INTRO TO QUANTUM COMPUTING

Week 22 Lab

RANDOMIZED BENCHMARKING

<insert TA name>

<insert date>

PROGRAM FOR TODAY

- Canvas attendance quiz
- Pre-lab zoom feedback
- Lab content
- Post-lab zoom feedback

CANVAS ATTENDANCE QUIZ

- Please log into Canvas and answer your lab section's quiz (using the password posted below and in the chat).
  - This is lab number:
  - Passcode:

- **Question:** Do you agree or disagree with the following statement? This course provides enough resources to answer my questions about the content. (e.g. Piazza, Office Hours, Homework Review Sessions, etc.)
- [Optional] What additional resources would be helpful?

- **This quiz is not graded, but counts for your lab attendance!**

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PRE-LAB ZOOM FEEDBACK

On a scale of 1 to 5, how would you rate your understanding of this week's content?

- 1 –Did not understand anything
- 2 – Understood some parts
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- 5 – The content was easy for me/I already knew all of the content

In lecture this week, Amir described criteria and benchmarks for physical qubit systems

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LEARNING OBJECTIVES FOR LAB 22

Implementing randomized benchmarking

- Errors in quantum computing
- Characterizing errors through benchmarking
- The steps in randomized benchmarking
- Coding randomized benchmarking

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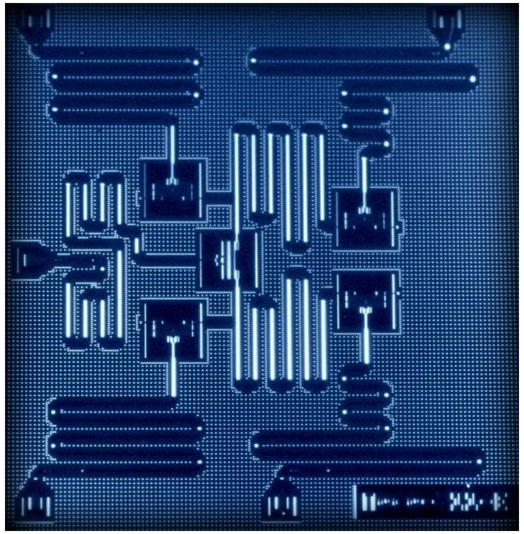
PHYSICAL QC SYSTEMS

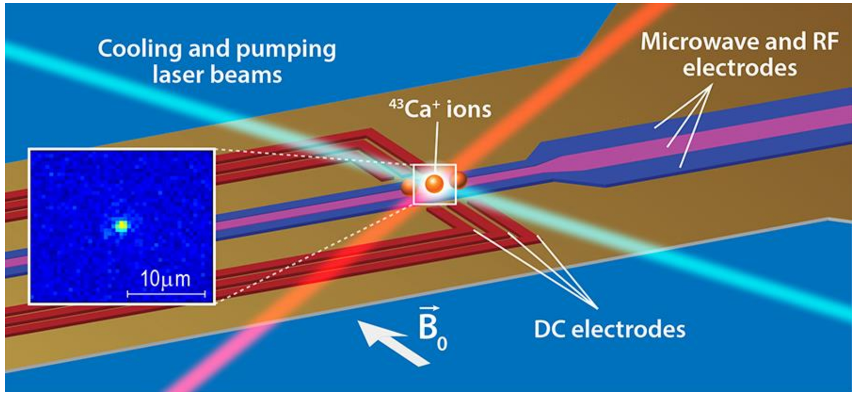
- There are several different systems being developed for qubits

- **Why?** Right now it is not clear which one will have the best performance for different types of applications

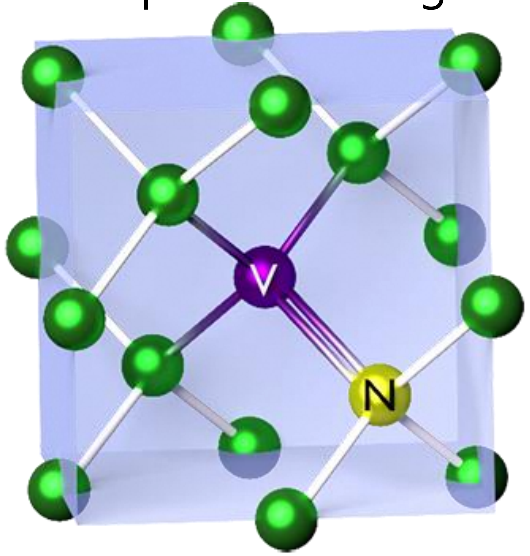
- Key performance metric - **errors**



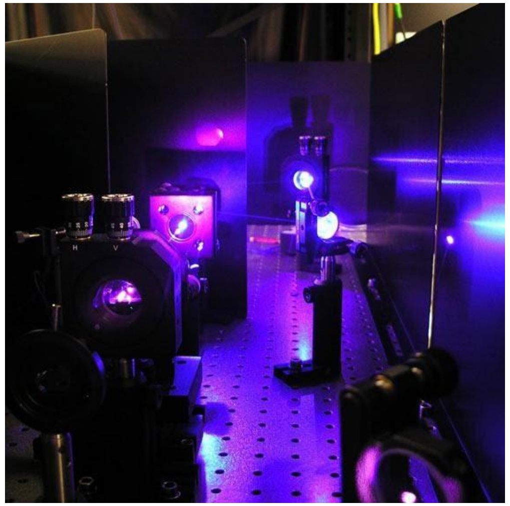
superconducting



trapped ion



diamond NV centers



photonic

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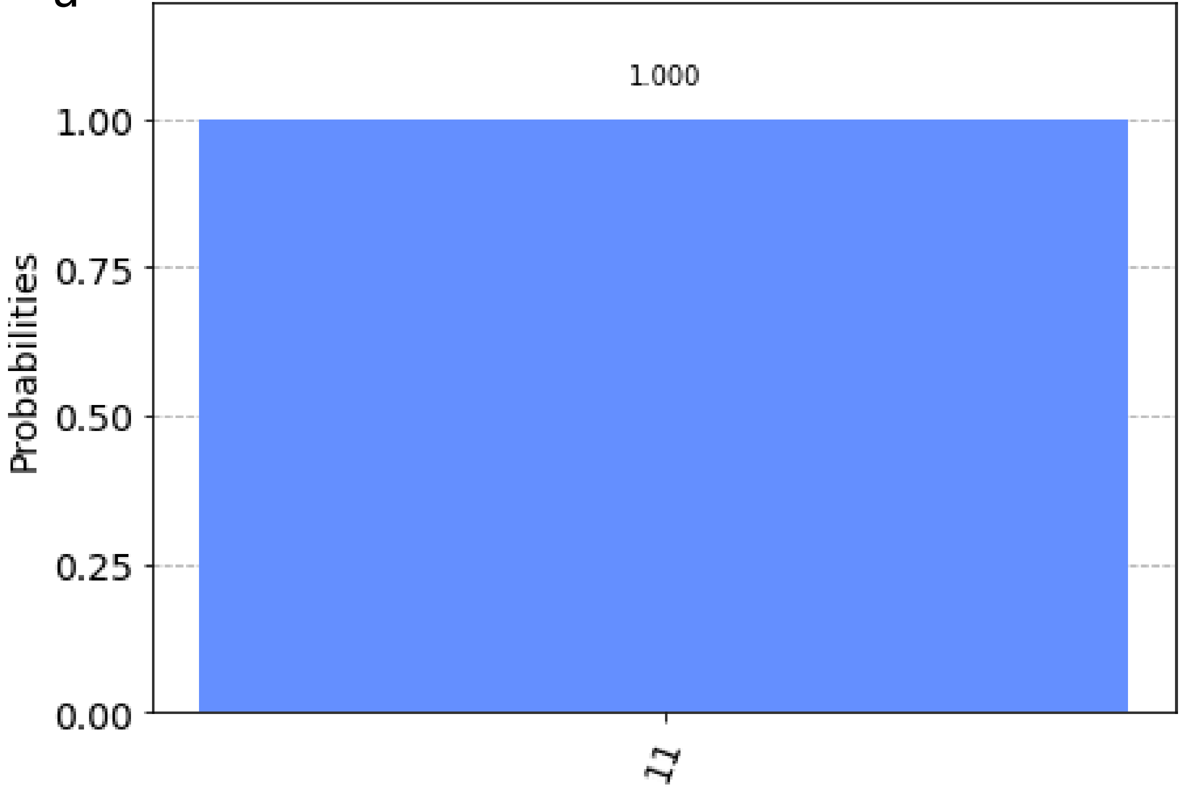
- Here are two executions of a Grover search. Can you guess which one was run on an actual quantum computer, and which one on an ideal simulator?

a



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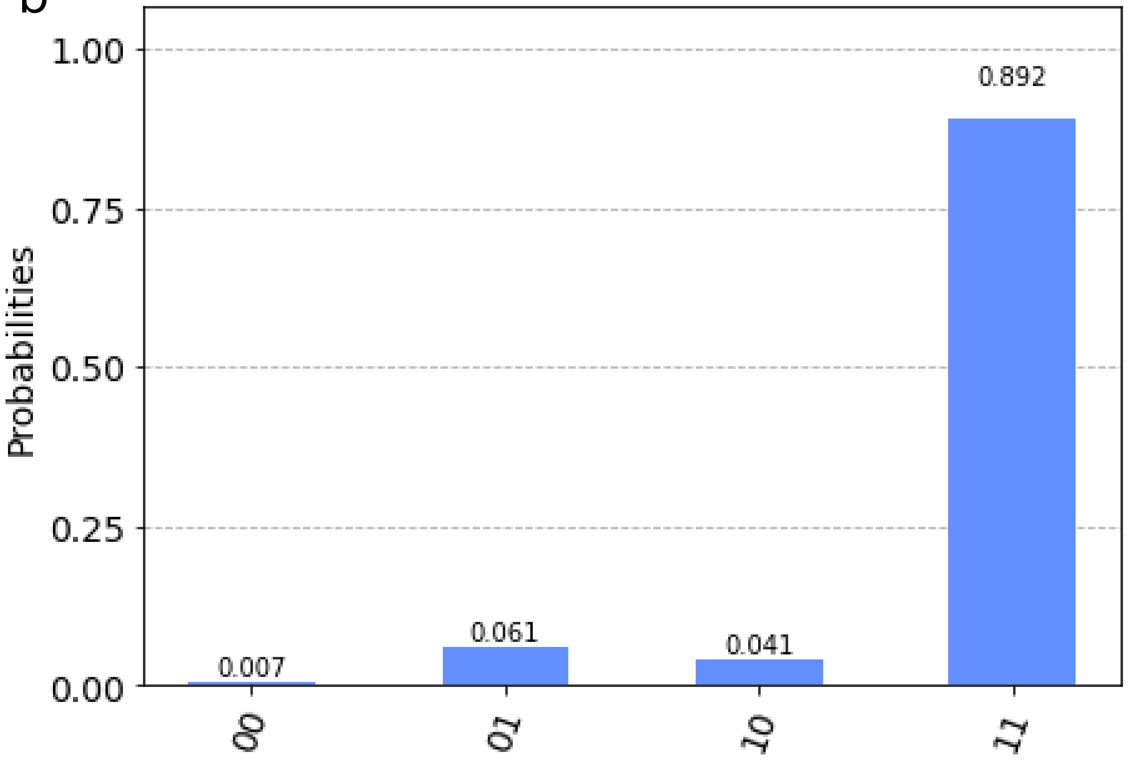

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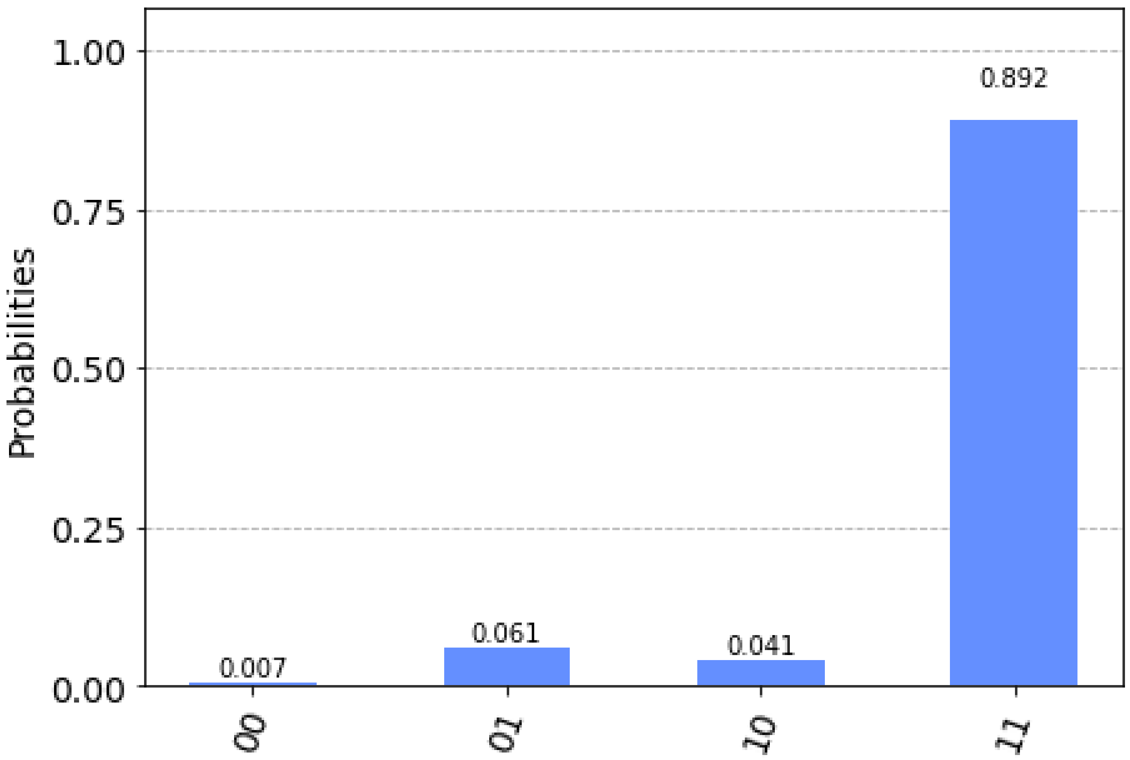
DIFFERENT TYPES OF ERRORS

- What are all the different errors you can think of?

- Qubit errors
- Gate errors
- Readout errors



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THE QC LANDSCAPE RIGHT NOW

- What is the status of QC right now?
  - We have quantum computers with tens of qubits
  - These QCs are noisy, make errors

- What can we do?
  - **Characterize errors (difficulty level - easy)**
  - Mitigate errors (difficulty level – medium)
  - Correct errors (difficulty level – hard)
  - Prevent errors (difficulty level – super hard)

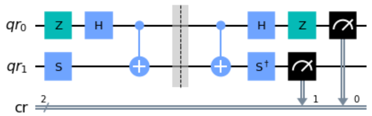
CHARACTERIZING ERRORS - TELEPHONE

- Have you ever played the game of Telephone?
- You whisper a message to your friend, who whispers it to their friend, and so on
- Up to how many levels of friends can you reliably send a message?

QUANTUM TELEPHONE

- Which circuit do you expect to have more errors?

a



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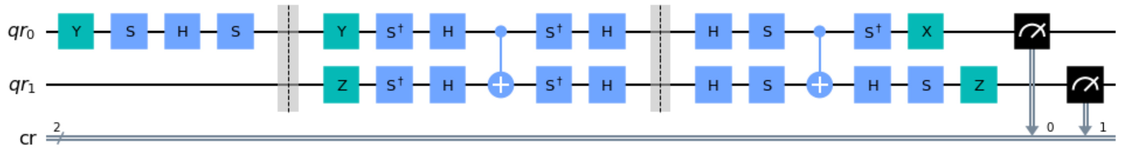

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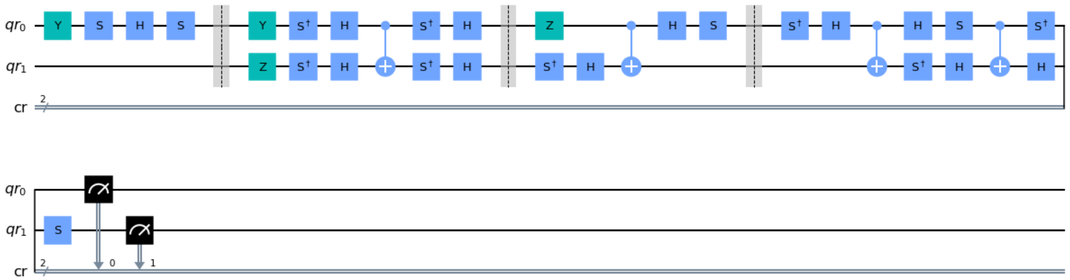

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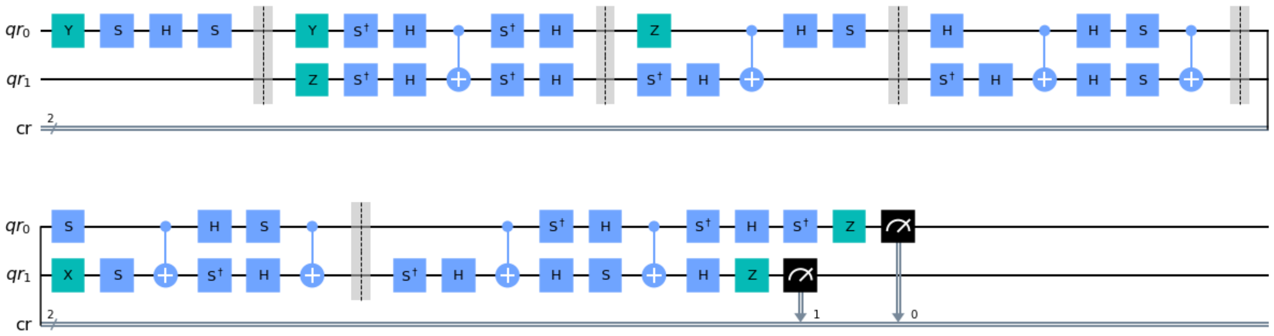

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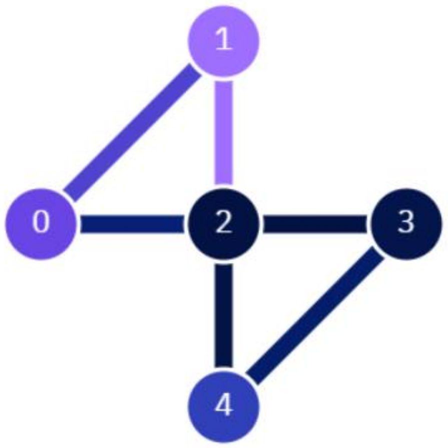
USING DIFFERENT TELEPHONES

- On which quantum computer will there be fewer errors?

1) ibmq_5_yorktown



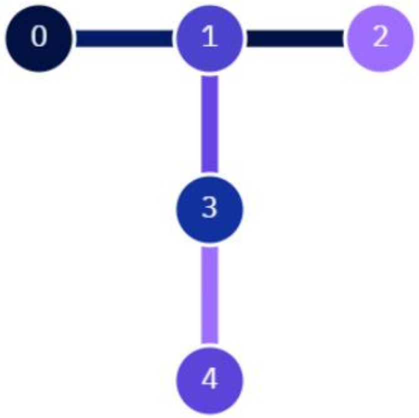
Avg. CNOT Error: 2.726e-2

Avg. Readout Error: 6.916e-2

Avg. T1: 53.74 us

Avg. T2: 33.09 us

2) ibmq_belem



Avg. CNOT Error: 2.448e-2

Avg. Readout Error: 3.674e-2

Avg. T1: 87.26 us

Avg. T2: 98.59 us

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RANDOMIZED BENCHMARKING

- Let's quantify our intuition – we'll simulate these circuits on ibmq_5_yorktown and ibmq_belem and see how many errors there are

- This process is called **randomized benchmarking**
  - The "message" we want to send is 00..0 – our circuits should ideally produce the state $|00..0\rangle$ as the result
  - We'll give the same circuit to both QCs to compare their performance
  - From the performance, we can extract the **average gate fidelity**

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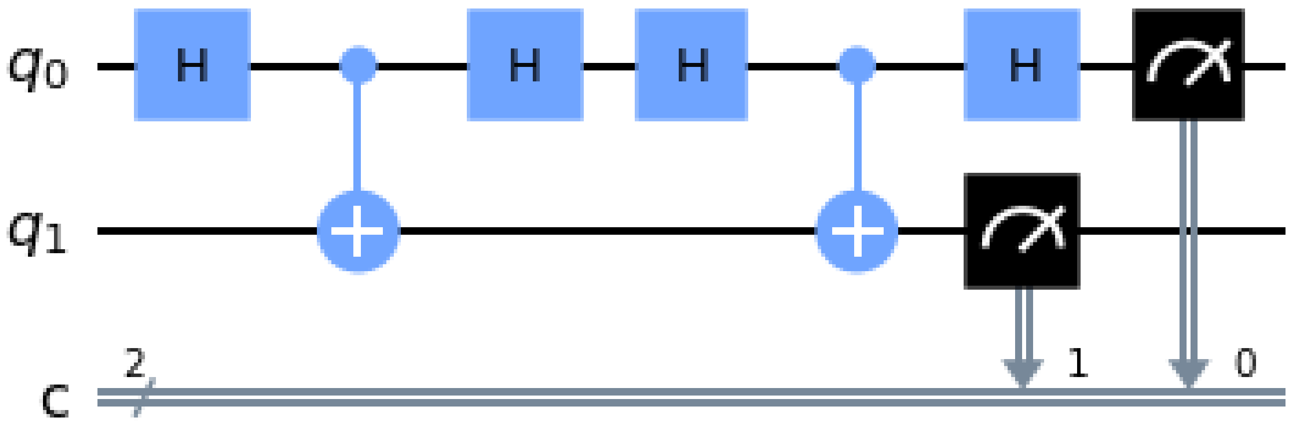
EXAMPLE OF BENCHMARKING CIRCUIT

- What is the output of this circuit?



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GENERATING RANDOM CIRCUITS

- Qiskit has a useful function that lets us generate random circuits of a given length

- This function is **randomized_benchmarking_seq()** in the library **qiskit.ignis.verification.randomized_benchmarking**

```
import qiskit.ignis.verification.randomized_benchmarking as rb
```

```
rb_circs, _ = rb.randomized_benchmarking_seq(length_vector, rb_pattern)
```

2-D list of circuits

another output that we ignore

list of circuit lengths

number and pattern of qubits

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INCLUDING NOISE MODELS IN QISKIT

- It will be really time consuming to run these circuits on actual QCs!
- Instead, we will use qasm_simulator, but add a **noise model** to it to mimic the noise of an actual QC

- Step 1: Importing NoiseModel

  from qiskit.providers.aer.noise import NoiseModel
- Step 2: Choosing which QC's noise you want to mimic

  backend = provider.get_backend('ibmq_belem')
- Step 3: Create a noise model from that QC

  noise_model = NoiseModel.from_backend(backend)
- Step 4: Run a job using that noise model

  job= execute(qc, backend = 'qasm_simulator', noise_model=noise_model, shots = 1024)

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STEPS IN RANDOMIZED BENCHMARKING

1. Create a noise model for the QCs we want to compare

```
backend_belem = provider.get_backend('ibmq_belem')
noise_model_belem = NoiseModel.from_backend(backend_belem)
```


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STEPS IN RANDOMIZED BENCHMARKING

2. Creating randomized circuits of different lengths

```
rb_circs, _ = rb.randomized_benchmarking_seq(length_vector = lengths, rb_pattern = pattern)
```

We will use lengths between 1 and 200, and we will simulate 3 qubit circuits

STEPS IN RANDOMIZED BENCHMARKING

3. Running the circuits using the noise models from step 1

```
#getting results using the belem noise model
job_belem = execute(rb_circs[0][i], backend, noise_model=noise_model_belem, shots = sh)
results_belem = job_belem.result()
counts_belem = results_belem.get_counts()
count_000_belem[i] = counts_belem["000"] #extracting the 000 counts from belem results
```

STEPS IN RANDOMIZED BENCHMARKING

4. Comparing results

```
plt.plot(lengths, count_000_belem/sh, marker = 's')
plt.plot(lengths, count_000_yorktown/sh, marker = 'o')
```


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TIME TO CODE!

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KEY TAKEAWAYS

- Randomized benchmarking is the process of testing randomly generated circuits on different quantum processors to compare their error performance

- We can simulate the error performance of different processors in qiskit by using the NoiseModel function

- **Gate fidelity** can be extracted from the results of randomized benchmarking

- **Connectivity** is also an important metric in determining processor performance. If there is a direct connection between two qubits, we can apply two-qubit gates on them with fewer errors

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FURTHER READING AND RESOURCES

- [Qiskit textbook page on randomized benchmarking]
- [Qiskit textbook page on error correction]
- [Video on mitigating noise on real QCs]
- [Lecture on quantum error correction]
- [Introduction to decoherence]
- [Lecture on decoherence in quantum computers]

POST-LAB ZOOM FEEDBACK

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