IC-TP-G13

June 6, 2021

1 Interação e Concorrência

1.1 Trabalho Prático - Grupo 13

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[11]:
```
# importing Qiskit
from qiskit import Aer, IBMQ
from qiskit import QuantumCircuit, ClassicalRegister, QuantumRegister
from qiskit import execute, transpile

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

import matplotlib.pyplot as plt
%matplotlib inline

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

Sabendo que o número do nosso grupo é $N = 13$

Temos de de usar um *quantum algorithm* para encontrar s numa lista não ordenada, tal que

$$s = N mod 8$$

[12]:
```
N = 13
s = N % 8
s
```

[12]: 5

Passando o valor de s para binário, ficamos com:

[13]:
```
w = bin(s)[2:]
w # winner
```

[13]:
```
'101'
```

Portanto, como 5 em binário é 101, iremos precisar de preparar um circuito quântico de 3 qubits

[14]:
```
x = 3
print('Número de qubits: ', x)
```

```
Número de qubits:  3
```

[57]:
```
qr_x      = QuantumRegister(x, 'x')
cr        = ClassicalRegister(x, 'cr')
qc_Grover = QuantumCircuit(qr_x,cr) # circuito quântico
```

O algoritmo adotado pelo nosso grupo foi o algoritmo de *Grover*. Este é um algoritmo de pesquisa dividido em três fases, nomeadamente *inicializao*, *orculo* e *amplificao* (*diffuser*).

Portanto, iremos inicializar todos os estados com a mesma amplitude, isto é, inicializar todos os qubits com uma *gate* de *Hadammar*.

$$\sum_{x_i} |x_i\rangle$$

Para tal criamos a seguinte função:

[58]:
```
def init(qc_Grover):
    qc_Grover.h(0)
    qc_Grover.h(1)
    qc_Grover.h(2)
```

1.1.1 Implementação do Oracle

Para computar um *quantum algorithm* baseado em um determinada função, podemos implementar uma espécie de *black box* da função. Passamos um *input* x e recebemos um *output* $f(x)$.

Para resolver os problemas, podemos definir o oráculo da seguinte forma: marcamos a nossa solução (ou soluções) com uma fase negativa (-1) para que desta forma, possamos usar o *Grover's algorithm* para resolver.

$$U_w|x\rangle \Rightarrow x \neq w \rightarrow |x\rangle$$
$$U_w|x\rangle \Rightarrow x = w \rightarrow -|x\rangle$$

Tomando o valor w como sendo 101 resultará na seguinte matriz:

$$U_w = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

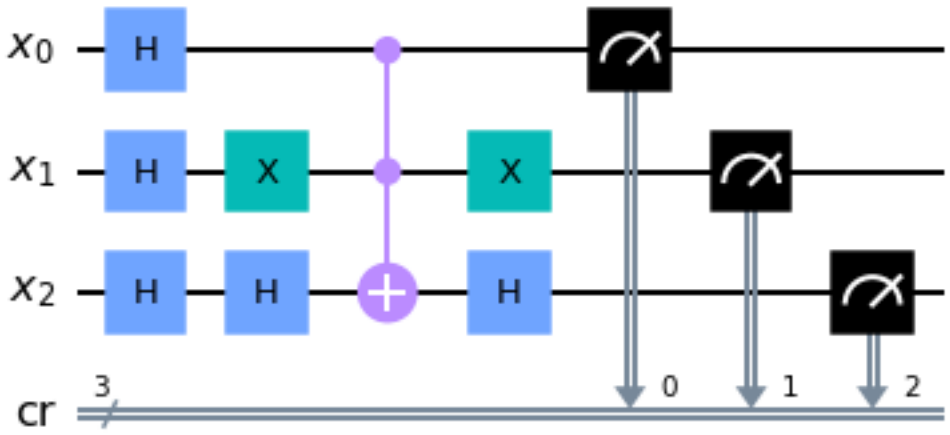
[59]:
```
def phase_oracle(qc_Grover, qr_x):
    qc_Grover.x(qr_x[1])
    qc_Grover.h(qr_x[2])
    qc_Grover.ccx(qr_x[0], qr_x[1], qr_x[2])
    qc_Grover.x(qr_x[1])
    qc_Grover.h(qr_x[2])
```

Se neste momento medíssemos a base $|x>$, a superposição colapsaria, de acordo com o que nos foi explicado nas aulas (*Schrdinger's cat*), tendo cada uma das bases a probabilidade de $\frac{1}{N} = \frac{1}{2^n}$ e as nossas chances de encontrar o valor w, *priori*, estaria entre 1 e 2^n.

Aplica-se portanto a reflexão do oráculo. Esta transformação significa que a amplitude média à frente do estado de w tornar-se-á negativa (foi diminuída).

[60]:
```
init(qc_Grover)

phase_oracle(qc_Grover, qr_x)

qc_Grover.measure(qr_x,cr)

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

[60]:



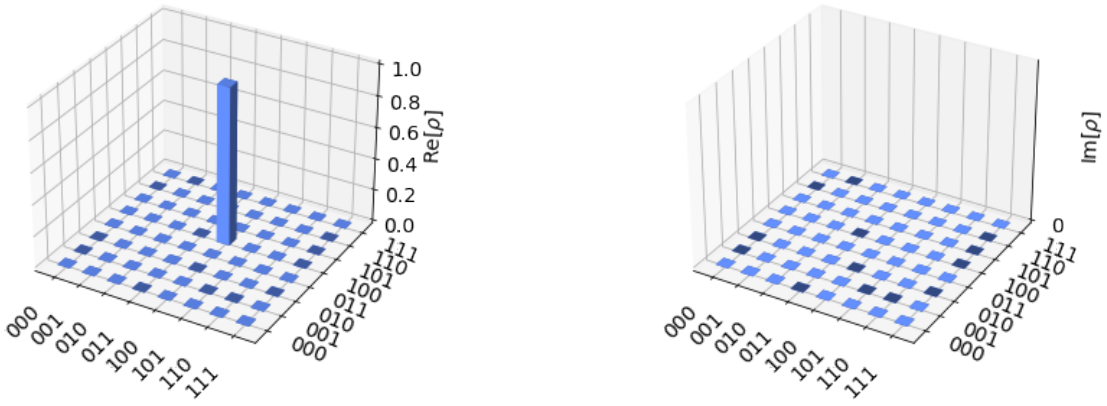
[61]:
```
backend_state = Aer.get_backend('statevector_simulator') # the device to run on
```

[62]:
```
result = execute(qc_Grover, backend_state).result()
psi1  = result.get_statevector(qc_Grover)

print(psi1)
```

```
[ 0.+0.j  0.+0.j  0.+0.j  0.+0.j  1.+0.j -0.+0.j  0.+0.j  0.+0.j]
```

[63]:
```
plot_state_city(psi1)
```

[63]:



1.1.2 Diffuser

O computador quântico utiliza a amplificação/$diffuser$ de modo a aumentar a probabilidade. Este processo amplifica a amplitude do w diminuindo a dos outros. Fazendo com que a amplitude de w se destaque relativamente às outras, tornando a probabilidade de se escolher o estado w muito maior.

[64]:
```
def diffuser(qc_Grover,qr_x):
    qc_Grover.h(qr_x[0])
    qc_Grover.x(qr_x[0])
    qc_Grover.h(qr_x[1])
    qc_Grover.h(qr_x[2])
    qc_Grover.x(qr_x[1])
    qc_Grover.x(qr_x[2])
    qc_Grover.h(qr_x[2])
    qc_Grover.ccx(qr_x[0], qr_x[1], qr_x[2])
    qc_Grover.x(qr_x[0])
    qc_Grover.x(qr_x[1])
    qc_Grover.h(qr_x[2])
```

```
    qc_Grover.h(qr_x[0])
    qc_Grover.h(qr_x[1])
    qc_Grover.x(qr_x[2])
    qc_Grover.h(qr_x[2])
```

A fase do oráculo e do *diffuser* terá de ser repetida aproximadamente $\sqrt{N}$ vezes para conseguirmos uma boa medição.

[66]:
```
import math as math

times= round(math.sqrt(2**x))
print(times)
```

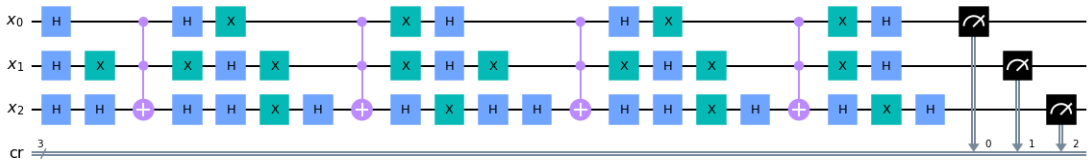
```
3
```

1.1.3 Implementação Completa em Qiskit

O *qc_Grover* vai inicializar o quantum circuit

[67]:
```
cr        = ClassicalRegister(x,'cr')
qc_Grover = QuantumCircuit(qr_x,cr)

init(qc_Grover)

for t in range(2):
    # phase oracle
    phase_oracle(qc_Grover, qr_x)
    # diffuser
    diffuser(qc_Grover,qr_x)

qc_Grover.measure(qr_x,cr)

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

[67]:



[68]:
```
backend_state = Aer.get_backend('statevector_simulator') # the device to run on
```

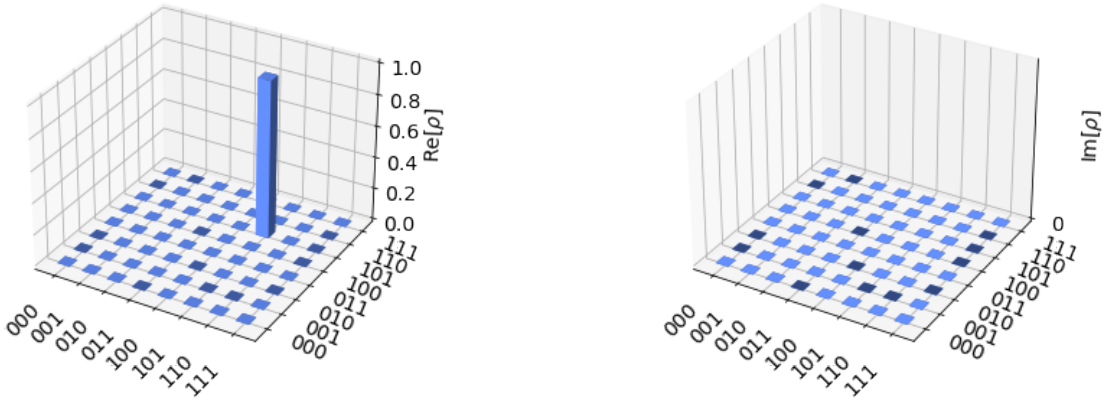
[69]:
```
result = execute(qc_Grover, backend_state).result()
psi2 = result.get_statevector(qc_Grover)
```

[70]:
```
print(psi2.real)
```

```
[-0. -0. -0. -0.  0.  1.  0. -0.]
```

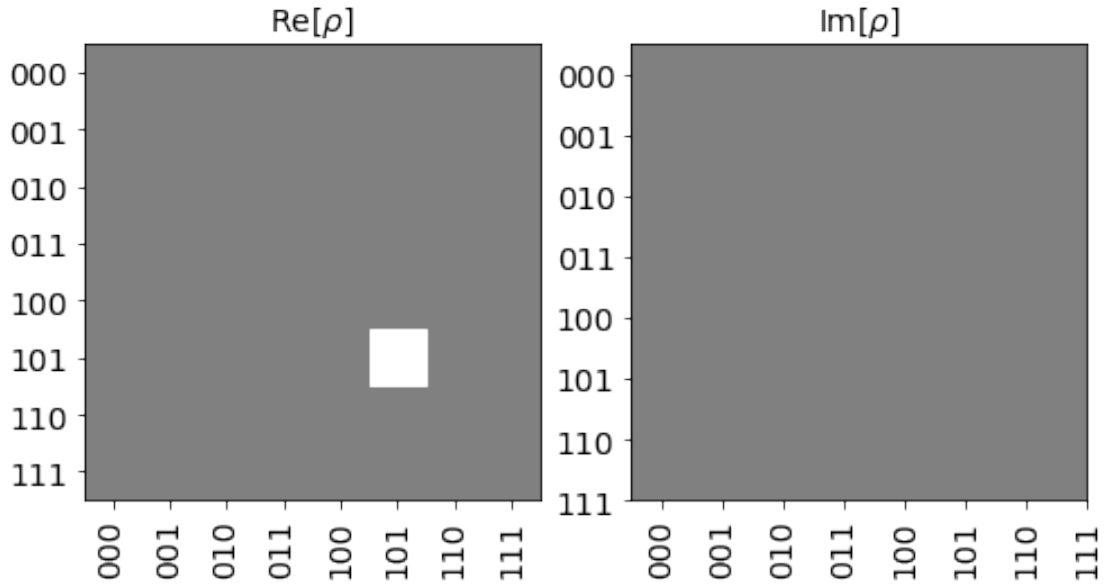
[71]:
```
plot_state_city(psi2)
```

[71]:



[72]:
```
plot_state_hinton(psi2)
```

[72]:



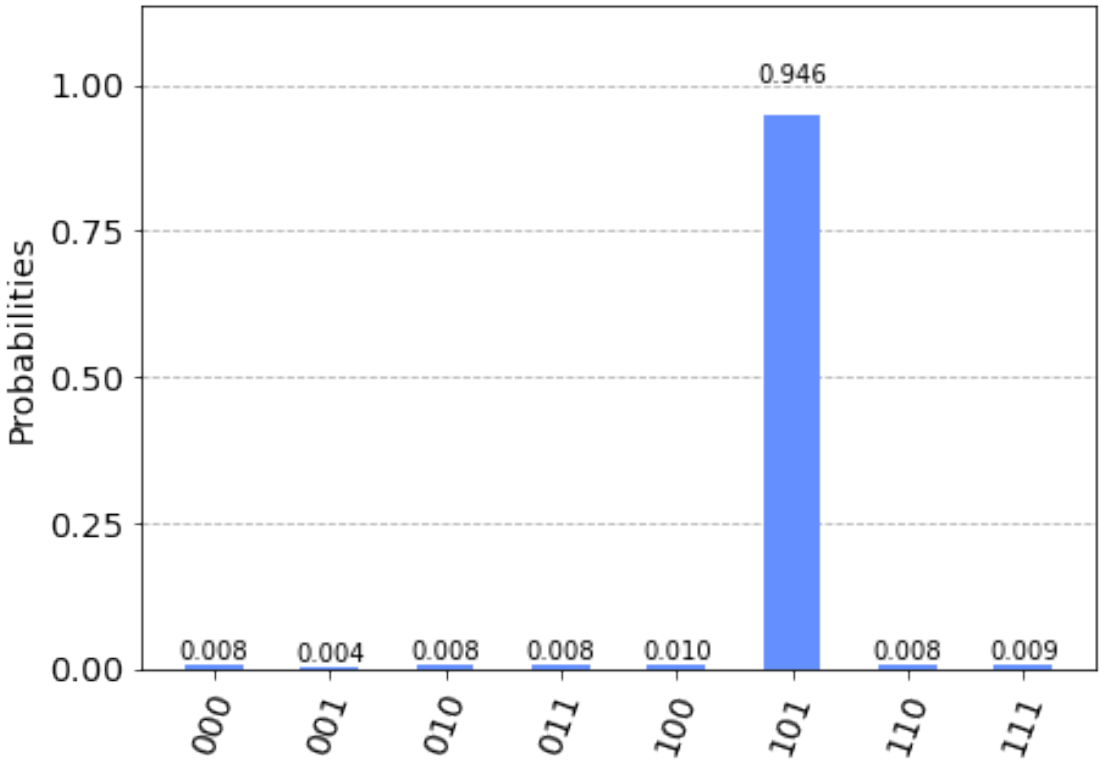
Agora iremos correr o circuito num simulador.

[73]:
```
backend = Aer.get_backend("qasm_simulator")
```

[76]:
```
shots=1024
result = execute(qc_Grover, backend, shots=shots).result()
counts_sim = result.get_counts(qc_Grover)
```

```
plot_histogram(counts_sim)
```

[76]:



Era espectável que após a execução de várias repetições tanto do oráculo como do difusor, a probabilidade de se escolher o estado w fosse de 100% (numa situação ideal), uma vez que a amplitude continuaria sempre a subir. Porém, é normal que nunca se atinja esta percentagem, uma vez que os outros estados também têm amplitude, possuindo uma pequena fatia deste 100%.

[128]:
```
qc_Grover.depth()
```

[128]:
```
22
```

1.1.4 Noise Simulator

[77]:
```
provider = IBMQ.load_account()
provider.backends()
```

[77]:
```
[<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')>]
```

[78]:
```
# Backend overview
import qiskit.tools.jupyter

%qiskit_backend_overview
```

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

[79]:
```
backend_device = provider.get_backend('ibmq_16_melbourne')
print("Running on: ", backend_device)
```

```
Running on:  ibmq_16_melbourne
```

Nesta parte, devemos escolher o que tem o menor valor de T1 e T2, pois a chance de erros é maior uma vez que valores baixos destes atributos indicam que os qubits perdem as suas propriedades quânticas mais rapidamente

[80]:
```
coupling_map = backend_device.configuration().coupling_map
```

[81]:
```
from qiskit.providers.aer.noise import NoiseModel
```

[82]:
```
# Construct the noise model from backend properties
noise_model = NoiseModel.from_backend(backend_device)
print(noise_model)
```

```
NoiseModel:
  Basis gates: ['cx', 'id', 'rz', 'sx', 'x']
  Instructions with noise: ['sx', 'measure', 'cx', 'id', 'x']
```

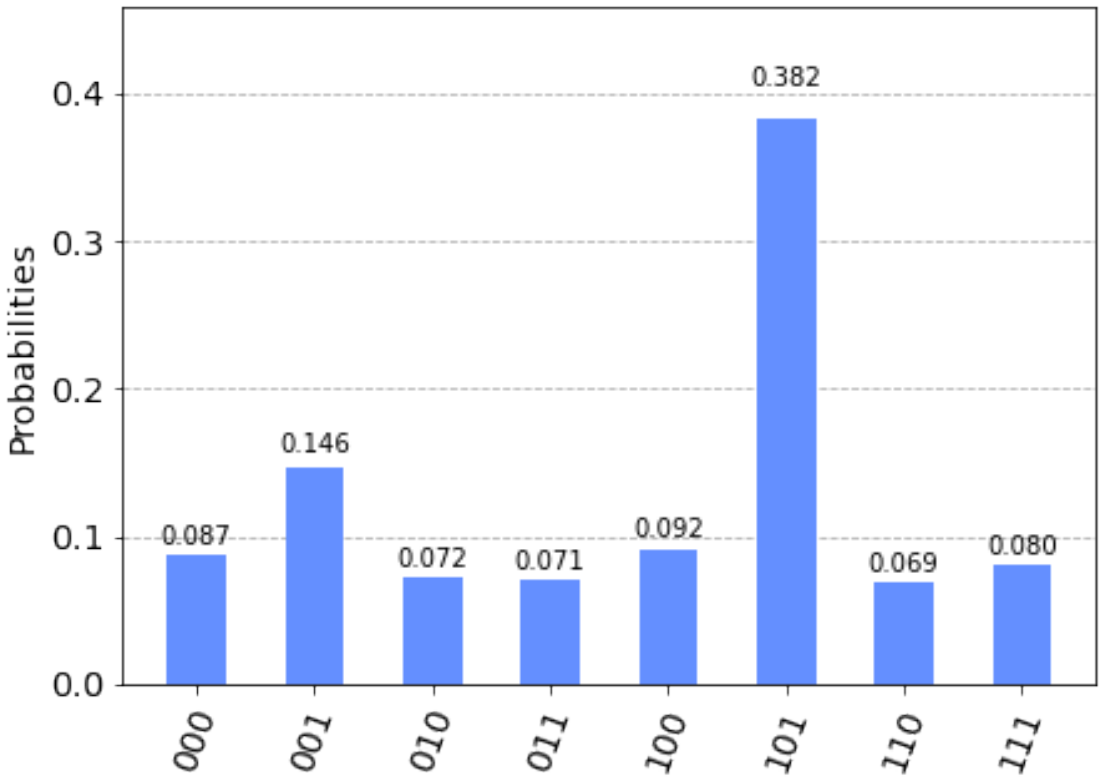
```
  Qubits with noise: [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14]
  Specific qubit errors: [('id', [0]), ('id', [1]), ('id', [2]), ('id', [3]),
('id', [4]), ('id', [5]), ('id', [6]), ('id', [7]), ('id', [8]), ('id', [9]),
('id', [10]), ('id', [11]), ('id', [12]), ('id', [13]), ('id', [14]), ('sx',
[0]), ('sx', [1]), ('sx', [2]), ('sx', [3]), ('sx', [4]), ('sx', [5]), ('sx',
[6]), ('sx', [7]), ('sx', [8]), ('sx', [9]), ('sx', [10]), ('sx', [11]), ('sx',
[12]), ('sx', [13]), ('sx', [14]), ('x', [0]), ('x', [1]), ('x', [2]), ('x',
[3]), ('x', [4]), ('x', [5]), ('x', [6]), ('x', [7]), ('x', [8]), ('x', [9]),
('x', [10]), ('x', [11]), ('x', [12]), ('x', [13]), ('x', [14]), ('cx', [14,
0]), ('cx', [0, 14]), ('cx', [14, 13]), ('cx', [13, 14]), ('cx', [6, 8]), ('cx',
[8, 6]), ('cx', [5, 9]), ('cx', [9, 5]), ('cx', [4, 10]), ('cx', [10, 4]),
('cx', [11, 3]), ('cx', [3, 11]), ('cx', [12, 2]), ('cx', [2, 12]), ('cx', [13,
1]), ('cx', [1, 13]), ('cx', [13, 12]), ('cx', [12, 13]), ('cx', [11, 12]),
('cx', [12, 11]), ('cx', [10, 11]), ('cx', [11, 10]), ('cx', [9, 10]), ('cx',
[10, 9]), ('cx', [9, 8]), ('cx', [8, 9]), ('cx', [7, 8]), ('cx', [8, 7]), ('cx',
[5, 6]), ('cx', [6, 5]), ('cx', [5, 4]), ('cx', [4, 5]), ('cx', [4, 3]), ('cx',
[3, 4]), ('cx', [2, 3]), ('cx', [3, 2]), ('cx', [1, 2]), ('cx', [2, 1]), ('cx',
[1, 0]), ('cx', [0, 1]), ('measure', [0]), ('measure', [1]), ('measure', [2]),
('measure', [3]), ('measure', [4]), ('measure', [5]), ('measure', [6]),
('measure', [7]), ('measure', [8]), ('measure', [9]), ('measure', [10]),
('measure', [11]), ('measure', [12]), ('measure', [13]), ('measure', [14])]
```

[83]:
```
# Get the basis gates for the noise model
basis_gates = noise_model.basis_gates
print(basis_gates)
```

```
['cx', 'id', 'rz', 'sx', 'x']
```

[84]:
```
# 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)
plot_histogram(counts_noise)
```

[84]:



1.1.5 Comparação dos Resultados

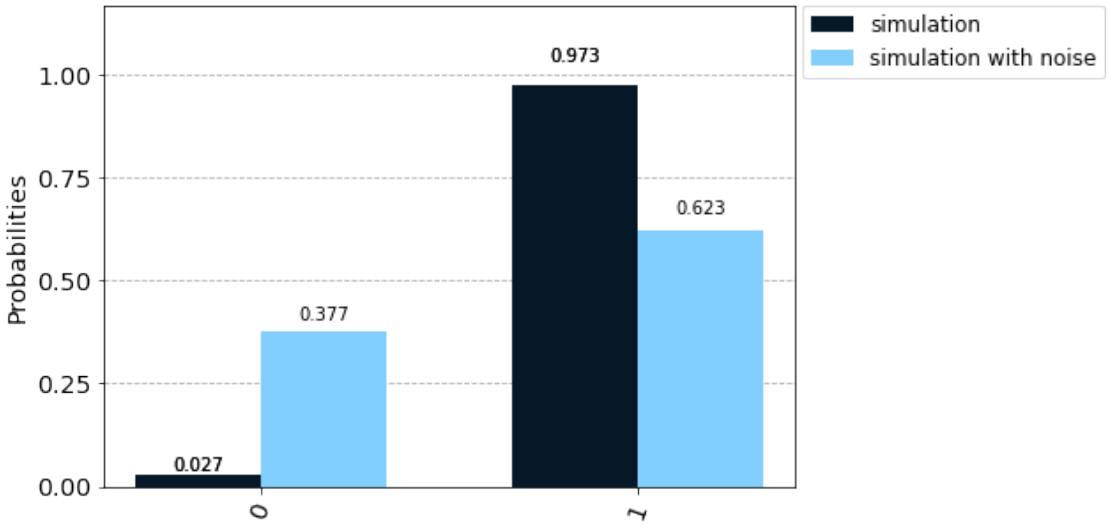
[85]:
```
def resume(counts):
    s0=s1=0
    k=counts.keys()
    lk=list(k)
    for c in lk:
        if c[0]=='0':
            s0 = s0 + counts.get(c)
        else:
            s1 = s1 + counts.get(c)
    return({'0':s0, '1':s1})
```

[86]:
```
c = resume(counts_sim)
```

[87]:
```
c_noise = resume(counts_noise)
```

[88]:
```
plot_histogram([c,c_noise], legend= ['simulation','simulation with noise'],␣
↪color=['#061727','#82cfff'])
```

[88]:



Como era expectável, podemos verificar pelo gráfico que existe uma grande quantidade de erros

1.1.6 Correr num Quantum Computer

[17]:
```
provider = IBMQ.load_account()
provider.backends()
```

[17]:
```
[<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')>]
```

[90]:
```
# Backend overview
import qiskit.tools.jupyter

%qiskit_backend_overview
```

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

[19]:
```
from qiskit.tools.monitor import backend_overview, backend_monitor

backend_overview()
```

```
ibmq_manila
-----------
Num. Qubits:  5
Pending Jobs: 0
Least busy:   True
Operational:  True
Avg. T1:      145.5
Avg. T2:      67.0

ibmq_quito
----------
Num. Qubits:  5
Pending Jobs: 5
Least busy:   False
Operational:  True
Avg. T1:      75.2
Avg. T2:      73.2

ibmq_belem
----------
Num. Qubits:  5
Pending Jobs: 0
Least busy:   False
Operational:  True
Avg. T1:      79.3
Avg. T2:      91.6

ibmq_lima
---------
Num. Qubits:  5
Pending Jobs: 0
Least busy:   False
Operational:  True
Avg. T1:      69.2
Avg. T2:      64.9

ibmq_santiago
-------------
Num. Qubits:  5
Pending Jobs: 6
Least busy:   False
Operational:  True
Avg. T1:      146.5
Avg. T2:      136.4

ibmq_athens
-----------
Num. Qubits:  5
Pending Jobs: 0
Least busy:   False
Operational:  True
Avg. T1:      85.2
Avg. T2:      120.6

ibmq_armonk
-----------
Num. Qubits:  1
Pending Jobs: 28
Least busy:   False
Operational:  True
Avg. T1:      124.6
Avg. T2:      217.3

ibmq_16_melbourne
-----------------
Num. Qubits:  15
Pending Jobs: 2
Least busy:   False
Operational:  True
Avg. T1:      57.5
Avg. T2:      56.2

ibmqx2
------
Num. Qubits:  5
Pending Jobs: 0
Least busy:   False
Operational:  True
Avg. T1:      54.1
Avg. T2:      40.5
```

Escolhemos a *ibmq_santiago* devido ao Avgerage $T1$ *relaxation time* e $T2$ *coherence time*, pois valores baixos destes atributos indicam que os qubits perdem as suas propriedades quânticas mais rapidamente, e também por causa da quantidade de qubits superior ou igual a 3.

[20]:
```
backend_device = provider.get_backend('ibmq_santiago')
print("Running on: ", backend_device)
```

```
Running on:  ibmq_santiago
```

[22]:
```
backend_monitor(backend_device)
```

```
ibmq_santiago
=============
Configuration
-------------
    n_qubits: 5
    operational: True
    status_msg: active
    pending_jobs: 5
    backend_version: 1.3.22
    basis_gates: ['id', 'rz', 'sx', 'x', 'cx', 'reset']
    local: False
    simulator: False
    n_uchannels: 8
    supported_instructions: ['shiftf', 'measure', 'play', 'setf', 'rz', 'cx',
'u3', 'acquire', 'delay', 'id', 'reset', 'sx', 'u1', 'x', 'u2']
    coupling_map: [[0, 1], [1, 0], [1, 2], [2, 1], [2, 3], [3, 2], [3, 4], [4,
3]]
    memory: True
    description: 5 qubit device
    qubit_channel_mapping: [['u0', 'm0', 'd0', 'u1'], ['m1', 'u3', 'u0', 'd1',
'u1', 'u2'], ['u4', 'm2', 'u3', 'd2', 'u5', 'u2'], ['u4', 'u6', 'm3', 'u7',
'u5', 'd3'], ['u7', 'm4', 'd4', 'u6']]
    rep_times: [0.001]
    url: None
    hamiltonian: {'description': 'Qubits are modeled as Duffing oscillators. In
this case, the system includes higher energy states, i.e. not just |0> and |1>.
The Pauli operators are generalized via the following set of
transformations:\n\n$(\\mathbb{I}-\\sigma_{i}^z)/2 \\rightarrow O_i \\equiv
b^\\dagger_{i} b_{i}$,\n\n$\\sigma_{+} \\rightarrow b^\\dagger$,\n\n$\\sigma_{-}
\\rightarrow b$,\n\n$\\sigma_{i}^X \\rightarrow b^\\dagger_{i} +
b_{i}$.\n\nQubits are coupled through resonator buses. The provided Hamiltonian
has been projected into the zero excitation subspace of the resonator buses
leading to an effective qubit-qubit flip-flop interaction. The qubit resonance
frequencies in the Hamiltonian are the cavity dressed frequencies and not
```

exactly what is returned by the backend defaults, which also includes the dressing due to the qubit-qubit interactions.\n\nQuantities are returned in angular frequencies, with units 2*pi*GHz.\n\nWARNING: Currently not all system Hamiltonian information is available to the public, missing values have been replaced with 0.\n', 'h_latex': '\\begin{align} \\mathcal{H}/\\hbar = & \\sum_{i =0}^{4}\\left(\\frac{\\omega_{q,i}}{2}(\\mathbb{I}-\\sigma_i^{z})+\\frac{\\Delta _{i}}{2}(O_i^2-O_i)+\\Omega_{d,i}D_i(t)\\sigma_i^{X}\\right) \\\\ & + J_{0,1}(\\sigma_{0}^{+}\\sigma_{1}^{-}+\\sigma_{0}^{-}\\sigma_{1}^{+}) + J_{3,4}(\\sigma_{3}^{+}\\sigma_{4}^{-}+\\sigma_{3}^{-}\\sigma_{4}^{+}) + J_{2,3}(\\sigma_{2}^{+}\\sigma_{3}^{-}+\\sigma_{2}^{-}\\sigma_{3}^{+}) + J_{1,2}(\\sigma_{1}^{+}\\sigma_{2}^{-}+\\sigma_{1}^{-}\\sigma_{2}^{+}) \\\\ & + \\Omega_{d,0}(U_{0}^{(0,1)}(t))\\sigma_{0}^{X} + \\Omega_{d,1}(U_{1}^{(1,0)}(t)+U_{2}^{(1,2)}(t))\\sigma_{1}^{X} \\\\ & + \\Omega_{d,2}(U_{3}^{(2,1)}(t)+U_{4}^{(2,3)}(t))\\sigma_{2}^{X} + \\Omega_{d,3}(U_{6}^{(3,4)}(t)+U_{5}^{(3,2)}(t))\\sigma_{3}^{X} \\\\ & + \\Omega_{d,4}(U_{7}^{(4,3)}(t))\\sigma_{4}^{X} \\\\ \\end{align}', 'h_str': ['_SUM[i,0,4,wq{i}/2*(I{i}-Z{i})]', '_SUM[i,0,4,delta{i}/2*O{i}*O{i}]', '_SUM[i,0,4,-delta{i}/2*O{i}]', '_SUM[i,0,4,omegad{i}*X{i}||D{i}]', 'jq0q1*Sp0*Sm1', 'jq0q1*Sm0*Sp1', 'jq3q4*Sp3*Sm4', 'jq3q4*Sm3*Sp4', 'jq2q3*Sp2*Sm3', 'jq2q3*Sm2*Sp3', 'jq1q2*Sp1*Sm2', 'jq1q2*Sm1*Sp2', 'omegad1*X0||U0', 'omegad0*X1||U1', 'omegad2*X1||U2', 'omegad1*X2||U3', 'omegad3*X2||U4', 'omegad4*X3||U6', 'omegad2*X3||U5', 'omegad3*X4||U7'], 'osc': {}, 'qub': {'0': 3, '1': 3, '2': 3, '3': 3, '4': 3}, 'vars': {'delta0': -2.1481278490714906, 'delta1': -2.0623435150768743, 'delta2': -2.1429828509850863, 'delta3': -2.137118237032298, 'delta4': -2.154596484455155, 'jq0q1': 0.007378105608801839, 'jq1q2': 0.007268700678758498, 'jq2q3': 0.007255936195908655, 'jq3q4': 0.006881064755295536, 'omegad0': 1.011137872642343, 'omegad1': 0.9860187056541215, 'omegad2': 1.0018026333654275, 'omegad3': 1.0073346201781475, 'omegad4': 1.0008689448135097, 'wq0': 30.369326284658154, 'wq1': 29.051000320192983, 'wq2': 30.288289457980554, 'wq3': 29.796805745616194, 'wq4': 30.261843869801826}}
    n_registers: 1
    allow_q_object: True
    dtm: 0.2222222222222222
    credits_required: True
    qubit_lo_range: [[4.33342839657397e+18, 5.333428396573969e+18], [4.1236103027229476e+18, 5.123610302722947e+18], [4.3205309850357484e+18, 5.320530985035748e+18], [4.242308922763805e+18, 5.242308922763806e+18], [4.316322038954131e+18, 5.316322038954131e+18]]
    allow_object_storage: True
    sample_name: family: Falcon, revision: 4, segment: L
    meas_levels: [1, 2]
    pulse_num_channels: 9
    meas_kernels: ['hw_qmfk']
    input_allowed: ['job']
    meas_map: [[0, 1, 2, 3, 4]]
    parametric_pulses: ['gaussian', 'gaussian_square', 'drag', 'constant']
    dynamic_reprate_enabled: True

```
    online_date: 2020-06-03 04:00:00+00:00
    dt: 0.2222222222222222
    discriminators: ['linear_discriminator', 'quadratic_discriminator',
'hw_qmfk']
    processor_type: {'family': 'Falcon', 'revision': 4, 'segment': 'L'}
    multi_meas_enabled: True
    backend_name: ibmq_santiago
    channels: {'acquire0': {'operates': {'qubits': [0]}, 'purpose': 'acquire',
'type': 'acquire'}, 'acquire1': {'operates': {'qubits': [1]}, 'purpose':
'acquire', 'type': 'acquire'}, 'acquire2': {'operates': {'qubits': [2]},
'purpose': 'acquire', 'type': 'acquire'}, 'acquire3': {'operates': {'qubits':
[3]}, 'purpose': 'acquire', 'type': 'acquire'}, 'acquire4': {'operates':
{'qubits': [4]}, 'purpose': 'acquire', 'type': 'acquire'}, 'd0': {'operates':
{'qubits': [0]}, 'purpose': 'drive', 'type': 'drive'}, 'd1': {'operates':
{'qubits': [1]}, 'purpose': 'drive', 'type': 'drive'}, 'd2': {'operates':
{'qubits': [2]}, 'purpose': 'drive', 'type': 'drive'}, 'd3': {'operates':
{'qubits': [3]}, 'purpose': 'drive', 'type': 'drive'}, 'd4': {'operates':
{'qubits': [4]}, 'purpose': 'drive', 'type': 'drive'}, 'm0': {'operates':
{'qubits': [0]}, 'purpose': 'measure', 'type': 'measure'}, 'm1': {'operates':
{'qubits': [1]}, 'purpose': 'measure', 'type': 'measure'}, 'm2': {'operates':
{'qubits': [2]}, 'purpose': 'measure', 'type': 'measure'}, 'm3': {'operates':
{'qubits': [3]}, 'purpose': 'measure', 'type': 'measure'}, 'm4': {'operates':
{'qubits': [4]}, 'purpose': 'measure', 'type': 'measure'}, 'u0': {'operates':
{'qubits': [0, 1]}, 'purpose': 'cross-resonance', 'type': 'control'}, 'u1':
{'operates': {'qubits': [1, 0]}, 'purpose': 'cross-resonance', 'type':
'control'}, 'u2': {'operates': {'qubits': [1, 2]}, 'purpose': 'cross-resonance',
'type': 'control'}, 'u3': {'operates': {'qubits': [2, 1]}, 'purpose': 'cross-
resonance', 'type': 'control'}, 'u4': {'operates': {'qubits': [2, 3]},
'purpose': 'cross-resonance', 'type': 'control'}, 'u5': {'operates': {'qubits':
[3, 2]}, 'purpose': 'cross-resonance', 'type': 'control'}, 'u6': {'operates':
{'qubits': [3, 4]}, 'purpose': 'cross-resonance', 'type': 'control'}, 'u7':
{'operates': {'qubits': [4, 3]}, 'purpose': 'cross-resonance', 'type':
'control'}}
    pulse_num_qubits: 3
    u_channel_lo: [[{'q': 1, 'scale': (1+0j)}], [{'q': 0, 'scale': (1+0j)}],
[{'q': 2, 'scale': (1+0j)}], [{'q': 1, 'scale': (1+0j)}], [{'q': 3, 'scale':
(1+0j)}], [{'q': 2, 'scale': (1+0j)}], [{'q': 4, 'scale': (1+0j)}], [{'q': 3,
'scale': (1+0j)}]]
    conditional_latency: []
    acquisition_latency: []
    quantum_volume: 32
    default_rep_delay: 250.0
    open_pulse: False
    rep_delay_range: [0.0, 500.0]
    meas_lo_range: [[6.952624018e+18, 7.952624018e+18], [6.701014434e+18,
7.701014434e+18], [6.837332258e+18, 7.837332258e+18], [6.901770712e+18,
7.901770712e+18], [6.775814414e+18, 7.775814414e+18]]
    max_shots: 8192
```

```
    uchannels_enabled: True
    conditional: False
    max_experiments: 75

Qubits [Name / Freq / T1 / T2 / RZ err / SX err / X err / Readout err]
--------------------------------------------------------------------
    Q0 / 4.83343 GHz / 162.34929 us / 240.32302 us / 0.00000 / 0.00027 / 0.00027
/ 0.01770
    Q1 / 4.62361 GHz / 131.33661 us / 108.48683 us / 0.00000 / 0.00016 / 0.00016
/ 0.00970
    Q2 / 4.82053 GHz / 140.37440 us / 97.48492 us / 0.00000 / 0.00022 / 0.00022
/ 0.01010
    Q3 / 4.74231 GHz / 182.22586 us / 98.64605 us / 0.00000 / 0.00018 / 0.00018
/ 0.00480
    Q4 / 4.81632 GHz / 115.98140 us / 136.96134 us / 0.00000 / 0.00044 / 0.00044
/ 0.01720

Multi-Qubit Gates [Name / Type / Gate Error]
--------------------------------------------
    cx4_3 / cx / 0.00610
    cx3_4 / cx / 0.00610
    cx2_3 / cx / 0.00567
    cx3_2 / cx / 0.00567
    cx2_1 / cx / 0.00592
    cx1_2 / cx / 0.00592
    cx0_1 / cx / 0.00610
    cx1_0 / cx / 0.00610
```

[91]:
```
%qiskit_job_watcher
```

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

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

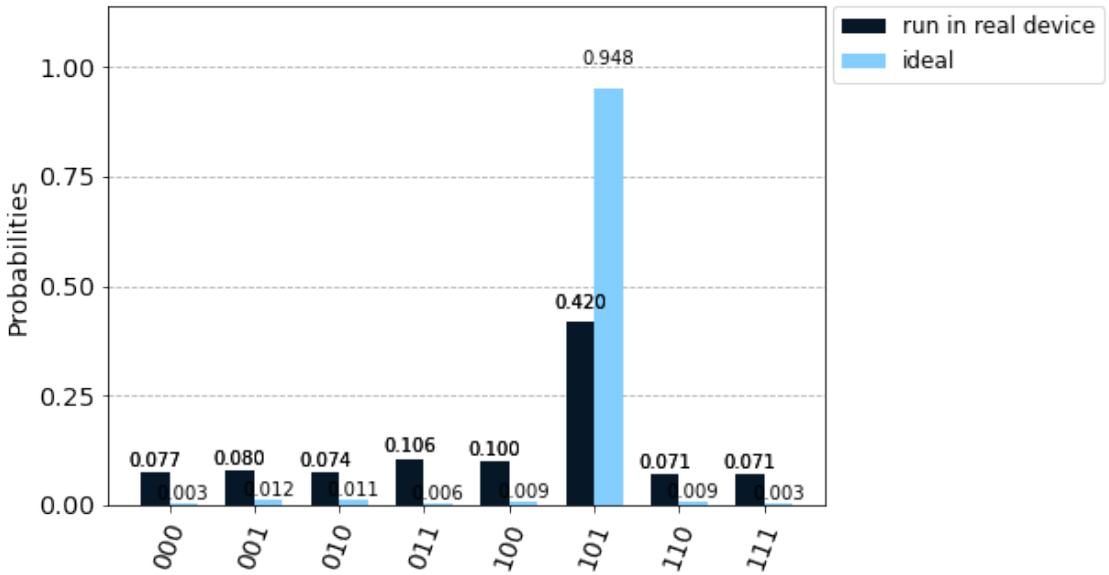
[24]:
```
job_r = execute(qc_Grover, backend_device, shots=shots)

jobID_r = job_r.job_id()

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

```
JOB ID: 60bb51b55f4eaa46e7dae995
```

[26]:
```
job_get=backend_device.retrieve_job("60bb51b55f4eaa46e7dae995")

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

[27]:
```
plot_histogram([counts_run, counts_sim ], legend=[ 'run in real device',␣
↪'ideal'], color=['#061727','#82cfff'])
```

[27]:



Desta forma, concluímos que há uma maior chance de medir |101>. Os outros resultados ocorrem devido aos erros da computação quântica.

1.1.7 IGNIS

É uma calibração usada para diminuir os erros de medição.

1.1.8 Calibration Matrix

Como temos 3 qubits, precisamos de um circuito de calibração da ordem $2^3 = 8$

[28]:
```
# Generate the calibration circuits
qr = QuantumRegister(x)
meas_calibs, state_labels = complete_meas_cal(qubit_list=[0,1,2], qr=qr,␣
↪circlabel='mcal')
```

[29]:
```
state_labels
```

[29]:
```
['000', '001', '010', '011', '100', '101', '110', '111']
```

Num caso idealista onde não existiria barulho/erro, a matriz de calibração seria uma matriz identidade $8x8$. Mas, uma vez que estamos a aplicar num dispositvo quântico real, haverá sempre algum barulho/erro.

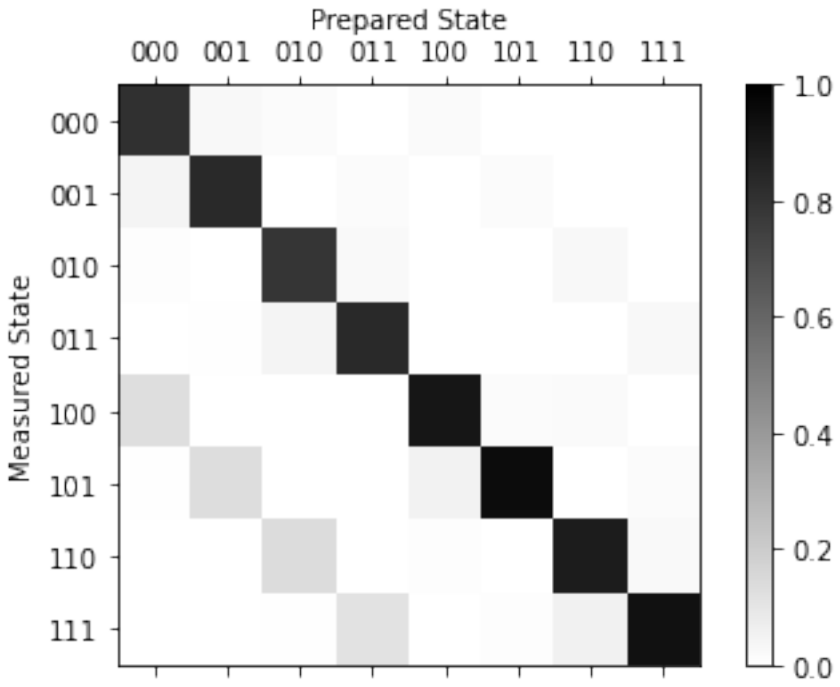
[30]:
```
job_ignis = execute(meas_calibs, backend=backend_device, shots=shots)

jobID_run_ignis = job_ignis.job_id()
```

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

```
JOB ID: 60bb51da1eb02401eacee63d
```

[31]:
```
job_get=backend_device.retrieve_job("60b7883fdd5b829f163c1415")

cal_results = job_get.result()
```

[32]:
```
meas_fitter = CompleteMeasFitter(cal_results, state_labels, circlabel='mcal')

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



1.1.9 Análise de Resultados

A *average assignment fidelity* é o traço da diagonal da matriz anterior.

[33]:
```
# Medida de fidelidade
print("Average Measurement Fidelity: %f" % meas_fitter.readout_fidelity())
```

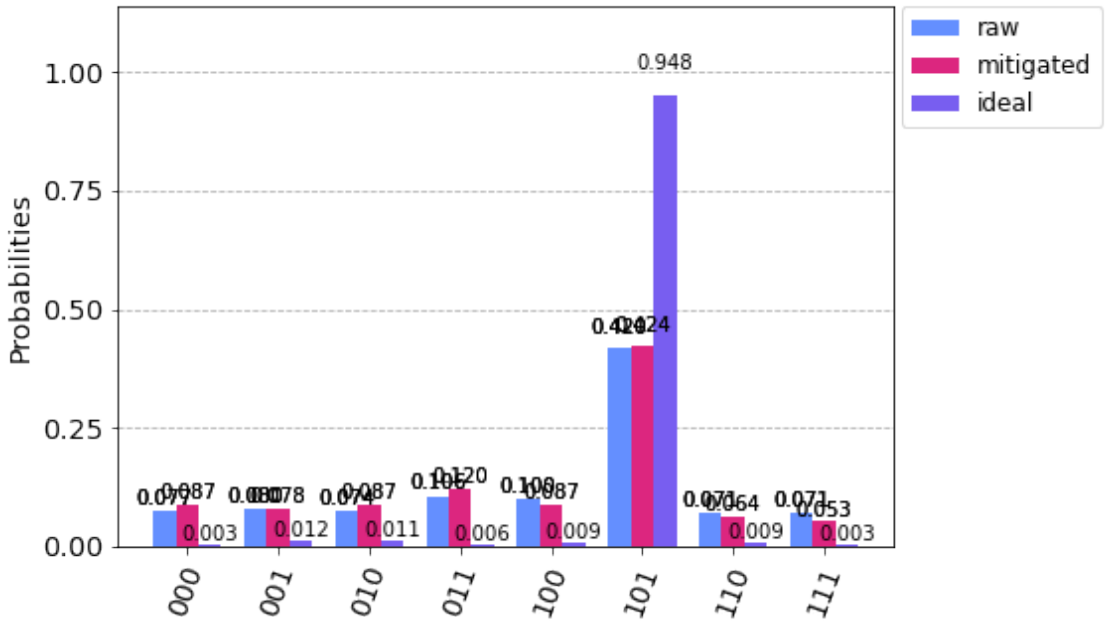
```
Average Measurement Fidelity: 0.868042
```

1.1.10 Calibração

[34]:
```
# Filtro
meas_filter = meas_fitter.filter

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

[35]:
```
plot_histogram([counts_run, mitigated_counts, counts_sim], legend=['raw',␣
↪'mitigated', 'ideal'])
```

[35]:



1.1.11 Conclusão

O algoritmo de Grover é relativamente simples, umas vez que a inserção das primeiras *Hadamard gates* colocam os qubits numa situação em que o estado das suas fases tem importância. O oráculo muda-as, já o difusor reorganiza-as para que mais tarde possam ser aplicadas novamente as *Hadamard gates* para assim obter o w esperado. Portanto podemos concluir que somente o oráculo é alterado e o $diffuser$ mantém-se inalterado.

Além disso, a mitigação de erros foi capaz de aumentar ligeiramente a probabilidade de ocorrência no nosso estado marcado.

1.1.12 BIBLIOGRAFIA

Para a elaboração deste trabalho, consultamos as seguintes páginas da web, para o esclarecimento de dúvidas:

- Practical Guide

- Qiskit Documentation
- IBM Composer
- Grover's Algorithm
- Interação e Concorrência - Página da Disciplina