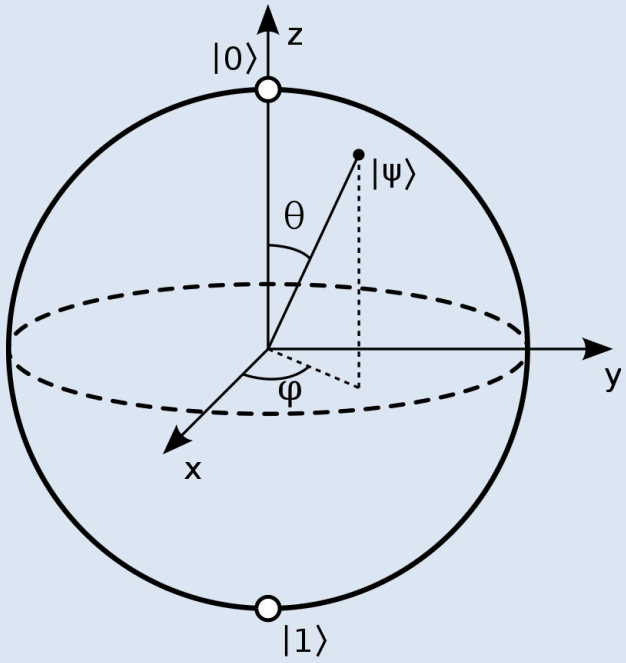
Basics

- Single Qubit: $|\psi\rangle = \cos\frac{\theta}{2}|0\rangle + e^{i\phi}\sin\frac{\theta}{2}|1\rangle$

- Bit and Phase information

  - Measurement:
    - formally: projection onto a basis

  - Change
    - Bit-Flip $X(a|0\rangle + b|1\rangle) = b|0\rangle + a|1\rangle$
    - Phase-Flip $Z(a|0\rangle + b|1\rangle) = a|0\rangle - b|1\rangle$



Bases

- Computational Basis $= \left(|0\rangle \equiv \binom{1}{0}, |1\rangle \equiv \binom{0}{1}\right)$

$$Z|0\rangle = |0\rangle \ , \quad Z|1\rangle = -|1\rangle$$
$$X|0\rangle = |1\rangle \ , \quad X|1\rangle = |0\rangle$$

- Hadamard Basis $= \left(|+\rangle \equiv \frac{|0\rangle+|1\rangle}{\sqrt{2}}, |-\rangle \equiv \frac{|0\rangle-|1\rangle}{\sqrt{2}}\right)$

$$X|+\rangle = |+\rangle \ , \quad X|-\rangle = -|-\rangle$$
$$Z|+\rangle = |-\rangle \ , \quad Z|-\rangle = |+\rangle$$

- Conversion

$$H|0\rangle = |+\rangle \ , \quad H|1\rangle = |-\rangle \ , \quad H^2 = \mathbb{1}$$

Basics

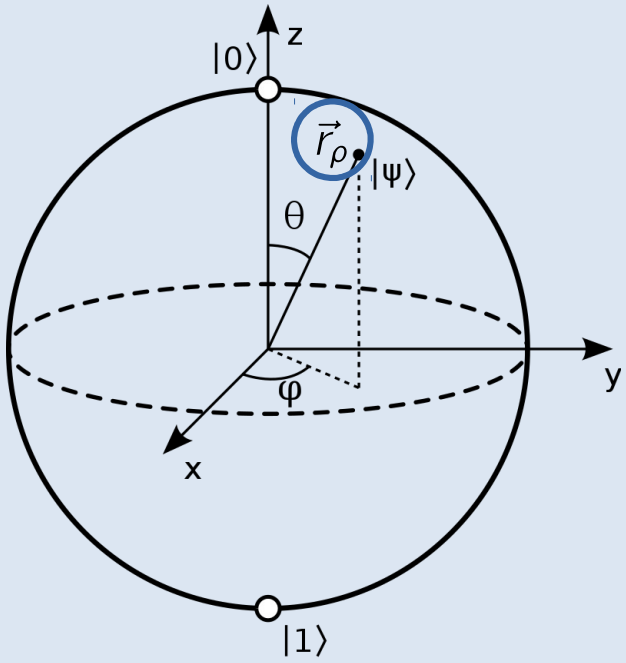
- Bloch Sphere:

$$\rho = |\psi\rangle\langle\psi|$$
$$= \frac{1}{2}(\mathbb{1} + X\cos\phi\sin\theta + Y\sin\phi\sin\theta + Z\cos\theta)$$
$$= \frac{1}{2}(\mathbb{1} + \vec{r}_\rho \cdot \vec{\sigma})$$

- Rotations:

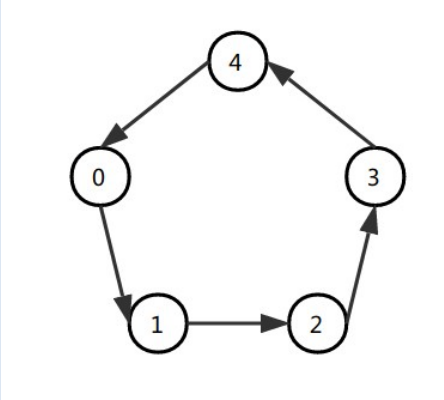
$$R_{\hat{n}}(\alpha) = \exp\left(-i\frac{\alpha}{2}\hat{n}\cdot\vec{\sigma}\right)$$

$$\mathrm{R}_{\hat{x}}(\pi) = X\,, \quad R_{\hat{z}}(\pi) = Z \quad (R_{\hat{y}}(\pi) = Y)$$

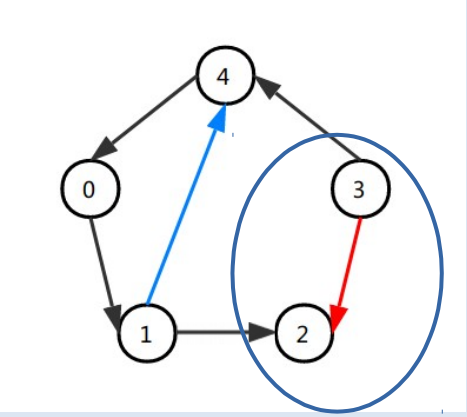


Running 2-Qubit Gates & Connectivity

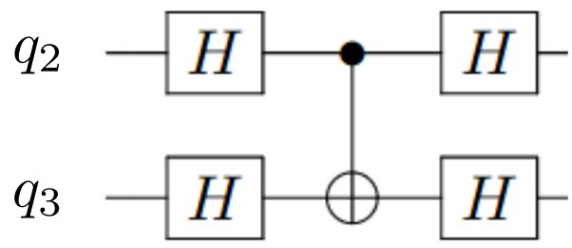
Suppose a device has this layout:



But we want to do this:



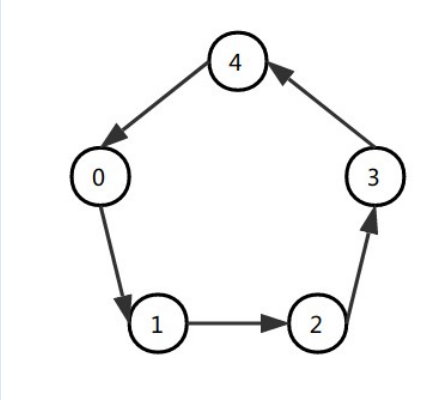
Wrong **direction**! Circumvent it with



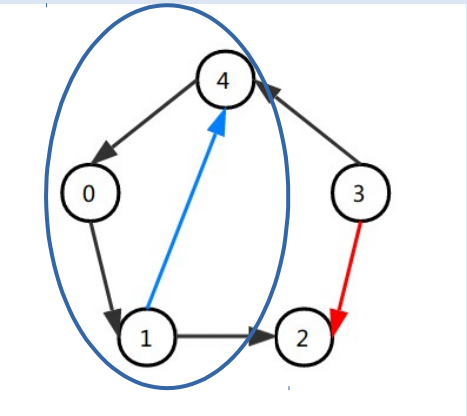
[adaped from Zhang et al., arXiv:1807.01703, 2018]

Running 2-Qubit Gates & Connectivity

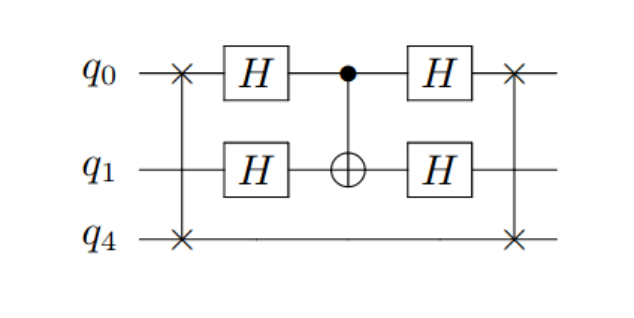
Suppose a device has this layout:



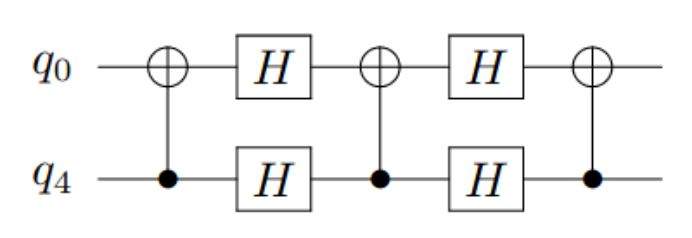
But we want to do this:



No direct connection available! Circumvent it with e.g.



SWAP, CNOT, SWAP



SWAP(q0, q4)

[adaped from Zhang et al., arXiv:1807.01703, 2018]

Running 2-Qubit Gates & Connectivity

→ Minimize the *cost* for given quantum algorithm on a given hardware layout

- Software: Compilation/Transpilation
- Hardware: optimized layout for specific algorithms

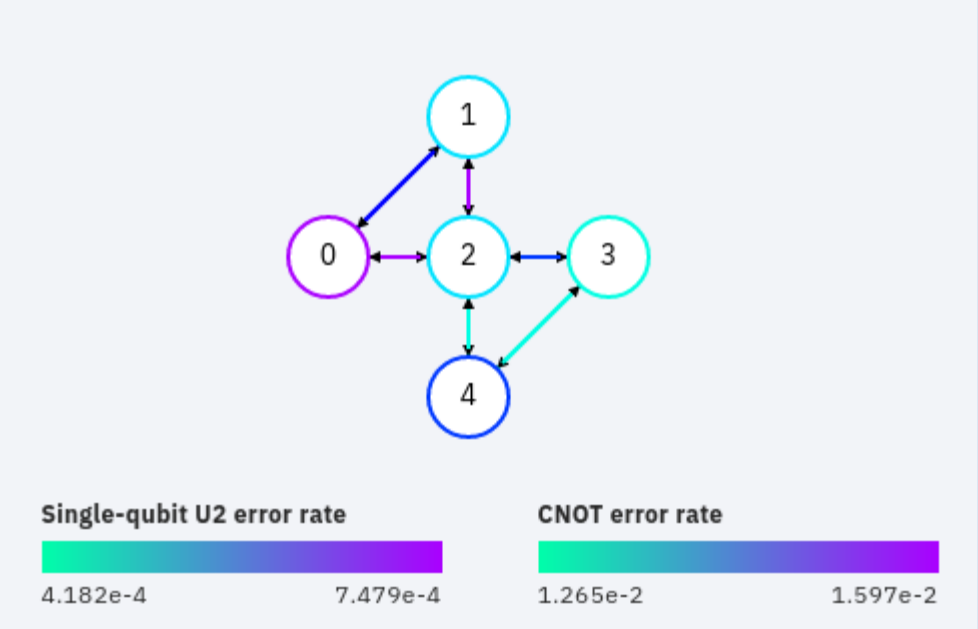
Example:

- Device:
ibmqx2 (Yorktown)

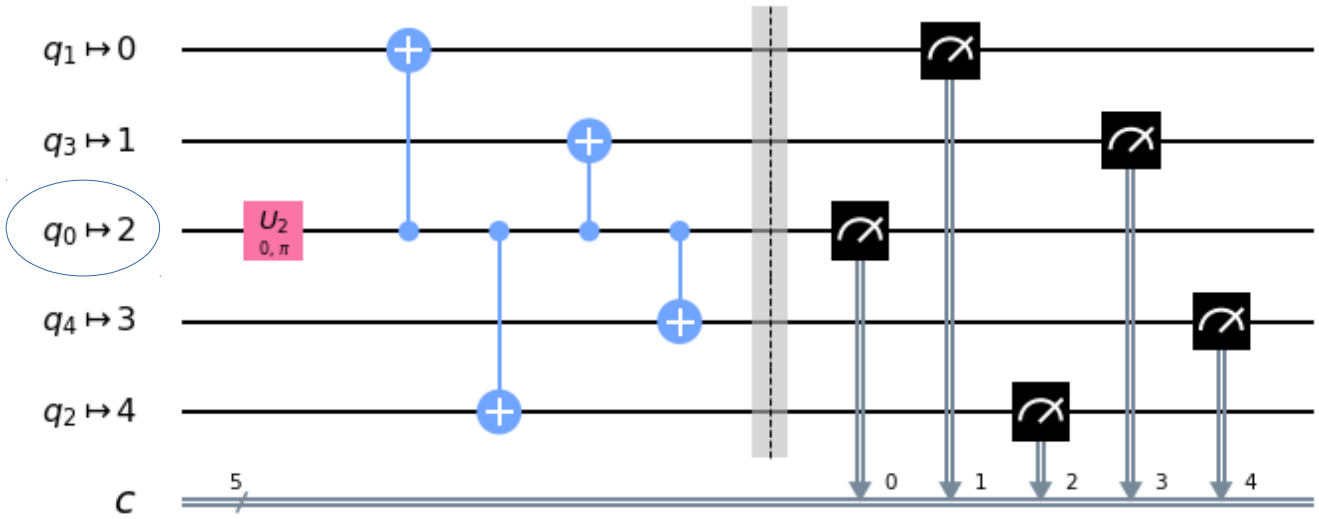
- Algorithm:
GHZ state preparation

$|00000\rangle \rightarrow$

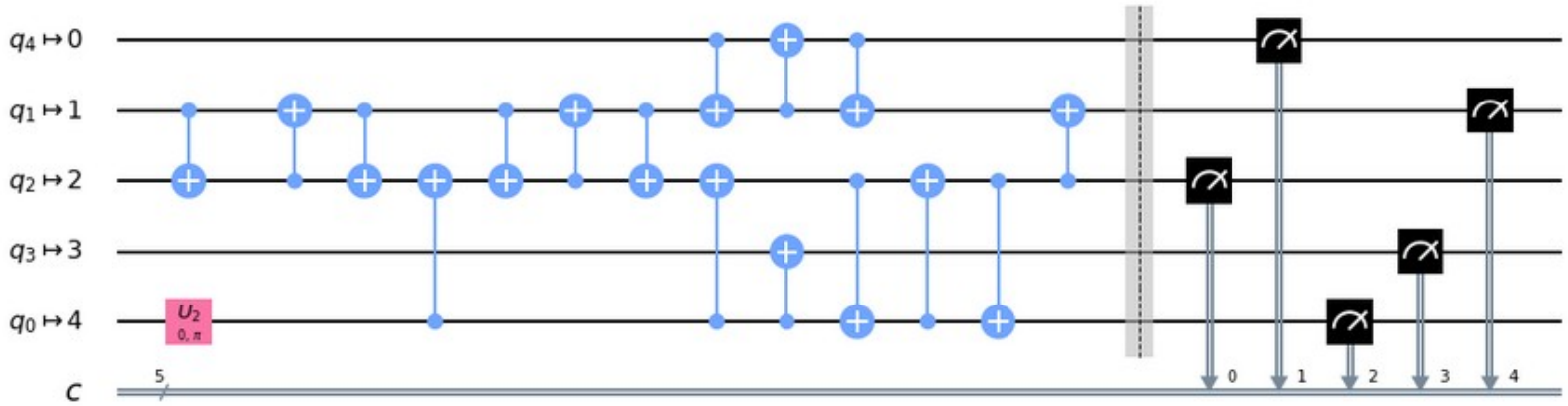
$\frac{1}{\sqrt{2}}(|00000\rangle + |11111\rangle)$



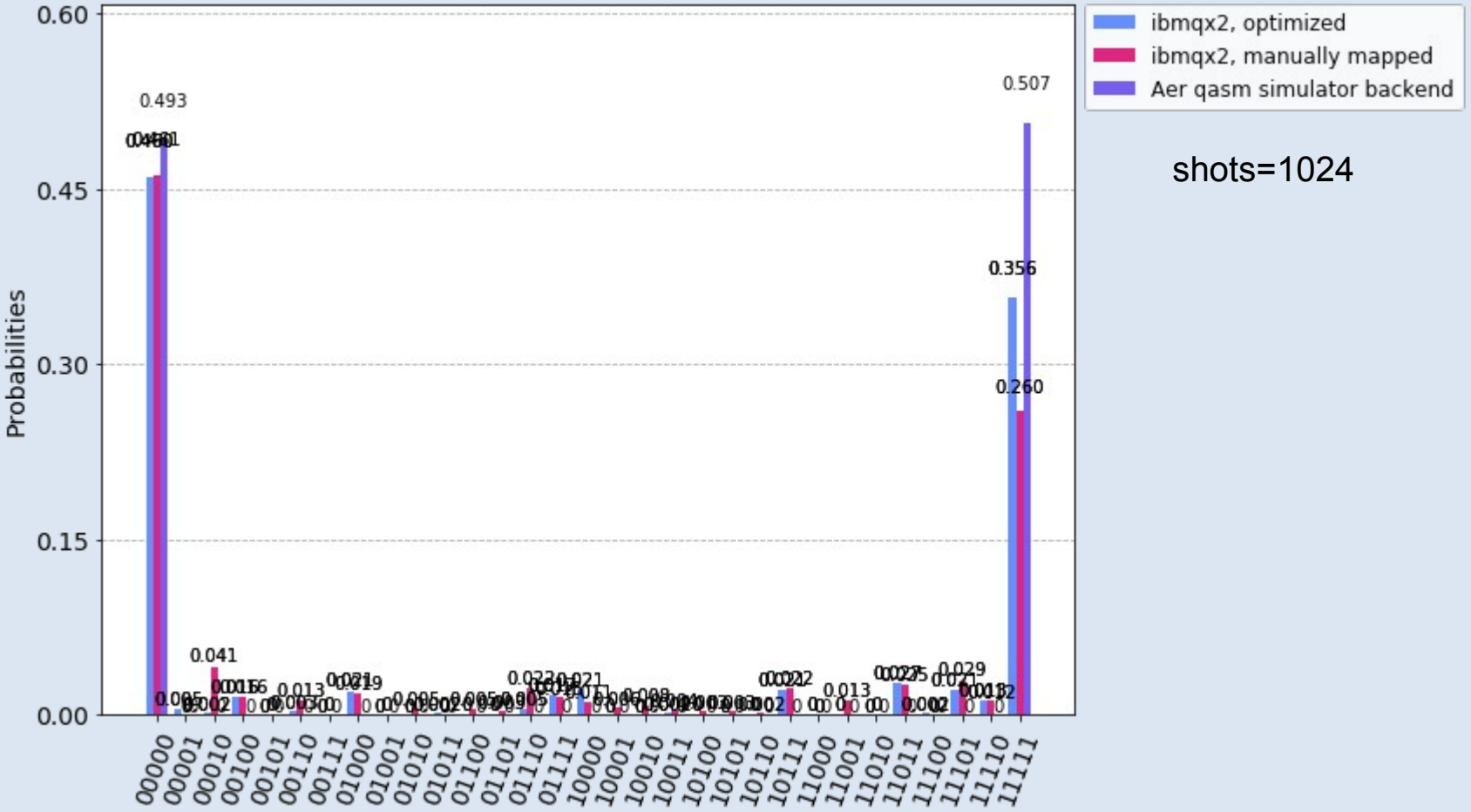
```
auto_mapped_ghz_circ = compiler.transpile(ghz, provider.get_backend('ibmqx2'), optimization_level=3)
auto_mapped_ghz_circ.draw(output='mpl')
```




```
custom_mapped_ghz_circ = compiler.transpile(ghz, provider.get_backend('ibmqx2'),
                                            initial_layout=[4,1,2,3,0], optimization_level=0)
custom_mapped_ghz_circ.draw(output='mpl')
```



Running 2-Qubit Gates & Connectivity



→ in this case: optimized circuit performed better