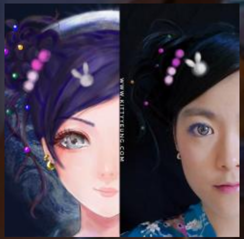
# Introduction to Quantum Computing



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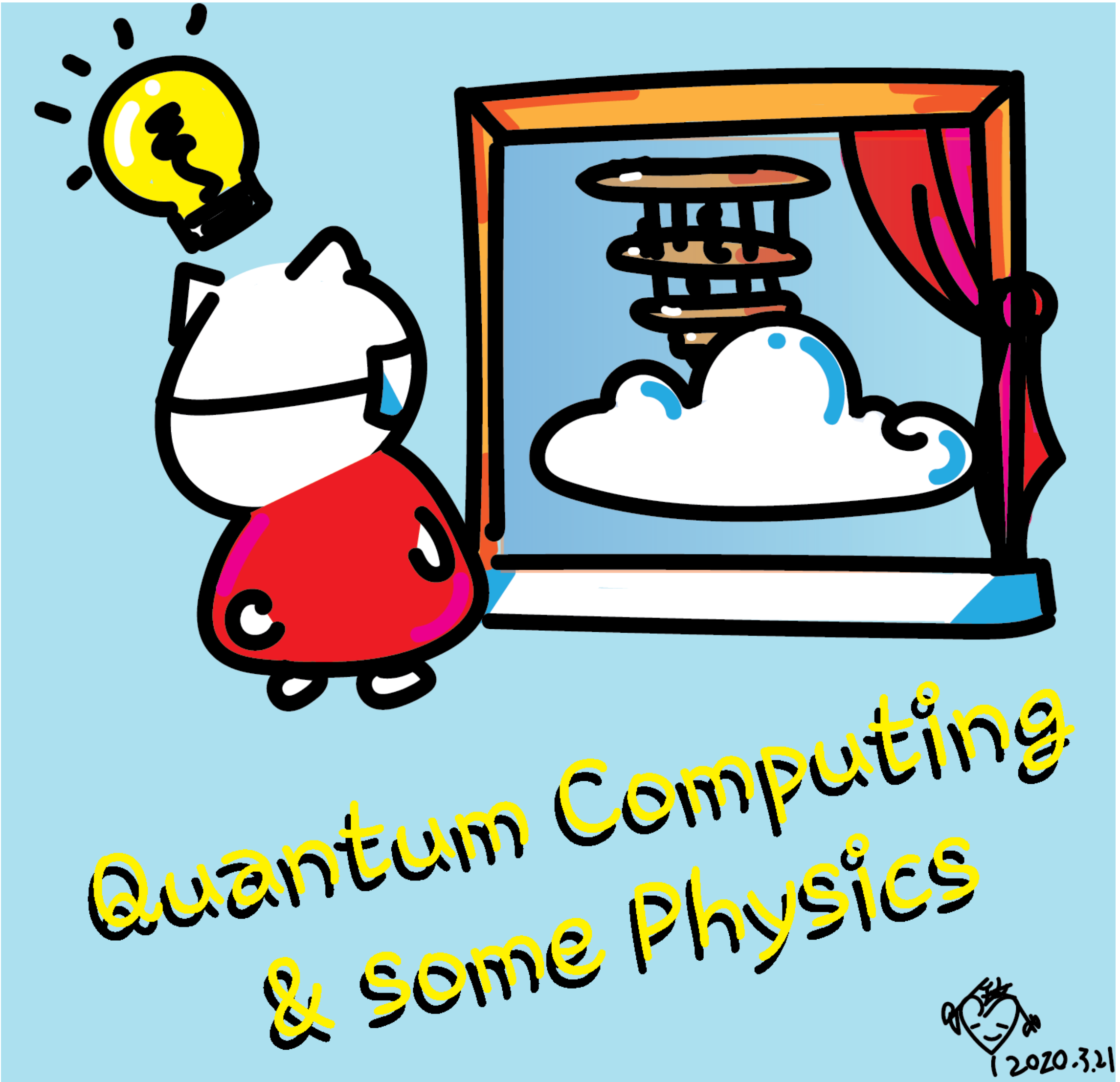
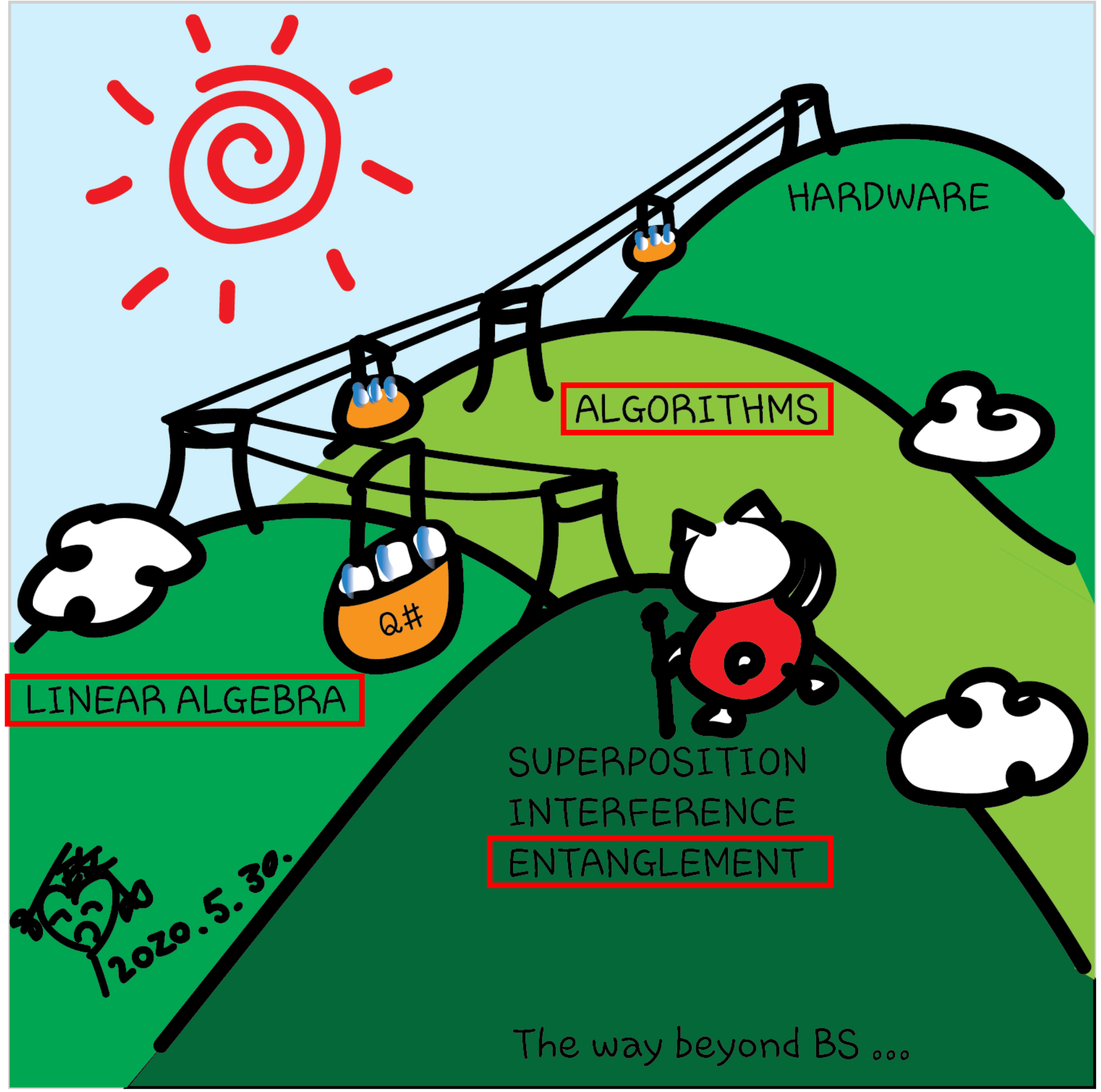
July 12, 2020
Hackaday, session 14
Other communities, session 6

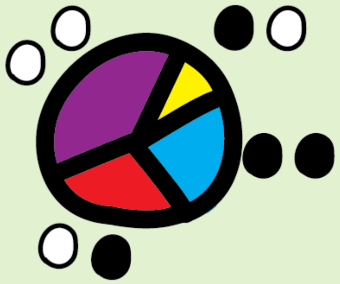
# Class structure

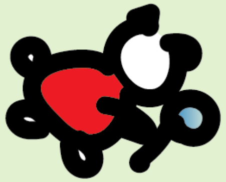
- Comics on Hackaday – Introduction to Quantum Computing every Sun
- 30 mins – 1 hour every Sun, one concept (theory, hardware, programming), Q&A
- Contribute to Q# documentation http://docs.microsoft.com/quantum
- Coding through Quantum Katas https://github.com/Microsoft/QuantumKatas/
- Discuss in Hackaday project comments throughout the week
- Take notes

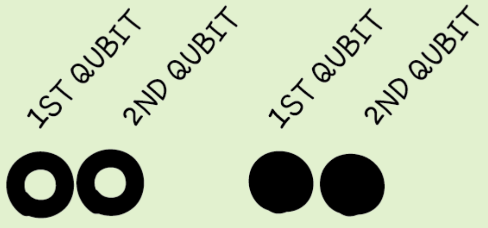



HARDWARE
ALGORITHMS
Q#
LINEAR ALGEBRA
SUPERPOSITION
INTERFERENCE
ENTANGLEMENT
2020.5.30.
The way beyond BS ...

We've seen in page 9 that with two qubits, there are four possible configurations: both qubits in $|0\rangle$s or $|1\rangle$s, or one in $|0\rangle$ with the other in $|1\rangle$. What if we make the $|0\rangle|0\rangle$ case in superposition with the $|1\rangle|1\rangle$ case? Or $|0\rangle|1\rangle$ in superposition with $|1\rangle|0\rangle$?



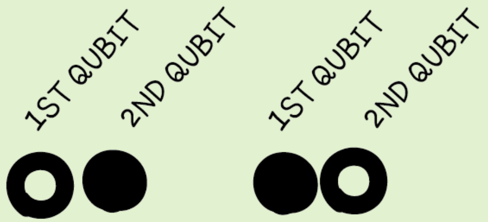





$a|0\quad 0\rangle + d|1\quad 1\rangle$

If we set the system to be in this case, we know that if we measure the first qubit and get $|0\rangle$, the second qubit must be in $|0\rangle$, without needing to measure it.

We can also measure the second qubit to know what the first qubit is without measuring it.


$b|0\quad 1\rangle + c|1\quad 0\rangle$

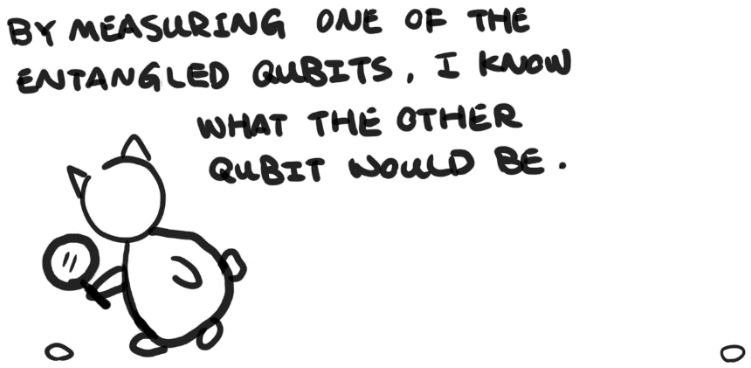
Similarly in this case, if the first qubit is $|0\rangle$, the second qubit must be $|1\rangle$. If the first is $|1\rangle$, the second must be $|0\rangle$.

The qubits are correlated. This is called "entanglement".

# Entanglement

Bell states

$|\varphi^{\pm}\rangle = \frac{|01\rangle \pm |10\rangle}{\sqrt{2}}$ and $|\phi^{\pm}\rangle = \frac{|00\rangle \pm |11\rangle}{\sqrt{2}}$



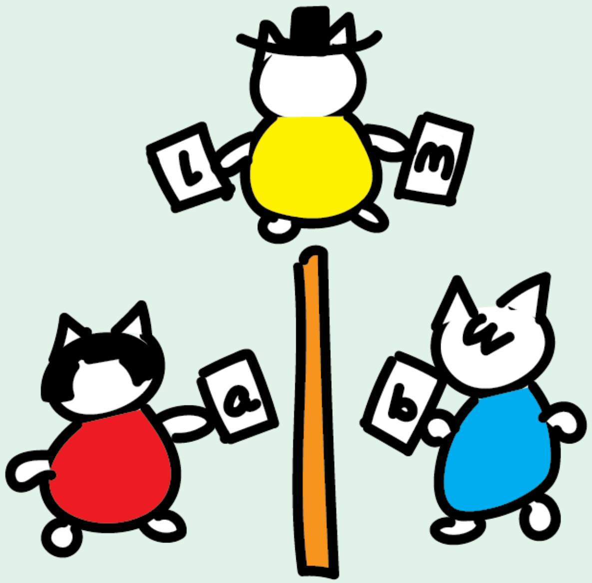

Take $|\phi^{+}\rangle$ as an example, upon measuring the first qubit, one obtains two possible results:

1. First qubit is 0, get a state $|\phi'\rangle = |00\rangle$ with probability ½.
2. First qubit is 1, get a state $|\phi''\rangle = |11\rangle$ with probability ½.

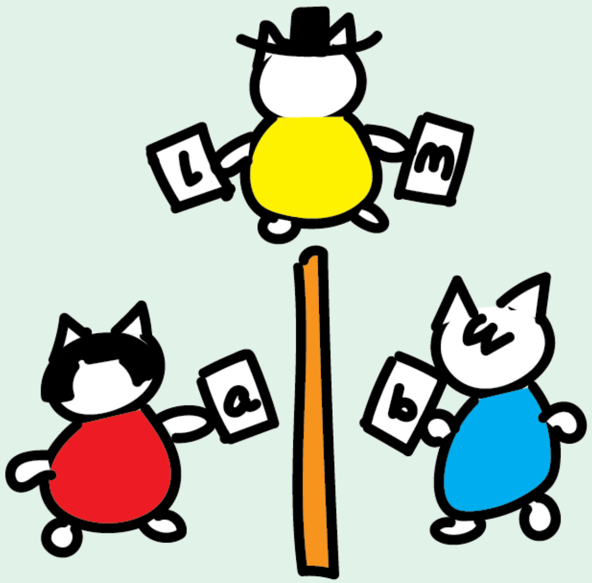
If the second qubit is measured, the result is the same as the above. This means that measuring one qubit tells us what the other qubit is.

# CHSH Game

- CHSH stands for John Clauser, Michael Horne, Abner Shimony, and Richard Holt. Paper published in 1969




Alice and Bob go to a casino and play the CHSH game. They are physically separated and cannot communicate. The referee shows Alice a bit "L" and Bob a bit "M" in either 0 or 1. Alice and Bob need to report their bits "a" and "b" to the referee. If $L \cdot M = a \oplus b$, they win. Otherwise, they lose. Alice and Bob can set up a strategy beforehand.

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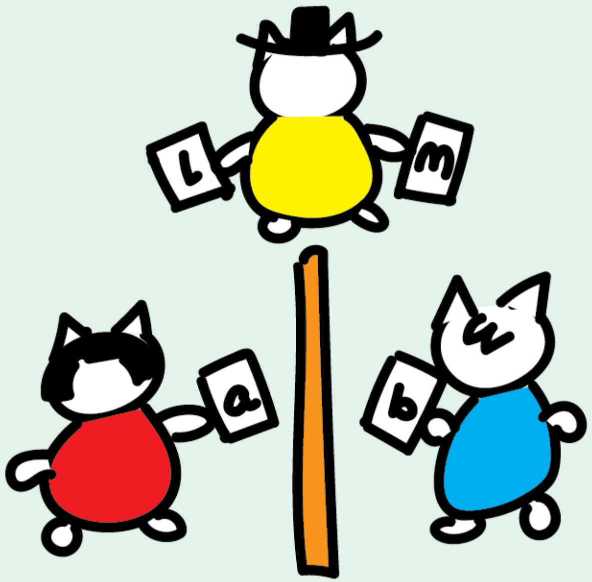
| L | M | win if $L \cdot M = a \oplus b$ | a | b |
|---|---|---|---|---|
| 0 | 0 | 0 | 0<br>1 | 0<br>1 |
| 0 | 1 | 0 | | |
| 1 | 0 | 0 | | |
| 1 | 1 | 1 | 0<br>1 | 1<br>0 |

| a | b |
|---|---|
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |

CLASSICAL STRATEGY $\leq$75% chance of winning

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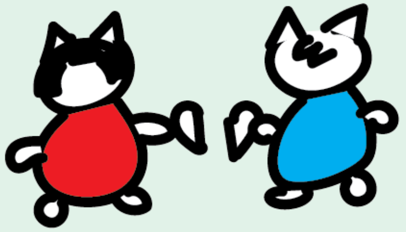
<table>
<tr><th>L</th><th>M</th><th>win if L·M=a⊕b</th><th>a</th><th>b</th></tr>
<tr><td>0</td><td>0</td><td>0</td><td rowspan="3">0<br>1</td><td rowspan="3">0<br>1</td></tr>
<tr><td>0</td><td>1</td><td>0</td></tr>
<tr><td>1</td><td>0</td><td>0</td></tr>
<tr><td>1</td><td>1</td><td>1</td><td>0<br>1</td><td>1<br>0</td></tr>
</table>

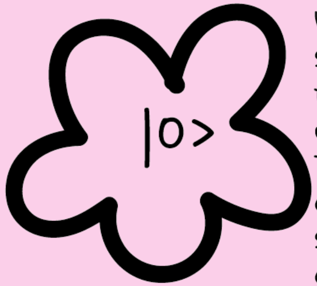
| a | b |
|---|---|
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |

CLASSICAL STRATEGY
≤75% chance of winning

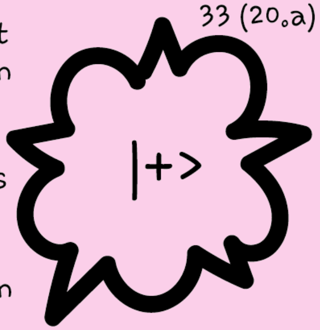


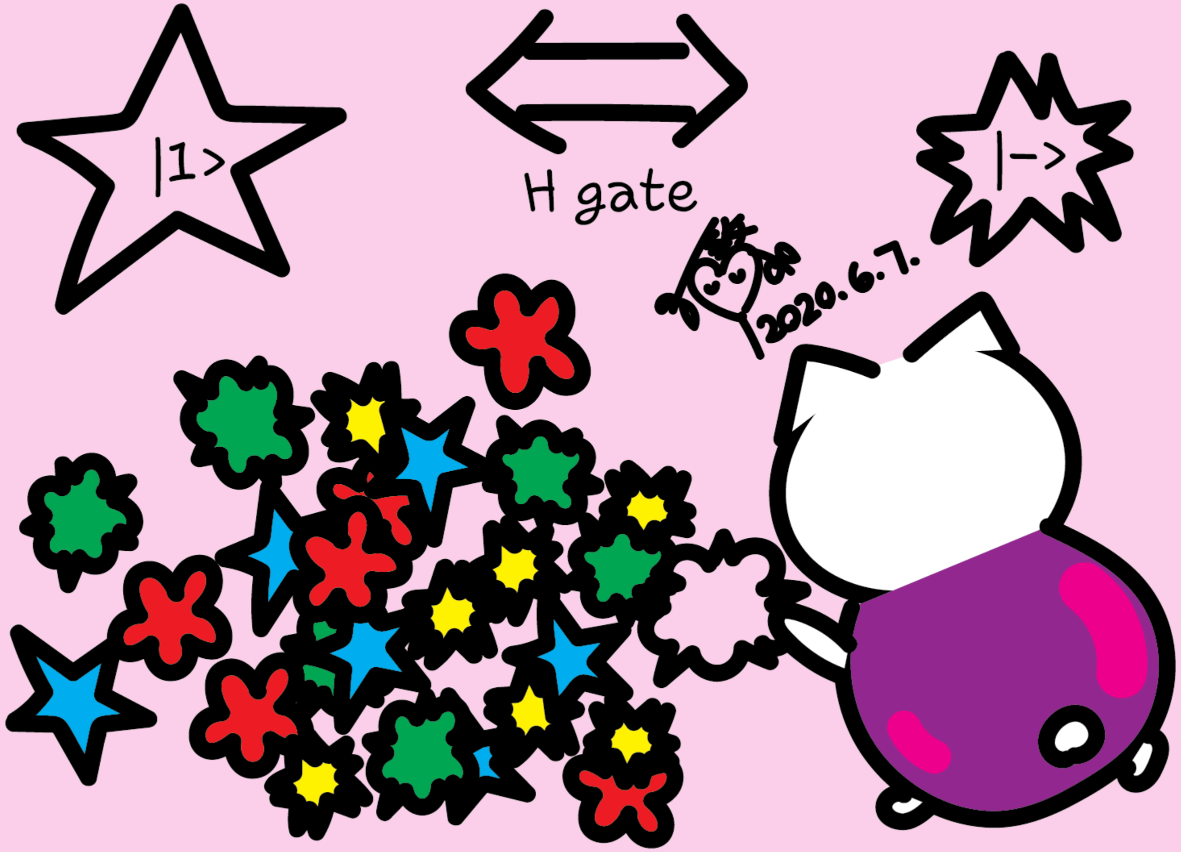
QUANTUM STRATEGY
≥85% chance of winning!

Of course, that involves entanglement. They pre-entangle qubits to $1/\sqrt{2}(|00\rangle+|11\rangle)$.




We can use |0> and |1> to describe a qubit state. The measurement results will be in terms of |0> and |1>. But we can equally use |+> and |-> to describe a qubit state. The measurement results will be in terms of |+> and |->. The combination of these sets of states that are used to describe other states are called a basis. Gates can transform the basis of measurements.

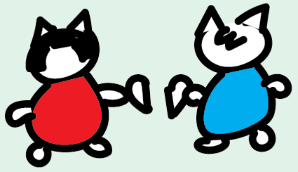


| L | M | win if L∘M=a⊕b | a | b |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 | 1 |
| 1 | 0 | 0 | | |
| 1 | 1 | 1 | 0<br>1 | 1<br>0 |

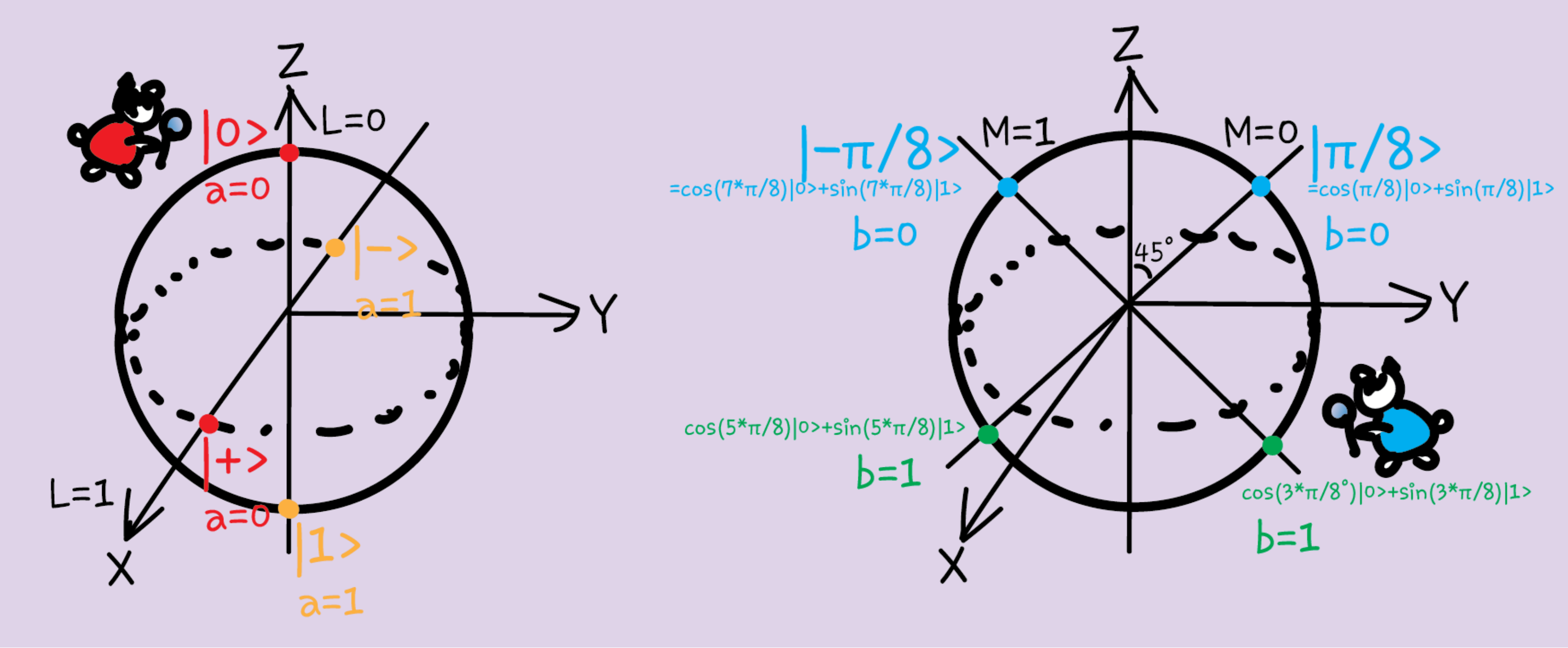
| a | b |
|---|---|
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |
| 0 | 0 |

CLASSICAL STRATEGY
≤75% chance of winning



QUANTUM STRATEGY
≥85% chance of winning!

Of course, that involves entanglement.
They pre-entangle qubits to 1/√2(|00>+|11>).



# Q# exercise:

**QDK Sample code**

https://docs.microsoft.com/quantum/

**Homework**

- The Quantum Katas project (tutorials and exercises for learning quantum computing) https://github.com/Microsoft/QuantumKatas
- **CHSH Game**

# General rotation

In general, rotation gates, R, about an axis can be described by the angles $\phi$ and $\theta$:

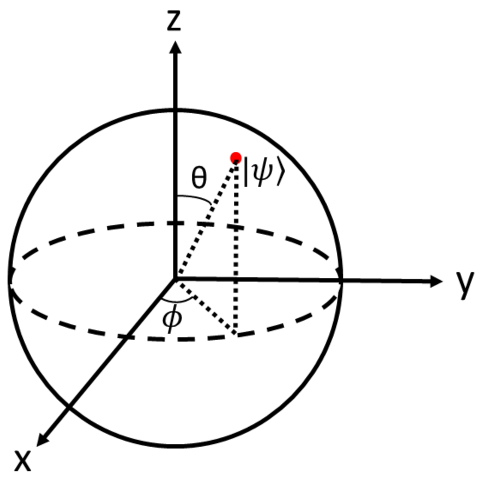
$$R_z(\phi) = \begin{bmatrix} e^{-i\phi/2} & 0 \\ 0 & e^{i\phi/2} \end{bmatrix},$$

$$R_y(\theta) = \begin{bmatrix} \cos\frac{\theta}{2} & -\sin\frac{\theta}{2} \\ \sin\frac{\theta}{2} & \cos\frac{\theta}{2} \end{bmatrix},$$

and

$$R_x(\theta) = \begin{bmatrix} \cos\frac{\theta}{2} & -i\sin\frac{\theta}{2} \\ -i\sin\frac{\theta}{2} & \cos\frac{\theta}{2} \end{bmatrix}$$

$$=R_z\left(\frac{\pi}{2}\right)R_y(\theta)R_z\left(-\frac{\pi}{2}\right).$$




https://review.docs.microsoft.com/en-us/quantum/concepts/the-qubit?branch=tensor-product

# More discussions

- The CHSH Game: Lecture 7 of Quantum Computation at CMU Ryan O'Donnell

- https://www.youtube.com/watch?v=1nh-pjxnM4I

- Classical scenarios

# No-Cloning Theorem

Assume we have a function, Copy, such that:

$$\text{Copy}\ ( |\psi\rangle \otimes |0\rangle ) = |\psi\rangle \otimes |\psi\rangle,$$

which would expand out to (substituting for $|\psi\rangle$):

$$= (\alpha|0\rangle + \beta|1\rangle ) \otimes (\alpha|0\rangle + \beta|1\rangle )$$

$$= \alpha^2|00\rangle + \beta^2|11\rangle + \alpha\beta( |01\rangle + |10\rangle ) . \qquad (1)$$

You can also evaluate the Copy function by expanding $|\psi\rangle$ first:

$$\text{Copy}\ ( |\psi\rangle \otimes |0\rangle ) = \text{Copy}\ ( \alpha|0\rangle \otimes |0\rangle + \beta|1\rangle \otimes |0\rangle )$$

$$= \alpha\ ( \text{Copy}\ |00\rangle ) + \beta\ ( \text{Copy}\ |10\rangle )$$

$$= \alpha|00\rangle + \beta|11\rangle. \qquad (2)$$

Here we have our contradiction, because both (1) and (2) cannot be true at the same time for an arbitrary state.

# Participate

- July 16 Azure Quantum Developer Workshop https://aka.ms/AQDW

# Questions

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