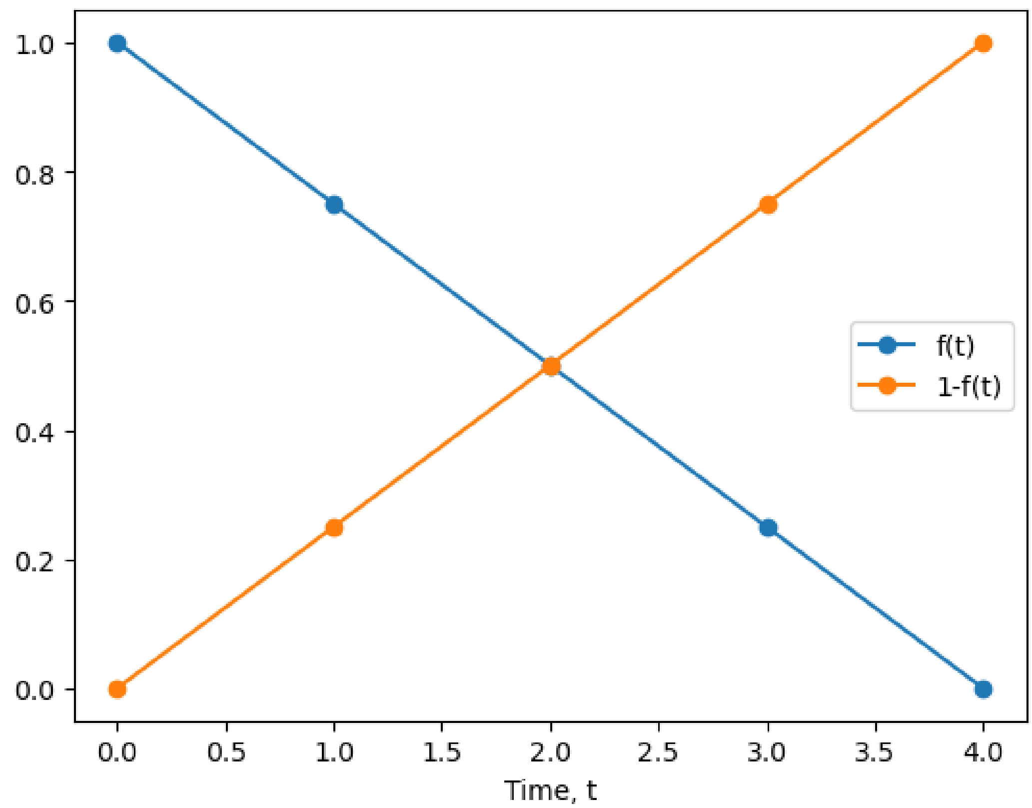
adiabatic

April 30, 2024

[ ]:
```
import matplotlib.pyplot as plt
import numpy as np

plt.plot(np.linspace(1,0,5), marker='o', label="f(t)");
plt.plot(np.linspace(0,1,5), marker='o', label="1-f(t)");
plt.xlabel("Time, t");
plt.legend();
```



1 Question:

In the next cell: explain what $\hat{U}^H$ does to the states, ket{0} and ket{1} in terms of $\hat{x}$.:

0 and 1, once passed through the Hadamard become the +/- states, the eigenvalues of X. Thus, they remain in the same state after going through the X. The - (formerly 1) gets an overall phase of -1.

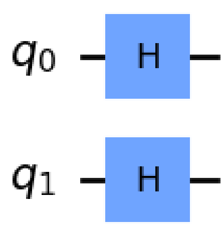
[ ]:
```
import numpy as np
import matplotlib.pyplot as plt
from qiskit import *
from qiskit.tools.visualization import plot_histogram
# from qiskit.tools.visualization import plot_bloch_multivector

sim = Aer.get_backend('statevector_simulator')

circ = QuantumCircuit(2,0)
circ.h(0)
circ.h(1)
circ.draw(output = 'mpl')
```

```
/home/firt/miniconda3/envs/molssi_best_practices/lib/python3.11/site-
packages/qiskit/visualization/circuit/matplotlib.py:266: FutureWarning: The
default matplotlib drawer scheme will be changed to "iqp" in a following
release. To silence this warning, specify the current default explicitly as
style="clifford", or the new default as style="iqp".
  self._style, def_font_ratio = load_style(self._style)
```

[ ]:



[ ]:
```
plot_histogram(execute(circ, backend = sim).result().get_counts(circ))
```

```
/tmp/ipykernel_161913/2706169862.py:1: DeprecationWarning: The function
``qiskit.execute_function.execute()`` is deprecated as of qiskit 0.46.0. It will
be removed in the Qiskit 1.0 release. This function combines ``transpile`` and
``backend.run``, which is covered by ``Sampler`` :mod:`~qiskit.primitives`.
Alternatively, you can also run :func:`.transpile` followed by
``backend.run()``.
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plot_histogram() ``data`` argument with QuasiDistribution, ProbDistribution, or
a distribution dictionary is deprecated as of qiskit-terra 0.22.0. It will be
```
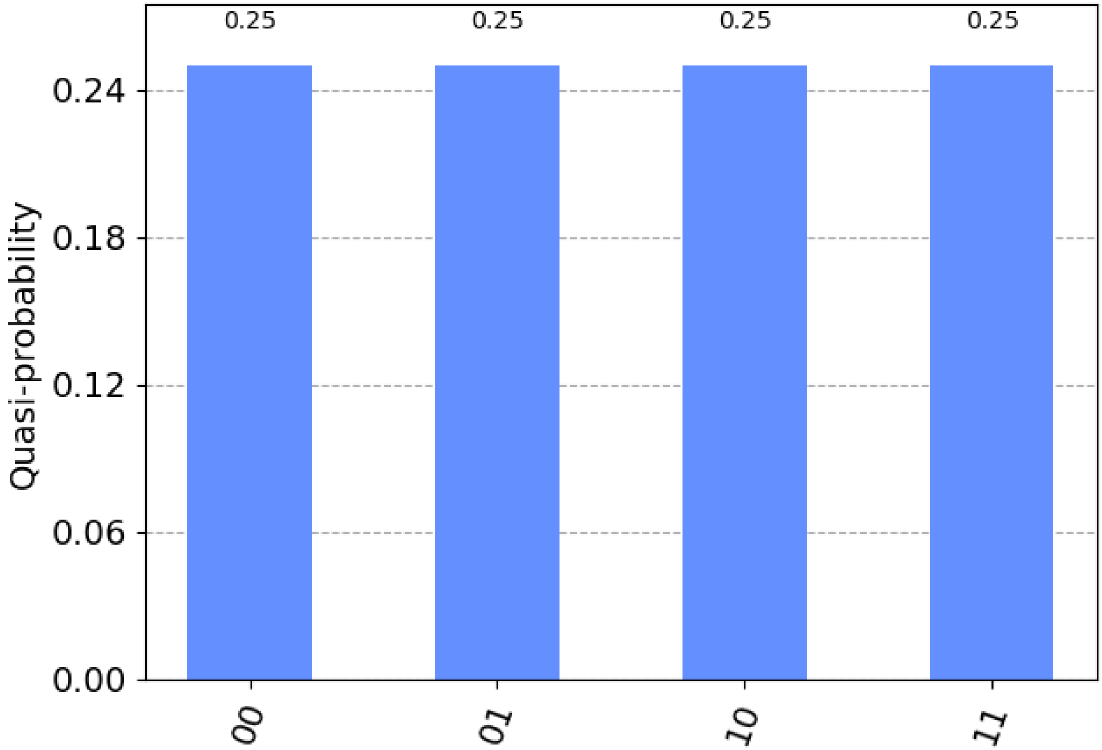
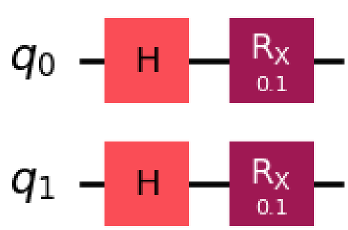

```
removed no earlier than 3 months after the release date. Instead, use
``plot_distribution()``.
  plot_histogram(execute(circ, backend = sim).result().get_counts(circ))
```

[ ]:



[ ]:
```
circ = QuantumCircuit(2,0)
circ.h(0)
circ.h(1)
circ.rx(.1,0)
circ.rx(.1,1)
circ.draw(output = 'mpl', style="iqp")
```

[ ]:



[ ]:

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plot_histogram(execute(circ, backend = sim).result().get_counts(circ))
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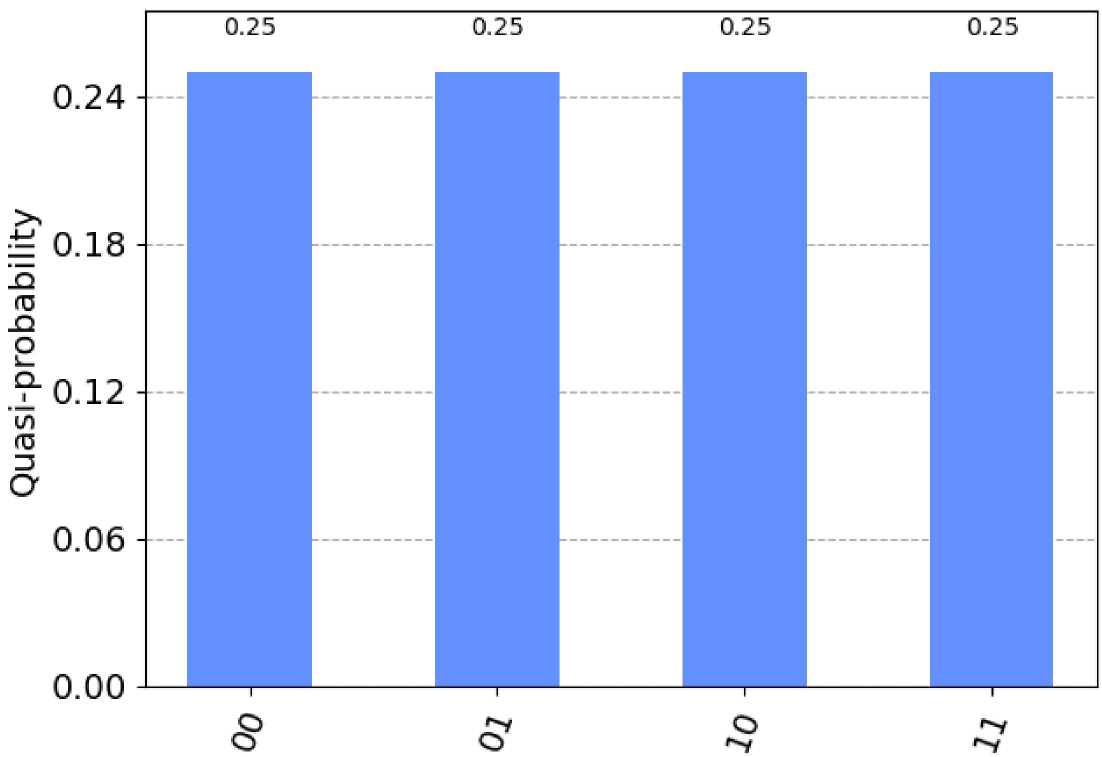
[ ]:



2 Question:

Explain why the measured probability stayed the same in the above plot:

We are applying two X gates to two eigenvalues of X (+), so the state and thus the probability doesn't change.

2.1 Second time step

Now we must implement the following operator: $e^{-i\left(.75\hat{H}_0+.25\hat{H}_1\right)\Delta t}$.

Unfortunately, $\sigma^z\sigma^x \neq \sigma^z\sigma^x$ and so we can't exactly trotterize this. However, because $\Delta t \ll 1$, we can approximate this in a product form, and this will become increasingly more accurate as we take smaller time steps.

$$\hat{H}_0 = -\sigma_0^x - \sigma_1^x$$
$$\hat{H}_1 = J\sigma_0^z\sigma_1^z + \mu\sigma_1^z + \mu\sigma_1^z$$

$$e^{-i(-.75\sigma_0^x-.75\sigma_1^x+.25J\sigma_0^z\sigma_0^z+.25\mu\sigma_1^z+.25\mu\sigma_1^z)\Delta t} \approx e^{.75i\sigma_0^x\Delta t}e^{.75i\sigma_1^x\Delta t}e^{-.25iJ\sigma_0^z\sigma_1^z\Delta t}e^{-.25i\mu\sigma_0^z\Delta t}e^{-.25i\mu\sigma_1^z\Delta t}$$

Notice here that we are using a new gate, `RZZ`. This is a 2-qubit gate that rotates about the product of two σ^z operators.

[ ]:
```python
circ = QuantumCircuit(2,0)
# initialize
circ.h(0)
circ.h(1)

# time step 1
circ.rx(.1,0)
circ.rx(.1,1)

# time step 2
circ.rx(-.075,0)
circ.rx(-.075,1)
circ.rzz(.025,0,1)
circ.rz(.0025,0)
circ.rz(.0025,1)

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

```
/home/firt/miniconda3/envs/molssi_best_practices/lib/python3.11/site-
packages/qiskit/visualization/circuit/matplotlib.py:266: FutureWarning: The
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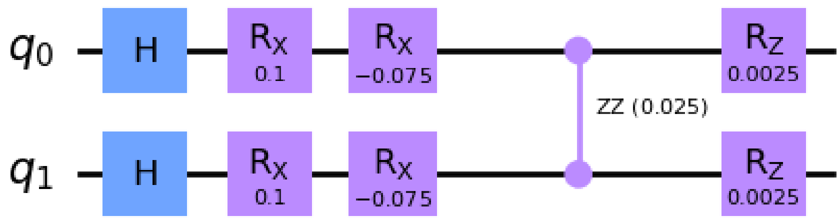
[ ]:



From here we can recognize the pattern and start to generalize with a function!

2.2 Automate the circuit building

Because each step will have the same gates, but different angles, we can simply write a function to create the circuit.

[ ]:
```python
import montecarlo

def form_circuit(beta, ham: montecarlo.IsingHamiltonian):
    """
    Form the circuit for adiabatic evolution

        H = J\sum_{ij} \sigma_i^z \sigma_j^z + \mu\sum_i\sigma_i^z
    """
    # initializing crap stuff
    N = len(ham.J)
    circ = QuantumCircuit(N,0)

    # Initia states
    for i in range(N):
        circ.h(i)

    # Loop through time steps
    for b in beta:
        for j in range(N):
            circ.rx(b, j)
        for j in range(len(ham.J)):
            for coupling in ham.J[j]:
                circ.rzz(-coupling[1] * (1 - b), j, coupling[0])
        for j in range(N):
            circ.rz(-ham.mu[j] * (1 - b), j)


    return circ
```

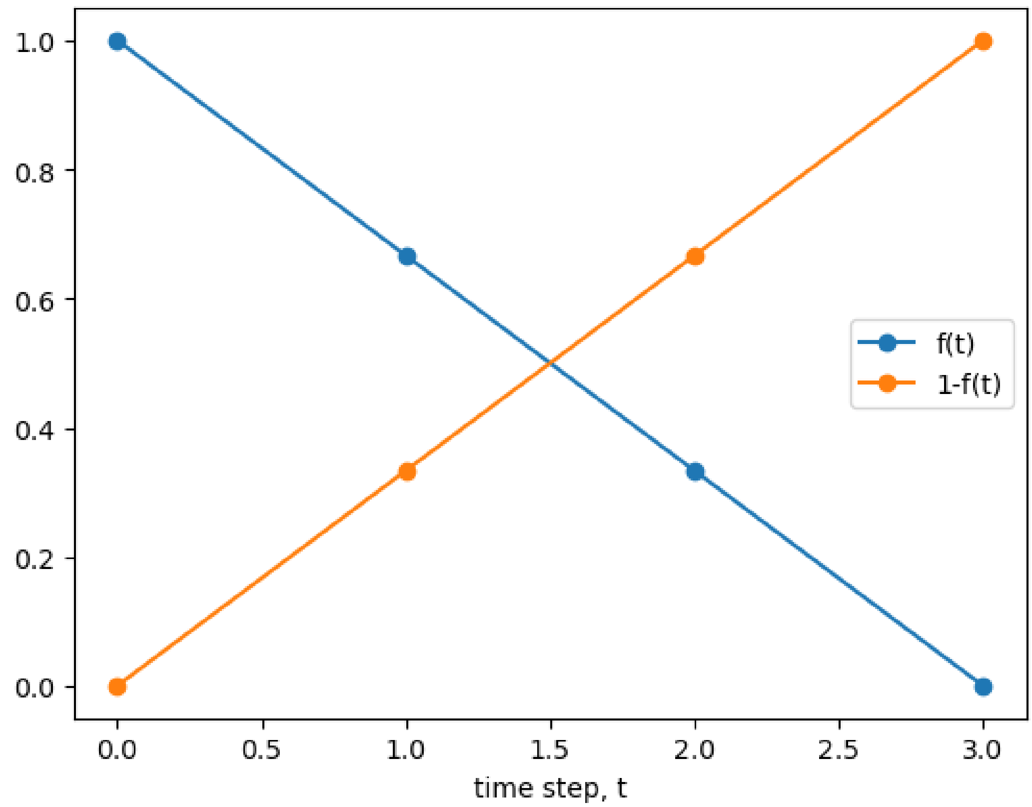
2.3 Plot for Arbitrary steps and qubits

Try out different numbers of steps and different Hamiltonians. - $\hat{H}(t) = \beta(t)\hat{H}_0 + \gamma(t)\hat{H}_1$

[ ]:
```
# form Hamiltonian
def build_1d_Hamiltonian(N, Jval, mu=0.0):
    """
    Build a 1D Hamiltonian with a single J value (Jval)
    """
    mus = [0.0 for i in range(N)]
    J = [[] for i in range(N)]
    for site in range(N-1):
        J[site].append((site+1, Jval))
    return montecarlo.IsingHamiltonian(J,mus)

ham = build_1d_Hamiltonian(N=3, Jval=1)

# let's add a local mu value to the first spin
ham.mu[0] = 1.2

# Testing
print(ham.J[1][0][1])
print(ham.J)
```

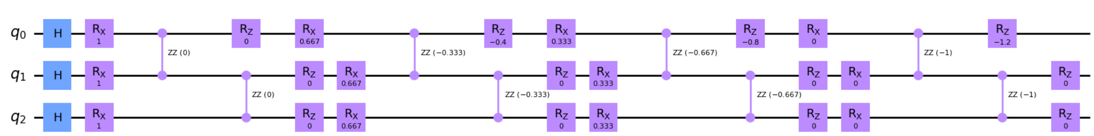
```
1
[[(1, 1)], [(2, 1)], []]
```

[ ]:
```
# create the adiabatic parameters
n_steps = 3
beta = []
gamma = []
for i in range(n_steps+1):
    beta.append(1-i/n_steps)
    gamma.append(i/n_steps)

plt.plot(beta, label="f(t)", marker="o")
plt.plot(gamma, label="1-f(t)", marker="o");
plt.xlabel("time step, t")
plt.legend();
```



[ ]:
```python
# Create the quantum circuit

circ = form_circuit(beta, ham)
circ.draw(output="mpl")
```

[ ]:



[ ]:
```python
sim = Aer.get_backend('statevector_simulator')
result_sv = execute(circ, backend = sim).result()
state_vec = result_sv.get_statevector()
plot_histogram(result_sv.get_counts(circ))
```

```
/tmp/ipykernel_161913/480607385.py:2: DeprecationWarning: The function
``qiskit.execute_function.execute()`` is deprecated as of qiskit 0.46.0. It will
be removed in the Qiskit 1.0 release. This function combines ``transpile`` and
``backend.run``, which is covered by ``Sampler`` :mod:`~qiskit.primitives`.
```

```
Alternatively, you can also run :func:`.transpile` followed by
``backend.run()``.
  result_sv = execute(circ, backend = sim).result()
/tmp/ipykernel_161913/480607385.py:4: DeprecationWarning: Using plot_histogram()
``data`` argument with QuasiDistribution, ProbDistribution, or a distribution
dictionary is deprecated as of qiskit-terra 0.22.0. It will be removed no
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``plot_distribution()``.
  plot_histogram(result_sv.get_counts(circ))
```
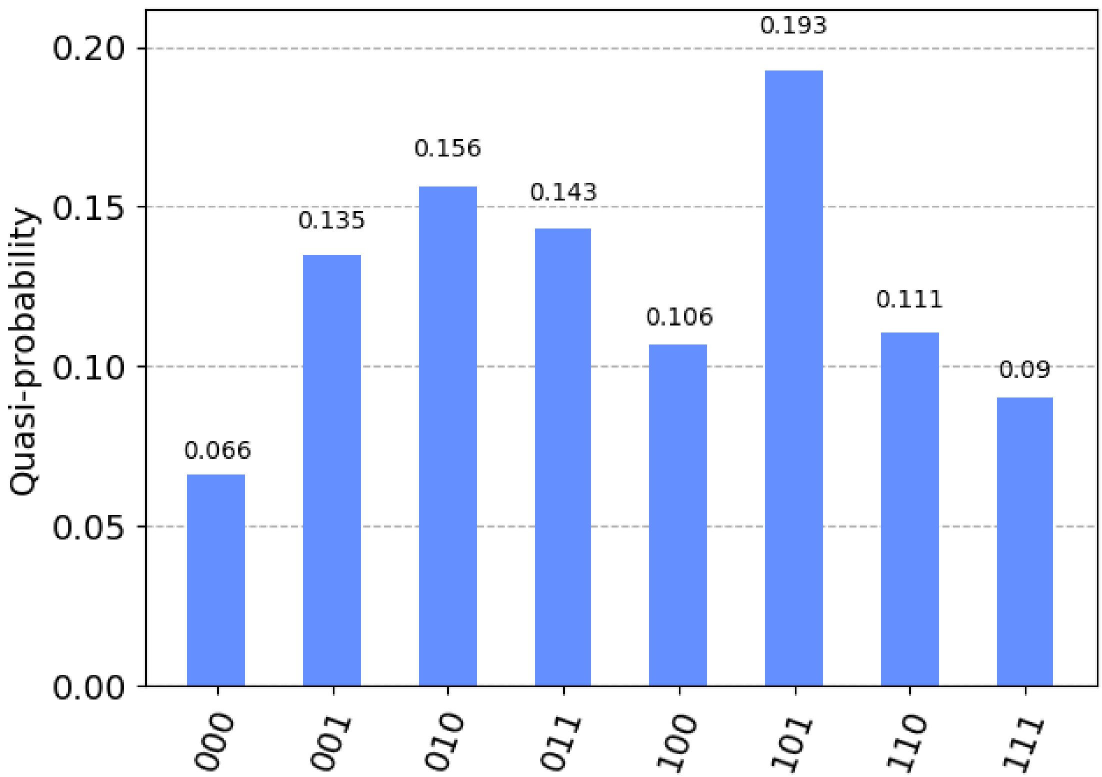

[ ]:



[ ]:
```python
samples = result_sv.get_counts(circ)
max(samples, key=samples.get)
```

[ ]: '101'

[ ]:
```python
# Let's check to see that our answers are correct, by computing them directly␣
↪(using adding the code you wrote in graph_energy.ipynb to your package)
emin, cmin = ham.get_lowest_energy_config(verbose=1)
print(" Energy minimum = %12.8f %s"%(emin, cmin))
```

```
Energy minimum =  -3.20000000 None
```

3 Question:

What are the probabilities for measuring the correct bitstring using the following number of time steps (i.e., values of `n_steps`): 1. `n_steps` = 2 1. `n_steps` = 4 1. `n_steps` = 8 1. `n_steps` = 10

1. 2 steps -> 0.125
2. 4 steps -> 0.287
3. 8 steps -> 0.524
4. 10 steps -> 0.627