rigetti

Shallow pyQuil circuits

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pyQuil: High-level quantum programming

Code examples | Classical control flow | Quantum state preparation | Grove

pyQuil: QVM/QPU Connection

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First step: Establish connection to Rigetti's server

```
>>> from pyquil.api import QVMConnection

>>> qvm = QVMConnection()
```

pyQuil: Program

Second step: Define an empty pyQuil program

```
>>> from pyquil.api import QVMConnection
>>> from pyquil.quil import Program
```

```
>>> qvm = QVMConnection()
>>> p = Program()
```

pyQuil: Quantum circuit

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Third step: Define a quantum circuit by modifying the Program()

```
>>> from pyquil.api import QVMConnection
>>> from pyquil.quil import Program
>>> from pyquil.gates import X, H, CNOT

>>> qvm = QVMConnection()
>>> p = Program()

>>> p.inst(H(0), H(1))
```

pyQuil: Quantum circuit

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There is **many different ways** of defining programs!

```
>>> p.inst(H(0), H(1))
```

→ 1. In one .inst() call

```
>>> p.inst(H(0)).inst(H(1))
```

→ 2. in multiple .inst() calls

```
>>> quil = """
H 0
H 1
"""
>>> p = Program(quil)
```

→ 3. First define Quil then load into Program()

pyQuil: Quantum circuit

There is **many different ways** of defining programs!

```
>>> p.inst(H(0), H(1))
```
→ 1. In one .inst() call

```
>>> p.inst(H(0)).inst(H(1))
```
→ 2. in multiple .inst() calls

```
>>> quil = """
H 0
H 1
"""
>>> p = Program(quil)
```
→ 3. First define Quil then load into Program()

```
>>> p = Program("H 0\nH 1")
```
→ 4. In one-line as Quil

```
>>> p.inst([H(0), H(1)])
```
→ 5. With a list of gates

```
>>> p.inst(H(i) for i in range(2))
```
→ 6. Using a generator (so cool!)

pyQuil: Quantum circuit

Fourth step: Don't forget to measure!

```
>>> from pyquil.api import QVMConnection
>>> from pyquil.quil import Program
>>> from pyquil.gates import X, H, CNOT, MEASURE

>>> qvm = QVMConnection()
>>> p = Program()

>>> p.inst(H(0), H(1))
>>> p.inst(MEASURE(0, 0))
```

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Fourth step: Don't forget to measure!

```
>>> from pyquil.api import QVMConnection
>>> from pyquil.quil import Program
>>> from pyquil.gates import X, H, CNOT, MEASURE

>>> qvm = QVMConnection()
>>> p = Program()

>>> p.inst(H(0), H(1))
>>> p.inst(MEASURE(0, 0))
```

Quantum register   Classical register

pyQuil: Shared classical memory

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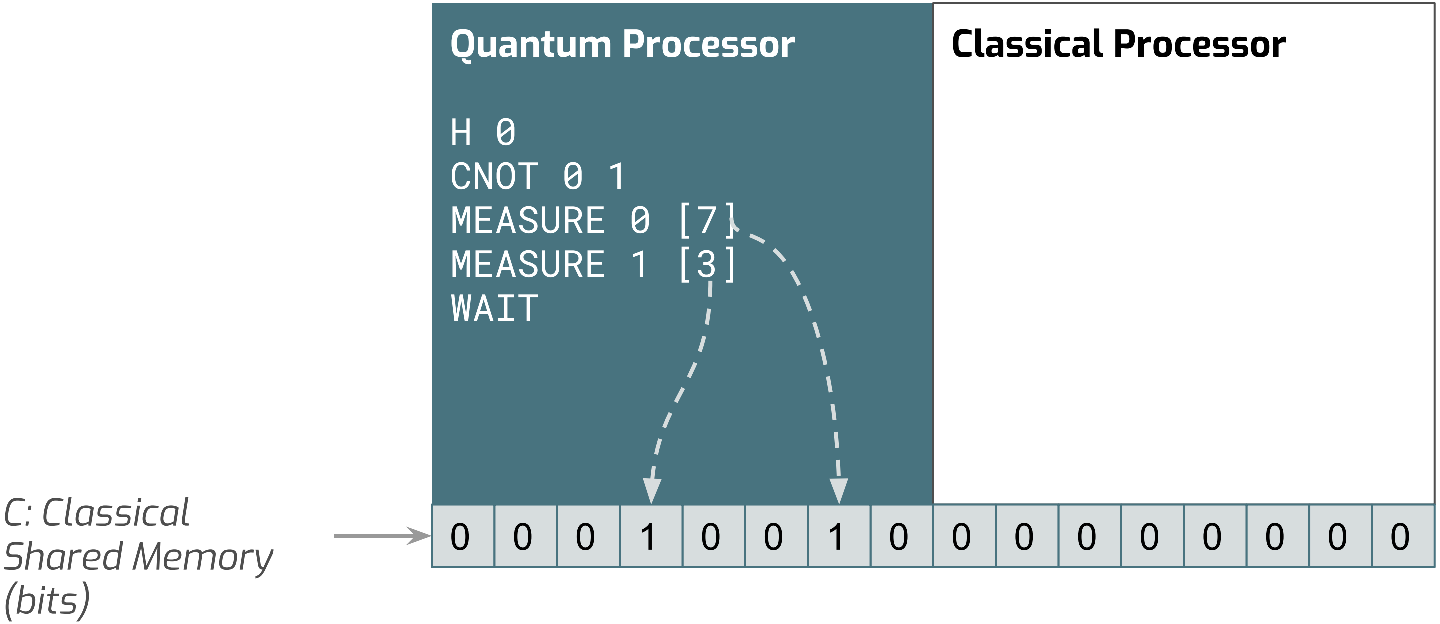

You can define the classical address! It doesn't need to be the qubit index.

pyQuil: Quantum circuit

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There is **many different ways** of measuring!

```
>>> p.inst(MEASURE(0, 0))
```

1. In a .inst() call

```
>>> p.measure(0, 0)
```

2. With a „measure() call

```
>>> quil = """
H 0
H 1
MEASURE 0 [0]
"""
>>> p = Program(quil)
```

3. Defining it in Quil

```
>>> p = Program("H 0\nH 1\nMEASURE 0 [0]")
```

4. In a one-liner as Quil

pyQuil: Quantum circuit

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Fifth step: Run the circuit on the QVM!

```
>>> from pyquil.api import QVMConnection
>>> from pyquil.quil import Program
>>> from pyquil.gates import X, H, CNOT, MEASURE

>>> qvm = QVMConnection()
>>> p = Program()


>>> p.inst(H(0), H(1))
>>> p.inst(MEASURE(0, 0))
>>> p.inst(MEASURE(1, 1))

>>> results = qvm.run(p, trials=10)
```

Don't forget measuring qubit 1!

If you use **qvm.run()** you will have to **define explicit measurements.**

pyQuil: Quantum circuit

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QVM: run() vs. run_and_measure()

```
>>> p.inst(H(0), H(1))
>>> p.inst(MEASURE(0, 0))
>>> p.inst(MEASURE(1, 1))

>>> results = qvm.run(p, trials=10)
```

Results:

```
[[1, 0], [0, 0], [1, 0], [1, 0], [1, 1],
[1, 1], [1, 0], [0, 0], [0, 0], [0, 0]]
```

```
>>> p.inst(H(0), H(1))
>>> p.inst(MEASURE(0, 0))
>>> p.inst(MEASURE(1, 1))

>>> results = qvm.run_and_measure(p, [0, 1], trials=10)
```

Results:

```
[[0, 1], [0, 1], [0, 1], [0, 1], [0, 1],
[0, 1], [0, 1], [0, 1], [0, 1], [0, 1]]
```

?

If you use **qvm.run()** you will sample from the distribution but using **qvm.run_and_measure()** will always give you the same result.

pyQuil: Quantum circuit

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QVM: run() vs. run_and_measure()

```
>>> p.inst(H(0), H(1))
>>> p.inst(MEASURE(0, 0))
>>> p.inst(MEASURE(1, 1))

>>> results = qvm.run(p, trials=10)
```

Results:

[[1, 0], [0, 0], [1, 0], [1, 0], [1, 1],
[1, 1], [1, 0], [0, 0], [0, 0], [0, 0]] ✓

```
>>> p.inst(H(0), H(1))
>>> p.inst(MEASURE(0, 0))
>>> p.inst(MEASURE(1, 1))

>>> results = qvm.run_and_measure(p, [0, 1], trials=10)
```

Results:

[[0, 1], [0, 1], [0, 1], [0, 1], [0, 1],
[0, 1], [0, 1], [0, 1], [0, 1], [0, 1]] ?

The reason being that **qvm.run_and_measure()** **determines the final wavefunction once** and then samples from it.

pyQuil: Quantum circuit

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QVM: run() vs. run_and_measure()

```
>>> p.inst(H(0), H(1))
>>> p.inst(MEASURE(0, 0))
>>> p.inst(MEASURE(1, 1))

>>> results = qvm.run(p, trials=10)
```

Results:

[[1, 0], [0, 0], [1, 0], [1, 0], [1, 1],
[1, 1], [1, 0], [0, 0], [0, 0], [0, 0]] ✔

Classical addresses in shared memory

```
>>> p.inst(H(0), H(1))
>>> ~~p.inst(MEASURE(0, 0))~~
>>> ~~p.inst(MEASURE(1, 1))~~

>>> results = qvm.run_and_measure(p, [0, 1], trials=10)
```

Results:

[[1, 0], [0, 0], [1, 0], [1, 0], [1, 1],
[1, 1], [1, 0], [0, 0], [0, 0], [0, 0]] ✔

Do NOT include measurements into the Program()
if using **qvm.run_and_measure()!**

pyQuil: Classical control flow

When programming classical computers we often use **if/else** statements. For example:

```
>>> state = lambda: random.randint(0,1)

>>> if state is heads:
>>>     state = tails
>>> else:
>>>     pass

>>> print('It's tails!')
```

How can we implement this with pyQuil?

pyQuil: Classical control flow

Classical

```
>>> state = lambda: random.randint(0,1)

>>> if state is heads:
>>>     state = tails
>>> else:
>>>     pass

>>> print('It's tails!')
```

Quantum

```
>>> state_register  = 0
>>> branching_prog = Program(H(0))
>>> branching_prog.measure(0,  state_register)
```

Quantum coin flip

pyQuil: Classical control flow

Code examples | **Classical control flow** | Quantum state preparation | Grove

Classical

```
>>> state = lambda: random.randint(0,1)

>>> if state is heads:
>>>     state = tails
>>> else:
>>>     pass

>>> print('It's tails!')
```

Quantum

```
>>> state_register  = 0
>>> branching_prog = Program(H(0))
>>> branching_prog.measure(0,  state_register)

>>> then_branch = Program(X(0))
>>> else_branch = Program()
>>> branching_prog.if_then(state_register,
then_branch, else_branch)

>>> branching_prog.measure(0,  state_register)

>>> print('It's tails!')
```

if/else statement

pyQuil: Classical control flow

Code examples | **Classical control flow** | Quantum state preparation | Grove

The **if_then()** statement in **pyQuil** and **QUIL**

```
>>> state_register  = 0
>>> branching_prog = Program(H(0))
>>> branching_prog.measure(0,  state_register)

>>> then_branch = Program(X(0))
>>> else_branch = Program()
>>> branching_prog.if_then(state_register,   then_branch,
else_branch)

>>> branching_prog.measure(0,  state_register)


>>> print('It's tails!')
```

```
H 0
MEASURE 0 [0]
JUMP-WHEN @THEN3 [0]
JUMP @END4
LABEL @THEN3
X 0
LABEL @END4
MEASURE 0 [0]
```

pyQuil: Classical control flow

When programming classical computers we often use **while** statements. For example:

Coin flip

```
>>> wait = True
>>> check_if_go_time = lambda: random.randint(0,1)

>>> while wait:
>>>     wait = check_if_go_time()

>>> print('Go!')
```

How can we implement this with pyQuil?

pyQuil: Classical control flow

Classical

```
>>> wait = True

>>> check_if_go_time = lambda:
random.randint(0,1)

>>> while wait:
>>>     wait = check_if_go_time()

>>> print('Go!')
```

Quantum

```
>>> wait = 2
>>> init_register = Program(TRUE([wait]))
```

Keeps initializing the classical register *wait* to True

pyQuil: Classical control flow

Code examples | **Classical control flow** | Quantum state preparation | Grove

Classical

```
>>> wait = True

>>> check_if_go_time = lambda: random.randint(0,1)

>>> while wait:
>>>     wait = check_if_go_time()

>>> print('Go!')
```

Quantum

```
>>> wait = 2
>>> init_register = Program(TRUE([wait]))

>>> check_if_go_time = Program(H(0)).measure(0, wait)
```

Quantum coin flip

pyQuil: Classical control flow

Code examples | **Classical control flow** | Quantum state preparation | Grove

Classical

```
>>> wait = True

>>> check_if_go_time = lambda: random.randint(0,1)

>>> while wait:
>>>     wait = check_if_go_time()

>>> print('Go!')
```

Quantum

```
>>> wait = 2
>>> init_register = Program(TRUE([wait]))

>>> check_if_go_time = Program(H(0)).measure(0, wait)

>>> loop_prog = init_register.while_do(wait, check_if_go_time)

>>> qvm.run(loop_prog)
>>> print('Go!')
```

A quantum while loop!

pyQuil: Classical control flow

The **while_do()** statement in **pyQuil** and **QUIL**

```
>>> wait = 2
>>> init_register = Program(TRUE([wait]))

>>> check_if_go_time =
Program(H(0)).measure(0, wait)

>>> loop_prog = init_register.while_do(wait,
check_if_go_time)

>>> qvm.run(loop_prog)
>>> print('Go!')
```

```
TRUE [2]
LABEL @START1
JUMP-UNLESS @END2 [2]
H 0
MEASURE 0 [2]
JUMP @START1
LABEL @END2
```

Quantum state preparation

For many quantum algorithms you need to
load data into a quantum computer:

$$\mathbf{a} = \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ \dots \\ a_N \end{bmatrix}$$

$$|\Psi\rangle = \sum_{i=0}^{N-1} \frac{a_i}{|\mathbf{a}|} |i\rangle$$

Quantum state preparation

This is a **non-trivial problem** and still an **active field of research**.
In the near future, you might still have to prepare quantum states manually.

$$\mathbf{a} = \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ \dots \\ a_N \end{bmatrix} \Rightarrow |\Psi\rangle = \sum_{i=0}^{N-1} \frac{a_i}{|\mathbf{a}|} |i\rangle$$

Grove

Code examples | Classical control flow | Quantum state preparation | **Grove**

Grove

Grove is a library of quantum algorithms implemented in **pyQuil**:

- Variational Quantum Eigensolver (**VQE**)
- Quantum Approximate Optimization Algorithm (**QAOA**)
- Quantum Fourier Transform (**QFT**)
- **Phase Estimation** Algorithm
- **Grover** Search
- Arbitrary **State Generation**

In **tomorrow's tutorial** you will explore VQE and QAOA in more depth.

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Now, please start working through the exercises in the Jupyter Notebook for **Tutorial 3**

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