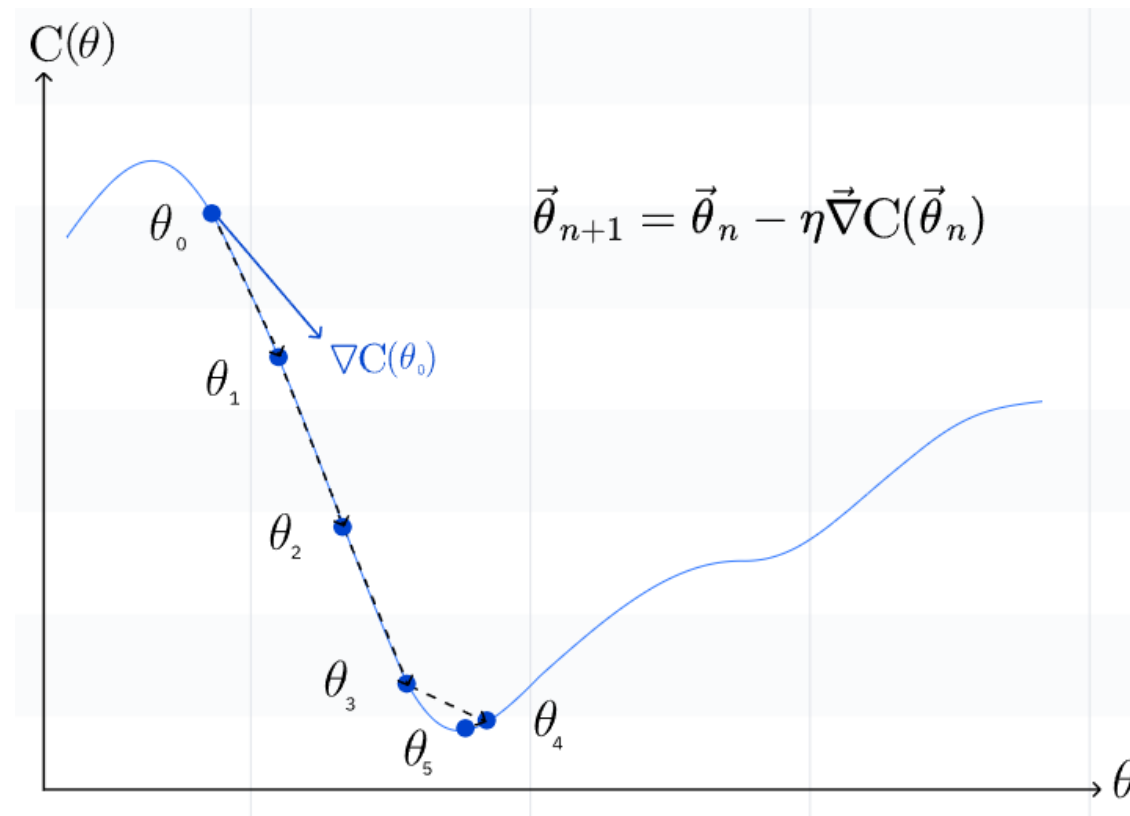
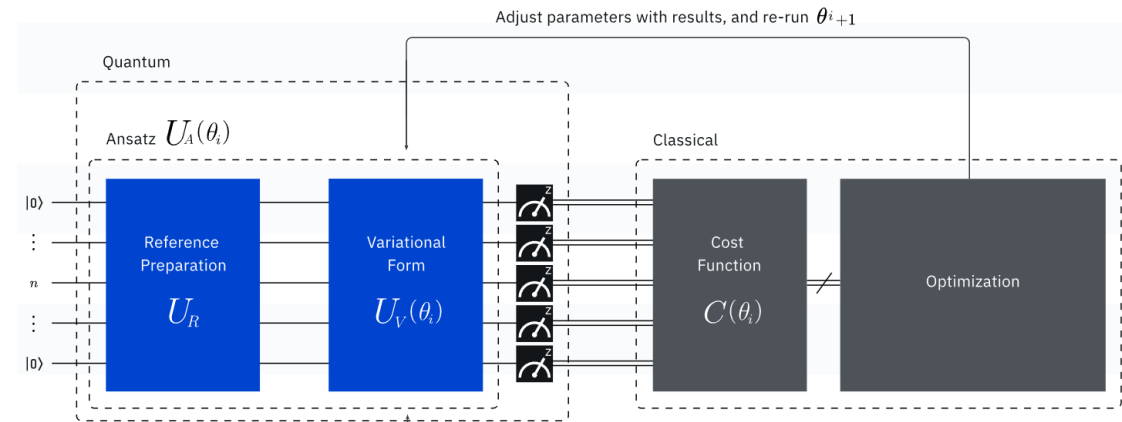
Our objective is to minimize the expectation value of the observable representing energy (Hamiltonian $\hat{\mathcal{H}}$):

$$\min_{\vec{\theta}} \langle \psi(\vec{\theta}) | \hat{\mathcal{H}} | \psi(\vec{\theta}) \rangle$$

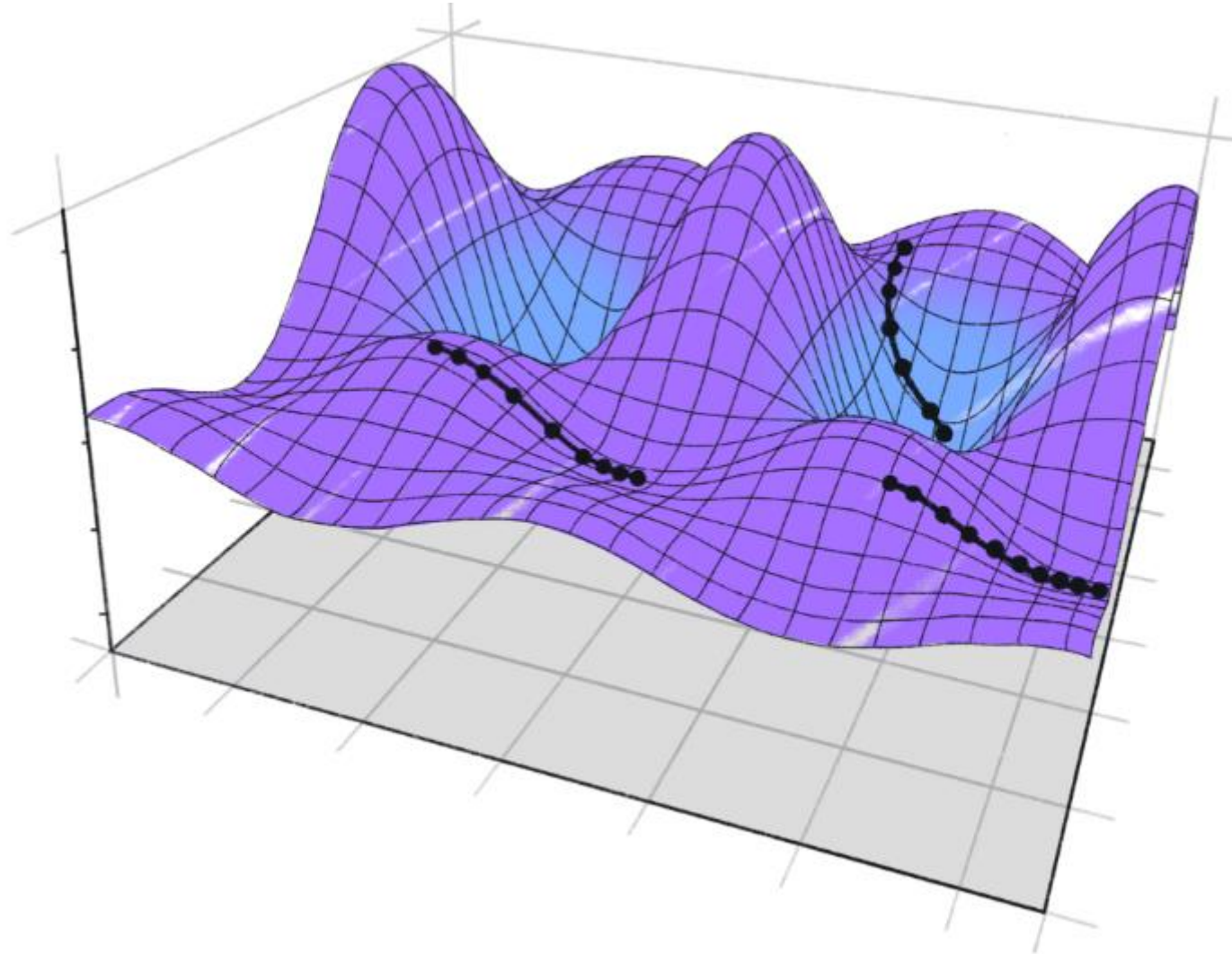
We can use the “Estimator” primitive to evaluate the expectation value and pass this value to an optimizer to minimize.

We will get a set of optimal parameter values $\overrightarrow{\theta^*}$

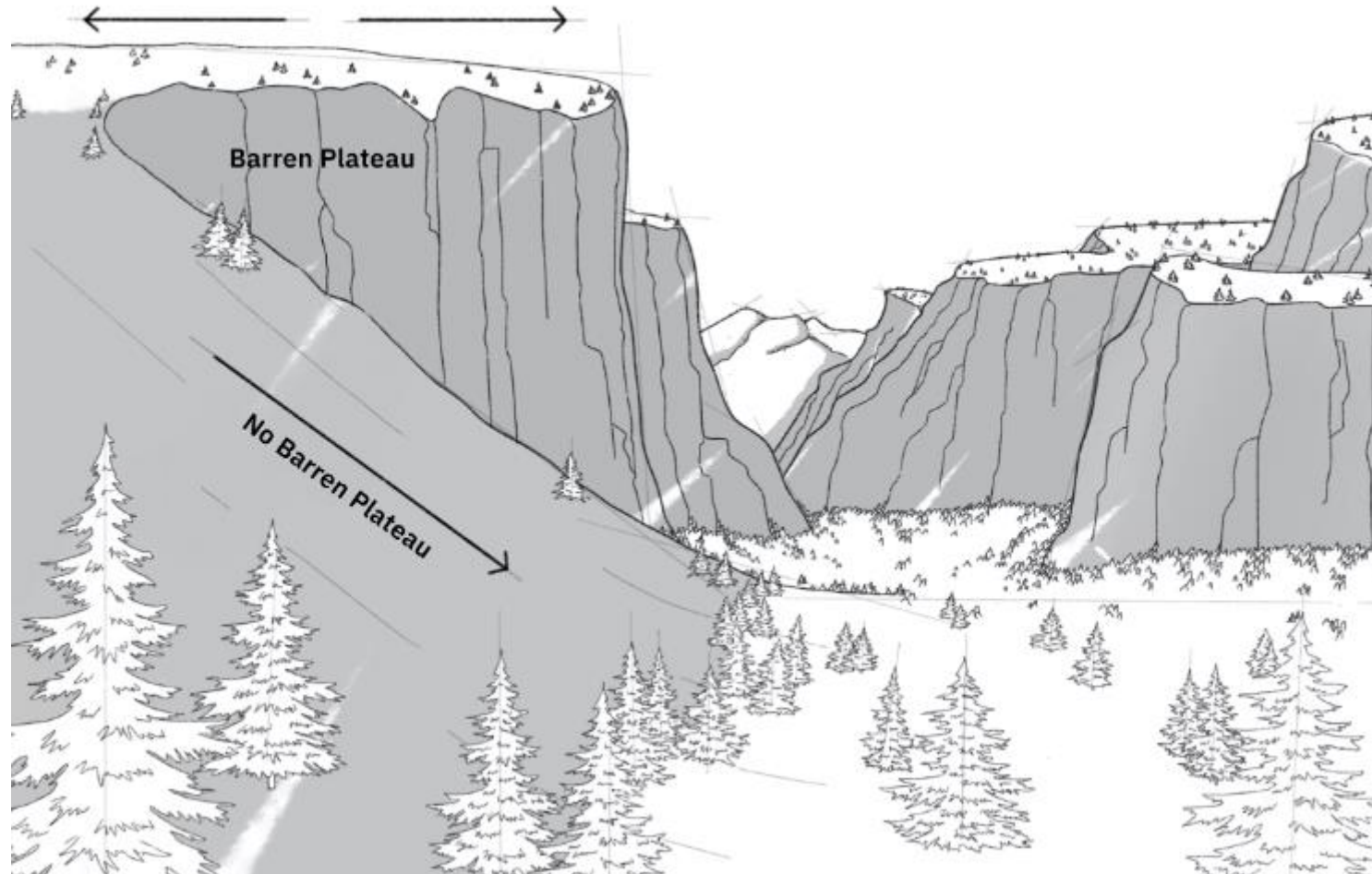
Optimization



Barren Plateaus



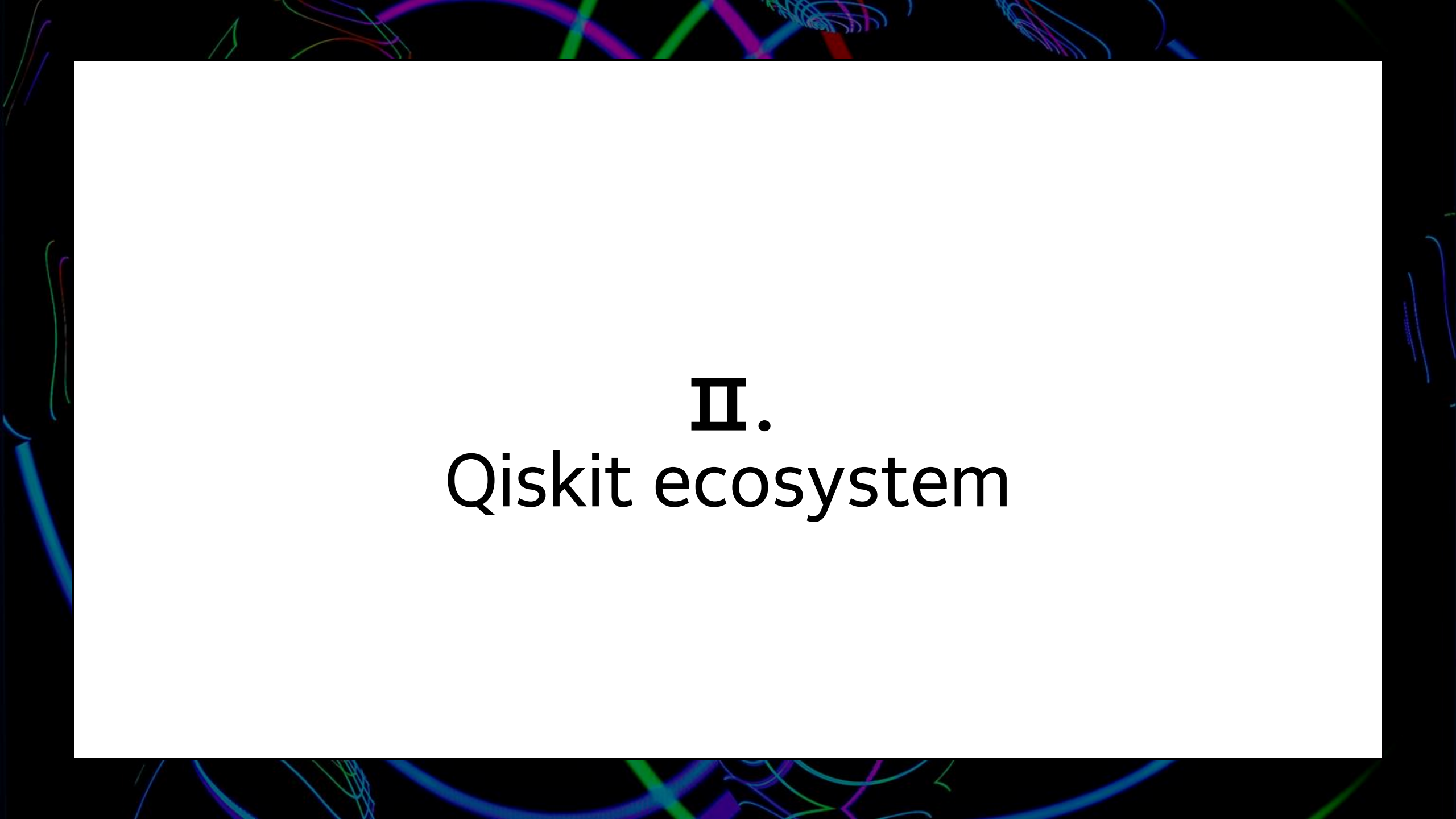
Barren Plateaus



Example: Variational Quantum Eigensolver(VQE)

VQE (Variational Quantum Eigensolver) is an algorithm designed to solve eigenvalue problems on a quantum computer, primarily used in quantum chemistry and quantum physics to find the minimum energy state of a molecule.

<https://learning.quantum.ibm.com/course/variational-algorithm-design/instances-and-extensions>



II. Qiskit ecosystem

Qiskit Ecosystem

<https://www.ibm.com/quantum/ecosystem>