Introduction to Quantum Programming

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IITiS PAN

April 27, 2018
QIPLSIGML—Machine Learning meets Quantum Computation

Our goals

- Understand the difference between quantum and classical programming.

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- Introduce various approaches to quantum programming.
- Write some code.
  ($\equiv$ *Talk is cheap. Show me the quantum code.*)

Quantum programming

Quantum programming

What is quantum programming?

Quantum programming is a process that leads from an original formulation of a computing problem to executable quantum computer programs.

Quantum programming

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What is quantum programming?

- *The only way to learn a new quantum programming language is by writing programs in it.*
- *The process of preparing programs for a quantum computer is especially attractive because it not only can be economically and scientifically rewarding, it can also be an aesthetic experience much like composing poetry or music.*
- *Only the modern quantum computer has made quantum programming both challenging and relevant.*

Quantum programming

Why bother?

- Use real quantum computers.

Quantum programming

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- Play with quantum mechanics.

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- Use real quantum computers.
- Play with quantum mechanics.
- Stretch your imagination by creating a new programming language with quantum elements...
- ...or a language for describing quantum mechanics.

Quantum programming

How to do quantum programming?

- Level 0: Manipulation of quantum gates.

Quantum programming

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- Level 0: Manipulation of quantum gates.
- Level 1: Programming QRAM.

Quantum programming

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- Level 0: Manipulation of quantum gates.
- Level 1: Programming QRAM.
- Level 2: High-level programming.

Manipulation of quantum gates

Manipulation of quantum gates

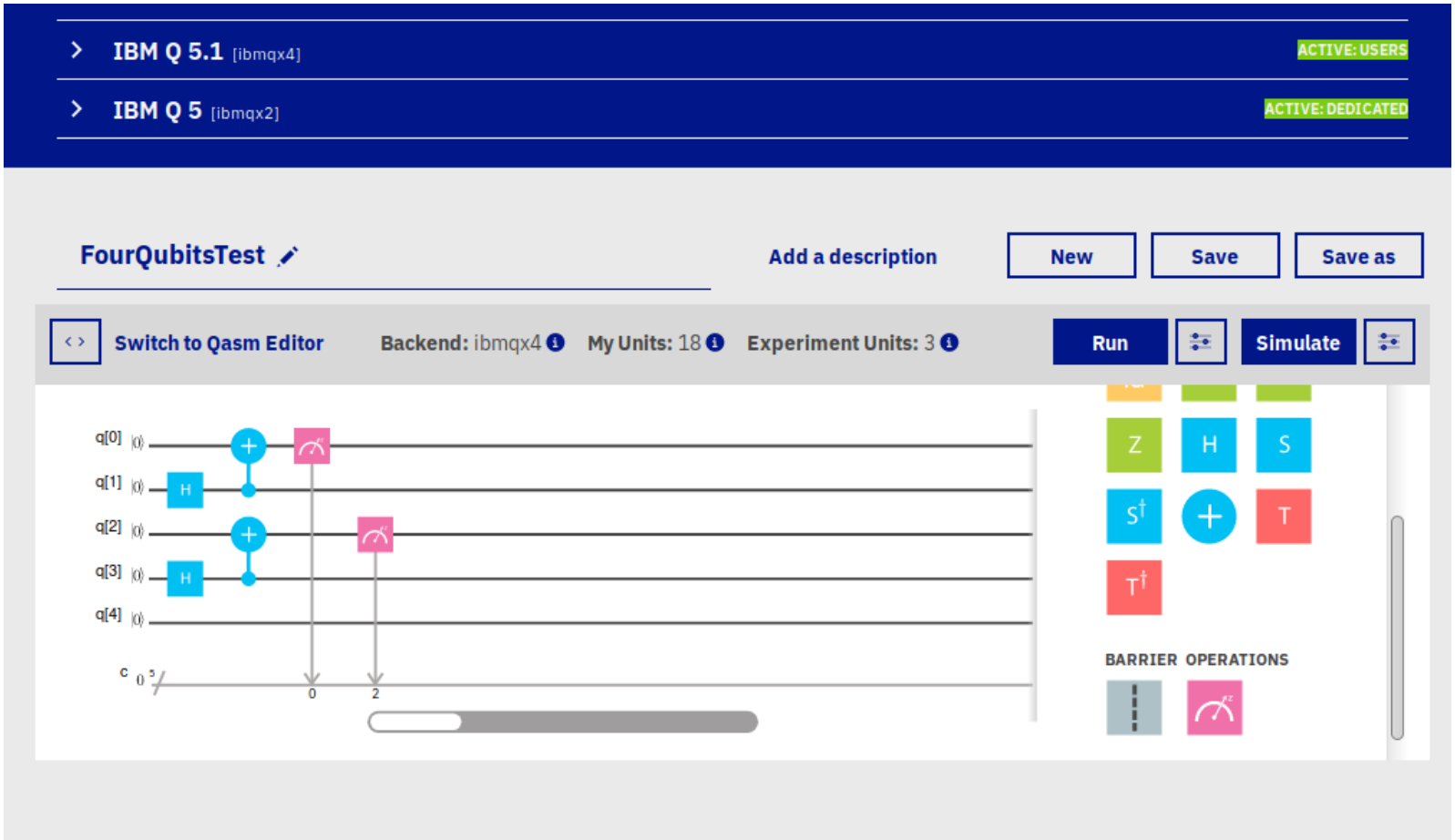
Level 0

Direct usage of quantum gates.

- Visual manipulation of gates and circuits.
- Multiplication of matrices and vectors.

Manipulation of quantum gates

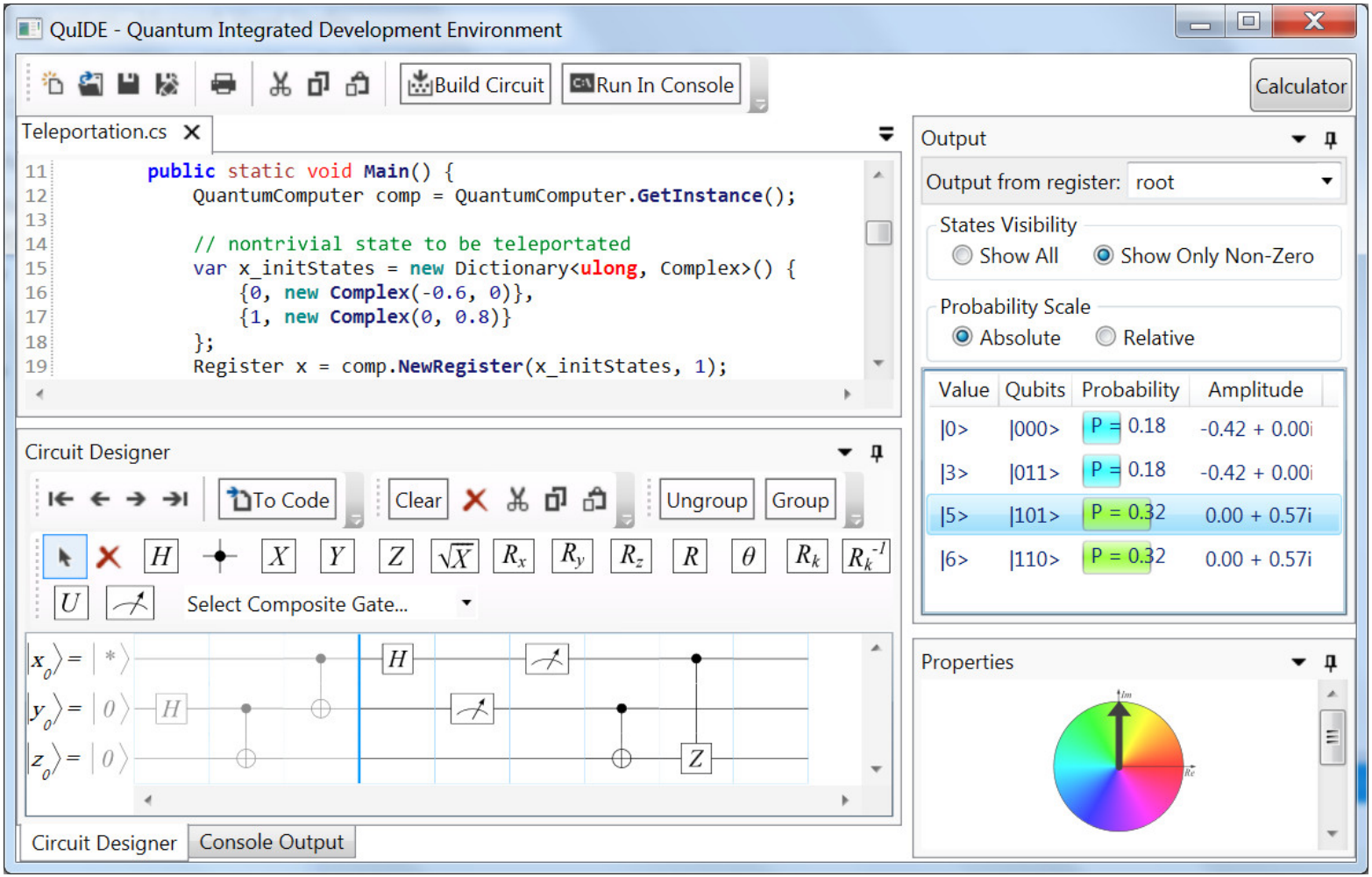
Visual manipulation of gates and circuits



`https://quantumexperience.ng.bluemix.net/qx/editor`

Manipulation of quantum gates

Visual manipulation of gates and circuits



http://www.quide.eu/ and https://bitbucket.org/quide/

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- Useful for testing small circuits.
- Not so much for real algorithms.
- You have to live with connectivity limitations (IBM Q).
- But you can use a real quantum computer!

Manipulation of quantum gates

Alternative approach: Manipulation of vectors and matrices

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- *Real Programmers do Quantum Computing in FORTRAN.*

Manipulation of quantum gates

Alternative approach: Manipulation of vectors and matrices

For example, in Julia...

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Examples in Wolfram can be found in the GitHub repo

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  - ...it is very easy to implement classical control.
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- Missing: the memory management.
- And in most cases you don't need all the power/libraries/etc coming with the host language.

Manipulation of quantum gates

Where to go next?

- IBM Q Experience:
  `https://quantumexperience.ng.bluemix.net/qx/editor`

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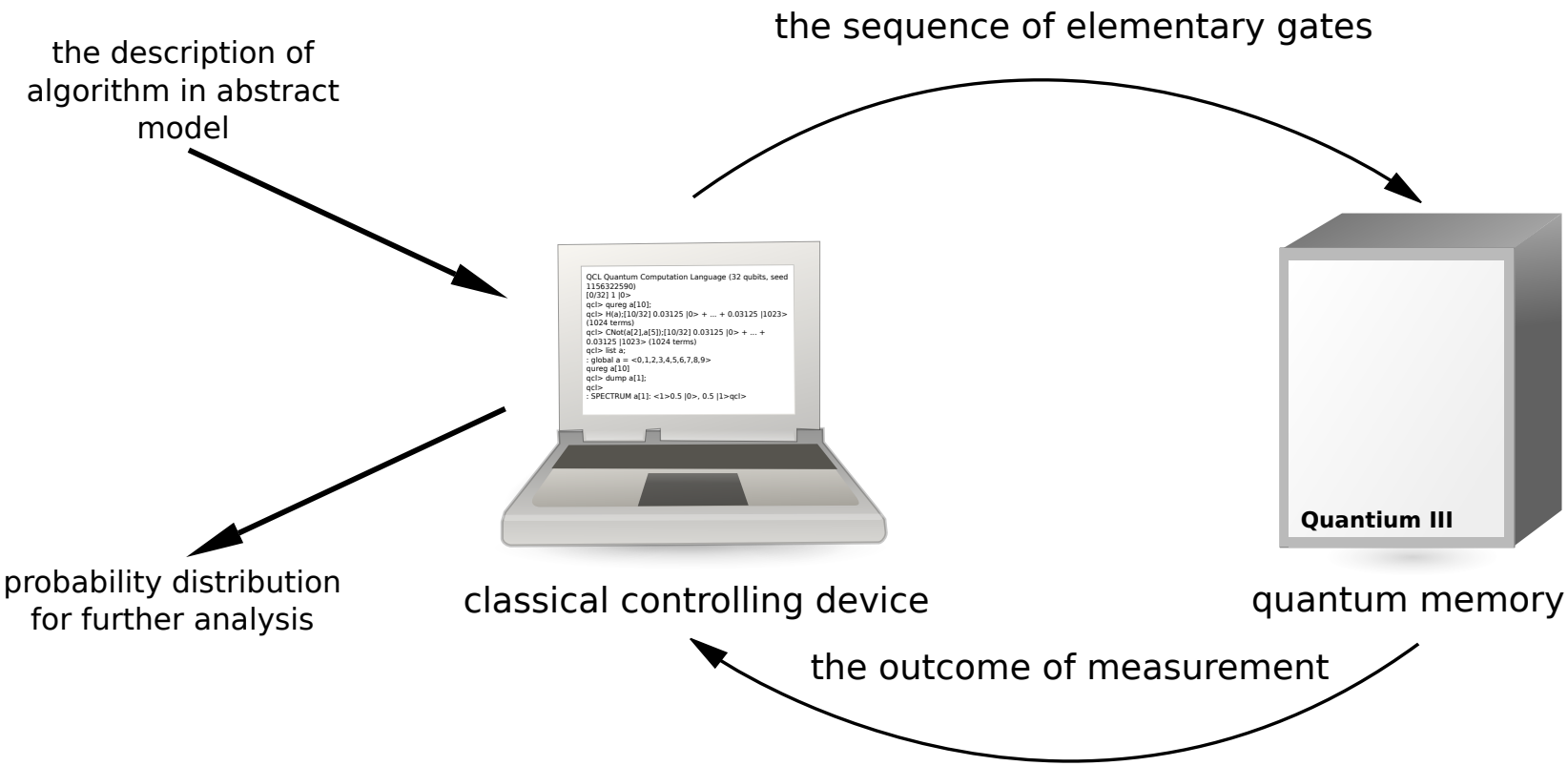
- Many more at Quantiki
  `https://quantiki.org/wiki/list-qc-simulators`

Programming QRAM

Programming QRAM

What is QRAM?

QRAM ≡ Quantum Random Access Machine



Programming QRAM

Advantages of QRAM

- data abstraction

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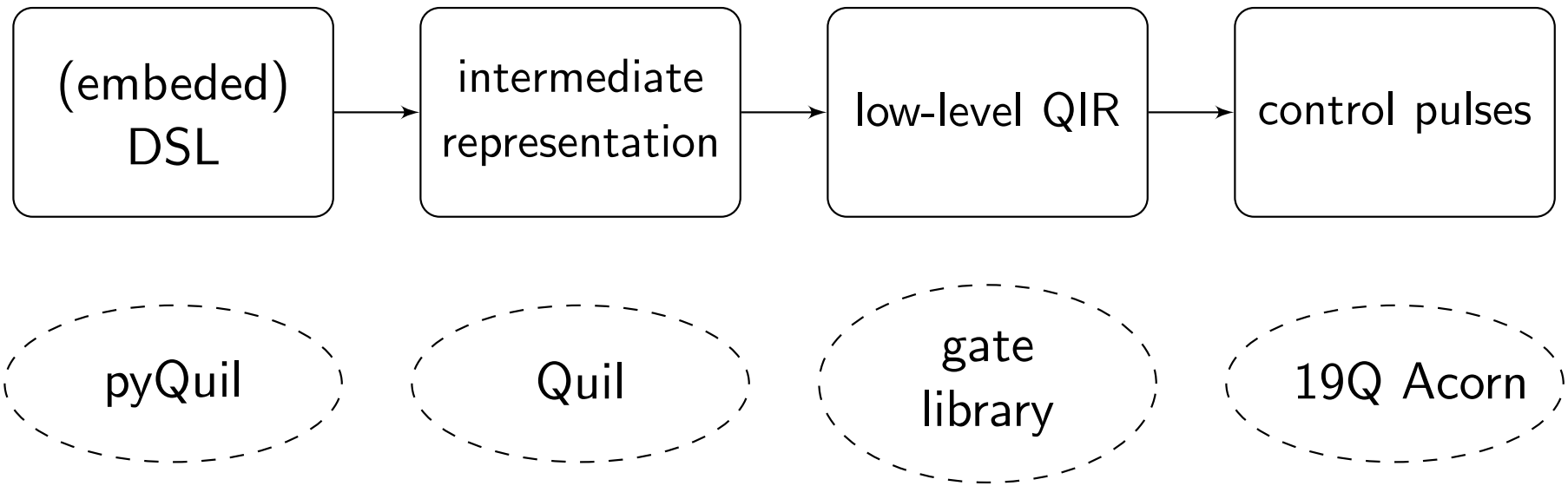
- data abstraction $\equiv$ allocation of quantum memory
- compound quantum operations $\equiv$ functions encapsulating sequence of quantum gates or quantum primitives
- classical control of quantum operations $\equiv$ loops, ifs etc. mixed with quantum code

Programming QRAM

Software architecture



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Programming QRAM

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- embedded domain specific language $\rightarrow$ C/Python/Wolfram/Haskell with library of functions
- data abstraction $\rightarrow$ allocation of classical and quantum registers based on qu(b|d)its
- quantum functions $\rightarrow$ custom elementary gates defined by matrices or compound statements
- classical control of quantum memory $\rightarrow$ by using host language

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...its advantages...

- easy to learn and use

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- easy to learn and use
- auto-magic quantum memory management
- integration with classical machine

Programming QRAM

...and its disadvantages

- very similar to low-level code

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...and its disadvantages

- very similar to low-level code
- lack of expressibility

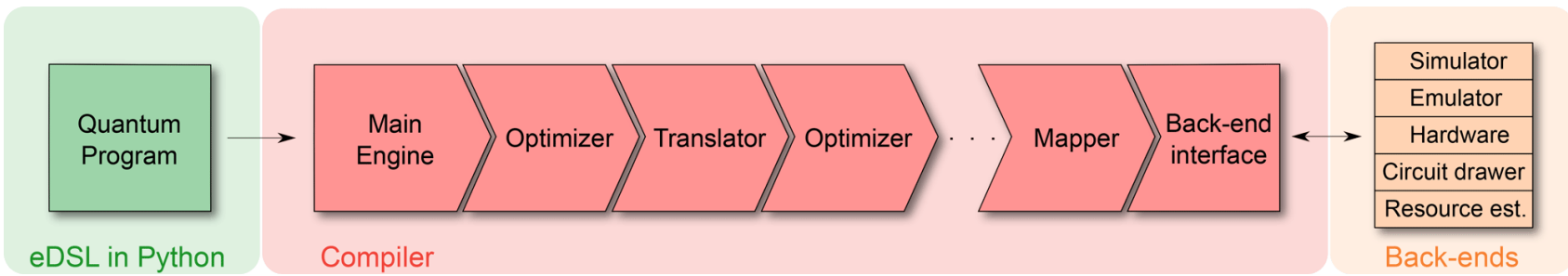
Programming QRAM

Example 1: ProjectQ

- Python library developed by ETH (`https://projectq.ch/`)
- offers various targets
  - hardware (IBM Q Experience)
  - resource counter (???)
  - graphical circuit representation

Programming QRAM

Example 1: ProjectQ



Programming QRAM

Example 1: ProjectQ

Nice features

- Natural (for physicist) syntax for executing quantum gates.
- Meta instructions for quantum-controlled quantum operations and support for reverse call

Programming QRAM

Example 1: ProjectQ

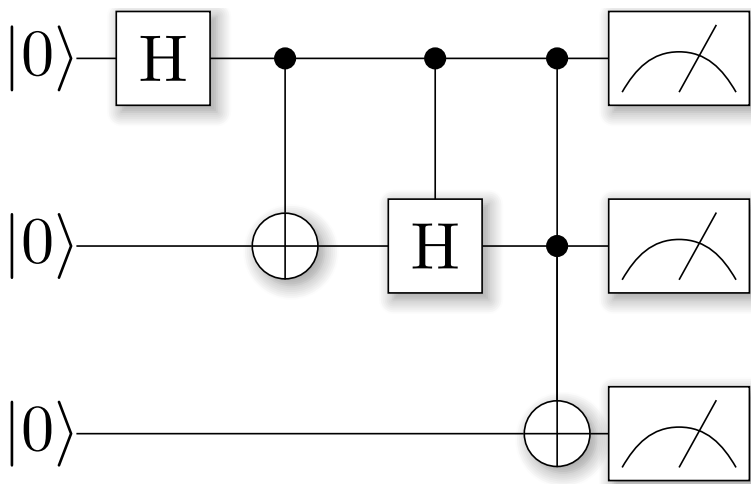
Some examples...

Programming QRAM

Example 1: ProjectQ

Metainstruction `Control`

Execution of the code is based on the state of quantum register.

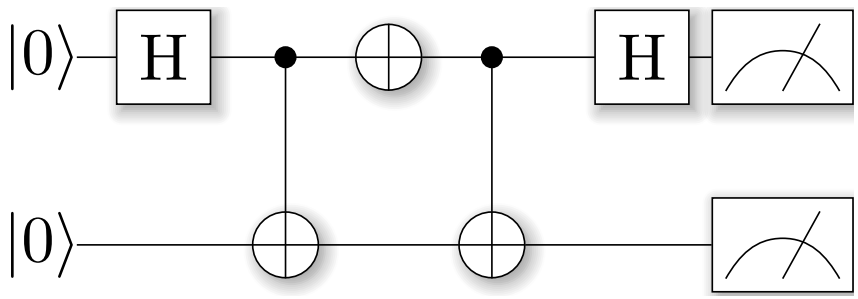


Programming QRAM

Example 1: ProjectQ

Metainstruction `Dagger`

Reverse execution of the quantum code.



Programming QRAM

Example 2: Rigetti Forest and pyQuil

- Quil $\equiv$ quantum assembly language.

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- Access to Rigetti 19Q-Acorn quantum computer!

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- Access to Rigetti 19Q-Acorn quantum computer!
- More during the third day: Adam Szady, Quantum programming with (Py)Quil.

High-level programming

Domain specific languages

Level 2

Domain specific language with data and function abstraction.

- QCL (`http://tph.tuwien.ac.at/~oemer/qcl.html`)
- LanQ (`http://lanq.sourceforge.net/`)
- QPL anc cQPL (`https://arxiv.org/abs/quant-ph/0511145`)
- Scaffold (`https://github.com/epiqc/ScaffCC`)

High-level programming

Example 1: QCL – focus on quantum computing

- First release in 1998, last in 2014 (`http://tph.tuwien.ac.at/~oemer/qcl.html`).

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- Architecture independent programming language for quantum computers.

High-level programming

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Features

- Syntax for reversibility (uncomputing).

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High-level programming

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Features

- Syntax for reversibility (uncomputing).
- Different types of quantum memory for better optimization.
- Quantum conditions — quantum-controlled execution (generalization of controlled gates).
- Various types of compound statements (related with memory management): quantum operators, quantum functions, procedures.

High-level programming

Example 1: QCL – focus on quantum computing

Advanced quantum memory management using types:

- `qureg` — basic type for quantum registers,

High-level programming

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Advanced quantum memory management using types:

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- `quscratch` — has to be empty before and after the call.

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Types of quantum functions:

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Types of quantum functions:

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- `qufunct` — used to implement irreversible functions,
- `operator` — compound quantum operation.

High-level programming

Example 1: QCL – focus on quantum computing

Some examples...

High-level programming

Example 2: cQPL – focus on quantum communication

- QPL (formal specification) and cQPL (implementation of QPL, `https://arxiv.org/abs/quant-ph/0511145`)

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- Functional paradigm.
- No publicly available implementation.

High-level programming

Example 2: cQPL – focus on quantum communication

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- Functional paradigm.
- No publicly available implementation.
- Syntax for creating quantum communication channels by sharing (entangled) qubits.

What next?

- **IF** D-Wave **GOTO** Andy Mason and Sheir Yarkoni, Tutorial on programming the D-Wave system
- **IF** IBM **GOTO** Ram Dušić Hren, IBM Q Experience: Hands-on workshop
- **IF** Rigetti **GOTO** Adam Szady, Quantum programming with (Py)Quil

Q?

https://github.com/jmiszczak/qprog-tutorial