Covalent

# Quantum Machine Learning using Covalent

## A QAOA application

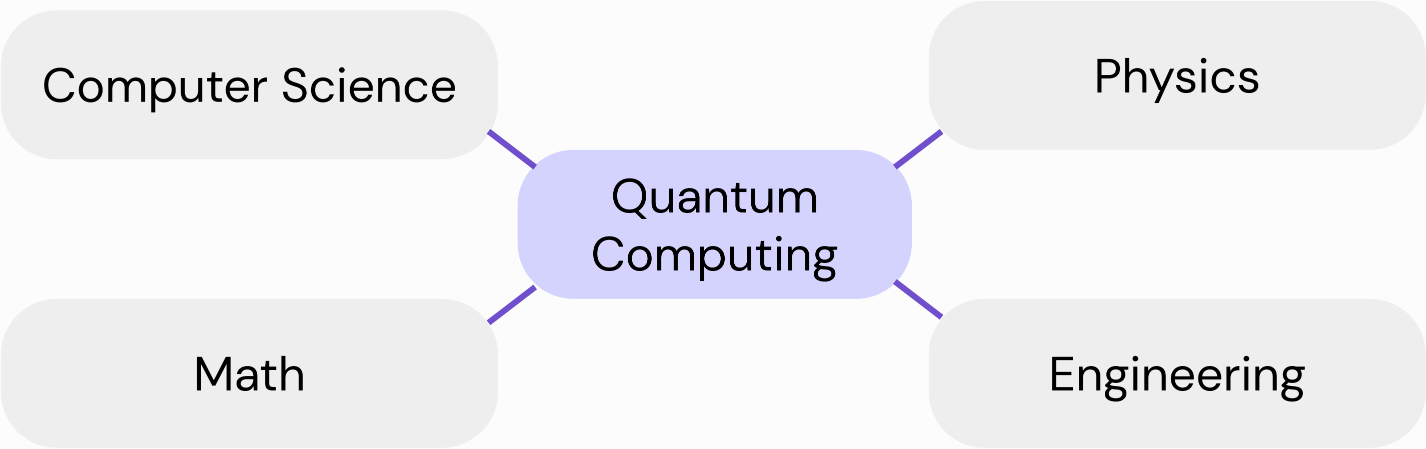
Covalent

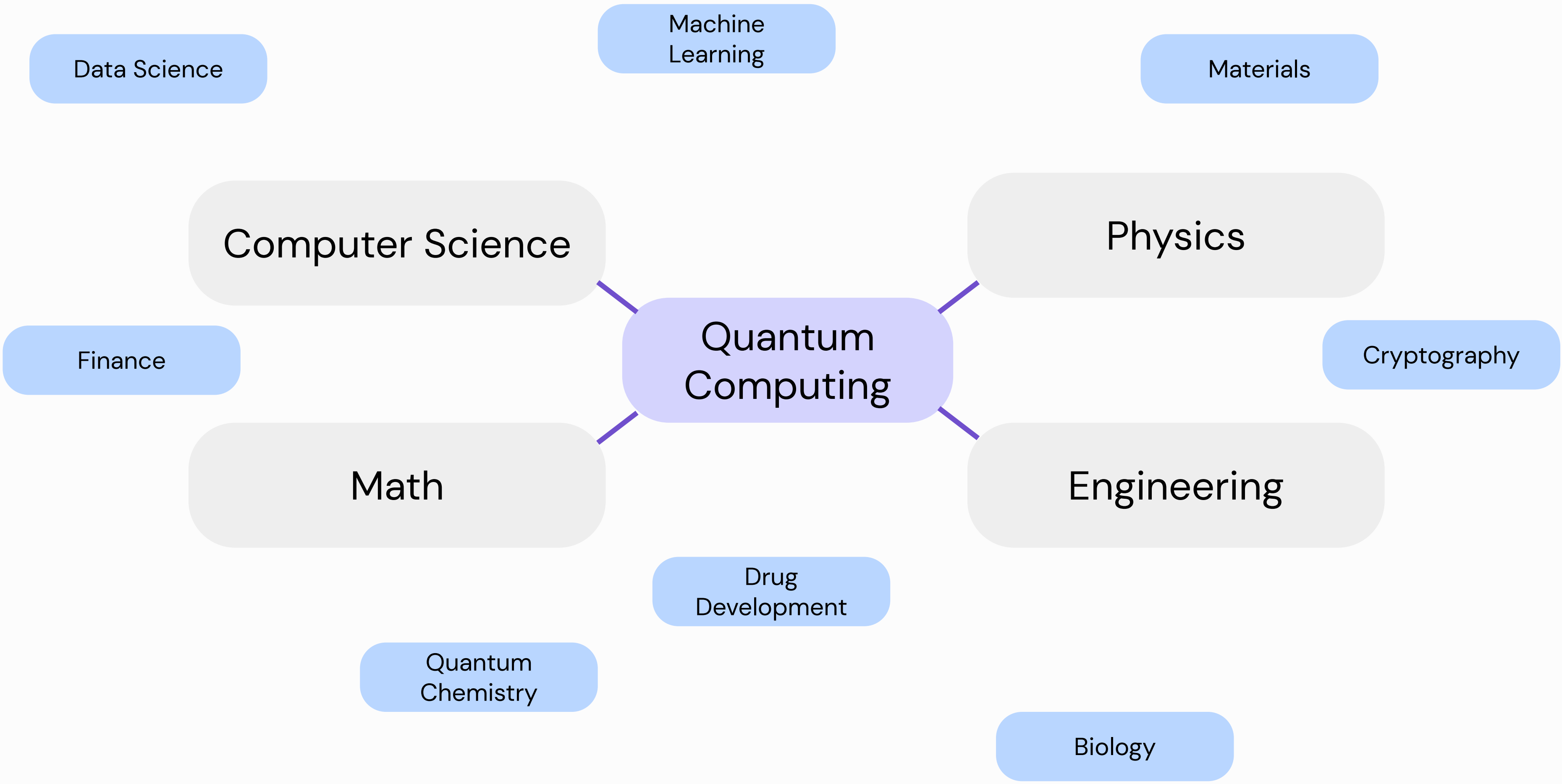
# Anna Hughes, PhD
# Quantum Software Engineer

Some text to explain relevant role / background

# Introduction to Quantum Computing

Subheading


Computer Science
Physics
Quantum Computing
Math
Engineering


Data Science
Machine Learning
Materials
Computer Science
Physics
Quantum Computing
Finance
Cryptography
Math
Engineering
Drug Development
Quantum Chemistry
Biology

**1994**
Shor's Algorithm

**2009**
Yale creates first solid-state quantum processor

**2011**
D-Wave develops first commercial quantum annealer

**2013**
Google launches Quantum AI Labs

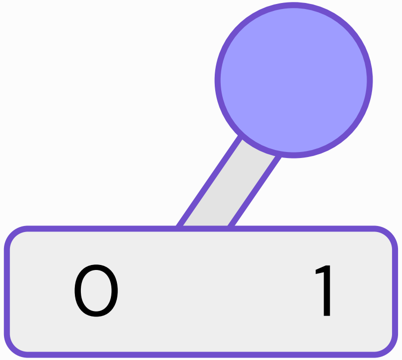
**2017**
IBM builds 16-qubit quantum computer

**2017**
Harvard builds 51-qubit quantum computer

**2019**
Google claims quantum supremacy

# Classical Computers

Composed of **bits**, which can take on values of 0 or 1



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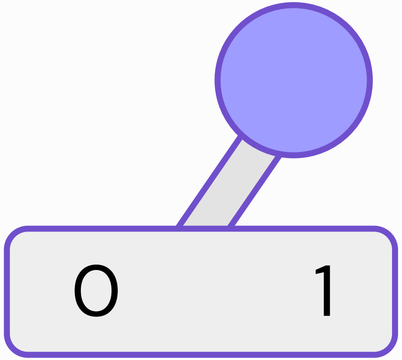


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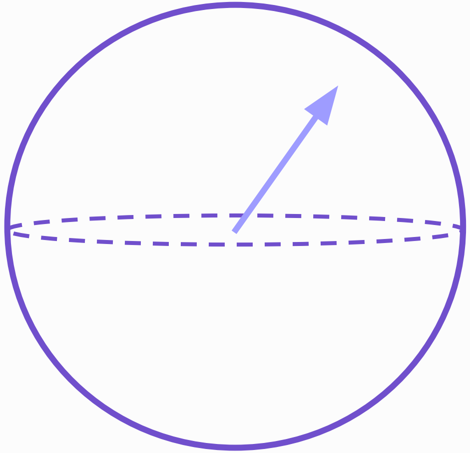
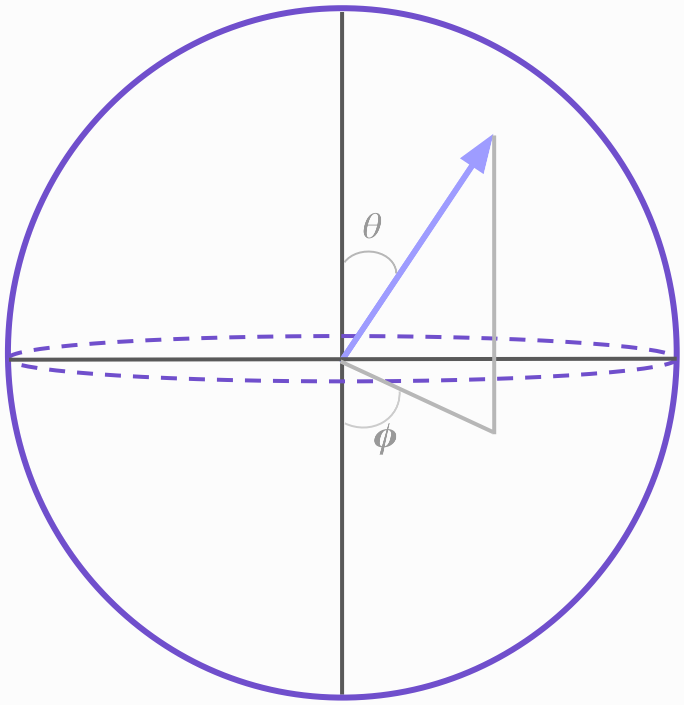


# Bloch Sphere



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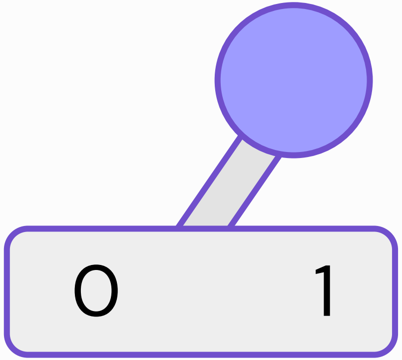


Deterministic measurements

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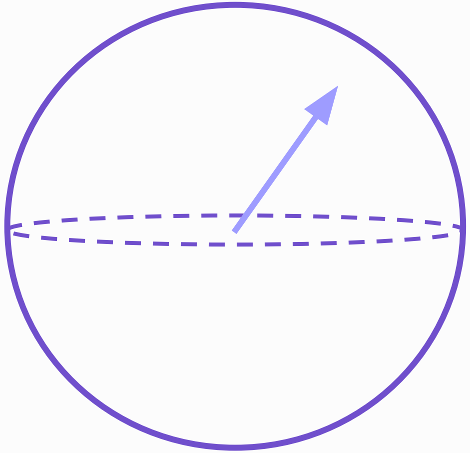

Probabilistic measurements

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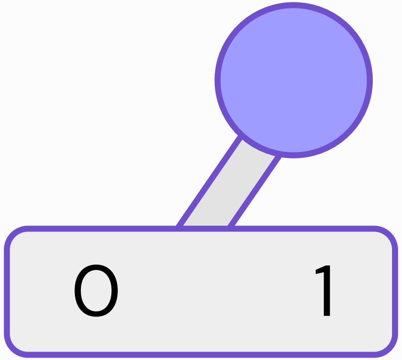


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## Quantum Computers

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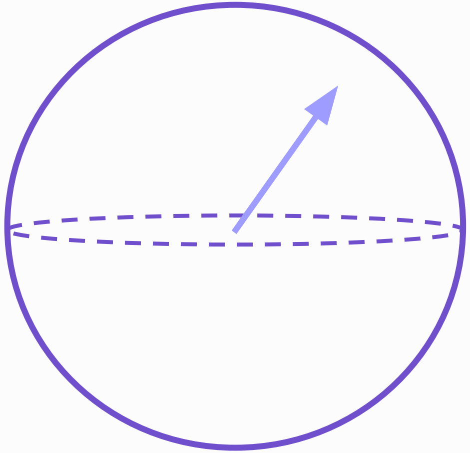
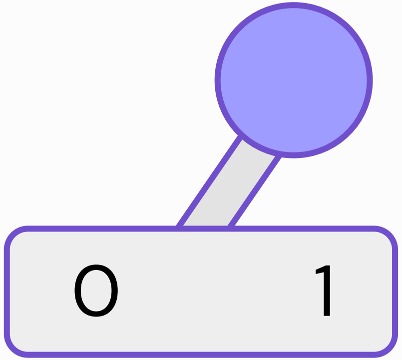


Probabilistic measurements

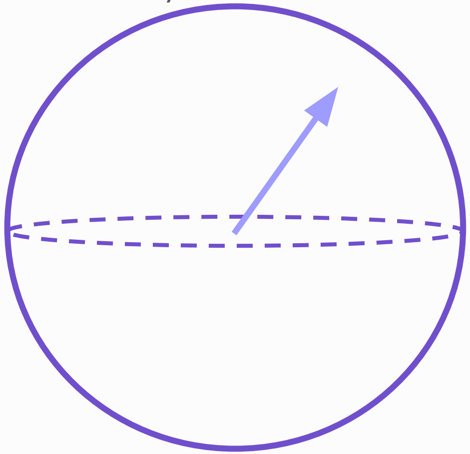
## Classical Computers

If you have N bits, you have $2^N$ states that you can only execute 1 at a time (or in parallel)



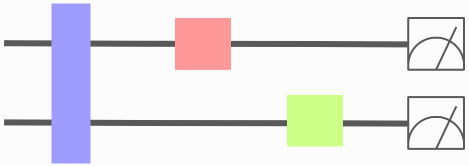

## Quantum Computers

If you have N qubits, you can encode all 2N components into one state simultaneously



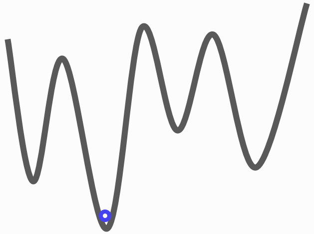
Probabilistic measurements

# Types of Quantum Computers



## Gate-Based

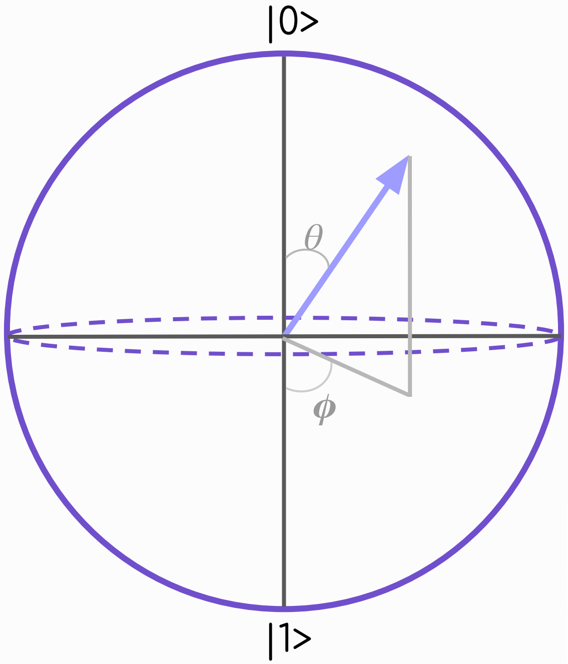
- Broad applications
- Apply gates, or circuit operations, to quantum state
- 



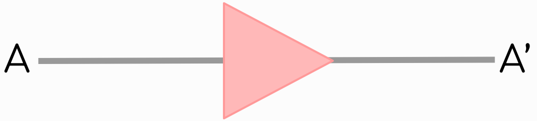
## Quantum Annealers

- Can solve optimization problems: search an energy landscape for the lowest-energy solution
- Problem encoded as a Hamiltonian
- 

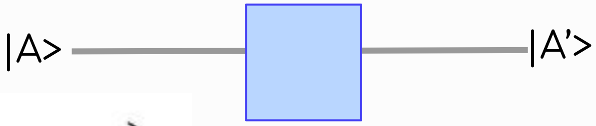
# Quantum Gates




- Classical NOT Gate

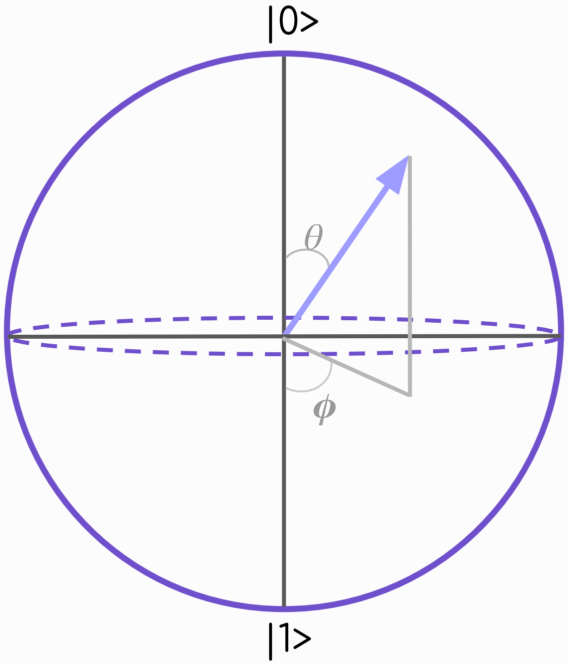



- Pauli X Gate




$$\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

# Quantum Gates




- Pauli X Gate

$$\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

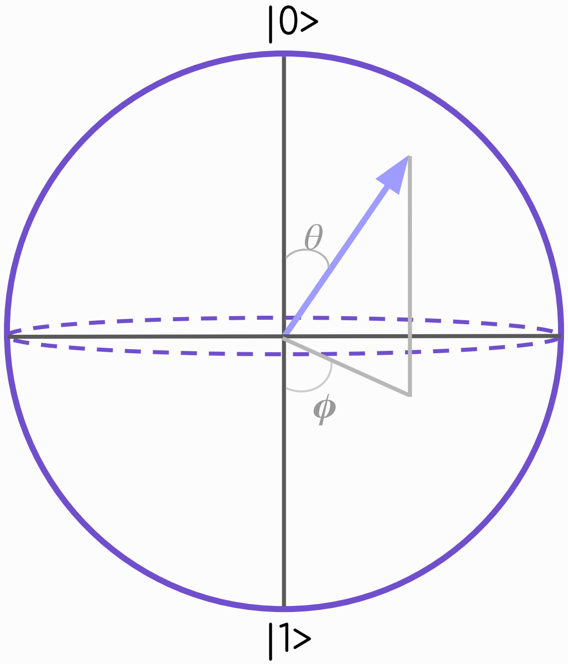
- Pauli Y Gate

$$\begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$$

- Pauli Z Gate

$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

# Quantum Gates

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- Pauli Z Gate

$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

- Hadamard Gate

$$\frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

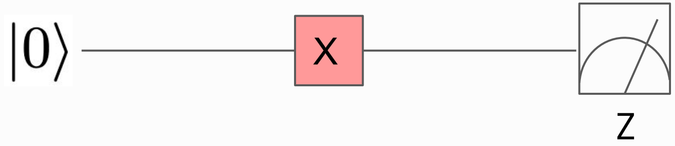
- Controlled NOT Gate

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

- Toffoli Gate

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

# Building a Quantum Circuit



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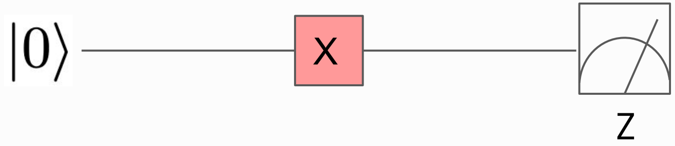
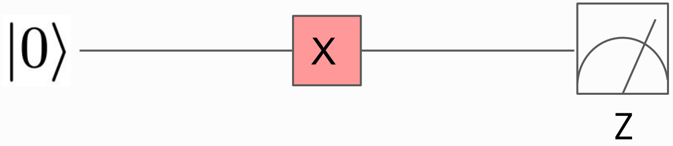



$$\begin{bmatrix}1\\0\end{bmatrix} \quad \begin{bmatrix}0&1\\1&0\end{bmatrix}\begin{bmatrix}1\\0\end{bmatrix} \quad \begin{bmatrix}1&0\\0&-1\end{bmatrix}\begin{bmatrix}0\\1\end{bmatrix}$$

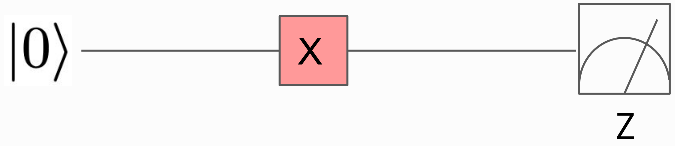
# Building a Quantum Circuit




$$\begin{bmatrix}1\\0\end{bmatrix} \qquad \begin{bmatrix}0 & 1\\1 & 0\end{bmatrix}\begin{bmatrix}1\\0\end{bmatrix} \qquad \begin{bmatrix}1 & 0\\0 & -1\end{bmatrix}\begin{bmatrix}0\\1\end{bmatrix}$$

$$|0\rangle \qquad \sigma_x\,|0\rangle = |1\rangle \qquad \langle 1|\,\sigma_z\,|1\rangle$$

# Building a Quantum Circuit

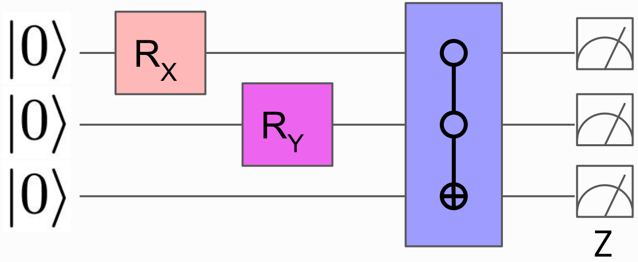



```
import pennylane as qml

dev1 = qml.device("default.qubit", wires=1)

@qml.qnode(dev1)
def circuit():
    qml.PauliY(wires=0)
    return qml.expval(qml.PauliZ(0))
```

# Building a Quantum Circuit




```python
import pennylane as qml
dev1 = qml.device("default.qubit", wires=3)
@qml.qnode(dev1)
def circuit(params):
    qml.RX(params[0], wires=0)
    qml.RX(params[0], wires=1)
    qml.Toffoli(wires=[0,1,2])
    return qml.expval(qml.PauliZ(0)),
qml.expval(qml.PauliZ(1)), qml.expval(qml.PauliZ(2))
```

# Introduction to Quantum Machine Learning

Subheading

# Machine Learning

- A model is developed to describe and make predictions about data
- Model parameters are tuned using a training dataset
- The model is assessed by making predictions about a test dataset

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- A model is developed to describe and make predictions about data
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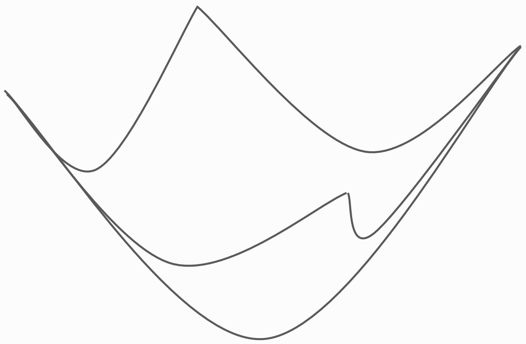
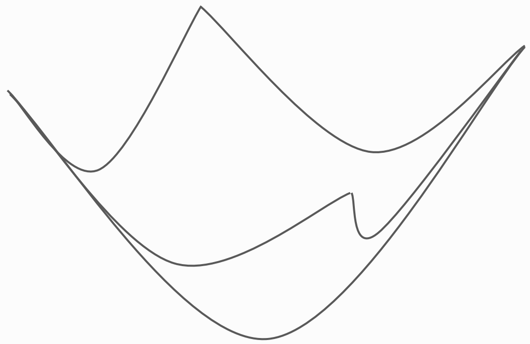
Optimizing a cost function



# Machine Learning Example

A model is developed to describe and make predictions about data

Optimizing a cost function



# Machine Learning Example

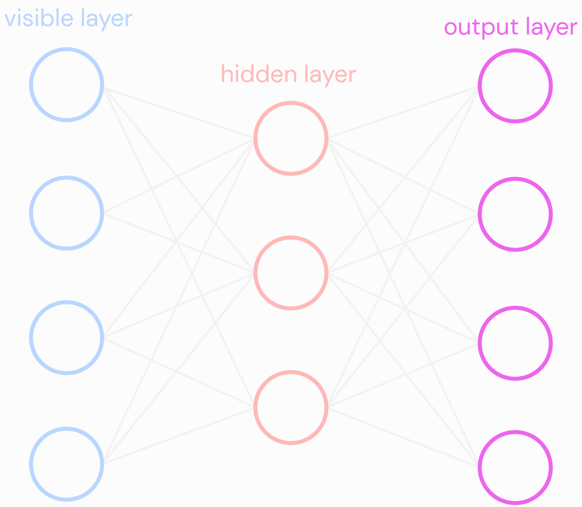
## Overfitting

Era of high-throughput calculations. Running massive parallel jobs at scale.

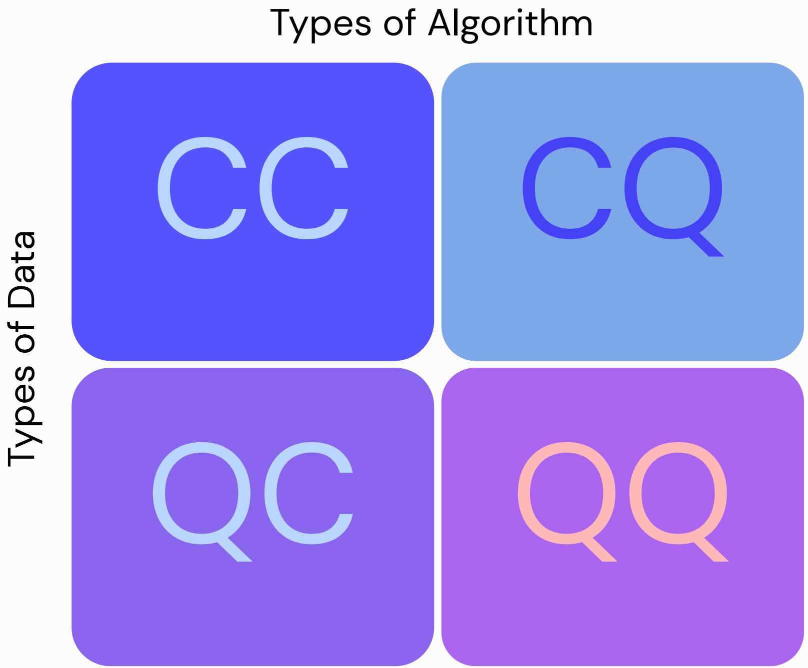
## Underfitting

High performance computing in the age of rapid prototyping and experimentation.

# Neural Networks



# Quantum Machine Learning



# Quantum Machine Learning

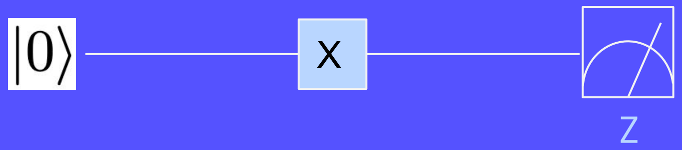
Types of Algorithm

Types of Data

## CQ

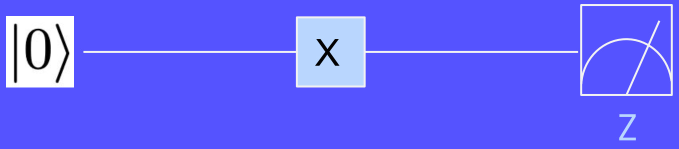
classical data with quantum algorithms

# Parameterized Quantum Circuits




This circuit does not have tunable parameters

# Parameterized Quantum Circuits

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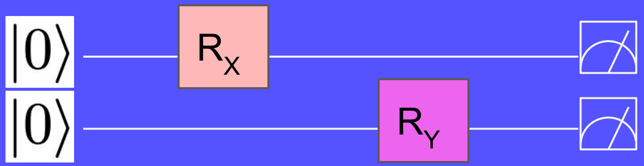
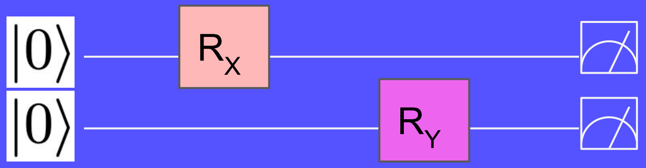



The input angles in $R_X$ and $R_Y$ are tunable parameters

# Parameterized Quantum Circuits



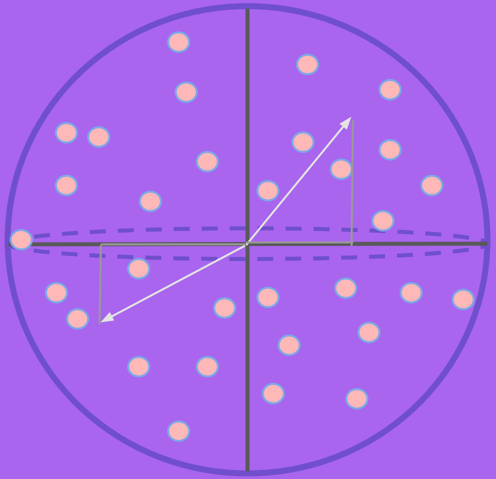

The input angles in $R_X$ and $R_Y$ are tunable parameters

A quantum circuit with tunable parameters consists of unitary operations $U(\theta)$ performed on n qubits

# Parameterized Quantum Circuits

## Expressibility.

We want our quantum circuit to be able to span a wide subset of Hilbert Space!



## Entanglement.

Entangled qubits are difficult to simulate using a classical simulator.

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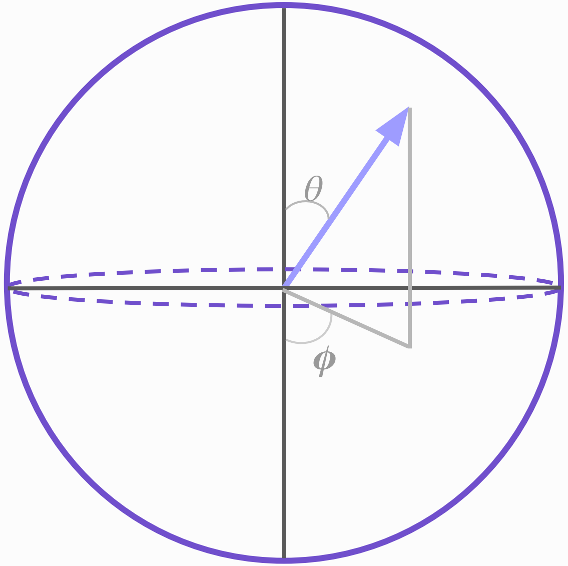

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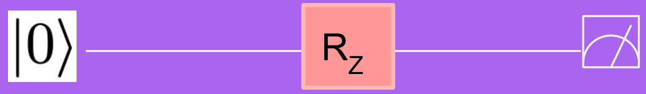


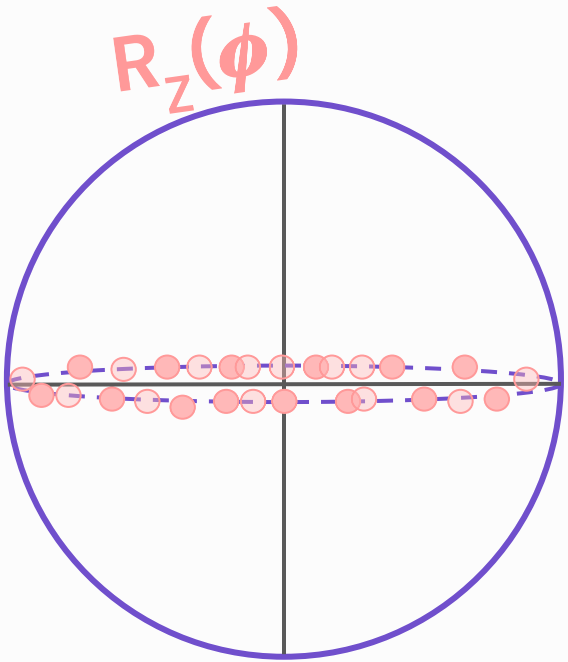

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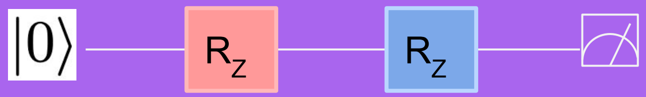


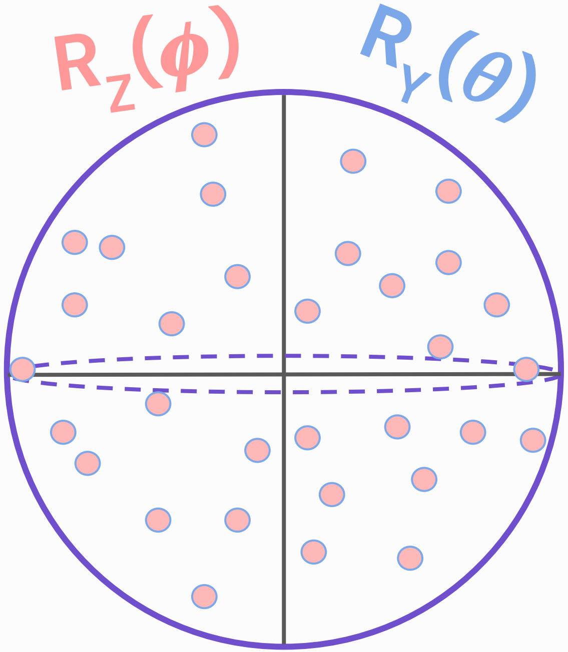

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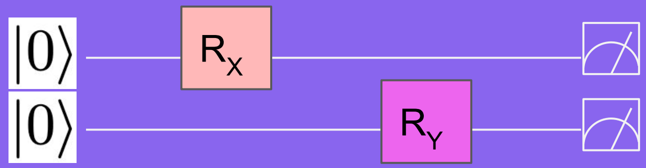

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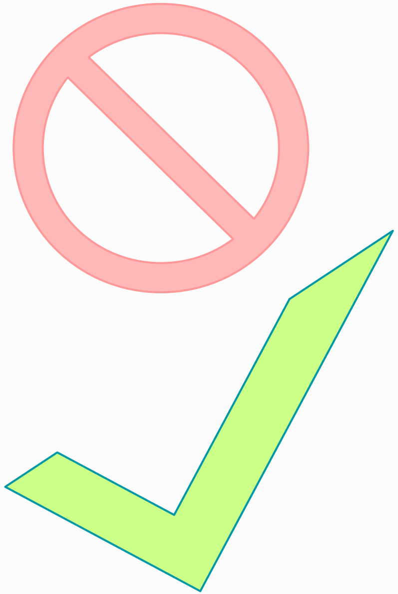

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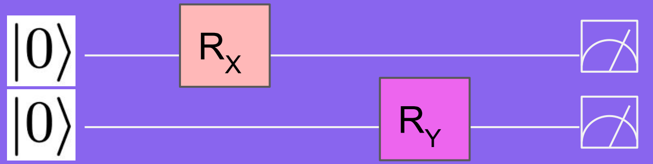
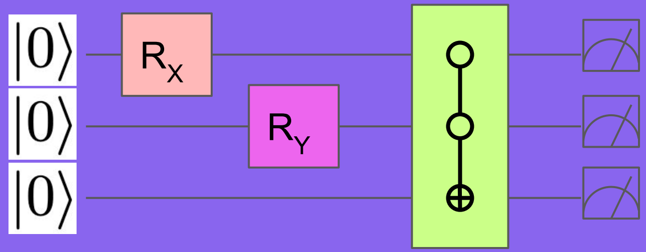
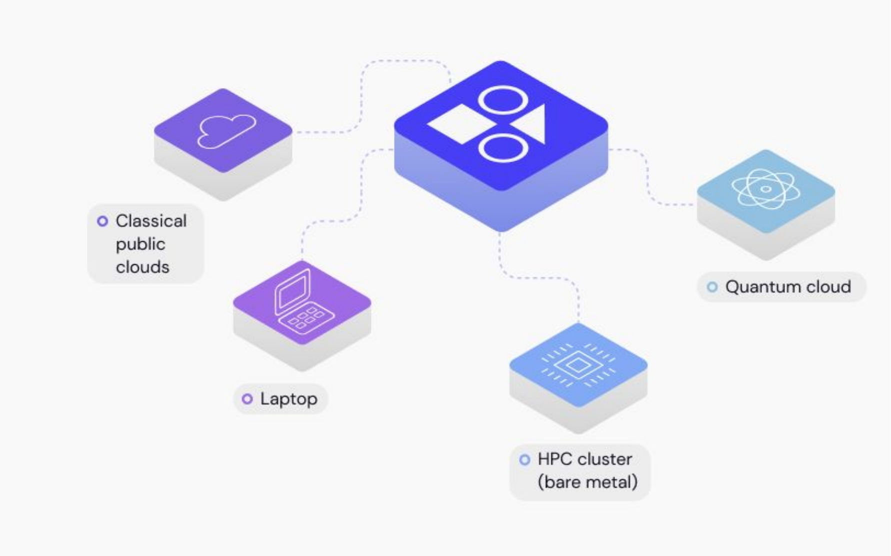


# Covalent is an open source workflow orchestration platform for quantum and high performance computing

Covalent is designed to make your experiments:

- Modular
- Scalable
- Reproducible



# Why does Covalent exist?

## Computational research

Time spent on research

Time spent on Writing, Debugging, Executing, Maintaining research code

# Challenges.

Experimental-Organization

## Manageability.

- Organize 1000s of experiments
- Experimental versioning of multiple runs
- Input/parameters logging for each run
- Checkpointing costly computations
- Job failure management
- Real time monitoring

## Reproducibility.

- Environment saving/caching
- Hardware metadata caching
- Inputs/parameters logging
- Experiment dependant device setup

## Shareability.

- Experiment organization
- Clear and intuitive code structure
- Reproducible experiment parameters and setup

# Challenges

## Computational

### Hardware-potpourri

Hybrid research / experiments. Single experiment now contains CPU+GPU+QPU+TPU

### Interactive HPC

High performance computing in the age of rapid prototyping and experimentation.

### Distributed computation

Era of high-throughput calculations. Running massive parallel jobs at scale.

### Limited resource

Long queue time, quantum queues and Server-less HPC!

# How Covalent can help.

## Solution 1.

Hybrid research / experiments.
Single experiment now contains CPU+GPU+QPU+TPU

## Solution 2.

High performance computing in the age of rapid prototyping and experimentation.

## Solution 3.

Era of high-throughput calculations. Running massive parallel jobs at scale.

## Solution 4.

Long queue time, quantum queues and Server-less HPC!

# 3. Real-time monitoring

**Visual overview**

*Visualize an share your workflow to transfer knowledge as fast as possible*

**Status/Error updates**

*Get real time Updates on errors and completion*

**Checkpoints**

*Stores anything and everything automatically without a single line of code*

**Meta-data**

*Maintains details from environment to hardwares used*

**Parameter**

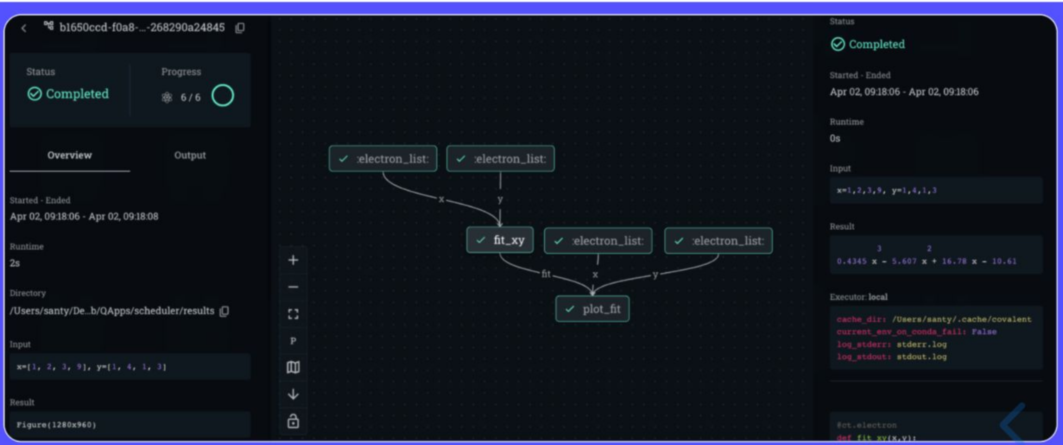
*Never forget the hyper-parameters that worked*

**Interactive**

*Start/stop/manage your HPC jobs right from the UI*

Beautiful and interactive UI

*bring your workflows to life!*



# Where Covalent fits in the stack.

# Ecosystem

## Classical resources

- SLURM Executer
- AWS-Fargate Executer
- AWS-Batch Executer
- Azzure Executer Coming soon
- GCP Executer Coming soon
- Kubernetes Executer Coming soon

Many more .....

## Quantum resources

- AWS-Braket-jobs Executer Coming soon
- Qiskit-Runtime Executer Coming soon

Many more .....

## Any and all package!

Many more .....

## Language Support

julia Coming soon

- Or, Write your own !

# There is more.

Pythonic workflows

Automatic checkpointing

Multiple language support

Little-to-no overhead

Customizable

Reproducibility

Code locally, un anywhere

Covalent.

It's Open-Source!

Intuitive User-interface

Natively hybrid workflows

Native parallelization

Variety of executers

Code isolation

Parameter caching

Cloud Agnostic

Interactive jobs

Start locally and scale

# Comparison table.

## Languages.

- Python
- C / C++
- Julia*
- Bash

## Executors.

- Local executors
- Slurm
- AWS*
- GCP*
- Azure*

*Roadmap item

# Code.

```
# Transaction in Python
session.start_transaction()
order = { line_items : [ { ite10m : 5, quantity: 6 } ] }
db.orders.insertOne( order, session=session );
```

# Code.

```
# Transaction in Python

session.start_transaction()
order = { line_items : [ { ite10m : 5, quantity: 6 } ] }
db.orders.insertOne( order, session=session );
for x in order.line_items:
 db.inventory.update(
   { _id  : x.item } ,
   { $inc : { number : -1 * x.quantity } },
   session=session

session.start_transaction()
```



```
# Transaction in Python

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```


```
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order = { line_items : [ { ite10m : 5, quantity: 6 } ] }
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```

# Code.

```python
# Transaction in Python

session.start_transaction()
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```


```python
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# Transaction in Python

session.start_transaction()
order = { line_items : [ { ite10m : 5, quantity: 6 } ] }
db.orders.insertOne( order, session=session );
```
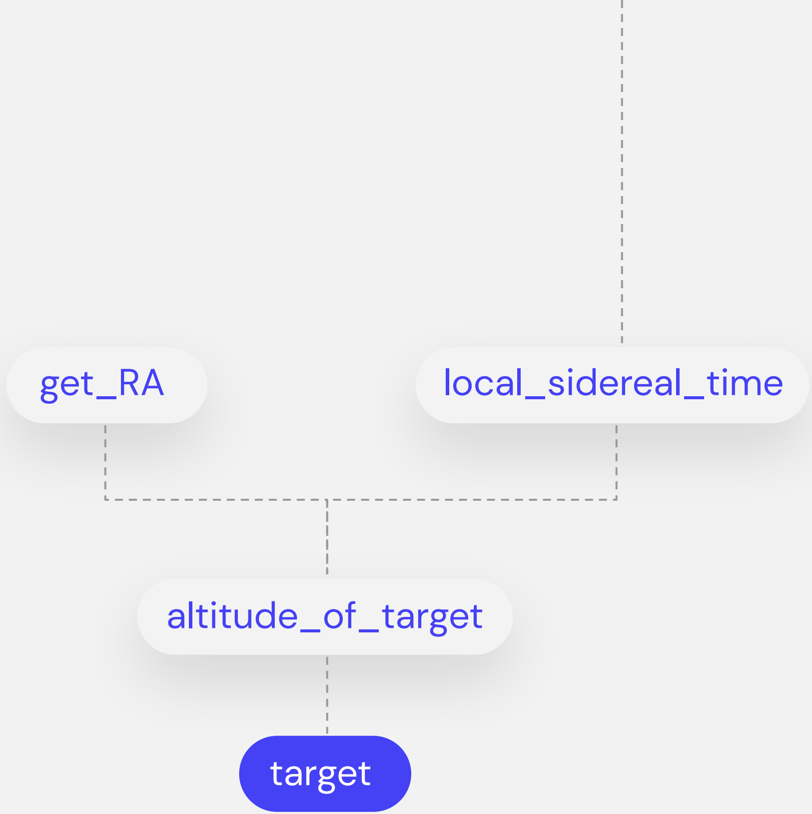

# Components.

Diagram



# Optimizing financial portfolios on superconducting and trapped ion quantum computers.

A combinatorial optimization problem arises whenever we are presented with a number of choices and we task ourselves with selecting the best choice. One example surfaces from a problem often posed by delivery companies: “given a set of possible vehicle routes, which one permits the driver to deliver all parcels the fastest?” Another is asked in telecommunications: “given a set number of approved locations for broadcast antennas, which sites should be used to maximize the reach of mobile phone signal?”

Lastly, and directly related to this post, a financial investor asks: “Given a list of stocks and a budget for how many different stocks can be bought, which assignment maximizes the amount of cash accumulated over time with the minimal amount of risk?”.

# Appendix / Page Break

Subheading

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# Thank You

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# Manage, deploy & scale workloads across the worlds most advanced computing hardware.

Workflows are composed of python decorators that create what we call lattices and electrons. Electrons are workflow components and lattices are groups of electrons.