Quantum Game Club

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Purdue University | College of Engineering

Roadmap of the Talk

Intro to Quantum Computing

- Principles of Quantum Mechanics
- Quantum Gates and Circuits
- NISQ Era

Club Structure

- Student Body
- Club Structure
- Opportunities

Past and Ongoing Projects

- Quantum Art
- Quantum Games
- Quantum Simulation
- Quantum Machine Learning
- Industry Collaboration

Differences from Classical Computing

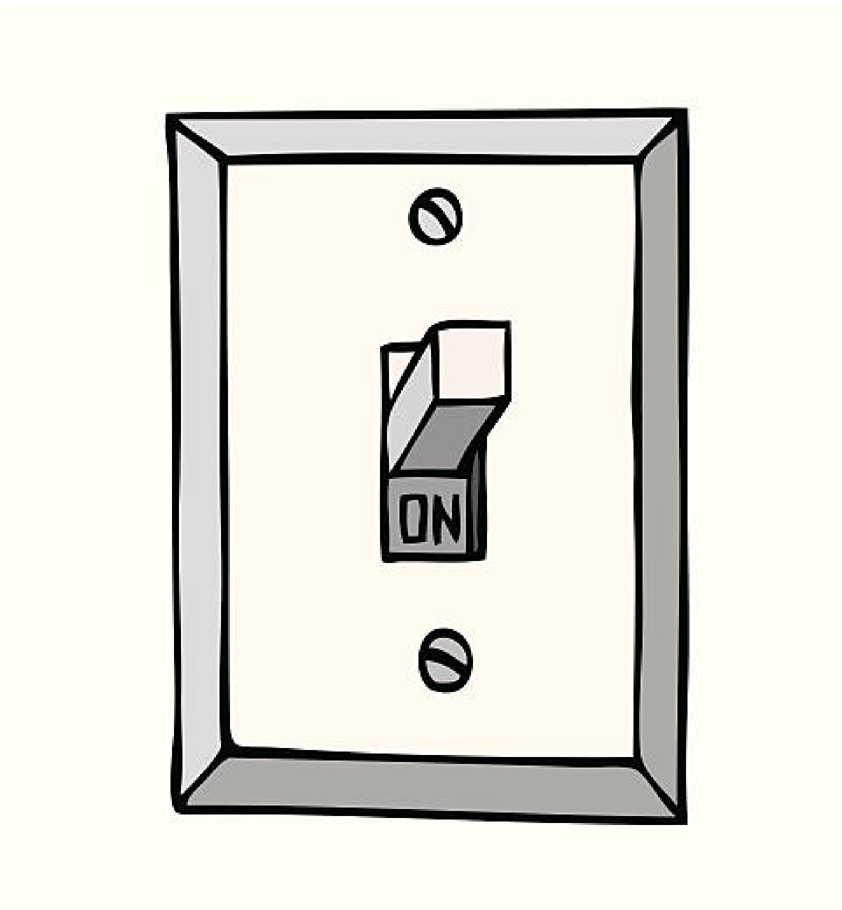
- Unlike classical bits, quantum bits, qubits, allow superposition and entanglement, offering exponential computational advantages
- Qubits follow quantum mechanics principles to process information
  - Superposition
  - Entanglement
  - Interference

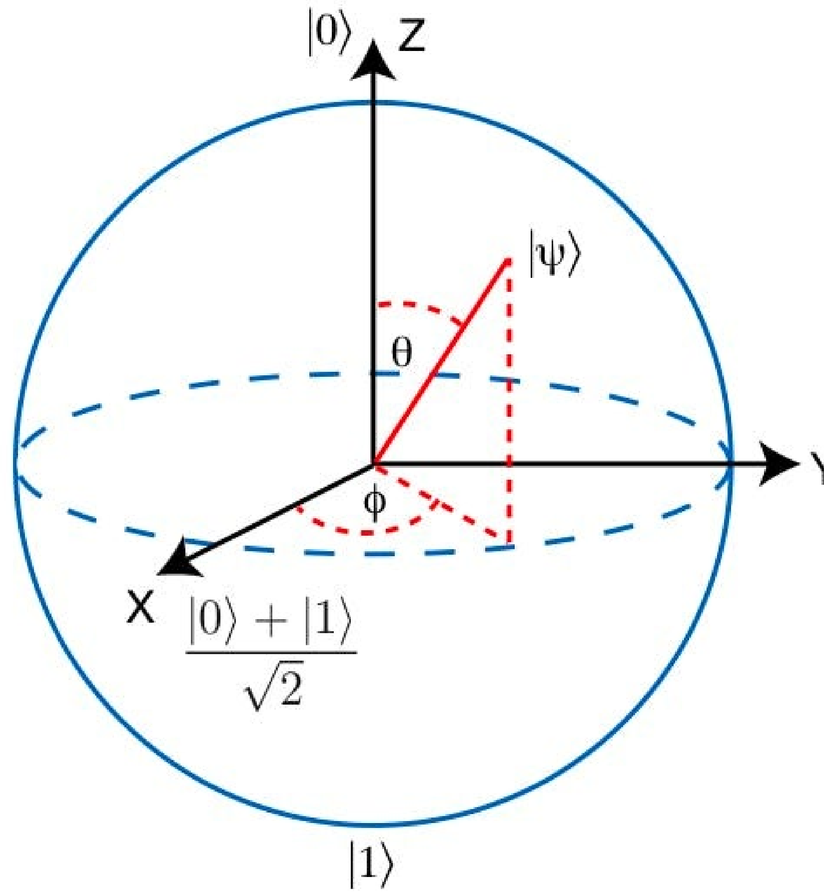
> “if you want to make a simulation of Nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem because it doesn't look so easy.”
>
> Richard Feynman

Superposition

Classical bit: 0 or 1

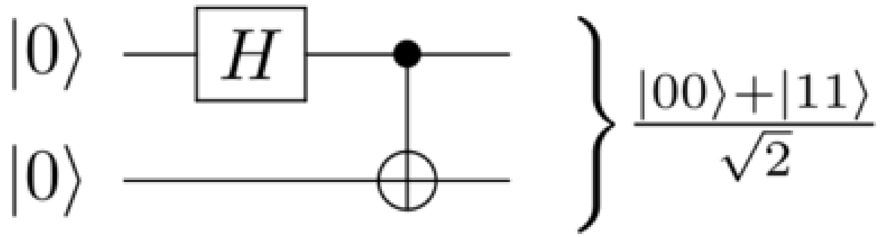
Quantum bit: $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$

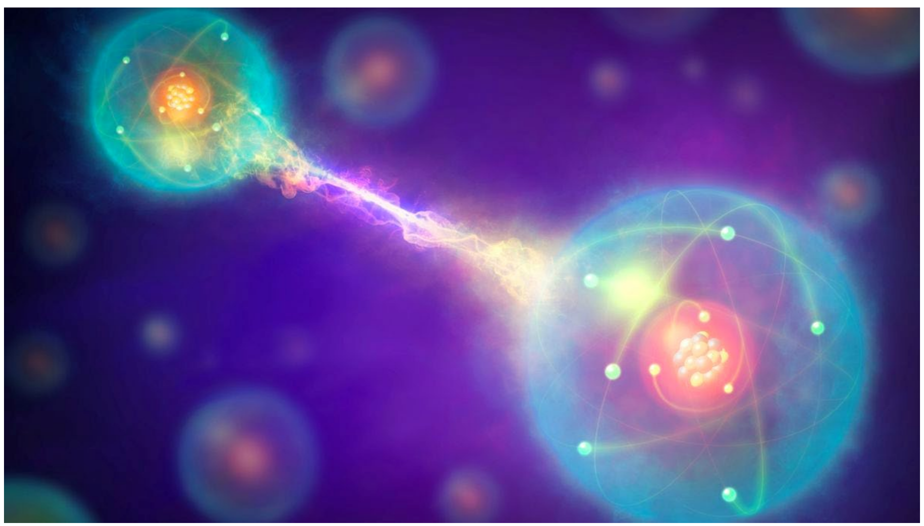




Entanglement

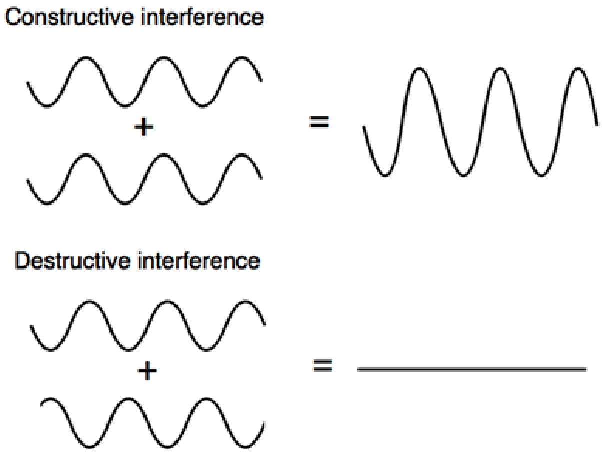
Bell State

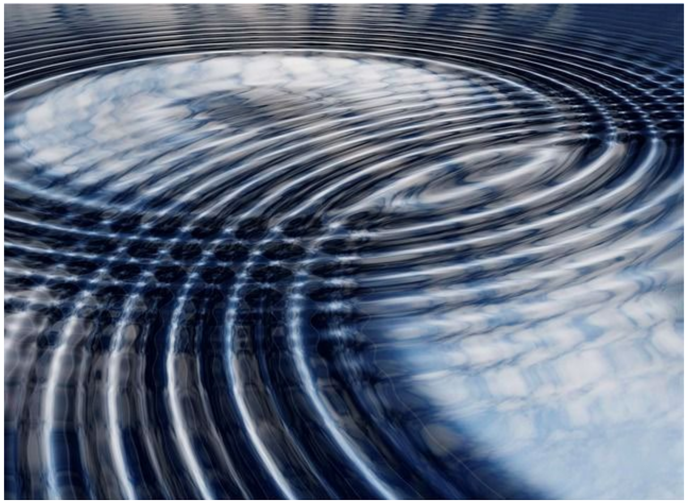




- Non-local correlation between qubits, even when separated by large distances.
- Demonstrated through Bell states, showcasing entangled qubit pairs.

Interference





- In quantum mechanics, particles like electrons and photons exhibit both wave-like and particle-like properties.
- When two or more quantum states are in superposition, their probability amplitudes can interfere constructively or destructively.

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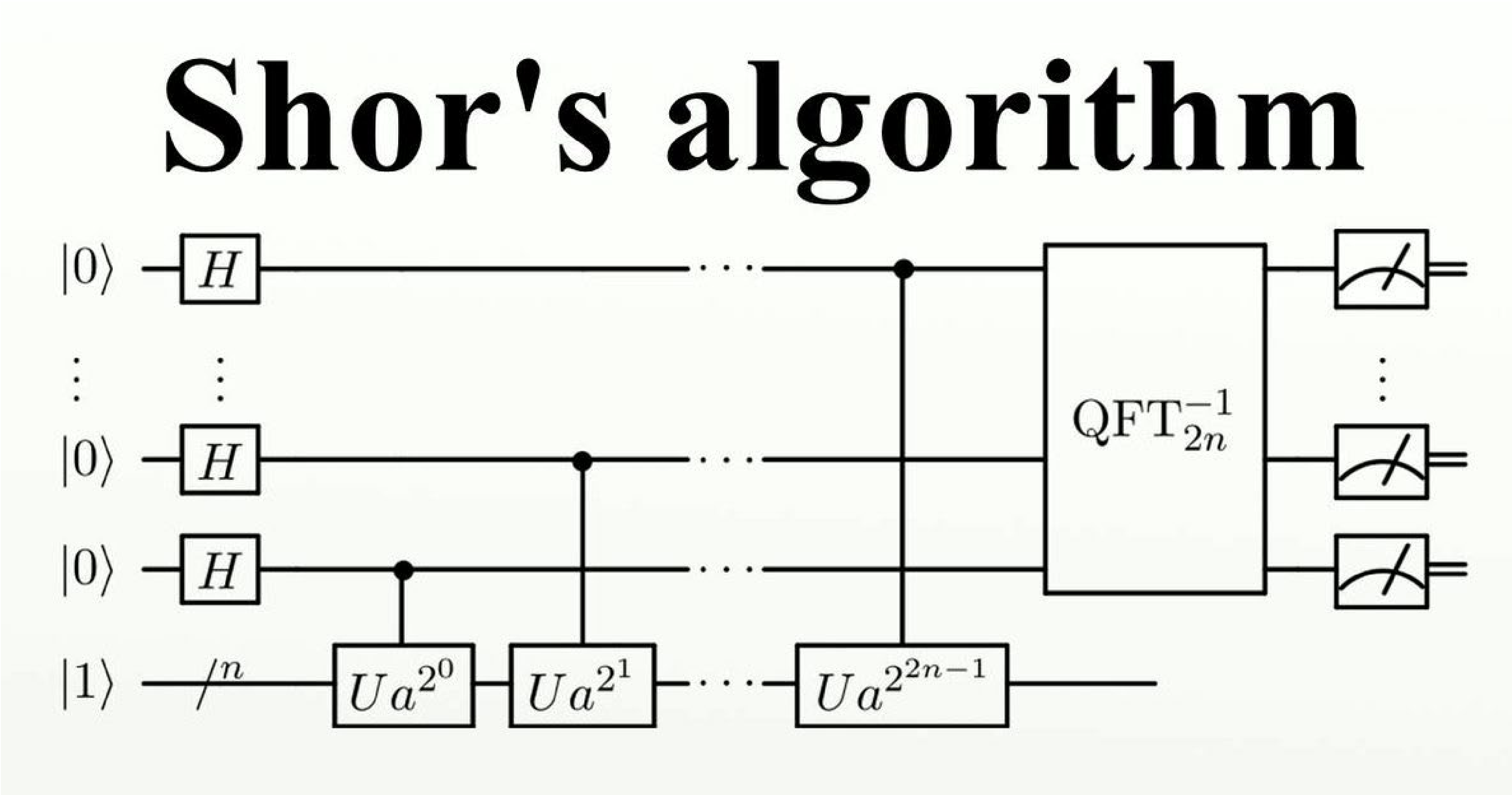
Quantum Algorithms

Prepare Design Circuit Measurement



Applications

More to be discovered!

Optimization	Simulation	Machine learning	Adiabatic Quantum Computing	Cryptography
Quantum computers excel at solving complex optimization problems, such as portfolio optimization, traffic flow optimization, and supply chain management. Algorithms like the Quantum Approximate Optimization Algorithm (QAOA) leverage quantum parallelism to explore vast solution spaces more efficiently than classical counterparts.	Quantum computers can simulate molecular interactions and properties with high precision. This is valuable in drug discovery for predicting molecular structures and interactions, as well as in material science for designing new materials with specific properties.	Quantum computers have the potential to process large datasets and complex models more efficiently, aim to enhance pattern recognition, classification, and optimization tasks.	A quantum system is slowly evolved from an initial Hamiltonian (easy to prepare) to a final Hamiltonian (represents the problem). The solution to the problem corresponds to the ground state of the final Hamiltonian.	Quantum computers have the potential to break widely used encryption algorithms, such as RSA and ECC, through Shor's algorithm. Conversely, quantum cryptography enables the development of unbreakable cryptographic systems, leveraging principles like quantum key distribution (QKD) for secure communication.

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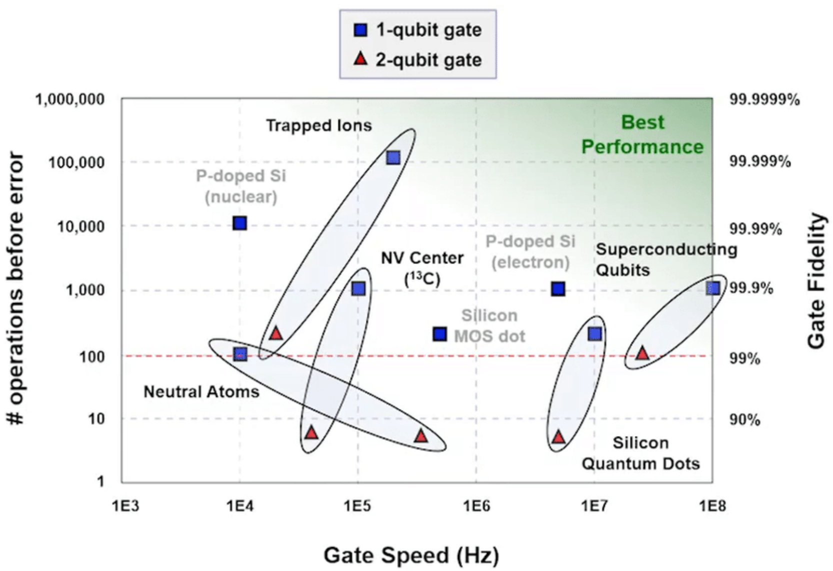
Noisy Intermediate-Scale Quantum era

NISQ



- Decoherence and Noise:
  - Quantum information is sensitive to its environment, leading to decoherence and noise that can cause errors.
- Error Rates:
  - The high error rates in NISQ devices pose challenges for performing reliable and accurate quantum computations.
- Limited Gate Fidelity:
  - The fidelity of quantum gates may be limited, impacting the overall performance of quantum circuits.

Mission Statement

To create and foster a diverse community of intellectual engineers and scientists by providing the necessary education and resources to have fun inventing quantum activities and to share knowledge and excitement while interacting with quantum machines and concepts. We envision developing device abstraction concepts and human-machine interfaces related to quantum technologies.

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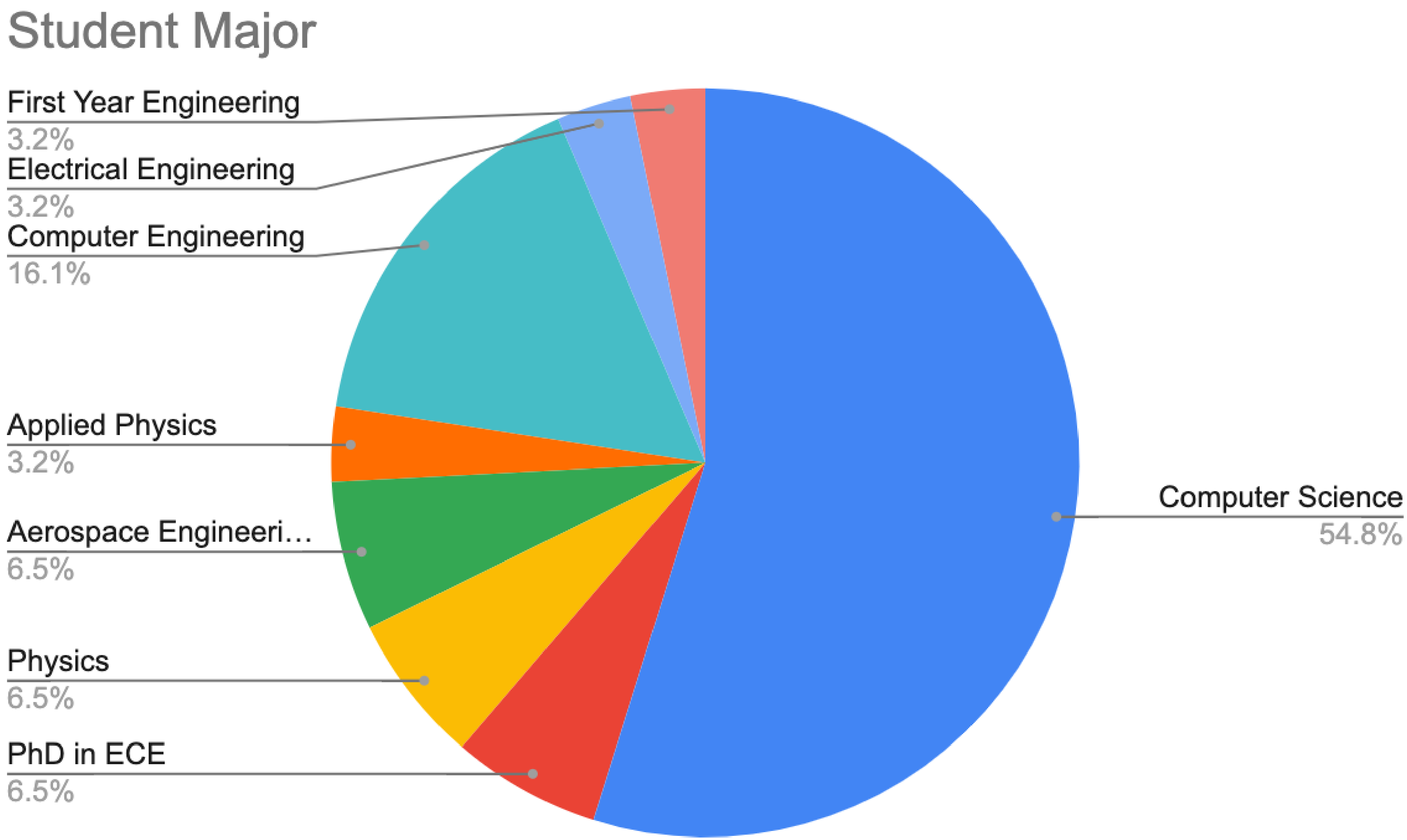
Student Demographics



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Meeting Structure

- Recruitment once every academic year during the first semester
- During the onboarding phase:
  - Lecture (~20-30 minutes)
  - Breakout discussion with short coding exercise (~30-40 minutes)

Problem Set - Logic Gate Replication

The goat of this project is to recreate classical computational logic gates using quantum circuits. At the end you will be tasked with creating a half adder circuit.

First, we import the necessary libraries.

You should know how to do this by now.

In [1]:
```
# Import the necessary libraries
```

Problem 1: XOR Gate

First we will create a circuit that implements the XOR gate. This gate is the simplest logic gate to recreate as it only requires a single CNOT gate. Please use qubit 1 as your target qubit.

Input: you will receive two bits as input, please initialize the circuit with these two bits as qubit states
Output: your function should should return a single classical bit as output

In [2]:
```
def xorGate(bit1, bit2):
    # initialize the quantum circuit
    q = QuantumRegister(2)
    c = ClassicalRegister(2)
    qc = QuantumCircuit(q, c)

    # TODO:

    # this part has already been done for you
    qc.measure(q, c)
    backend = Aer.get_backend('qasm_simulator')
    job = execute(qc, backend, shots=1024)
    result = job.result()
    counts = result.get_counts(qc)
    return list(counts.items())[0][0][0]
```

Use the following code to test your implementation of the XOR gate.

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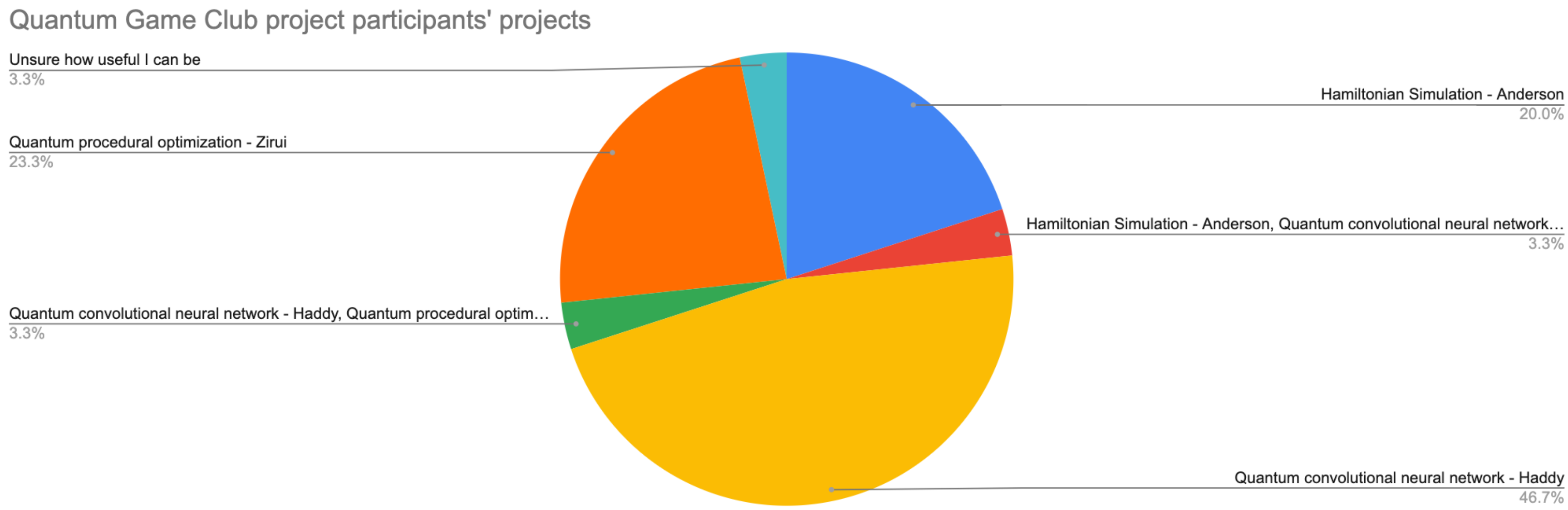
Meeting Structure

Continued

- Second Falf the Fall Sem and Spring Sem: New members transition into ongoing projects or undertake their own projects
- Summer: Qualified members are grouped into various projects based on interests



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Further Opportunities

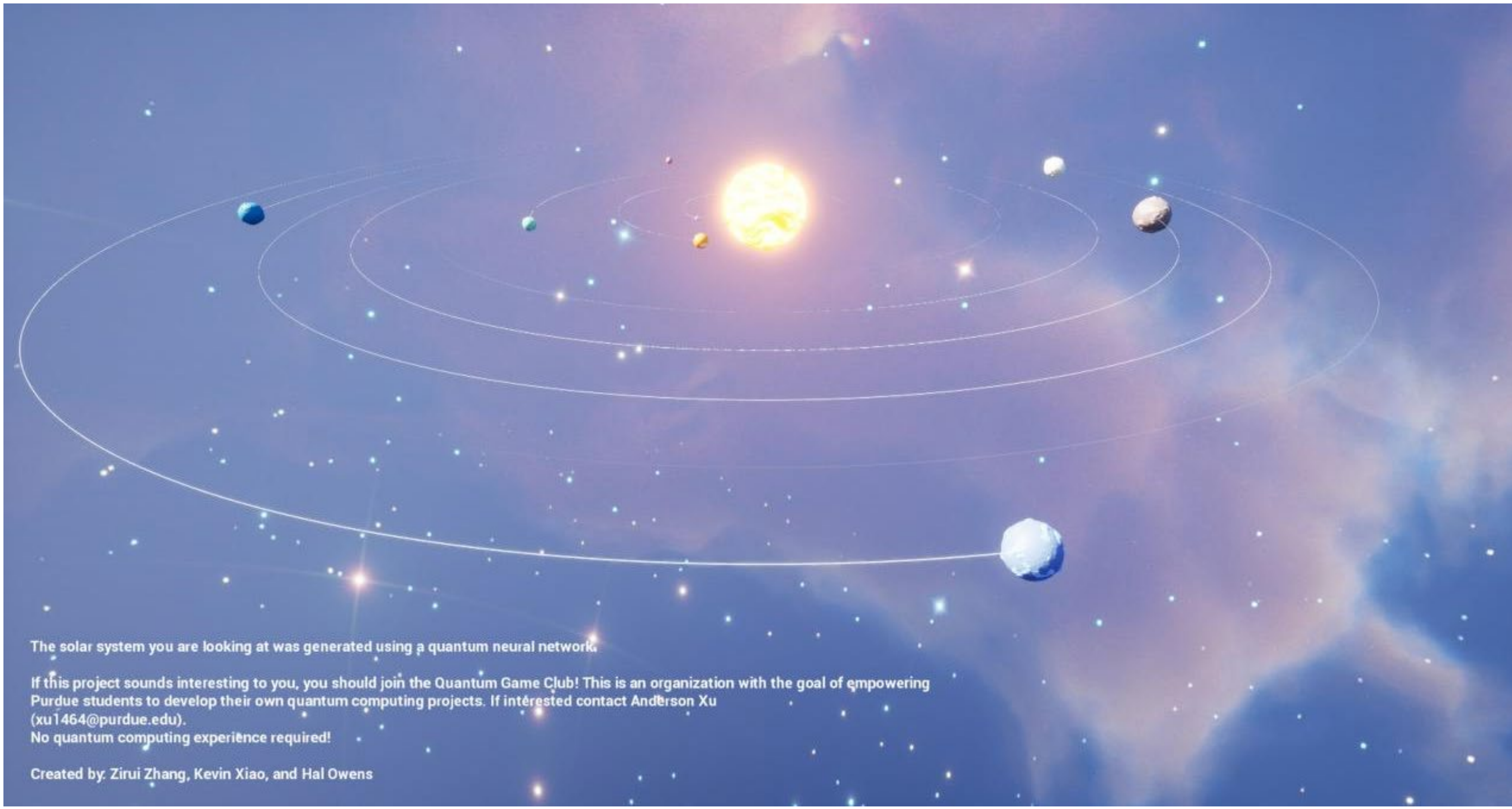
- Collaboration Northwestern University
- Quantum Hackathons
  - MIT
  - Chicago Quantum Exchange
- Qiskit Fall Fest
- Purdue Quantum Open House
- Women's Quantum Workshop
- Vertically Integrated Project (VIP)

Past/Ongoing Projects Overview

- Quantum Art
- Quantum Games
- Quantum Simulation
- Quantum Optimization
- Quantum Machine Learning
  - Quantum Convolutional Neural Network
  - Quantum Bayesian Network
  - Quantum Neuromorphic Computing

Quantum Art

Visualizing the noise in a real quantum machine via Blender and Qiskit



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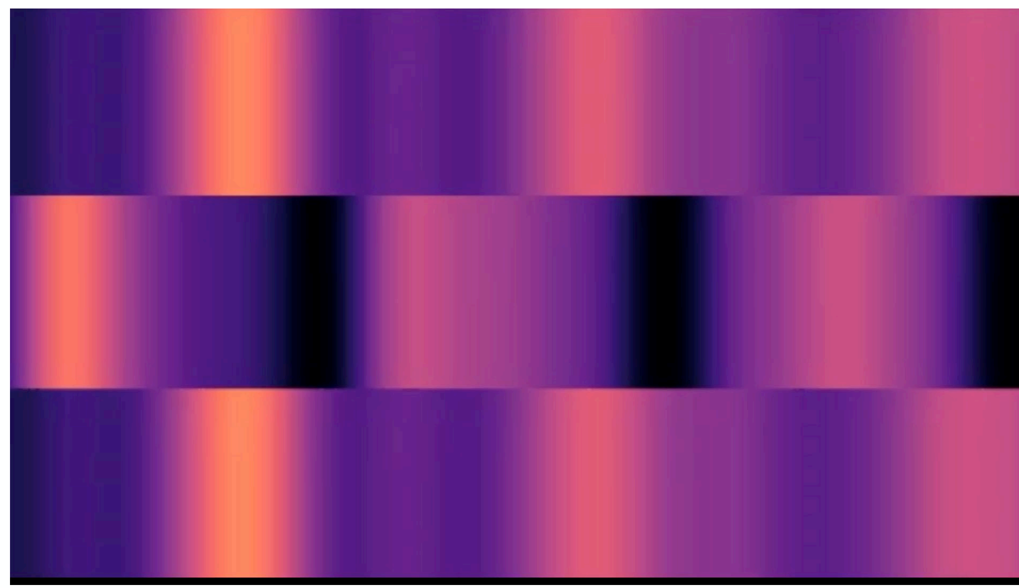
Quantum Art

Explaining advanced quantum phenomena using story telling

- A jazz bandleader wants to create the most modern, cutting-edge, CHAOTIC music he can. But various quantum phenomena are standing in his way…
  - Quantum Entanglement
  - Quantum Scar
  - Anderson Localization

|QuEra⟩ Computing Inc.

Qiskit



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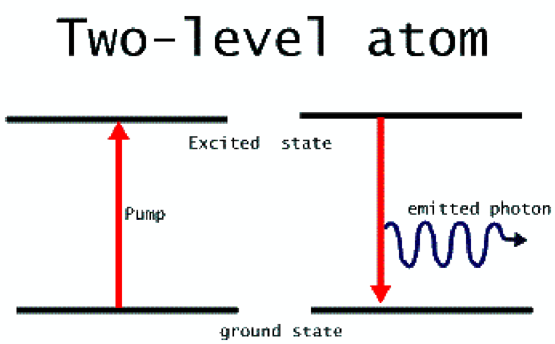
Past/Ongoing Project Overview

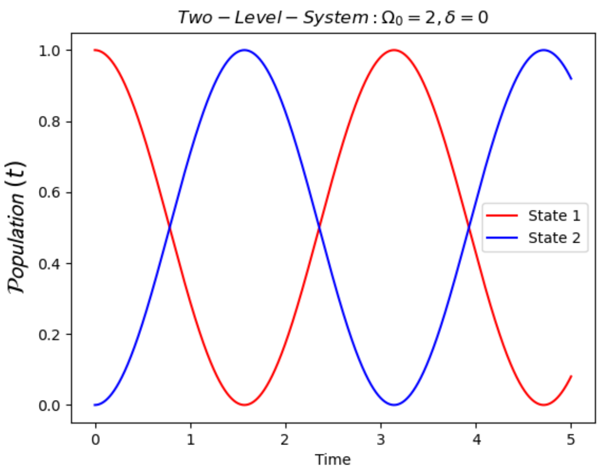
Quantum Game

Stimulated Raman Adiabatic Passage (STIRAP)

- The laser light is tuned to match the energy difference between the ground state and the excited state.
- The population of the system can be described by the following time-dependent Schrödinger's equation

$$i\hbar\frac{\partial}{\partial t}|\Psi(t)\rangle = \frac{\hbar}{2}\begin{pmatrix} \delta & \Omega_0 \\ \Omega_0 & -\delta \end{pmatrix}|\Psi(t)\rangle$$





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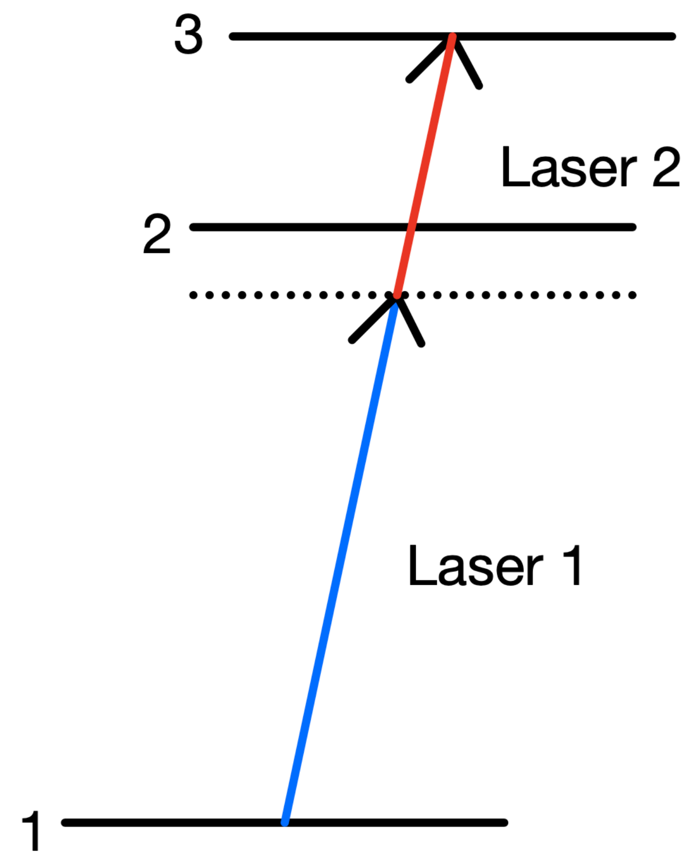
Quantum Game

Stimulated Raman Adiabatic Passage (STIRAP) — Step up the difficulty

Now we have three levels…

$$i\frac{\partial}{\partial t}|\Psi(t)\rangle = \begin{pmatrix} 0 & \frac{1}{2}\Omega_P(t) & 0 \\ \frac{1}{2}\Omega_P(t) & -\Delta & \frac{1}{2}\Omega_S(t) \\ 0 & \frac{1}{2}\Omega_S(t) & 0 \end{pmatrix}|\Psi(t)\rangle$$

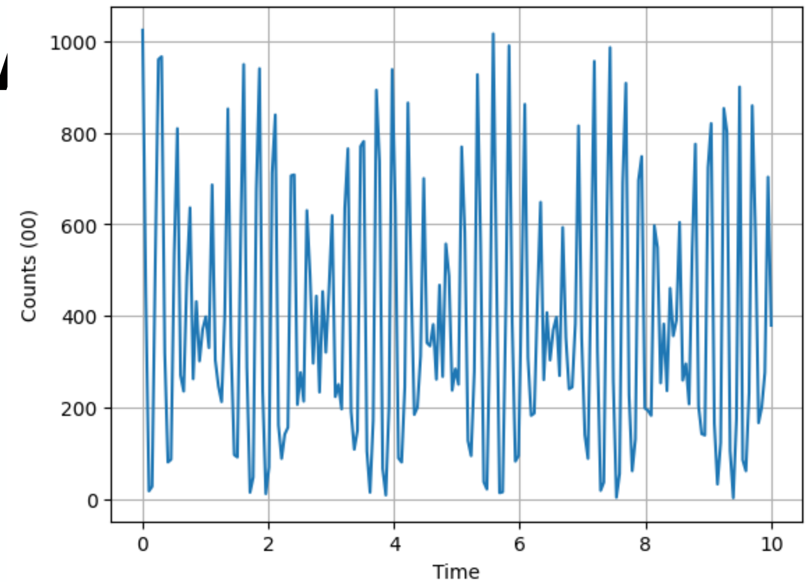
Play the game online!

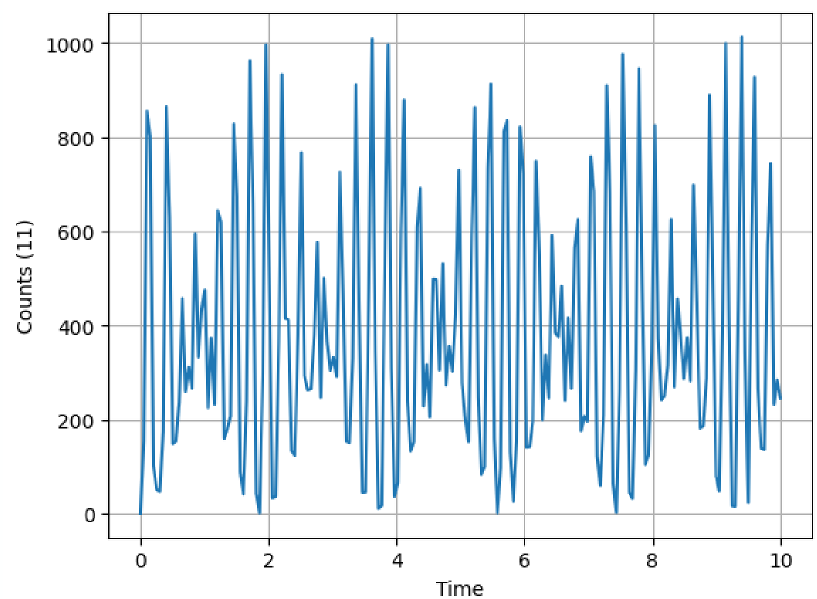


Hamiltonian Simulation

Transverse Field Ising Model

- a lattice of spins that can be in either an "up" or "down" state.
- Spins interact with each other through the Ising interaction, which is a pairwise coupling between adjacent spins.
- In addition to the interaction term, there is a transverse magnetic field acting perpendicular to the direction of the spins.
- Interactive tool in development.

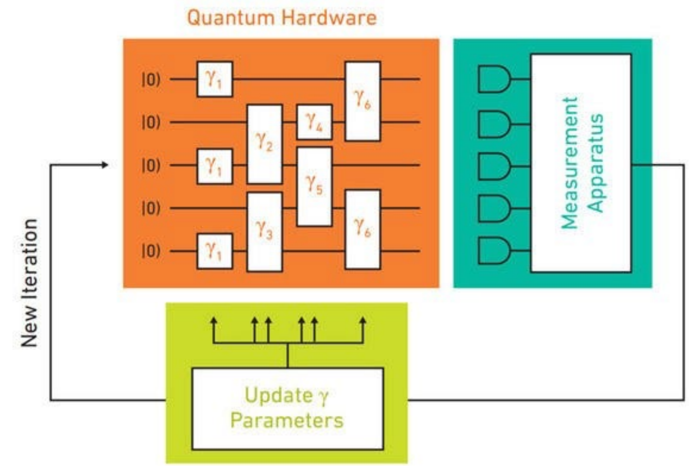


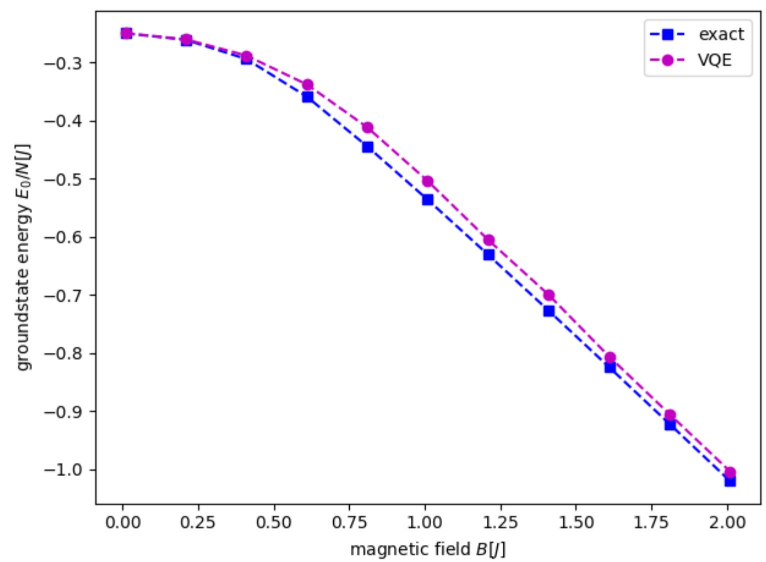


Hamiltonian Simulation

Solving Transverse Field Ising Model Usi

- The VQE algorithm belongs to the class of hybrid quantum algorithms, that are widely believed to be the working horse for the current NISQ (noisy intermediate-scale quantum) era.
- VQE can be used to calculate the ground state energy of molecular systems, optimize the geometry of molecules, predict reaction mechanisms, etc.



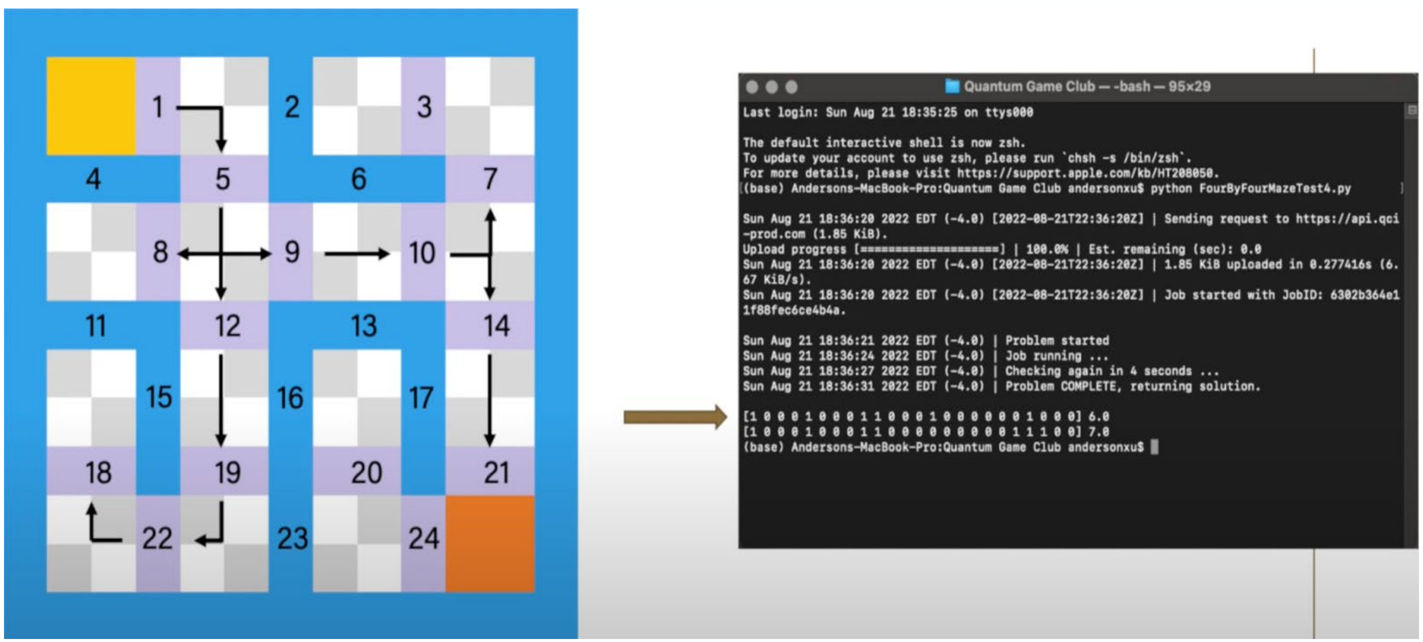


Quantum Optimization

Solving an arbitrary maze

QCi QUANTUM COMPUTING INC.

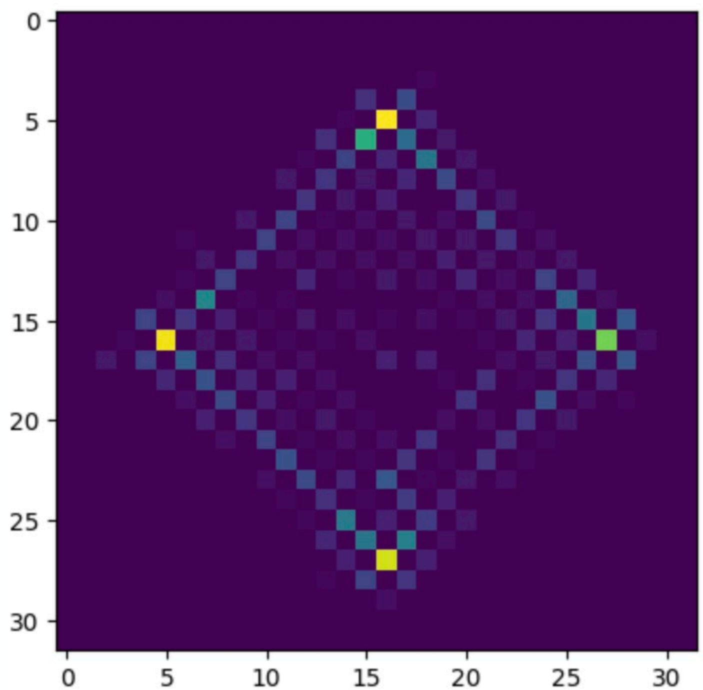
- The maze is traversed and mapped into a spanning tree and then transformed into a set of linear constraint functions. The constraint functions and an objective matrix are used to optimize the solution using Qatalyst.



Quantum Optimization

Expanding to more graph problems

- Quantum random walk for graph coloring problem.



- Proposal to utilize quantum computing for energy grid optimization currently competing in the DoE EnergyTech University Prize 2024 Challenge.

- Further topics of interest
  - Traveling Salesman Problem using Grover's search
  - Quantum Max-Cut Problem

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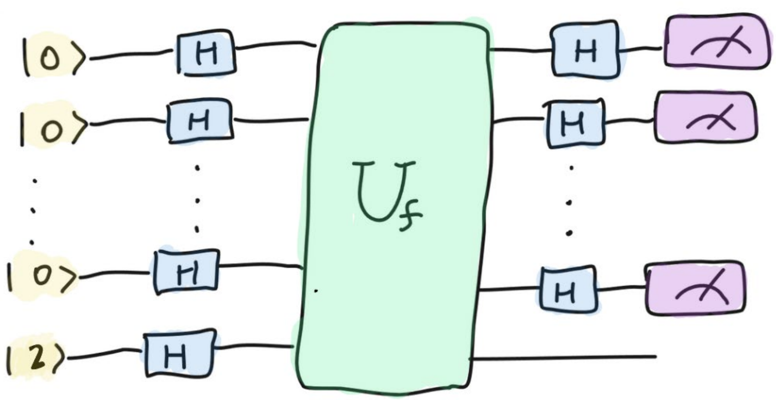
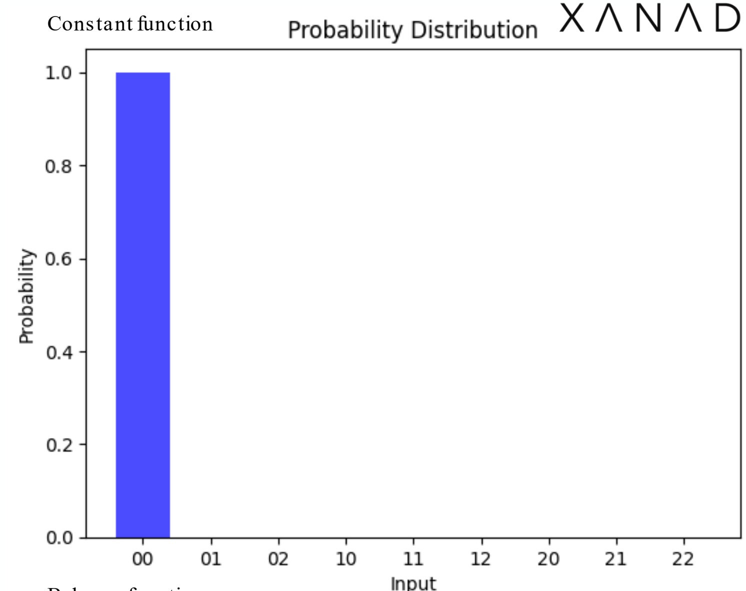
Expanding to Higher Level Systems

Deutsch-Jozsa Algorithm using Qutrits

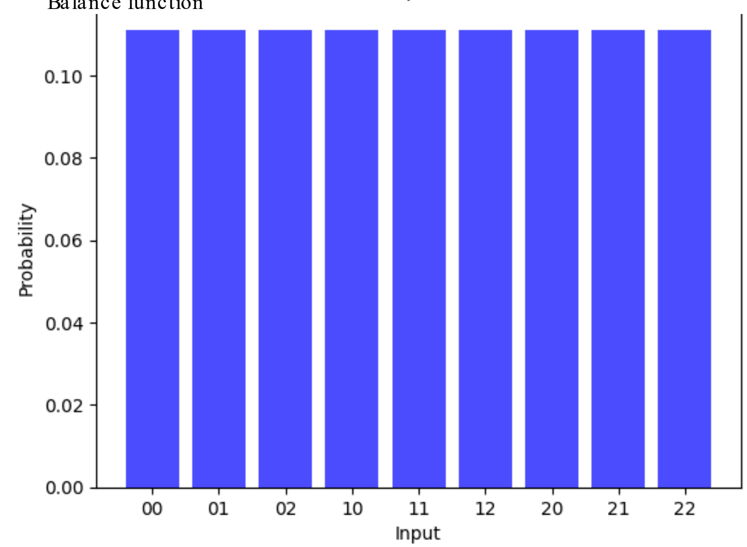
- Used to determine if a given function is constant (output is the same for all inputs) or balanced (outputs 0 for half the inputs and 1 for the other half).



Constant function



Balance function



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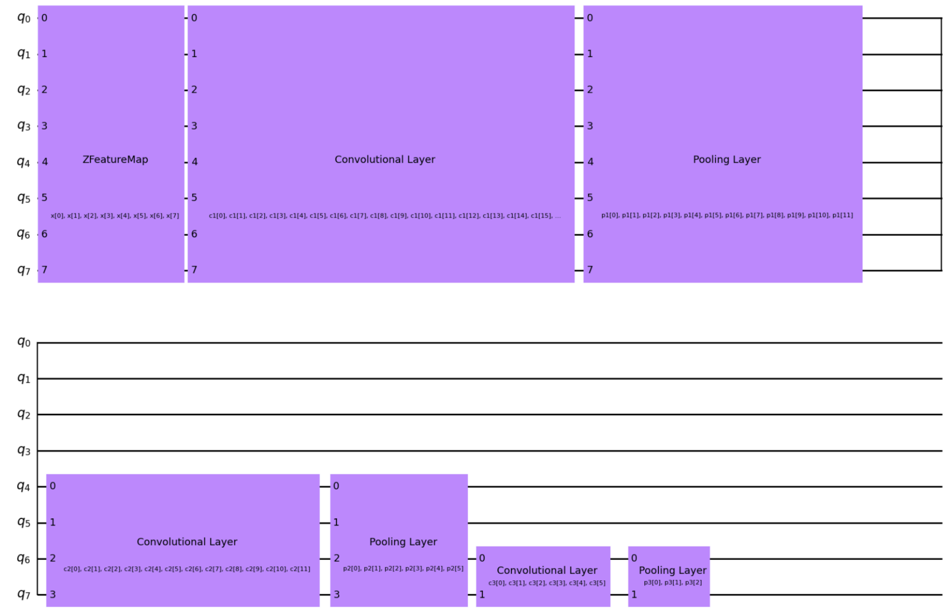
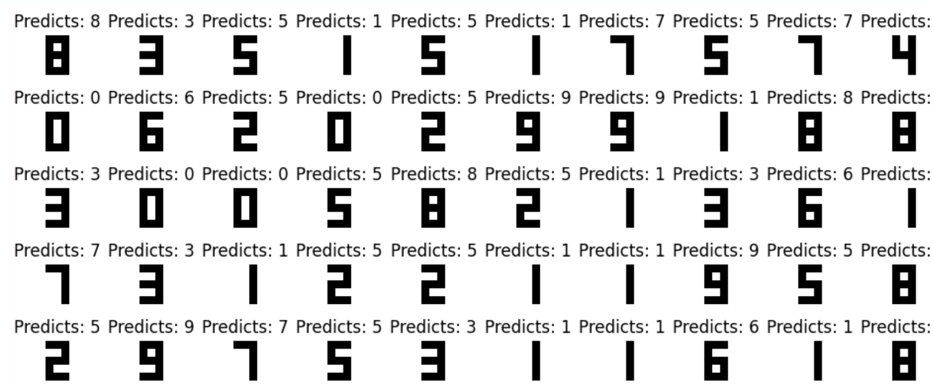
Quantum Machine Learning

Quantum Convolutional Neural Net

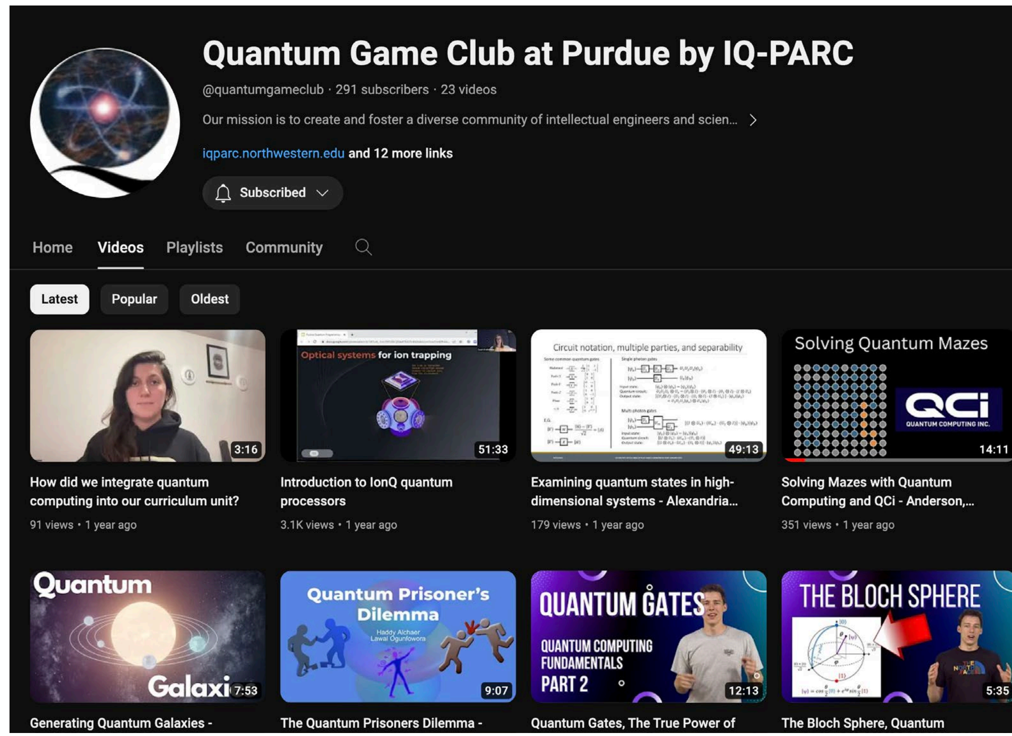
- Using QCNN to classify digits and shapes.
- Capabilities limited by qubits available.





Digital Library

- Github Repo:
  - https://github.com/IQPARC
- YouTube Channel
  - @quantumgameclub



Thank You

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