Trabalho_Pratico_Grupo_2

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1 Algoritmo de Groover

Em 1996, Lov Grover apresentou um algoritmo de procura desordenada.

Considerando uma lista de 0 até N, existe um objeto w que se quer localizar nessa mesma lista.

0	0	0		1		0	0
0	1	2	...	w	...	$N-1$	$N=2^n$

Num computador clássico:

- o pior caso é N;
- caso médio é $\frac{N}{2}$.

Num computador quântico:

- o pior caso é $\sqrt{N}$.

[120]:
```
# importing Qiskit
from qiskit import Aer, IBMQ
from qiskit import QuantumCircuit, ClassicalRegister, QuantumRegister
from qiskit import execute, transpile

from qiskit.tools.visualization import plot_histogram, plot_state_city,␣
↪plot_state_hinton

import matplotlib.pyplot as plt
%matplotlib inline

from qiskit.providers.aer.noise import NoiseModel
import operator
```

[121]:
```
w = 2 % 8
print(w)
```

```
2
```

[122]:
```
wb = bin(w)[2:]

print(wb)
```

```
10
```

[123]:
```
x = 3
print('number of qubits: ', x)
```

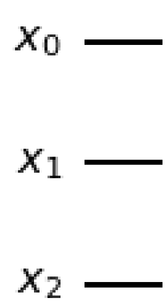
```
number of qubits:  3
```

[124]:
```
qr_x = QuantumRegister(x, 'x')
```

[125]:
```
backend = Aer.get_backend("qasm_simulator")
backend_vector = Aer.get_backend('statevector_simulator')
```

[126]:
```
qc_Grover= QuantumCircuit(qr_x)
qc_Grover.draw(output = 'mpl')
```

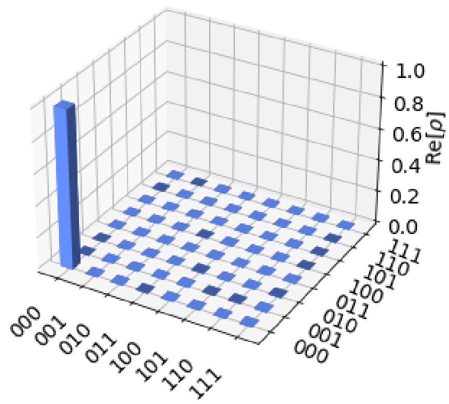
[126]:

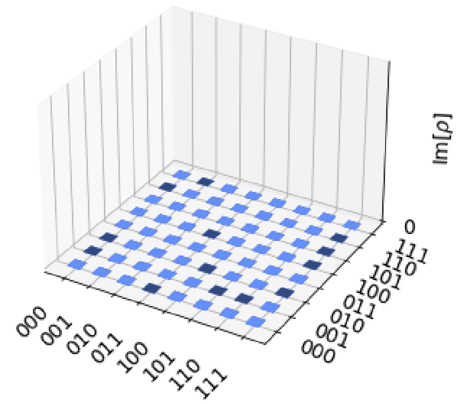


[127]:
```
result = execute(qc_Grover, backend_vector).result()
qstate= result.get_statevector(qc_Grover)
print("state-vector antes de inicializar: \n", qstate)
plot_state_city(qstate)
```

```
state-vector antes de inicializar:
 [1.+0.j 0.+0.j 0.+0.j 0.+0.j 0.+0.j 0.+0.j 0.+0.j 0.+0.j]
```

[127]:





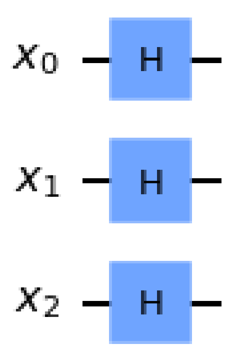
A função initialize inicia todos os qubits, ou seja, vai colocá-los em superposição usando portas Hadamard. Irá retornar um novo circuito quântico.

$|\psi_1\rangle = \frac{1}{\sqrt{8}}(|000\rangle + |001\rangle + |010\rangle + |011\rangle + |100\rangle + |101\rangle + |110\rangle + |111\rangle)$

[128]:
```
def initialize(qc_Grover,qubits):
    for q in qubits:
        qc_Grover.h(q)
    return qc_Grover
```

[129]:
```
# init
qc_Grover = initialize(qc_Grover, qr_x)
qc_Grover.draw(output = 'mpl')
```

[129]:

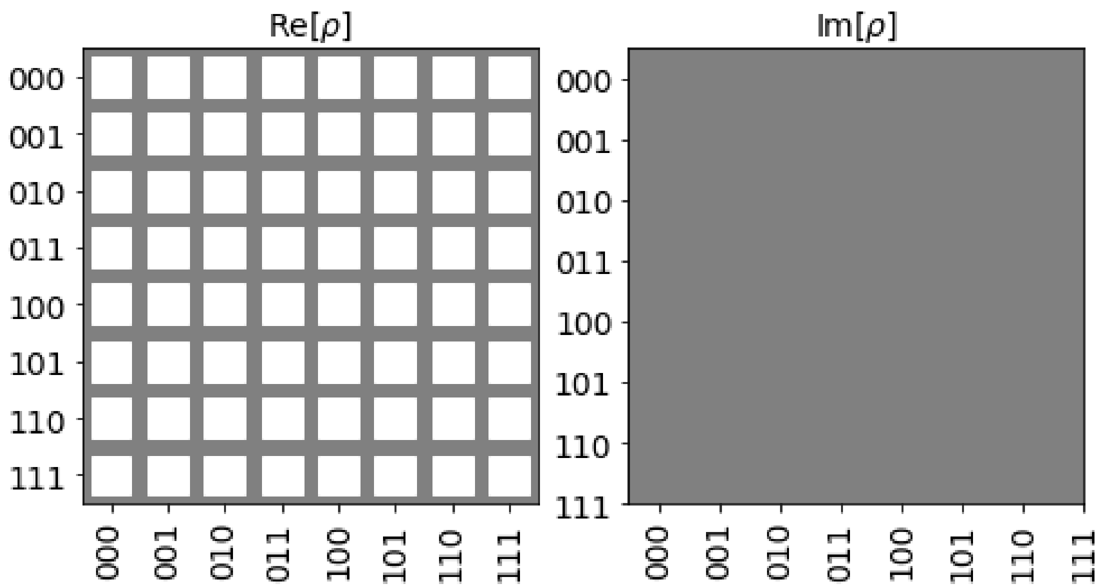


[130]:
```
result = execute(qc_Grover, backend_vector).result()
qstate= result.get_statevector(qc_Grover)
```

```
print("state-vector depois de inicializar: \n", qstate)
plot_state_hinton(qstate)
```

```
state-vector depois de inicializar:
 [0.35355339+0.j 0.35355339+0.j 0.35355339+0.j 0.35355339+0.j
 0.35355339+0.j 0.35355339+0.j 0.35355339+0.j 0.35355339+0.j]
```

[130]:



Como o nosso | w ⟩ = | 010 ⟩, o que significa que queremos que o computador quântico descubra este estado e ignore os outros. Para isso, começámos por marcar os qubits que queremos que fiquem a 0, neste caso são os qubits 0 e 2. Após isto, queremos decompor o control Z(porta ccz), usando as portas hadamard e ccx

$|\psi_2\rangle = \frac{1}{\sqrt{8}}(|000\rangle + |001\rangle - |010\rangle + |011\rangle + |100\rangle + |101\rangle + |110\rangle + |111\rangle)$

[131]:
```
def phase_oracle2(nqubits):
    qc = QuantumCircuit(nqubits)
    qc.x(0)
    qc.x(2)
    qc.h(2)
    qc.ccx(0,1,2)
    qc.h(2)
    qc.x(0)
    qc.x(2)

    oracle = qc.to_gate()
    oracle.name = "U$_\omega$"

    return oracle
```

1. Aplicação da porta **Hadamard**

$$|\psi_{3a}\rangle = \frac{1}{2}(|000\rangle + |011\rangle + |100\rangle - |111\rangle)$$

2. Aplicação da porta **X** aos qubits

$$|\psi_{3b}\rangle = \frac{1}{2}(-|000\rangle + |011\rangle + |100\rangle + |111\rangle)$$

3. Aplicação da porta **control Z**

$$|\psi_{3c}\rangle = \frac{1}{2}(-|000\rangle + |011\rangle + |100\rangle - |111\rangle)$$

4. Aplicação da porta **X** aos qubits

$$|\psi_{3d}\rangle = \frac{1}{2}(-|000\rangle + |011\rangle + |100\rangle - |111\rangle)$$

5. Aplicação da porta **Hadamard** aos qubits

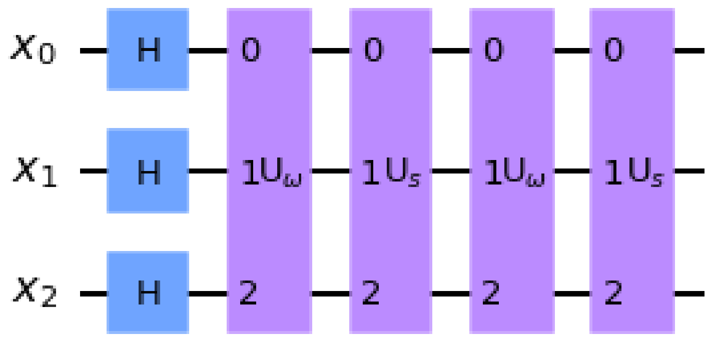
$$|\psi_{3d}\rangle = \frac{1}{2}(-|010\rangle)$$

[132]:
```
def diffuser(nqubits):
    qc = QuantumCircuit(nqubits)
    for qubit in range(nqubits):
        qc.h(qubit)

    for qubit in range(nqubits):
        qc.x(qubit)

    qc.h(nqubits-1)
    qc.ccx(0,1,2)
    qc.h(nqubits-1)

    for qubit in range(nqubits):
        qc.x(qubit)

    for qubit in range(nqubits):
        qc.h(qubit)

    U_s = qc.to_gate()
    U_s.name = "U$_s$"

    return U_s
```

[133]:

```python
# oracle and difuser

for t in range(2):
    # phase oracle 2
    qc_Grover.append(phase_oracle2(x), qr_x)

    # diffuser
    qc_Grover.append(diffuser(x), qr_x)

qc_Grover.draw(output = 'mpl')
```

[133]:

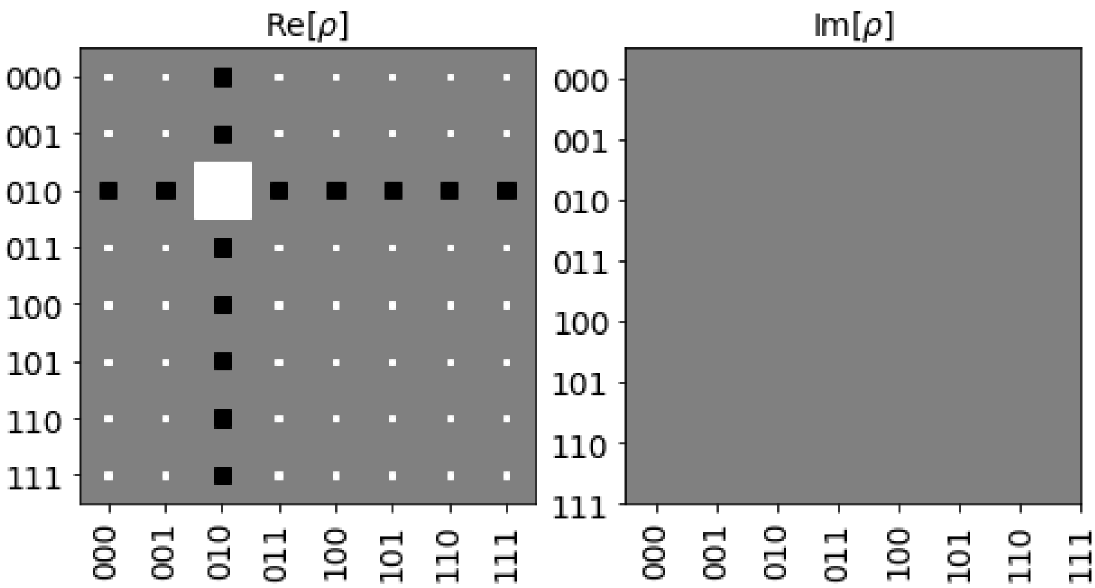


[134]:

```python
result = execute(qc_Grover, backend_vector).result()
qstate= result.get_statevector(qc_Grover)
print("state-vector depois do óraculo: \n", qstate)
plot_state_hinton(qstate)
```

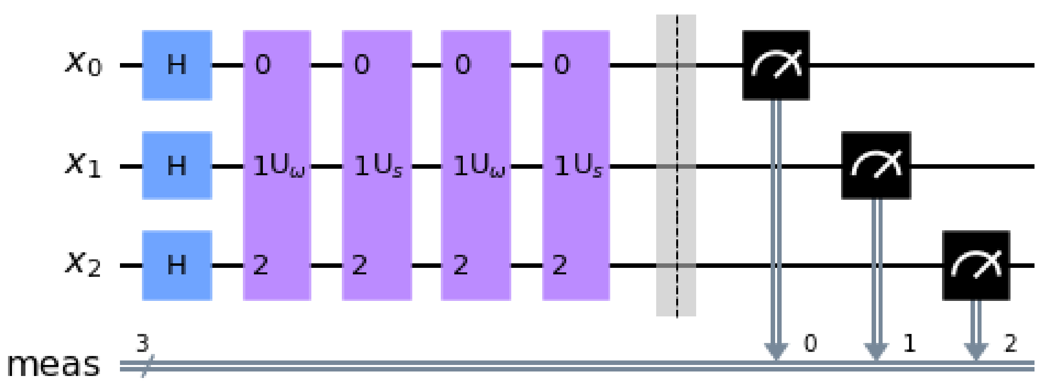
```
state-vector depois do óraculo:
 [-0.08838835+2.16489014e-17j -0.08838835+3.24733521e-17j
  0.97227182+1.08244507e-17j -0.08838835+1.51542310e-16j
 -0.08838835-1.08244507e-17j -0.08838835+2.16489014e-17j
 -0.08838835-2.16489014e-17j -0.08838835+5.41222535e-17j]
```

[134]:



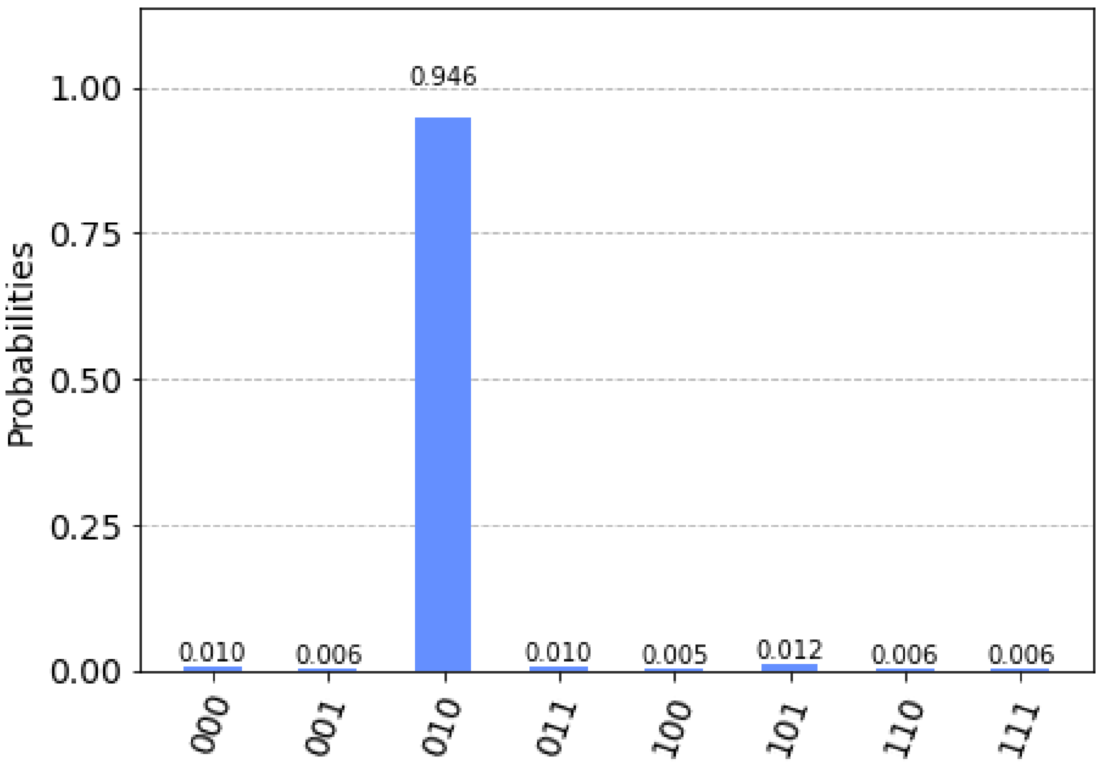
[135]:
```python
qc_Grover.measure_all()

qc_Grover.draw(output='mpl')
```

[135]:



[136]:
```python
shots=1024
result = execute(qc_Grover, backend, shots=shots).result()
counts_sim = result.get_counts(qc_Grover)
plot_histogram(counts_sim)
```

[136]:



2 IBM Q Backend

[137]:
```
#save_account needs to be run only once
IBMQ.
 ↪save_account('76e1c12758b397a2b16afb3b44325fbd498983773831531426ea6acf41712cf0e431919a898d4e9
```

```
configrc.store_credentials:WARNING:2021-06-05 18:14:56,708: Credentials already
present. Set overwrite=True to overwrite.
```

[138]:
```
provider = IBMQ.load_account()
provider.backends()
```

[138]:
```
[<IBMQSimulator('ibmq_qasm_simulator') from IBMQ(hub='ibm-q', group='open',
project='main')>,
 <IBMQBackend('ibmqx2') from IBMQ(hub='ibm-q', group='open', project='main')>,
 <IBMQBackend('ibmq_16_melbourne') from IBMQ(hub='ibm-q', group='open',
project='main')>,
 <IBMQBackend('ibmq_armonk') from IBMQ(hub='ibm-q', group='open',
project='main')>,
 <IBMQBackend('ibmq_athens') from IBMQ(hub='ibm-q', group='open',
project='main')>,
```

```
 <IBMQBackend('ibmq_santiago') from IBMQ(hub='ibm-q', group='open',
project='main')>,
 <IBMQBackend('ibmq_lima') from IBMQ(hub='ibm-q', group='open',
project='main')>,
 <IBMQBackend('ibmq_belem') from IBMQ(hub='ibm-q', group='open',
project='main')>,
 <IBMQBackend('ibmq_quito') from IBMQ(hub='ibm-q', group='open',
project='main')>,
 <IBMQSimulator('simulator_statevector') from IBMQ(hub='ibm-q', group='open',
project='main')>,
 <IBMQSimulator('simulator_mps') from IBMQ(hub='ibm-q', group='open',
project='main')>,
 <IBMQSimulator('simulator_extended_stabilizer') from IBMQ(hub='ibm-q',
group='open', project='main')>,
 <IBMQSimulator('simulator_stabilizer') from IBMQ(hub='ibm-q', group='open',
project='main')>,
 <IBMQBackend('ibmq_manila') from IBMQ(hub='ibm-q', group='open',
project='main')>]
```

[139]:
```
import qiskit.tools.jupyter

%qiskit_backend_overview
```

```
VBox(children=(HTML(value="<h2 style ='color:#ffffff; background-color:#000000;
↪padding-top: 1%; padding-bottom...
```

[140]:
```
from qiskit.tools.monitor import backend_overview, backend_monitor

backend_overview()
```

```
ibmq_manila                 ibmq_quito                  ibmq_belem
-----------                 ----------                  ----------
Num. Qubits:  5             Num. Qubits:  5             Num. Qubits:  5
Pending Jobs: 2             Pending Jobs: 6             Pending Jobs: 2
Least busy:   False         Least busy:   False         Least busy:   False
Operational:  True          Operational:  True          Operational:  True
Avg. T1:      151.0         Avg. T1:      75.2          Avg. T1:      79.3
Avg. T2:      67.0          Avg. T2:      73.2          Avg. T2:      91.6



ibmq_lima                   ibmq_santiago               ibmq_athens
---------                   -------------               -----------
Num. Qubits:  5             Num. Qubits:  5             Num. Qubits:  5
Pending Jobs: 5             Pending Jobs: 10            Pending Jobs: 0
Least busy:   False         Least busy:   False         Least busy:   True
Operational:  True          Operational:  True          Operational:  True
Avg. T1:      69.2          Avg. T1:      136.2         Avg. T1:      95.9
```

```
Avg. T2:      64.9            Avg. T2:      136.4           Avg. T2:      120.6



ibmq_armonk                   ibmq_16_melbourne             ibmqx2
-----------                   -----------------             ------
Num. Qubits:  1               Num. Qubits:  15              Num. Qubits:  5
Pending Jobs: 31              Pending Jobs: 1               Pending Jobs: 5
Least busy:   False           Least busy:   False           Least busy:   False
Operational:  True            Operational:  True            Operational:  True
Avg. T1:      124.6           Avg. T1:      57.5            Avg. T1:      54.1
Avg. T2:      217.3           Avg. T2:      56.2            Avg. T2:      40.5
```

2.1 Simulador de Ruído

A função *backend_device_chooser* recebe como parâmetro um device e vai definir o backend device.

[141]:
```
#aqui tem de escolher com base na optimização

def backend_device_chooser(device):
    backend_device = provider.get_backend(device)
    print("Running on: ", backend_device)
    return backend_device
```

A função *coupling* receber o backend device como parâmetro e retorna o coupling_map.

[142]:
```
def coupling(backend_device):
    coupling_map = backend_device.configuration().coupling_map
    return coupling_map
```

A função *noise_model_construction* recebe como parâmetro o backend device e define o noise_model de acordo com esse backend device.

[143]:
```
def noise_model_construction(backend_device):
    # Construct the noise model from backend properties
    noise_model = NoiseModel.from_backend(backend_device)
    #print(noise_model)
    return noise_model
```

A função *basis_gates_model* recebe como parâmetro o noise_model e retorna o basis gate desse noise model.

[144]:
```
def basis_gates_model(noise_model):
    # Get the basis gates for the noise model
    basis_gates = noise_model.basis_gates
    #print(basis_gates)
```

```
    return basis_gates
```

A função *noise_calculation* recebe como parâmetro tudo que foi retornado nas funções anteriores. Executa uma simulação do ruído e retorna o contador de ruído do nosso circuito quântico.

```
[145]: def noise_calculation(backend_device, noise_model, basis_gates, coupling_map):
           # Execute noisy simulation and get counts
           result_noise = execute(qc_Grover, backend,
                                  noise_model=noise_model,
                                  coupling_map=coupling_map,
                                  basis_gates=basis_gates).result()

           counts_noise = result_noise.get_counts(qc_Grover)
           return counts_noise
```

A função *maximum* recebe como parâmetro um dicionário onde a chave é nome do device e o value é o *counts_noise*. Vai determinar o device que tem maior valor e vai retornar o nome do device com maior valor, ou seja, o que tem menos ruído.

```
[146]: def maximum(devices_adj):
           device_name = ""
           maximum = 0
           for device in devices_adj:
               if devices_adj[device]["010"] > maximum:
                   maximum = devices_adj[device]["010"]
                   device_name = device
           return device_name
```

A função *choose_device_main* percorre a lista com todos os devices possíveis e executa as funções implementadas anteriormente. Vai retornar o counts_noise do dispositivo com menos ruído e o backend device.

```
[170]: def choose_device_main():
           devices = ["ibmq_manila", "ibmq_quito", "ibmq_belem", "ibmq_lima",␣
        ↪"ibmq_santiago","ibmq_athens",
                   "ibmq_16_melbourne","ibmqx2"]
           devices_adj = {}

           for device in devices:
               backend_device = backend_device_chooser(device)
               coupling_map = coupling(backend_device)
               noise_model = noise_model_construction(backend_device)
               basis_gates = basis_gates_model(noise_model)
               counts_noise = noise_calculation(backend_device, noise_model,␣
        ↪basis_gates, coupling_map)
               #print(noise_results)
               if device not in devices_adj:
                   devices_adj[device] = counts_noise
```

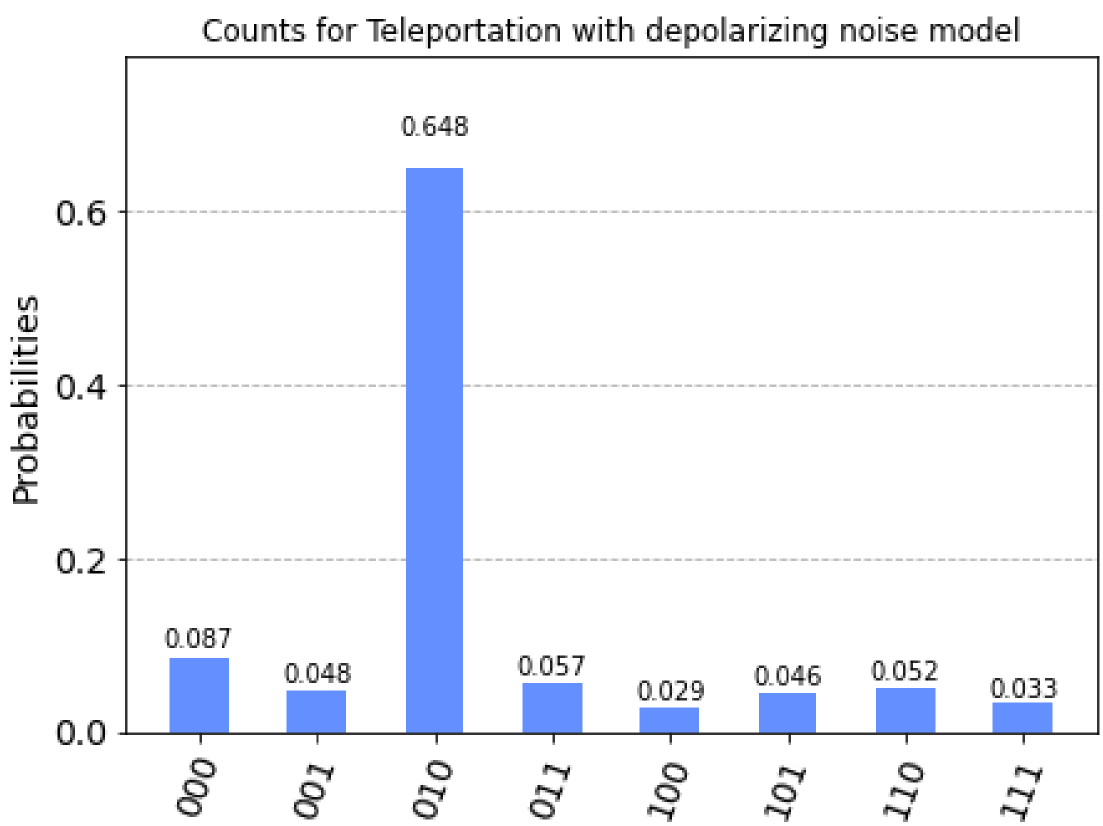
```
    #print("\nNoise on 010: ", devices_adj)
    device_name = maximum(devices_adj)

    print("Device Choosen", device_name)

    return devices_adj[device_name],backend_device
```

[171]:
```
counts_noise,backend_device = choose_device_main()
```

```
Running on:  ibmq_manila
Running on:  ibmq_quito
Running on:  ibmq_belem
Running on:  ibmq_lima
Running on:  ibmq_santiago
Running on:  ibmq_athens
Running on:  ibmq_16_melbourne
Running on:  ibmqx2
Device Choosen ibmq_santiago
```

[153]:
```
plot_histogram(counts_noise, title="Counts for Teleportation with depolarizing␣
 ↪noise model")
```

[153]:



2.2 Execução numa IBM Q Backend

[1]:
```
#backend_monitor(backend_device)
```

[155]:
```
%qiskit_job_watcher
```

```
Accordion(children=(VBox(layout=Layout(max_width='710px', min_width='710px')),),␣
↪layout=Layout(max_height='500...
```

```
<IPython.core.display.Javascript object>
```

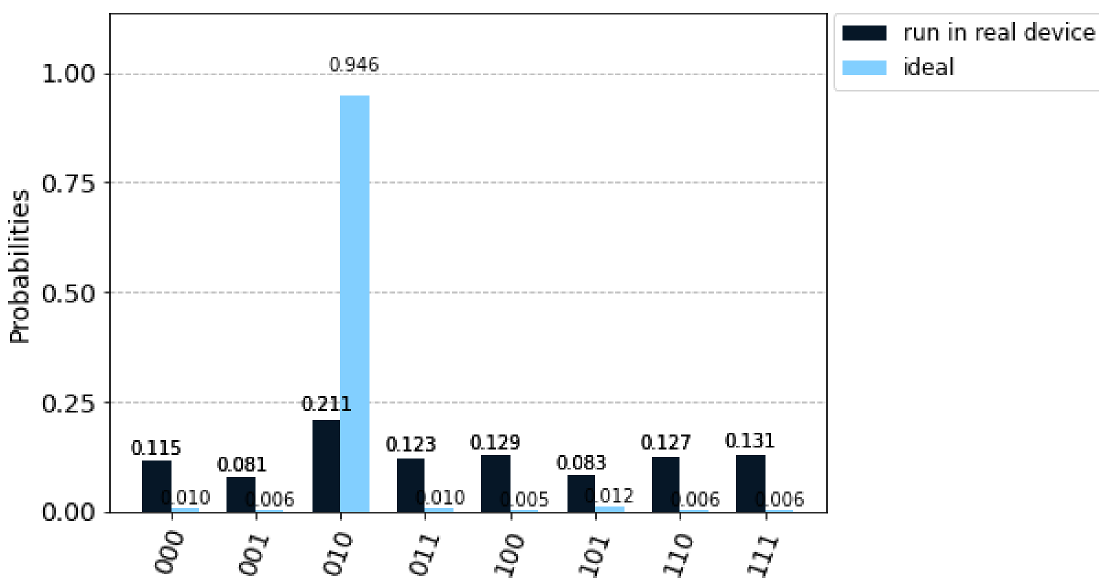
[156]:
```
job_r = execute(qc_Grover, backend_device, shots=shots)

jobID_r = job_r.job_id()

print('JOB ID: {}'.format(jobID_r))
```

```
JOB ID: 60bbb1bc00aded148e6a6fec
```

[158]:
```
#ibmq_essex 1 times the oracle:
job_get=backend_device.retrieve_job("60bbb1bc00aded148e6a6fec")

result_r = job_get.result()
counts_run = result_r.get_counts(qc_Grover)
```

[159]:
```
plot_histogram([counts_run, counts_sim ], legend=[ 'run in real device',␣
↪'ideal'], color=['#061727','#82cfff'])
```

[159]:



3 IGNIS

[161]:
```
# Import measurement calibration functions
from qiskit.ignis.mitigation.measurement import (complete_meas_cal,␣
 ↪tensored_meas_cal,
                                                  CompleteMeasFitter,␣
 ↪TensoredMeasFitter)
```

3.1 Matriz de Calibração

Gerar a lista das medidas dos circuitos de calibração.

O circuito cria a lista dos estados base.

Como só usámos 3 qubits, precisámos de $2^3 = 8$ circuitos de calibração.

[162]:
```
# Generate the calibration circuits
qr = QuantumRegister(x)
meas_calibs, state_labels = complete_meas_cal(qubit_list=[0,1,2], qr=qr,␣
 ↪circlabel='mcal')
```

[163]:
```
state_labels
```

[163]:
```
['000', '001', '010', '011', '100', '101', '110', '111']
```

3.2 Cálculo da matriz de calibração

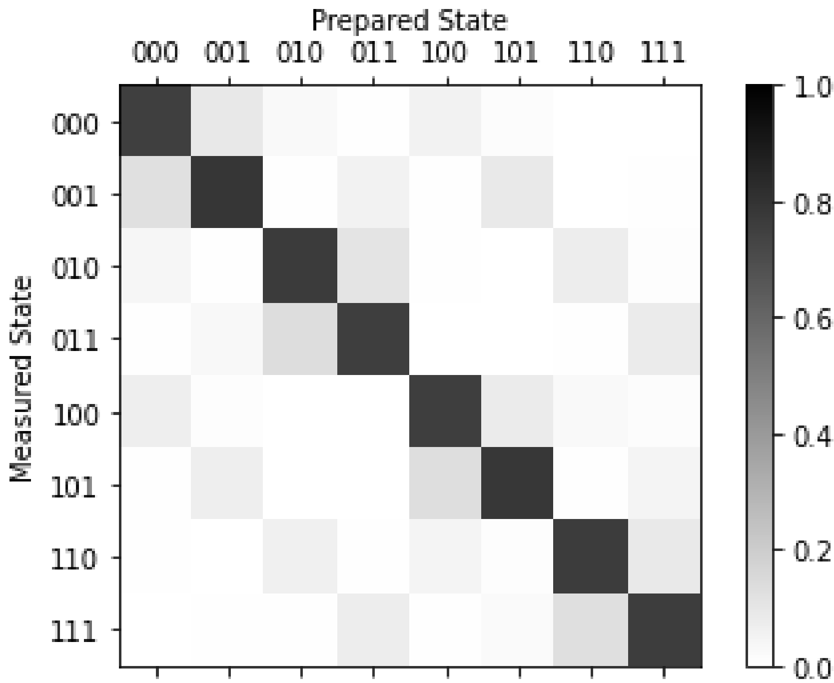
Caso não haja ruído no dispositivo, a matriz de calibração deverá ser uma matriz identidade $8 * 8$. Visto que o cálculo da matriz é feito a partir de um dispositivo quântico real, irá haver algum ruído.

[164]:
```
job_ignis = execute(meas_calibs, backend=backend_device, shots=shots)

jobID_run_ignis = job_ignis.job_id()

print('JOB ID: {}'.format(jobID_run_ignis))
```

```
JOB ID: 60bbb25636b2bea37724fe3d
```

[165]:
```
job_get=backend_device.retrieve_job("60bbb25636b2bea37724fe3d")

cal_results = job_get.result()
```

[166]:
```
meas_fitter = CompleteMeasFitter(cal_results, state_labels, circlabel='mcal')

# Plot the calibration matrix
meas_fitter.plot_calibration()
```



3.3 Análise de resultados

A fidelidade média de atribuição é a diagonal principal da matriz anterior.

[167]:
```
print("Average Measurement Fidelity: %f" % meas_fitter.readout_fidelity())
```

```
Average Measurement Fidelity: 0.765137
```

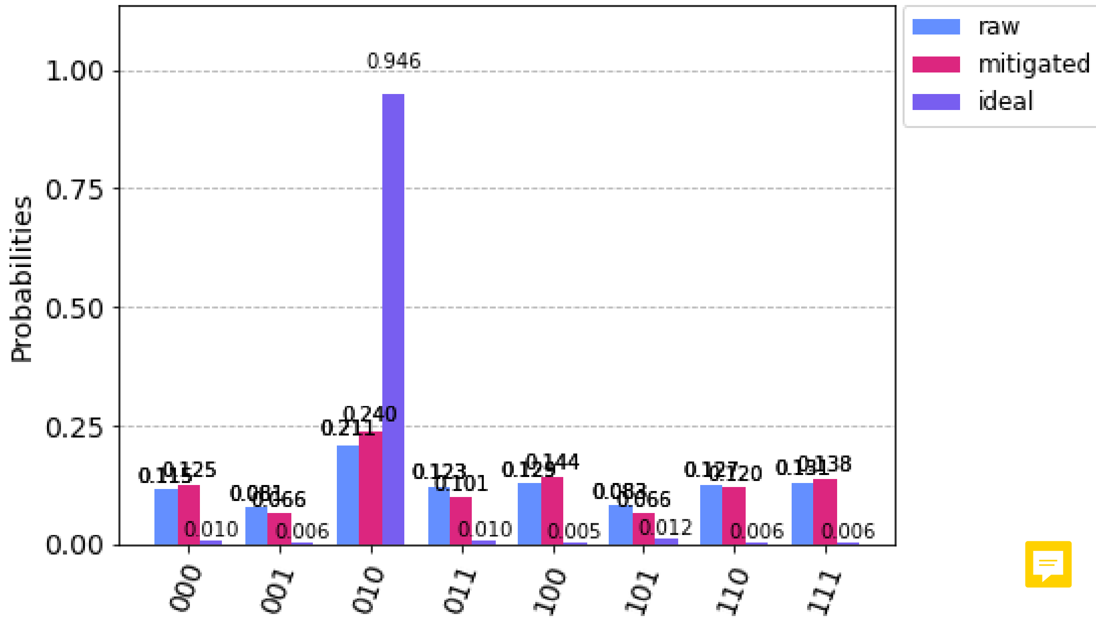
3.4 Aplicação da calibração

Aplicámos um filtro para obter mitigated_counts.

[168]:
```
# Get the filter object
meas_filter = meas_fitter.filter

# Results with mitigation
mitigated_results = meas_filter.apply(result_r)
mitigated_counts = mitigated_results.get_counts()
```

[169]:
```
plot_histogram([counts_run, mitigated_counts, counts_sim], legend=['raw',␣
↪'mitigated', 'ideal'])
```

[169]:



4 Referências

Aulas práticas.

https://qiskit.org/textbook/ch-algorithms/grover.html