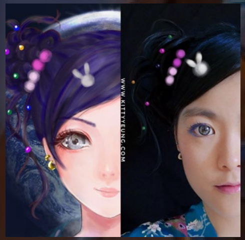
Introduction to Quantum Computing



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March 29, 2020
Hackaday

Class structure

- Comics on Hackaday – Introduction to Quantum Computing every Wed & Sun

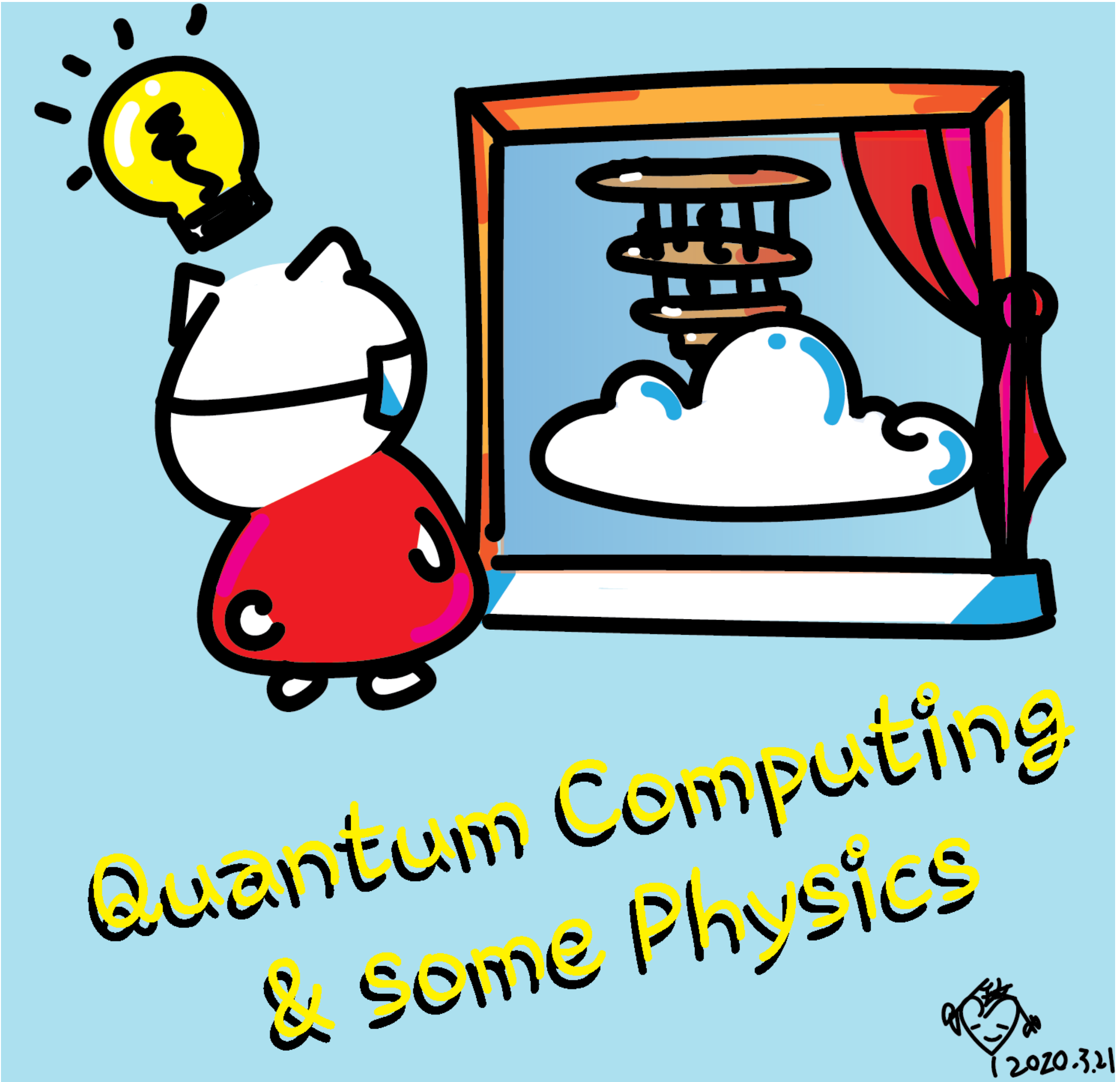
- 30 mins every Sun, one concept (theory, hardware, programming), Q&A

- 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



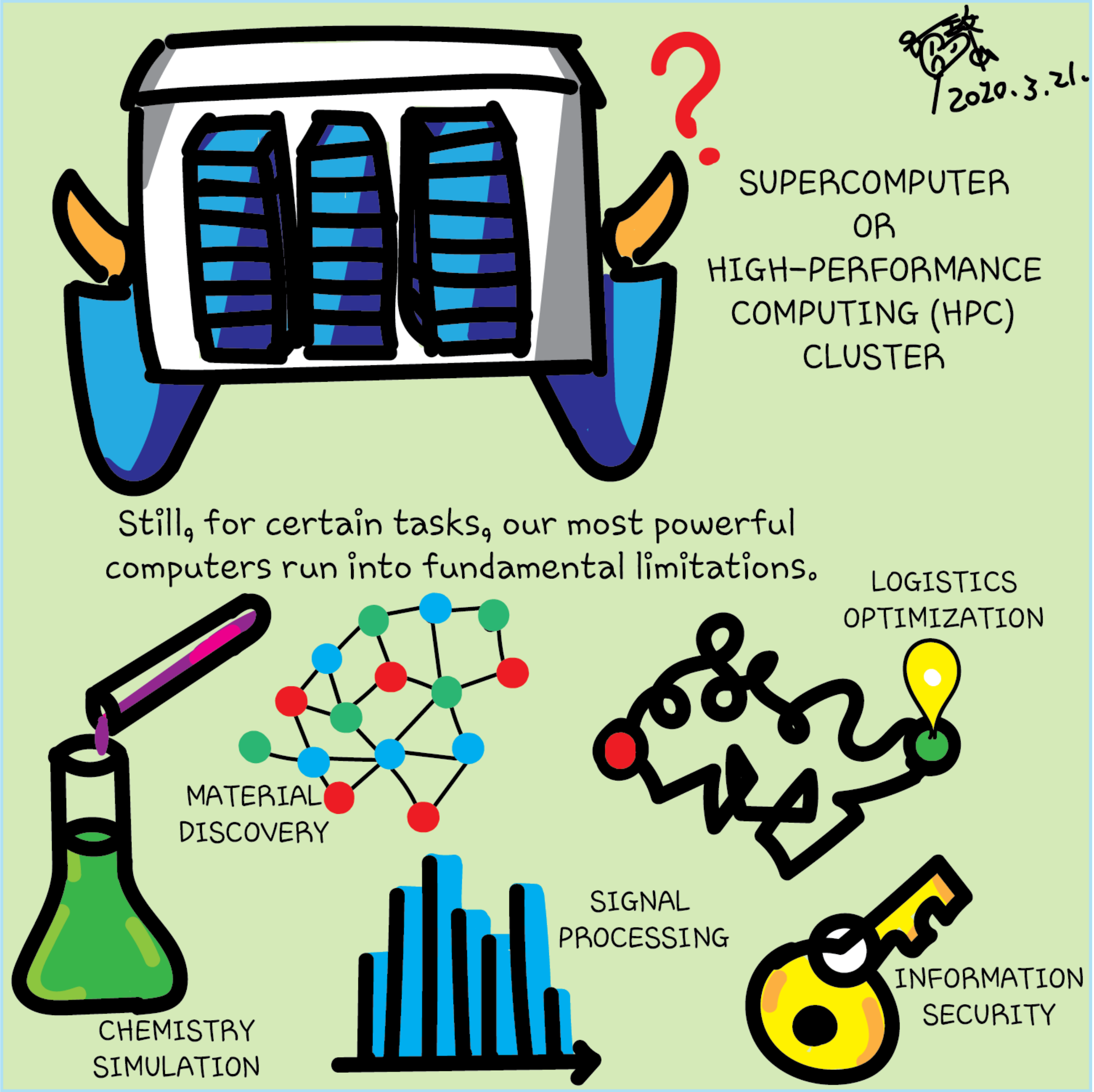
Reinforcement learning for natural intelligence

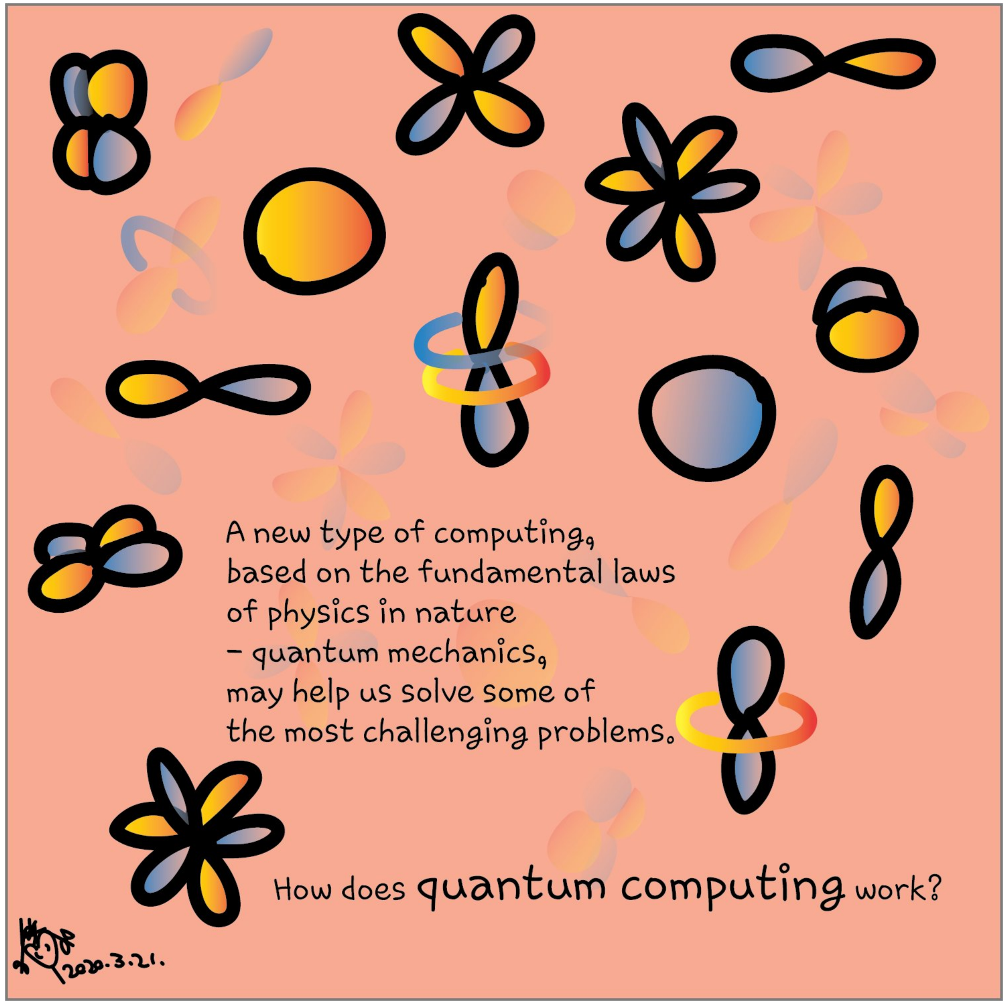
- Interactive class, feel free to ask questions
- Anything confusing? I’ll try to explain a different way

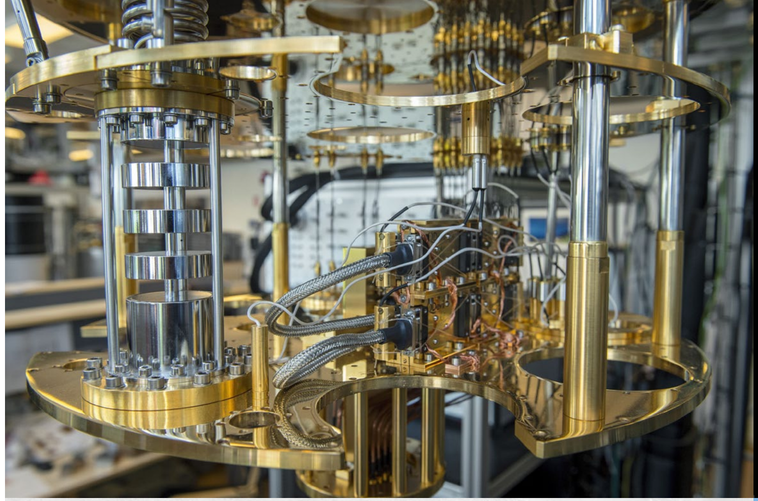
Our world now runs on computers
2020.3.21
– they are machines we task to carry out work more efficiently than we ever do manually.
DATA CENTER SERVERS
PUBLIC HEALTH
MOBILITY
EDUCATION
PRODUCTION
People and things are connected through the internet.

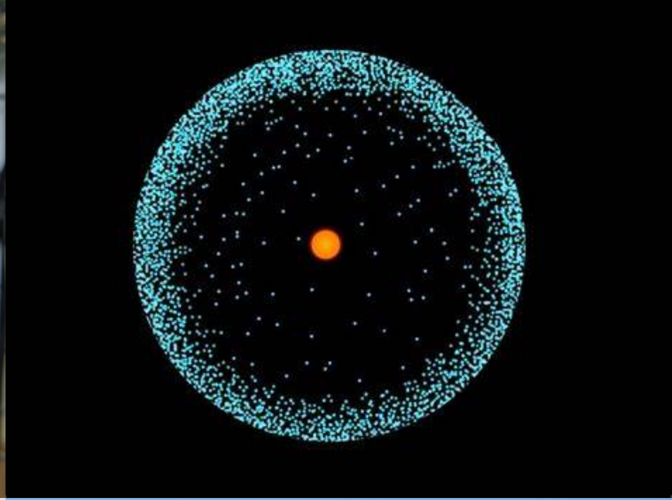
Applications

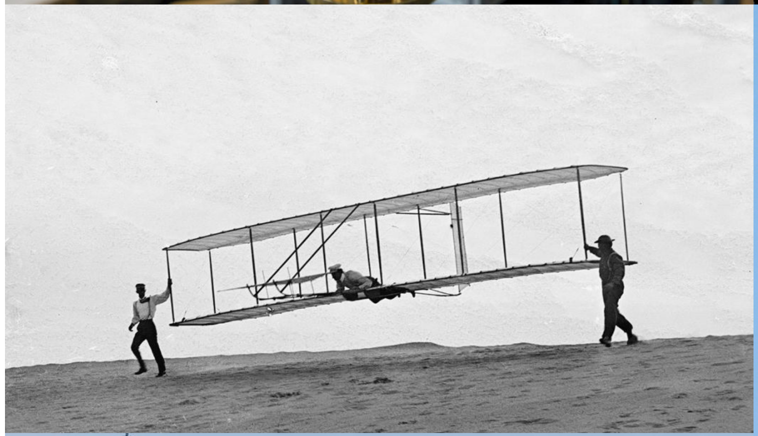
- Quantum simulations
- Algorithms
- Cryptography

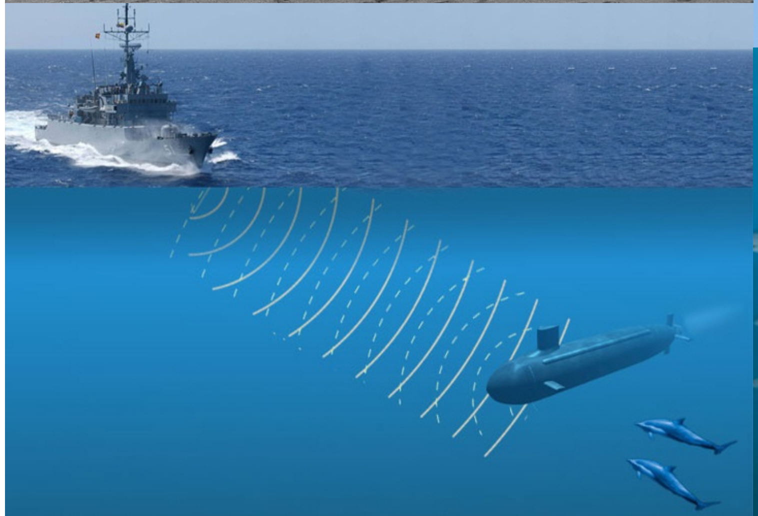


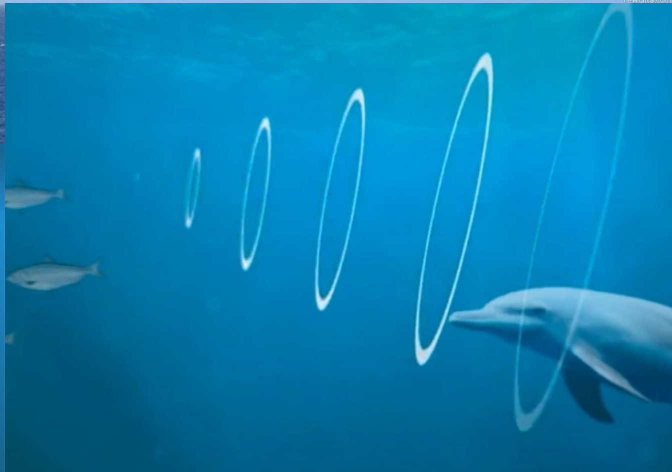

A new type of computing,
based on the fundamental laws
of physics in nature
– quantum mechanics,
may help us solve some of
the most challenging problems.
How does quantum computing work?
2020.3.21.











What is it?

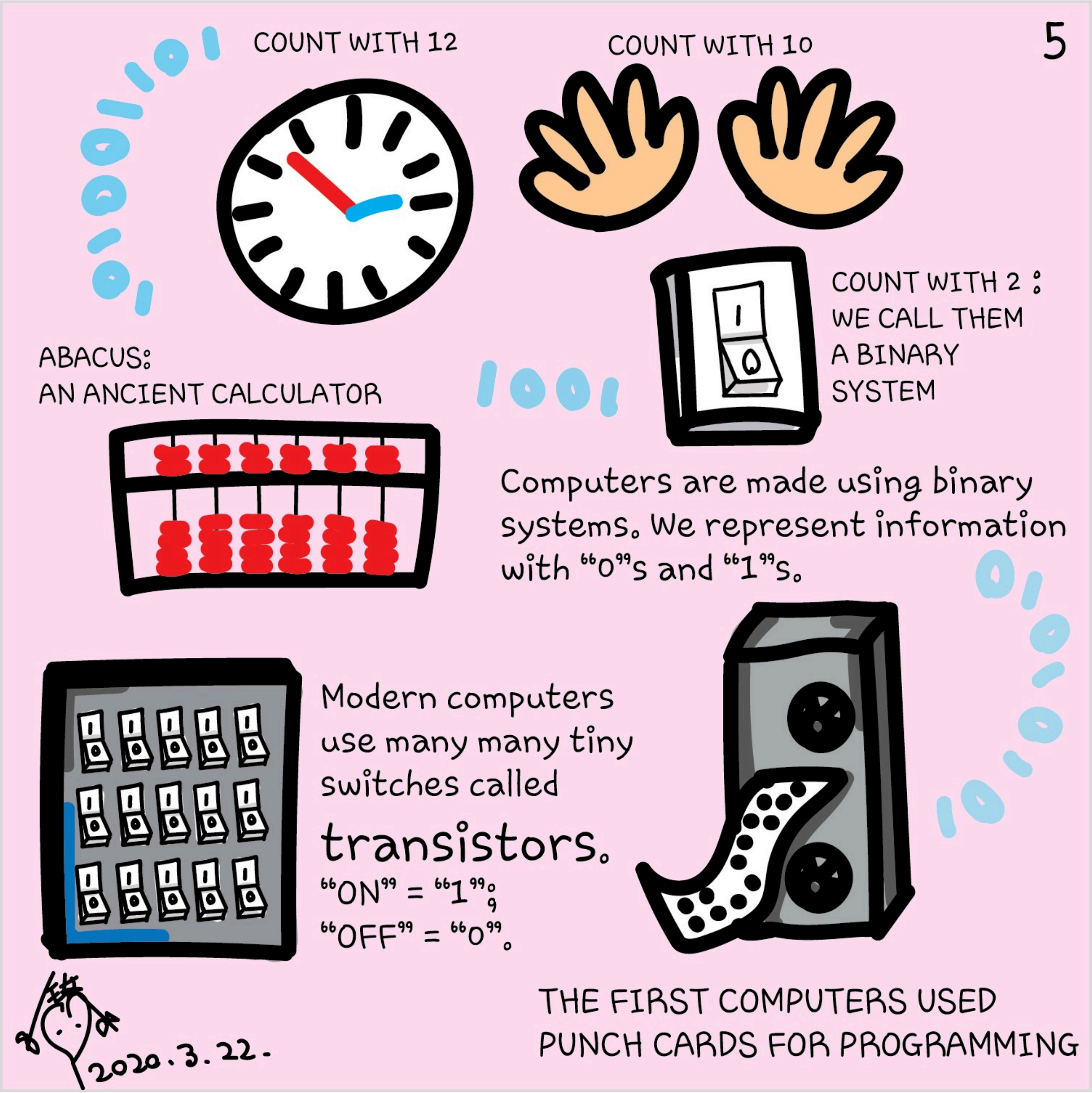
Performing calculations based on the laws of quantum mechanics

1980 & 1982: Manin & Feynman proposed the idea of creating machines based on the laws of quantum mechanics

1985: David Deutsch developed Quantum Turing machine, showing that quantum circuits are universal

1994: Peter Shor came up with a quantum algorithm to factor very large numbers in polynomial time

1997: Grover developed a quantum search algorithm with $O(\sqrt{N})$ complexity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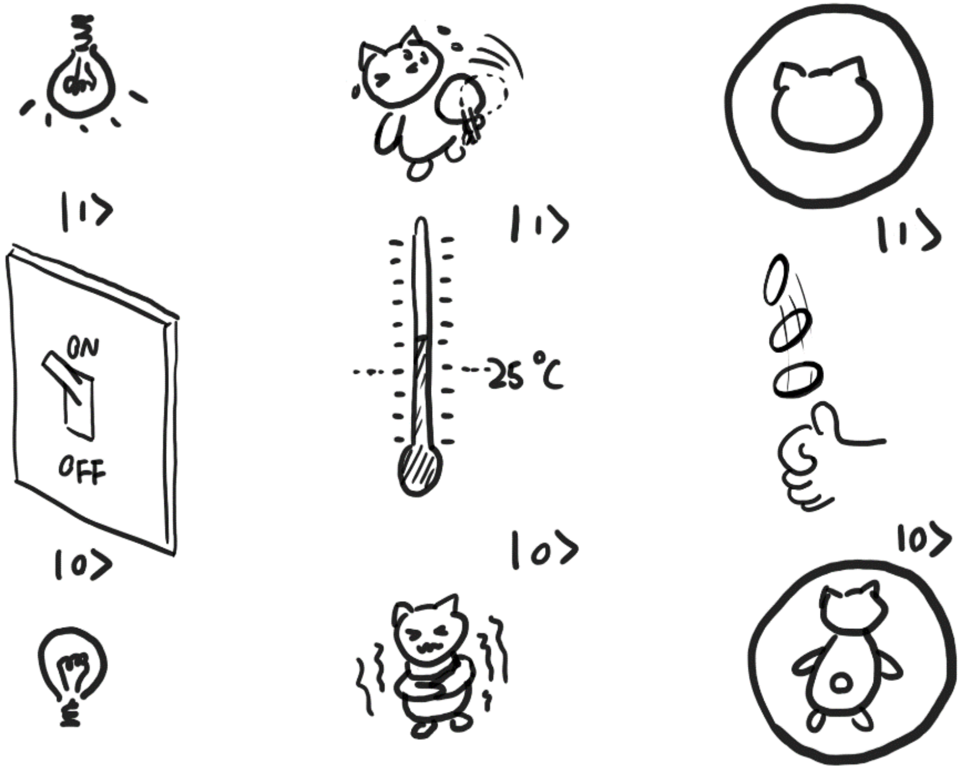
COUNT WITH 12
COUNT WITH 10
COUNT WITH 2 :
WE CALL THEM
A BINARY
SYSTEM
ABACUS:
AN ANCIENT CALCULATOR
Computers are made using binary systems. We represent information with "0"s and "1"s.
Modern computers use many many tiny switches called
transistors.
"ON" = "1";
"OFF" = "0".
THE FIRST COMPUTERS USED
PUNCH CARDS FOR PROGRAMMING
2020.3.22.

States – classical bits

$$|0\rangle = \begin{pmatrix}1\\0\end{pmatrix}, \quad |1\rangle = \begin{pmatrix}0\\1\end{pmatrix}$$



MULTIPLE CLASSICAL BITS OF "0"s & "1"s.

$$|0\rangle = \begin{pmatrix}1\\0\end{pmatrix}, \qquad |1\rangle = \begin{pmatrix}0\\1\end{pmatrix}$$

$$|00\rangle = \begin{pmatrix}1\\0\end{pmatrix} \otimes \begin{pmatrix}1\\0\end{pmatrix} = \begin{pmatrix}1\\0\\0\\0\end{pmatrix}.$$

$$|01\rangle = \begin{pmatrix}1\\0\end{pmatrix} \otimes \begin{pmatrix}0\\1\end{pmatrix} = \begin{pmatrix}0\\1\\0\\0\end{pmatrix},$$

$$|10\rangle = \begin{pmatrix}0\\1\end{pmatrix} \otimes \begin{pmatrix}1\\0\end{pmatrix} = \begin{pmatrix}0\\0\\1\\0\end{pmatrix},$$

$$|11\rangle = \begin{pmatrix}0\\1\end{pmatrix} \otimes \begin{pmatrix}0\\1\end{pmatrix} = \begin{pmatrix}0\\0\\0\\1\end{pmatrix}.$$

Math insert - Tensor product--

How does tensor product $\otimes$ work?

$$\begin{pmatrix}x_0\\x_1\end{pmatrix} \otimes \begin{pmatrix}y_0\\y_1\end{pmatrix} = \begin{pmatrix}x_0\begin{pmatrix}y_0\\y_1\end{pmatrix}\\ x_1\begin{pmatrix}y_0\\y_1\end{pmatrix}\end{pmatrix} = \begin{pmatrix}x_0y_0\\x_0y_1\\x_1y_0\\x_1y_1\end{pmatrix}$$

and

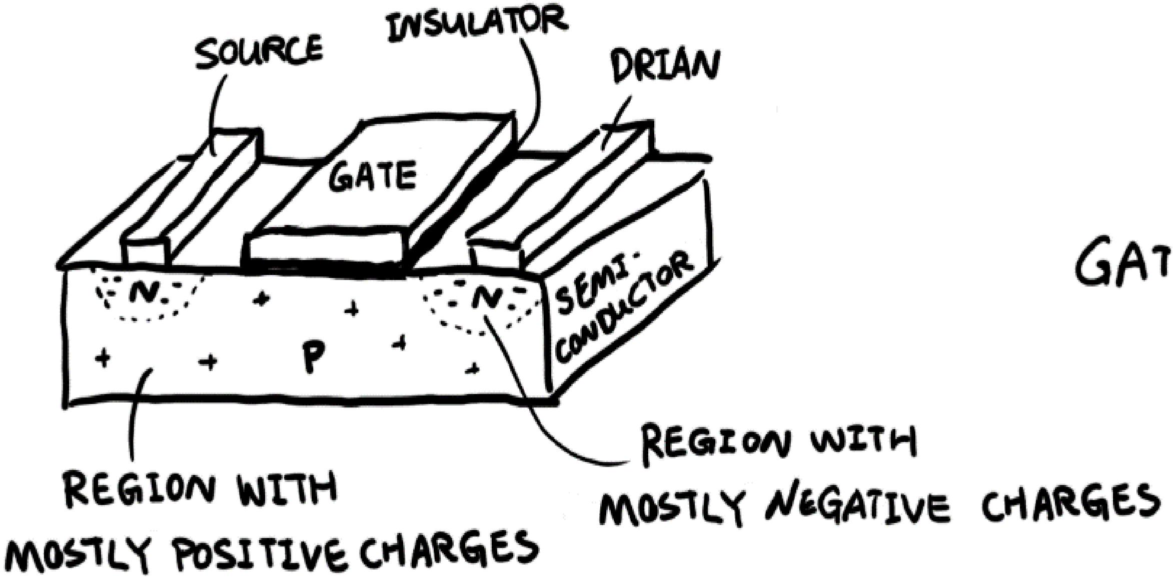
$$\begin{pmatrix}x_0\\x_1\end{pmatrix} \otimes \begin{pmatrix}y_0\\y_1\end{pmatrix} \otimes \begin{pmatrix}z_0\\z_1\end{pmatrix} = \begin{pmatrix}x_0y_0z_0\\x_0y_0z_1\\x_0y_1z_0\\x_0y_1z_1\\x_1y_0z_0\\x_1y_0z_1\\x_1y_1z_0\\x_1y_1z_1\end{pmatrix}$$

and so on.

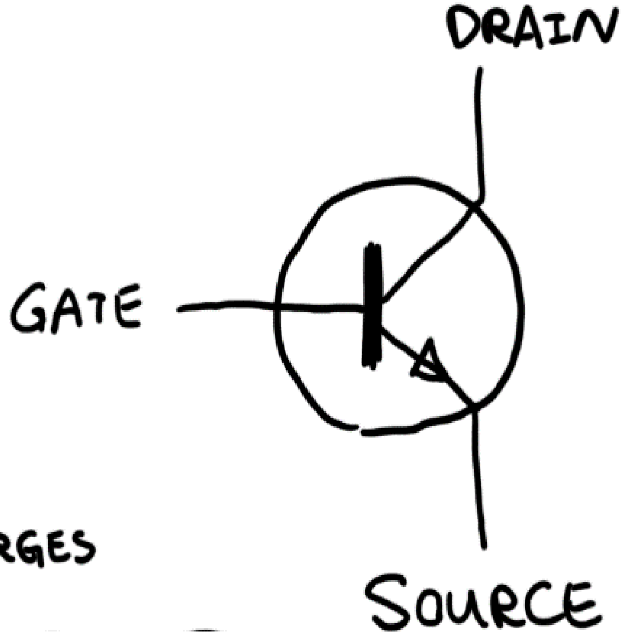
For example, the number 4 can be represented with a three-bit string 100. We can write

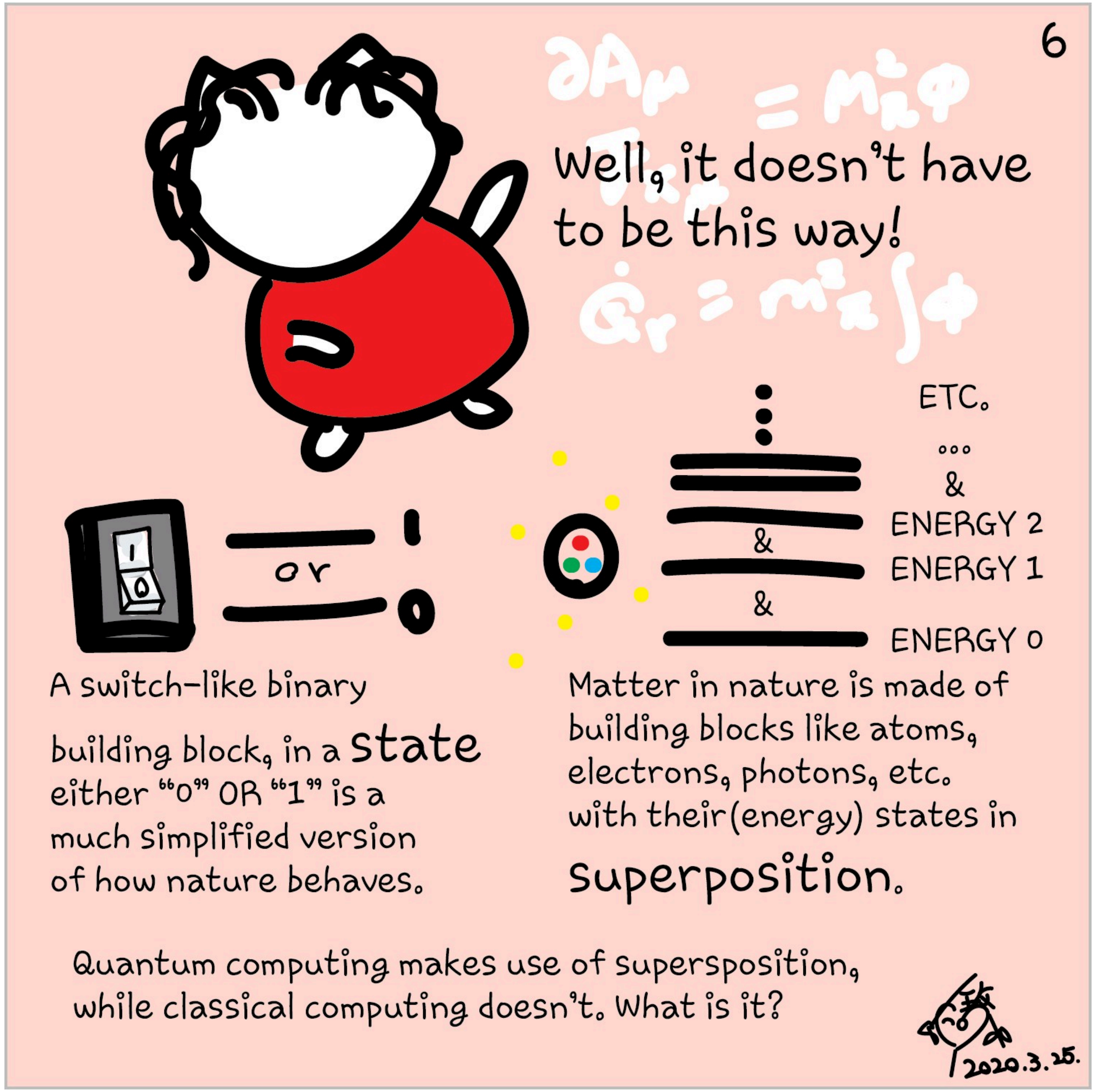
$$|4\rangle = |100\rangle = \begin{pmatrix}0\\1\end{pmatrix} \otimes \begin{pmatrix}1\\0\end{pmatrix} \otimes \begin{pmatrix}1\\0\end{pmatrix} = \begin{pmatrix}0\\0\\0\\0\\1\\0\\0\\0\end{pmatrix}.$$

MATERIAL CROSS-SECTION



CIRCUIT SYMBOL

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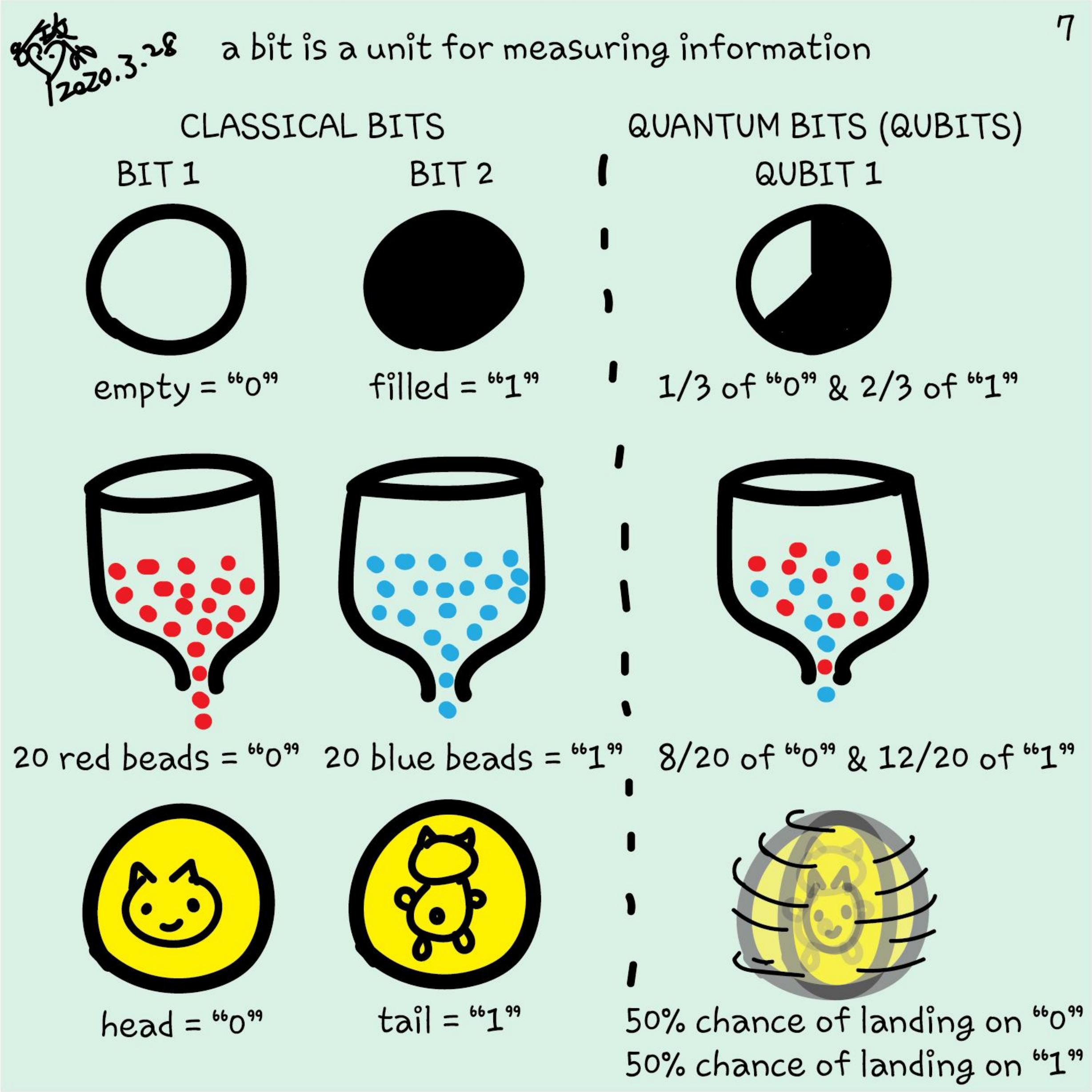
Well, it doesn't have to be this way!
ETC.
...
&
ENERGY 2
&
ENERGY 1
&
ENERGY 0
1
or
0
A switch-like binary building block, in a state either "0" OR "1" is a much simplified version of how nature behaves.
Matter in nature is made of building blocks like atoms, electrons, photons, etc. with their (energy) states in superposition.
Quantum computing makes use of supersposition, while classical computing doesn't. What is it?
2020.3.25.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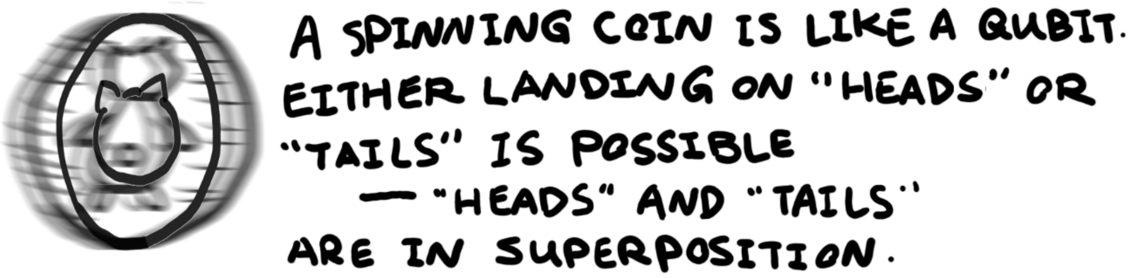
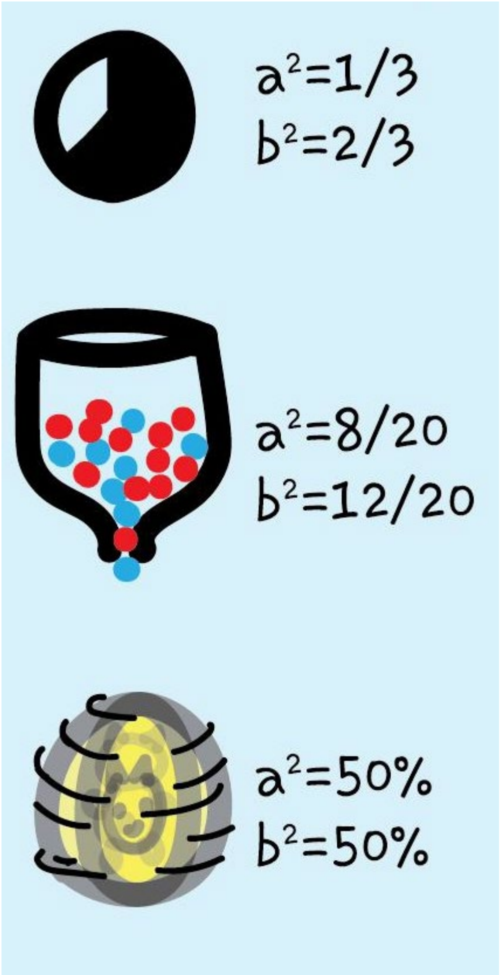
2020.3.28
a bit is a unit for measuring information
CLASSICAL BITS
BIT 1
BIT 2
QUANTUM BITS (QUBITS)
QUBIT 1
empty = "0"
filled = "1"
1/3 of "0" & 2/3 of "1"
20 red beads = "0"
20 blue beads = "1"
8/20 of "0" & 12/20 of "1"
head = "0"
tail = "1"
50% chance of landing on "0"
50% chance of landing on "1"

Quantum bits – qubits

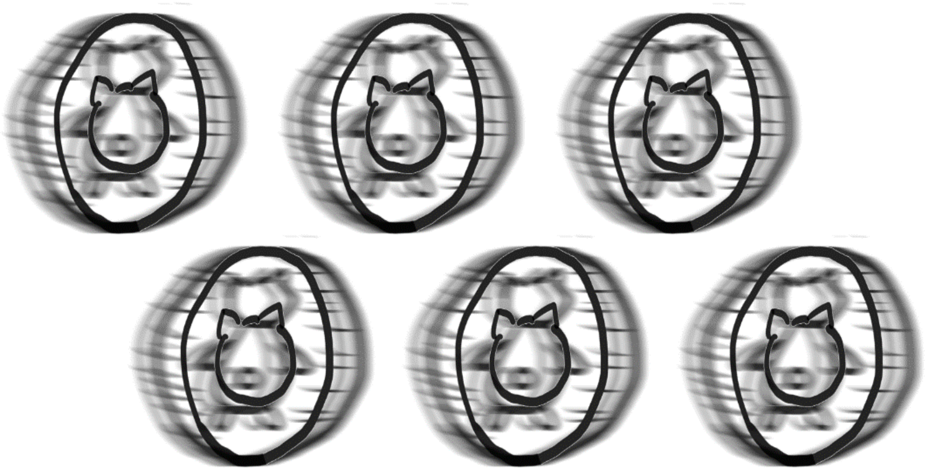




$$|\psi\rangle = \binom{a}{b} = a|0\rangle + b|1\rangle$$

$$|a|^2 + |b|^2 = 1$$

Quantum bits – qubits



Two qubits:

$$|\psi\rangle = \begin{pmatrix} a \\ b \end{pmatrix} \otimes \begin{pmatrix} c \\ d \end{pmatrix}$$

$$= \begin{pmatrix} ac \\ ad \\ bc \\ bd \end{pmatrix}$$

$$= ac|00\rangle + ad|01\rangle + bc|10\rangle + bd|11\rangle$$

$$|ac|^2 + |ad|^2 + |bc|^2 + |bd|^2 = 1$$