QHack

Quantum Coding Challenges

CHALLENGE COMPLETED View successful submissions

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Cascadar

200 points

Backstory

Zenda and Reece have determined Doc Trine's cell number in hyperjail. Searching through Trine's notebooks, they find another note, explaining how the hypercube is patrolled by a fearsome quantum warden, which is able to place itself in a superposition and inspect multiple cells at once. To avoid detection and rescue Doc Trine, they need to build a quantum radar!

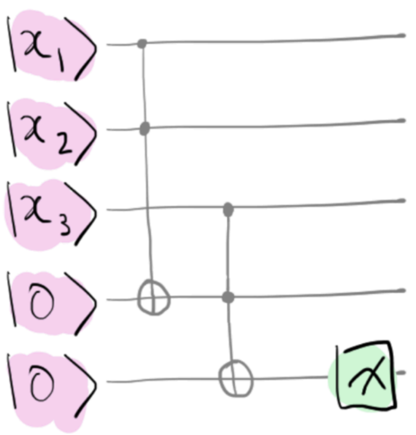
A quantum radar

The quantum guard can place itself in a superposition

$$|\text{guard}\rangle = \sum_x g_x|x\rangle,$$

where $x \in \{0,1\}^5$ ranges over all cell numbers, and g_x are complex-valued amplitudes. Seen in this way, $|g_x|^2$ is the probability that the guard is at position $|x\rangle$. They know that Doc Trine is located in a cell $c = (1, 1, 0, 0, 1)$. Ideally, they would like to wait until the guard's attention, captured by the probability $|g_c|^2$, is sufficiently low.

In this challenge, we will look for a way to be able to measure $|g_c|^2$. Unfortunately, there isn't much equipment in the office, and what is there is noisy! But Trine has left a collection of "Toffoli cascades" lying around, circuits made from a string of noisy Toffoli gates. Here is an example for three input qubits $|x_1\rangle|x_2\rangle|x_3\rangle$:



Measuring the last qubit in the computational basis gives $|(x_1 \cdot x_2 \cdot x_3)\rangle$ with probability 1, where $x_1 \cdot x_2 \cdot x_3$ indicates the *product* of classical bits x_1, x_2, and x_3. There is a Toffoli cascade acting on 5 input qubits (and with four auxiliary qubits) that Zenda and Reece can use, as well as some Pauli X gates. All are subject to *depolarizing noise*, such that after each gate, the state on each qubit is replaced with something random with probability λ.

Your task: use noisy Toffoli cascades and noisy-Pauli X gates to build a *quantum radar*, which outputs $|g_c|^2$, the guard's attention on Trine's cell. The guard state will be an input, along with four auxiliary qubits starting in the $|0\rangle$ state.

Challenge code

In the code below, you are given various functions:

- `noisy_PauliX`: which applies the Pauli-X gate and then a layer of depolarizing noise with parameter `lmbda`. (The noise is added for you.)
- `Toffoli_cascade`: a cascade of noisy Toffoli gates (noise parameter `lmbda`) which help compute a product, as in the circuit pictured above, with the input qubits on `in_wires` and auxiliary system `aux_wires`. (The noise is added for you.)
- `cascadar`: which takes a `guard_state (numpy.tensor)` and returns $|g_c|^2$, using noisy equipment with parameter `lmbda`. **You must complete this function.**

Inputs

The noisy quantum radar `cascadar` takes as input the guard state `guard_state (numpy.tensor)`, and a noise parameter `lmbda (float)` controlling the depolarizing noise.

Output

Your `cascadar` function should gives the correct probability $|g_c|^2$ for test cases, including the effects of noise.

If your solution matches the correct one within the given tolerance specified in `check` (in this case it's a `1e-4` relative error tolerance), the output will be `"Correct!"` Otherwise, you will receive a `"Wrong answer"` prompt.

Code

Help

```python
import json
import pennylane as qml
import pennylane.numpy as np
```

```python
def noisy_PauliX(wire, lmbda):
    """A Pauli-X gate followed by depolarizing noise.

    Args:
        lmbda (float): The parameter defining the depolarizing channel.
        wire (int): The wire the depolarizing channel acts on.
    """
    qml.PauliX(wire)
    qml.DepolarizingChannel(lmbda, wires=wire)

def Toffoli_cascade(in_wires, aux_wires, lmbda):
    """A cascade of noisy Toffolis to help compute the product.

    Args:
        in_wires (list(int)): The input qubits.
        aux_wires (list(int)): The auxiliary qubits.
        lmbda (float): The probability of erasing the state of a qubit.
    """
    n = len(in_wires)
    qml.Toffoli(wires=[in_wires[0], in_wires[1], aux_wires[0]])
    qml.DepolarizingChannel(lmbda, wires=in_wires[0])
    qml.DepolarizingChannel(lmbda, wires=in_wires[1])
    qml.DepolarizingChannel(lmbda, wires=aux_wires[0])
    for i in range(n - 2):
        qml.Toffoli(wires=[in_wires[i + 2], aux_wires[i], aux_wires[i + 1]])
        qml.DepolarizingChannel(lmbda, wires=in_wires[i + 2])
        qml.DepolarizingChannel(lmbda, wires=aux_wires[i])
        qml.DepolarizingChannel(lmbda, wires=aux_wires[i + 1])

# Build a quantum radar to check how much attention is on Trine's cell
def cascadar(guard_state, lmbda):
    """Return the squared amplitude |g_c|^2 of the guard state, for c = (1, 1, 0, 0, 1).

    Args:
        guard_state (numpy.tensor): A 2**5 = 32 component vector encoding the guard state.
        lmbda (float): The probability of erasing the state of a qubit.
```

```python
        # Put your code here #

        return

    output = circuit()

    # if you want to post-process the output, put code here also #

    return
```

```python
# These functions are responsible for testing the solution.
def run(test_case_input: str) -> str:

    guard_state, lmbda = json.loads(test_case_input)
    output = cascadar(guard_state, lmbda)

    return str(output)

def check(solution_output: str, expected_output: str) -> None:

    solution_output = json.loads(solution_output)
    expected_output = json.loads(expected_output)
    assert np.allclose(
        solution_output, expected_output, rtol=1e-4
    ), "Your quantum radar isn't quite working properly!"
```

```python
test_cases = [['[[0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0
```

```python
for i, (input_, expected_output) in enumerate(test_cases):
    print(f"Running test case {i} with input '{input_}'...")

    try:
        output = run(input_)

    except Exception as exc:
        print(f"Runtime Error. {exc}")

    else:
        if message := check(output, expected_output):
            print(f"Wrong Answer. Have: '{output}'. Want: '{expected_output}'.")

        else:
            print("Correct!")
```

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