Solutions for tasks and retrospective

Assignment 01: Introduction to QC

Task 1: Climate Case

Topic 1: Improving Navigation

- How were Quantum Computers used to avoid traffic jams in Lisbon during the WebSummit in 2019?
    - To enable smooth traffic during the WebSummit in 2019 Volkswagen equipped nine MAN buses with quantum navigation systems. These systems calculated the quickest individual route for each bus in real time and gave recommendations through an app.
    - This approach enabled bus drivers to avoid congestion at an early stage and hence reduced the travel time for the passengers.

- For which kind of navigation use cases is Volkswagen currently developing solutions with quantum algorithms?
    - Quantum algorithms can either be used for individual road users or for urban traffic planning.
    - Besides reducing travel time and avoiding congestion through better navigation, Quantum Computers could also be used to send real time information about available e-charging stations and free parking spaces.

Topic 2: Developing better batteries

- Why are we facing obstacles when improving batteries at the moment?
    - We don't know what is going on inside a battery and therefore we cannot understand the interaction of molecules inside a battery.
    - Although we know how to make batteries, it is hard to improve them without knowing what is going on inside.
    - Right now there is no supercomputer on the planet that has enough power to accurately simulate how batteries work. Therefore, we currently have to approximate the chemical reactions in a battery using classical algorithms, which are not really good at the moment.
    - Due to the lack of knowledge about how a battery works, improving the efficiency of batteries is a continuous process of trial and error which takes decades.

- How can Quantum Computers contribute to solving those problems?
    - As Quantum Computers are built with quantum mechanical systems at their heart, they can simulate chemical reactions far more efficiently compared to classical supercomputers.
    - Those simulations enable researches to explore new materials to develop more efficient batteries.

Retrospective

1. What are the limitations of Classical Computers?
    - Classical Computers have limited computation power as transistors in the devices are already as small as they can be built.
    - Therefore, some problems are not able to be solved on Classical Computers as it would take too much time or require more computation power.

2. What are the advantages of Quantum Computers compared to Classical Computers?
    - Quantum Computers are built on the same foundational principles as nature, therefore we can mimic the behavior of nature with them and understand how nature works
    - Quantum Computers have a higher computation power compared to Classical Computers and are therefore able to solve more complex problems in less time
    - The faster calculation time improves the energy efficiency of Quantum Computers compared to Classical Computers

3. How can Quantum Computing contribute to sustainability in the automotive industry?
    - Quantum Computers can improve real time navigation to avoid traffic jams and therefore reduce CO_2 emissions.
    - With quantum computing it can be simulated how batteries work and hence better batteries can be developed to increase the range and acceptance of electric vehicles.

Assignment 02: From bits to qubits

Task 1: Calculating CO2 savings with route optimization

1. Calculate the CO2 emissions for all of the suggested routes
   - Route 1 (blue route): 0.003 t = 3 kg
   - Route 2 (green route): 0.004 t = 4 kg
   - Route 3 (red route): 0.004 t = 4 kg

2. Calculate the CO2 savings in kilogram when comparing the routes with the highest and lowest CO2 emissions
   - Highest CO2 emissions: Green route and red route with each 4 kg
   - Lowest CO2 emissions: Blue route with 3 kg

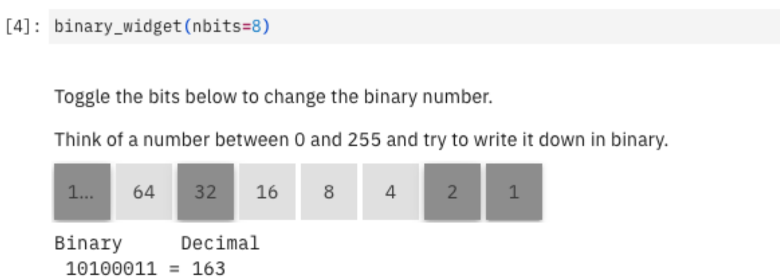
   → Saving: 4 kg – 3 kg = 1 kg

3. Imagine 163 people use the same navigation system per day and choose the route with the lowest CO2 emissions. Calculate the CO2 savings we achieved through route optimization per day in kilograms.

   → Total savings: 1 kg * 163 people = 163 kg

4. Please write your result in Binary:

Decimal (Input)	Transition	Binary (Output)
163	$(1*2^7)+(0*2^6)+(1*2^5)+(0*2^4)+(0*2^3)+(0*2^2)+(1*2^1)+(1*2^0)$	10100011



Task 2: Write the name of the route with the shortest distance in binary

- g = 1100111
- r = 1110010
- e = 1100101
- e = 1100101
- n = 1101110
- space = 100000
- r = 1110010
- o = 1101111
- u = 1110101
- t = 1110100
- e = 1100101

→ green route = 1100111 1110010 1100101 1100101 1101110 100000 1110010 1101111 1110101 1110100 1100101

```
[2]: a_binary_string = "1100111 1110010 1100101 1100101 1101110 100000 1110010 1101111 1110101 1110100 1100101"
```

```
[3]: binary_values = a_binary_string.split()
```

```
[4]: ascii_string = " "
```

```
[5]: for binary_value in binary_values:
         an_integer = int(binary_value, 2)
         ascii_character = chr(an_integer)
         ascii_string += ascii_character
```

```
[6]: print(ascii_string)

     green route
```

Retrospective

1. Why is a Quantum Computer faster in route optimization compared to a Classical Computer?
    - The Quantum Computer uses communication between qubits (“public of qubits”) and hence does not need to go through every route separately like a Classical Computer reducing the required time to select the optimal route.

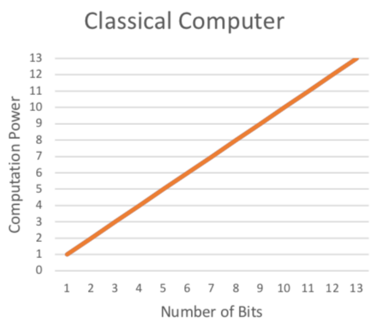
2. What is a string?
    - A string is a sequence of characters.

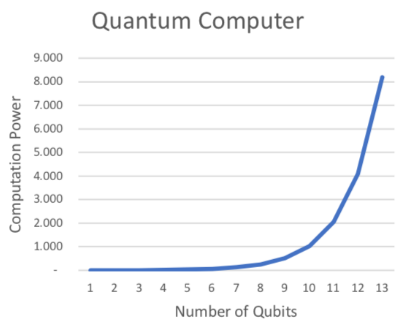
3. How many bits form 1 byte?
    - 8 bits form 1 byte

4. How many distinct values can a byte have?
    - With one byte we can represent the number 0 and the number 1 – 255. Therefore one byte can have 256 distinct values.

5. What is the difference in the values of bits and qubits?
    - A bit can only have the value 0 or 1, while a qubit can also be a combination of both values with certain probabilities. For example, a qubit can be with 70% in state 0 and 30% in state 1.

6. How does the computation power grows when comparing Classical Computers with Quantum Computers?
    - A Classical Computers computation power grows linearly while in Quantum Computers we can observe an exponential growth of computation power.





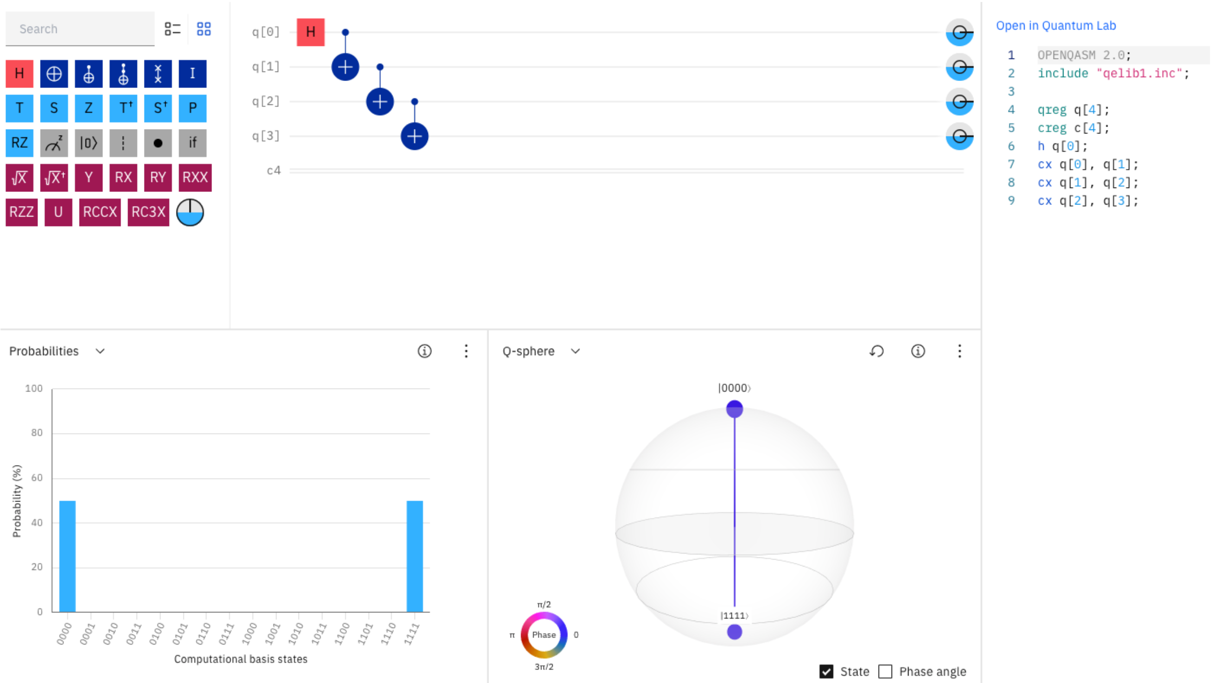
7. What is the name of the gate to flip the value of a bit?
    - The NOT-gate changes the value of a bit from 0 to 1 and vice versa

Assignment 03: Quantum gates, circuits and registers

Task 1: Think about another way how the CNOT-gates could be used to achieve the same result

Instead of transferring the superposition from q0 to q1, q2 and q3 we can also use the target qubit of the first CNOT-gate as the control qubit for the second CNOT-gate.

This indicates that we transferred the H-gate from q0 to q1 with the first CNOT-gate. In order to transfer the H-gate to q2 we don't have to use a CNOT-gate from q0 to q2 as we can also transfer the H-gate by using a CNOT-gate from q1 to q2. We can also add a CNOT-gate from q2 to q3 to transfer the H-gate to the last qubit in our circuit.



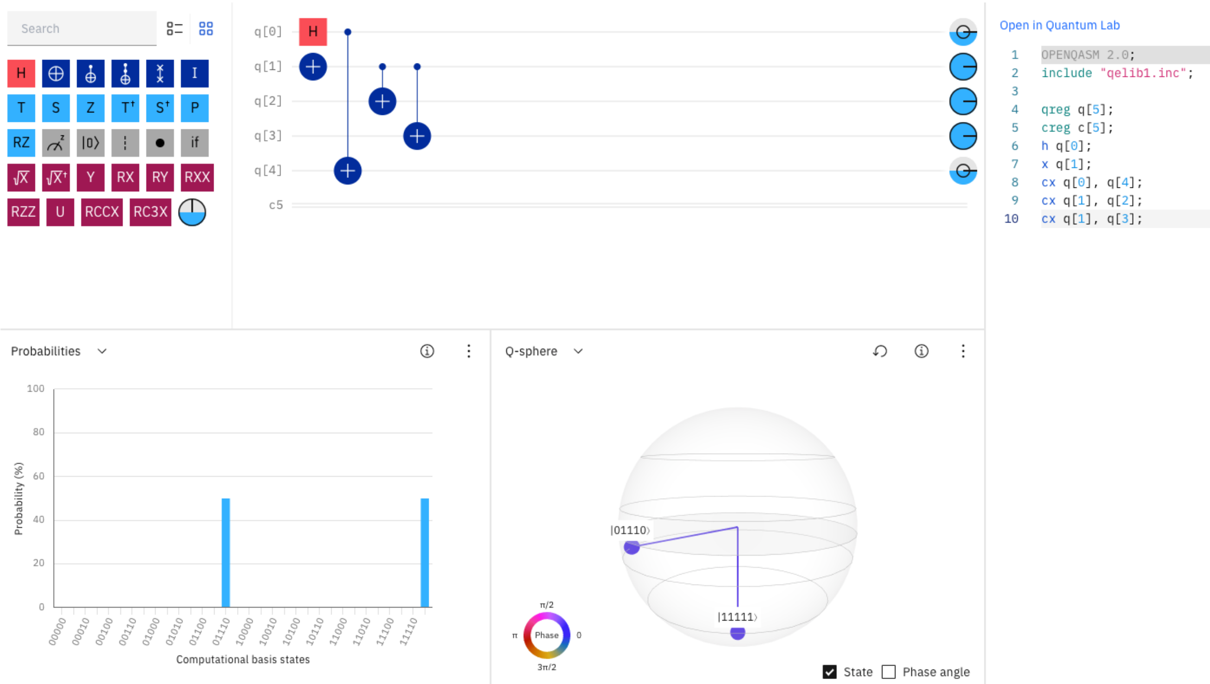
Task 2: Try to create a circuit that leads to the following outcomes with a 50/50 probability: 01110, 11111

As we expect the qubits to be in the states 01110 and 11111 with a 50/50 chance we can infer the following probabilities for each qubit:

- Qubit 0: 50/50 chance to be in state 0 or 1
- Qubit 1: 100% probability to be in state 1
- Qubit 2: 100% probability to be in state 1
- Qubit 3: 100% probability to be in state 1
- Qubit 4: 50/50 chance to be in state 0 or 1

Whenever we observe that a qubit as a 50/50 chance to be in state 0 or 1 we know that the qubit is in superposition and hence we need to apply a H-gate. This logic can be applied for q0 and q4. As we are only allowed to use one H-gate we can add the H-gate to q0 and transfer it with a CNOT-gate to q4.

As we know from the assignment all qubits start with state 0. Therefore, we can conclude that we need to apply a gate which flips the state of q1, q2 and q3 from 0 to 1. You might remember that this can be achieved with using a X-gate/NOT-gate. Again, as we are only allowed to use one X-gate, we can transfer the X-gate applied on q1 by using CNOT-gates to q2 and q3.



Retrospective

1. What is a quantum register?
    - A quantum register is a group of qubits and hence is the analogue to the processor register of a Classical Computer.

2. Which components are usually needed to build a quantum circuit?
    - A quantum circuit usually starts with the initialization of qubits by creating a quantum register.
    - In the next step quantum gates are performed to manipulate the states of the qubits.
    - A quantum circuit usually ends with a measurement operation.

3. How is the gate called that does not change the state of a qubit and in which situations it might be useful to use this gate?
    - The gate which does not change the state of a qubit is called identity gate.
    - The application of the identity gate is useful when it comes to simulations and error models, that aim to measure the error rate of a Quantum Computer.

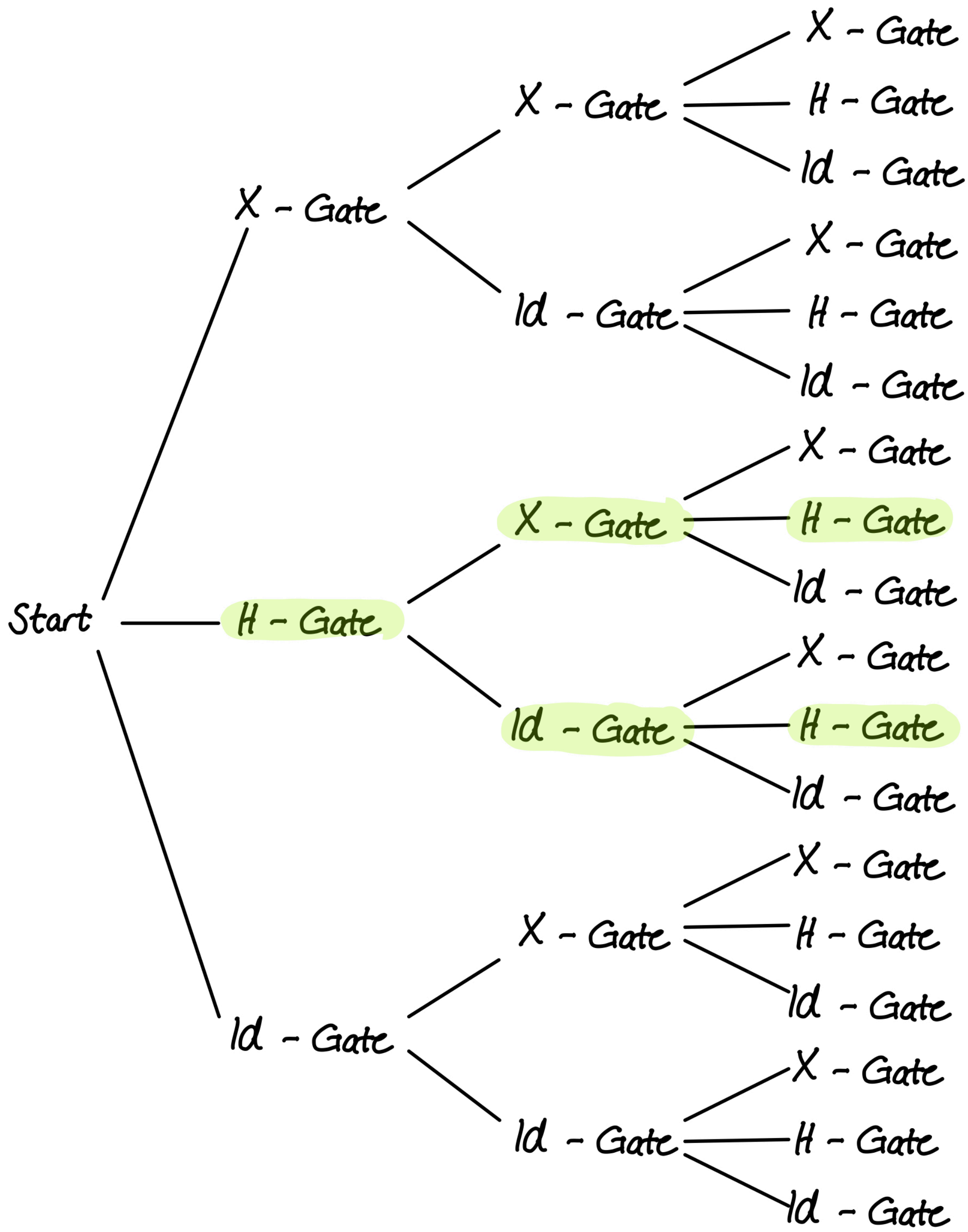
4. What is the effect of applying a X-gate and how is this effect visualized in the Bloch sphere?
    - A X-gate flips the value of a qubit. Its effect is visualized as a 180-degree rotation around x-axis of the Bloch sphere.

5. You want to transfer the state of qubit 2 to qubit 6. Which gate do you have to apply and what specifications do you need to make?
    - We need to apply a controlled X-gate where q2 is the control qubit, while q6 is the target qubit.

Assignment 04: Superposition and Entanglement

Task: Identify a strategy that always allows you to win the coin toss game by using superposition.

As mentioned in the assignment, the solution of potential strategies can be simplified by using a decision tree. The highlighted paths indicate the two potential solutions. Therefore, we can conclude that whenever you choose a Hadamard-gate in both of your turns, you will always be the winner independent from whether Taylor uses a X-gate or an Id-gate. You are provided with the evidence in the code below.



```
[4]: interact(Move_Y1, move_Y1={'id Gate':0,'X Gate':1, 'H Gate':2});
```

move_Y1 H Gate

```
[5]: interact(Move_T1, move_T1={'id Gate':0,'X Gate':1});
```

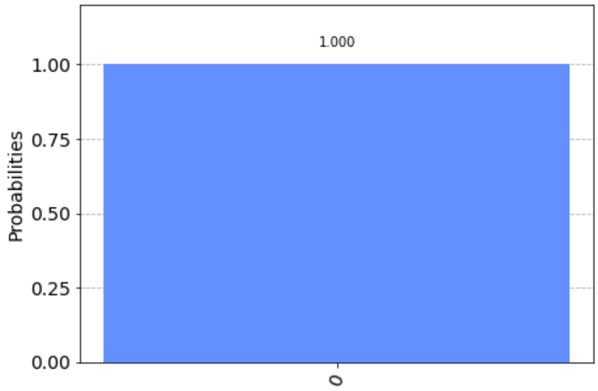
move_T1 X Gate

```
[6]: interact(Move_Y2, move_Y2={'id Gate':0,'X Gate':1, 'H Gate':2});
```

move_Y2 H Gate

```
{'0': 200}
The winner is you
```

[8]:



Retrospective

1. Which gate do we need to enable qubits to be in superposition?
   - The Hadamard-gate enables qubits to be in superposition.

2. What does the principle of superposition imply on quantum states?
   - Superposition implies that a qubit is in a combination of state 0 and state 1 with certain probabilities.

3. What principle from quantum mechanics is involved when independent objects share common behaviors even across large distances?
   - The principle of entanglement indicates that distant independent objects can share common behaviors.

4. Which gates have to be performed on qubits to create entanglement?
   - To create entanglement a Hadamard-gate and a controlled X-gate is needed.

5. Is entanglement limited to two particles or qubits?
   - No, entanglement is not limited to a particular number of qubits/particles.

Assignment 05: Measurement assignment

Retrospective

1. What is the observer effect about?
    - The observer effect states that the act of observing might disturb the observed system. While the observer effect can be neglected in most cases in the real world, in quantum mechanics it was found that observing/measuring affects the experimental outcome.

2. What are different internal and external factors that can create noise for Quantum Computers?
    - External factors: e.g. magnetic fields, variation in temperature, vibrations and impurities in the material of qubits
    - Internal factors: e.g. interactions between qubits

3. What can be applied to reduce the error rate of a Quantum Computer?
    - Error mitigation techniques like the error mitigation filter are used to estimate the error and hence incorporate it in the model

Assignment 06: Quantum algorithms

Retrospective

1. What is the main task of Shor's algorithm?
    - Shor's algorithm is designed to factor integers exponentially faster than any known classical algorithm.

2. Why do we need Post Quantum Cryptography?
    - By using Shor's algorithm Quantum Computers could easily break any encryption key that relies on factorization.
    - To ensure data security whenever Quantum Computers are used in practice new encryption approaches have to be developed.

3. What is the main task of Grover's algorithm?
    - Grover's algorithm is a search algorithm that is designed to search unstructured databases.

4. How can Grover's algorithm contribute to sustainability?
    - Grover's algorithm can also be applied for optimization problems like land optimization. With improving land usage we can reduce our impact on the planet by preserving the soil while ensuring food supply.

5. In which context do we need Quantum Teleportation?
    - Quantum teleportation is needed to transfer information from one qubit to another. This can be particular important for developing a quantum internet.

6. Which requirements are needed to enable Quantum Teleportation?
    - To enable Quantum Teleportation, the qubits have to be entangled.