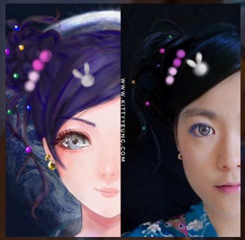
Introduction to Quantum Computing



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June 28, 2020
Hackaday, session 13
Other communities, session 5

Class structure

- [Comics on Hackaday – Introduction to Quantum Computing](#) every Sun

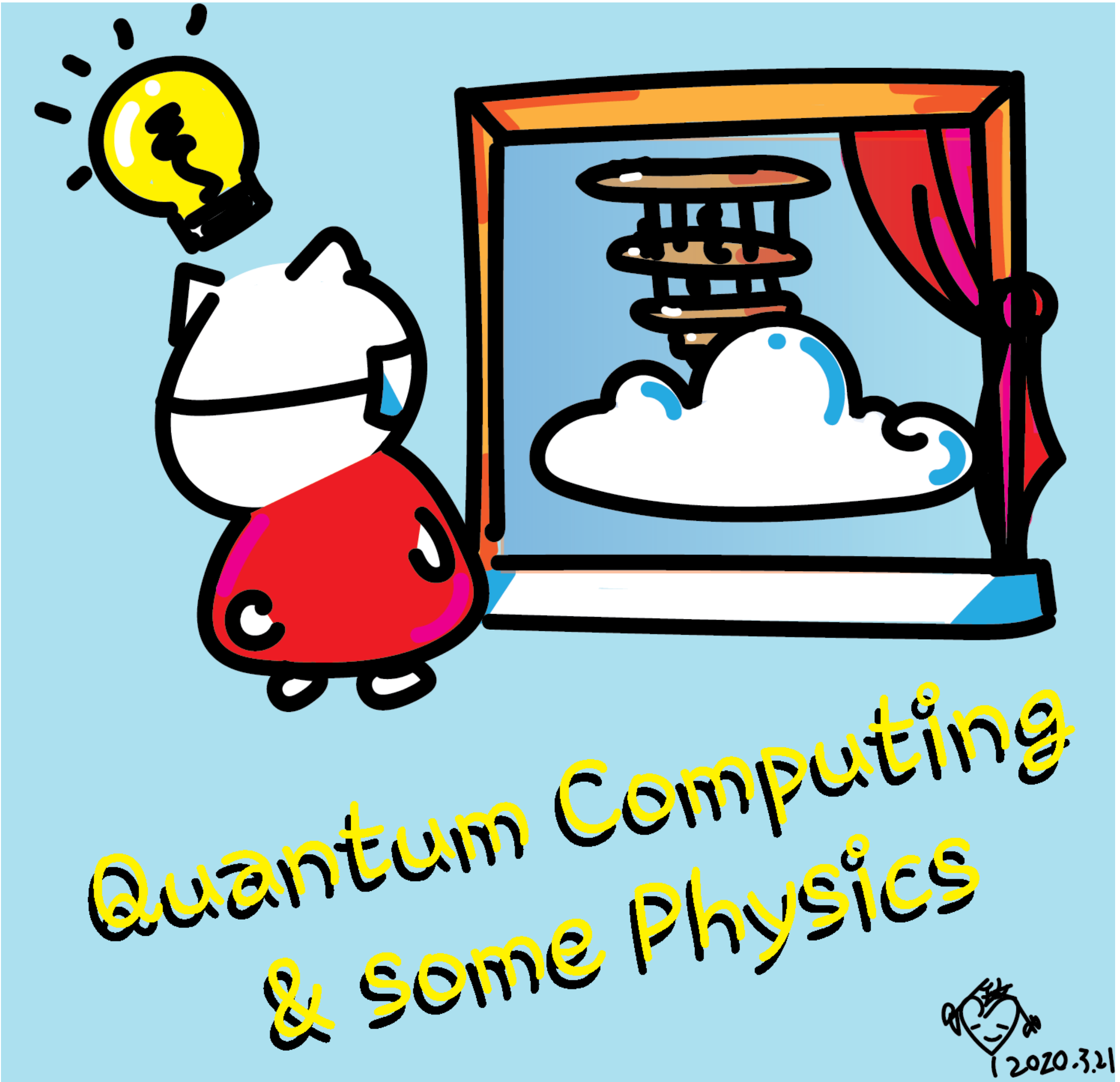
- 30 mins – 1 hour every Sun, one concept (theory, hardware, programming), Q&A

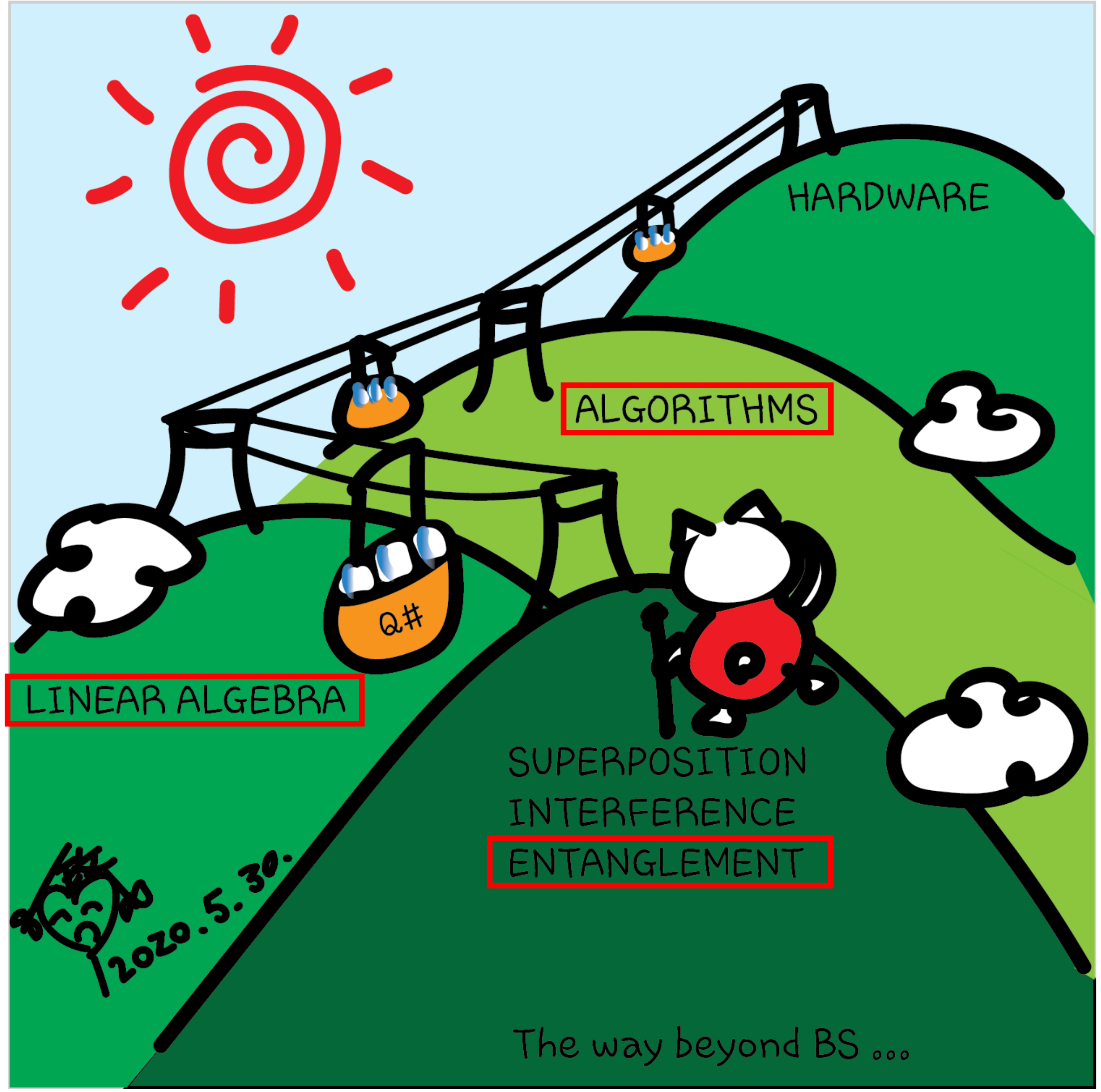
- Contribute to Q# documentation http://docs.microsoft.com/quantum

- Coding through Quantum Katas https://github.com/Microsoft/QuantumKatas/

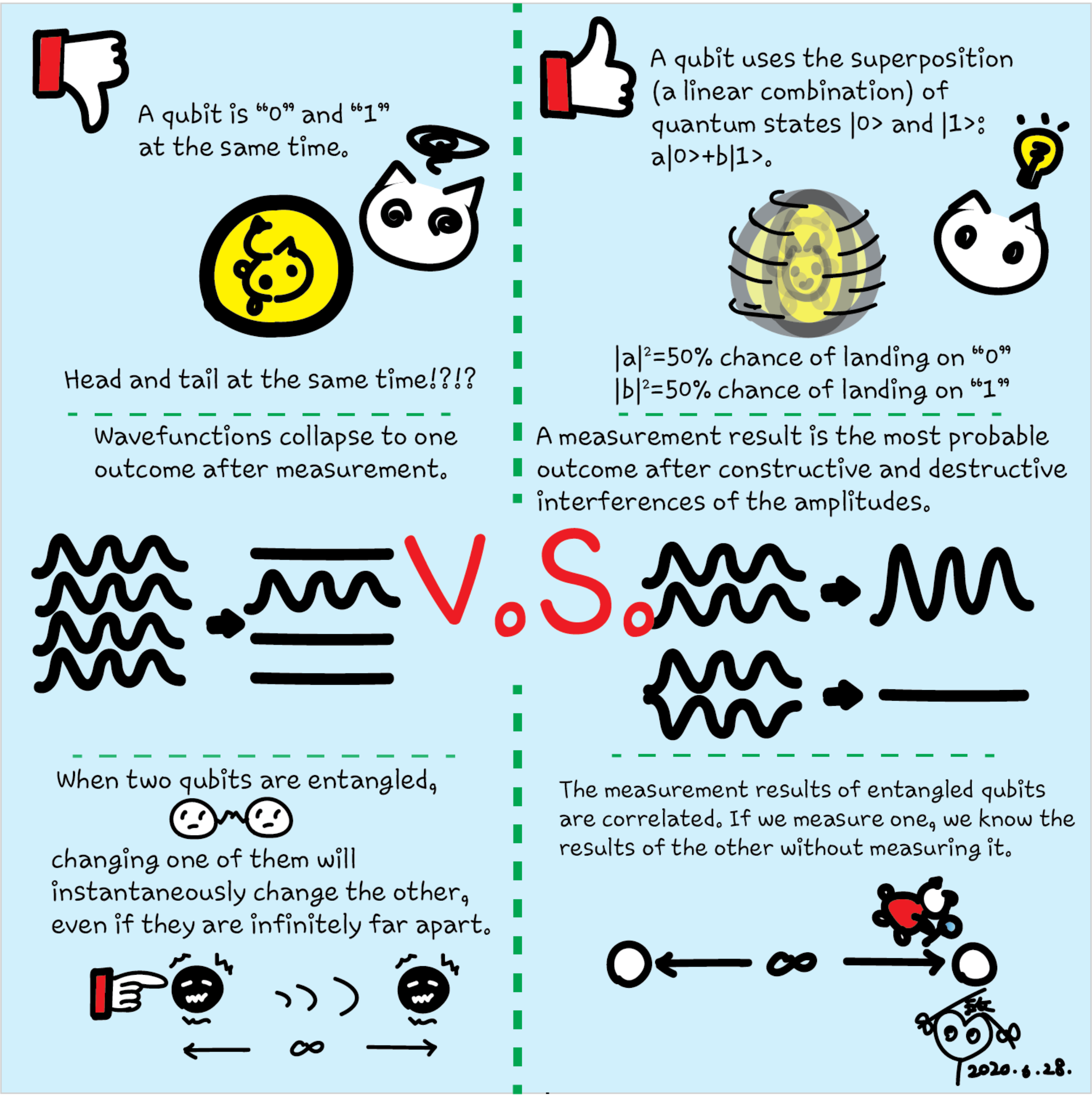
- Discuss in Hackaday project comments throughout the week

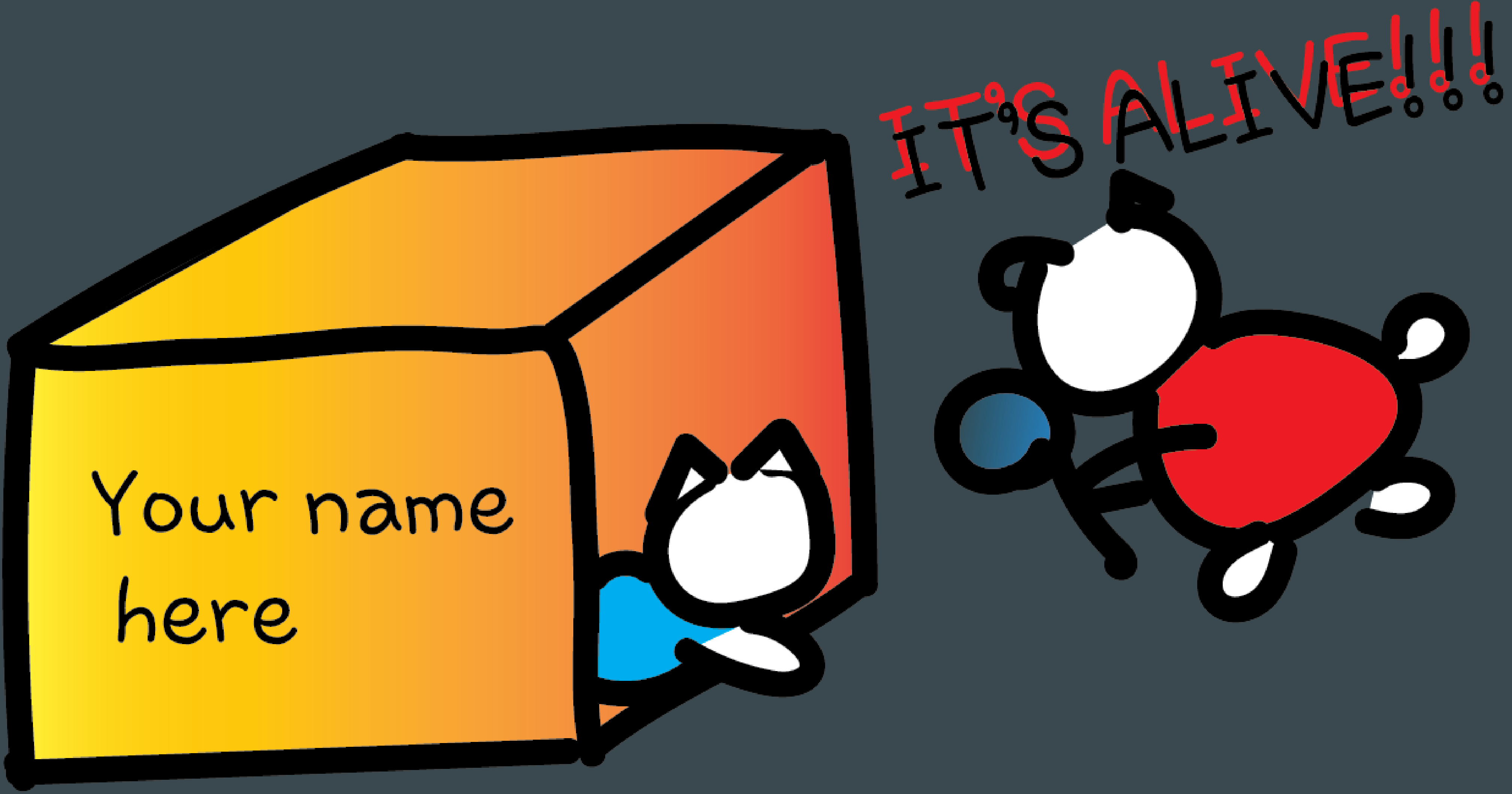
- Take notes





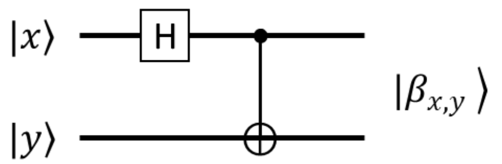
HARDWARE
ALGORITHMS
Q#
LINEAR ALGEBRA
SUPERPOSITION
INTERFERENCE
ENTANGLEMENT
2020.5.30.
The way beyond BS ...


A qubit is "0" and "1" at the same time.
Head and tail at the same time!?!?
Wavefunctions collapse to one outcome after measurement.
When two qubits are entangled,
changing one of them will instantaneously change the other, even if they are infinitely far apart.
A qubit uses the superposition (a linear combination) of quantum states |0> and |1>: a|0>+b|1>.
$|a|^2$=50% chance of landing on "0"
$|b|^2$=50% chance of landing on "1"
V.S.
A measurement result is the most probable outcome after constructive and destructive interferences of the amplitudes.
The measurement results of entangled qubits are correlated. If we measure one, we know the results of the other without measuring it.
2020.6.28.



THE OUT-OF-THE-BOX THINKER

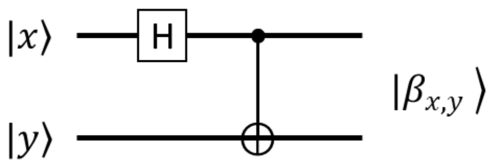
Creating Bell states (entanglement)



In	Out
$\|00\rangle$	$(\|00\rangle + \|11\rangle)/\sqrt{2} \equiv \|\beta_{00}\rangle$
$\|01\rangle$	$(\|01\rangle + \|10\rangle)/\sqrt{2} \equiv \|\beta_{01}\rangle$
$\|10\rangle$	$(\|00\rangle - \|11\rangle)/\sqrt{2} \equiv \|\beta_{10}\rangle$
$\|11\rangle$	$(\|01\rangle - \|10\rangle)/\sqrt{2} \equiv \|\beta_{11}\rangle$

Try proving this table

Creating Bell states (entanglement)



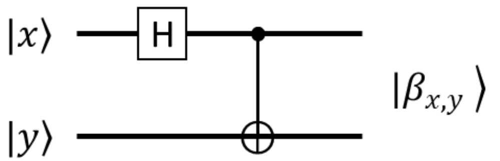
In	Out
$\lvert 00\rangle$	$(\lvert 00\rangle + \lvert 11\rangle)/\sqrt{2} \equiv \lvert\beta_{00}\rangle$
$\lvert 01\rangle$	$(\lvert 01\rangle + \lvert 10\rangle)/\sqrt{2} \equiv \lvert\beta_{01}\rangle$
$\lvert 10\rangle$	$(\lvert 00\rangle - \lvert 11\rangle)/\sqrt{2} \equiv \lvert\beta_{10}\rangle$
$\lvert 11\rangle$	$(\lvert 01\rangle - \lvert 10\rangle)/\sqrt{2} \equiv \lvert\beta_{11}\rangle$

$$H|0\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$$

$$H|1\rangle = \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle)$$

Try proving this table

Creating Bell states (entanglement)



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Try proving this table

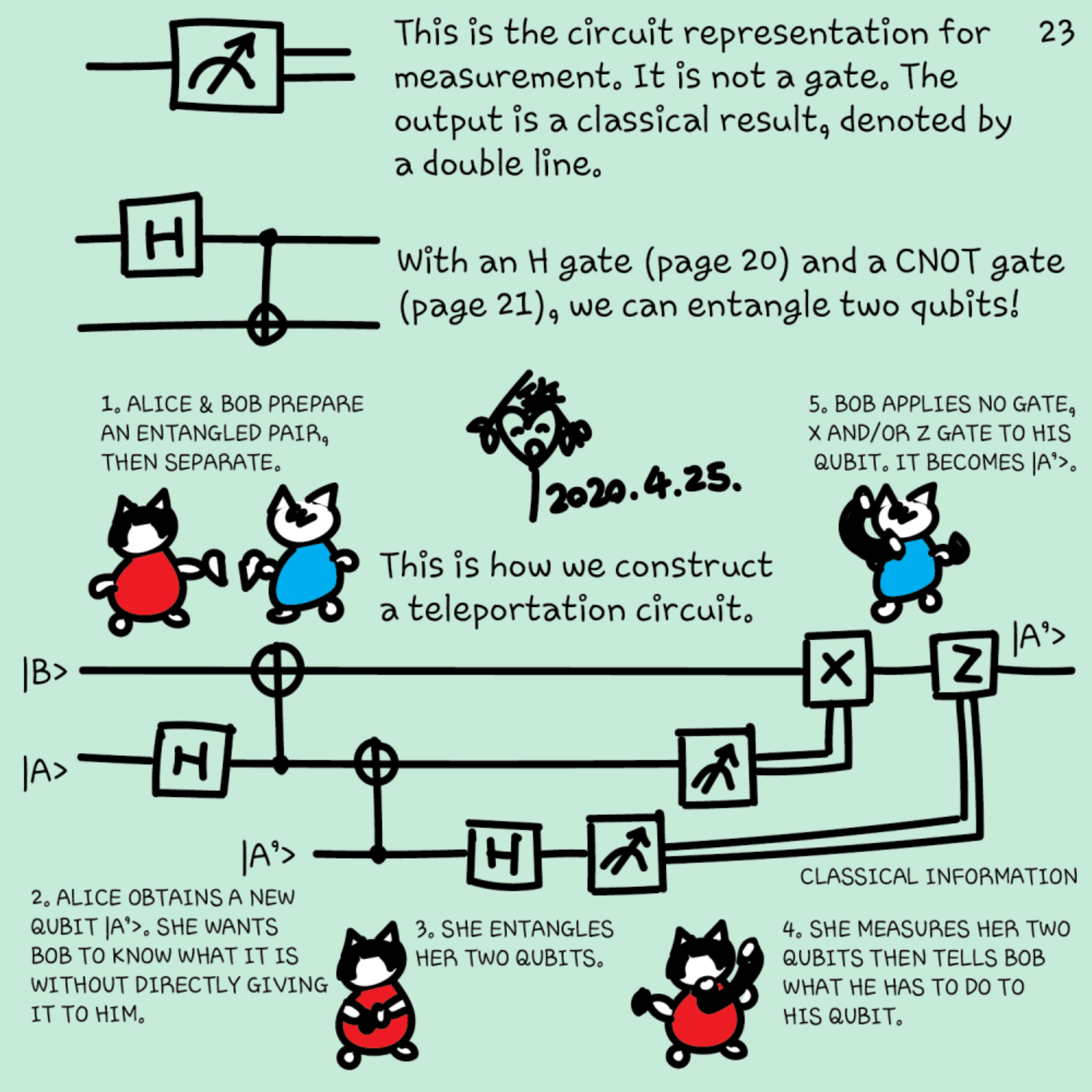
$$H|0\rangle\,|0\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)|0\rangle$$

$$H|0\rangle\,|1\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)|1\rangle$$

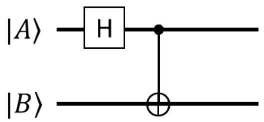
$$H|1\rangle\,|0\rangle = \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle)|0\rangle$$

$$H|1\rangle\,|1\rangle = \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle)|1\rangle$$

Apply CNOT



First two qubits	Third qubit	Alice tells Bob to
00	$[\alpha\|0\rangle + \beta\|1\rangle]$	do nothing
01	$[\alpha\|1\rangle + \beta\|0\rangle]$	apply X
10	$[\alpha\|0\rangle - \beta\|1\rangle]$	apply Z
11	$[\alpha\|1\rangle - \beta\|0\rangle]$	apply X and Z



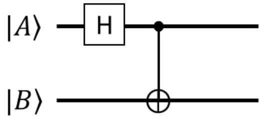
$$|\phi^+\rangle = \frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

Q# exercise:

Option 1: No installation, web-based Jupyter Notebooks

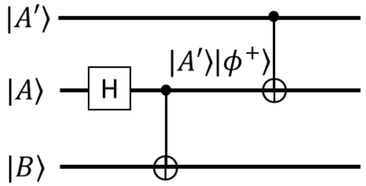
- The Quantum Katas project (tutorials and exercises for learning quantum computing) https://github.com/Microsoft/QuantumKatas
- **Teleportation**
- Tasks 1.1-1.4

Teleportation



$$|\phi^+\rangle = \frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

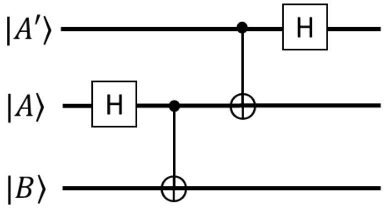
$$\boxed{\text{Let } |A'\rangle = \alpha|0\rangle + \beta|1\rangle}$$



$$|A'\rangle|\phi^+\rangle = (\alpha|0\rangle + \beta|1\rangle)\,\frac{|00\rangle+|11\rangle}{\sqrt{2}}$$

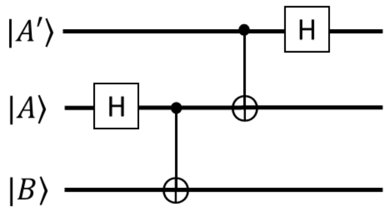
$$= \frac{1}{\sqrt{2}}(\alpha|000\rangle + \alpha|011\rangle + \beta|100\rangle + \beta|111\rangle).$$

$$CNOT|A'\rangle|\phi^+\rangle = \frac{1}{\sqrt{2}}(\alpha|000\rangle + \alpha|011\rangle + \beta|110\rangle + \beta|101\rangle)$$

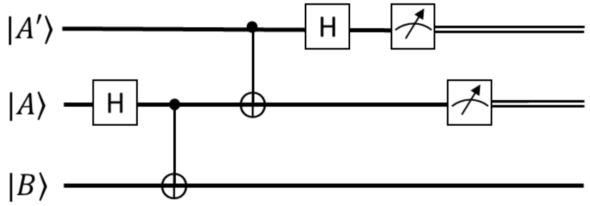


$$\frac{1}{2}[|00\rangle(\alpha|0\rangle + \beta|1\rangle) + |01\rangle(\alpha|1\rangle + \beta|0\rangle) + |10\rangle(\alpha|0\rangle - \beta|1\rangle) + |11\rangle(\alpha|1\rangle - \beta|0\rangle)]$$

$$\frac{1}{\sqrt{2}}\left[\alpha\left(\frac{|0\rangle+|1\rangle}{\sqrt{2}}\right)|00\rangle + \alpha\left(\frac{|0\rangle+|1\rangle}{\sqrt{2}}\right)|11\rangle + \beta\left(\frac{|0\rangle-|1\rangle}{\sqrt{2}}\right)|10\rangle + \beta\left(\frac{|0\rangle-|1\rangle}{\sqrt{2}}\right)|01\rangle\right]$$



$$\frac{1}{2}[|00\rangle(\alpha|0\rangle+\beta|1\rangle)+|01\rangle(\alpha|1\rangle+\beta|0\rangle)$$
$$+|10\rangle(\alpha|0\rangle-\beta|1\rangle)+|11\rangle(\alpha|1\rangle-\beta|0\rangle)]$$



If the first qubit is 0, the state after measurement becomes

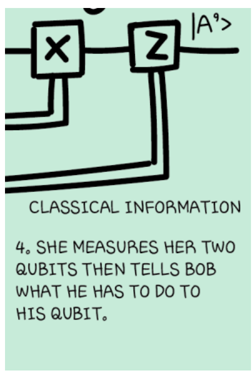
$$\frac{1}{2}[|00\rangle(\alpha|0\rangle+\beta|1\rangle)+|01\rangle(\alpha|1\rangle+\beta|0\rangle)]\ .$$

If then another measurement is done on the second qubit and it is 0, the state becomes

$$\frac{1}{2}[|00\rangle(\alpha|0\rangle+\beta|1\rangle)]\ .$$

This also tells us that the third qubit is in state $[\alpha|0\rangle+\beta|1\rangle]$.

First two qubits	Third qubit	Alice tells Bob to
00	$[\alpha|0\rangle+\beta|1\rangle]$	do nothing
01	$[\alpha|1\rangle+\beta|0\rangle]$	apply X
10	$[\alpha|0\rangle-\beta|1\rangle]$	apply Z
11	$[\alpha|1\rangle-\beta|0\rangle]$	apply X and Z



Q# exercise:

Option 1: No installation, web-based Jupyter Notebooks

- The Quantum Katas project (tutorials and exercises for learning quantum computing) https://github.com/Microsoft/QuantumKatas
- **Teleportation**
- Tasks 3.1
- Controlled Z and X
- Tasks 4 highly recommended (3 entangled qubits)

For certificate 1

- Complete any one quantum kata
- Take a screenshot or photo
- Post on Twitter or LinkedIn
- Tag the following
- **Twitter:** @KittyArtPhysics @MSFTQuantum @QSharpCommunity #QSharp #QuantumComputing #comics #physics
- **LinkedIn:** @Kitty Y. M Yeung #MSFTQuantum #QSharp #QuantumComputing #comics #physics

We can use entanglement to our advantage, such as in communication or encryption.

First prepare a Bell state, e.g. $(|01\rangle+|10\rangle)/\sqrt{2}$

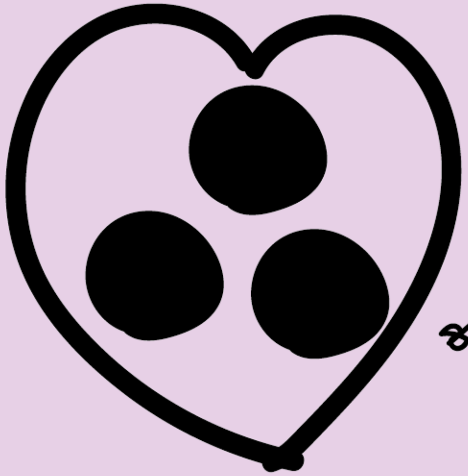
Give the 1st qubit to Alice, and the 2nd to Bob.

ALICE

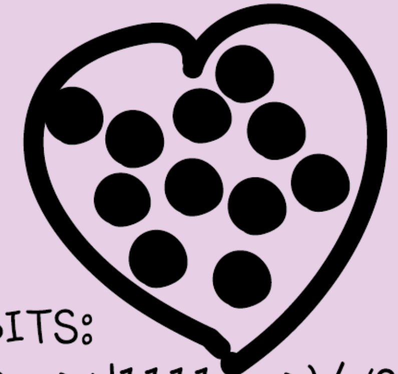
BOB

If Alice measures and gets $|0\rangle$, she knows Bob will get $|1\rangle$. If she wants him to get $|0\rangle$, She'll ask him to flip his qubit.

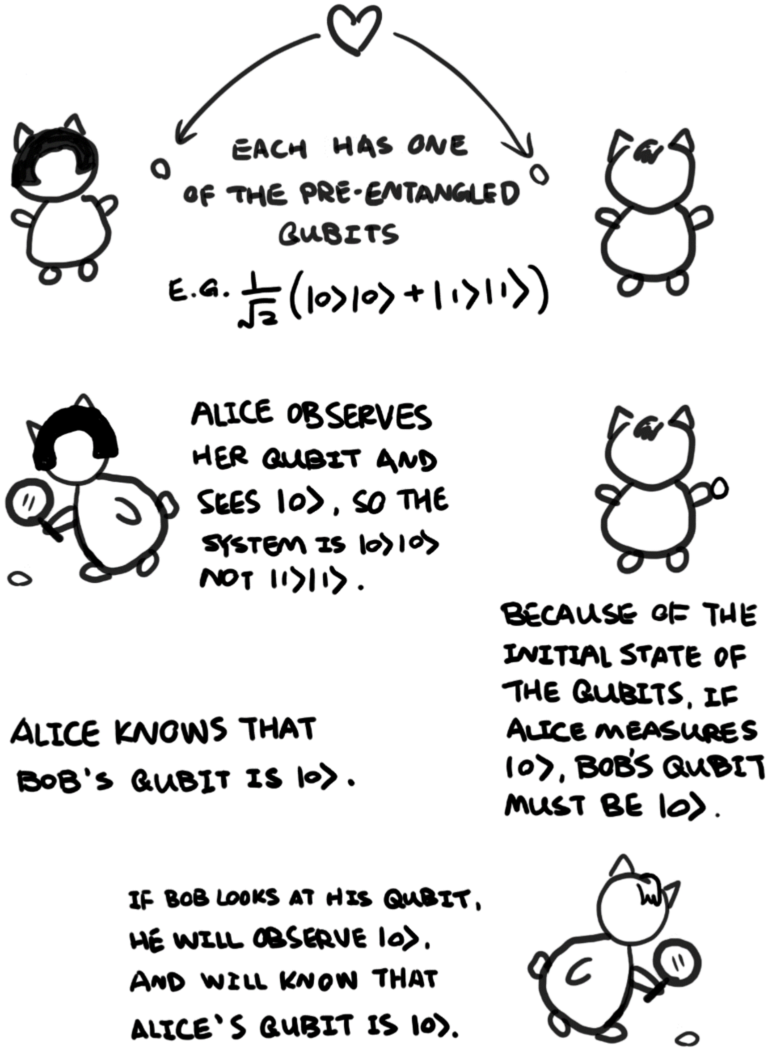
Of course, entanglement can happen between any number of qubits. The multi-qubit counterpart of Bell states are called the Greenberger-Horne-Zeilinger (GHZ) states.



THREE QUBITS:
$(|000\rangle+|111\rangle)/\sqrt{2}$



N QUBITS:
$(|0000\ldots\rangle+|1111\ldots\rangle)/\sqrt{2}$
$=(|0\rangle^{\otimes N}+|1\rangle^{\otimes N})/\sqrt{2}$



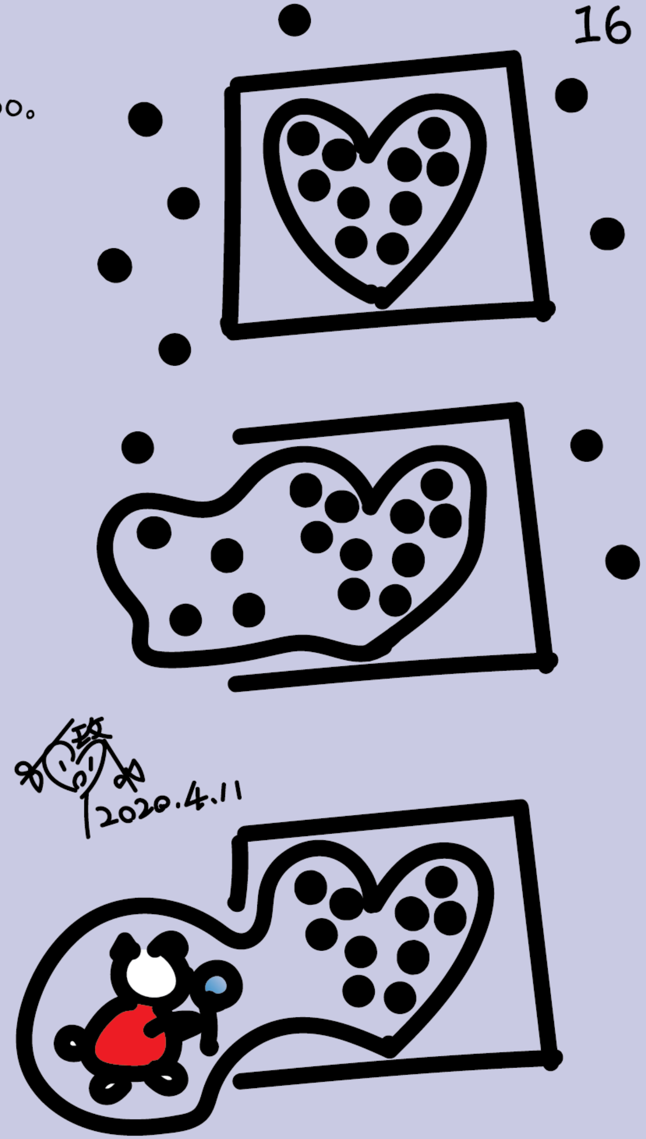
However, entanglement can be disadvantageous, too.

If the qubits are not perfectly isolated,

entanglement with their environment can easily happen, causing the qubits to **decohere** from each other.

Measurements also cause decoherence, when the measuring device acts as the environment that entangles with the qubits.

Therefore, measurements must be delicately done. Otherwise, they cause errors.



Participate

- Azure Quantum Developer Workshop https://aka.ms/AQDW

Questions

- Post in chat or on Hackaday project https://hackaday.io/project/168554-introduction-to-quantum-computing
- Past Recordings on Hackaday project or my YouTube https://www.youtube.com/c/DrKittyYeung

July 5

No class