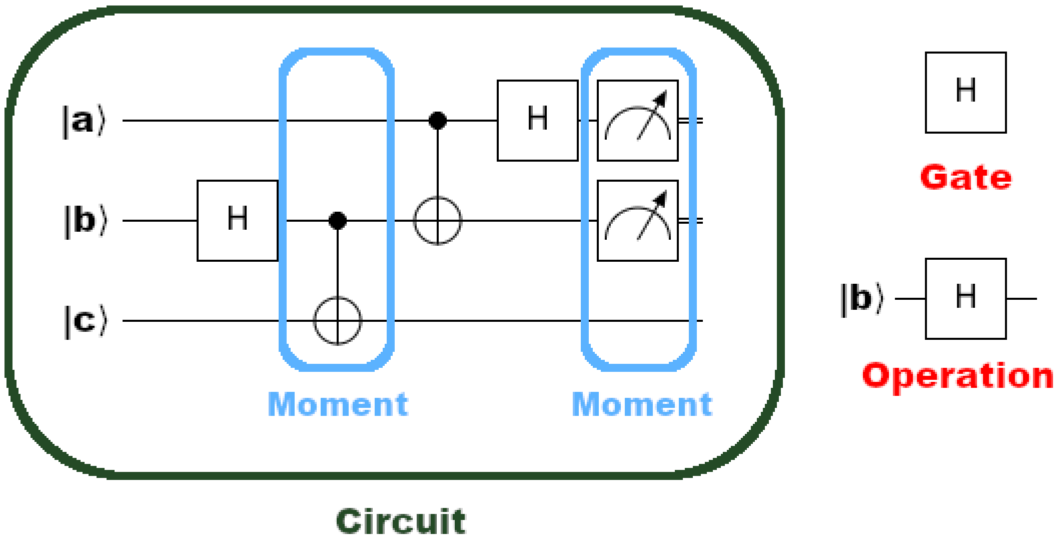
Gates and operations

[Run in Google Colab](https://colab.research.google.com/github/quantumlib/Cirq/blob/main/docs/build/gates.ipynb) (https://colab.research.google.com/github/quantumlib/Cirq/blob/main/docs/build/gates.ipynb) | View source on GitHub (https://github.com

```
try:
    import cirq
except ImportError:
    print("installing cirq...")
    !pip install --quiet cirq
    print("installed cirq.")
    import cirq
```

A `Gate` is an effect that can be applied to a collection of qubits (objects with a `Qid`). `Gates` can be applied to qubits by calling their `on` method, or, alternatively calling the gate on the qubits. The object created by such calls is an `Operation`. Alternatively, a `Gate` can be thought of as a factory (https://en.wikipedia.org/wiki/Factory_method_pattern) that, given input qubits, generates an associated `GateOperation` object.

Gates versus operations



The above example shows the first half of a quantum teleportation circuit, found in many quantum computation textbooks. This example uses three different gates: a Hadamard (H), controlled-Not (CNOT), and measurement. These are represented in cirq by `cirq.H`, `cirq.CNOT`, and `cirq.measure`, respectively.

In this example, a Hadamard is an example of a `Gate` object that can be applied in many different circumstances and to many different qubits. Note that the above example has two instances of an H gate but applied to different qubits. This is an example of one `Gate` type with two `Operation` instances, one applied to the qubit '|b⟩' and the other applied to qubit '|a⟩'.

Gates can generally be applied to any type of qubit (`NamedQubit`, `LineQubit`, `GridQubit`, etc. - see Qubits (/cirq/build/qubits) for more details) to create an Operation.

The following example shows how to construct each of these gates and operations.

```
# This examples uses named qubits to remain abstract.
# However, we can also use LineQubits or GridQubits to specify a geometry
a = cirq.NamedQubit('a')
b = cirq.NamedQubit('b')
c = cirq.NamedQubit('c')

# Example Operations, that correspond to the moments above
print(cirq.H(b))
print(cirq.CNOT(b, c))
print(cirq.CNOT(a, b))
print(cirq.H(a))
print(cirq.measure(a,b))
```

```
H(b)
CNOT(b, c)
CNOT(a, b)
H(a)
cirq.MeasurementGate(2, cirq.MeasurementKey(name='a,b'), ())(a, b)
```

This would create the operations needed to comprise the circuit from the above diagram. The next step would be composing these operations into moments and circuits. For more on those types, see the documentation on Circuits (/cirq/build/circuits).

Immutability of Gates and Operations

Gates and Operations in Cirq are considered to be immutable objects. This means that a `cirq.Gate` or `cirq.Operation` should not be modified after its creation. If attributes of these objects need to be modified, a new object should be created.

Modifying these objects in-place could cause unexpected behavior. For instance, changing the qubits of an existing `cirq.Operation` object could cause an existing `cirq.Moment` that contains this object to have operations with overlapping qubits.

Other gate features

Most `Gate`s operate on a specific number of qubits, which can be accessed by the `num_qubits()` function. One notable exception is the `MeasurementGate` which can be applied to a variable number of qubits.

Most gates also have a unitary matrix representation, which can be accessed by `cirq.unitary(gate)`.

Not all `Gate`s correspond to unitary evolution. They may represent a probabilistic mixture of unitaries, or a general quantum channel. The component unitaries and associated probabilities of a mixture can be accessed by `cirq.mixture(gate)`. The Kraus operator representation of a channel can be accessed by `cirq.kraus(gate)`. Non-unitary gates are often used in the simulation of noise. See noise documentation (https://quantumai.google/cirq/simulate/noisy_simulation) for more details.

Many arithmetic operators will work in the expected way when applied to gates. For instance, `cirq.X**0.5` represents a square root of X gate. These can also be applied to Operators for a more compact representation, such as `cirq.X(q1)**0.5` will be a square root of X gate applied to the q1 qubit. This functionality depends on the "magic methods" of the gate being defined (see below for details).

Gates can be converted to a controlled version by using `Gate.controlled()`. In general, this returns an instance of a `ControlledGate`. However, for certain special cases where the controlled version of the gate is also a known gate, this returns the instance of that gate. For instance, `cirq.X.controlled()` returns a `cirq.CNOT` gate. Operations have similar functionality `Operation.controlled_by()`, such as `cirq.X(q0).controlled_by(q1)`.

Common gates

Cirq supports a number of gates natively, with the opportunity to extend these gates for more advanced use cases.

Measurement gate

cirq.MeasurementGate This is a measurement in the computational basis. This gate can be applied to a variable number of qubits. The function `cirq.measure(q0, q1, ...)` can also be used as a short-hand to create a `MeasurementGate` .

Single qubit gates

Most single-qubit gates can be thought of as rotation around an axis in the Bloch Sphere (https://en.wikipedia.org/wiki/Bloch_sphere) representation and are usually referred to by their axis of rotation. Some operators use the notation of a 'half-turn' which is defined as a 180 degree (pi radians) rotation around the axis.

cirq.X / cirq.Y / cirq.Z The Pauli gates (https://en.wikipedia.org/wiki/Quantum_logic_gate#Pauli-X_gate) X, Y, and Z which rotate the state around the associated axis by one half-turn.

cirq.rx(rads) A rotation about the Pauli 'X' axis in terms of radians. This is equivalent to `exp(-i X rads / 2) = cos(rads/2) I - i sin(rads/2) X`

cirq.ry(rads) A rotation about the Pauli 'Y' axis in terms of radians. This is equivalent to `exp(-i Y rads / 2) = cos(rads/2) I - i sin(rads/2) Y`

cirq.rz(rads) A rotation about the Pauli 'Z' axis in terms of radians. This is equivalent to `exp(-i Z rads / 2) = cos(rads/2) I - i sin(rads/2) Z`

cirq.XPowGate(exponent=t) Rotations about the Pauli `X` axis, equivalent to `cirq.X**t`. See `cirq.XPowGate` for its unitary matrix. Note that this has a global phase of e^{i·π·t/2} versus the traditionally defined rotation matrix, which can be modified by the optional parameter `global_shift`.

cirq.YPowGate(exponent=t) Rotations about the Pauli `Y` axis, equivalent to `cirq.Y**t`. See `cirq.YPowGate` for its unitary matrix. Note that this has a global phase of e^{i·π·t/2} versus the traditionally defined rotation matrix, which can be modified by the optional parameter `global_shift`.

cirq.ZPowGate(exponent=t) Rotations about the Pauli `Z` axis, equivalent to `cirq.Z**t`. See `cirq.ZPowGate` for its unitary matrix. Note that this has a global phase of e^{i·π·t/2} versus the traditionally defined rotation matrix, which can be modified by the optional parameter `global_shift`.

cirq.PhasedXPowGate This gate is a rotation about an axis in the XY plane of the Bloch sphere. The `PhasedXPowGate` takes two parameters, `exponent` and `phase_exponent`. The gate is equivalent to the circuit ──`Z^-p`──`X^t`──`Z^p`── where `p` is the `phase_exponent` and `t` is the `exponent`.

cirq.PhasedXZGate This gate is like a `cirq.PhasedXPowGate` above, but it also includes an extra phase about the z axis. `PhasedXZGate` takes three parameters, `x_exponent`, `z_exponent`, and `axis_phase_exponent`. The gate is equivalent to the circuit ──`Z^(-a)`─`X^x`─`Z^a`───`Z^z`── where `x` is the `x_exponent`, `z` is the `z_exponent`, and `a` is the `axis_phase_exponent`.

cirq.H / cirq.HPowGate The Hadamard gate is a rotation around the X+Z axis. `cirq.HPowGate(exponent=t)` is a variable rotation of t turns around this axis. `cirq.H` is a π rotation and is equivalent to `cirq.HPowGate(exponent=1)`

S The square root of Z gate, equivalent to `cirq.Z**0.5`

T The fourth root of Z gate, equivalent to `cirq.Z**0.25`.

Two qubit gates

cirq.CZ / cirq.CZPowGate The controlled-Z gate. A two qubit gate that phases the |11⟩ state. `cirq.CZPowGate(exponent=t)` is equivalent to `cirq.CZ**t` and has a matrix representation of `exp(i pi |11⟩⟨11| t)`.

cirq.CNOT / cirq.CNotPowGate The controlled-X gate. This gate swaps the |11⟩ and |10⟩ states. `cirq.CNotPowGate(exponent=t)` is equivalent to `cirq.CNOT**t` .

cirq.SWAP / cirq.SwapPowGate The swap gate swaps the |01⟩ and |10⟩ states. `cirq.SWAP**t` is the same as `cirq.SwapPowGate(exponent = t)`

cirq.ISWAP / cirq.ISwapPowGate The iSwap gate swaps the |01⟩ and |10⟩ states and adds a relative phase of i. `cirq.ISWAP**t` is the same as `cirq.ISwapPowGate(exponent = t)`

Parity gates: The gates `cirq.XX`, `cirq.YY`, and `cirq.ZZ` are equivalent to performing the equivalent one-qubit Pauli gates on both qubits. The gates `cirq.XXPowGate`, `cirq.YYPowGate`, and `cirq.ZZPowGate` are the powers of these gates.

Other gates

cirq.MatrixGate: A gate defined by its unitary matrix in the form of a numpy ndarray.

cirq.WaitGate: This gate does nothing for a specified `cirq.Duration` amount of time. This is useful for conducting T1 and T2 decay experiments.

cirq.CCNOT, cirq.CCX, cirq.TOFFOLI, cirq.CCXPowGate: Three qubit gates representing a controlled-controlled-X gate and powers of this gate.

cirq.CCZ, cirq.CCZPowGate: Three qubit gates representing a controlled-controlled-Z gate and power of this gate.

CSWAP, CSwapGate, FREDKIN: Three qubit gates representing a controlled-SWAP gate.

TwoQubitDiagonalGate, ThreeQubitDiagonalGate: Two and three qubit gates which are diagonal in the computational basis.

QubitPermutationGate A gate that permutes a given set of qubits.

Advanced: create your own gates

If the above gates are not sufficient for your use case, it is fairly simple to create your own gate. In order to do so, you can define your class and inherit the `cirq.Gate` class and define the functionality in your class. For more information, see this guide (/cirq/build/custom_gates).