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# projectq Documentation

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**a**

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ProjectQ is an open-source software framework for quantum computing. It aims at providing tools which facilitate **inventing, implementing, testing, debugging, and running** quantum algorithms using either classical hardware or actual quantum devices.

The **four core principles** of this open-source effort are

1. **Open & Free:** *ProjectQ is released under the Apache 2 license*
2. **Simple learning curve:** *It is implemented in Python and has an intuitive syntax*
3. **Easily extensible:** *Anyone can contribute to the compiler, the embedded domain-specific language, and libraries*
4. **Code quality:** *Code reviews, continuous integration testing (unit and functional tests)*

#### Please cite

- Damian S. Steiger, Thomas Häner, and Matthias Troyer “ProjectQ: An Open Source Software Framework for Quantum Computing” [[arxiv:1612.08091](#)]
- Thomas Häner, Damian S. Steiger, Krysta M. Svore, and Matthias Troyer “A Software Methodology for Compiling Quantum Programs” [[arxiv:1604.01401](#)]

#### Contents

- *Tutorial:* Tutorial containing instructions on how to get started with ProjectQ.
- *Examples:* Example implementations of few quantum algorithms
- *Code Documentation:* The code documentation of ProjectQ.



### Getting started

To start using ProjectQ, simply run

```
python -m pip install --user projectq
```

or, alternatively, [clone/download](#) this repo (e.g., to your `/home` directory) and run

```
cd /home/projectq
python -m pip install --user .
```

ProjectQ comes with a high-performance quantum simulator written in C++. Please see the detailed OS specific installation instructions below to make sure that you are installing the fastest version.

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**Note:** The setup will try to build a C++-Simulator, which is much faster than the Python implementation. If it fails, you may use the `--without-cppsimulator` parameter, i.e.,

```
python -m pip install --user --global-option=--without-cppsimulator .
```

and the framework will use the **slow Python simulator instead**. Note that this only works if the installation has been tried once without the `--without-cppsimulator` parameter and hence all requirements are now installed. See the instructions below if you want to run larger simulations. The Python simulator works perfectly fine for the small examples (e.g., running Shor's algorithm for factoring 15 or 21).

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**Note:** If building the C++-Simulator does not work out of the box, consider specifying a different compiler. For example:

```
env CC=g++-5 python -m pip install --user projectq
```

Please note that the compiler you specify must support **C++11!**

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**Note:** Please use pip version v6.1.0 or higher as this ensures that dependencies are installed in the [correct order](#).

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**Note:** ProjectQ should be installed on each computer individually as the C++ simulator compilation creates binaries which are optimized for the specific hardware on which it is being installed (potentially using our AVX version and `-march=native`). Therefore, sharing the same ProjectQ installation across different hardware can cause problems.

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## Detailed instructions and OS-specific hints

### Ubuntu:

After having installed the build tools (for g++):

```
sudo apt-get install build-essential
```

You only need to install Python (and the package manager). For version 3, run

```
sudo apt-get install python3 python3-pip
```

When you then run

```
sudo pip3 install --user projectq
```

all dependencies (such as numpy and pybind11) should be installed automatically.

### Windows:

It is easiest to install a pre-compiled version of Python, including numpy and many more useful packages. One way to do so is using, e.g., the Python3.5 installers from [python.org](http://python.org) or [ANACONDA](#). Installing ProjectQ right away will succeed for the (slow) Python simulator (i.e., with the `-without-cppsimulator` flag). For a compiled version of the simulator, install the Visual C++ Build Tools and the Microsoft Windows SDK prior to doing a pip install. The built simulator will not support multi-threading due to the limited OpenMP support of msvc.

Should you want to run multi-threaded simulations, you can install a compiler which supports newer OpenMP versions, such as MinGW GCC and then manually build the C++ simulator with OpenMP enabled.

### macOS:

These are the steps to install ProjectQ on a new Mac:

In order to install the fast C++ simulator, we require that your system has a C++ compiler (see option 3 below on how to only install the slower Python simulator via the `-without-cppsimulator` parameter)

Below you will find two options to install the fast C++ simulator. The first one is the easiest and requires only the standard compiler which Apple distributes with XCode. The second option uses macports to install the simulator with additional support for multi-threading by using OpenMP, which makes it slightly faster. We show how to install the required C++ compiler (clang) which supports OpenMP and additionally, we show how to install a newer python version.

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**Note:** Depending on your system you might need to use `sudo` for the installation.

---

1. Installation using XCode and the default python:



Install XCode by opening a terminal and running the following command:

```
xcode-select --install
```

Next, you will need to install Python and pip. See option 2 for information on how to install a newer python version with macports. Here, we are using the standard python which is preinstalled with macOS. Pip can be installed by:

```
sudo easy_install pip
```

Now, you can install ProjectQ with the C++ simulator using the standard command:

```
python -m pip install --user projectq
```

## 2. Installation using macports:

Either use the standard python and install pip as shown in option 1 or better use macports to install a newer python version, e.g., Python 3.5 and the corresponding pip. Visit [macports.org](http://macports.org) and install the latest version (afterwards open a new terminal). Then, use macports to install Python 3.5 by

```
sudo port install python35
```

It might show a warning that if you intend to use python from the terminal, you should also install

```
sudo port install py35-readline
```

Install pip by

```
sudo port install py35-pip
```

Next, we can install ProjectQ with the high performance simulator written in C++. First, we will need to install a suitable compiler with support for **C++11**, OpenMP, and intrinsics. The best option is to install clang 3.9 also using macports (note: gcc installed via macports does not work)

```
sudo port install clang-3.9
```

ProjectQ is now installed by:

```
env CC=clang-mp-3.9 env CXX=clang++-mp-3.9 python3.5 -m pip install --
↪user projectq
```

## 3. Installation with only the slow Python simulator:

While this simulator works fine for small examples, it is suggested to install the high performance simulator written in C++.

If you just want to install ProjectQ with the (slow) Python simulator and no compiler, then first try to install ProjectQ with the default compiler

```
python -m pip install --user projectq
```

which most likely will fail. Then, try again with the flag `--without-cppsimulator`:

```
python -m pip install --user --global-option=--without-cppsimulator_
↪projectq
```

## The ProjectQ syntax

Our goal is to have an intuitive syntax in order to enable an easy learning curve. Therefore, ProjectQ features a lean syntax which is close to the mathematical notation used in physics.

For example, consider applying an x-rotation by an angle  $\theta$  to a qubit. In ProjectQ, this looks as follows:

```
Rx(theta) | qubit
```

whereas the corresponding notation in physics would be

$$R_x(\theta) | \text{qubit} \rangle$$

Moreover, the `|`-operator separates the classical arguments (on the left) from the quantum arguments (on the right). Next, you will see a basic quantum program using this syntax. Further examples can be found in the docs (*Examples* in the panel on the left) and in the ProjectQ examples folder on [GitHub](#).

## Basic quantum program

To check out the ProjectQ syntax in action and to see whether the installation worked, try to run the following basic example

```
from projectq import MainEngine # import the main compiler engine
from projectq.ops import H, Measure # import the operations we want to perform
↳ (Hadamard and measurement)

eng = MainEngine() # create a default compiler (the back-end is a simulator)
qubit = eng.allocate_qubit() # allocate 1 qubit

H | qubit # apply a Hadamard gate
Measure | qubit # measure the qubit

eng.flush() # flush all gates (and execute measurements)
print("Measured {}".format(int(qubit))) # output measurement result
```

Which creates random bits (0 or 1).

All of these example codes **and more** can be found on [GitHub](#).

## Quantum Random Numbers

The most basic example is a quantum random number generator (QRNG). It can be found in the examples-folder of ProjectQ. The code looks as follows

```
from projectq.ops import H, Measure
from projectq import MainEngine

# create a main compiler engine
eng = MainEngine()

# allocate one qubit
q1 = eng.allocate_qubit()

# put it in superposition
H | q1

# measure
Measure | q1

eng.flush()
# print the result:
print("Measured: {}".format(int(q1)))
```

Running this code three times may yield, e.g.,

```
$ python examples/quantum_random_numbers.py
Measured: 0
$ python examples/quantum_random_numbers.py
Measured: 0
```

```
$ python examples/quantum_random_numbers.py
Measured: 1
```

These values are obtained by simulating this quantum algorithm classically. By changing three lines of code, we can run an actual quantum random number generator using the IBM Quantum Experience back-end:

```
$ python examples/quantum_random_numbers_ibm.py
Measured: 1
$ python examples/quantum_random_numbers_ibm.py
Measured: 0
```

All you need to do is:

- Create an account for [IBM's Quantum Experience](#)
- And perform these minor changes:

```
--- ../examples/quantum_random_numbers.py
+++ ../examples/quantum_random_numbers_ibm.py
@@ -1,8 +1,10 @@
+import projectq.setups.ibm
  from projectq.ops import H, Measure
  from projectq import MainEngine
+from projectq.backends import IBMBackend

  # create a main compiler engine
-eng = MainEngine()
+eng = MainEngine(IBMBackend())

  # allocate one qubit
  q1 = eng.allocate_qubit()
```

## Quantum Teleportation

Alice has a qubit in some interesting state  $|\psi\rangle$ , which she would like to show to Bob. This does not really make sense, since Bob would not be able to look at the qubit without collapsing the superposition; but let's just assume Alice wants to send her state to Bob for some reason. What she can do is use quantum teleportation to achieve this task. Yet, this only works if Alice and Bob share a Bell-pair (which luckily happens to be the case). A Bell-pair is a pair of qubits in the state

$$|A\rangle \otimes |B\rangle = \frac{1}{\sqrt{2}} (|0\rangle \otimes |0\rangle + |1\rangle \otimes |1\rangle)$$

They can create a Bell-pair using a very simple circuit which first applies a Hadamard gate to the first qubit, and then flips the second qubit conditional on the first qubit being in  $|1\rangle$ . The circuit diagram can be generated by calling the function

```
def create_bell_pair(eng):
    b1 = eng.allocate_qubit()
    b2 = eng.allocate_qubit()

    H | b1
    CNOT | (b1, b2)

    return b1, b2
```

with a main compiler engine which has a CircuitDrawer back-end, i.e.,

```
from projectq import MainEngine
from projectq.backends import CircuitDrawer

from teleport import create_bell_pair

# create a main compiler engine
drawing_engine = CircuitDrawer()
eng = MainEngine(drawing_engine)

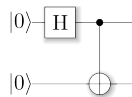
create_bell_pair(eng)

eng.flush()
print(drawing_engine.get_latex())
```

The resulting LaTeX code can be compiled to produce the circuit diagram:

```
$ python examples/bellpair_circuit.py > bellpair_circuit.tex
$ pdflatex bellpair_circuit.tex
```

The output looks as follows:



Now, this Bell-pair can be used to achieve the quantum teleportation: Alice entangles her qubit with her share of the Bell-pair. Then, she measures both qubits; one in the Z-basis (Measure) and one in the Hadamard basis (Hadamard, then Measure). She then sends her measurement results to Bob who, depending on these outcomes, applies a Pauli-X or -Z gate.

The complete example looks as follows:

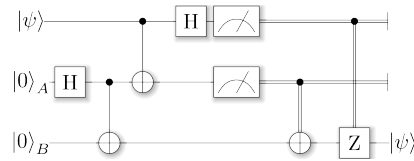
```
1 import projectq.setups.default
2 from projectq.ops import H, X, Z, Rz, CNOT, Measure
3 from projectq import MainEngine
4 from projectq.meta import Dagger, Control
5
6
7 def create_bell_pair(eng):
8     b1 = eng.allocate_qubit()
9     b2 = eng.allocate_qubit()
10
11     H | b1
12     CNOT | (b1, b2)
13
14     return b1, b2
15
16
17 def run_teleport(eng, state_creation_function, verbose=False):
18     # make a Bell-pair
19     b1, b2 = create_bell_pair(eng)
20
21     # Alice creates a nice state to send
22     psi = eng.allocate_qubit()
23     if verbose:
24         print("Alice is creating her state from scratch, i.e., |0>.")
25     state_creation_function(eng, psi)
```

```
26
27     # entangle it with Alice's b1
28     CNOT | (psi, b1)
29     if verbose:
30         print("Alice entangled her qubit with her share of the Bell-pair.")
31
32     # measure two values (once in Hadamard basis) and send the bits to Bob
33     H | psi
34     Measure | (psi, b1)
35     msg_to_bob = [int(psi), int(b1)]
36     if verbose:
37         print("Alice is sending the message {} to Bob.".format(msg_to_bob))
38
39     # Bob may have to apply up to two operation depending on the message sent
40     # by Alice:
41     with Control(eng, b1):
42         X | b2
43     with Control(eng, psi):
44         Z | b2
45
46     # try to uncompute the psi state
47     if verbose:
48         print("Bob is trying to uncompute the state.")
49     with Dagger(eng):
50         state_creation_function(eng, b2)
51
52     # check whether the uncompute was successful. The simulator only allows to
53     # delete qubits which are in a computational basis state.
54     del b2
55     eng.flush()
56
57     if verbose:
58         print("Bob successfully arrived at |0>")
59
60
61 if __name__ == "__main__":
62     # create a main compiler engine with a simulator backend:
63     eng = MainEngine()
64
65     # define our state-creation routine, which transforms a |0> to the state
66     # we would like to send. Bob can then try to uncompute it and, if he
67     # arrives back at |0>, we know that the teleportation worked.
68     def create_state(eng, qb):
69         H | qb
70         Rz(1.21) | qb
71
72     # run the teleport and then, let Bob try to uncompute his qubit:
73     run_teleport(eng, create_state, verbose=True)
```

and the corresponding circuit can be generated using

```
$ python examples/teleport_circuit.py > teleport_circuit.tex
$ pdflatex teleport_circuit.tex
```

which produces (after renaming of the qubits inside the tex-file):



## Shor's algorithm for factoring

As a third example, consider Shor's algorithm for factoring, which for a given (large) number  $N$  determines the two prime factor  $p_1$  and  $p_2$  such that  $p_1 \cdot p_2 = N$  in polynomial time! This is a superpolynomial speed-up over the best known classical algorithm (which is the number field sieve) and enables the breaking of modern encryption schemes such as RSA on a future quantum computer.

**A tiny bit of number theory** There is a small amount of number theory involved, which reduces the problem of factoring to period-finding of the function

$$f(x) = a^x \bmod N$$

for some  $a$  (relative prime to  $N$ , otherwise we get a factor right away anyway by calling  $\text{gcd}(a, N)$ ). The period  $r$  for a function  $f(x)$  is the number for which  $f(x) = f(x + r) \forall x$  holds. In this case, this means that  $a^x = a^{x+r} \pmod{N} \forall x$ . Therefore,  $a^r = 1 + qN$  for some integer  $q$  and hence,  $a^r - 1 = (a^{r/2} - 1)(a^{r/2} + 1) = qN$ . This suggests that using the gcd on  $N$  and  $a^{r/2} \pm 1$  we may find a factor of  $N$ !

**Factoring on a quantum computer: An example** At the heart of Shor's algorithm lies modular exponentiation of a classically known constant (denoted by  $a$  in the code) by a quantum superposition of numbers  $x$ , i.e.,

$$|x\rangle|0\rangle \mapsto |x\rangle|a^x \bmod N\rangle$$

Using  $N = 15$  and  $a = 2$ , and applying this operation to the uniform superposition over all  $x$  leads to the superposition (modulo renormalization)

$$|0\rangle|1\rangle + |1\rangle|2\rangle + |2\rangle|4\rangle + |3\rangle|8\rangle + |4\rangle|1\rangle + |5\rangle|2\rangle + |6\rangle|4\rangle + \dots$$

In Shor's algorithm, the second register will not be touched again before the end of the quantum program, which means it might as well be measured now. Let's assume we measure 2; this collapses the state above to

$$|1\rangle|2\rangle + |5\rangle|2\rangle + |9\rangle|2\rangle + \dots$$

The period of  $a$  modulo  $N$  can now be read off. On a quantum computer, this information can be accessed by applying an inverse quantum Fourier transform to the  $x$ -register, followed by a measurement of  $x$ .

**Implementation** There is an implementation of Shor's algorithm in the examples folder. It uses the implementation by Beauregard, [arxiv:0205095](https://arxiv.org/abs/0205095) to factor an  $n$ -bit number using  $2n+3$  qubits. In this implementation, the modular exponentiation is carried out using modular multiplication and shift. Furthermore it uses the semi-classical quantum Fourier transform [see [arxiv:9511007](https://arxiv.org/abs/9511007)]: Pulling the final measurement of the  $x$ -register through the final inverse quantum Fourier transform allows to run the  $2n$  modular multiplications serially, which keeps one from having to store the  $2n$  qubits of  $x$ .

Let's run it using the ProjectQ simulator:

```
$ python3 examples/shor.py

projectq
-----
Implementation of Shor's algorithm.
```

```
Number to factor: 15

Factoring N = 15: 00000001

Factors found :-> : 3 * 5 = 15
```

Simulating Shor’s algorithm at the level of single-qubit gates and CNOTs already takes quite a bit of time for larger numbers than 15. To turn on our **emulation feature**, which does not decompose the modular arithmetic to low-level gates, but carries it out directly instead, we can change the line

```
91
92     # return the (potential) period
93     return r
94
95
96     # Filter function, which defines the gate set for the first optimization
97     # (don't decompose QFTs and iQFTs to make cancellation easier)
98     def high_level_gates(eng, cmd):
99         g = cmd.gate
100        if g == QFT or get_inverse(g) == QFT or g == Swap:
101            return True
102        if isinstance(g, BasicMathGate):
```

in `examples/shor.py` to *return True*. This allows to factor, e.g.  $N = 4,028,033$  in under 3 minutes on a regular laptop!

The most important part of the code is

```
56     measurements = [0] * (2 * n) # will hold the 2n measurement results
57
58     ctrl_qubit = eng.allocate_qubit()
59
60     for k in range(2 * n):
61         current_a = pow(a, 1 << (2 * n - 1 - k), N)
62         # one iteration of 1-qubit QPE
63         H | ctrl_qubit
64         with Control(eng, ctrl_qubit):
65             MultiplyByConstantModN(current_a, N) | x
66
67         # perform inverse QFT --> Rotations conditioned on previous outcomes
68         for i in range(k):
69             if measurements[i]:
70                 R(-math.pi/(1 << (k - i))) | ctrl_qubit
71         H | ctrl_qubit
72
73         # and measure
74         Measure | ctrl_qubit
```

which executes the  $2n$  modular multiplications conditioned on a control qubit *ctrl\_qubit* in a uniform superposition of 0 and 1. The control qubit is then measured after performing the semi-classical inverse quantum Fourier transform and the measurement outcome is saved in the list *measurements*, followed by a reset of the control qubit to state 0.



Welcome to the package documentation of ProjectQ. You may now browse through the entire documentation and discover the capabilities of the ProjectQ framework.

For a detailed documentation of a subpackage or module, click on its name below:

## backends

### Module contents

Contains back-ends for ProjectQ.

This includes:

- a debugging tool to print all received commands (CommandPrinter)
- a circuit drawing engine (which can be used anywhere within the compilation chain)
- a simulator with emulation capabilities
- a resource counter (counts gates and keeps track of the maximal width of the circuit)
- an interface to the IBM Quantum Experience chip (and simulator).

**class** `projectq.backends.CircuitDrawer` (*accept\_input=False, default\_measure=0*)

`CircuitDrawer` is a compiler engine which generates TikZ code for drawing quantum circuits.

The circuit can be modified by editing the `settings.json` file which is generated upon first execution. This includes adjusting the gate width, height, shadowing, line thickness, and many more options.

After initializing the `CircuitDrawer`, it can also be given the mapping from qubit IDs to wire location (via the `set_qubit_locations()` function):

```
circuit_backend = CircuitDrawer()
circuit_backend.set_qubit_locations({0: 1, 1: 0}) # swap lines 0 and 1
eng = MainEngine(circuit_backend)
```

```
... # run quantum algorithm on this main engine

print(circuit_backend.get_latex()) # prints LaTeX code
```

To see the qubit IDs in the generated circuit, simply set the *draw\_id* option in the settings.json file under “gates”: “AllocateQubitGate” to True:

```
"gates": {
  "AllocateQubitGate": {
    "draw_id": True,
    "height": 0.15,
    "width": 0.2,
    "pre_offset": 0.1,
    "offset": 0.1
  },
  ...
```

The settings.json file has the following structure:

```
{
  "control": { # settings for control "circle"
    "shadow": false,
    "size": 0.1
  },
  "gate_shadow": true, # enable/disable shadows for all gates
  "gates": {
    "GateClassString": {
      GATE_PROPERTIES
    }
    "GateClassString2": {
      ...
    },
  },
  "lines": { # settings for qubit lines
    "double_classical": true, # draw double-lines for
      # classical bits
    "double_lines_sep": 0.04, # gap between the two lines
      # for double lines
    "init_quantum": true, # start out with quantum bits
    "style": "very thin" # line style
  }
}
```

All gates (except for the ones requiring special treatment) support the following properties:

```
"GateClassString": {
  "height": GATE_HEIGHT,
  "width": GATE_WIDTH
  "pre_offset": OFFSET_BEFORE_PLACEMENT,
  "offset": OFFSET_AFTER_PLACEMENT,
},
```

**\_\_init\_\_** (accept\_input=False, default\_measure=0)  
Initialize a circuit drawing engine.

The TikZ code generator uses a settings file (settings.json), which can be altered by the user. It contains gate widths, heights, offsets, etc.

### Parameters

- **accept\_input** (*bool*) – If `accept_input` is true, the printer queries the user to input measurement results if the `CircuitDrawer` is the last engine. Otherwise, all measurements yield the result `default_measure` (0 or 1).
- **default\_measure** (*bool*) – Default value to use as measurement results if `accept_input` is False and there is no underlying backend to register real measurement results.

**get\_latex()**

Return the latex document string representing the circuit.

Simply write this string into a tex-file or, alternatively, pipe the output directly to, e.g., `pdflatex`:

```
python3 my_circuit.py | pdflatex
```

where `my_circuit.py` calls this function and prints it to the terminal.

**is\_available** (*cmd*)

Specialized implementation of `is_available`: Returns True if the `CircuitDrawer` is the last engine (since it can print any command).

**Parameters** `cmd` (*Command*) – Command for which to check availability (all `Commands` can be printed).

**Returns** True, unless the next engine cannot handle the `Command` (if there is a next engine).

**Return type** availability (*bool*)

**receive** (*command\_list*)

Receive a list of commands from the previous engine, print the commands, and then send them on to the next engine.

**Parameters** `command_list` (*list<Command>*) – List of `Commands` to print (and potentially send on to the next engine).

**set\_qubit\_locations** (*id\_to\_loc*)

Sets the qubit lines to use for the qubits explicitly.

To figure out the qubit IDs, simply use the setting `draw_id` in the settings file. It is located in “gates”:”AllocateQubitGate”. If `draw_id` is True, the qubit IDs are drawn in red.

**Parameters** `id_to_loc` (*dict*) – Dictionary mapping qubit ids to qubit line numbers.

**Raises** `RuntimeError` – If the mapping has already begun (this function needs be called before any gates have been received).

**class** `projectq.backends.ClassicalSimulator`

A simple introspective simulator that only permits classical operations.

Allows allocation, deallocation, measuring (no-op), flushing (no-op), controls, NOTs, and any `BasicMathGate`. Supports reading/writing directly from/to bits and registers of bits.

**read\_bit** (*qubit*)

Reads a bit.

**Parameters** `qubit` (`projectq.types.Qubit`) – The bit to read.

**Returns** 0 if the target bit is off, 1 if it’s on.

**Return type** `int`

**read\_register** (*qureg*)

Reads a group of bits as a little-endian integer.

**Parameters** `qureg` (`projectq.types.Qureg`) – The group of bits to read, in little-endian order.

**Returns** Little-endian register value.

**Return type** `int`

**write\_bit** (`qubit`, `value`)

Resets/sets a bit to the given value.

**Parameters**

- **qubit** (`projectq.types.Qubit`) – The bit to write.
- **value** (`bool` / `int`) – Writes 1 if this value is truthy, else 0.

**write\_register** (`qureg`, `value`)

Sets a group of bits to store a little-endian integer value.

**Parameters**

- **qureg** (`projectq.types.Qureg`) – The bits to write, in little-endian order.
- **value** (`int`) – The integer value to store. Must fit in the register.

**class** `projectq.backends.CommandPrinter` (`accept_input=True`, `default_measure=False`,  
`in_place=False`)

`CommandPrinter` is a compiler engine which prints commands to stdout prior to sending them on to the next compiler engine.

**\_\_init\_\_** (`accept_input=True`, `default_measure=False`, `in_place=False`)

Initialize a `CommandPrinter`.

**Parameters**

- **accept\_input** (`bool`) – If `accept_input` is true, the printer queries the user to input measurement results if the `CommandPrinter` is the last engine. Otherwise, all measurements yield `default_measure`.
- **default\_measure** (`bool`) – Default measurement result (if `accept_input` is `False`).
- **in\_place** (`bool`) – If `in_place` is true, all output is written on the same line of the terminal.

**is\_available** (`cmd`)

Specialized implementation of `is_available`: Returns `True` if the `CommandPrinter` is the last engine (since it can print any command).

**Parameters** `cmd` (`Command`) – Command of which to check availability (all `Commands` can be printed).

**Returns**

**True, unless the next engine cannot handle** the `Command` (if there is a next engine).

**Return type** `availability` (`bool`)

**receive** (`command_list`)

Receive a list of commands from the previous engine, print the commands, and then send them on to the next engine.

**Parameters** `command_list` (`list` <`Command`>) – List of `Commands` to print (and potentially send on to the next engine).

**class** `projectq.backends.IBMBackend` (*use\_hardware=False, num\_runs=1024, verbose=False, user=None, password=None, device='ibmqx2'*)

The IBM Backend class, which stores the circuit, transforms it to JSON QASM, and sends the circuit through the IBM API.

**\_\_init\_\_** (*use\_hardware=False, num\_runs=1024, verbose=False, user=None, password=None, device='ibmqx2'*)

Initialize the Backend object.

#### Parameters

- **use\_hardware** (*bool*) – If True, the code is run on the IBM quantum chip (instead of using the IBM simulator)
- **num\_runs** (*int*) – Number of runs to collect statistics. (default is 1024)
- **verbose** (*bool*) – If True, statistics are printed, in addition to the measurement result being registered (at the end of the circuit).
- **user** (*string*) – IBM Quantum Experience user name
- **password** (*string*) – IBM Quantum Experience password
- **device** (*string*) – Device to use ('ibmqx2' or 'ibmqx4') if use\_hardware is set to True. Default is ibmqx2.

**get\_probabilities** (*qreg*)

Return the list of basis states with corresponding probabilities.

The measured bits are ordered according to the supplied quantum register, i.e., the left-most bit in the state-string corresponds to the first qubit in the supplied quantum register.

**Warning:** Only call this function after the circuit has been executed!

**Parameters** *qreg* (*list<Qubit>*) – Quantum register determining the order of the qubits.

**Returns** Dictionary mapping n-bit strings to probabilities.

**Return type** *probability\_dict* (*dict*)

**Raises** `RuntimeError` – If no data is available (i.e., if the circuit has not been executed). Or if a qubit was supplied which was not present in the circuit (might have gotten optimized away).

**is\_available** (*cmd*)

Return true if the command can be executed.

The IBM quantum chip can do X, Y, Z, T, Tdag, S, Sdag, and CX / CNOT.

**Parameters** *cmd* (*Command*) – Command for which to check availability

**receive** (*command\_list*)

Receives a command list and, for each command, stores it until completion.

**Parameters** *command\_list* – List of commands to execute

**class** `projectq.backends.ResourceCounter`

`ResourceCounter` is a compiler engine which counts the number of gates and max. number of active qubits.

**gate\_counts**

*dict* – Dictionary of gate counts. The keys are string representations of the gate.

**max\_width**

*int* – Maximal width (=max. number of active qubits at any given point).

**\_\_init\_\_** ()

Initialize a resource counter engine.

Sets all statistics to zero.

**is\_available** (*cmd*)

Specialized implementation of `is_available`: Returns True if the ResourceCounter is the last engine (since it can count any command).

**Parameters** *cmd* (*Command*) – Command for which to check availability (all Commands can be counted).

**Returns**

**True, unless the next engine cannot handle** the Command (if there is a next engine).

**Return type** availability (bool)

**receive** (*command\_list*)

Receive a list of commands from the previous engine, print the commands, and then send them on to the next engine.

**Parameters** *command\_list* (*list<Command>*) – List of commands to receive (and count).

**class** `projectq.backends.Simulator` (*gate\_fusion=False, rnd\_seed=None*)

Simulator is a compiler engine which simulates a quantum computer using C++-based kernels.

OpenMP is enabled and the number of threads can be controlled using the `OMP_NUM_THREADS` environment variable, i.e.

```
export OMP_NUM_THREADS=4 # use 4 threads
export OMP_PROC_BIND=spread # bind threads to processors by spreading
```

**\_\_init\_\_** (*gate\_fusion=False, rnd\_seed=None*)

Construct the C++/Python-simulator object and initialize it with a random seed.

**Parameters**

- **gate\_fusion** (*bool*) – If True, gates are cached and only executed once a certain gate-size has been reached (only has an effect for the c++ simulator).
- **rnd\_seed** (*int*) – Random seed (uses `random.randint(0, 1024)` by default).

Example of `gate_fusion`: Instead of applying a Hadamard gate to 5 qubits, the simulator calculates the kronecker product of the 1-qubit matrices and then applies 1 5-qubit gate. This increases operational intensity and keeps the simulator from having to iterate through the state vector multiple times. Depending on the system (and, especially, number of threads), this may or may not be beneficial.

---

**Note:** If the C++ Simulator extension was not built or cannot be found, the Simulator defaults to a Python implementation of the kernels. While this is much slower, it is still good enough to run basic quantum algorithms.

If you need to run large simulations, check out the tutorial in the docs which gives further hints on how to build the C++ extension.

---

**apply\_qubit\_operator** (*qubit\_operator, qureg*)

Apply a (possibly non-unitary) `qubit_operator` to the current wave function represented by the supplied quantum register.

**Parameters**

- **qubit\_operator** (`projectq.ops.QubitOperator`) – Operator to apply.
- **qureg** (`list [Qubit]`, `Qureg`) – Quantum bits to which to apply the operator.

**Warning:** This function allows applying non-unitary gates and it will not re-normalize the wave function! It is for numerical experiments only and should not be used for other purposes.

---

**Note:** Make sure all previous commands (especially allocations) have passed through the compilation chain (call `main_engine.flush()` to make sure).

---

**Raises** `Exception` – If `qubit_operator` acts on more qubits than present in the `qureg` argument.

**cheat ()**

Access the ordering of the qubits and the state vector directly.

This is a cheat function which enables, e.g., more efficient evaluation of expectation values and debugging.

**Returns** A tuple where the first entry is a dictionary mapping qubit indices to bit-locations and the second entry is the corresponding state vector.

---

**Note:** Make sure all previous commands have passed through the compilation chain (call `main_engine.flush()` to make sure).

---

**collapse\_wavefunction (qureg, values)**

Collapse a quantum register onto a classical basis state.

**Parameters**

- **qureg** (`Qureg` | `list [Qubit]`) – Qubits to collapse.
- **values** (`list [bool]`) – Measurement outcome for each of the qubits in `qureg`.

**Raises** `RuntimeError` – If an outcome has probability (approximately) 0 or if unknown qubits are provided (see note).

---

**Note:** Make sure all previous commands have passed through the compilation chain (call `main_engine.flush()` to make sure).

---

**get\_amplitude (bit\_string, qureg)**

Return the probability amplitude of the supplied `bit_string`. The ordering is given by the quantum register `qureg`, which must contain all allocated qubits.

**Parameters**

- **bit\_string** (`list [bool | int]` | `string [0|1]`) – Computational basis state
- **qureg** (`Qureg` | `list [Qubit]`) – Quantum register determining the ordering. Must contain all allocated qubits.

**Returns** Probability amplitude of the provided bit string.

---

**Note:** Make sure all previous commands (especially allocations) have passed through the compilation chain (call `main_engine.flush()` to make sure).

---

**get\_expectation\_value** (*qubit\_operator*, *qureg*)

Get the expectation value of *qubit\_operator* w.r.t. the current wave function represented by the supplied quantum register.

**Parameters**

- **qubit\_operator** (`projectq.ops.QubitOperator`) – Operator to measure.
- **qureg** (`list [Qubit]`, `Qureg`) – Quantum bits to measure.

**Returns** Expectation value

---

**Note:** Make sure all previous commands (especially allocations) have passed through the compilation chain (call `main_engine.flush()` to make sure).

---

**Raises** `Exception` – If *qubit\_operator* acts on more qubits than present in the *qureg* argument.

**get\_probability** (*bit\_string*, *qureg*)

Return the probability of the outcome *bit\_string* when measuring the quantum register *qureg*.

**Parameters**

- **bit\_string** (`list [bool|int]` | `string [0|1]`) – Measurement outcome.
- **qureg** (`Qureg` | `list [Qubit]`) – Quantum register.

**Returns** Probability of measuring the provided bit string.

---

**Note:** Make sure all previous commands (especially allocations) have passed through the compilation chain (call `main_engine.flush()` to make sure).

---

**is\_available** (*cmd*)

Specialized implementation of `is_available`: The simulator can deal with all arbitrarily-controlled single-qubit gates which provide a gate-matrix (via `gate.matrix`).

**Parameters** **cmd** (`Command`) – Command for which to check availability (single- qubit gate, arbitrary controls)

**Returns** True if it can be simulated and False otherwise.

**receive** (*command\_list*)

Receive a list of commands from the previous engine and handle them (simulate them classically) prior to sending them on to the next engine.

**Parameters** **command\_list** (`list <Command>`) – List of commands to execute on the simulator.

**set\_wavefunction** (*wavefunction*, *qureg*)

Set the wavefunction and the qubit ordering of the simulator.

The simulator will adopt the ordering of *qureg* (instead of reordering the wavefunction).

**Parameters**



- **wavefunction** (*list[complex]*) – Array of complex amplitudes describing the wavefunction (must be normalized).
- **qureg** (*Qureg/list[Qubit]*) – Quantum register determining the ordering. Must contain all allocated qubits.

---

**Note:** Make sure all previous commands (especially allocations) have passed through the compilation chain (call `main_engine.flush()` to make sure).

---

## cengines

The ProjectQ compiler engines package.

### Module contents

**class** `projectq.cengines.AutoReplacer` (*decompositionRuleSet, decomposition\_chooser=<function AutoReplacer.<lambda>>*)

The AutoReplacer is a compiler engine which uses `engine.is_available` in order to determine which commands need to be replaced/decomposed/compiled further. The loaded setup is used to find decomposition rules appropriate for each command (e.g., `setups.default`).

**\_\_init\_\_** (*decompositionRuleSet, decomposition\_chooser=<function AutoReplacer.<lambda>>*)  
Initialize an AutoReplacer.

**Parameters** `decomposition_chooser` (*function*) – A function which, given the Command to decompose and a list of potential Decomposition objects, determines (and then returns) the ‘best’ decomposition.

The default decomposition chooser simply returns the first list element, i.e., calling

```
repl = AutoReplacer()
```

Amounts to

```
def decomposition_chooser(cmd, decomp_list):
    return decomp_list[0]
repl = AutoReplacer(decomposition_chooser)
```

**receive** (*command\_list*)

Receive a list of commands from the previous compiler engine and, if necessary, replace/decompose the gates according to the decomposition rules in the loaded setup.

**Parameters** `command_list` (*list<Command>*) – List of commands to handle.

**class** `projectq.cengines.BasicEngine`

Basic compiler engine: All compiler engines are derived from this class. It provides basic functionality such as qubit allocation/deallocation and functions that provide information about the engine’s position (e.g., `next_engine`).

This information is provided by the MainEngine, which initializes all further engines.

**next\_engine**

*BasicEngine* – Next compiler engine (or the back-end).

**main\_engine**

*MainEngine* – Reference to the main compiler engine.

**is\_last\_engine**

*bool* – True for the last engine, which is the back-end.

**\_\_init\_\_()**

Initialize the basic engine.

Initializes local variables such as `_next_engine`, `_main_engine`, etc. to None.

**allocate\_qubit** (*dirty=False*)

Return a new qubit as a list containing 1 qubit object (quantum register of size 1).

Allocates a new qubit by getting a (new) qubit id from the MainEngine, creating the qubit object, and then sending an AllocateQubit command down the pipeline. If `dirty=True`, the fresh qubit can be replaced by a pre-allocated one (in an unknown, dirty, initial state). Dirty qubits must be returned to their initial states before they are deallocated / freed.

All allocated qubits are added to the MainEngine's set of active qubits as weak references. This allows proper clean-up at the end of the Python program (using `atexit`), deallocating all qubits which are still alive. Qubit ids of dirty qubits are registered in MainEngine's `dirty_qubits` set.

**Parameters** `dirty` (*bool*) – If True, indicates that the allocated qubit may be dirty (i.e., in an arbitrary initial state).

**Returns** Qureg of length 1, where the first entry is the allocated qubit.

**allocate\_quireg** (*n*)

Allocate *n* qubits and return them as a quantum register, which is a list of qubit objects.

**Parameters** `n` (*int*) – Number of qubits to allocate

**Returns** Qureg of length *n*, a list of *n* newly allocated qubits.

**deallocate\_qubit** (*qubit*)

Deallocate a qubit (and sends the deallocation command down the pipeline). If the qubit was allocated as a dirty qubit, add `DirtyQubitTag()` to Deallocate command.

**Parameters** `qubit` (*BasicQubit*) – Qubit to deallocate.

**Raises** `ValueError` – Qubit already deallocated. Caller likely has a bug.

**is\_available** (*cmd*)

Default implementation of `is_available`: Ask the next engine whether a command is available, i.e., whether it can be executed by the next engine(s).

**Parameters** `cmd` (*Command*) – Command for which to check availability.

**Returns** True if the command can be executed.

**Raises** `LastEngineException` – If `is_last_engine` is True but `is_available` is not implemented.

**is\_meta\_tag\_supported** (*meta\_tag*)

Check if there is a compiler engine handling the meta tag

**Parameters**

- `engine` – First engine to check (then iteratively calls `getNextEngine`)
- `meta_tag` – Meta tag class for which to check support

**Returns** True if one of the further compiler engines is a meta tag handler, i.e., `engine.is_meta_tag_handler(meta_tag)` returns True.

**Return type** supported (bool)

**send** (*command\_list*)

Forward the list of commands to the next engine in the pipeline.

**class** `projectq.engines.CommandModifier` (*cmd\_mod\_fun*)

CommandModifier is a compiler engine which applies a function to all incoming commands, sending on the resulting command instead of the original one.

**\_\_init\_\_** (*cmd\_mod\_fun*)

Initialize the CommandModifier.

**Parameters** `cmd_mod_fun` (*function*) – Function which, given a command `cmd`, returns the command it should send instead.

### Example

```
def cmd_mod_fun(cmd):
    cmd.tags += [MyOwnTag()]
    compiler_engine = CommandModifier(cmd_mod_fun)
    ...
```

**receive** (*command\_list*)

Receive a list of commands from the previous engine, modify all commands, and send them on to the next engine.

**Parameters** `command_list` (*list<Command>*) – List of commands to receive and then (after modification) send on.

**class** `projectq.engines.CompareEngine`

CompareEngine is an engine which saves all commands. It is only intended for testing purposes. Two CompareEngine backends can be compared and return True if they contain the same commands.

**class** `projectq.engines.DecompositionRule` (*gate\_class*, *gate\_decomposer*,  
*gate\_recognizer=<function Rule.<lambda>>*)

A rule for breaking down specific gates into sequences of simpler gates.

**\_\_init\_\_** (*gate\_class*, *gate\_decomposer*, *gate\_recognizer=<function Rule.<lambda>>*)

#### Parameters

- **gate\_class** (*type*) – The type of gate that this rule decomposes.  
The gate class is redundant information used to make lookups faster when iterating over a circuit and deciding “which rules apply to this gate?” again and again.  
Note that this parameter is a gate type, not a gate instance. You supply `gate_class=MyGate` or `gate_class=MyGate().__class__`, not `gate_class=MyGate()`.
- **gate\_decomposer** (*function* [`projectq.ops.Command`]) – Function which, given the command to decompose, applies a sequence of gates corresponding to the high-level function of a gate of type `gate_class`.
- **(function** [`projectq.ops.Command`] (*gate\_recognizer*) – boolean): A predicate that determines if the decomposition applies to the given command (on top of the filtering by `gate_class`).

For example, a decomposition rule may only to apply rotation gates that rotate by a specific angle.

If no `gate_recognizer` is given, the decomposition applies to all gates matching the `gate_class`.

**class** `projectq.engines.DecompositionRuleSet` (*rules=None, modules=None*)

A collection of indexed decomposition rules.

`__init__` (*rules=None, modules=None*)

**Parameters**

- **list** [`DecompositionRule`] (*rules*) – Initial decomposition rules.
- **modules** (*iterable* [`ModuleWithDecompositionRuleSet`]) – A list of things with an “`all_defined_decomposition_rules`” property containing decomposition rules to add to the rule set.

`add_decomposition_rule` (*rule*)

Add a decomposition rule to the rule set.

**Parameters** **rule** (`DecompositionRuleGate`) – The decomposition rule to add.

**class** `projectq.engines.DummyEngine` (*save\_commands=False*)

DummyEngine used for testing.

The DummyEngine forwards all commands directly to next engine. If `self.is_last_engine == True` it just discards all gates. By setting `save_commands == True` all commands get saved as a list in `self.received_commands`. Elements are appended to this list so they are ordered according to when they are received.

`__init__` (*save\_commands=False*)

Initialize DummyEngine

**Parameters** **save\_commands** (*default = False*) – If True, commands are saved in `self.received_commands`.

**class** `projectq.engines.ForwarderEngine` (*engine, cmd\_mod\_fun=None*)

A ForwarderEngine is a trivial engine which forwards all commands to the next engine.

It is mainly used as a substitute for the MainEngine at lower levels such that meta operations still work (e.g., with Compute).

`__init__` (*engine, cmd\_mod\_fun=None*)

Initialize a ForwarderEngine.

**Parameters**

- **engine** (`BasicEngine`) – Engine to forward all commands to.
- **cmd\_mod\_fun** (*function*) – Function which is called before sending a command. Each command `cmd` is replaced by the command it returns when getting called with `cmd`.

`receive` (*command\_list*)

Forward all commands to the next engine.

**class** `projectq.engines.IBMCNOTMapper`

CNOT mapper for the IBM backend.

Maps a given circuit to the IBM Quantum Experience chip. If necessary, it will flip around the CNOT gate by first applying Hadamard gates to both qubits, then CNOT with swapped control and target qubit, and finally Hadamard gates to both qubits. Furthermore, it adds `QubitPlacementTags` to Allocate gate commands.

---

**Note:** The mapper has to be run once on the entire circuit.

---

**Warning:** If the provided circuit cannot be mapped to the hardware layout without performing Swaps, the mapping procedure **raises an Exception**.

`__init__()`

Initialize an IBM CNOT Mapper compiler engine.

Resets the mapping.

`is_available(cmd)`

Check if the IBM backend can perform the Command `cmd` and return True if so.

**Parameters** `cmd` (`Command`) – The command to check

`receive(command_list)`

Receives a command list and, for each command, stores it until completion.

**Parameters** `command_list` (*list of Command objects*) – list of commands to receive.

**Raises** `Exception` – If mapping the CNOT gates to 1 qubit would require Swaps. The current version only supports remapping of CNOT gates without performing any Swaps due to the large costs associated with Swapping given the CNOT constraints.

`class projectq.engines.InstructionFilter(filterfun)`

The `InstructionFilter` is a compiler engine which changes the behavior of `is_available` according to a filter function. All commands are passed to this function, which then returns whether this command can be executed (True) or needs replacement (False).

`__init__(filterfun)`

Initializer: The provided `filterfun` returns True for all commands which do not need replacement and False for commands that do.

**Parameters** `filterfun` (*function*) – Filter function which returns True for available commands, and False otherwise. `filterfun` will be called as `filterfun(self, cmd)`.

`is_available(cmd)`

Specialized implementation of `BasicBackend.is_available`: Forwards this call to the filter function given to the constructor.

**Parameters** `cmd` (`Command`) – Command for which to check availability.

`receive(command_list)`

Forward all commands to the next engine.

**Parameters** `command_list` (*list<Command>*) – List of commands to receive.

`exception projectq.engines.LastEngineException(engine)`

Exception thrown when the last engine tries to access the next one. (Next engine does not exist)

The default implementation of `isAvailable` simply asks the next engine whether the command is available. An engine which legally may be the last engine, this behavior needs to be adapted (see `BasicEngine.isAvailable`).

`class projectq.engines.LocalOptimizer(m=5)`

`LocalOptimizer` is a compiler engine which optimizes locally (merging rotations, cancelling gates with their inverse) in a local window of user- defined size.

It stores all commands in a list of lists, where each qubit has its own gate pipeline. After adding a gate, it tries to merge / cancel successive gates using the `get_merged` and `get_inverse` functions of the gate (if available). For examples, see `BasicRotationGate`. Once a list corresponding to a qubit contains  $\geq m$  gates, the pipeline is sent on to the next engine.

`__init__` (*m=5*)

Initialize a LocalOptimizer object.

**Parameters** *m* (*int*) – Number of gates to cache per qubit, before sending on the first gate.

**receive** (*command\_list*)

Receive commands from the previous engine and cache them. If a flush gate arrives, the entire buffer is sent on.

**class** `projectq.engines.MainEngine` (*backend=None, engine\_list=None*)

The MainEngine class provides all functionality of the main compiler engine.

It initializes all further compiler engines (calls, e.g., `.next_engine=...`) and keeps track of measurement results and active qubits (and their IDs).

**next\_engine**

*BasicEngine* – Next compiler engine (or the back-end).

**main\_engine**

*MainEngine* – Self.

**active\_qubits**

*WeakSet* – WeakSet containing all active qubits

**dirty\_qubits**

*Set* – Containing all dirty qubit ids

**backend**

*BasicEngine* – Access the back-end.

`__init__` (*backend=None, engine\_list=None*)

Initialize the main compiler engine and all compiler engines.

Sets ‘next\_engine’- and ‘main\_engine’-attributes of all compiler engines and adds the back-end as the last engine.

**Parameters**

- **backend** (*BasicEngine*) – Backend to send the circuit to.
- **engine\_list** (*list<BasicEngine>*) – List of engines / backends to use as compiler engines.

### Example

```
from projectq import MainEngine
eng = MainEngine() # uses default setup and the Simulator
```

Alternatively, one can specify all compiler engines explicitly, e.g.,

### Example

```
from projectq.engines import (TagRemover, AutoReplacer,
                             LocalOptimizer,
                             DecompositionRuleSet)
from projectq.backends import Simulator
from projectq import MainEngine
rule_set = DecompositionRuleSet()
engines = [AutoReplacer(rule_set), TagRemover(),
```

```
LocalOptimizer(3)]
eng = MainEngine(Simulator(), engines)
```

**flush** (*deallocate\_qubits=False*)

Flush the entire circuit down the pipeline, clearing potential buffers (of, e.g., optimizers).

**Parameters** **deallocate\_qubits** (*bool*) – If True, deallocates all qubits that are still alive (invalidating references to them by setting their id to -1).

**get\_measurement\_result** (*qubit*)

Return the classical value of a measured qubit, given that an engine registered this result previously (see `setMeasurementResult`).

**Parameters** **qubit** (*BasicQubit*) – Qubit of which to get the measurement result.

## Example

```
from projectq.ops import H, Measure
from projectq import MainEngine
eng = MainEngine()
qubit = eng.allocate_qubit() # quantum register of size 1
H | qubit
Measure | qubit
eng.get_measurement_result(qubit[0]) == int(qubit)
```

**get\_new\_qubit\_id** ()

Returns a unique qubit id to be used for the next qubit allocation.

**Returns** New unique qubit id.

**Return type** `new_qubit_id` (*int*)

**receive** (*command\_list*)

Forward the list of commands to the first engine.

**Parameters** **command\_list** (*list<Command>*) – List of commands to receive (and then send on)

**set\_measurement\_result** (*qubit, value*)

Register a measurement result

The engine being responsible for measurement results needs to register these results with the master engine such that they are available when the user calls an `int()` or `bool()` conversion operator on a measured qubit.

**Parameters**

- **qubit** (*BasicQubit*) – Qubit for which to register the measurement result.
- **value** (*bool*) – Boolean value of the measurement outcome (True / False = 1 / 0 respectively).

```
class projectq.engines.TagRemover (tags=[<class 'projectq.meta._compute.ComputeTag'>,
                                       <class 'projectq.meta._compute.UncomputeTag'>])
```

TagRemover is a compiler engine which removes temporary command tags (see the tag classes such as `LoopTag` in `projectq.meta._loop`).

Removing tags is important (after having handled them if necessary) in order to enable optimizations across meta-function boundaries (compute/ action/uncompute or loops after unrolling)

```
__init__(tags=[<class 'projectq.meta._compute.ComputeTag'>, <class 'projectq.meta._compute.UncomputeTag'>])
```

Construct the TagRemover.

**Parameters** `tags` – A list of meta tag classes (e.g., [ComputeTag, UncomputeTag]) denoting the tags to remove

**receive** (`command_list`)

Receive a list of commands from the previous engine, remove all tags which are an instance of at least one of the meta tags provided in the constructor, and then send them on to the next compiler engine.

**Parameters** `command_list` (`list<Command>`) – List of commands to receive and then (after removing tags) send on.

## libs

The library collection of ProjectQ which, for now, only consists of a tiny math library. Soon, more libraries will be added.

## Subpackages

### math

A tiny math library which will be extended throughout the next weeks. Right now, it only contains the math functions necessary to run Beauregard’s implementation of Shor’s algorithm.

### Module contents

`class projectq.libs.math.AddConstant(a)`

Add a constant to a quantum number represented by a quantum register, stored from low- to high-bit.

#### Example

```
qnum = eng.allocate_quireg(5) # 5-qubit number
X | qnum[1] # qnum is now equal to 2
AddConstant(3) | qnum # qnum is now equal to 5
```

`__init__(a)`

Initializes the gate to the number to add.

**Parameters** `a` (`int`) – Number to add to a quantum register.

It also initializes its base class, BasicMathGate, with the corresponding function, so it can be emulated efficiently.

`get_inverse()`

Return the inverse gate (subtraction of the same constant).

`class projectq.libs.math.AddConstantModN(a, N)`

Add a constant to a quantum number represented by a quantum register modulo N.

The number is stored from low- to high-bit, i.e., `qnum[0]` is the LSB.



### Example

```
qnum = eng.allocate_qureg(5) # 5-qubit number
X | qnum[1] # qnum is now equal to 2
AddConstantModN(3, 4) | qnum # qnum is now equal to 1
```

`__init__(a, N)`

Initializes the gate to the number to add modulo N.

#### Parameters

- **a** (*int*) – Number to add to a quantum register ( $0 \leq a < N$ ).
- **N** (*int*) – Number modulo which the addition is carried out.

It also initializes its base class, `BasicMathGate`, with the corresponding function, so it can be emulated efficiently.

`get_inverse()`

Return the inverse gate (subtraction of the same number a modulo the same number N).

`class projectq.libs.math.MultiplyByConstantModN(a, N)`

Multiply a quantum number represented by a quantum register by a constant modulo N.

The number is stored from low- to high-bit, i.e., `qnum[0]` is the LSB.

### Example

```
qnum = eng.allocate_qureg(5) # 5-qubit number
X | qnum[2] # qnum is now equal to 4
MultiplyByConstantModN(3,5) | qnum # qnum is now 2.
```

`__init__(a, N)`

Initializes the gate to the number to multiply with modulo N.

#### Parameters

- **a** (*int*) – Number by which to multiply a quantum register ( $0 \leq a < N$ ).
- **N** (*int*) – Number modulo which the multiplication is carried out.

It also initializes its base class, `BasicMathGate`, with the corresponding function, so it can be emulated efficiently.

`projectq.libs.math.SubConstant(a)`

Subtract a constant from a quantum number represented by a quantum register, stored from low- to high-bit.

**Parameters** **a** (*int*) – Constant to subtract

### Example

```
qnum = eng.allocate_qureg(5) # 5-qubit number
X | qnum[2] # qnum is now equal to 4
SubConstant(3) | qnum # qnum is now equal to 1
```

`projectq.libs.math.SubConstantModN(a, N)`

Subtract a constant from a quantum number represented by a quantum register modulo N.

The number is stored from low- to high-bit, i.e., `qnum[0]` is the LSB.

### Parameters

- **a** (*int*) – Constant to add
- **N** (*int*) – Constant modulo which the addition of a should be carried out.

### Example

```
qunum = eng.allocate_quireg(3) # 3-qubit number
X | qunum[1] # qunum is now equal to 2
SubConstantModN(4,5) | qunum # qunum is now -2 = 6 = 1 (mod 5)
```

## Module contents

### meta

Contains meta statements which allow more optimal code while making it easier for users to write their code. Examples are *with Compute*, followed by an automatic uncompute or *with Control*, which allows the user to condition an entire code block upon the state of a qubit.

## Module contents

The projectq.meta package features meta instructions which help both the user and the compiler in writing/producing efficient code. It includes, e.g.,

- Loop (with Loop(eng): ...)
- Compute/Uncompute (with Compute(eng): ..., [...], Uncompute(eng))
- Control (with Control(eng, ctrl\_qubits): ...)
- Dagger (with Dagger(eng): ...)

**class** projectq.meta.**Compute** (*engine*)  
Start a compute-section.

### Example

```
with Compute(eng):
    do_something(qubits)
action(qubits)
Uncompute(eng) # runs inverse of the compute section
```

**Warning:** If qubits are allocated within the compute section, they must either be uncomputed and deallocated within that section or, alternatively, uncomputed and deallocated in the following uncompute section.

This means that the following examples are valid:

```

with Compute(eng) :
    anc = eng.allocate_qubit()
    do_something_with_ancilla(anc)
    ...
    uncompute_ancilla(anc)
    del anc

do_something_else(qubits)

Uncompute(eng)  # will allocate a new ancilla (with a different id)
                 # and then deallocate it again

```

```

with Compute(eng) :
    anc = eng.allocate_qubit()
    do_something_with_ancilla(anc)
    ...

do_something_else(qubits)

Uncompute(eng)  # will deallocate the ancilla!

```

After the uncompute section, ancilla qubits allocated within the compute section will be invalid (and deallocated). The same holds when using CustomUncompute.

Failure to comply with these rules results in an exception being thrown.

`__init__(engine)`

Initialize a Compute context.

**Parameters** `engine` (`BasicEngine`) – Engine which is the first to receive all commands (normally: `MainEngine`).

`class projectq.meta.ComputeTag`

Compute meta tag.

`class projectq.meta.Control(engine, qubits)`

Condition an entire code block on the value of qubits being 1.

## Example

```

with Control(eng, ctrlqubits):
    do_something(otherqubits)

```

`__init__(engine, qubits)`

Enter a controlled section.

### Parameters

- **engine** – Engine which handles the commands (usually `MainEngine`)
- **qubits** (*list of Qubit objects*) – Qubits to condition on

Enter the section using a with-statement:

```

with Control(eng, ctrlqubits):
    ...

```

**class** `projectq.meta.CustomUncompute` (*engine*)  
 Start a custom uncompute-section.

### Example

```
with Compute(eng):
    do_something(qubits)
action(qubits)
with CustomUncompute(eng):
    do_something_inverse(qubits)
```

**Raises** `QubitManagementError` – If qubits are allocated within `Compute` or within `CustomUncompute` context but are not deallocated.

`__init__` (*engine*)  
 Initialize a `CustomUncompute` context.

**Parameters** `engine` (`BasicEngine`) – Engine which is the first to receive all commands (normally: `MainEngine`).

**class** `projectq.meta.Dagger` (*engine*)  
 Invert an entire code block.

Use it with a `with`-statement, i.e.,

```
with Dagger(eng):
    [code to invert]
```

**Warning:** If the code to invert contains allocation of qubits, those qubits have to be deleted prior to exiting the ‘`with Dagger()`’ context.

This code is **NOT VALID**:

```
with Dagger(eng):
    qb = eng.allocate_qubit()
    H | qb # qb is still available!!!
```

The **correct way** of handling qubit (de-)allocation is as follows:

```
with Dagger(eng):
    qb = eng.allocate_qubit()
    ...
    del qb # sends deallocate gate (which becomes an allocate)
```

`__init__` (*engine*)  
 Enter an inverted section.

**Parameters** `engine` – Engine which handles the commands (usually `MainEngine`)

Example (executes an inverse QFT):

```
with Dagger(eng):
    QFT | qubits
```

**class** `projectq.meta.DirtyQubitTag`  
 Dirty qubit meta tag

**class** `projectq.meta.Loop(engine, num)`  
 Loop `n` times over an entire code block.

### Example

```
with Loop(eng, 4):
    # [quantum gates to be executed 4 times]
```

**Warning:** If the code in the loop contains allocation of qubits, those qubits have to be deleted prior to exiting the ‘with Loop()’ context.

This code is **NOT VALID**:

```
with Loop(eng, 4):
    qb = eng.allocate_qubit()
    H | qb # qb is still available!!!
```

The **correct way** of handling qubit (de-)allocation is as follows:

```
with Loop(eng, 4):
    qb = eng.allocate_qubit()
    ...
    del qb # sends deallocate gate
```

`__init__(engine, num)`  
 Enter a looped section.

#### Parameters

- **engine** – Engine handling the commands (usually MainEngine)
- **num** (*int*) – Number of loop iterations

### Example

```
with Loop(eng, 4):
    H | qb
    Rz(M_PI/3.) | qb
```

#### Raises

- `TypeError` – If number of iterations (`num`) is not an integer
- `ValueError` – If number of iterations (`num`) is not  $\geq 0$

**class** `projectq.meta.LoopTag(num)`  
 Loop meta tag

`__init__(num)`

`loop_tag_id = 0`

**class** `projectq.meta.QubitPlacementTag(position)`  
 Qubit placement meta tag

`__init__(position)`

`projectq.meta.Uncompute` (*engine*)  
Uncompute automatically.

### Example

```
with Compute(eng) :  
    do_something(qubits)  
action(qubits)  
Uncompute(eng) # runs inverse of the compute section
```

`class projectq.meta.UncomputeTag`  
Uncompute meta tag.

`projectq.meta.drop_engine_after` (*prev\_engine*)  
Removes an engine from the singly-linked list of engines.

**Parameters** `prev_engine` (`projectq.cengines.BasicEngine`) – The engine just before the engine to drop.

**Returns** The dropped engine.

**Return type** Engine

`projectq.meta.get_control_count` (*cmd*)  
Return the number of control qubits of the command object *cmd*

`projectq.meta.insert_engine` (*prev\_engine*, *engine\_to\_insert*)  
Inserts an engine into the singly-linked list of engines.

It also sets the correct `main_engine` for *engine\_to\_insert*.

#### Parameters

- **prev\_engine** (`projectq.cengines.BasicEngine`) – The engine just before the insertion point.
- **engine\_to\_insert** (`projectq.cengines.BasicEngine`) – The engine to insert at the insertion point.

## ops

The operations collection consists of various default gates and is a work-in-progress, as users start to work with ProjectQ.

### Module contents

`projectq.ops.All`  
alias of *Tensor*

`class projectq.ops.AllocateDirtyQubitGate`  
Dirty qubit allocation gate class

`class projectq.ops.AllocateQubitGate`  
Qubit allocation gate class

`class projectq.ops.BasicGate`  
Base class of all gates.

`__init__()`

Initialize a basic gate.

**Note:** Set interchangeable qubit indices! (`gate.interchangeable_qubit_indices`)

As an example, consider

```
ExampleGate | (a,b,c,d,e)
```

where a and b are interchangeable. Then, call this function as follows:

```
self.set_interchangeable_qubit_indices([[0,1]])
```

As another example, consider

```
ExampleGate2 | (a,b,c,d,e)
```

where a and b are interchangeable and, in addition, c, d, and e are interchangeable among themselves. Then, call this function as

```
self.set_interchangeable_qubit_indices([[0,1],[2,3,4]])
```

`__or__(qubits)`

Operator| overload which enables the syntax `Gate | qubits`.

### Example

1. `Gate | qubit`
2. `Gate | [qubit0, qubit1]`
3. `Gate | qureg`
4. `Gate | (qubit, )`
5. `Gate | (qureg, qubit)`

**Parameters** `qubits` – a Qubit object, a list of Qubit objects, a Qureg object, or a tuple of Qubit or Qureg objects (can be mixed).

`generate_command(qubits)`

Helper function to generate a command consisting of the gate and the qubits being acted upon.

**Parameters** `qubits` – see `BasicGate.make_tuple_of_qureg(qubits)`

**Returns** A Command object containing the gate and the qubits.

`get_inverse()`

Return the inverse gate.

Standard implementation of `get_inverse`:

**Raises** `NotInvertible` – inverse is not implemented

`get_merged(OTHER)`

Return this gate merged with another gate.

Standard implementation of `get_merged`:

**Raises** *NotMergeable* – merging is not implemented

**static** `make_tuple_of_quireg` (*qubits*)

Convert quantum input of “gate | quantum input” to internal formatting.

A Command object only accepts tuples of Quregs (list of Qubit objects) as qubits input parameter. However, with this function we allow the user to use a more flexible syntax:

1. Gate | qubit
2. Gate | [qubit0, qubit1]
3. Gate | qureg
4. Gate | (qubit, )
5. Gate | (quireg, qubit)

where qubit is a Qubit object and qureg is a Qureg object. This function takes the right hand side of | and transforms it to the correct input parameter of a Command object which is:

- 1.-> Gate | ([qubit], )
- 2.-> Gate | ([qubit0, qubit1], )
- 3.-> Gate | (quireg, )
- 4.-> Gate | ([qubit], )
- 5.-> Gate | (quireg, [qubit])

**Parameters** `qubits` – a Qubit object, a list of Qubit objects, a Qureg object, or a tuple of Qubit or Qureg objects (can be mixed).

**Returns** A tuple containing Qureg (or list of Qubits) objects.

**Return type** Canonical representation (tuple<quireg>)

**class** `projectq.ops.BasicMathGate` (*math\_fun*)

Base class for all math gates.

It allows efficient emulation by providing a mathematical representation which is given by the concrete gate which derives from this base class. The AddConstant gate, for example, registers a function of the form

```
def add(x):
    return (x+a,)
```

upon initialization. More generally, the function takes integers as parameters and returns a tuple / list of outputs, each entry corresponding to the function input. As an example, consider out-of-place multiplication, which takes two input registers and adds the result into a third, i.e., (a,b,c) -> (a,b,c+a\*b). The corresponding function then is

```
def multiply(a,b,c)
    return (a,b,c+a*b)
```

`__init__` (*math\_fun*)

Initialize a BasicMathGate by providing the mathematical function that it implements.

**Parameters** `math_fun` (*function*) – Function which takes as many int values as input, as the gate takes registers. For each of these values, it then returns the output (i.e., it returns a list/tuple of output values).



### Example

```
def add(a,b):
    return (a,a+b)
BasicMathGate.__init__(self, add)
```

If the gate acts on, e.g., fixed point numbers, the number of bits per register is also required in order to describe the action of such a mathematical gate. For this reason, there is

```
BasicMathGate.get_math_function(qubits)
```

which can be overwritten by the gate deriving from BasicMathGate.

### Example

```
def get_math_function(self, qubits):
    n = len(qubits[0])
    scal = 2.**n
    def math_fun(a):
        return (int(scal * (math.sin(math.pi * a / scal))),)
    return math_fun
```

#### `get_math_function` (*qubits*)

Return the math function which corresponds to the action of this math gate, given the input to the gate (a tuple of quantum registers).

**Parameters** `qubits` (*tuple*<Qureg>) – Qubits to which the math gate is being applied.

**Returns** Python function describing the action of this gate. (See BasicMathGate.\_\_init\_\_ for an example).

**Return type** `math_fun` (function)

#### `class` projectq.ops.**BasicPhaseGate** (*angle*)

Defines a base class of a phase gate.

A phase gate has a continuous parameter (the angle), labeled ‘angle’ / `self._angle`. Its inverse is the same gate with the negated argument. Phase gates of the same class can be merged by adding the angles. The continuous parameter is modulo  $2 * \pi$ , `self._angle` is in the interval  $[0, 2 * \pi)$ .

#### `__init__` (*angle*)

Initialize a basic rotation gate.

**Parameters** `angle` (*float*) – Angle of rotation (saved modulo  $2 * \pi$ )

#### `get_inverse` ()

Return the inverse of this rotation gate (negate the angle, return new object).

#### `get_merged` (*other*)

Return self merged with another gate.

Default implementation handles rotation gate of the same type, where angles are simply added.

**Parameters** `other` – Rotation gate of same type.

**Raises** `NotMergeable` – For non-rotation gates or rotation gates of different type.

**Returns** New object representing the merged gates.

**tex\_str()**

Return the Latex string representation of a BasicRotationGate.

Returns the class name and the angle as a subscript, i.e.

```
[CLASSNAME] $_{[ANGLE]} $
```

**class** projectq.ops.**BasicRotationGate**(*angle*)

Defines a base class of a rotation gate.

A rotation gate has a continuous parameter (the angle), labeled 'angle' / self.\_angle. Its inverse is the same gate with the negated argument. Rotation gates of the same class can be merged by adding the angles. The continuous parameter is modulo  $4 * \pi$ , self.\_angle is in the interval  $[0, 4 * \pi)$ .

**\_\_init\_\_**(*angle*)

Initialize a basic rotation gate.

**Parameters** *angle* (*float*) – Angle of rotation (saved modulo  $4 * \pi$ )

**get\_inverse**()

Return the inverse of this rotation gate (negate the angle, return new object).

**get\_merged**(*other*)

Return self merged with another gate.

Default implementation handles rotation gate of the same type, where angles are simply added.

**Parameters** *other* – Rotation gate of same type.

**Raises** *NotMergeable* – For non-rotation gates or rotation gates of different type.

**Returns** New object representing the merged gates.

**tex\_str**()

Return the Latex string representation of a BasicRotationGate.

Returns the class name and the angle as a subscript, i.e.

```
[CLASSNAME] $_{[ANGLE]} $
```

projectq.ops.**C**(*gate*, *n=1*)

Return n-controlled version of the provided gate.

**Parameters**

- **gate** – Gate to turn into its controlled version
- **n** – Number of controls (default: 1)

### Example

```
C(NOT) | (c, q) # equivalent to CNOT | (c, q)
```

**class** projectq.ops.**ClassicalInstructionGate**

Classical instruction gate.

Base class for all gates which are not quantum gates in the typical sense, e.g., measurement, allocation/deallocation, ...

**class** projectq.ops.**Command**(*engine*, *gate*, *qubits*, *controls=()*, *tags=()*)

Class used as a container to store commands. If a gate is applied to qubits, then the gate and qubits are saved in

a command object. Qubits are copied into WeakQubitRefs in order to allow early deallocation (would be kept alive otherwise). WeakQubitRef qubits don't send deallocate gate when destructed.

**gate**

The gate to execute

**qubits**

Tuple of qubit lists (e.g. Quregs). Interchangeable qubits are stored in a unique order

**control\_qubits**

The Qureg of control qubits in a unique order

**engine**

The engine (usually: MainEngine)

**tags**

The list of tag objects associated with this command (e.g., ComputeTag, UncomputeTag, LoopTag, ...). tag objects need to support ==, != (`__eq__` and `__ne__`) for comparison as used in e.g. TagRemover. New tags should always be added to the end of the list. This means that if there are e.g. two LoopTags in a command, tag[0] is from the inner scope while tag[1] is from the other scope as the other scope receives the command after the inner scope LoopEngine and hence adds its LoopTag to the end.

**all\_qubits**

A tuple of control\_qubits + qubits

`__init__` (*engine, gate, qubits, controls=(), tags=()*)

Initialize a Command object.

---

**Note:** control qubits (Command.control\_qubits) are stored as a list of qubits, and command tags (Command.tags) as a list of tag-objects. All functions within this class also work if WeakQubitRefs are supplied instead of normal Qubit objects (see WeakQubitRef).

---

**Parameters**

- **engine** (`projectq.engines.BasicEngine`) – engine which created the qubit (mostly the MainEngine)
- **gate** (`projectq.ops.Gate`) – Gate to be executed
- **qubits** (`tuple[Qureg]`) – Tuple of quantum registers (to which the gate is applied)
- **controls** (`Qureg/list[Qubit]`) – Qubits that condition the command.
- **tags** (`list[object]`) – Tags associated with the command.

**add\_control\_qubits** (*qubits*)

Add (additional) control qubits to this command object.

They are sorted to ensure a canonical order. Also Qubit objects are converted to WeakQubitRef objects to allow garbage collection and thus early deallocation of qubits.

**Parameters** *qubits* (*list of Qubit objects*) – List of qubits which control this gate, i.e., the gate is only executed if all qubits are in state 1.

**all\_qubits**

Get all qubits (gate and control qubits).

Returns a tuple T where T[0] is a quantum register (a list of WeakQubitRef objects) containing the control qubits and T[1:] contains the quantum registers to which the gate is applied.

**control\_qubits**

Returns Qureg of control qubits.

**engine**

Return engine to which the qubits belong / on which the gates are executed.

**get\_inverse()**

Get the command object corresponding to the inverse of this command.

Inverts the gate (if possible) and creates a new command object from the result.

**Raises** *NotInvertible* – If the gate does not provide an inverse (see BasicGate.get\_inverse)

**get\_merged(other)**

Merge this command with another one and return the merged command object.

**Parameters** *other* – Other command to merge with this one (self)

**Raises** *NotMergeable* – if the gates don't supply a get\_merged()-function or can't be merged for other reasons.

**interchangeable\_qubit\_indices**

Return nested list of qubit indices which are interchangeable.

Certain qubits can be interchanged (e.g., the qubit order for a Swap gate). To ensure that only those are sorted when determining the ordering (see `_order_qubits`), `self.interchangeable_qubit_indices` is used. .. rubric:: Example

If we can interchange qubits 0,1 and qubits 3,4,5, then this function returns `[[0,1],[3,4,5]]`

**class** `projectq.ops.ControlledGate(gate, n=1)`

Controlled version of a gate.

---

**Note:** Use the meta function `C()` to create a controlled gate

---

A wrapper class which enables (multi-) controlled gates. It overloads the `__or__`-operator, using the first qubits provided as control qubits. The `n` control-qubits need to be the first `n` qubits. They can be in separate quregs.

**Example**

```
ControlledGate(gate, 2) | (qb0, qb2, qb3) # qb0 & qb2 are controls
C(gate, 2) | (qb0, qb2, qb3) # This is much nicer.
C(gate, 2) | ([qb0, qb2], qb3) # Is equivalent
```

---

**Note:** Use `C()` rather than `ControlledGate`, i.e.,

```
C(X, 2) == Toffoli
```

---

**\_\_init\_\_(gate, n=1)**

Initialize a ControlledGate object.

**Parameters**

- **gate** – Gate to wrap.
- **n** (*int*) – Number of control qubits.

`__or__` (*qubits*)

Apply the controlled gate to qubits, using the first n qubits as controls.

**Note: The control qubits can be split across the first quregs.** However, the n-th control qubit needs to be the last qubit in a qureg. The following quregs belong to the gate.

**Parameters** `qubits` (*tuple of lists of Qubit objects*) – qubits to which to apply the gate.

`get_inverse` ()

Return inverse of a controlled gate, which is the controlled inverse gate.

**class** `projectq.ops.DaggeredGate` (*gate*)

Wrapper class allowing to execute the inverse of a gate, even when it does not define one.

If there is a replacement available, then there is also one for the inverse, namely the replacement function run in reverse, while inverting all gates. This class enables using this emulation automatically.

A `DaggeredGate` is returned automatically when employing the `get_inverse`-function on a gate which does not provide a `get_inverse`() member function.

### Example

```
with Dagger(eng) :
    MySpecialGate | qubits
```

will create a `DaggeredGate` if `MySpecialGate` does not implement `get_inverse`. If there is a decomposition function available, an auto-replacer engine can automatically replace the inverted gate by a call to the decomposition function inside a “with Dagger”-statement.

`__init__` (*gate*)

Initialize a `DaggeredGate` representing the inverse of the gate ‘gate’.

**Parameters** `gate` – Any gate object of which to represent the inverse.

`get_inverse` ()

Return the inverse gate (the inverse of the inverse of a gate is the gate itself).

`tex_str` ()

Return the Latex string representation of a `Daggered` gate.

**class** `projectq.ops.DeallocateQubitGate`

Qubit deallocation gate class

**class** `projectq.ops.EntangleGate`

Entangle gate (Hadamard on first qubit, followed by CNOTs applied to all other qubits).

**class** `projectq.ops.FastForwardingGate`

Base class for classical instruction gates which require a fast-forward through compiler engines that cache / buffer gates. Examples include `Measure` and `Deallocate`, which both should be executed asap, such that `Measure` results are available and resources are freed, respectively.

---

**Note:** The only requirement is that `FlushGate` commands run the entire circuit. `FastForwardingGate` objects can be used but the user cannot expect a measurement result to be available for all back-ends when calling only `Measure`. E.g., for the IBM Quantum Experience back-end, sending the circuit for each `Measure`-gate would be too inefficient, which is why a final

is required before the circuit gets sent through the API.

---

**class** `projectq.ops.FlushGate`  
Flush gate (denotes the end of the circuit).

---

**Note:** All compiler engines (engines) which cache/buffer gates are obligated to flush and send all gates to the next compiler engine (followed by the flush command).

---

**Note:** This gate is sent when calling

```
eng.flush()
```

on the MainEngine *eng*.

---

**class** `projectq.ops.HGate`  
Hadamard gate class

**class** `projectq.ops.MeasureGate`  
Measurement gate class

**exception** `projectq.ops.NotInvertible`  
Exception thrown when trying to invert a gate which is not invertable (or where the inverse is not implemented (yet)).

**exception** `projectq.ops.NotMergeable`  
Exception thrown when trying to merge two gates which are not mergeable (or where it is not implemented (yet)).

**class** `projectq.ops.Ph` (*angle*)  
Phase gate (global phase)

**class** `projectq.ops.QubitOperator` (*term=None, coefficient=1.0*)  
A sum of terms acting on qubits, e.g.,  $0.5 * 'X0 X5' + 0.3 * 'Z1 Z2'$ .

A term is an operator acting on n qubits and can be represented as:

`coefficient * local_operator[0] x ... x local_operator[n-1]`

where x is the tensor product. A local operator is a Pauli operator ('I', 'X', 'Y', or 'Z') which acts on one qubit. In math notation a term is, for example,  $0.5 * 'X0 X5'$ , which means that a Pauli X operator acts on qubit 0 and 5, while the identity operator acts on all other qubits.

A QubitOperator represents a sum of terms acting on qubits and overloads operations for easy manipulation of these objects by the user.

Note for a QubitOperator to be a Hamiltonian which is a hermitian operator, the coefficients of all terms must be real.

```
hamiltonian = 0.5 * QubitOperator('X0 X5') + 0.3 * QubitOperator('Z0')
```

#### terms

*dict* – **key:** A term represented by a tuple containing all non-trivial local Pauli operators ('X', 'Y', or 'Z'). A non-trivial local Pauli operator is specified by a tuple with the first element being an integer indicating the qubit on which a non-trivial local operator acts and the second element being a string, either 'X', 'Y', or 'Z', indicating which non-trivial Pauli operator acts on that qubit. Examples: ((1, 'X'),) or ((1, 'X'), (4, 'Z')) or the identity (). The tuples representing the non-trivial local terms are sorted according to the qubit number they act on, starting from 0. **value:** Coefficient of this term as a (complex) float

`__init__` (*term=None, coefficient=1.0*)

Initiates a QubitOperator.

The `init` function only allows to initialize one term. Additional terms have to be added using `+=` (which is fast) or using `+` of two QubitOperator objects:

### Example

```
ham = ((QubitOperator('X0 Y3', 0.5)
        + 0.6 * QubitOperator('X0 Y3'))
        # Equivalently
        ham2 = QubitOperator('X0 Y3', 0.5)
        ham2 += 0.6 * QubitOperator('X0 Y3')
```

**Note:** Adding terms to QubitOperator is faster using `+=` (as this is done by in-place addition). Specifying the coefficient in the `__init__` is faster than by multiplying a QubitOperator with a scalar as calls an out-of-place multiplication.

### Parameters

- **coefficient** (*complex float, optional*) – The coefficient of the first term of this QubitOperator. Default is 1.0.
- **term** (*optional, empty tuple, a tuple of tuples, or a string*) –
  1. Default is None which means there are no terms in the QubitOperator hence it is the “zero” Operator
  2. An empty tuple means there are no non-trivial Pauli operators acting on the qubits hence only identities with a coefficient (which by default is 1.0).
  3. A sorted tuple of tuples. The first element of each tuple is an integer indicating the qubit on which a non-trivial local operator acts, starting from zero. The second element of each tuple is a string, either ‘X’, ‘Y’ or ‘Z’, indicating which local operator acts on that qubit.
  4. A string of the form ‘X0 Z2 Y5’, indicating an X on qubit 0, Z on qubit 2, and Y on qubit 5. The string should be sorted by the qubit number. ‘’ is the identity.

**Raises** QubitOperatorError – Invalid operators provided to QubitOperator.

`compress` (*abs\_tol=1e-12*)

Eliminates all terms with coefficients close to zero and removes imaginary parts of coefficients that are close to zero.

**Parameters** `abs_tol` (*float*) – Absolute tolerance, must be at least 0.0

`isclose` (*other, rel\_tol=1e-12, abs\_tol=1e-12*)

Returns True if `other` (QubitOperator) is close to self.

Comparison is done for each term individually. Return True if the difference between each term in self and other is less than the relative tolerance w.r.t. either other or self (symmetric test) or if the difference is less than the absolute tolerance.

### Parameters

- **other** (QubitOperator) – QubitOperator to compare against.

- `rel_tol` (*float*) – Relative tolerance, must be greater than 0.0
- `abs_tol` (*float*) – Absolute tolerance, must be at least 0.0

**class** `projectq.ops.R` (*angle*)  
Phase-shift gate (equivalent to Rz up to a global phase)

**class** `projectq.ops.Rx` (*angle*)  
RotationX gate class

**class** `projectq.ops.Ry` (*angle*)  
RotationX gate class

**class** `projectq.ops.Rz` (*angle*)  
RotationZ gate class

**class** `projectq.ops.SGate`  
S gate class

**class** `projectq.ops.SelfInverseGate`  
Self-inverse basic gate class.  
  
Automatic implementation of the `get_inverse`-member function for self- inverse gates.

### Example

```
# get_inverse(H) == H, it is a self-inverse gate:  
get_inverse(H) | qubit
```

**class** `projectq.ops.SwapGate`  
Swap gate class (swaps 2 qubits)

**class** `projectq.ops.TGate`  
T gate class

**class** `projectq.ops.Tensor` (*gate*)  
Wrapper class allowing to apply a (single-qubit) gate to every qubit in a quantum register. Allowed syntax is to supply either a qureg or a tuple which contains only one qureg.

### Example

```
Tensor(H) | x # applies H to every qubit in the list of qubits x  
Tensor(H) | (x,) # alternative to be consistent with other syntax
```

`__init__` (*gate*)  
Initialize a Tensor object for the gate.

`__or__` (*qubits*)  
Applies the gate to every qubit in the quantum register qubits.

`get_inverse` ()  
Return the inverse of this tensored gate (which is the tensored inverse of the gate).

**class** `projectq.ops.TimeEvolution` (*time, hamiltonian*)  
Gate for time evolution under a Hamiltonian (QubitOperator object).

This gate is the unitary time evolution propagator:  $\exp(-i * H * t)$ , where H is the Hamiltonian of the system and t is the time. Note that -i factor is stored implicitly.



## Example

```

wavefunction = eng.allocate_qureg(5)
hamiltonian = 0.5 * QubitOperator("X0 Z1 Y5")
# Apply exp(-i * H * t) to the wavefunction:
TimeEvolution(time=2.0, hamiltonian=hamiltonian) | wavefunction

```

### time

*float, int* – time  $t$

### hamiltonian

*QubitOperator* – hamiltonian  $H$

`__init__` (*time, hamiltonian*)

Initialize time evolution gate.

---

**Note:** The hamiltonian must be hermitian and therefore only terms with real coefficients are allowed. Coefficients are internally converted to float.

---

### Parameters

- **time** (*float, or int*) – time to evolve under (can be negative).
- **hamiltonian** (*QubitOperator*) – hamiltonian to evolve under.

### Raises

- `TypeError` – If time is not a numeric type and hamiltonian is not a `QubitOperator`.
- `NotHermitianOperatorError` – If the input hamiltonian is not hermitian (only real coefficients).

`__or__` (*qubits*)

Operator| overload which enables the following syntax:

```

TimeEvolution(...) | qureg
TimeEvolution(...) | (qureg,)
TimeEvolution(...) | qubit
TimeEvolution(...) | (qubit,)

```

Unlike other gates, this gate is only allowed to be applied to one quantum register or one qubit.

Example:

```

wavefunction = eng.allocate_qureg(5)
hamiltonian = QubitOperator("X1 Y3", 0.5)
TimeEvolution(time=2.0, hamiltonian=hamiltonian) | wavefunction

```

While in the above example the `TimeEvolution` gate is applied to 5 qubits, the hamiltonian of this `TimeEvolution` gate acts only non-trivially on the two qubits `wavefunction[1]` and `wavefunction[3]`. Therefore, the operator| will rescale the indices in the hamiltonian and sends the equivalent of the following new gate to the MainEngine:

```

h = QubitOperator("X0 Y1", 0.5)
TimeEvolution(2.0, h) | [wavefunction[1], wavefunction[3]]

```

which is only a two qubit gate.

**Parameters** `qubits` – one Qubit object, one list of Qubit objects, one Qureg object, or a tuple of the former three cases.

`get_inverse()`

Return the inverse gate.

`get_merged(other)`

Return self merged with another TimeEvolution gate if possible.

**Two TimeEvolution gates are merged if:**

1. both have the same terms
2. the proportionality factor for each of the terms must have relative error  $\leq 1e-9$  compared to the proportionality factors of the other terms.

---

**Note:** While one could merge gates for which both hamiltonians commute, we are not doing this as in general the resulting gate would have to be decomposed again.

---

---

**Note:** We are not comparing if terms are proportional to each other with an absolute tolerance. It is up to the user to remove terms close to zero because we cannot choose a suitable absolute error which works for everyone. Use, e.g., a decomposition rule for that.

---

**Parameters** `other` – TimeEvolution gate

**Raises** `NotMergeable` – If the other gate is not a TimeEvolution gate or hamiltonians are not suitable for merging.

**Returns** New TimeEvolution gate equivalent to the two merged gates.

`class projectq.ops.XGate`

Pauli-X gate class

`class projectq.ops.YGate`

Pauli-Y gate class

`class projectq.ops.ZGate`

Pauli-Z gate class

`projectq.ops.apply_command(cmd)`

Apply a command.

Extracts the qubits-owning (target) engine from the Command object and sends the Command to it.

**Parameters** `cmd` (`Command`) – Command to apply

`projectq.ops.get_inverse(gate)`

Return the inverse of a gate.

Tries to call `gate.get_inverse` and, upon failure, creates a `DaggeredGate` instead.

**Parameters** `gate` – Gate of which to get the inverse

## Example

```
get_inverse(H) # returns a Hadamard gate (HGate object)
```

## setups

The setups package contains a collection of setups which can be loaded using an import statement. Each setup then loads its own set of decomposition rules and default compiler engines.

### Subpackages

#### decompositions

The decomposition package is a collection of gate decomposition / replacement rules which can be used by, e.g., the AutoReplacer engine.

#### Submodules

##### `projectq.setups.decompositions.crz2cxandrz` module

Registers a decomposition for controlled z-rotation gates.

It uses 2 z-rotations and 2 C<sup>n</sup> NOT gates to achieve this gate.

##### `projectq.setups.decompositions.entangle` module

Registers a decomposition for the Entangle gate.

Applies a Hadamard gate to the first qubit and then, conditioned on this first qubit, CNOT gates to all others.

##### `projectq.setups.decompositions.globalphase` module

Registers a decomposition rule for global phases.

Deletes global phase gates (which can be ignored).

##### `projectq.setups.decompositions.ph2r` module

Registers a decomposition for the controlled global phase gate.

Turns the controlled global phase gate into a (controlled) phase-shift gate. Each time this rule is applied, one control can be shaved off.

##### `projectq.setups.decompositions.qft2crandhadamard` module

Registers a decomposition rule for the quantum Fourier transform.

Decomposes the QFT gate into Hadamard and controlled phase-shift gates (R).

<b>Warning:</b> The final Swaps are not included, as those are simply a re-indexing of quantum registers.
---

### projectq.setups.decompositions.r2rzandph module

Registers a decomposition rule for the phase-shift gate.

Decomposes the (controlled) phase-shift gate using z-rotation and a global phase gate.

### projectq.setups.decompositions.swap2cnot module

Registers a decomposition to achieve a Swap gate.

Decomposes a Swap gate using 3 CNOT gates, where the one in the middle features as many control qubits as the Swap gate has control qubits.

### projectq.setups.decompositions.toffoli2cnotandtgate module

Registers a decomposition rule for the Toffoli gate.

Decomposes the Toffoli gate using Hadamard, T, Tdag, and CNOT gates.

## Module contents

### ibm

The IBM Setup imports the default IBM decomposition rules, compiler engines (featuring a CNOTMapper), and the IBM backend (IBMBackend).

## Module contents

Registers a variety of useful gate decompositions, specifically for the IBM quantum experience backend. Among others it includes:

- Controlled z-rotations → Controlled NOTs and single-qubit rotations
- Toffoli gate → CNOT and single-qubit gates
- m-Controlled global phases → (m-1)-controlled phase-shifts
- Global phases → ignore
- (controlled) Swap gates → CNOTs and Toffolis

**class** `projectq.setups.ibm.AutoReplacer` (*decompositionRuleSet*, *decomposition\_chooser*=<function AutoReplacer.<lambda>>)

The AutoReplacer is a compiler engine which uses `engine.is_available` in order to determine which commands need to be replaced/decomposed/compiled further. The loaded setup is used to find decomposition rules appropriate for each command (e.g., `setups.default`).

**\_\_init\_\_** (*decompositionRuleSet*, *decomposition\_chooser*=<function AutoReplacer.<lambda>>)  
Initialize an AutoReplacer.

**Parameters** `decomposition_chooser` (*function*) – A function which, given the Command to decompose and a list of potential Decomposition objects, determines (and then returns) the ‘best’ decomposition.

The default decomposition chooser simply returns the first list element, i.e., calling

```
repl = AutoReplacer()
```

Amounts to

```
def decomposition_chooser(cmd, decomp_list):
    return decomp_list[0]
repl = AutoReplacer(decomposition_chooser)
```

**receive** (*command\_list*)

Receive a list of commands from the previous compiler engine and, if necessary, replace/decompose the gates according to the decomposition rules in the loaded setup.

**Parameters** **command\_list** (*list*<*Command*>) – List of commands to handle.

**class** `projectq.setups.ibm.DecompositionRuleSet` (*rules=None, modules=None*)

A collection of indexed decomposition rules.

**\_\_init\_\_** (*rules=None, modules=None*)

**Parameters**

- **list** [**DecompositionRule**] (*rules*) – Initial decomposition rules.
- **modules** (*iterable* [*ModuleWithDecompositionRuleSet*]) – A list of things with an “all\_defined\_decomposition\_rules” property containing decomposition rules to add to the rule set.

**add\_decomposition\_rule** (*rule*)

Add a decomposition rule to the rule set.

**Parameters** **rule** (*DecompositionRuleGate*) – The decomposition rule to add.

**class** `projectq.setups.ibm.IBMCNOTMapper`

CNOT mapper for the IBM backend.

Maps a given circuit to the IBM Quantum Experience chip. If necessary, it will flip around the CNOT gate by first applying Hadamard gates to both qubits, then CNOT with swapped control and target qubit, and finally Hadamard gates to both qubits. Furthermore, it adds QubitPlacementTags to Allocate gate commands.

---

**Note:** The mapper has to be run once on the entire circuit.

---

**Warning:** If the provided circuit cannot be mapped to the hardware layout without performing Swaps, the mapping procedure **raises an Exception**.

**\_\_init\_\_** ()

Initialize an IBM CNOT Mapper compiler engine.

Resets the mapping.

**is\_available** (*cmd*)

Check if the IBM backend can perform the Command *cmd* and return True if so.

**Parameters** **cmd** (*Command*) – The command to check

**receive** (*command\_list*)

Receives a command list and, for each command, stores it until completion.

**Parameters** **command\_list** (*list of Command objects*) – list of commands to receive.

**Raises** `Exception` – If mapping the CNOT gates to 1 qubit would require Swaps. The current version only supports remapping of CNOT gates without performing any Swaps due to the large costs associated with Swapping given the CNOT constraints.

**class** `projectq.setups.ibm.LocalOptimizer` ( $m=5$ )

`LocalOptimizer` is a compiler engine which optimizes locally (merging rotations, cancelling gates with their inverse) in a local window of user- defined size.

It stores all commands in a list of lists, where each qubit has its own gate pipeline. After adding a gate, it tries to merge / cancel successive gates using the `get_merged` and `get_inverse` functions of the gate (if available). For examples, see `BasicRotationGate`. Once a list corresponding to a qubit contains  $\geq m$  gates, the pipeline is sent on to the next engine.

`__init__` ( $m=5$ )

Initialize a `LocalOptimizer` object.

**Parameters** `m` (*int*) – Number of gates to cache per qubit, before sending on the first gate.

**receive** (*command\_list*)

Receive commands from the previous engine and cache them. If a flush gate arrives, the entire buffer is sent on.

**class** `projectq.setups.ibm.TagRemover` ( $tags=[<class \text{ 'projectq.meta._compute.ComputeTag'>, <class \text{ 'projectq.meta._compute.UncomputeTag'>}]$ )

`TagRemover` is a compiler engine which removes temporary command tags (see the tag classes such as `LoopTag` in `projectq.meta._loop`).

Removing tags is important (after having handled them if necessary) in order to enable optimizations across meta-function boundaries (compute/ action/uncompute or loops after unrolling)

`__init__` ( $tags=[<class \text{ 'projectq.meta._compute.ComputeTag'>, <class \text{ 'projectq.meta._compute.UncomputeTag'>}]$ )

Construct the `TagRemover`.

**Parameters** `tags` – A list of meta tag classes (e.g., [`ComputeTag`, `UncomputeTag`]) denoting the tags to remove

**receive** (*command\_list*)

Receive a list of commands from the previous engine, remove all tags which are an instance of at least one of the meta tags provided in the constructor, and then send them on to the next compiler engine.

**Parameters** `command_list` (*list*`<Command>`) – List of commands to receive and then (after removing tags) send on.

## Submodules

### default module

The default module features a standard set of decomposition rules, compiler engines, and the simulator backend. Registers a variety of useful gate decompositions. Among others it includes

- Controlled z-rotations → Controlled NOTs and single-qubit rotations
- Toffoli gate → CNOT and single-qubit gates
- m-Controlled global phases → (m-1)-controlled phase-shifts
- Global phases → ignore
- (controlled) Swap gates → CNOTs and Toffolis

## Module contents

### types

The types package contains quantum types such as Qubit, Qureg, and WeakQubitRef. With further development of the math library, also quantum integers, quantum fixed point numbers etc. will be added.

## Module contents

**class** `projectq.types.BasicQubit` (*engine, idx*)

BasicQubit objects represent qubits.

They have an id and a reference to the owning engine.

`__bool__` ()

Access the result of a previous measurement and return False / True (0 / 1)

`__eq__` (*other*)

Compare with other qubit (Returns True if equal id and engine).

**Parameters** *other* (`BasicQubit`) – BasicQubit to which to compare this one

`__hash__` ()

Return the hash of this qubit.

Hash definition because of custom `__eq__`. Enables storing a qubit in, e.g., a set.

`__init__` (*engine, idx*)

Initialize a BasicQubit object.

#### Parameters

- **engine** – Owing engine / engine that created the qubit
- **idx** – Unique index of the qubit referenced by this qubit

`__int__` ()

Access the result of a previous measurement and return as integer (0 / 1).

`__nonzero__` ()

Access the result of a previous measurement for Python 2.7.

`__str__` ()

Return string representation of this qubit.

`__weakref__`

list of weak references to the object (if defined)

**class** `projectq.types.Qubit` (*engine, idx*)

Qubit class.

Represents a (logical-level) qubit with a unique index provided by the MainEngine. Once the qubit goes out of scope (and is garbage-collected), it deallocates itself automatically, allowing automatic resource management.

Thus the qubit is not copyable; only returns a reference to the same object.

`__copy__` ()

Non-copyable (returns reference to self).

---

**Note:** To prevent problems with automatic deallocation, qubits are not copyable!

---

`__deepcopy__` (*memo*)  
Non-deepcopyable (returns reference to self).

---

**Note:** To prevent problems with automatic deallocation, qubits are not deepcopyable!

---

`__del__` ()  
Destroy the qubit and deallocate it (automatically).

**class** `projectq.types.Qureg`  
Quantum register class.

Simplifies accessing measured values for single-qubit registers (no []- access necessary) and enables pretty-printing of general quantum registers (call `Qureg.__str__(qureg)`).

`__bool__` ()  
Return measured value if Qureg consists of 1 qubit only.

**Raises**

- Exception if more than 1 qubit resides in this register (then you
- need to specify which value to get using `qureg[??]`)

`__int__` ()  
Return measured value if Qureg consists of 1 qubit only.

**Raises**

- Exception if more than 1 qubit resides in this register (then you
- need to specify which value to get using `qureg[??]`)

`__nonzero__` ()  
Return measured value if Qureg consists of 1 qubit only for Python 2.7.

**Raises**

- Exception if more than 1 qubit resides in this register (then you
- need to specify which value to get using `qureg[??]`)

`__str__` ()  
Get string representation of a quantum register.

`__weakref__`  
list of weak references to the object (if defined)

**engine**  
Return owning engine.

**class** `projectq.types.WeakQubitRef` (*engine, idx*)  
WeakQubitRef objects are used inside the Command object.

Qubits feature automatic deallocation when destroyed. WeakQubitRefs, on the other hand, do not share this feature, allowing to copy them and pass them along the compiler pipeline, while the actual qubit objects may be garbage-collected (and, thus, cleaned up early). Otherwise there is no difference between a WeakQubitRef and a Qubit object.



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