Hands-on session based on Atos myQLM framework

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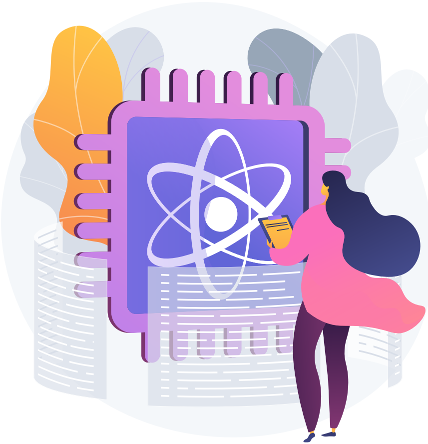
Plan

Atos framework overview

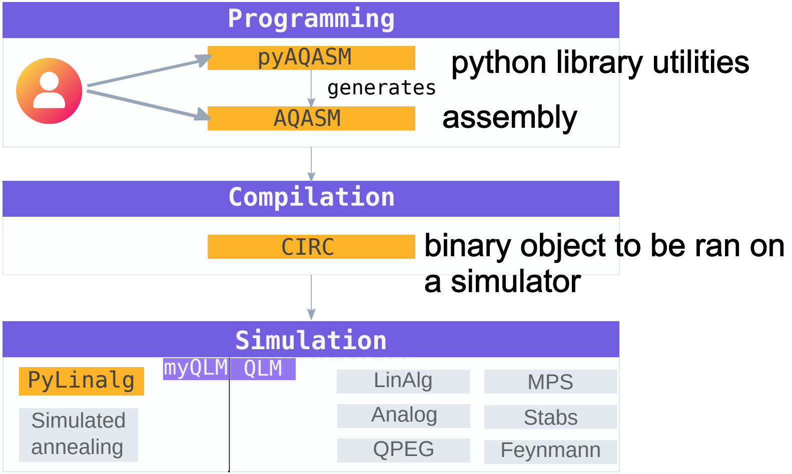
- 2 main projects
  - myQLM: open-source, can run on any computer and OS
  - QLM: closed-source, run on dedicated supercomputer, available for academia (included PoliMi) and enterprises
- Different simulators are available, based both on historical and state-of-the-art proposals
- We will focus on simple simulators
  - gate-model representation of quantum operators
  - based on linear-algebra matrix operations



Atos framework overview

- Main limiting factor in linear algebra simulation is memory
  - Given n qubits, naive way to represent a state is by using a vector of 2^n complex numbers
- 2 linear algebra simulators developed by Atos
  - **PyLinalg** on *myQLM*, written in *Python* (with *numpy* libraries), it allows to simulate 20-25 qubits on standard laptops
  - **LinAlg** on *QLM*, closed-source, allows to simulate up to 41 qubits (using 60TiB of memory)

Programming framework overview



Before continuing

Open myQLM notebooks

It will take time and we will need it later

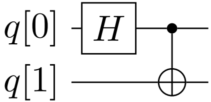
`https://github.com/Polimi-Courses/myqlm-notebooks/tree/polimi2022`

Plan

Atos Quantum Assembly (AQASM)

- Assembly language for quantum circuit description
  - no loop
  - no branching
  - no subroutines
- Standard gates defined
- Custom gates can be added

```
BEGIN
qubits 2
H q[0]
CNOT q[0], q[1]
END
```



Gates and operators

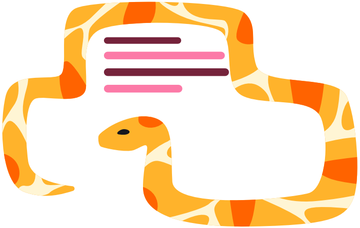
Gate	Keyword	Qubits
Hadamard	H	1
Pauli X	X	1
Pauli Y	Y	1
Pauli Z	Z	1
Identity	I	1
Phase	S	1
$\pi/8$	T	1
X rotation	RX[theta]	1
Y rotation	RY[theta]	1
Z rotation	RZ[theta]	1

Gate	Keyword	Qubits
CNOT	CNOT	2
CZ	CZ	2
iSWAP	ISWAP	2
$\sqrt{\text{SWAP}}$	SQRTSWAP	2
Toffoli	CCNOT	3

Operator	Keyword
Conjugate	CONJ
Transpose	TRANS
Dagger	DAG
Control	CTRL

PyAQASM

- Python library for generating AQASM files
- Used to simplify generation of quantum circuits
  - Loops for repeating gates
  - Functions and subroutines
  - ...
- Allows hybrid programming model
  - Controls, subroutines, ... handled with *classical programming paradigm*
  - Generated quantum circuits implement *quantum paradigm*



PyAQASM Gates and operators

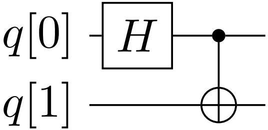
- Same gate set of AQASM
  - `H`, `X`, `CNOT`, `CCNOT`
- Operators on gates become functions

Operator	**AQASM**	**PyAQASM**
Conjugate	CONJ	`conj()`
Transpose	TRANS	`trans()`
Dagger	DAG	`dag()`
Control	CTRL	`ctrl(nbctrls=1)`

Example I — EPR pair


```
from qat.lang.AQASM import *

pr = Program()
qr = pr.qalloc(2)
pr.apply(H, qr[0])
pr.apply(CNOT, qr[0], qr[1])
# equivalently, pr.apply(CNOT, qr)
```

the program object encapsulates the quantum circuit

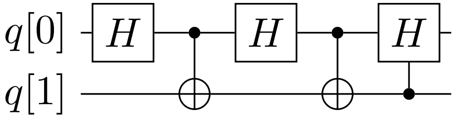


Hands on — EPR pair

```python
from qat.lang.AQASM import *

pr = Program()
qr = pr.qalloc(2)
pr.apply(H, qr[0])
pr.apply(CNOT, qr[0], qr[1])

    # We can export our
    # program into an AQASM file
    pr.export('pr.aqasm')
```

Example II


```python
from qat.lang.AQASM import *

pr = Program()
qr = pr.qalloc(2)
for _ in range(2):
    pr.apply(H, qr[0])
    pr.apply(CNOT, qr[0], qr[1])
pr.apply(H.ctrl(1), qr[1], qr[0])
```



CIRC object

- Binary format of a quantum circuit
- Generated through compilation of AQASM code
  - either via command-line utility or directly through PyAQASM
- Pivot of all QLM/myQLM stack
  - simulators
  - optimizers and plugins (not seen here)
  - more trivially, functions for circuit display

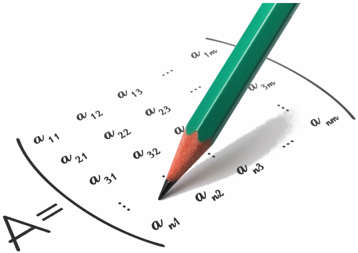
Hands on — EPR pair circuit


```python
from qat.lang.AQASM import *

pr = Program()
qr = pr.qalloc(2)
pr.apply(H, qr[0])
pr.apply(CNOT, qr[0], qr[1])
```

```python
    # We can export our program into a circuit object
    cr = pr.to_circ()
    # and save it to a file
    cr.dump('pr.circ')
```

PyLinalg

- Based on linear algebra
  - n qubits represented by a 2^n vector
  - memory is the bottleneck
- Simulation time function of number of gates
- PyLinalg exploits numpy libraries
- Different simulation modes available for the same circuit
  - generate full state vector
  - generate state vector of a subset of qubits
  - strictly emulate a QPU and generate a single basis state



Hands on — EPR pair simulation


```python
from qat.lang.AQASM import *

pr = Program()
qr = pr.qalloc(2)
pr.apply(H, qr[0])
pr.apply(CNOT, qr[0], qr[1])
```

```python
from qat.qpus import PyLinalg
qpu = PyLinalg()
# generate a job containing the circuit
# and some other information
job = cr.to_job()
# Result contains all the states with non-zero amplitude
result = qpu.submit(job)
```

Plan

PyAQASM advanced

- Classical operations
  - Hands on — Teleportation circuit
- Abstract and parametrized gates
  - Hands on — CCNOT decomposition in Clifford + T gate set
  - Hands on — Deutsch-Jozsa algorithm with abstract oracles
- Quantum subroutines and linking
  - Hands on — Deutsch-Jozsa algorithm with real oracles
  - Hands on — Bernstein-Vazirani algorithm
- A useful application for the Quantum Fourier Transform

Plan

My quantum experiments

- All the algorithms seen here can be found on my github repository `https://github.com/tigerjack/qat-experiments`
- A huge collection of useful extension to the quantum languages (routines, qubit management, . . .) used in my research projects can be found here `https://github.com/tigerjack/qat-utils`

Atos Resources

- https://atos.net/en/lp/myqlm
- https://join.slack.com/t/myqlmworkspace/shared_invite/zt-nvtt5hk3-BX53Dg5YhZaYWRnRoDtLUA?
- https://atos.net/en/solutions/quantum-learning-machine

Thanks for your attention Email

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