



IonQ iQuHack2025 Challenge

Before proceeding, register once. Then, comment out the registration function call to avoid re-registering when running the notebook again.

```
In [7]: import requests

def register():
    team_name = input("Enter your team name: ")
    in_person = input("Enter participation type - in-person or remote: ")
    data = []

    while email := input("Enter email separated by commas (enter to cancel): "):
        firstname = input("Enter your first name: ")
        lastname = input("Enter your last name: ")
        github = input("Enter your github handle: ")
        data.append((firstname, lastname, email, github))

    for firstname, lastname, email, github in data:
        url = f"https://ionquhack2025.azurewebsites.net/api/registration?TeamName={
        req = requests.post(url)
        print("\n\n\n"+req.text)

# Comment this out after registration:
# register()
```

Enter the `key` you've got on the previous step here:

```
In [27]: key = "61f7aaaf50e899e65f777e0e159408b5335faf68fd58ee21d8941de1907d3cfb"
```

Did you comment out the `register()` function call?

Please share your research process on GitHub: <https://github.com/iQuHACK/2025-IonQ/discussions>

Maximum Cut problem (max-cut) with variational Quantum Imaginary Time Evolution (varQITE) method

In this challenge, we demonstrate how to leverage [IonQ Forte](#)'s industry-leading capabilities to solve instances of the [NP-hard](#) combinatorial optimization problem known as [Maximum Cut \(MaxCut\)](#) using a [novel variational Quantum Imaginary Time Evolution \(varQITE\)](#) algorithm developed by IonQ in conjunction with researchers at Oak Ridge National Labs (ORNL).

What's the problem?

MaxCut 101

The Maximum Cut Problem (MaxCut) is a classic combinatorial optimization problem commonly used as an algorithm benchmark by scientific computing researchers. It has numerous applications in a variety of fields: for example, it is used in circuit desing as part of Very Large Scale Integration (VLSI) to find the optimal layout of circuit components; it is used in the study of social networks to identify communities; it is used in computer vision for image segmentation, etc.

MaxCut is a graph problem: given a graph $G = (V, E)$ with vertex set V and edge set E , it asks for a partition of V into sets S and T maximizing the number of edges crossing between S and T .

Think of it like this: you're trying to cut the graph into two pieces, and you want to make the cut so that it slices through as many edges as possible.

Prepare the code environment

First, we'll set up the coding environment and install necessary dependencies.

```
In [1]: pip install qiskit qiskit-aer networkx numpy pandas -q
```

Note: you may need to restart the kernel to use updated packages.

To ensure your code runs correctly everywhere, please only use the imported dependencies. Using external libraries may cause your submission to fail due to missing dependencies on our servers.

```
In [2]: ## IonQ, Inc., Copyright (c) 2025,  
## All rights reserved.  
## Use in source and binary forms of this software, without modification,  
## is permitted solely for the purpose of activities associated with the IonQ
```

```
# Hackathon at iQuHack2025 hosted by MIT and only during the Feb 1-2, 2025
# duration of such event.
```

```
import matplotlib.pyplot as plt
from IPython import display

import networkx as nx
import numpy as np
import pandas as pd
import time

from typing import List
from qiskit import QuantumCircuit, transpile
from qiskit.circuit import ParameterVector
from qiskit.quantum_info import SparsePauliOp
from qiskit_aer import AerSimulator
```

Graph definition

A simple graph, defined using the Python NetworkX library, will serve to illustrate the problem and you can explore further complexities.

```
In [3]: # other graphs candidates to check

import networkx as nx
import matplotlib.pyplot as plt
import random

#-> Cycle Graph C8
def cycle_graph_c8():
    G = nx.cycle_graph(8)
    plt.figure(figsize=(6, 6))
    pos = nx.circular_layout(G)
    nx.draw(G, pos, with_labels=True, node_color='lightblue', edge_color='gray', no
    plt.title("Cycle Graph C8")
    plt.show()
    return G

# Path Graph P16
def path_graph_p16():
    G = nx.path_graph(16)
    plt.figure(figsize=(12, 2))
    pos = nx.spring_layout(G, seed=42)
    nx.draw(G, pos, with_labels=True, node_color='lightgreen', edge_color='gray', n
    plt.title("Path Graph P16")
    plt.show()
    return G

#-> Complete Bipartite Graph K8,8
def complete_bipartite_graph_k88():
    G = nx.complete_bipartite_graph(8, 8)
    plt.figure(figsize=(8, 6))
    pos = nx.bipartite_layout(G, nodes=range(8))
```

```

    nx.draw(G, pos, with_labels=True, node_color=['lightcoral'] * 8 + ['lightblue']
            edge_color='gray', node_size=300)
    plt.title("Complete Bipartite Graph K8,8")
    plt.show()
    return G

#-> Complete Bipartite Graph K8,8
def complete_bipartite_graph_k_nn(n):
    G = nx.complete_bipartite_graph(n, n)
    plt.figure(figsize=(8, 6))
    pos = nx.bipartite_layout(G, nodes=range(n))
    nx.draw(G, pos, with_labels=True, node_color=['lightcoral'] * n + ['lightblue']
            edge_color='gray', node_size=300)
    plt.title("Complete Bipartite Graph K{},{}".format(n,n))
    plt.show()
    return G

# Star Graph S16
def star_graph_s16():
    G = nx.star_graph(16)
    plt.figure(figsize=(8, 8))
    pos = nx.spring_layout(G, seed=42)
    nx.draw(G, pos, with_labels=True, node_color='gold', edge_color='gray', node_si
    plt.title("Star Graph S16")
    plt.show()
    return G

# Grid Graph 8x4
def grid_graph_8x4():
    G = nx.grid_graph(dim=[8, 4])
    plt.figure(figsize=(12, 6))
    pos = {node: node for node in G.nodes()}
    nx.draw(G, pos, with_labels=True, node_color='lightblue', edge_color='gray', no
    plt.title("Grid Graph 8x4")
    plt.show()
    return G

# Grid Graph 8x4
def grid_graph_nxm(n,m):
    G = nx.grid_graph(dim=[n, m])
    plt.figure(figsize=(12, 6))
    pos = {node: node for node in G.nodes()}
    nx.draw(G, pos, with_labels=True, node_color='lightblue', edge_color='gray', no
    plt.title("Grid Graph {}x{}".format(n,m))
    plt.show()
    return G

#-> 4-Regular Graph with 8 Vertices
def regular_graph_4_8():
    G = nx.random_regular_graph(d=4, n=8, seed=42)
    plt.figure(figsize=(6, 6))
    pos = nx.circular_layout(G)
    nx.draw(G, pos, with_labels=True, node_color='lightgreen', edge_color='gray', n
    plt.title("4-Regular Graph with 8 Vertices")
    plt.show()

```

```

    return G

#-> Cubic (3-Regular) Graph with 16 Vertices
def cubic_graph_3_16():
    G = nx.random_regular_graph(d=3, n=16, seed=42)
    plt.figure(figsize=(8, 6))
    pos = nx.spring_layout(G, seed=42)
    nx.draw(G, pos, with_labels=True, node_color='lightcoral', edge_color='gray', n
    plt.title("Cubic (3-Regular) Graph with 16 Vertices")
    plt.show()
    return G

# Disjoint Union of Four C4 Cycles
def disjoint_union_c4():
    cycles = [nx.cycle_graph(4) for _ in range(4)]
    G = nx.disjoint_union_all(cycles)
    plt.figure(figsize=(12, 6))
    pos = {}
    shift_x = 0
    for component in nx.connected_components(G):
        subgraph = G.subgraph(component)
        pos_sub = nx.circular_layout(subgraph, scale=1, center=(shift_x, 0))
        pos.update(pos_sub)
        shift_x += 3
    nx.draw(G, pos, with_labels=True, node_color='lightblue', edge_color='gray', no
    plt.title("Disjoint Union of Four C4 Cycles")
    plt.show()
    return G

# Complete Bipartite Graph K16,16
def complete_bipartite_graph_k1616():
    G = nx.complete_bipartite_graph(16, 16)
    plt.figure(figsize=(12, 6))
    pos = nx.bipartite_layout(G, nodes=range(16))
    nx.draw(G, pos, with_labels=False, node_color=['lightcoral'] * 16 + ['lightblue
        edge_color='gray', node_size=100)
    plt.title("Complete Bipartite Graph K16,16")
    plt.show()
    return G

# 5-Dimensional Hypercube Graph Q5
def hypercube_graph_q5():
    G = nx.hypercube_graph(5)
    plt.figure(figsize=(10, 8))
    pos = nx.spring_layout(G, seed=42)
    nx.draw(G, pos, with_labels=False, node_color='lightgreen', edge_color='gray',
    plt.title("5-Dimensional Hypercube Graph Q5")
    plt.show()
    return G

# Tree Graph with 8 Vertices
def tree_graph_8():
    G = nx.balanced_tree(r=2, h=2)
    G.add_edge(6, 7)
    plt.figure(figsize=(8, 6))
    pos = nx.spring_layout(G, seed=42)

```

```

    nx.draw(G, pos, with_labels=True, node_color='lightblue', edge_color='gray', no
plt.title("Tree Graph with 8 Vertices")
plt.show()
    return G

# Wheel Graph W16
def wheel_graph_w16():
    G = nx.wheel_graph(16)
    plt.figure(figsize=(8, 8))
    pos = nx.circular_layout(G)
    nx.draw(G, pos, with_labels=True, node_color='lightcoral', edge_color='gray', n
plt.title("Wheel Graph W16")
plt.show()
    return G

#-> Random Connected Graph with 16 Vertices
def random_connected_graph_16(p=0.15):
    #n, p = 16, 0.25
    n=16
    while True:
        G = nx.erdos_renyi_graph(n, p, seed=random.randint(1, 10000))
        if nx.is_connected(G):
            break
    plt.figure(figsize=(10, 8))
    pos = nx.spring_layout(G, seed=42)
    nx.draw(G, pos, with_labels=False, node_color='lightgreen', edge_color='gray',
plt.title("Random Connected Graph with 16 Vertices")
plt.show()
    return G

# Expander Graph with 32 Vertices
def expander_graph_32():
    G = nx.random_regular_graph(4, 32, seed=42)
    plt.figure(figsize=(10, 8))
    pos = nx.spring_layout(G, seed=42)
    nx.draw(G, pos, with_labels=False, node_color='lightblue', edge_color='gray', n
plt.title("Expander Graph with 32 Vertices")
plt.show()
    return G

#-> Expander Graph with n Vertices
def expander_graph_n(n):
    G = nx.random_regular_graph(4, n, seed=42)
    plt.figure(figsize=(10, 8))
    pos = nx.spring_layout(G, seed=42)
    nx.draw(G, pos, with_labels=False, node_color='lightblue', edge_color='gray', n
plt.title("Expander Graph with {} Vertices".format(n))
plt.show()
    return G

# Planar Connected Graph with 16 Vertices
def planar_connected_graph_16():
    G = nx.grid_graph(dim=[8, 2])
    G = nx.convert_node_labels_to_integers(G)
    additional_edges = [(0, 9), (1, 10), (2, 11), (3, 12), (4, 13), (5, 14), (6, 15
                        (7, 15), (8, 7)]#, (6, 15), (14, 1), (1, 13), (10, 9), (0,

```

```

G.add_edges_from([e for e in additional_edges if e[0] < 16 and e[1] < 16])
assert nx.check_planarity(G)[0], "Graph is not planar."
pos = {node: (node // 2, node % 2) for node in G.nodes()}
plt.figure(figsize=(16, 8))
nx.draw(G, pos, with_labels=False, node_color='lightcoral', edge_color='gray',
plt.title("Planar Connected Graph with 16 Vertices")
plt.axis('equal')
plt.show()
return G

```

We've suggested a few graph ideas above.

The list below highlights those achievable with minimal computational resources, whether on a local laptop or a cloud instance. Some are simply too large.

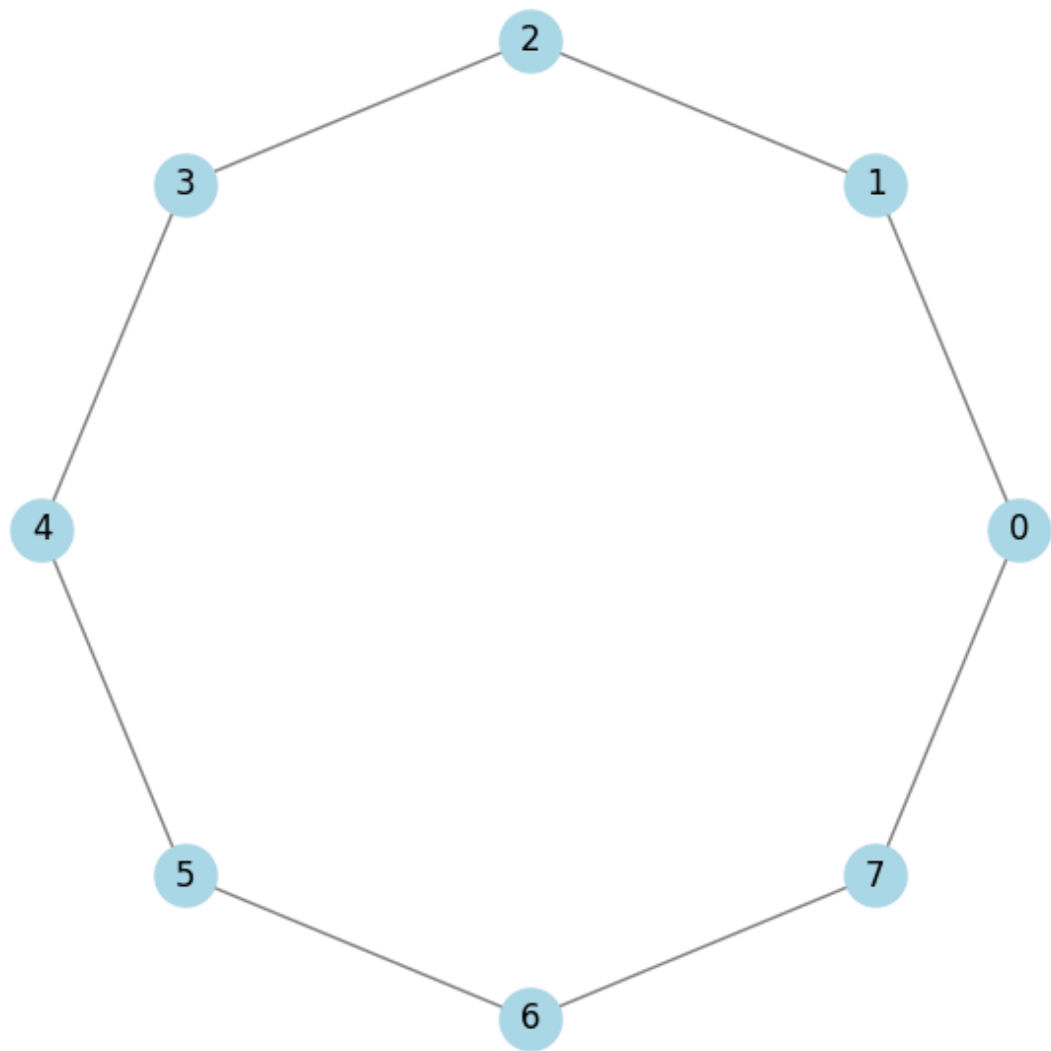
In [4]: *# Choose your favorite graph and build your winning ansatz!*

```

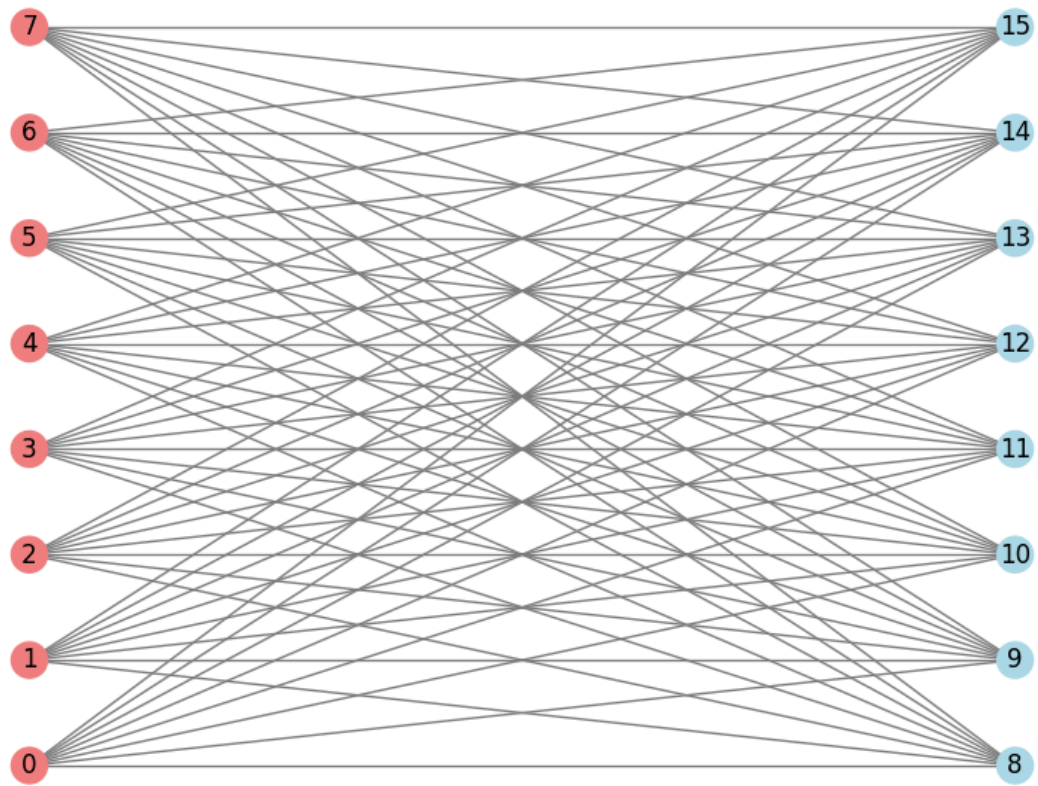
graph1 = cycle_graph_c8()
graph2 = complete_bipartite_graph_k88()
graph3 = complete_bipartite_graph_k_nn(5)
graph4 = regular_graph_4_8()
graph5 = cubic_graph_3_16()
graph6 = random_connected_graph_16(p=0.18)
graph7 = expander_graph_n(16)
#graph8 = -> make your own cool graph

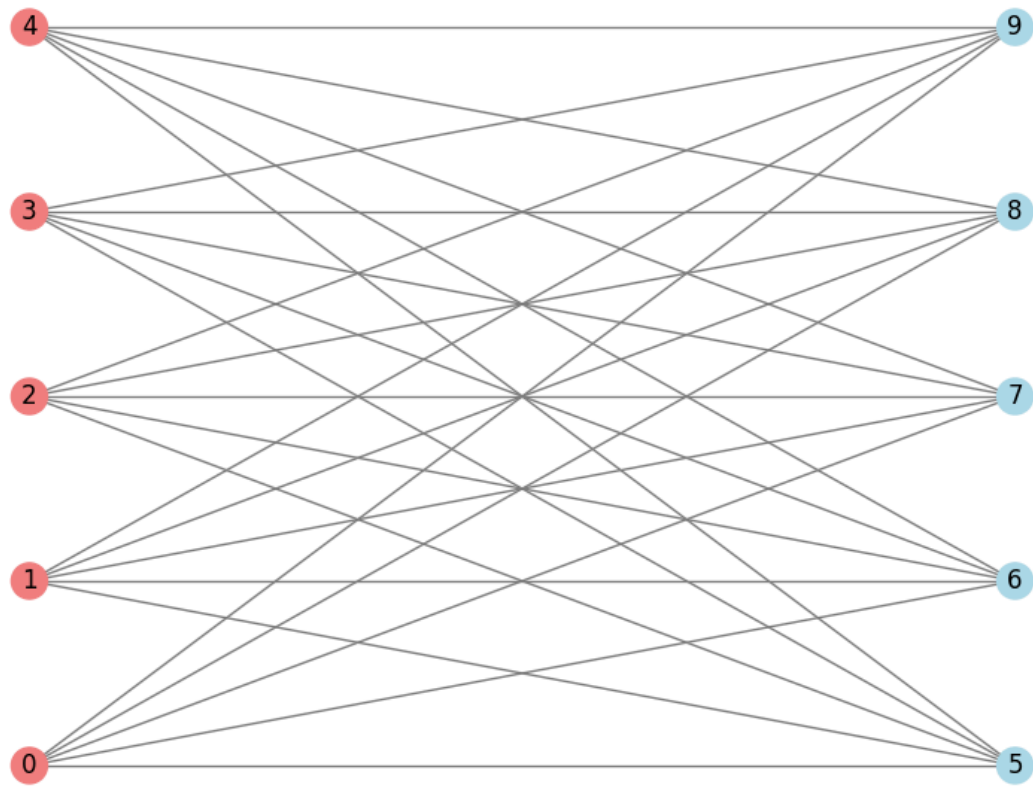
```

Cycle Graph C8

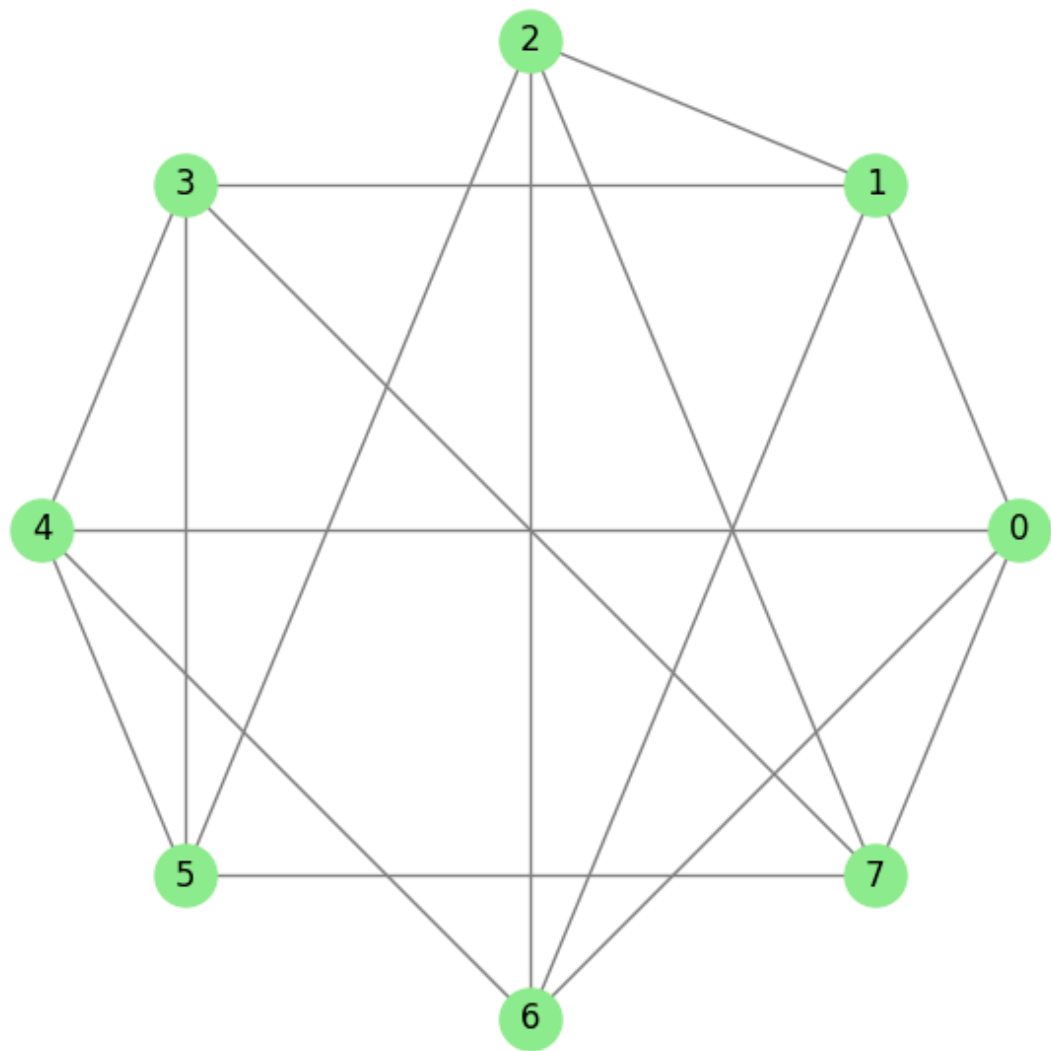


Complete Bipartite Graph K8,8

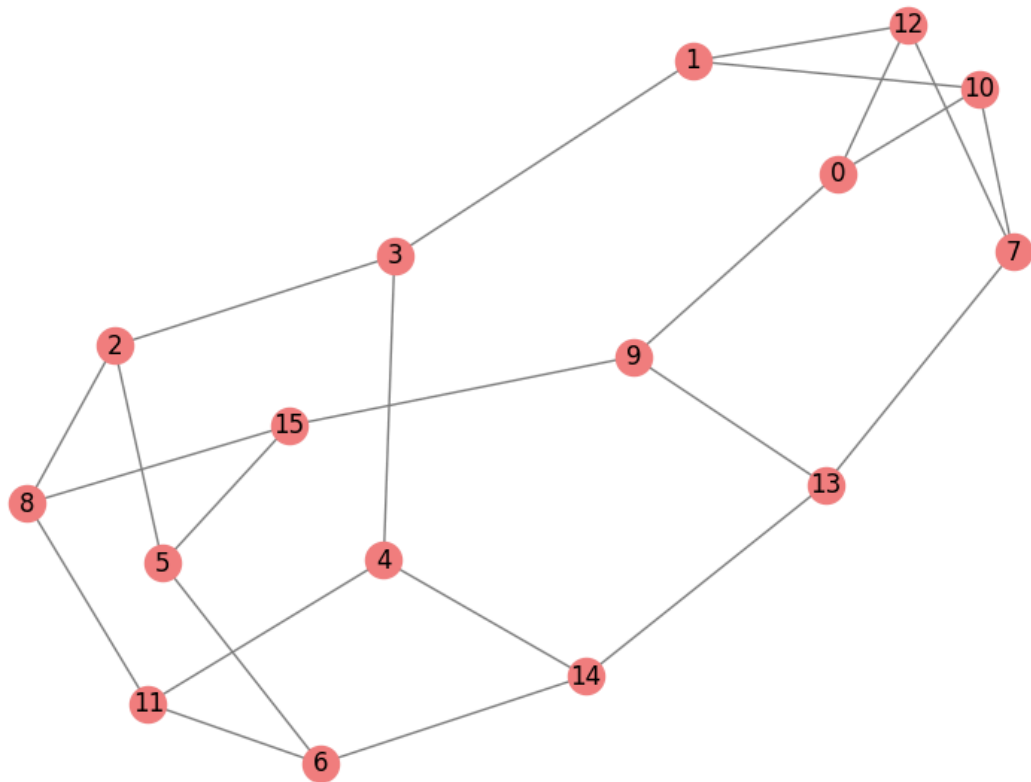


Complete Bipartite Graph $K_{5,5}$ 

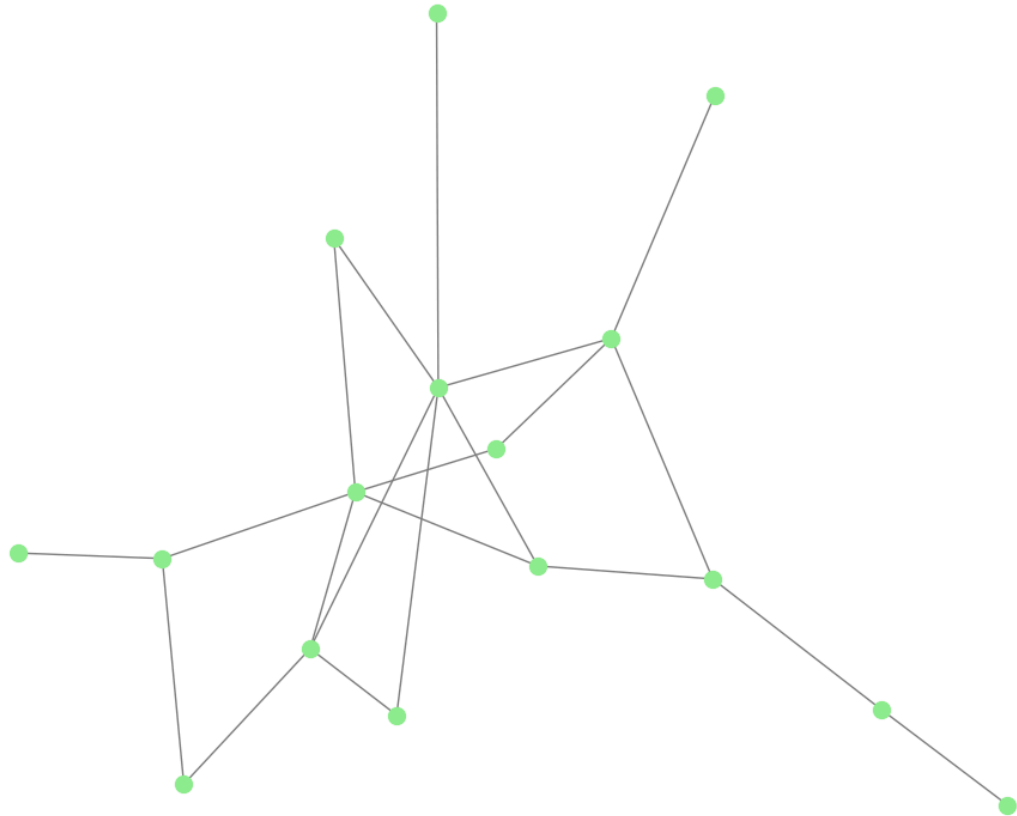
4-Regular Graph with 8 Vertices



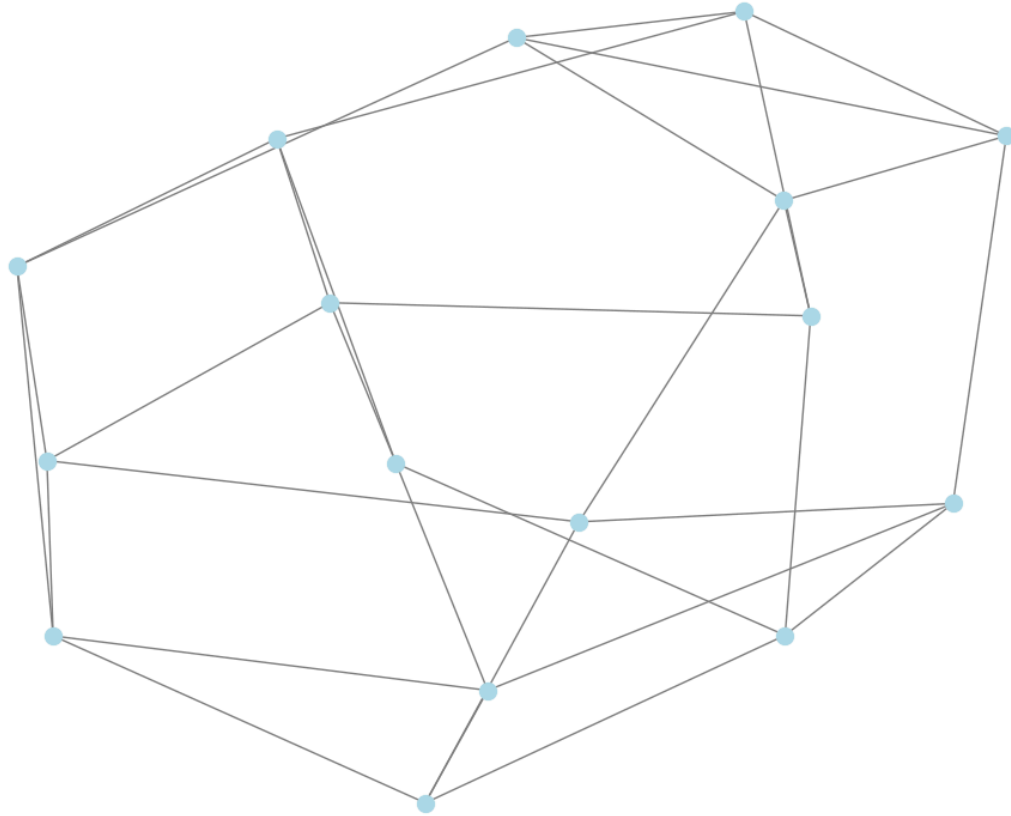
Cubic (3-Regular) Graph with 16 Vertices



Random Connected Graph with 16 Vertices



Expander Graph with 16 Vertices



Input graph

```
In [175... graph = graph2
graph
```

```
Out[175... <networkx.classes.graph.Graph at 0x208513ade90>
```

Play around with all of them

Quantum Circuit Generator

We start by generating parameterized circuit based on a given graph.

🤖 Note: Future experiments will focus on optimizing this circuit generator (this function below). Maximizing your score requires minimizing the number of gates in the generated parameterized circuit.

Set of Rules:

Rules: Do not rename the function, import external libraries (except Qiskit), or use classical solvers. Implement any needed algorithms (e.g., sorting) within the function. Minimize gate count. Run locally for all the graphs before submitting the results.

Let's iterate again.

This challenge requires you to work within the provided function's name and scope. You may only use Qiskit libraries. Do not import additional libraries or call external functions. If your solution requires operations like sorting, implement them directly within the function. Critically, do *not* use a classical algorithm to solve the problem and simply input the result. Optimize your code to minimize the number of quantum gates, while aiming for the correct solutions distribution. Thoroughly get your solution results to report at the end.

Important note: To confirm your results, please save this notebook including all cell outputs and upload it in the form here: <https://forms.gle/tAjnUd7b5t3oX3b2A> . To avoid exceeding the notebook's 10MB file size limit, please be mindful of the number of print statements you use. Feel free to modify the notebook as needed. However, please ensure your code is readable. Please thoroughly comment your code; we will evaluate your problem-solving approach based on the educational clarity of your explanations.

Good luck, and have fun!

In [176...

```
# Visualization will be performed in the cells below;

def build_ansatz(graph: nx.Graph) -> QuantumCircuit:

    ansatz = QuantumCircuit(graph.number_of_nodes())
    ansatz.h(range(graph.number_of_nodes()))

    theta = ParameterVector(r"$\theta$", graph.number_of_edges())
    for t, (u, v) in zip(theta, graph.edges):
        ansatz.cx(u, v)
        ansatz.ry(t, v)
        ansatz.cx(u, v)

    return ansatz
```

In [177...

```
# alternate method to make the ansatz

# function to generate a maximum spanning tree of the graph
def generate_max_spanning_tree(G):
    # for u, v in G.edges:
    #     G[u][v]['weight'] *= -1
    return nx.minimum_spanning_tree(G, algorithm='kruskal')

# function to return the graph with the spanning tree edges removed
def remove_spanning_tree_edges(G, T):
    H = G.copy()
    for edge in T.edges:
```

```
H.remove_edge(*edge)
return H
```

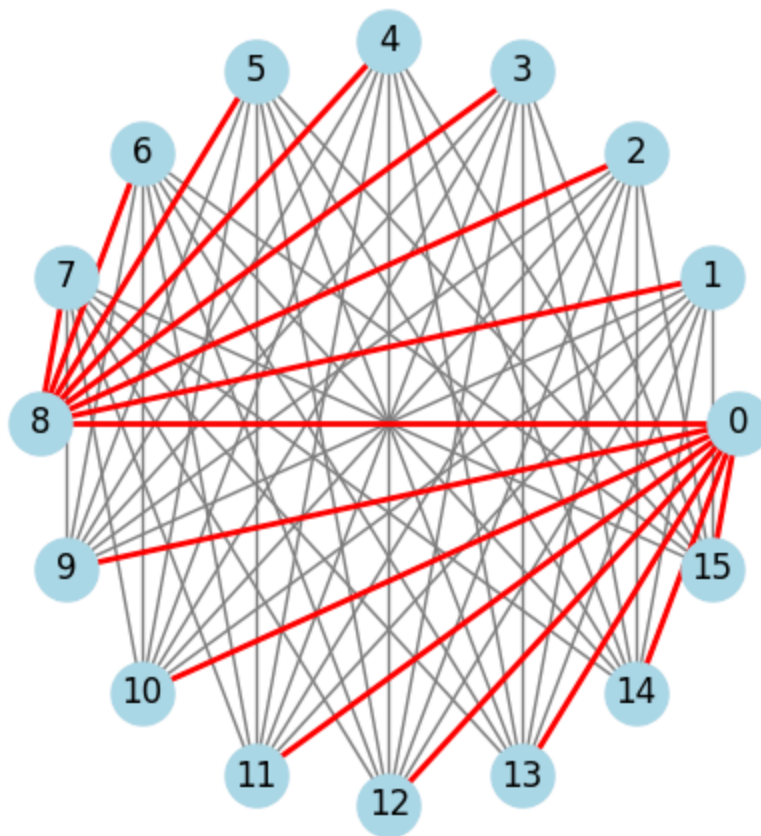
```
In [178... # get the maximum spanning tree of the graph by negating all the edge weights and c
T = generate_max_spanning_tree(graph)

# remove the edges of the spanning tree from the graph
H = remove_spanning_tree_edges(graph, T)

# visualize the tree and the graph with the tree edges removed
plt.figure(figsize=(12, 6))
plt.subplot(121)
pos = nx.circular_layout(graph)
nx.draw(graph, pos, with_labels=True, node_color='lightblue', edge_color='gray', no
nx.draw_networkx_edges(T, pos, edge_color='red', width=2)
plt.title("Graph with Maximum Spanning Tree")
```

```
Out[178... Text(0.5, 1.0, 'Graph with Maximum Spanning Tree')
```

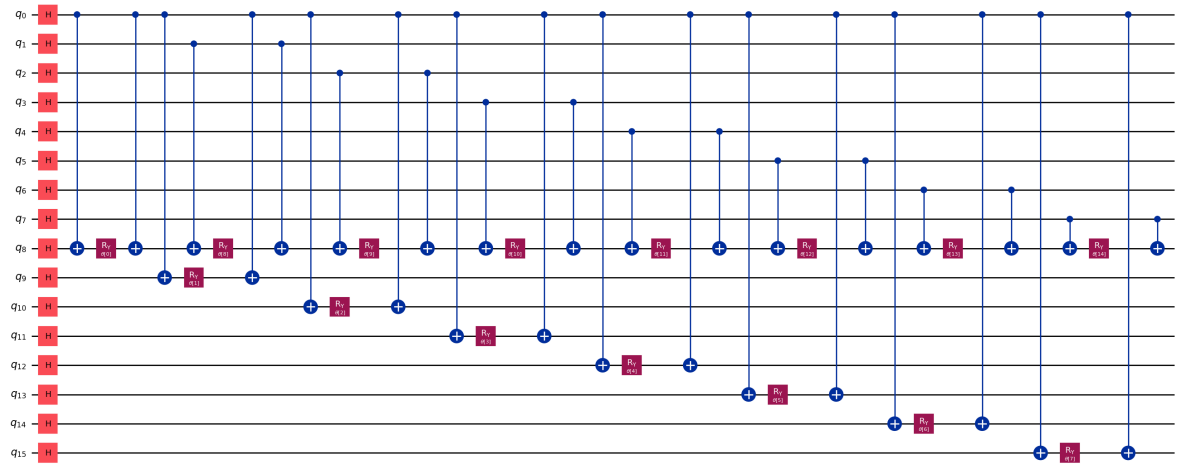
Graph with Maximum Spanning Tree



```
In [179... # build the ansatz circuit for both T and H
ansatz_T = build_ansatz(T)
ansatz_H = build_ansatz(H)
```

```
In [180... # visualize the ansatz circuit for the tree
ansatz_T.draw("mpl", fold=-1)
```

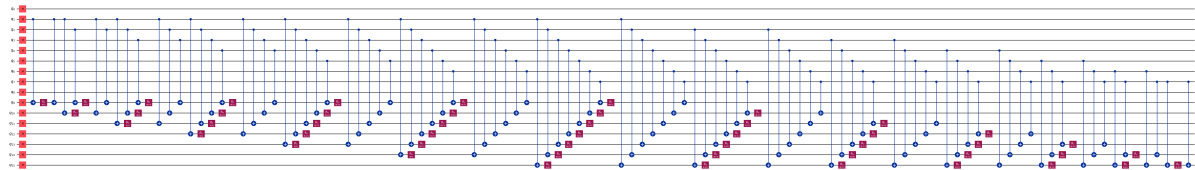

Out[180...



In [181...

```
# visualize the ansatz circuit for the graph with the tree edges removed
ansatz_H.draw("mpl", fold=-1)
```

Out[181...



On Parametrized Quantum Circuits

Parametrized quantum circuits (PQC) recently have gained significant attention as a prominent way to reach quantum advantage in many different fields. They are characterized by their use of varying parameters within quantum gates and can be optimized to solve specific problems, such as machine learning, quantum optimization, or quantum chemistry.

PQCs usually consist of three main parts:

1. Initialization: The qubits are set to a known starting state (usually $|0\rangle$) and then set into superposition with Hadamard gates.
2. Parameterized gates, such as rotation gates (R_x , R_y , R_z), and entanglement gates are adjustable. Their parameters can be optimized to reflect the relationships between the encoded problem data.
3. Measurement: After applying the parameterized gates, the qubits are measured to get results.

These circuits are important elements in Variational Quantum Algorithms (VQA), hybrid quantum-classical systems where classical optimization helps to improve quantum operations. Two most notable examples of VQAs are Variational Quantum Eigensolver (VQE), an algorithm that finds a ground state energy of a given Hamiltonian, and Quantum Approximate Optimization Algorithm (QAOA), which is designed for solving combinatorial optimization problems. Near-term quantum computers are noisy and limited in size, and PQCs provide a practical way for us to use them more effectively.

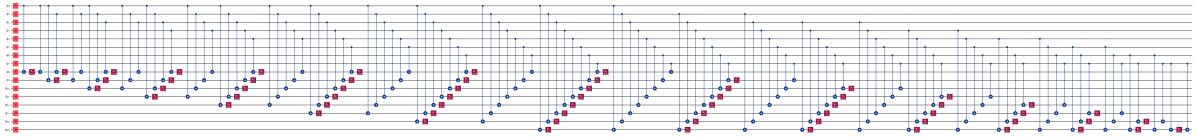
More on that topic: <https://arxiv.org/abs/2207.06850>

Back to the problem in hand

This function produces parametrized quantum circuits (PQCs), a visualization of which is provided below.

```
In [182...] ansatz = build_ansatz(graph)
ansatz.draw("mpl", fold=-1)
```

Out[182...]



Building the MaxCut Hamiltonian

Formally, we write MaxCut as a [Quadratic Program \(QP\)](#) with binary decision variables as follows. For each node $v \in V$, we let x_v denote a binary variable indicating whether v belongs to S or T . The objective is to maximize the number of cut edges:

$$\text{maximize}_x \sum_{(v,w) \in E} (x_v + x_w - 2x_v x_w)$$

Let's break this down. Notice that for each edge $e = (v, w)$ in the graph, the quantity $(x_v + x_w - 2x_v x_w)$ indicates whether e is *cut* by the partition represented by x ; that is, the quantity $(x_v + x_w - 2x_v x_w)$ is zero or one, and it equals one only if v and w lie on different sides of the partition specified by x .

The code cell below obtains a symbolic representation of the maximization objective corresponding to the graph above.

```
In [183...] def build_maxcut_hamiltonian(graph: nx.Graph) -> SparsePauliOp:
    """
    Build the MaxCut Hamiltonian for the given graph H = (|E|/2)*I - (1/2)*Σ_{(i,j)}
    """
    num_qubits = len(graph.nodes)
    edges = list(graph.edges())
    num_edges = len(edges)

    pauli_terms = ["I"*num_qubits] # start with identity
    coeffs = [-num_edges / 2]

    for (u, v) in edges: # for each edge, add -(1/2)*Z_i Z_j
        z_term = ["I"] * num_qubits
        z_term[u] = "Z"
        z_term[v] = "Z"
        pauli_terms.append("".join(z_term))
        coeffs.append(0.5)
```

```
return SparsePauliOp.from_list(list(zip(pauli_terms, coeffs)))
```

```
In [184... # get the maxcut hamiltonian for the tree
H_maxcut_T = build_maxcut_hamiltonian(T)

# get the maxcut hamiltonian for the graph with the tree edges removed
H_maxcut_H = build_maxcut_hamiltonian(H)
```

```
In [185... print(H_maxcut_T)
print(H_maxcut_H)
```

```
SparsePauliOp(['IIIIIIIIIIIIII', 'ZIIIIIIIZIIIIII', 'ZIIIIIIIZIIIIII', 'ZIIIIII
IIIZIIII', 'ZIIIIIIIIIZIIII', 'ZIIIIIIIIIIIZIII', 'ZIIIIIIIIIIIZII', 'ZIIIIIIIIII
IIZI', 'ZIIIIIIIIIIIIIZ', 'IZIIIIIIIZIIIIII', 'IIIZIIIIIZIIIIII', 'IIIZIIIIIZIIIIII
I', 'IIIIIZIIIZIIIIII', 'IIIIIZIIIZIIIIII', 'IIIIIZIIIZIIIIII', 'IIIIIIIZIIIIIIII'],
coeffs=[-7.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j,
0.5+0.j,
0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j,
0.5+0.j, 0.5+0.j])
SparsePauliOp(['IIIIIIIIIIIIIIII', 'IZIIIIIIIZIIIIII', 'IZIIIIIIIZIIIIII', 'IZIIIIII
IIIZIIII', 'IZIIIIIIIIIZIIII', 'IZIIIIIIIIIIIZII', 'IZIIIIIIIIIIIZI', 'IZIIIIIIIIII
IIIZ', 'IIIZIIIIIIIZIIIIII', 'IIIZIIIIIIIZIIIIII', 'IIIZIIIIIIIZIIIIII', 'IIIZIIIIIIIIIZII
I', 'IIIZIIIIIIIIIZII', 'IIIZIIIIIIIIIIIZI', 'IIIZIIIIIIIIIIIZ', 'IIIZIIIIIIIZIIIIII',
'IIIZIIIIIIIZIIIIII', 'IIIZIIIIIIIZIIIIII', 'IIIZIIIIIIIZIIIIII', 'IIIZIIIIIIIZIIIIII', 'II
ZIIIIIIIIIZI', 'IIIZIIIIIIIIIIIZ', 'IIIZIIIIIIIZIIIIII', 'IIIZIIIIIIIZIIIIII', 'IIIZII
IIIZIIII', 'IIIZIIIIIIIZIIII', 'IIIZIIIIIIIZII', 'IIIZIIIIIIIIIZI', 'IIIZIIIIII
IIIZ', 'IIIZIIIIIZIIIIII', 'IIIZIIIIIZIIIIII', 'IIIZIIIIIZIIIIII', 'IIIZIIIIIIIZII
I', 'IIIZIIIIIIIZII', 'IIIZIIIIIIIIIZI', 'IIIZIIIIIIIIIZ', 'IIIZIIIIIZIIIIII',
'IIIZIIIIIZIIIIII', 'IIIZIIIIIZIIIIII', 'IIIZIIIIIZIIII', 'IIIZIIIIIIIZII', 'II
IIIZIIIIIIIZI', 'IIIZIIIIIIIIIZ', 'IIIZIIIIIZIIIIII', 'IIIZIIIIIZIIIIII', 'IIIZII
ZIIIZIIII', 'IIIZIIIIIZIIIIII', 'IIIZIIIIIZIIIIIZII', 'IIIZIIIIIZIIIIIZI', 'IIIZIIIIIZII
IIIZ'],
coeffs=[-24.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+
0.j,
0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j,
0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j,
0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j,
0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j,
0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j, 0.5+0.j,
0.5+0.j, 0.5+0.j])
```

Let's keep this function contained within its own cell, as you might need to adapt it for various max-cut problem types later.

```
In [186... ham = build_maxcut_hamiltonian(graph)
ham
```

[illegible]

As a Hamiltonian energy minimization problem

Quantum MaxCut

Quantum computers are good at finding the ground state of particle systems evolving under the action of a given Hamiltonian. In this section, we'll construct a Hamiltonian whose energies are exactly the values of the MaxCut objective function. This correspondence will effectively translate our classical combinatorial optimization problem into a quantum problem, which we'll approach using our novel heuristic.

Given an objective function $C(x)$, with domain $x \in \{0, 1\}^n$, we'll produce a Hamiltonian H_C on n qubits such that

$$H_C \backslash \text{ket} x = C(x) \backslash \text{ket} x.$$

In the last equation, $|x\rangle$ denotes the n -qubit computational basis state indexed by the bit-string $x \in \{0, 1\}^n$. Thus the last equation says each of the 2^n computational basis states is an eigenvector of H_C , and the eigenvalue corresponding to $|x\rangle$ is $C(x)$; that is, H_C is diagonal with respect to the computational basis, and its energies are the values of the objective function C .

We'll obtain the Hamiltonian H_C by replacing each x_j in the expression of $C(x)$ by the operator

$$\hat{X}_j \coloneqq \frac{1}{2}(I - Z_j),$$

where I denotes the identity operator on n qubits and Z_j denotes the [Pauli-Z](#) operator acting on the j th qubit. Notice that \hat{X}_j is diagonal with respect to the computational basis, and its eigenvalues are zero and one; in particular,

$$\hat{X}_j \ket{x} = x_j \ket{x}.$$

MaxCut Hamiltonian

When we apply the Ising map construction to the MaxCut objective

$$M(x) = \sum_{(v,w) \in E} (x_v + x_w - 2x_v x_w)$$

we obtain the Hamiltonian

$$H_M = \sum_{(v,w) \in E} (X_v + X_w - 2X_v X_w) = \frac{1}{2} \sum_{(v,w) \in E} (2I - Z_v - Z_w - (I - Z_v)(I - Z_w)) = \frac{1}{2} |$$

In the last equation, $|E|$ denotes the number of edges in the graph.

Energy minimization via QITE

Enter varQITE

With the MaxCut Hamiltonian in hand, we can turn to minimizing its energy using our [novel quantum-classical varQITE heuristic](#). Much like any Variational Quantum Algorithm (VQA), our novel varQITE method provides a recipe for iteratively updating the parameters in a variational quantum circuit to minimize the expectation value of the MaxCut Hamiltonian, measured with respect to the parametrized state.

A key novelty is that our varQITE algorithm does *not* rely on a classical optimizer to update the circuit parameters; instead, it specifies an explicit update rule based on the solution of a system linear Ordinary Differential Equations (ODEs). The ODEs relate the gradient of the variational circuit parameters to the expected value of certain operators related to the MaxCut Hamiltonian, and they are derived from an [Ehrenfest Theorem](#) that applies to [imaginary time evolution](#). For details, see Equation (5) in our [varQITE paper](#).

In any case, setting up the ODE system at each step of the algorithm requires executing a batch of quantum circuits and running some post-processing to evaluate the results.

The code cell below illustrates how to set up the variational ansatz $\ket{\Psi}(\theta)$ introduced by our [varQITE paper](#) in Equation (2). We'll set up the required circuits and the ODEs further down.

Below is simplified version of Quantum Imaginary Time Evolution (QITE). It uses a finite differences approach to estimate gradients, then performs gradient descent updates.

In [187...

```
class QITEvolver:
    """
    A class to evolve a parametrized quantum state under the action of an Ising
    Hamiltonian according to the variational Quantum Imaginary Time Evolution
    (QITE) principle described in IonQ's latest joint paper with ORNL.
    """
    def __init__(self, hamiltonian: SparsePauliOp, ansatz: QuantumCircuit):
        self.hamiltonian = hamiltonian
        self.ansatz = ansatz

        # Define some constants
        self.backend = AerSimulator()
        self.num_shots = 10000
        self.energies, self.param_vals, self.runtime = list(), list(), list()

    def evolve(self, num_steps: int, lr: float = 0.4, verbose: bool = True):
        """
        Evolve the variational quantum state encoded by ``self.ansatz`` under
        the action of ``self.hamiltonian`` according to varQITE.
        """
        curr_params = np.zeros(self.ansatz.num_parameters)
        for k in range(num_steps):
            # Get circuits and measure on backend
            iter_qc = self.get_iteration_circuits(curr_params)
            job = self.backend.run(iter_qc, shots=self.num_shots)
            q0 = time.time()
            measurements = job.result().get_counts()
            quantum_exec_time = time.time() - q0

            # Update parameters-- set up defining ODE and step forward
            Gmat, dvec, curr_energy = self.get_defining_ode(measurements)
            dcurr_params = np.linalg.lstsq(Gmat, dvec, rcond=1e-2)[0]
            curr_params += lr * dcurr_params

            # Progress checkpoint!
            if verbose:
                self.print_status(measurements)
                self.energies.append(curr_energy)
                self.param_vals.append(curr_params.copy())
                self.runtime.append(quantum_exec_time)

    def get_defining_ode(self, measurements: List[dict[str, int]]):
        """
        Construct the dynamics matrix and load vector defining the varQITE
        iteration.
        """
        # Load sampled bitstrings and corresponding frequencies into NumPy arrays
```

```

dtype = np.dtype([("states", int, (self.ansatz.num_qubits,)), ("counts", "f",
measurements = [np.fromiter(map(lambda kv: (list(kv[0]), kv[1]), res.items()),
                                dtype=dtype, count=-1)])

# Set up the dynamics matrix by computing the gradient of each Pauli word
# with respect to each parameter in the ansatz using the parameter-shift rule
pauli_terms = [SparsePauliOp(op) for op, _ in self.hamiltonian.label_iter()]
Gmat = np.zeros((len(pauli_terms), self.ansatz.num_parameters))
for i, pauli_word in enumerate(pauli_terms):
    for j, jth_pair in enumerate(zip(measurements[1::2], measurements[2::2])):
        for pm, pm_shift in enumerate(jth_pair):
            Gmat[i, j] += (-1)**pm * expected_energy(pauli_word, pm_shift)

# Set up the Load vector
curr_energy = expected_energy(self.hamiltonian, measurements[0])
dvec = np.zeros(len(pauli_terms))
for i, pauli_word in enumerate(pauli_terms):
    rhs_op_energies = get_ising_energies(pauli_word, measurements[0]["state"])
    rhs_op_energies *= get_ising_energies(self.hamiltonian, measurements[0])
    dvec[i] = -np.dot(rhs_op_energies, measurements[0]["counts"]) / self.num_parameters
return Gmat, dvec, curr_energy

def get_iteration_circuits(self, curr_params: np.array):
    """
    Get the bound circuits that need to be evaluated to step forward
    according to QITE.
    """
    # Use this circuit to estimate your Hamiltonian's expected value
    circuits = [self.ansatz.assign_parameters(curr_params)]

    # Use these circuits to compute gradients
    for k in np.arange(curr_params.shape[0]):
        for j in range(2):
            pm_shift = curr_params.copy()
            pm_shift[k] += (-1)**j * np.pi/2
            circuits += [self.ansatz.assign_parameters(pm_shift)]

    # Add measurement gates and return
    [qc.measure_all() for qc in circuits]
    return circuits

def plot_convergence(self):
    """
    Plot the convergence of the expected value of ``self.hamiltonian`` with
    respect to the (imaginary) time steps.
    """
    plt.plot(self.energies)
    plt.xlabel("(Imaginary) Time step")
    plt.ylabel("Hamiltonian energy")
    plt.title("Convergence of the expected energy")

def print_status(self, measurements):
    """
    Print summary statistics describing a QITE run.
    """
    stats = pd.DataFrame({
        "curr_energy": self.energies,

```

```

        "num_circuits": [len(measurements)] * len(self.energies),
        "quantum_exec_time": self.runtime
    })
    stats.index.name = "step"
    display.clear_output(wait=True)
    display.display(stats)

```

A few utility functions:

```

In [188... def compute_cut_size(graph, bitstring):
    """
    Get the cut size of the partition of ``graph`` described by the given
    ``bitstring``.
    """
    cut_sz = 0
    for (u, v) in graph.edges:
        if bitstring[u] != bitstring[v]:
            cut_sz += 1
    return cut_sz

```

```

In [189... def get_ising_energies(
    operator: SparsePauliOp,
    states: np.array
):
    """
    Get the energies of the given Ising ``operator`` that correspond to the
    given ``states``.
    """
    # Unroll Hamiltonian data into NumPy arrays
    paulis = np.array([list(ops) for ops, _ in operator.label_iter()]) != "I"
    coeffs = operator.coeffs.real

    # Vectorized energies computation
    energies = (-1) ** (states @ paulis.T) @ coeffs
    return energies

```

```

In [190... def expected_energy(
    hamiltonian: SparsePauliOp,
    measurements: np.array
):
    """
    Compute the expected energy of the given ``hamiltonian`` with respect to
    the observed ``measurement``.

    The latter is assumed to be a NumPy records array with fields ``states``
    --describing the observed bit-strings as an integer array-- and ``counts``,
    describing the corresponding observed frequency of each state.
    """
    energies = get_ising_energies(hamiltonian, measurements["states"])
    return np.dot(energies, measurements["counts"]) / measurements["counts"].sum()

```

```

In [191... def interpret_solution(graph, bitstring):
    """
    Visualize the given ``bitstring`` as a partition of the given ``graph``.

```



```

"""
pos = nx.spring_layout(graph, seed=42)
set_0 = [i for i, b in enumerate(bitstring) if b == '0']
set_1 = [i for i, b in enumerate(bitstring) if b == '1']

plt.figure(figsize=(4, 4))
nx.draw_networkx_nodes(graph, pos=pos, nodelist=set_0, node_color='blue', node_s
nx.draw_networkx_nodes(graph, pos=pos, nodelist=set_1, node_color='red', node_s

cut_edges = []
non_cut_edges = []
for (u, v) in graph.edges:
    if bitstring[u] != bitstring[v]:
        cut_edges.append((u, v))
    else:
        non_cut_edges.append((u, v))

nx.draw_networkx_edges(graph, pos=pos, edgelist=non_cut_edges, edge_color='gray
nx.draw_networkx_edges(graph, pos=pos, edgelist=cut_edges, edge_color='green',

nx.draw_networkx_labels(graph, pos=pos, font_color='white', font_weight='bold')
plt.axis('off')
plt.show()

```

In [192...

```

%%time

# Set up your QITEvolver and evolve!
qit_evolver = QITEvolver(ham, ansatz)
qit_evolver.evolve(num_steps=40, lr=0.1, verbose=True) # lr was 0.5

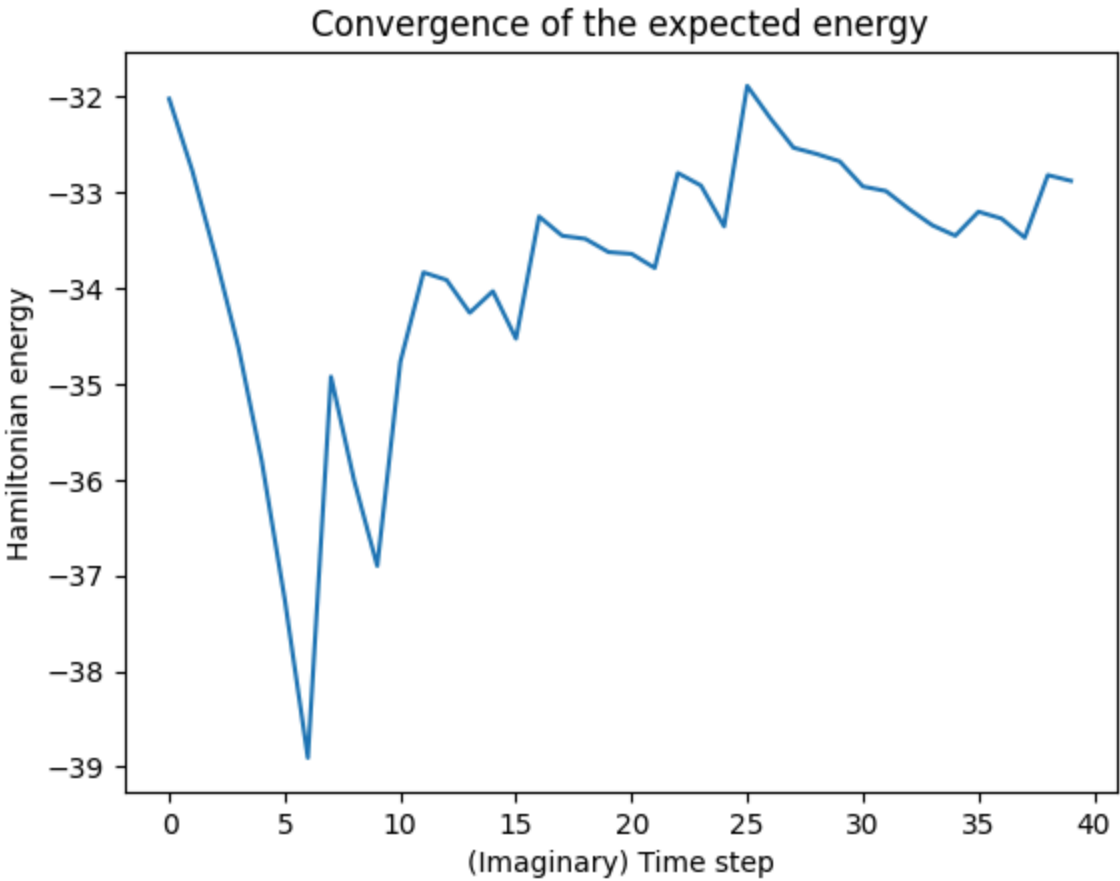
# Visualize your results!
qit_evolver.plot_convergence()

```

	curr_energy	num_circuits	quantum_exec_time
step			
0	-32.0210	129	8.496968
1	-32.7714	129	8.521482
2	-33.6638	129	8.909161
3	-34.6190	129	8.457213
4	-35.7988	129	8.056215
5	-37.2502	129	8.092783
6	-38.9064	129	7.427391
7	-34.9244	129	7.413255
8	-36.0080	129	7.330729
9	-36.9016	129	7.411046
10	-34.7674	129	7.447611
11	-33.8350	129	7.372254
12	-33.9140	129	8.304105
13	-34.2564	129	7.743254
14	-34.0314	129	7.726531
15	-34.5266	129	7.685688
16	-33.2512	129	7.716587
17	-33.4520	129	7.471822
18	-33.4842	129	7.498002
19	-33.6224	129	7.619817
20	-33.6412	129	7.690128
21	-33.7882	129	7.701979
22	-32.7966	129	7.519255
23	-32.9272	129	7.471488
24	-33.3540	129	7.394501
25	-31.8858	129	7.405335
26	-32.2240	129	7.466327
27	-32.5320	129	7.635705
28	-32.5974	129	7.589071

	curr_energy	num_circuits	quantum_exec_time
step			
29	-32.6748	129	7.455195
30	-32.9372	129	7.599163
31	-32.9848	129	7.446787
32	-33.1728	129	7.583451
33	-33.3418	129	7.632469
34	-33.4518	129	7.454536
35	-33.2008	129	7.337145
36	-33.2724	129	7.488172
37	-33.4714	129	7.488357
38	-32.8184	129	7.465259

CPU times: total: 53min 5s
Wall time: 9min 1s



```
In [193... %%time

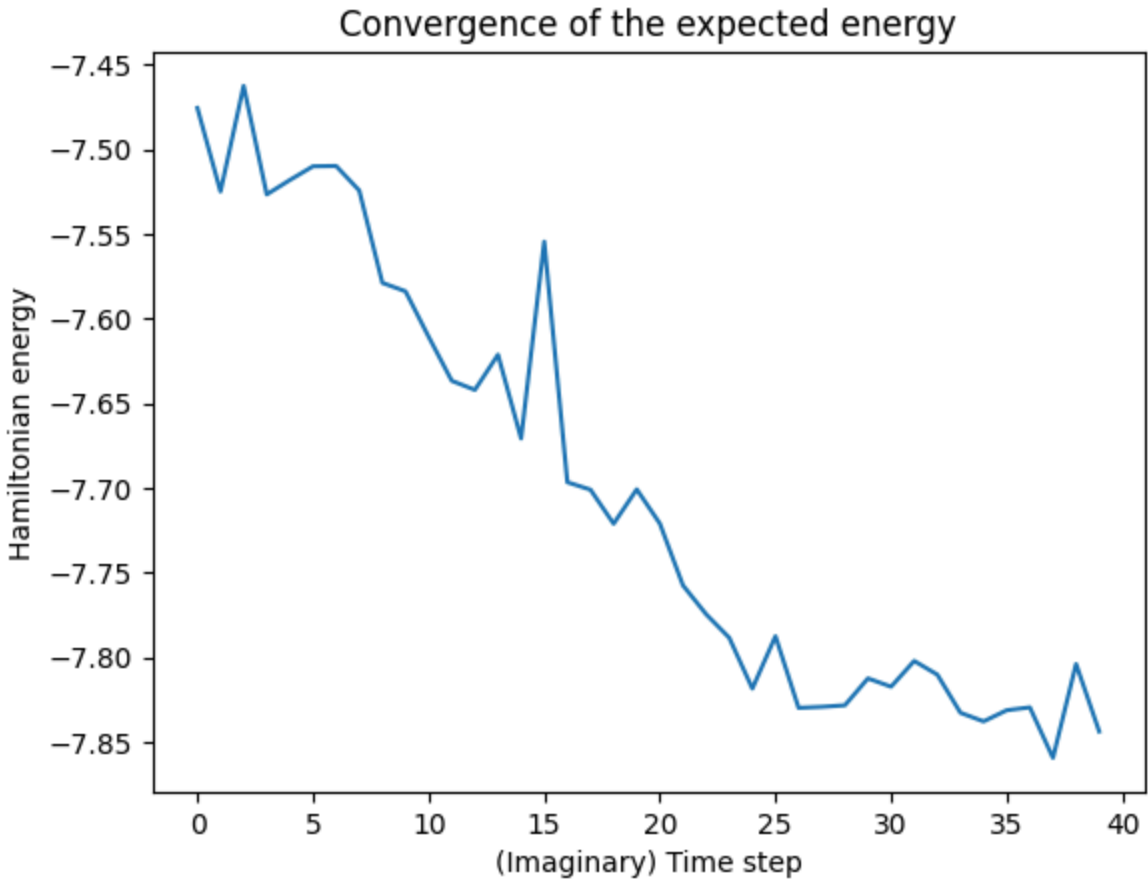
# Set up QITEvolver for the tree
qit_evolver_T = QITEvolver(H_maxcut_T, ansatz_T)
```

```
qit_evolver_T.evolve(num_steps=40, lr=0.1, verbose=True)  
  
# Visualize your results!  
qit_evolver_T.plot_convergence()
```

	curr_energy	num_circuits	quantum_exec_time
step			
0	-7.4756	31	2.030194
1	-7.5249	31	1.831772
2	-7.4625	31	1.743337
3	-7.5266	31	1.734323
4	-7.5181	31	1.413544
5	-7.5100	31	1.428574
6	-7.5098	31	1.573481
7	-7.5243	31	1.750522
8	-7.5788	31	1.296432
9	-7.5838	31	1.366805
10	-7.6106	31	1.515268
11	-7.6366	31	1.423098
12	-7.6420	31	1.683608
13	-7.6212	31	1.489899
14	-7.6707	31	1.408074
15	-7.5545	31	1.361778
16	-7.6965	31	1.517777
17	-7.7009	31	1.412985
18	-7.7210	31	1.419712
19	-7.7007	31	1.480575
20	-7.7209	31	1.533872
21	-7.7574	31	1.530904
22	-7.7744	31	1.454162
23	-7.7883	31	1.533661
24	-7.8183	31	1.616114
25	-7.7874	31	1.522295
26	-7.8297	31	1.587826
27	-7.8291	31	1.569455
28	-7.8282	31	1.431864

	curr_energy	num_circuits	quantum_exec_time
step			
29	-7.8123	31	1.667975
30	-7.8172	31	1.430647
31	-7.8020	31	1.571160
32	-7.8101	31	1.601140
33	-7.8326	31	1.611406
34	-7.8377	31	1.541447
35	-7.8311	31	1.481787
36	-7.8294	31	1.565989
37	-7.8592	31	1.575904
38	-7.8038	31	1.559955

CPU times: total: 9min 20s
Wall time: 1min 25s



In [194...

```
%%time

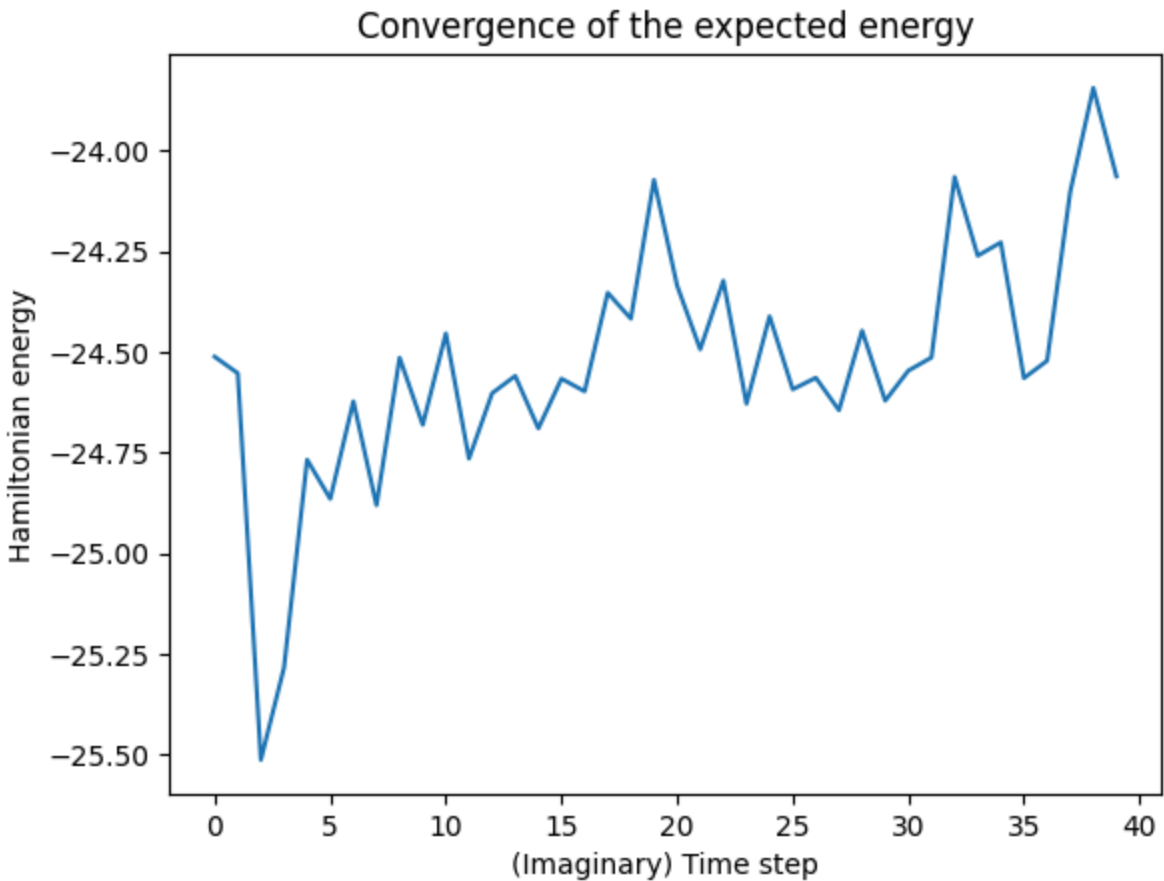
# Set up your QITEvolver for the graph with the tree edges removed
qit_evolver_H = QITEvolver(H_maxcut_H, ansatz_H)
```

```
qit_evolver_H.evolve(num_steps=40, lr=0.1, verbose=True)  
  
# Visualize your results!  
qit_evolver_H.plot_convergence()
```

	curr_energy	num_circuits	quantum_exec_time
step			
0	-24.5116	99	6.323721
1	-24.5526	99	5.576729
2	-25.5141	99	5.702343
3	-25.2849	99	5.870480
4	-24.7678	99	5.637227
5	-24.8651	99	5.647389
6	-24.6225	99	5.637022
7	-24.8810	99	5.688437
8	-24.5140	99	5.330035
9	-24.6810	99	5.434075
10	-24.4537	99	5.558734
11	-24.7650	99	5.671575
12	-24.6024	99	5.538614
13	-24.5594	99	5.704190
14	-24.6898	99	5.816499
15	-24.5663	99	5.814508
16	-24.5977	99	5.483931
17	-24.3528	99	5.811251
18	-24.4170	99	5.549092
19	-24.0718	99	5.993787
20	-24.3347	99	5.668170
21	-24.4932	99	5.633124
22	-24.3225	99	5.644973
23	-24.6285	99	5.667669
24	-24.4111	99	5.685087
25	-24.5928	99	5.657249
26	-24.5640	99	5.587073
27	-24.6446	99	5.531774
28	-24.4468	99	5.562001

	curr_energy	num_circuits	quantum_exec_time
step			
29	-24.6210	99	5.747257
30	-24.5463	99	5.654338
31	-24.5136	99	5.681399
32	-24.0646	99	5.633836
33	-24.2605	99	5.648268
34	-24.2274	99	5.433340
35	-24.5648	99	5.501632
36	-24.5217	99	5.410464
37	-24.1017	99	5.377815
38	-23.8430	99	5.493388

CPU times: total: 39min 41s
Wall time: 6min 6s



Check out your best / most frequent cut!

Following the variational quantum imaginary time evolution (vQITE) loop, we sample the quantum circuit to obtain classical bitstrings. The most frequent bitstring represents our solution, the final score though will take into account all of the right solutions...

In [195... `from qiskit_aer import AerSimulator`

```
shots = 100_000
backend = AerSimulator()
```

In [199... *# Sample your optimized quantum state using Aer for the tree*

```
optimized_state_T = ansatz_T.assign_parameters(qit_evolver_T.param_vals[-1])
optimized_state_T.measure_all()
counts_T = backend.run(optimized_state_T, shots=shots).result().get_counts()

# Find the sampled bitstring with the largest cut value
cut_vals_T = sorted(((bs, compute_cut_size(T, bs)) for bs in counts_T), key=lambda
best_bs_T = cut_vals_T[-1][0]

# Now find the most likely MaxCut solution as sampled from your optimized state
# We'll leave this part up to you!!!
most_likely_soln = ""

print(counts_T)
```

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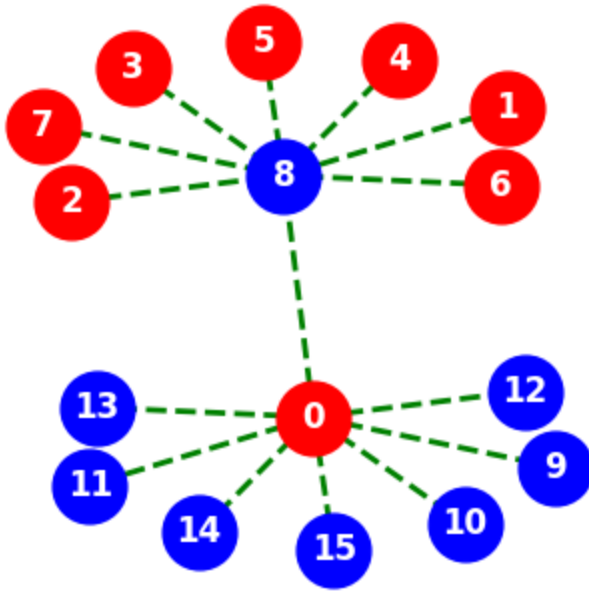
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In [200... interpret_solution(T, best_bs_T)
print("Cut value: "+str(compute_cut_size(T, best_bs_T)))
print(T, best_bs_T)

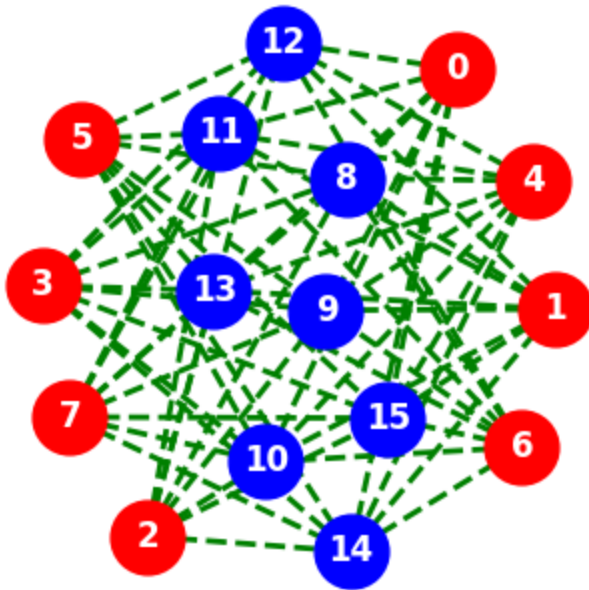
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Cut value: 15

Graph named 'complete_bipartite_graph(8, 8)' with 16 nodes and 15 edges 11111110000000

```
In [201... # interpret the same solution, but with the whole graph instead of the tree
interpret_solution(graph, best_bs_T)
print("Cut value: "+str(compute_cut_size(graph, best_bs_T)))
print(graph, best_bs_T)
```



Cut value: 64

Graph named 'complete_bipartite_graph(8, 8)' with 16 nodes and 64 edges 11111110000000

```
In [202... # Sample your optimized quantum state using Aer for the tree

optimized_state_H = ansatz_H.assign_parameters(qit_evolver_H.param_vals[-1])
optimized_state_H.measure_all()
```

```
counts_H = backend.run(optimized_state_H, shots=shots).result().get_counts()

# Find the sampled bitstring with the largest cut value
cut_vals_H = sorted(((bs, compute_cut_size(H, bs)) for bs in counts_H), key=lambda
best_bs_H = cut_vals_H[-1][0]

# Now find the most likely MaxCut solution as sampled from your optimized state
# We'll leave this part up to you!!!
most_likely_soln = ""

print(counts_H)
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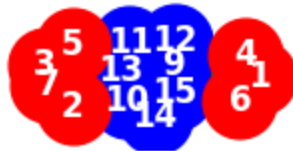
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```

In [203...

```
interpret_solution(H, best_bs_H)
print("Cut value: "+str(compute_cut_size(H, best_bs_H)))
print(H, best_bs_H)
```

0

8

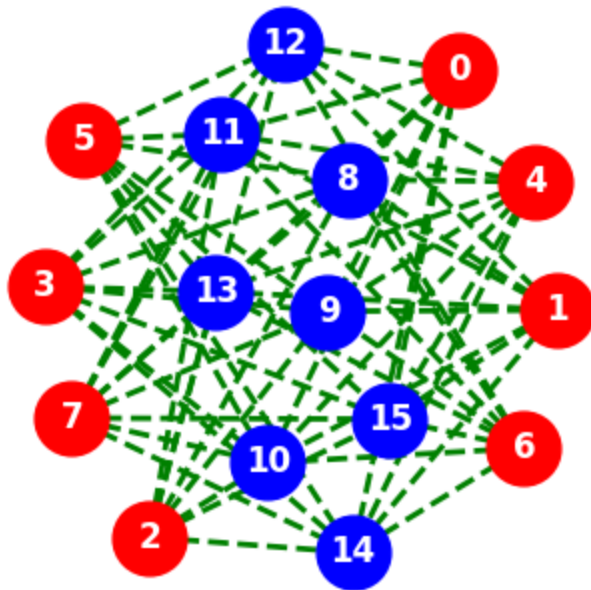


Cut value: 49

Graph named 'complete_bipartite_graph(8, 8)' with 16 nodes and 49 edges 11111110000
0000

In [204...

```
interpret_solution(graph, best_bs_H)
print("Cut value: "+str(compute_cut_size(graph, best_bs_H)))
print(graph, best_bs_H)
```



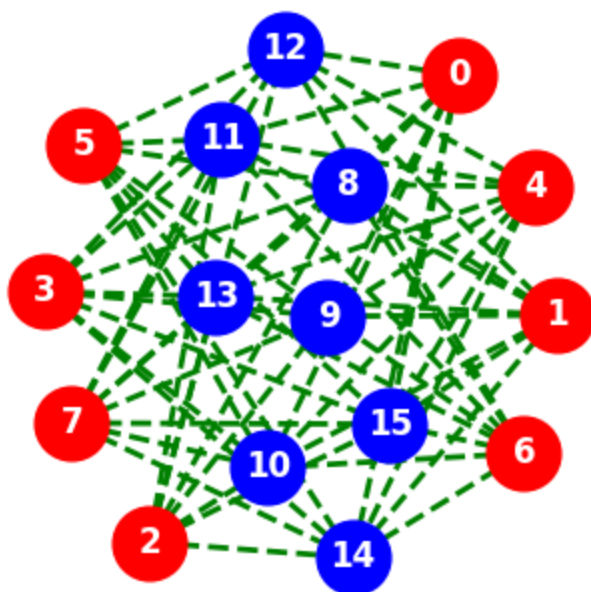
Cut value: 64

Graph named 'complete_bipartite_graph(8, 8)' with 16 nodes and 64 edges 11111110000000

```
In [205... # choose the better result from best_bs_T and best_bs_H
best_bs_final = best_bs_H if compute_cut_size(H, best_bs_H) > compute_cut_size(T, best_bs_T) else best_bs_T
final_cut_value = compute_cut_size(graph, best_bs_final)

# choose the better result ansatz from ansatz_T and ansatz_H
ansatz_final = ansatz_H if compute_cut_size(H, best_bs_H) > compute_cut_size(T, best_bs_T) else ansatz_T

interpret_solution(graph, best_bs_final)
print("Cut value: "+str(final_cut_value))
print(graph, best_bs_final)
```



Cut value: 64

Graph named 'complete_bipartite_graph(8, 8)' with 16 nodes and 64 edges 1111111100000000

```
In [206... # from qiskit_aer import AerSimulator

# shots = 100_000

# Sample your optimized quantum state using Aer
# backend = AerSimulator()
optimized_state = ansatz.assign_parameters(qit_evolver.param_vals[-1])
optimized_state.measure_all()
counts = backend.run(optimized_state, shots=shots).result().get_counts()

# Find the sampled bitstring with the largest cut value
cut_vals = sorted(((bs, compute_cut_size(graph, bs)) for bs in counts), key=lambda
best_bs = cut_vals[-1][0]

# Now find the most likely MaxCut solution as sampled from your optimized state
# We'll leave this part up to you!!!
most_likely_soln = ""

print(counts)
```

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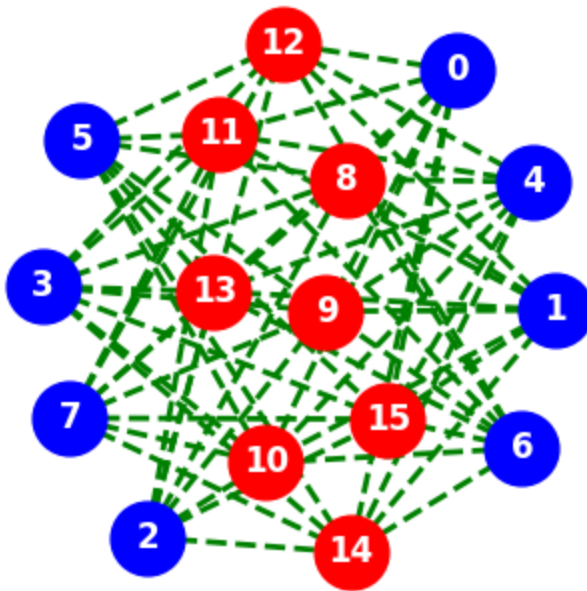
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```

```
In [207... interpret_solution(graph, best_bs)
print("Cut value: "+str(compute_cut_size(graph, best_bs)))
print(graph, best_bs)
```



Cut value: 64

Graph named 'complete_bipartite_graph(8, 8)' with 16 nodes and 64 edges 0000000011111111

Drumroll please... the scores!

```
In [208... %%time
# Brute-force approach with conditional checks

verbose = False

G = graph
n = len(G.nodes())
```

```

w = np.zeros([n, n])
for i in range(n):
    for j in range(n):
        temp = G.get_edge_data(i, j, default=0)
        if temp != 0:
            w[i, j] = 1.0
if verbose:
    print(w)

best_cost_brute = 0
best_cost_balanced = 0
best_cost_connected = 0

for b in range(2**n):
    x = [int(t) for t in reversed(list(bin(b)[2:].zfill(n)))]

    # Create subgraphs based on the partition
    subgraph0 = G.subgraph([i for i, val in enumerate(x) if val == 0])
    subgraph1 = G.subgraph([i for i, val in enumerate(x) if val == 1])

    bs = "".join(str(i) for i in x)

    # Check if subgraphs are not empty
    if len(subgraph0.nodes) > 0 and len(subgraph1.nodes) > 0:
        cost = 0
        for i in range(n):
            for j in range(n):
                cost = cost + w[i, j] * x[i] * (1 - x[j])
        if best_cost_brute < cost:
            best_cost_brute = cost
            xbest_brute = x
            XS_brut = []
        if best_cost_brute == cost:
            XS_brut.append(bs)

    outstr = "case = " + str(x) + " cost = " + str(cost)

    if (len(subgraph1.nodes)-len(subgraph0.nodes))**2 <= 1:
        outstr += " balanced"
        if best_cost_balanced < cost:
            best_cost_balanced = cost
            xbest_balanced = x
            XS_balanced = []
        if best_cost_balanced == cost:
            XS_balanced.append(bs)

    if nx.is_connected(subgraph0) and nx.is_connected(subgraph1):
        outstr += " connected"
        if best_cost_connected < cost:
            best_cost_connected = cost
            xbest_connected = x
            XS_connected = []
        if best_cost_connected == cost:
            XS_connected.append(bs)
if verbose:
    print(outstr)

```

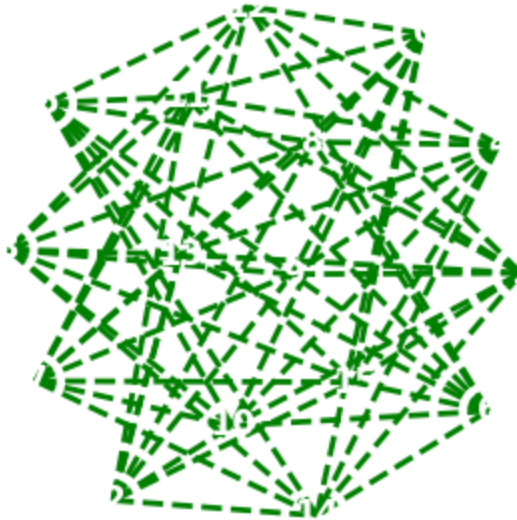
CPU times: total: 5.33 s

Wall time: 10 s

```
In [209... # This is classical brute force solver results:
interpret_solution(graph, xbest_brute)
print(graph, xbest_brute)
print("\nBest solution = " + str(xbest_brute) + " cost = " + str(best_cost_brute))
print(XS_brut)

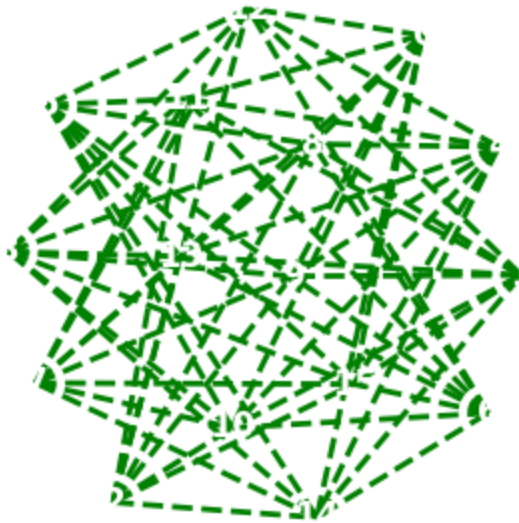
interpret_solution(graph, xbest_balanced)
print(graph, xbest_balanced)
print("\nBest balanced = " + str(xbest_balanced) + " cost = " + str(best_cost_balanced))
print(XS_balanced)

interpret_solution(graph, xbest_connected)
print(graph, xbest_connected)
print("\nBest connected = " + str(xbest_connected) + " cost = " + str(best_cost_connected))
print(XS_connected)
plt.show()
```



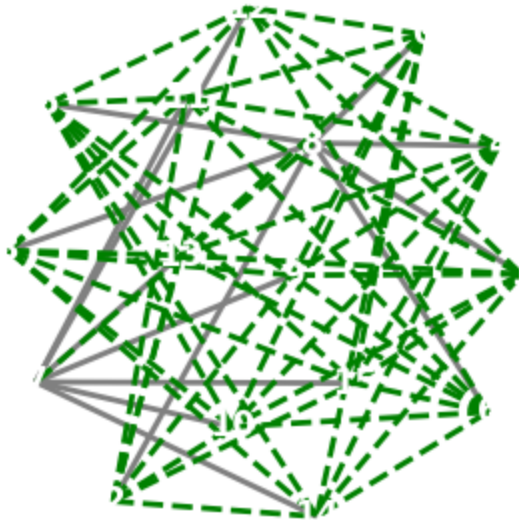
Graph named 'complete_bipartite_graph(8, 8)' with 16 nodes and 64 edges [1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0]

Best solution = [1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0] cost = 64.0
 ['1111111100000000', '0000000011111111']



Graph named 'complete_bipartite_graph(8, 8)' with 16 nodes and 64 edges [1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0]

Best balanced = [1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0] cost = 64.0
['1111111100000000', '0000000011111111']



Graph named 'complete_bipartite_graph(8, 8)' with 16 nodes and 64 edges [1, 1, 1, 1, 1, 1, 1, 0, 1, 0, 0, 0, 0, 0, 0, 0]

Best connected = [1, 1, 1, 1, 1, 1, 1, 0, 1, 0, 0, 0, 0, 0, 0, 0] cost = 50.0

```
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'0000001001111111', '0000000101111111']
```

In [210... *# And this is how we calculate the shots counted toward scores for each class of th*

```
sum_counts = 0
for bs in counts:
    if bs in XS_brut:
        sum_counts += counts[bs]

print(f"Pure max-cut: {sum_counts} out of {shots}")

sum_balanced_counts = 0
for bs in counts:
    if bs in XS_balanced:
        sum_balanced_counts += counts[bs]

print(f"Balanced max-cut: {sum_balanced_counts} out of {shots}")

sum_connected_counts = 0
for bs in counts:
    if bs in XS_connected:
        sum_connected_counts += counts[bs]
```

```
print(f"Connected max-cut: {sum_connected_counts} out of {shots}")
```

Pure max-cut: 1 out of 100000

Balanced max-cut: 1 out of 100000

Connected max-cut: 31 out of 100000

In [211...

```
def final_score(graph, XS_brut, counts, shots, ansatz, challenge):

    if(challenge=='base'):
        sum_counts = 0
        for bs in counts:
            if bs in XS_brut:
                sum_counts += counts[bs]
    elif(challenge=='balanced'):
        sum_balanced_counts = 0
        for bs in counts:
            if bs in XS_balanced:
                sum_balanced_counts += counts[bs]
        sum_counts = sum_balanced_counts
    elif(challenge=='connected'):
        sum_connected_counts = 0
        for bs in counts:
            if bs in XS_connected:
                sum_connected_counts += counts[bs]
        sum_counts = sum_connected_counts

    transpiled_ansatz = transpile(ansatz, basis_gates = ['cx', 'rz', 'sx', 'x'])
    cx_count = transpiled_ansatz.count_ops()['cx']
    score = (4*2*graph.number_of_edges()/(4*2*graph.number_of_edges() + cx_count))

    return np.round(score,5)
```

In [212...

```
print("Base score: " + str(final_score(graph, XS_brut, counts, shots, ansatz, 'base')))
print("Balanced score: " + str(final_score(graph, XS_brut, counts, shots, ansatz, 'balan
print("Connected score: " + str(final_score(graph, XS_brut, counts, shots, ansatz, 'conn
```

Base score: 1e-05

Balanced score: 1e-05

Connected score: 0.00025

In [213...

```
# calculate our version of the score for the final solution
print("Base score: " + str(final_score(graph, XS_brut, counts, shots, ansatz_H, 'base')))
print("Balanced score: " + str(final_score(graph, XS_brut, counts, shots, ansatz_H, 'bal
print("Connected score: " + str(final_score(graph, XS_brut, counts, shots, ansatz_H, 'co
```

Base score: 1e-05

Balanced score: 1e-05

Connected score: 0.00026

In [214...

```
# calculate our version of the score for the final solution
print("Base score: " + str(final_score(graph, XS_brut, counts, shots, ansatz_T, 'base')))
print("Balanced score: " + str(final_score(graph, XS_brut, counts, shots, ansatz_T, 'bal
print("Connected score: " + str(final_score(graph, XS_brut, counts, shots, ansatz_T, 'co
```

Base score: $1e-05$
Balanced score: $1e-05$
Connected score: 0.00029

This is the main challenge: design optimal ansatz generators and Hamiltonians for the max-cut problem, subject to three specific conditions. Solutions for each condition can be submitted independently; however, a unified approach applicable to all three conditions will receive additional credit.

Submit your results

I guess this is the most important part. You probably want to report your results.

Please, follow the link: <https://forms.gle/gkpSCe7HGr7QHZXQ6>

Let's revisit the problem statement. **This is important!!!** We have three scoring methods to report:

1. Counts shots achieving the optimal max-cut value. Sorry, no approximation value this time.
2. Adds a balance constraint—subgraphs must have equal cardinality.
3. Requires connected subgraphs—all vertices within a subgraph must be mutually reachable.

For **in-person participants**: Prepare a presentation that explains your research and demonstrates the value of your proposed solution.

Can you solve this? Good luck!

Feedback

If you have any suggestions or recommendations about the hackathon challenge, please, don't hesitate to leave your comment here: <https://iter.ly/u42um>



In []: