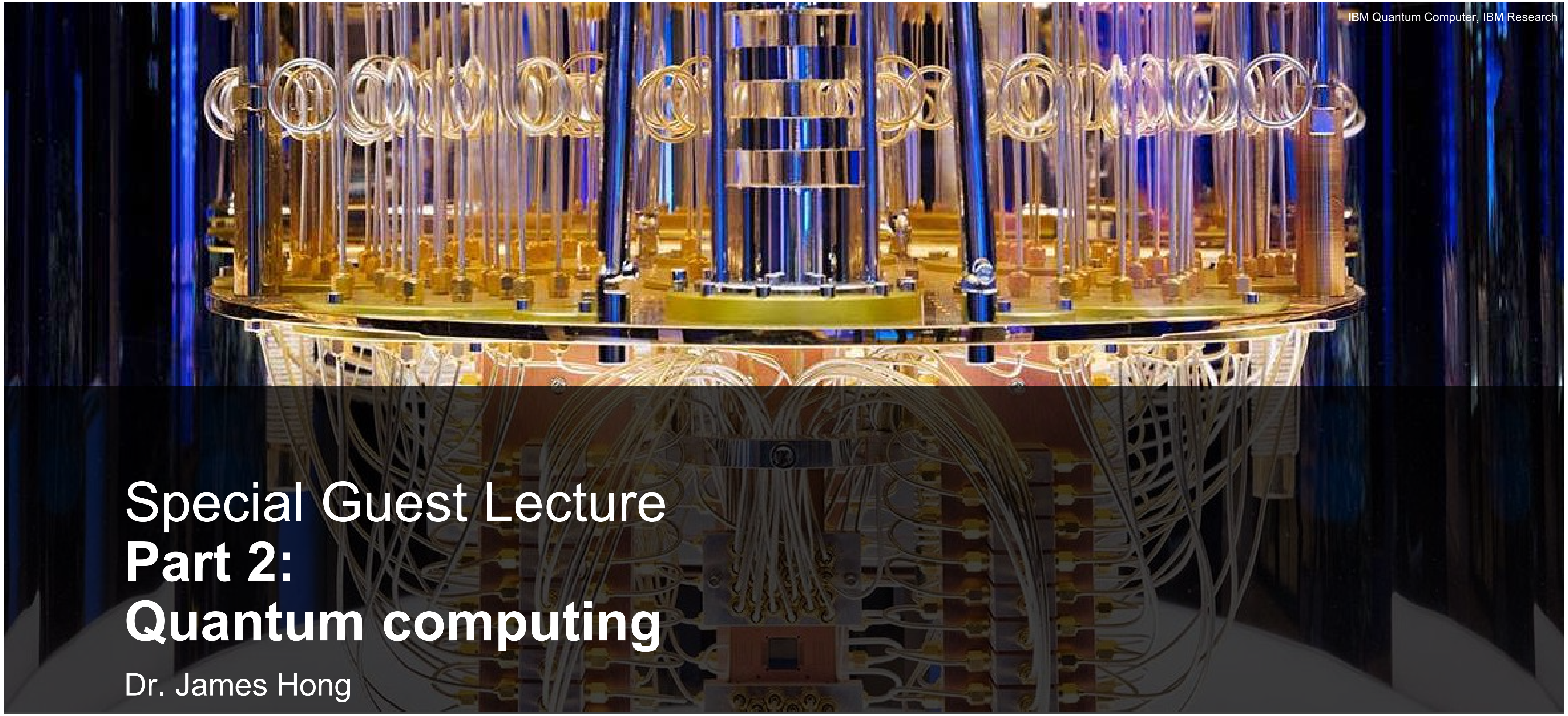
IBM Quantum Computer, IBM Research

Special Guest Lecture
Part 2:
Quantum computing

Dr. James Hong

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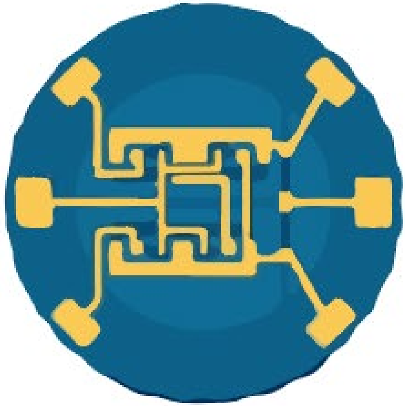
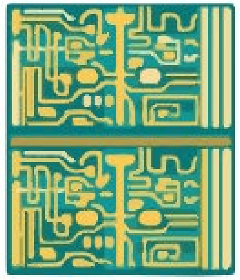
Overview

- Moore's Law
- Basics of computing
- Quantum computing 101
- An example of quantum computing vs. classical computing

Technology reaching its limits



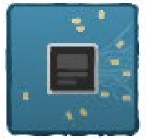
1960s



1970s

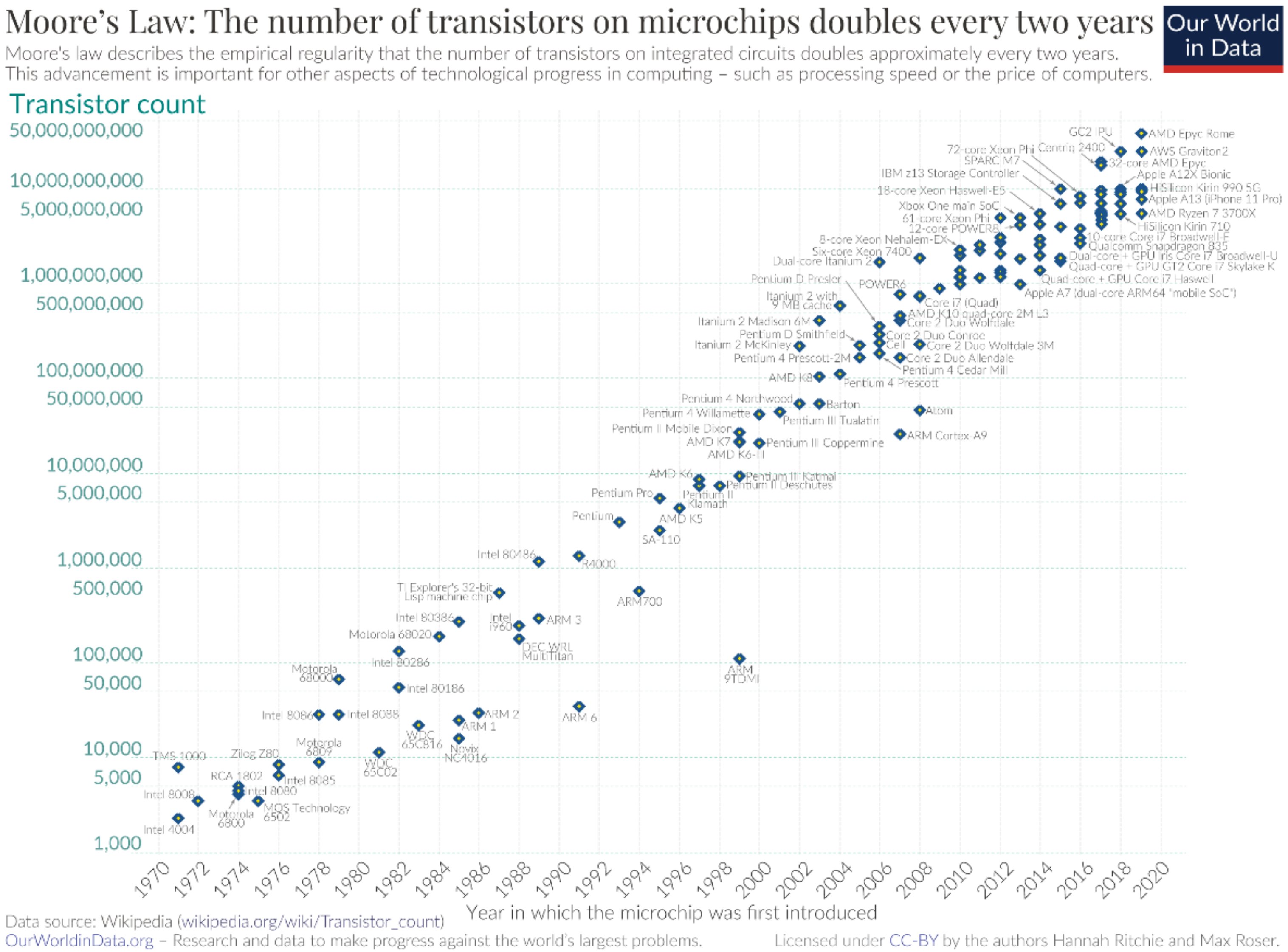
1980s

Transistors are approaching size of 1 atom



Now

Moore’s Law



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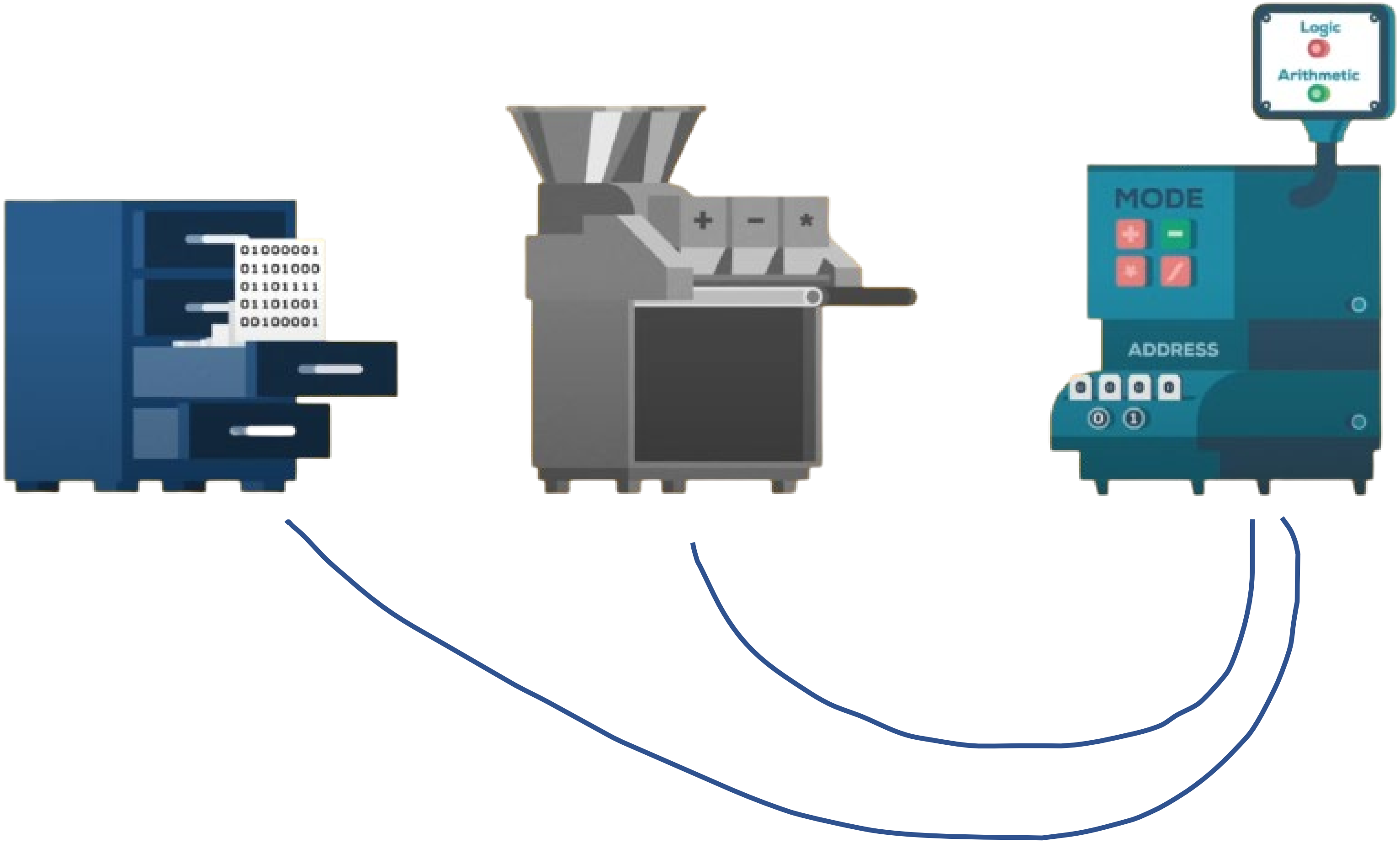
The structure of a basic computer

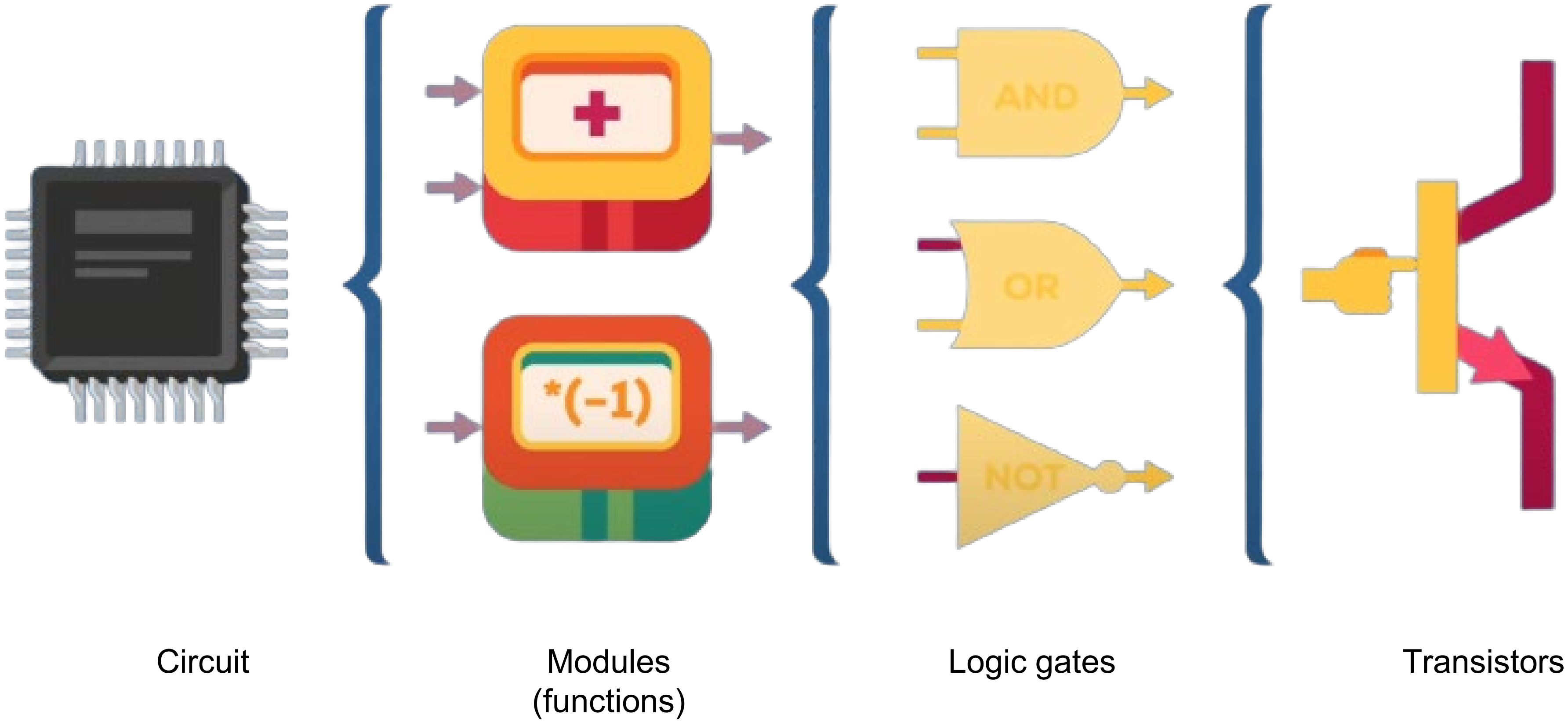
Memory
(Storage)

Arithmetic Unit
(Processing)

Control Unit
(Command)

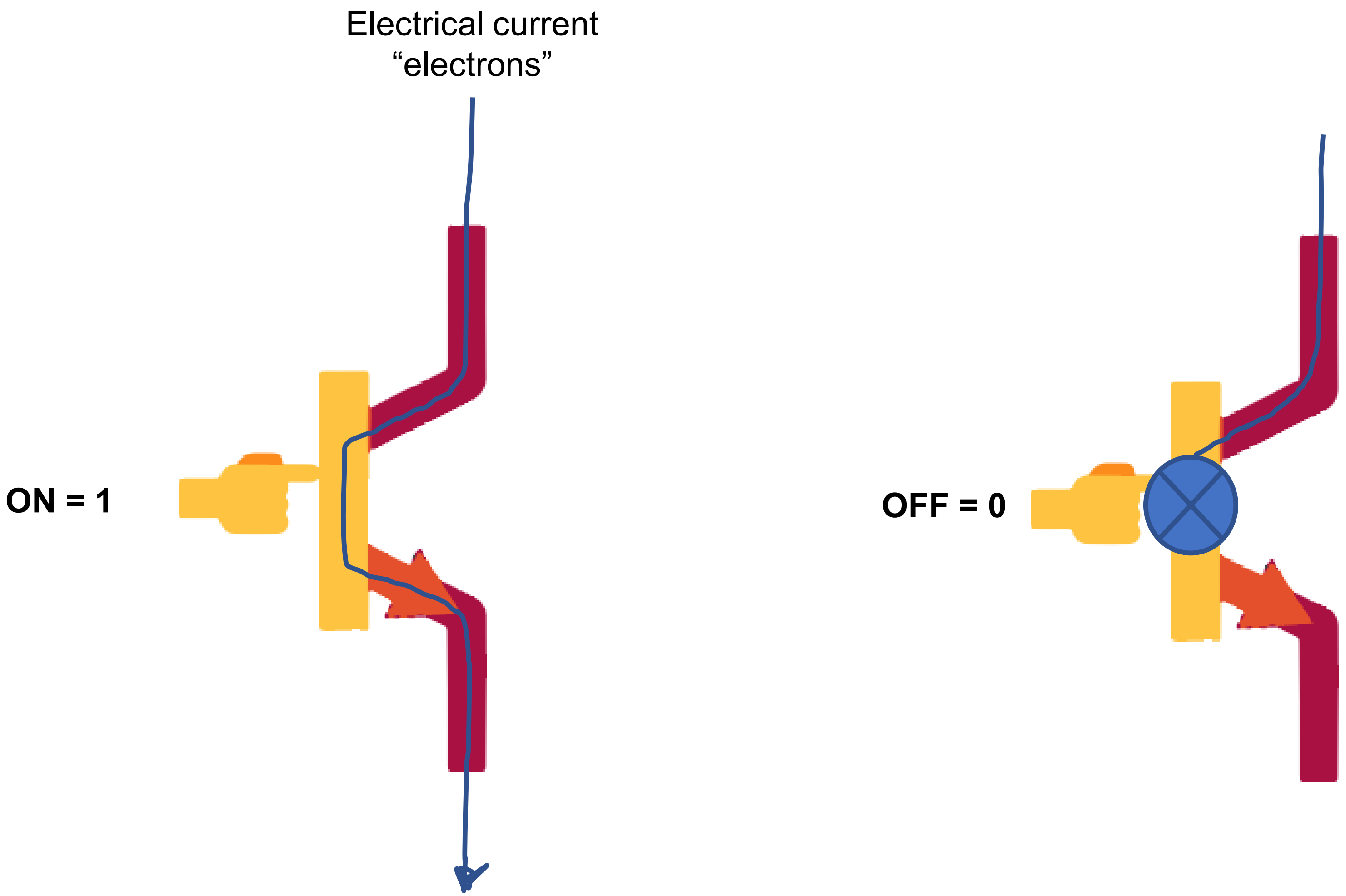


Inside a circuit



The transistor and a bit

Binary state

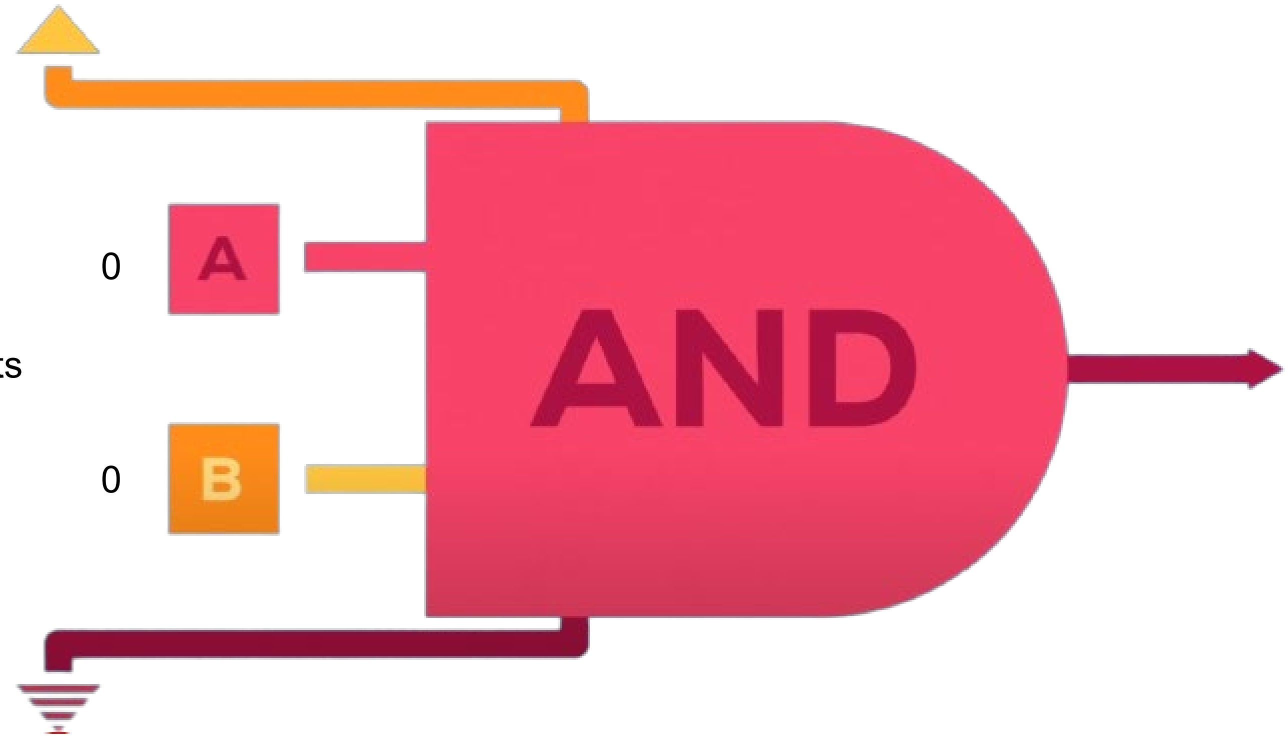


Transistors combine to form logic gates

Two bits

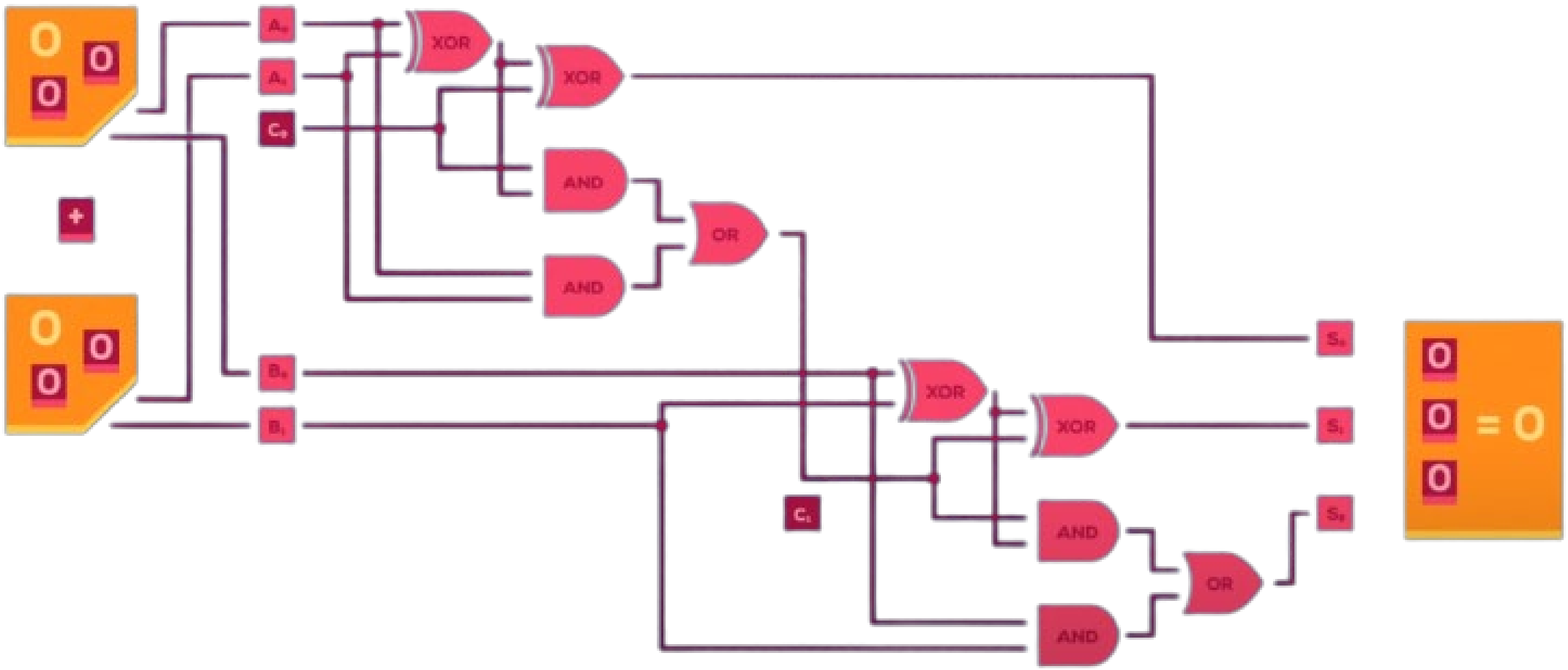
0

0

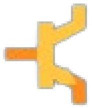


A	B	Z
0	0	0
0	1	0
1	0	0
1	1	1

Transistors + logic gates = modules



Small objects have quantum physical behaviour



14 nm

HIV

120 nm

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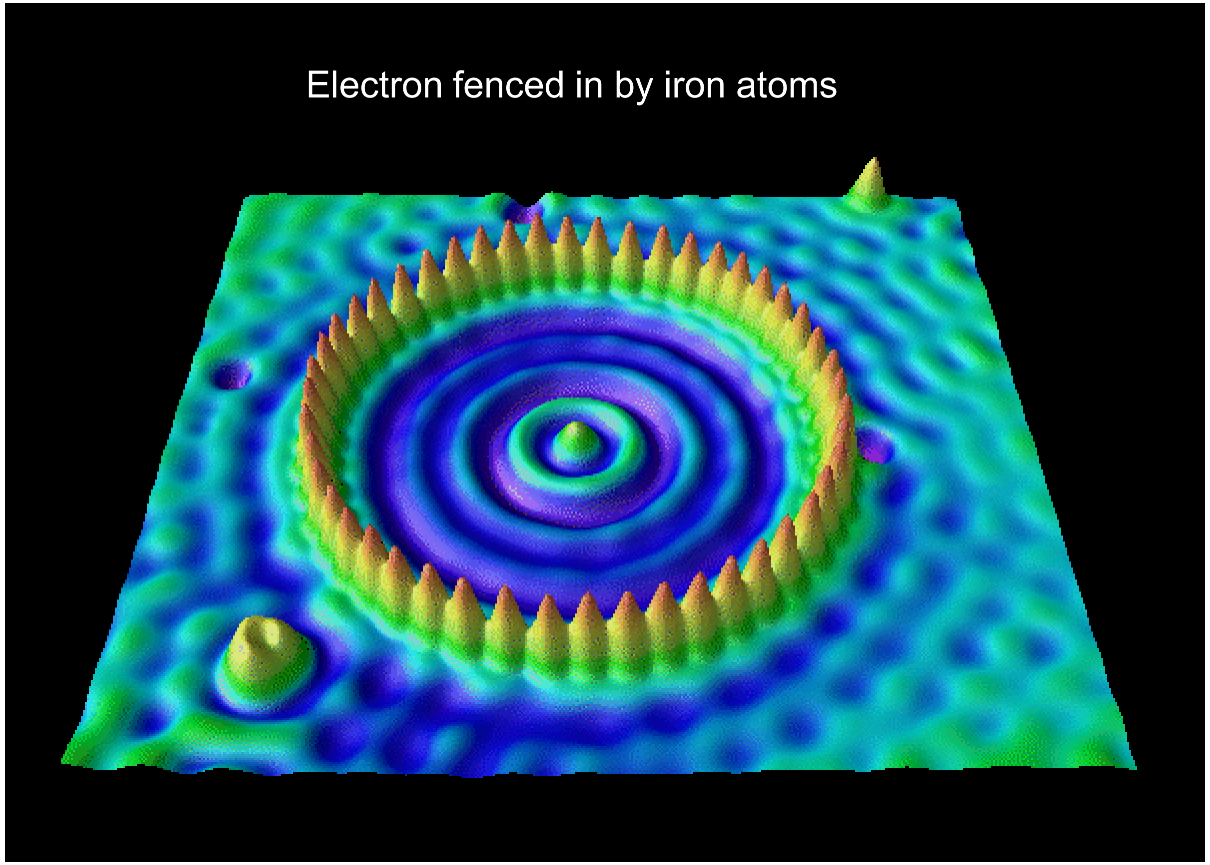
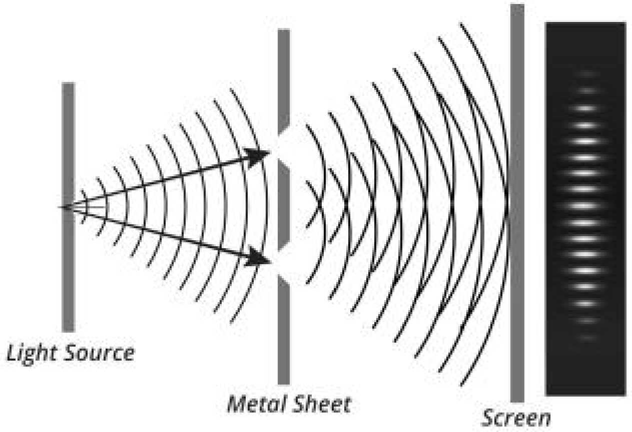
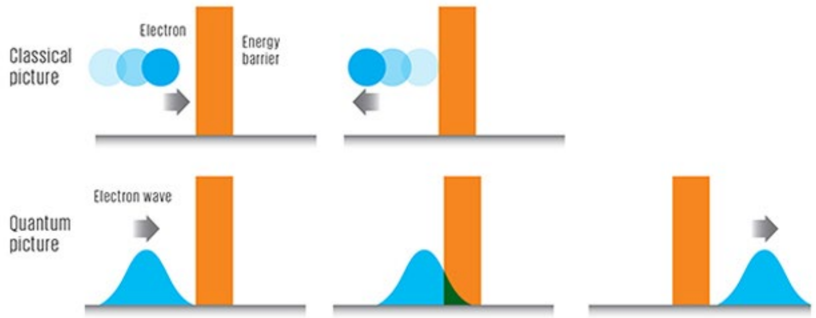
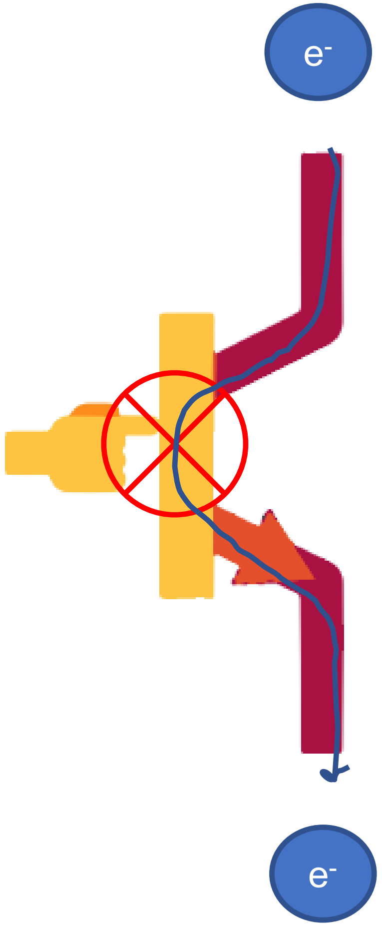
Quantum object can have wave-like behaviour





Subatomic transistors cannot regulate electrons





"Quantum tunneling"

Exploiting quantum weirdness, a qubit

1) Quantum superposition

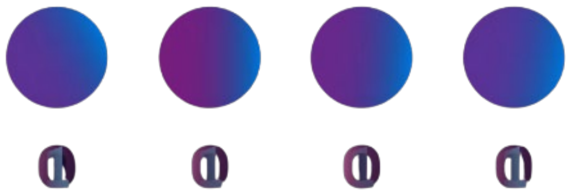
Can be both
0 and 1

Like a coin flip while still in the air

Collapses into 0 or 1 if measured

Quantum vs classical information storage

4 bits = 2^4 combinations = one combination at a time

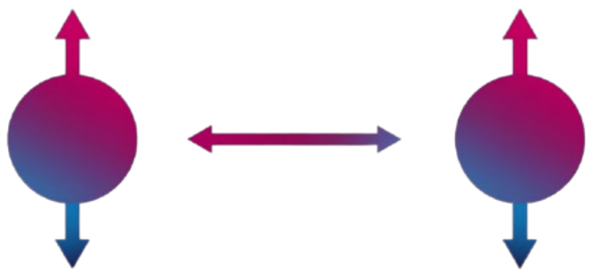


4 qubits = can be in all 16 combinations at the same time

20 qubits = 1 million values simultaneously

More quantum weirdness

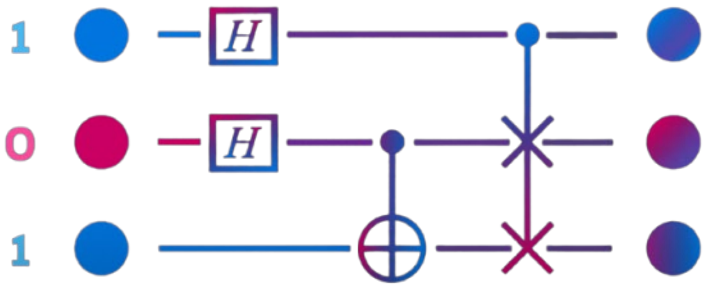
2) Quantum entanglement



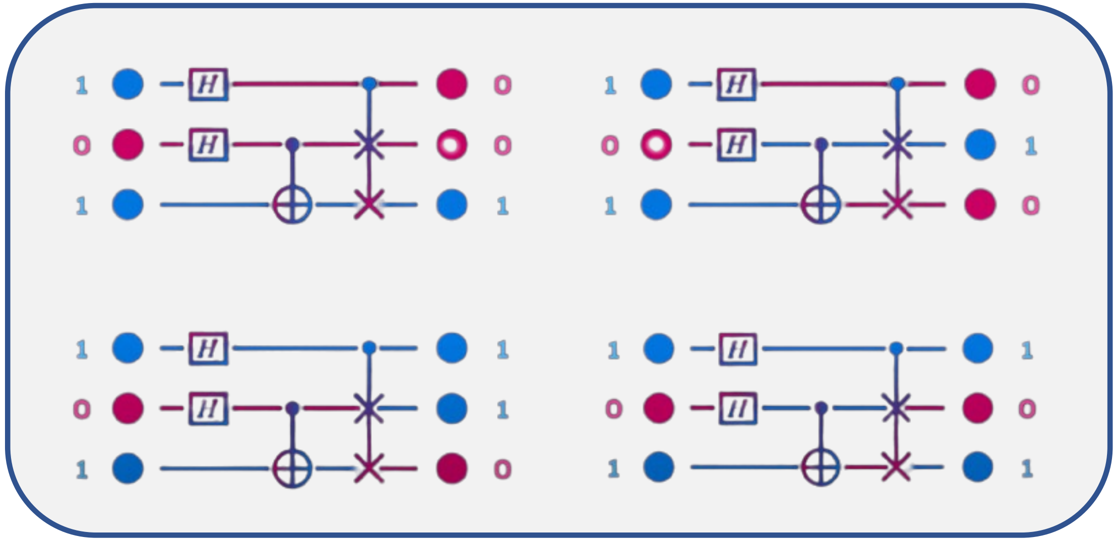
Entangled qubits

When one qubit is measured both will become 1

Quantum circuits

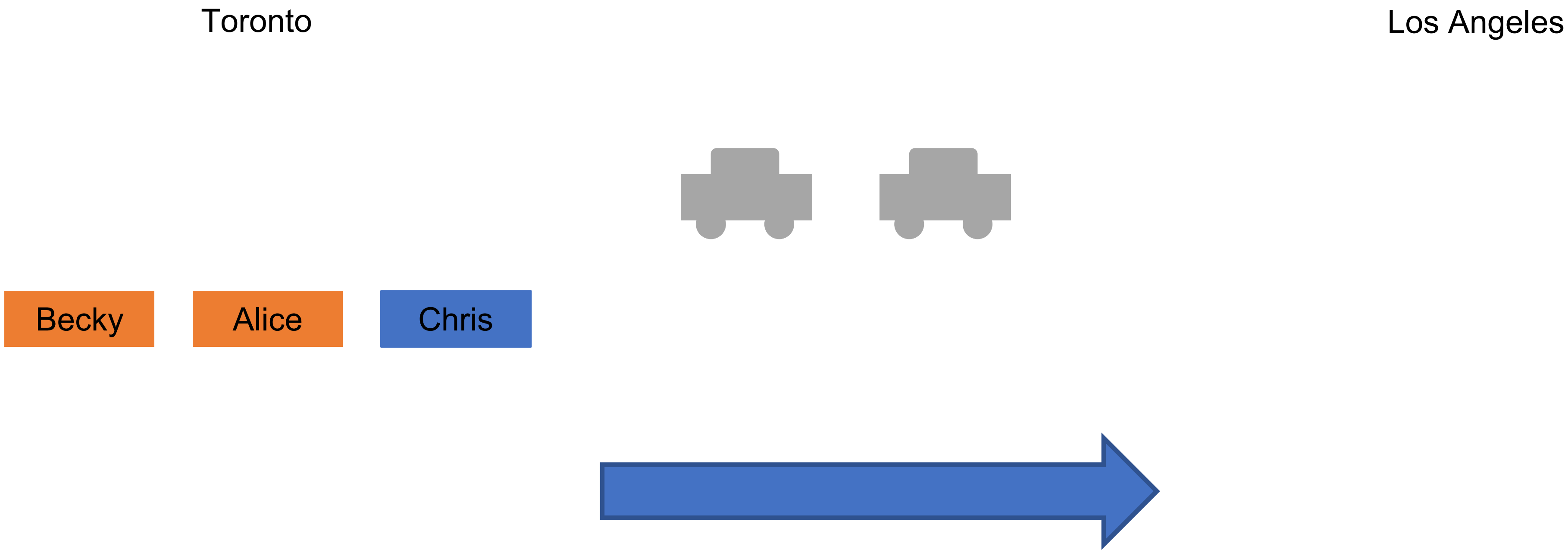


Getting all the solutions at once



An example to help

Maximize the number of **friend pairs** that share the same car
Minimize the number of **enemy pairs** that share the same car



Classical solution

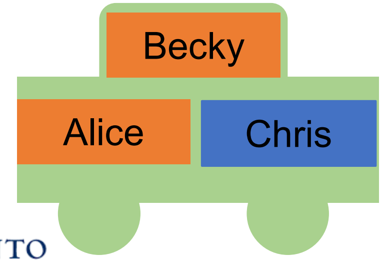
Maximize the number of **friend pairs** that share the same car
Minimize the number of **enemy pairs** that share the same car

Toronto

Los Angeles

Becky Alice Chris

1. Store data with bits
2. Taxi #1 = 0, Taxi #2 = 1
3. Each person has only two choices so all combinations can be represented in 3 bits



A B C
= 1 1 1

Score of this option is 1 friend pair – 2 enemy pairs = -1

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Classical solution, cont.

This problem is fairly simple. It quickly becomes too difficult to solve with a regular computer as we increase the number of people in this problem.

A	B	C	Score
0	0	0	-1
0	**0**	**1**	**1**
0	1	0	-1
0	1	1	-1
1	0	0	-1
1	0	1	-1
1	**1**	**0**	**1**
1	1	1	-1

Two solutions that have equal score

Classical computing fails with scaling

- 3 people = 8 configurations
- 4 people = 16 configurations
- With *N* people, 2^N configurations = classical approach
- Becomes impossible to solve with a regular computer

Quantum solutions scale very well

- Classical = 3 bits = 1 of 8 configurations at a time
- Quantum = 3 qubits = 8 of 8 configurations at a time
- When you apply some sort of computation on these 3 qubits, you are computating **in all of those 8 configurations at the same time**
- Even with 100 people = 100 qubits, the number of operations required to solve the problem is 1

What does the quantum computer need?

- All potential solutions represented with qubits
- A function that turns each potential solution into a score
- In this case, this is the function that counts the numbers of friend pairs and enemy pairs sharing the same car

The reality with the quantum solution

- There are errors when running a quantum computer
- So, instead of finding the best solution, it might find the second-best solution, the third best solution, and so on
- These errors become more prominent as the problem becomes more and more complex
- So, in practice, you will probably want to run the same operation on a quantum computer dozens of times or hundreds of times. Then pick the best result out of the many results you get

Don’t fret if this is confusing