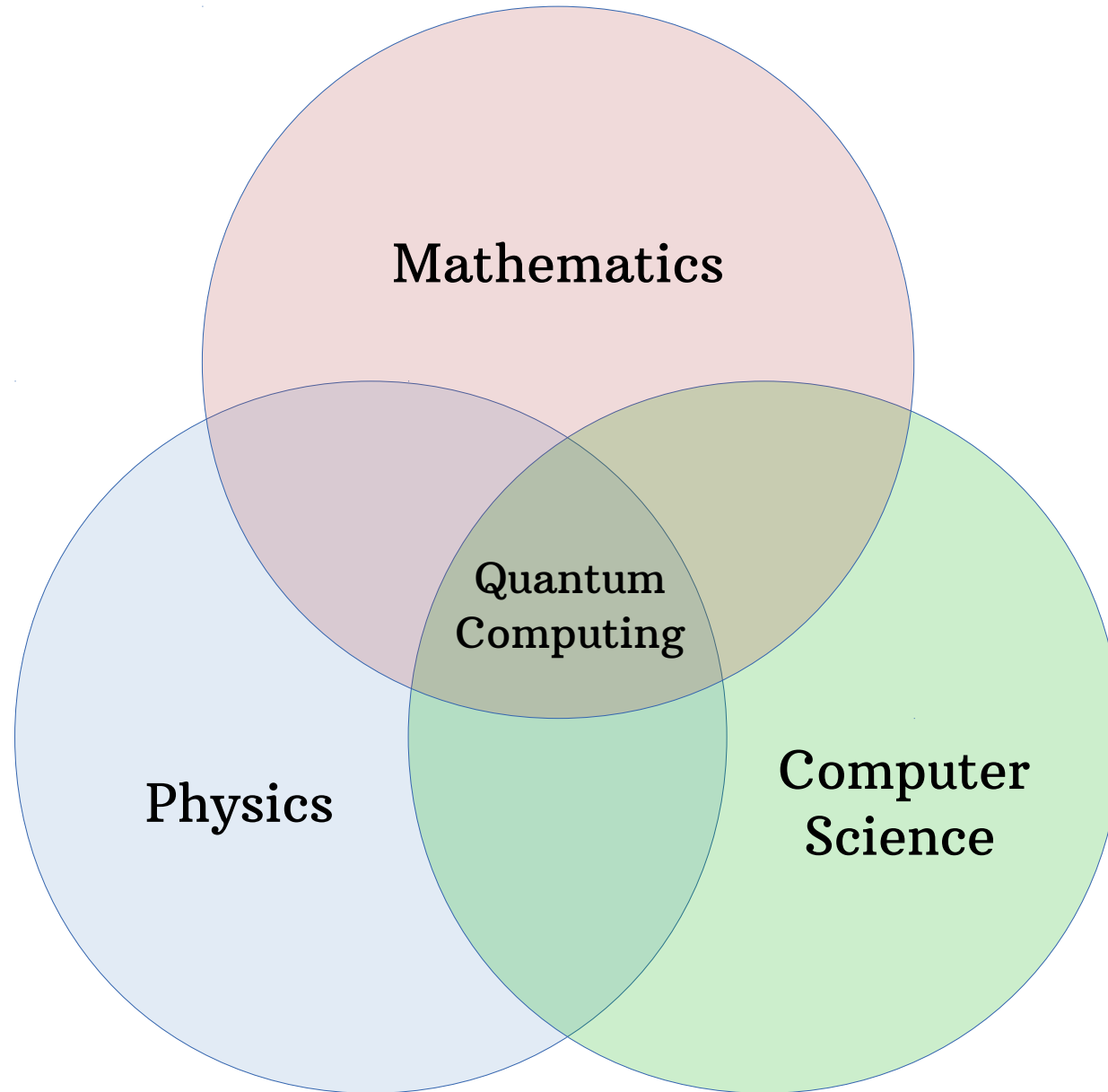


How to teleport your cat?



Māris Ozols
University of Cambridge

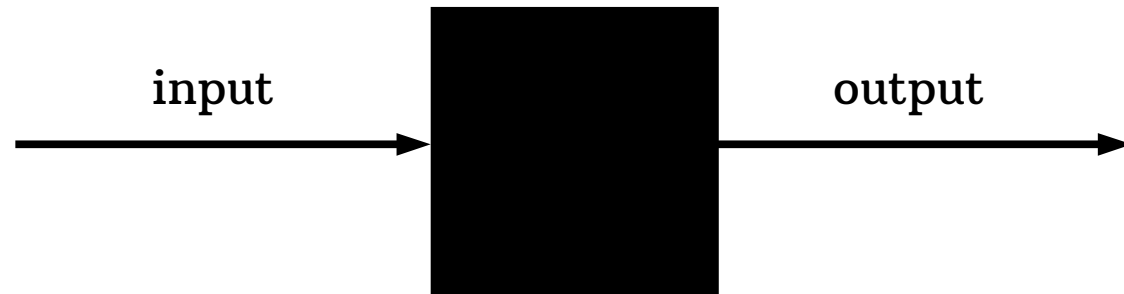
What is quantum computing?



What is a computer?

What is a computer?

A physical device for processing information





MacBook Pro (2012)



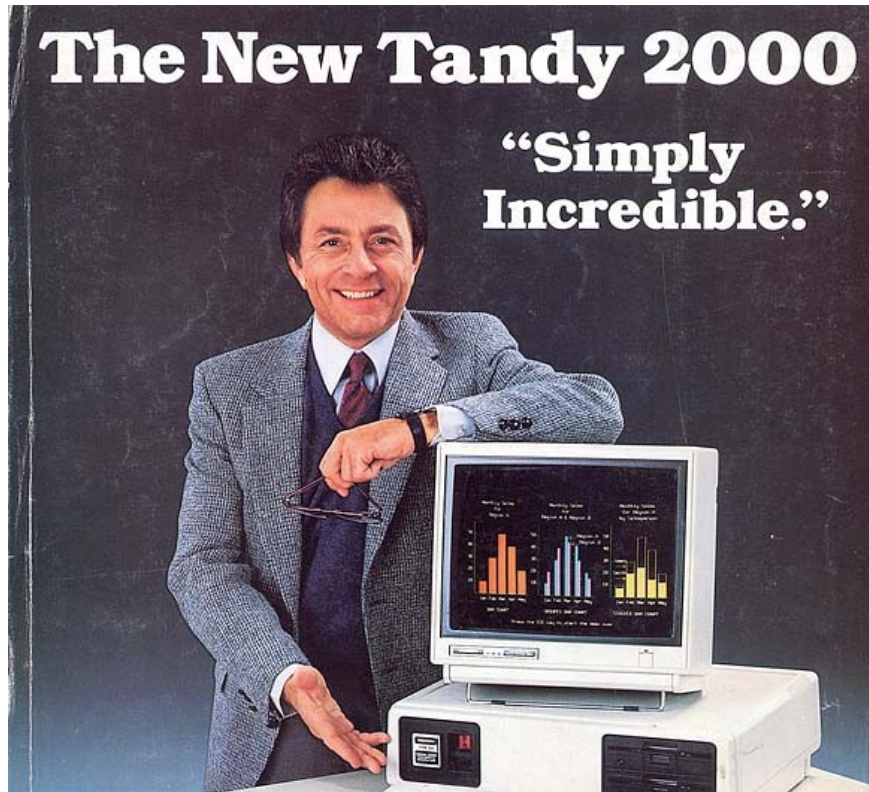
iPhone 6 (2014)



Apple IIc (1984)

The New Tandy 2000

“Simply Incredible.”



Meet the incredible new Tandy® 2000 Personal Computer. A truly remarkable machine that you should get to know. Why? Because the Tandy 2000 offers more than other MS-DOS computers on the market.

For instance, it's faster than the others. It offers more disk storage, and more detailed graphics. Expansion couldn't be easier. Even the IBM PC can't compare.

With the Tandy 2000, you get to choose from the

most popular and advanced MS-DOS software around, from word processing to electronic filing to spreadsheet analysis.

The beautiful, ergonomic design makes the Tandy TRS-80 Model 2000 a wonder to look at and a breeze to use. And don't forget Radio Shack's extensive service network.

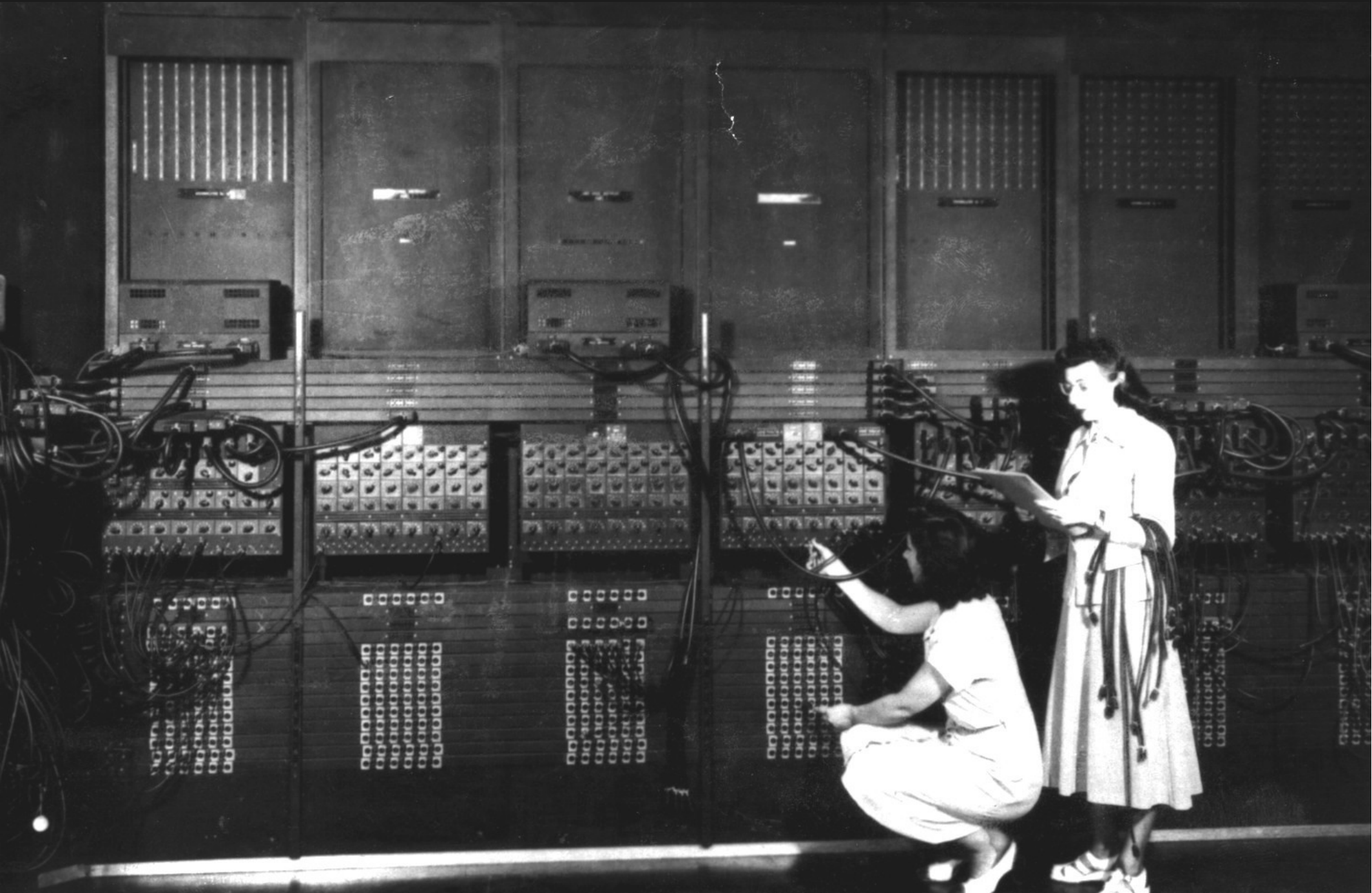
Ultra-High performance Tandy TRS-80® Model 2000 systems start at \$2999. Incredible? You bet!

Available at over 1100
Radio Shack® Computer Centers and at
participating Radio Shack stores and dealers
Radio Shack
COMPUTER CENTERS
A DIVISION OF TANDY CORPORATION

Prices apply at Radio Shack Computer Centers and participating stores and dealers. MS is a registered trademark of Microsoft. IBM is a registered trademark of International Business Machines Corp.
Circle 281 on inquiry card.

Tandy 2000 (1983)

ENIAC (1946)

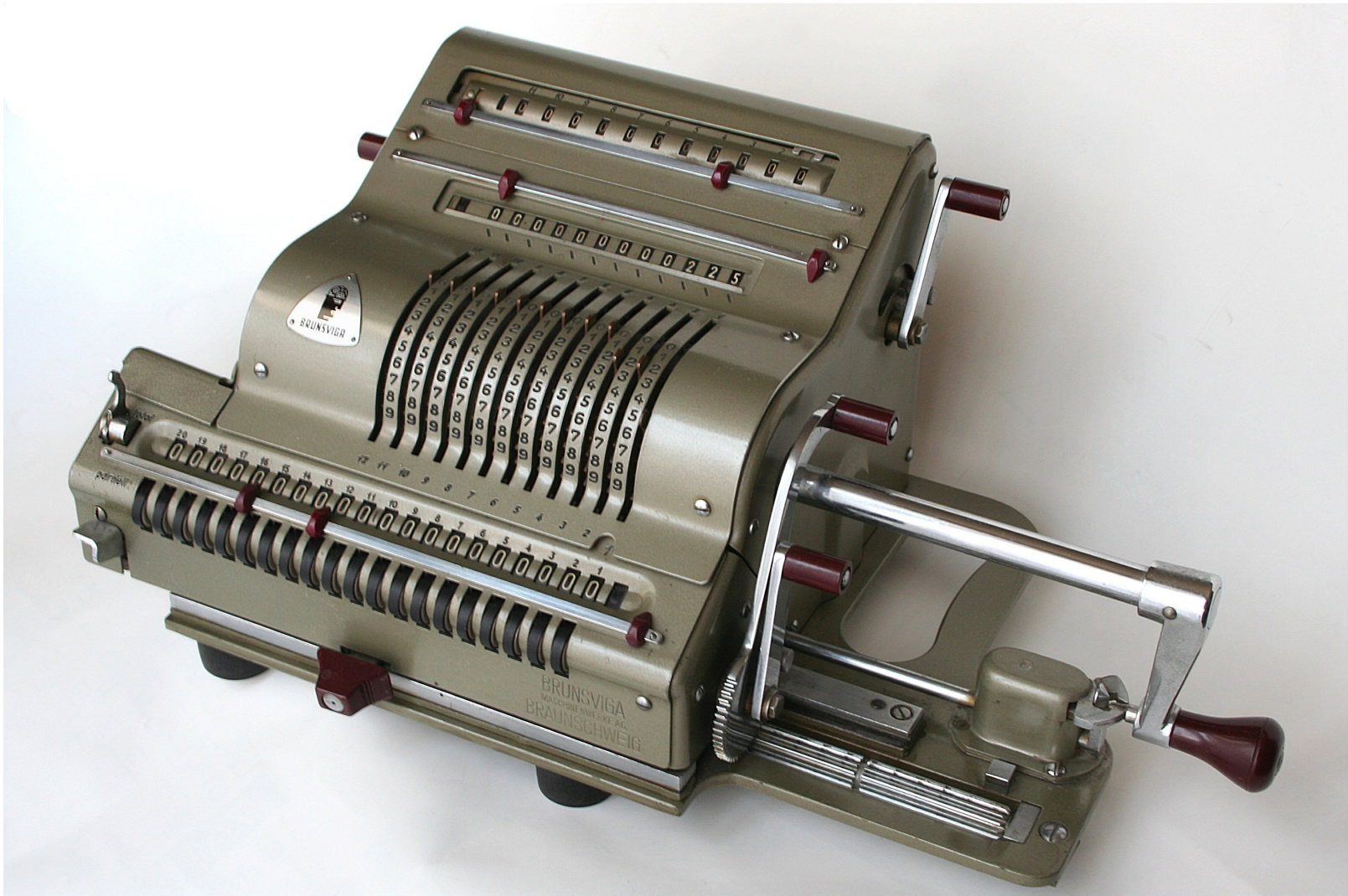




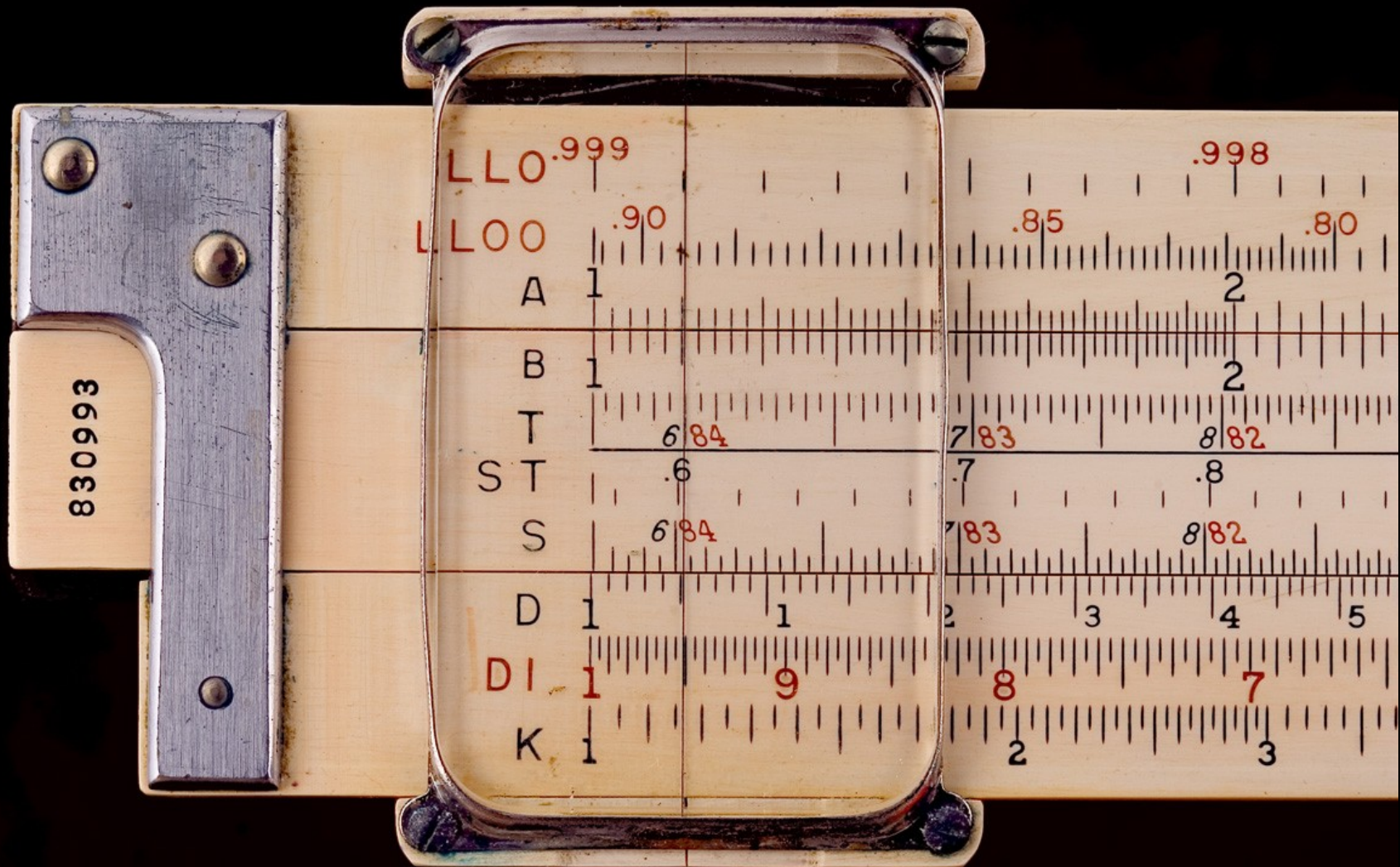
??????



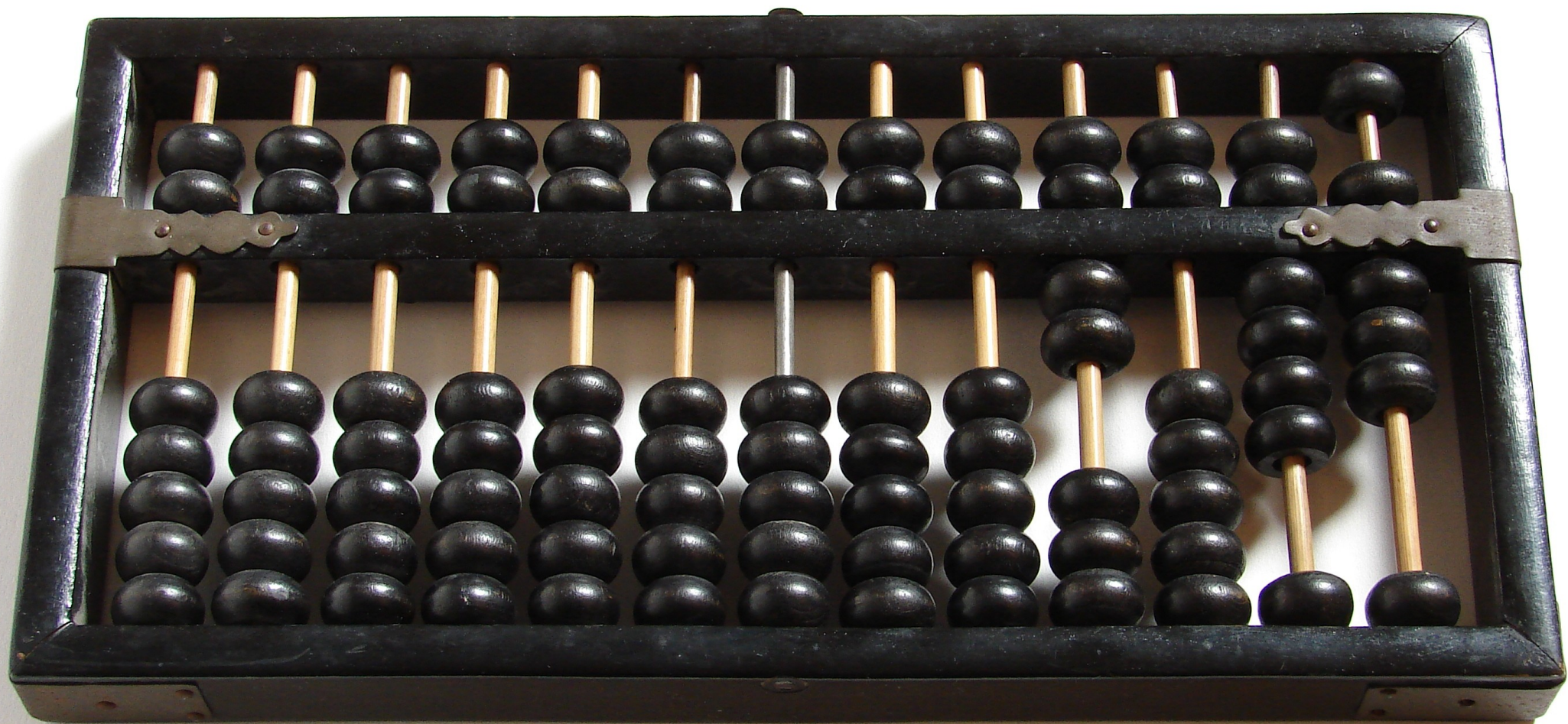
This is **not** a computer



Brunsviga (1950s)



Keuffel & Esser slide rule (1940)



Suanpan (Chinese abacus)

Primitive forms of computation



Could one use

spaghetti

needle

rope

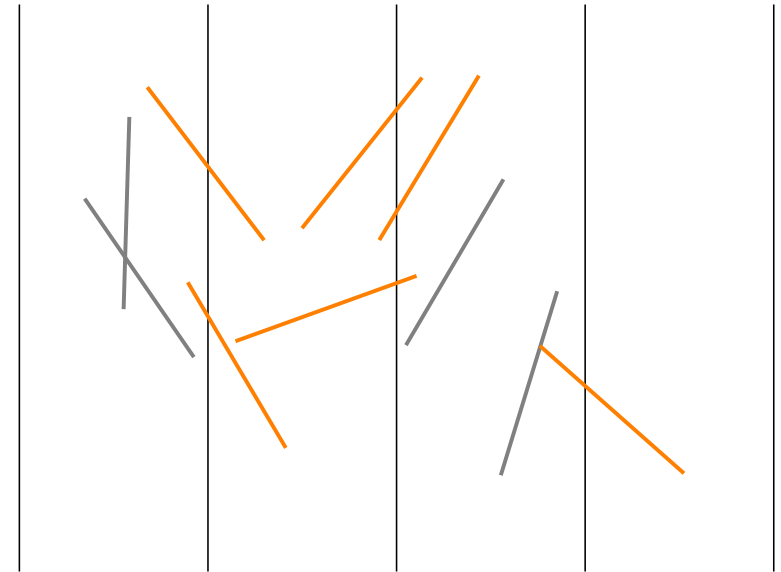
toast

bicycle

to compute?



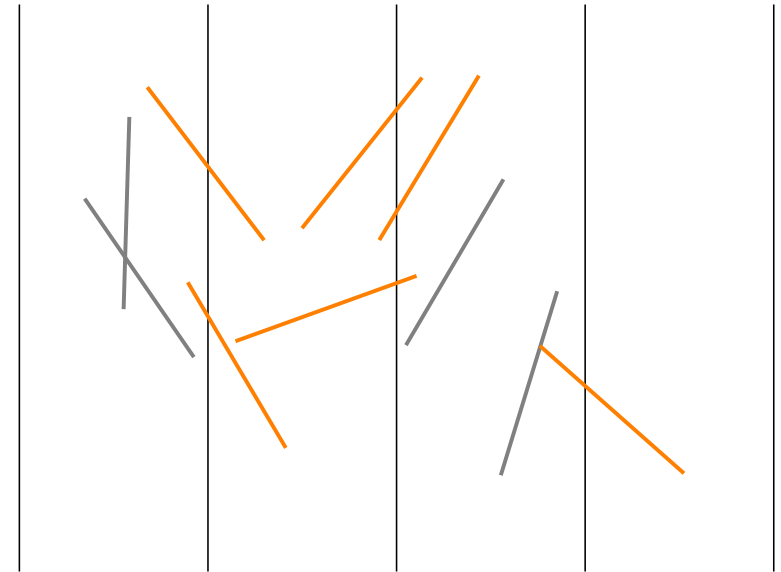
Georges-Louis Leclerc,
Comte de Buffon
(1707-1788)



Buffon's needle



Georges-Louis Leclerc,
Comte de Buffon
(1707-1788)



Prob. to cross a line = $2/\pi$

$$\frac{2 \text{ (total \# of needles)}}{\text{(\# of needles crossing a line)}} \approx \pi$$



$2 \cdot 1000 / 631 \approx 3.169$

Sagrada Família





Catenary



Gateway Arch in St. Louis



An upside-down rope model of Sagrada Família



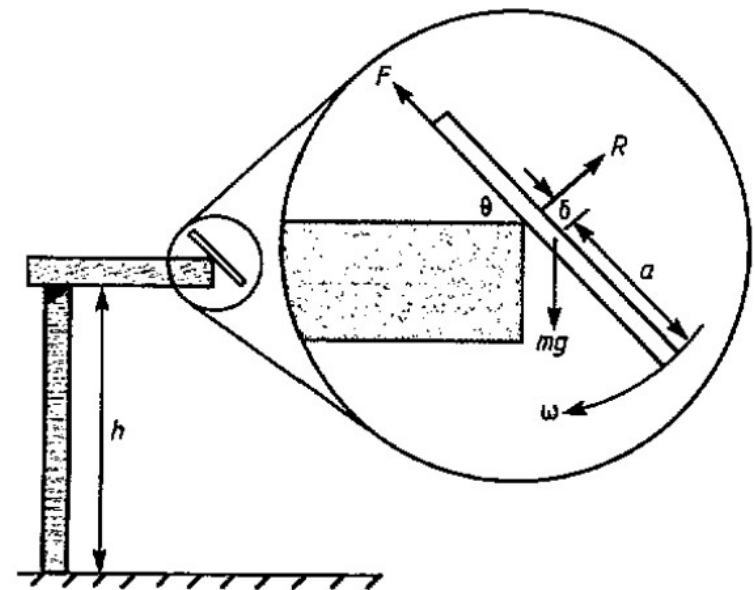
Tumbling toast, Murphy's Law and the fundamental constants

Robert A J Matthews

Department of Applied Mathematics and Computer Science, University of Aston, Birmingham B4 7ET UK†

Received 20 February 1995, in final form 31 March 1995

Abstract. We investigate the dynamics of toast tumbling from a table to the floor. Popular opinion is that the final state is usually butter-side down, and constitutes *prima facie* evidence of Murphy's Law ('If it can go wrong, it will'). The orthodox view, in contrast, is that the phenomenon is essentially random, with a 50/50 split of possible outcomes. We show that toast does indeed have an inherent tendency to land butter-side down for a wide range of conditions. Furthermore, we show that this outcome is ultimately ascribable to the values of the fundamental constants. As such, this manifestation of Murphy's Law appears to be an ineluctable feature of our universe.



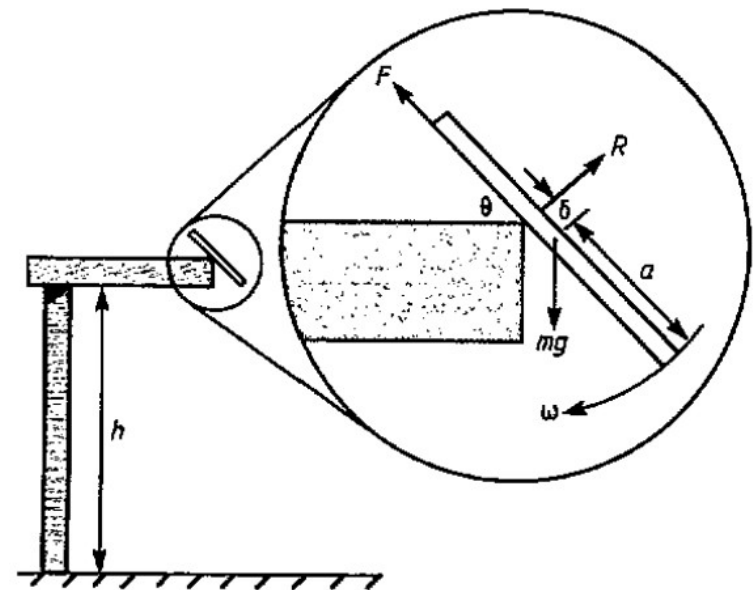
Tumbling toast, Murphy's Law and the fundamental constants

Robert A J Matthews

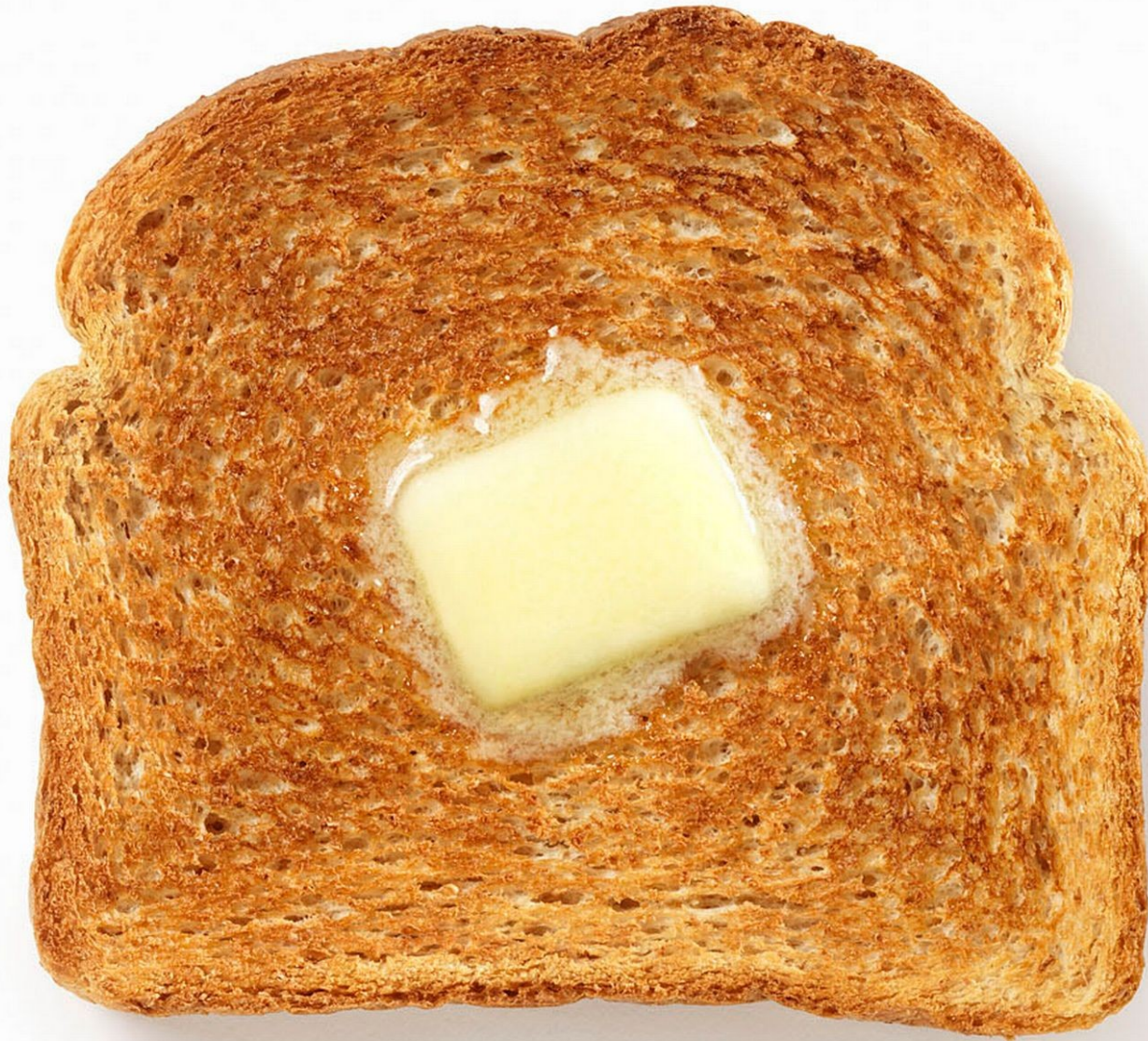
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1996 Ig Nobel prize in physics!



Every system is perfectly suited for simulating itself!



(Image: John Hart, Centre for Sports Engineering Research Sheffield Hallam University)



Which one is computation?



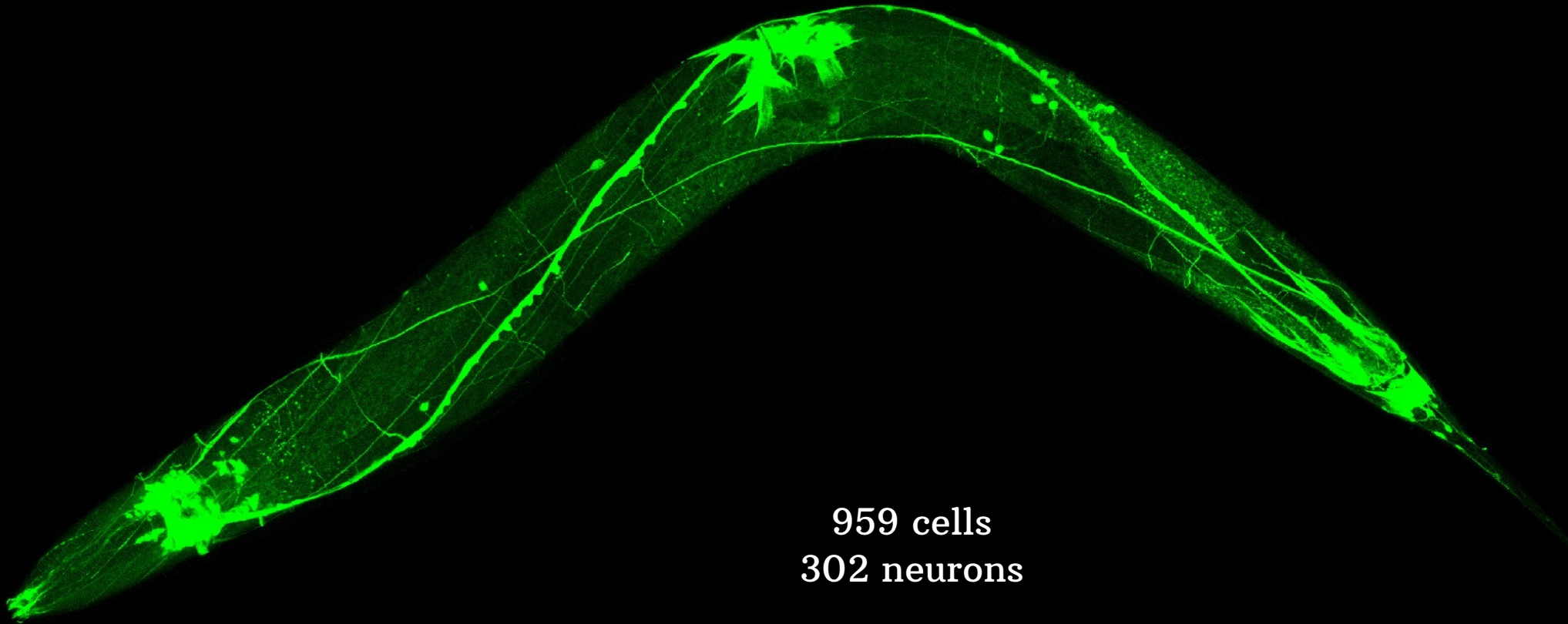
Computer is a **physical** device for processing information

Bicycle is a physical device too...

**Which of these computers
is the best?**

**Computer A is better than computer B
if A can simulate B**

C. elegans



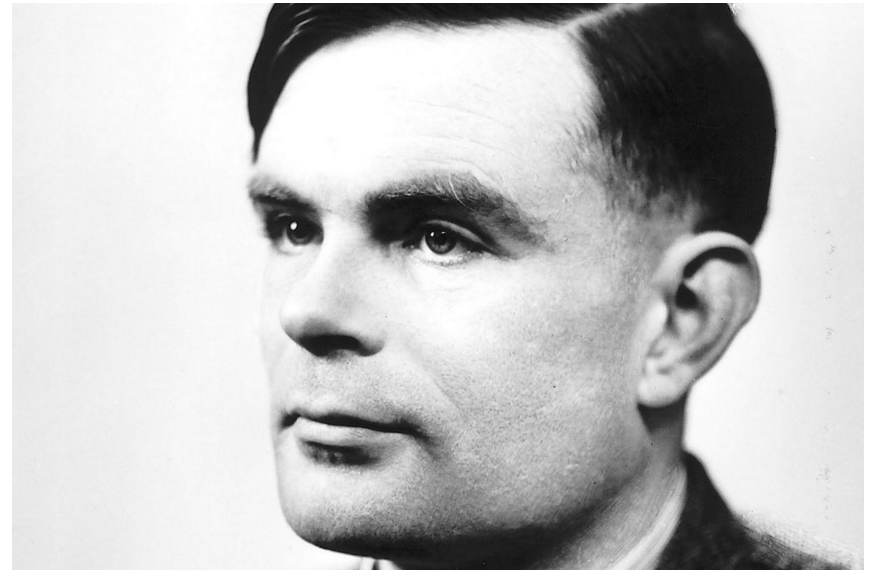
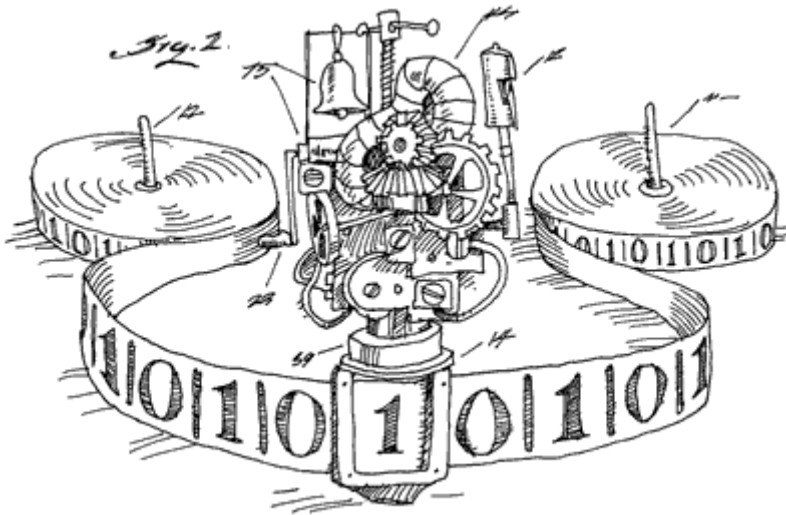
959 cells
302 neurons

A project is underway to simulate it...

<http://www.openworm.org/>

A universal computer

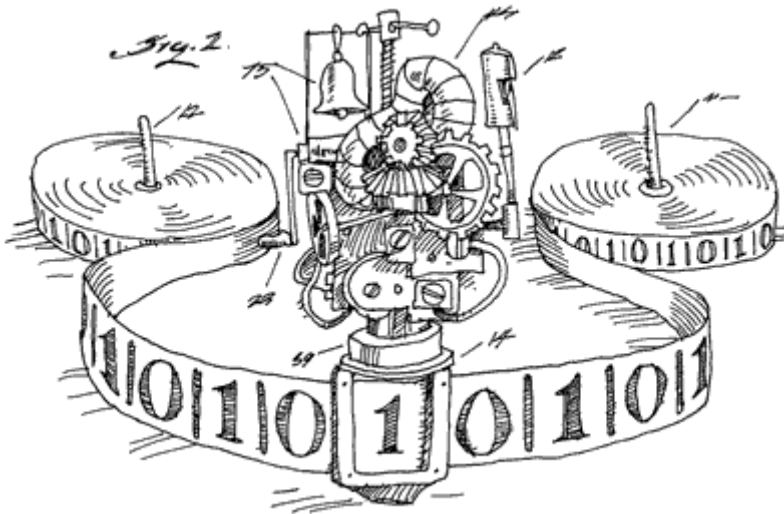
Turing machine



Alan Turing

A universal computer

Turing machine



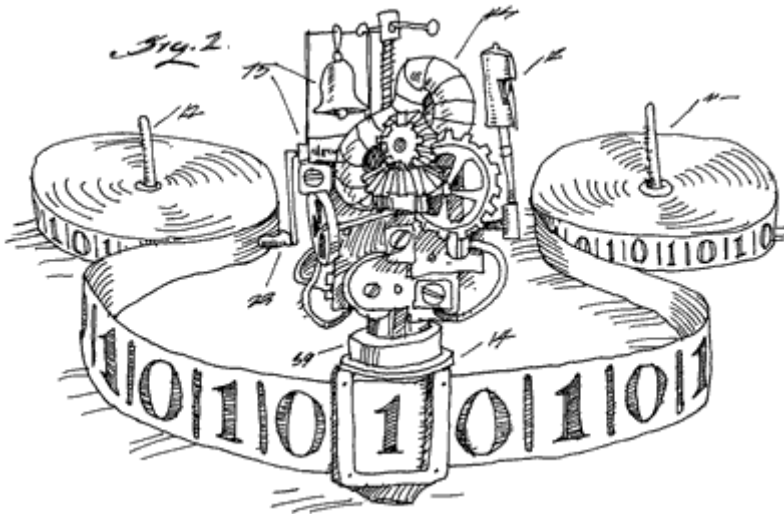
Alan Turing

Equivalent to Turing machine:

- lambda calculus
- cellular automata (game of life)
- unrestricted formal grammars
- various programming languages
(C++, Pascal, Java, Lisp, Prolog, ...)

A universal computer

Turing machine



Alan Turing

Equivalent to Turing machine:

- lambda calculus
- cellular automata (game of life)
- unrestricted formal grammars
- various programming languages (C++, Pascal, Java, Lisp, Prolog, ...)

Physical Church–Turing thesis

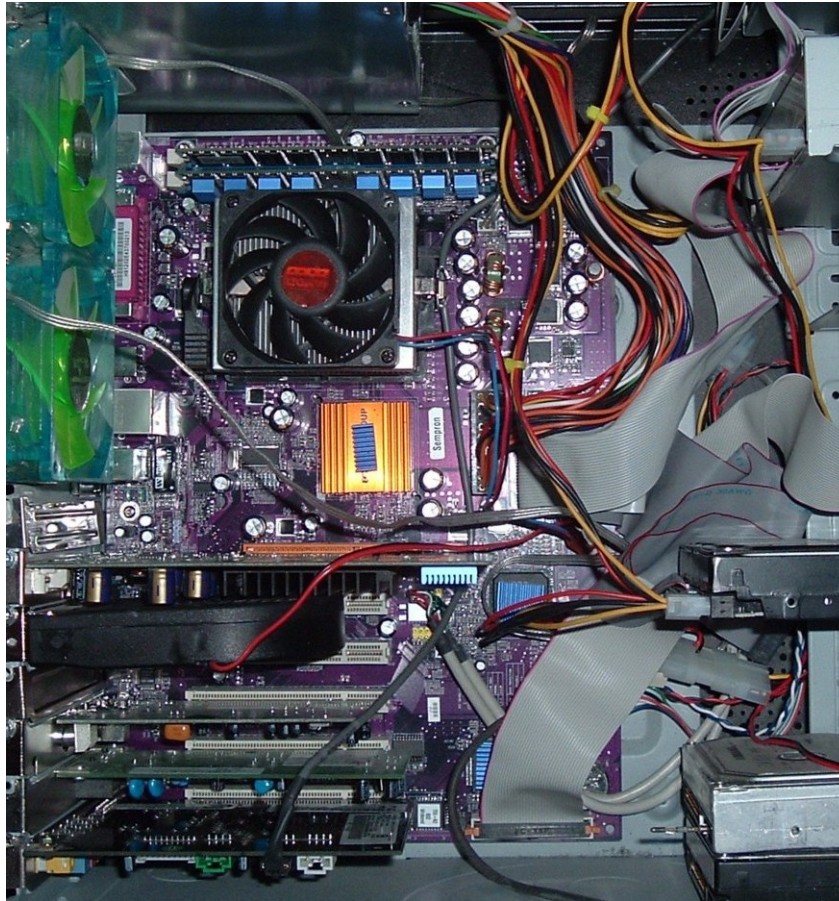
All physically computable functions are computable by a Turing machine

Computation and physics

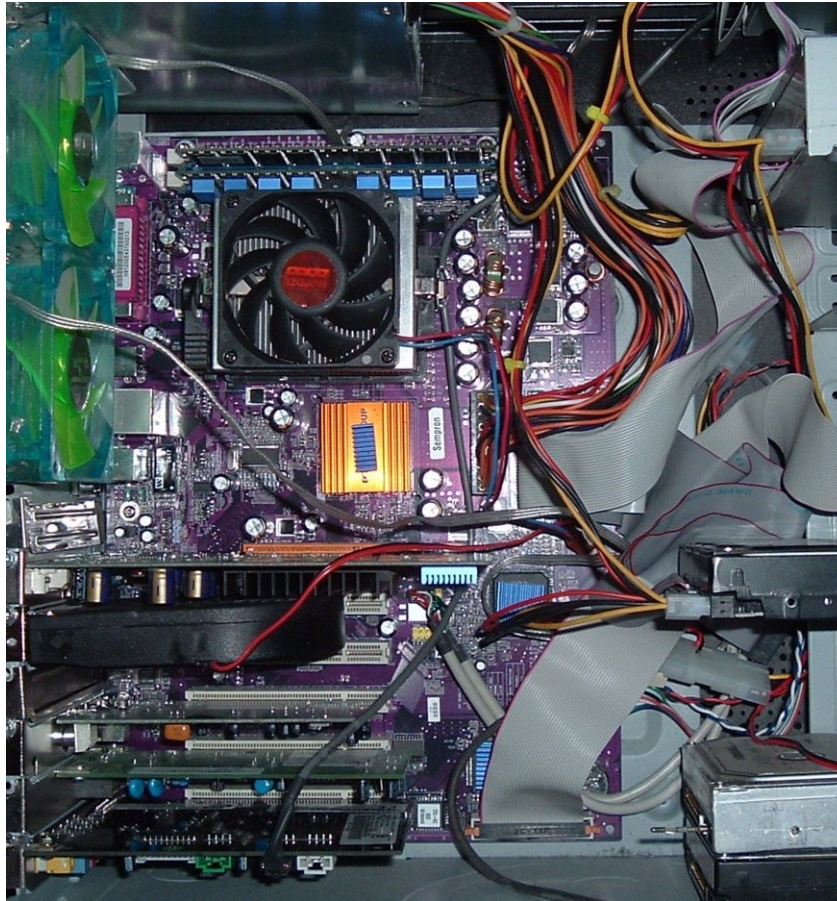
Computer is a **physical** device for processing information

What it can or cannot compute (and how fast) is limited by the underlying laws of physics

What are computers made of?

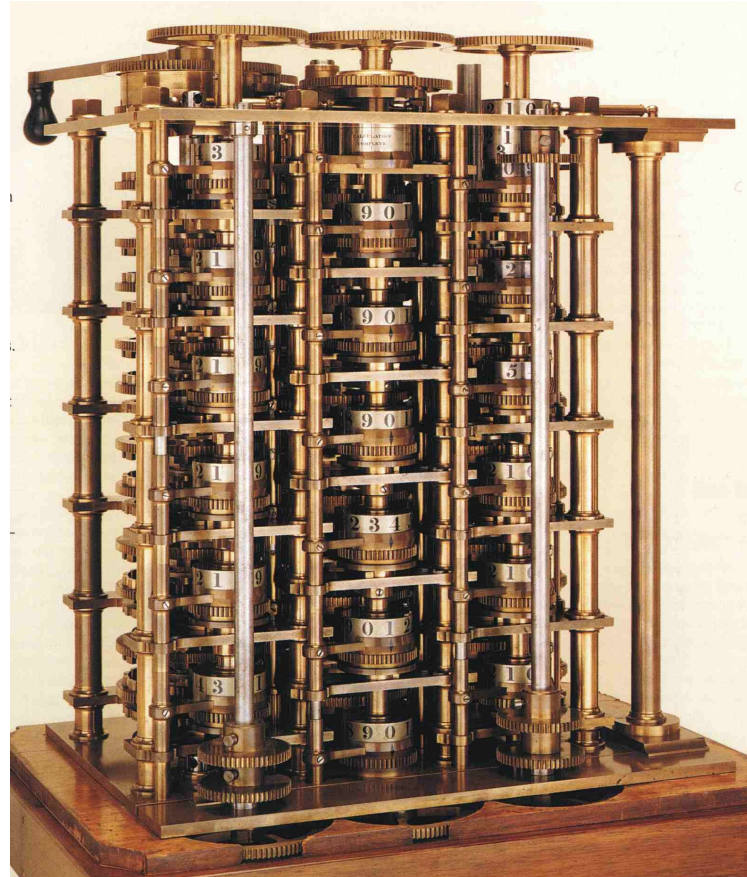


What are computers made of?



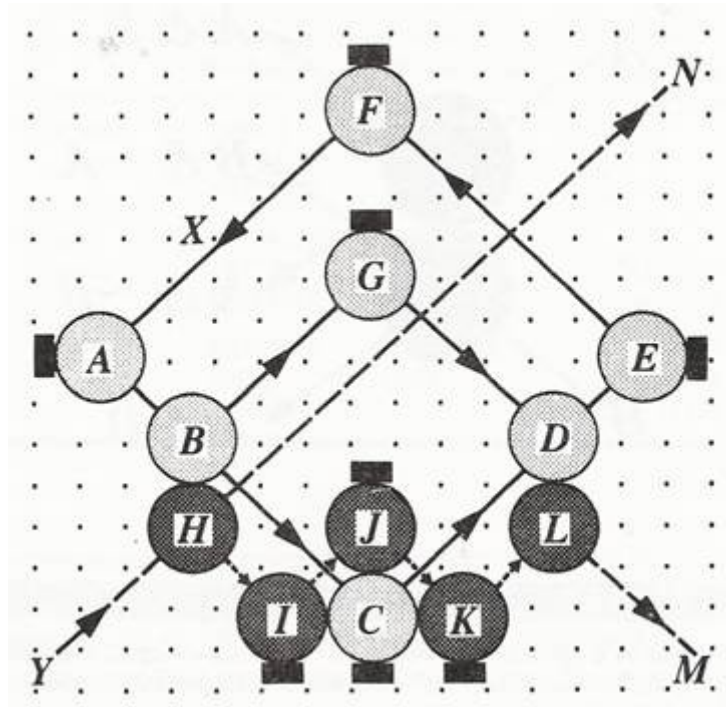
Transistors

Analytical Engine



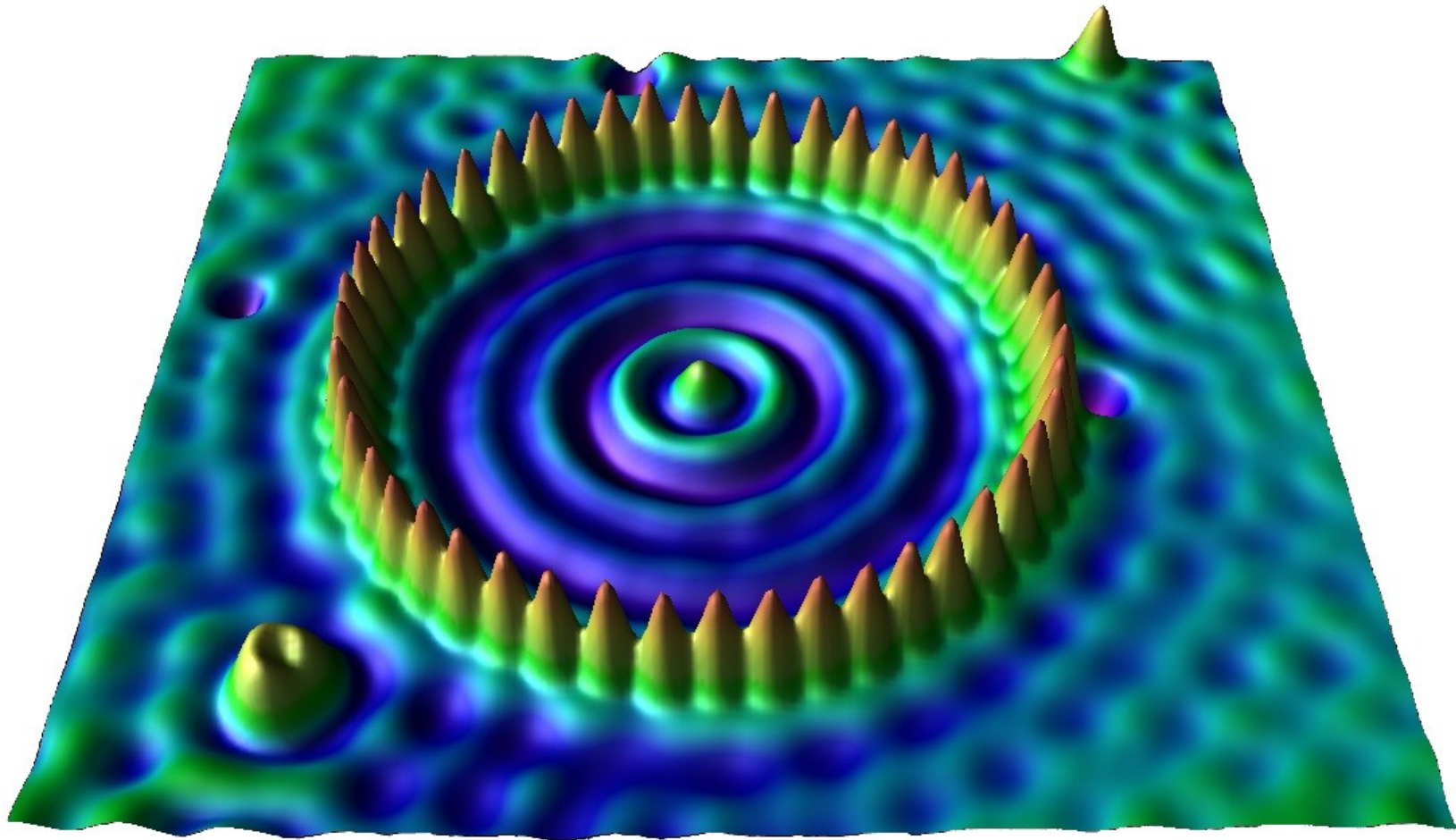
Designed by Charles Babbage in 1837

Billiard ball computer



Charles Bennett (1988)

Quantum mechanics



Simulating physics



Richard Feynman

Simulating quantum physics on a computer is very hard...

Would it be easier if the computer itself would operate based on the laws of quantum physics?

Simulating physics



Richard Feynman

Simulating quantum physics on a computer is very hard...

Would it be easier if the computer itself would operate based on the laws of quantum physics?

Q: What kind of information would such computer process?

What is information?

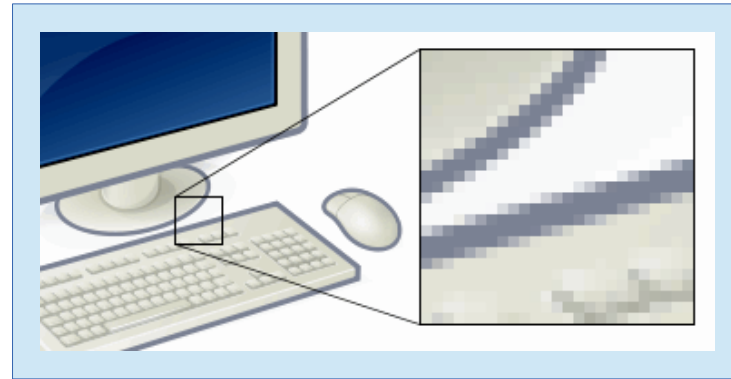
What is information?

Information is a sequence of zeros and ones

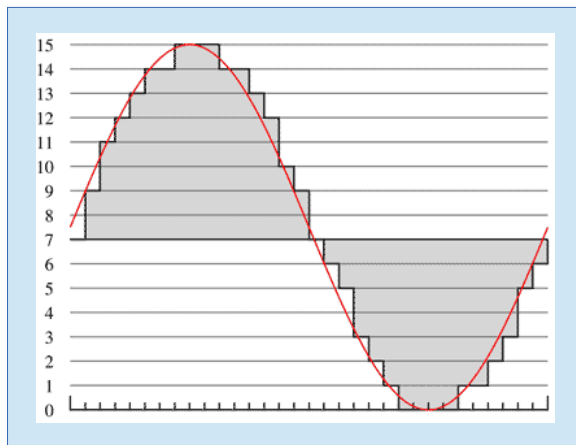
Information

```
A = 01000001  
B = 01000010  
C = 01000011  
D = 01000100  
E = 01000101  
F = 01000110  
G = ...
```

Text



Image



Sound

```
0100100101101110110  
11011110111001001100  
000010110001100111  
110010000101010011  
1010001010101100...
```

00100101 01010000 01000100 01000110 00101101 00110001 00101110 00110100 00001010 00100101 11000011 10100100
11000011 10111100 11000011 10110110 11000011 10011111 00001010 00110010 00100000 00110000 00100000 01101111
01100010 01101010 00001010 00111100 00111100 00101111 01001100 01100101 01101110 01100111 01110100 01101000
00100000 00110011 00100000 00110000 00100000 01010010 00101111 01000110 01101001 01101100 01110100 01100101
01110010 00101111 01000110 01101100 01100001 01110100 01100101 01000100 01100101 01100011 01101111 01100100
01100101 00111110 00111110 00001010 01110011 01110100 01110010 01100101 01100001 01101101 00001010 01111000
10011100 10000101 01010001 01001101 01001011 00000011 00110001 00010000 10111101 11100111 01010111 11001100
10111001 11010000 11101101 01001100 10111110 01110110 00000011 11001011 01000010 00111111 01000101 01101111
10010101 10000000 00000111 11110001 10100100 01010110 10010001 01010110 10110001 00010111 11111111 10111110
00101111 11001001 10100110 00010101 01000101 01001010 00001000 01101111 00110010 01111001 01111001 00110011
01101111 11000010 10001101 11010000 10010111 11111010 00100100 10100110 00101001 00110111 10011010 11011010
01100000 00011010 01001111 00101110 00111000 11000100 11000111 01100111 01110101 00110111 10100001 01110111
00100101 10010100 11010110 11110001 01000101 01110001 10111010 10100000 10000011 01001010 10100100 00110110
11000111 01111011 00101010 01110001 01111110 10111011 10101111 00100010 00101001 00101000 10110111 10101111
01101010 00110111 01010001 00001100 11000101 10111010 00101111 10101001 10011000 10101010 01100010 01111110
10101011 10100100 00010110 11010011 10000010 11000010 00100010 00101010 00010011 11000000 10110111 10001100
11100110 11100011 00010011 11001101 00110110 01101000 11010000 01010010 11011100 11110101 00101100 01000011
01111100 01010011 11101011 10101000 10110110 01111111 11111000 10101110 01110001 10010111 00011110 01111000
11100111 00011010 10011011 00011111 01011001 00001110 10001000 01111100 00000000 10111101 00001011 11110100
01111000 01010000 10110011 11101011 10000011 10100101 11010101 00000111 00100101 01011010 10011001 11000111
11101101 11010101 01111001 00110000 00101000 10100000 00101001 00011110 01001001 00011010 00001001 00011101
00011011 00001100 01010100 10111100 00110100 10000001 10011100 00010001 10001100 00100011 00010111 11010100
01100100 00111100 00001010 11011110 10100111 10001010 01010011 11001011 00111101 01111011 10000000 11101011
11011001 00000000 01101100 11001111 00010110 00100000 00111101 00111011 01000000 01011011 11101110 01110100
01001001 11011010 10010010 00000100 11111000 01000010 01101001 11001111 00100111 01000000 01010111 10011000
10100011 01011000 00101000 11010010 10100011 11001010 10101000 00111001 00000111 10011000 00010011 01100101
01010001 01001110 10100001 11000000 01001000 01011001 10010110 11010011 10101010 11010110 01111011 10001000
00110111 01110101 00100110 00111111 00111101 00011010 11110001 11111000 00010111 01101011 00110000 11001001
11010001 10010011 11101110 10001010 10100111 00110101 01101111 00000110 10011011 01010101 10100101 00010111
00011110 01110100 00101111 10010010 10110100 10000001 00111010 10100111 00001100 01101011 00110100 10001110
01000000 11111110 11010011 11010110 01011101 10000000 10110110 01110100 11110101 10000011 00110100 11100010

First few bits of this PDF file

Bit

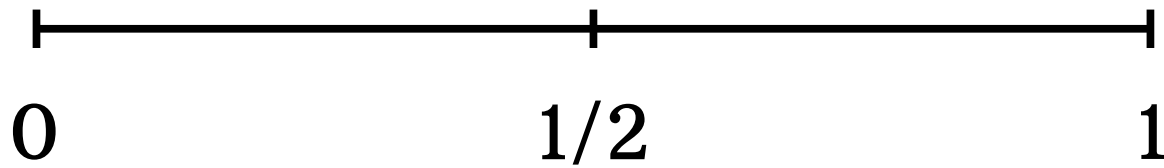


0



1

Probabilistic bit



Probability

$$\text{Reverse Side} = \frac{1}{2} \text{Obverse Side} + \frac{1}{2} \text{Reverse Side}$$
A diagram illustrating a probability equation. On the left is the reverse side of a coin (the harp). This is followed by an equals sign, then a fraction 1/2, then the obverse side of the coin (the profile of Elizabeth II), followed by a plus sign, a fraction 1/2, and finally the reverse side of the coin.

$$\frac{1}{2} \text{Reverse Side} + \frac{1}{2} \text{Reverse Side} = \frac{1}{4} \text{Obverse Side} + \frac{3}{4} \text{Reverse Side}$$
A diagram illustrating a probability equation. On the left, a sad face emoji is above the fraction 1/2, followed by the reverse side of a coin. This is followed by a plus sign, a happy face emoji above the fraction 1/2, followed by the reverse side of a coin. This is followed by an equals sign, then a fraction 1/4, then the obverse side of the coin, followed by a plus sign, a fraction 3/4, and finally the reverse side of the coin.

Party invitation

Name	Coming?
John	Y
Sarah	N
Peter	-
Anna	-
Tom	N
Rebecca	Y
Andy	-
Kathy	-
Richard	-
Total:	2-7

Party invitation

Name	Coming?	Chances?
John	Y	0.1
Sarah	N	0.1
Peter	-	0.8
Anna	-	0.5
Tom	N	0.0
Rebecca	Y	1.0
Andy	-	0.6
Kathy	-	0.3
Richard	-	0.7
Total:	2-7	4.1

What is information?

Information is what gives you advantage in betting

Will it rain tomorrow?

Cambridge, UK

Thursday

Chance of Rain



6 °C | °F

Precipitation: 40%

Humidity: 83%

Wind: 13 mph

Temperature

Precipitation

Wind



Wed



5° -1°

Thu



6° 0°

Fri



4° 0°

Sat



7° 3°

Sun



8° 1°

Mon



7° 2°

Tue



7° 2°

Wed



7° 1°

Probability as a stock price

2012.PRES.OBAMA

Dec 06, 2010 - Nov 07, 2012

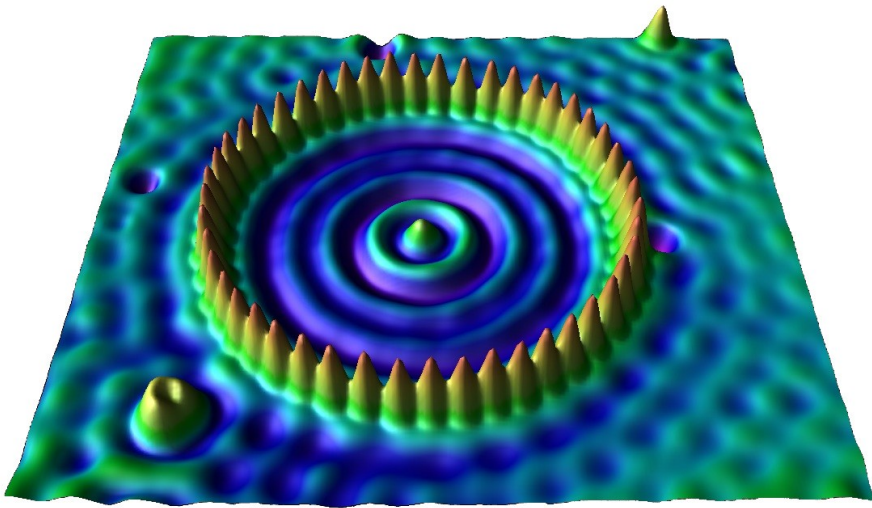
<https://www.intrade.com/v4/markets/contract/?contractId=743474>



Probability that Barack Obama will
be re-elected as US president in 2012

What is a quantum computer?

What is a quantum computer?



Quantum mechanics

+



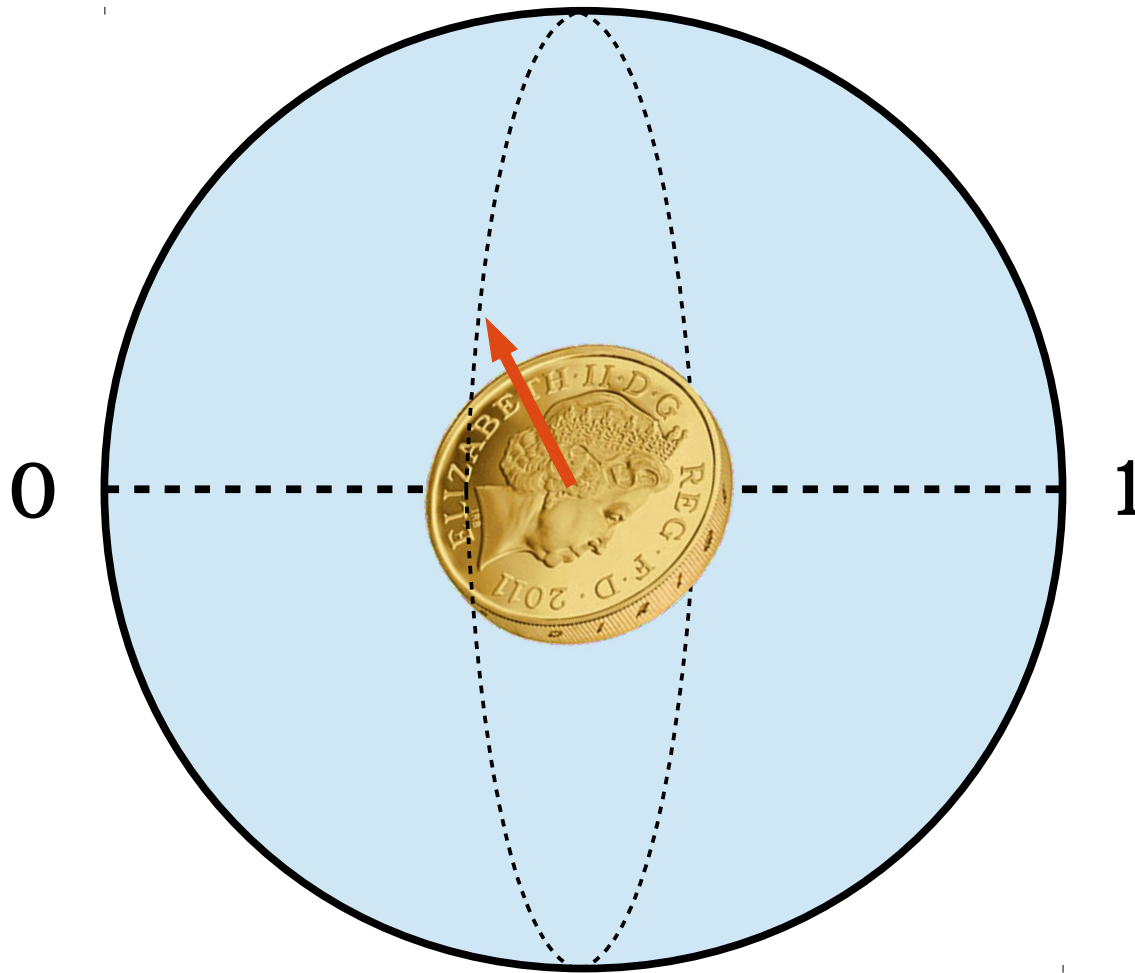
Computer

Quantum computer is a device for processing quantum information

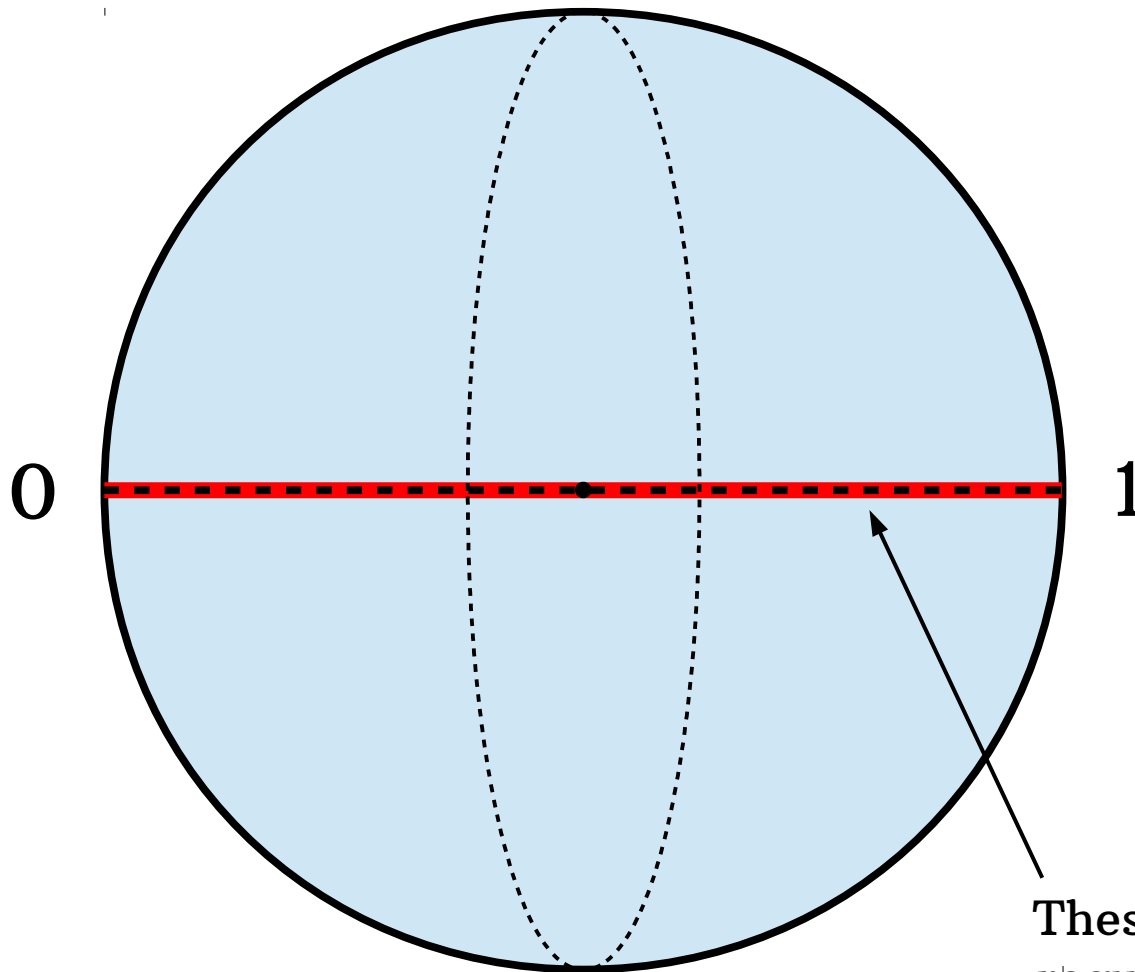
What is quantum information?

Quantum information is what gives you advantage in betting when **quantum phenomena** are involved

Quantum coin



Quantum coin



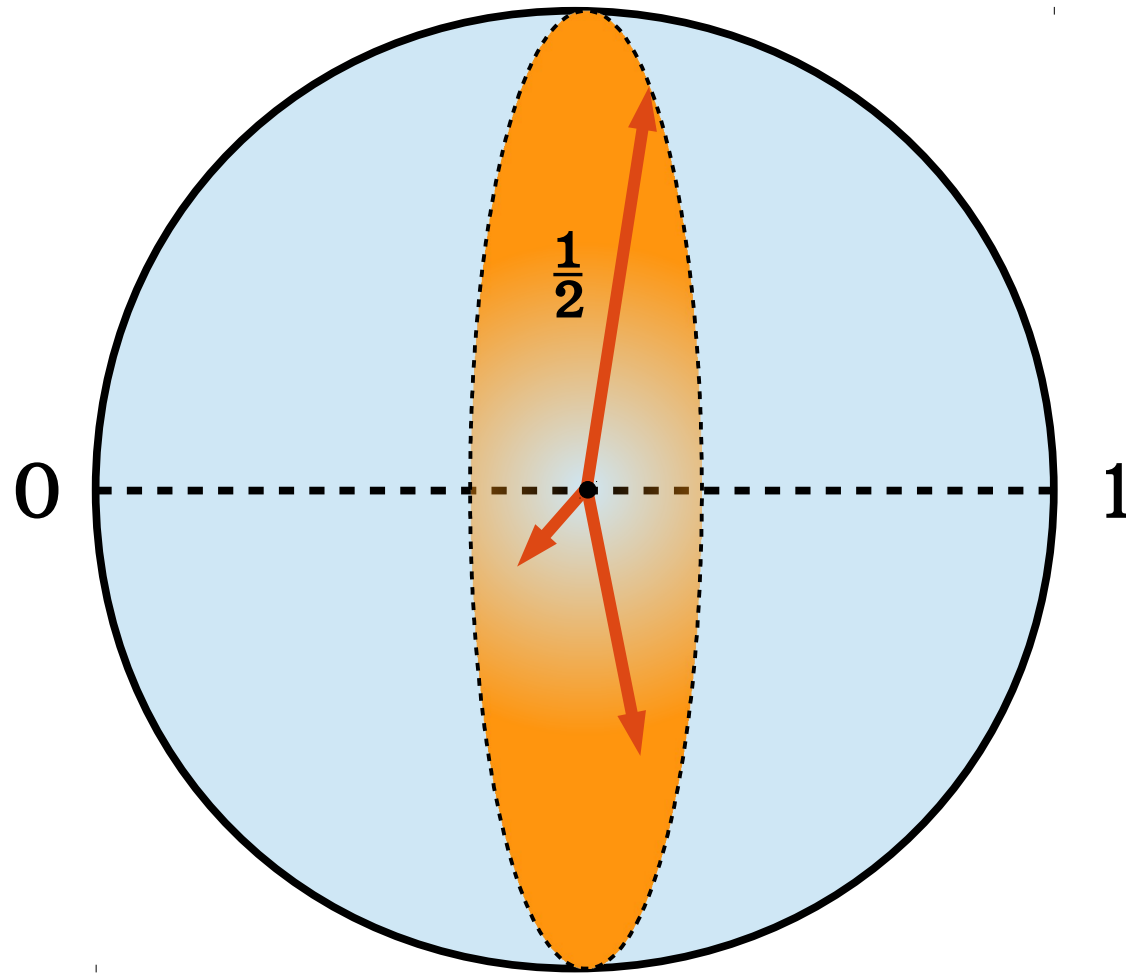
Measurement



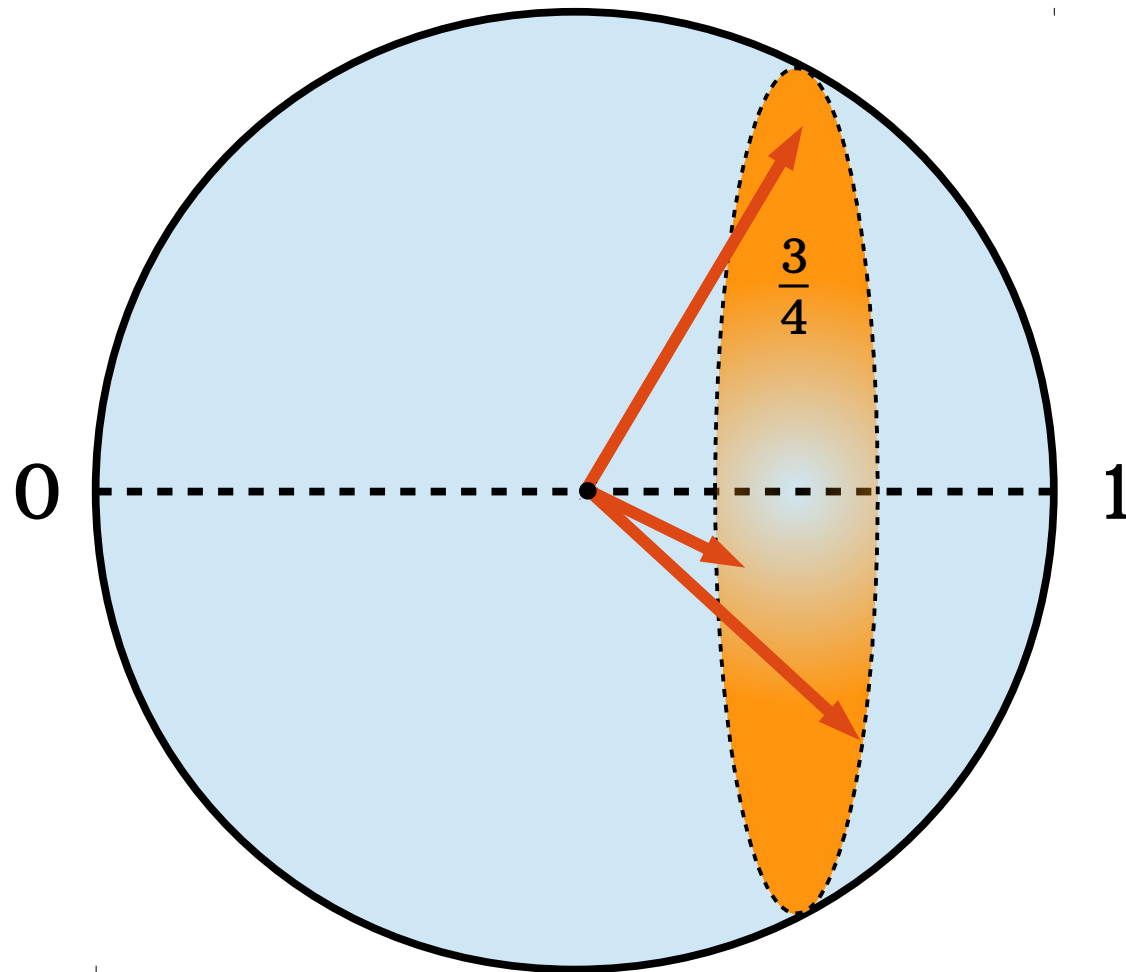
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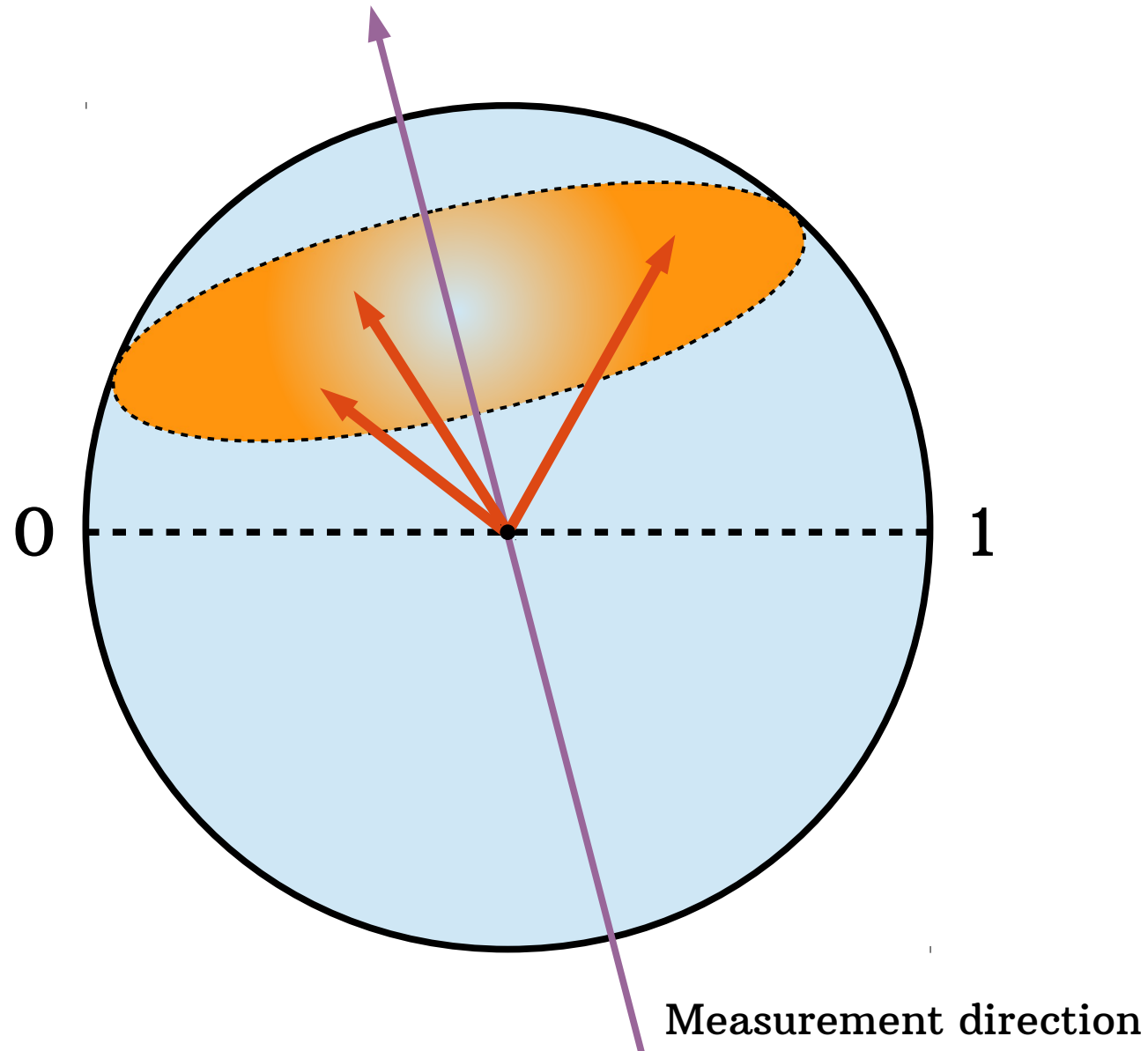
Outcome probabilities



Outcome probabilities



Arbitrary measurement



Quantum teleportation

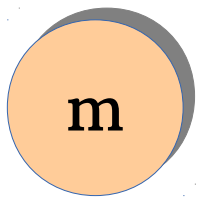
One-time pad



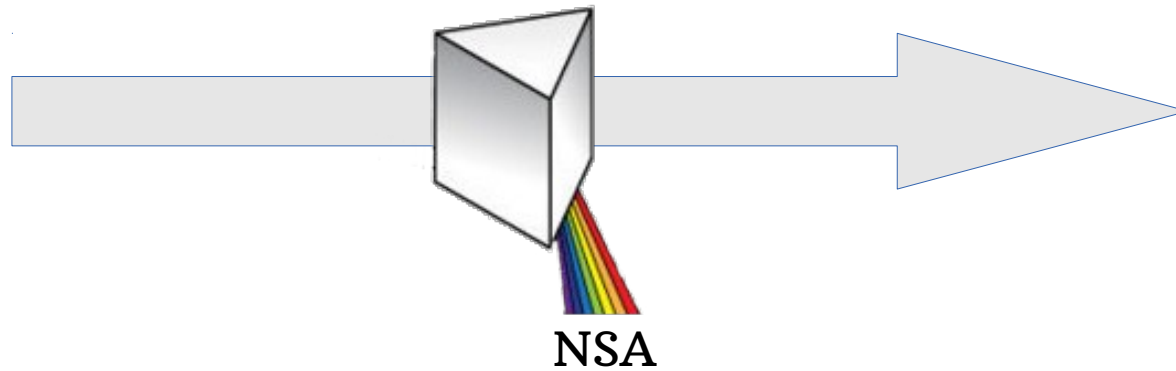
Alice



Bob



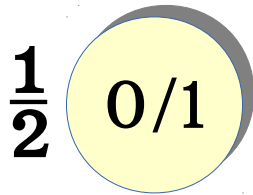
Secret
message



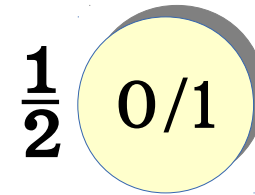
One-time pad



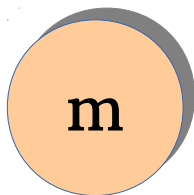
Alice



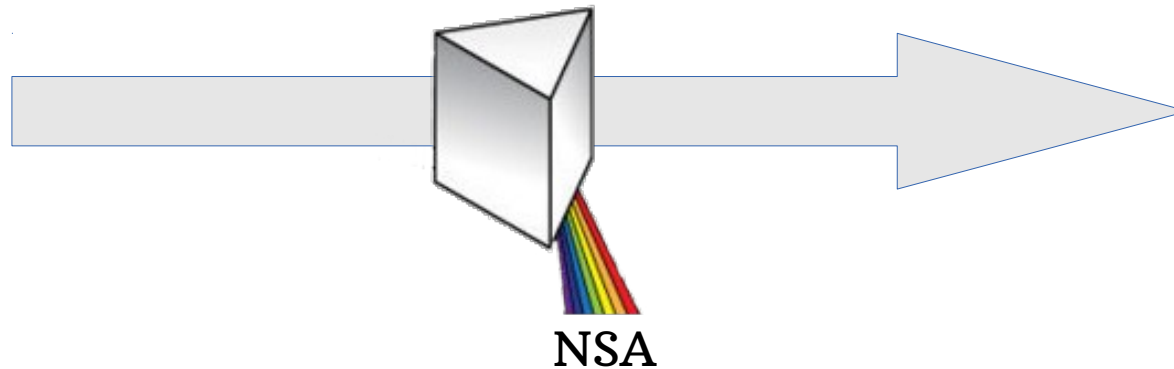
Privately shared random bit



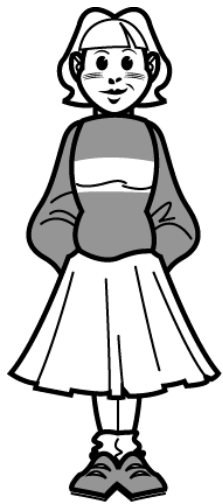
Bob



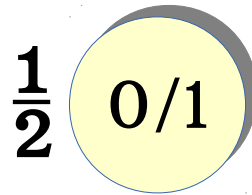
Secret message



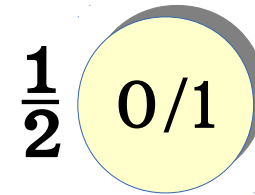
One-time pad



Alice



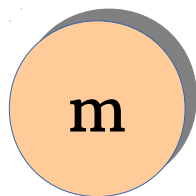
Privately shared random bit



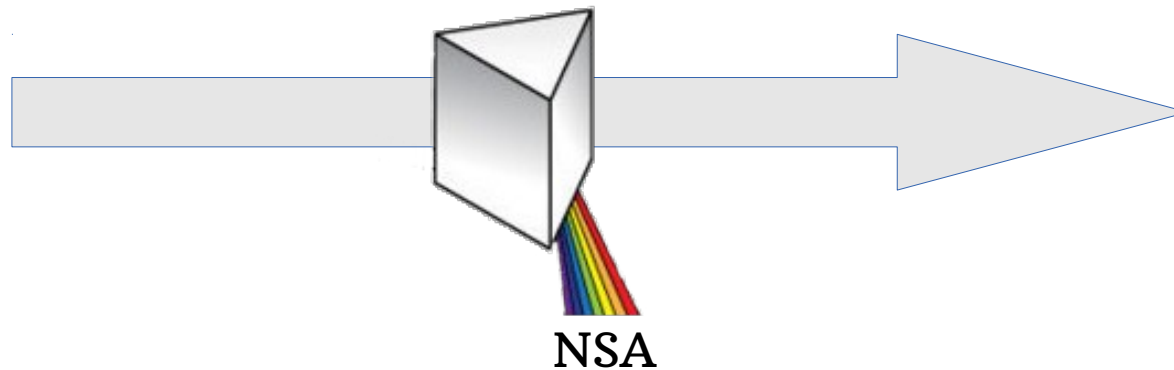
Bob

Trick

If the shared random bit is 1,
invert the message bit m .
Otherwise, send m as it is.



Secret
message



Trading resources

One-time pad:

1 privately shared random bit
1 bit of public communication = 1 bit of secret communication

Quantum teleportation:

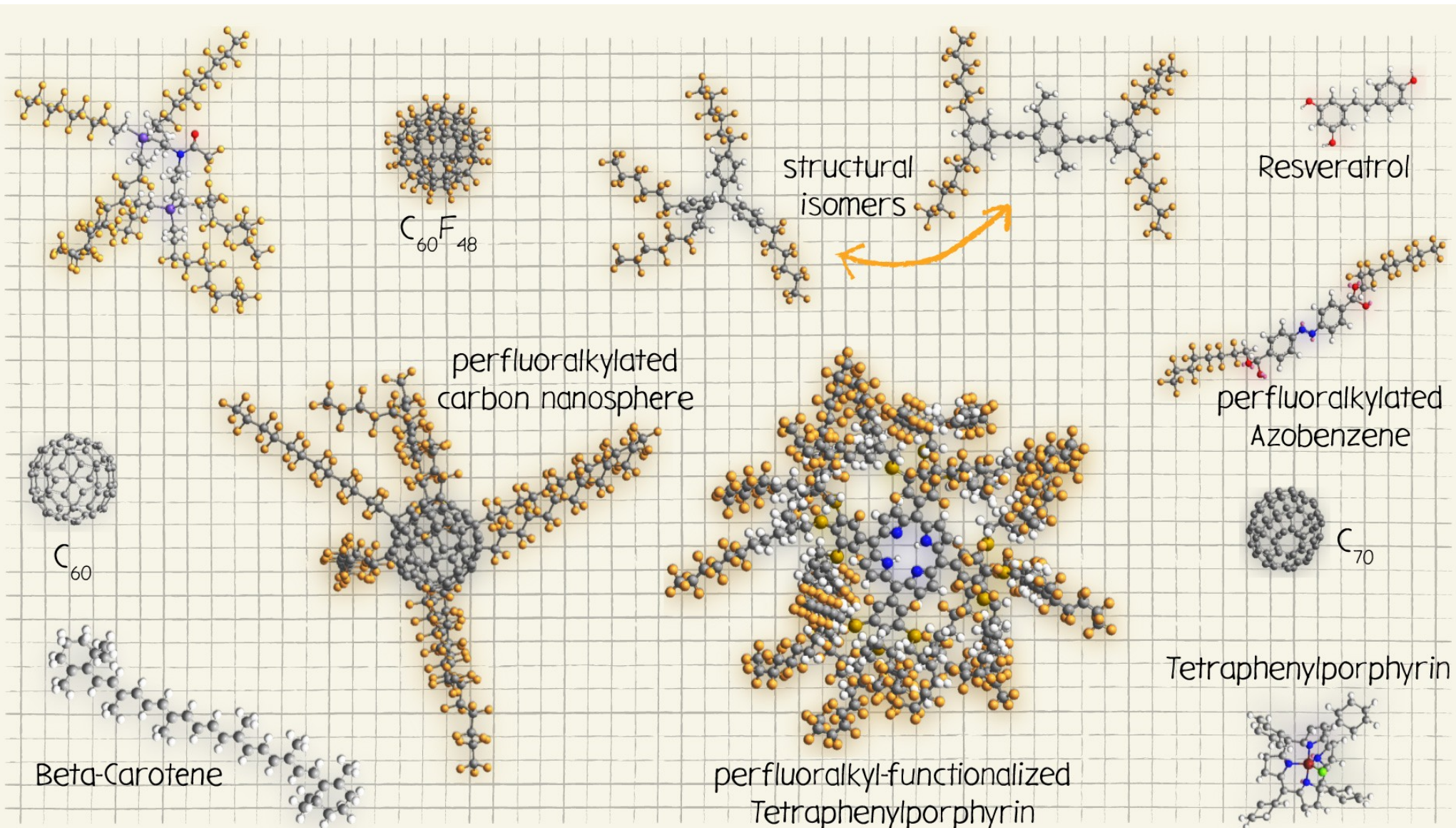
1 shared entangled quantum bit
2 bits of public communication = 1 bit of quantum communication

Can I teleport my cat?

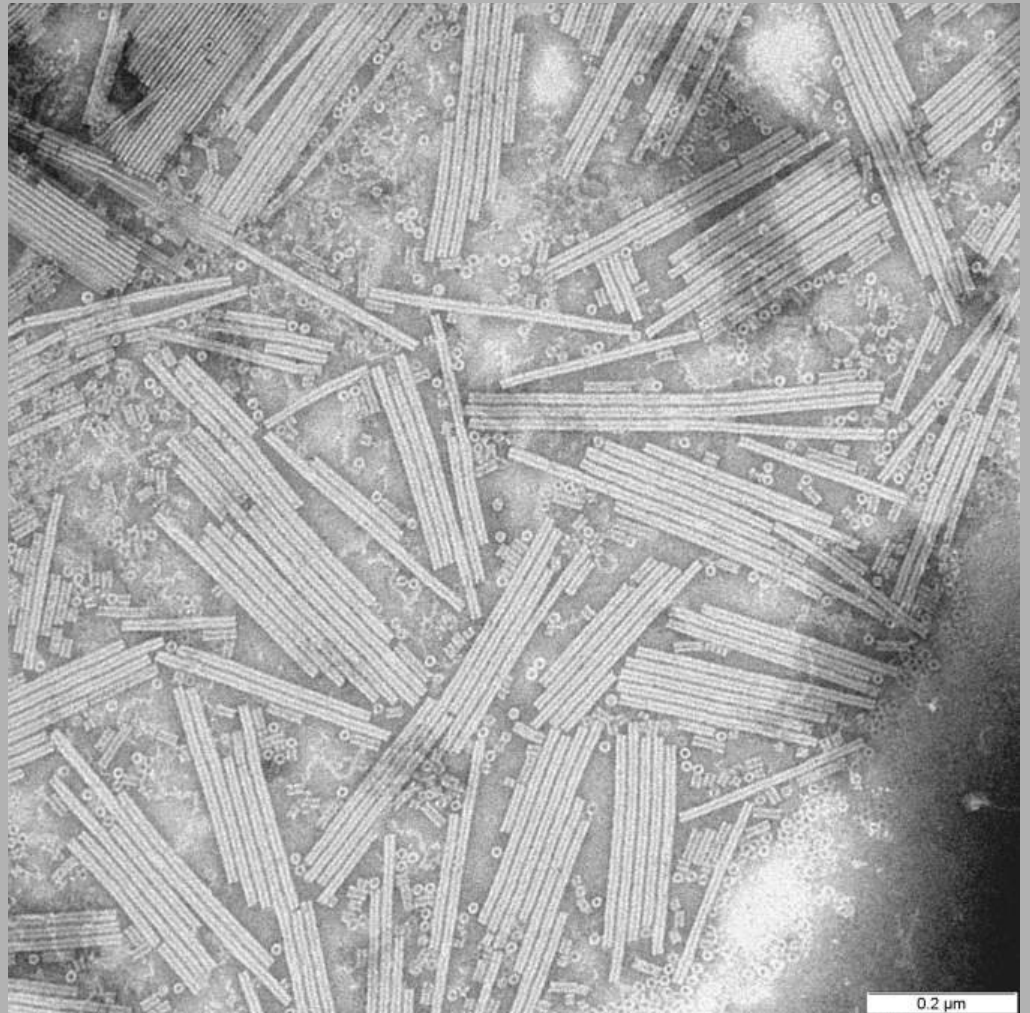
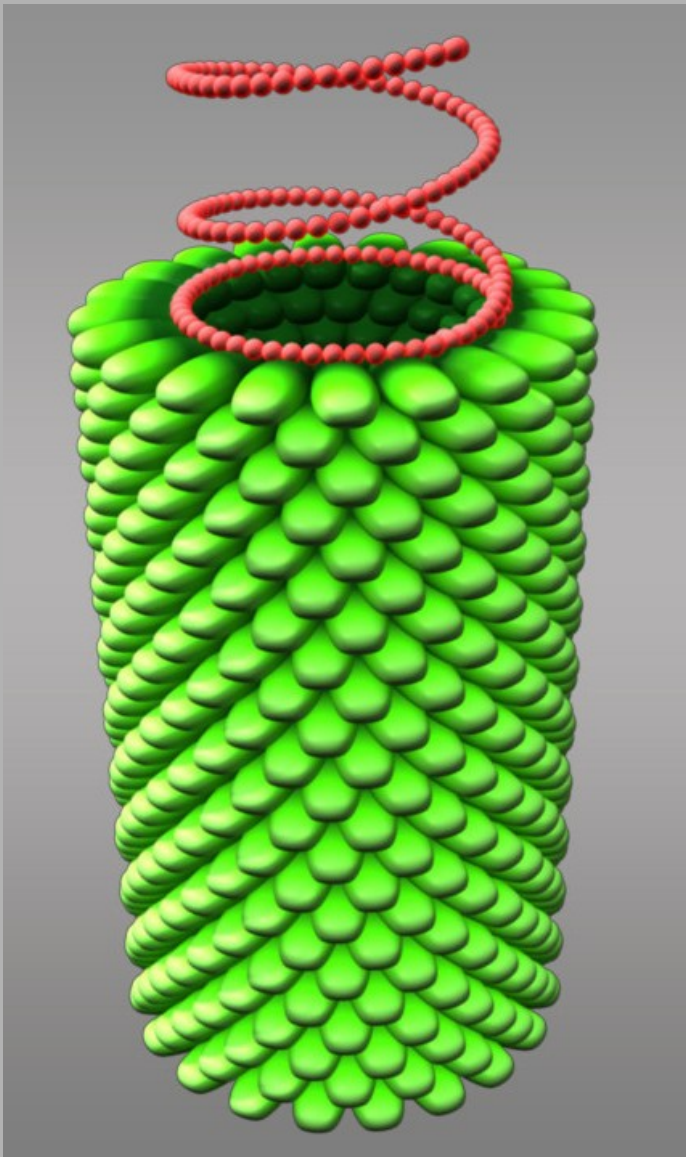


Large systems with quantum behaviour

<http://interactive.quantumnano.at/advanced/motivation/>



Tobacco mosaic virus

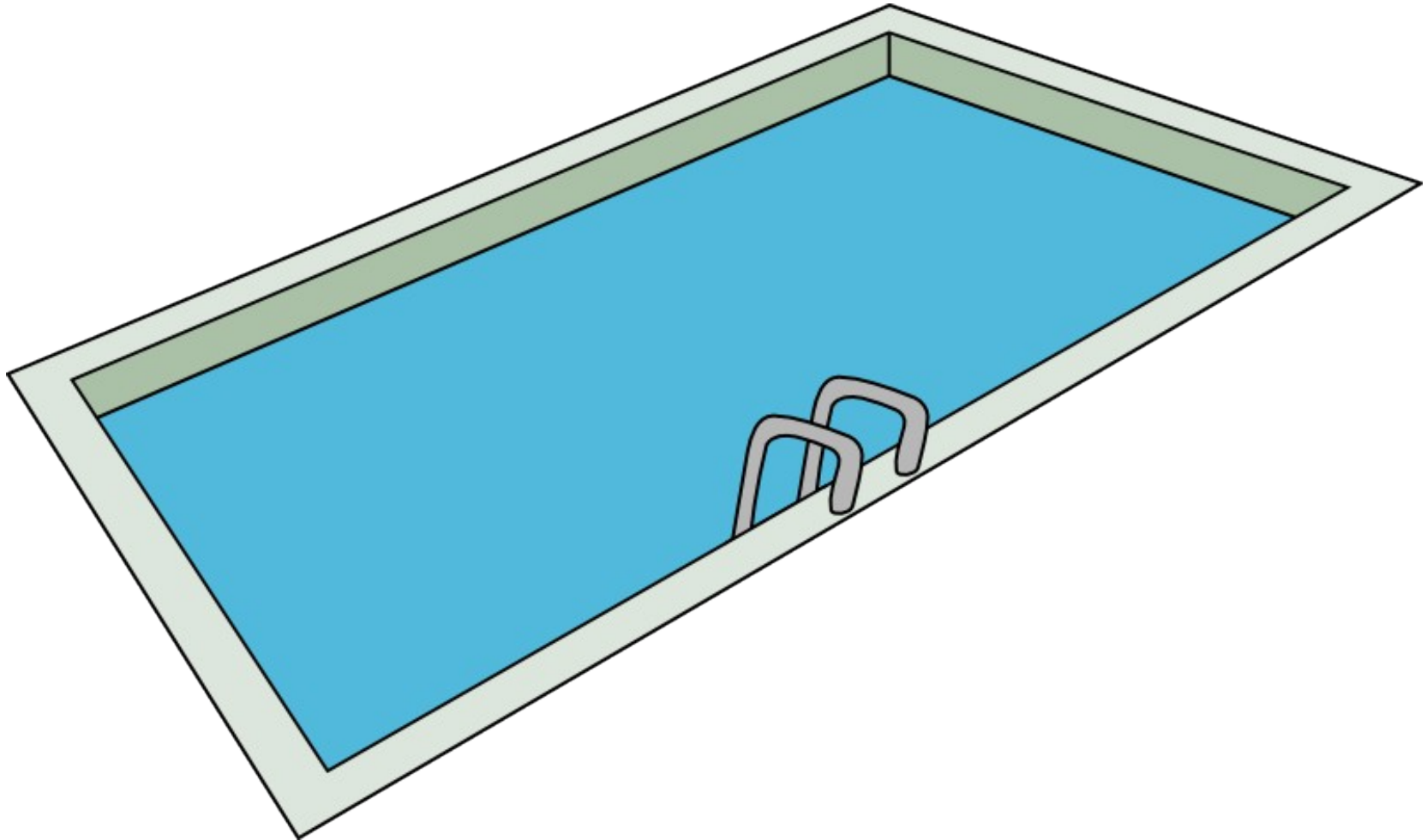


Not there yet...

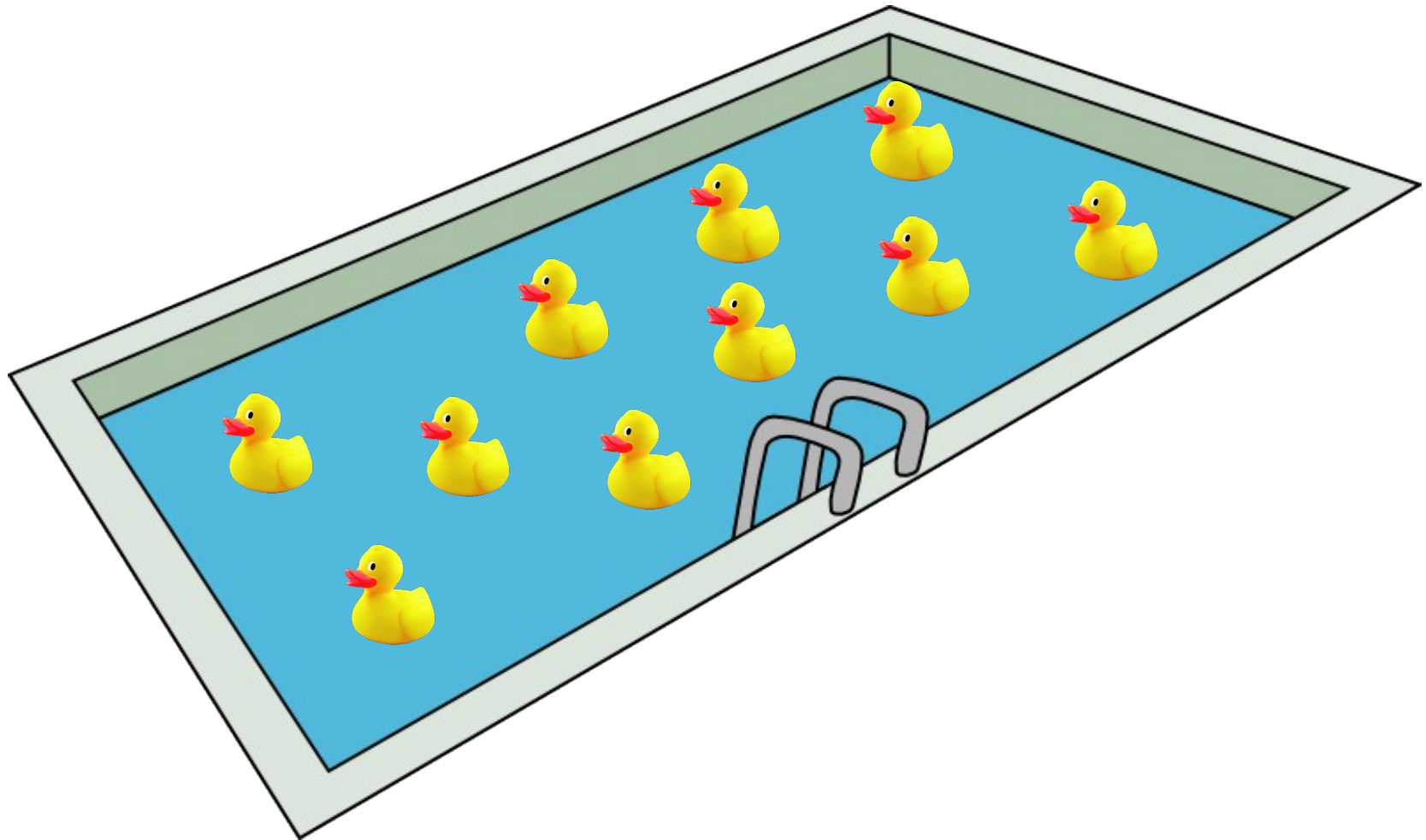


Thank you!

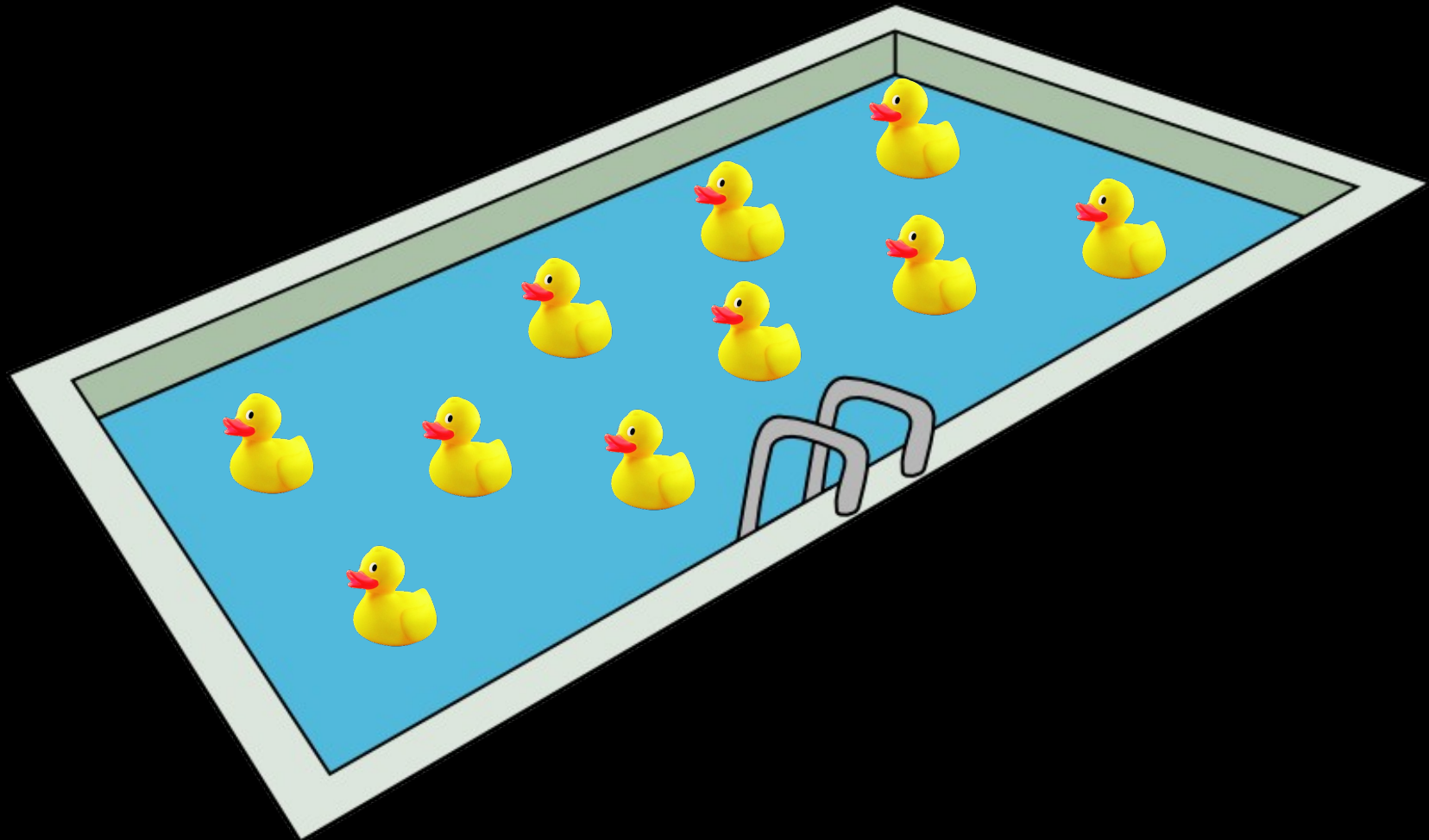
Quantum search



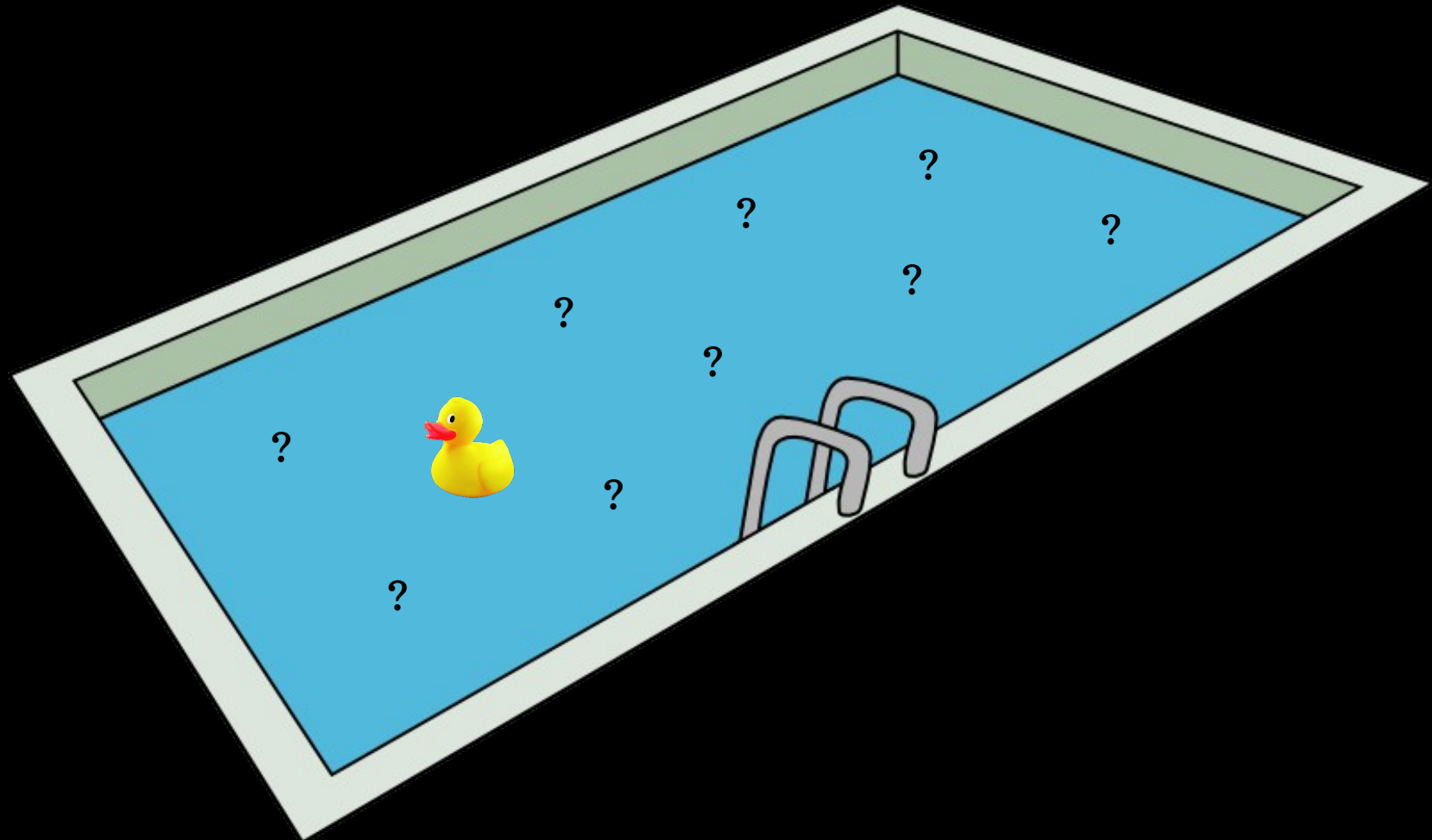
Quantum search



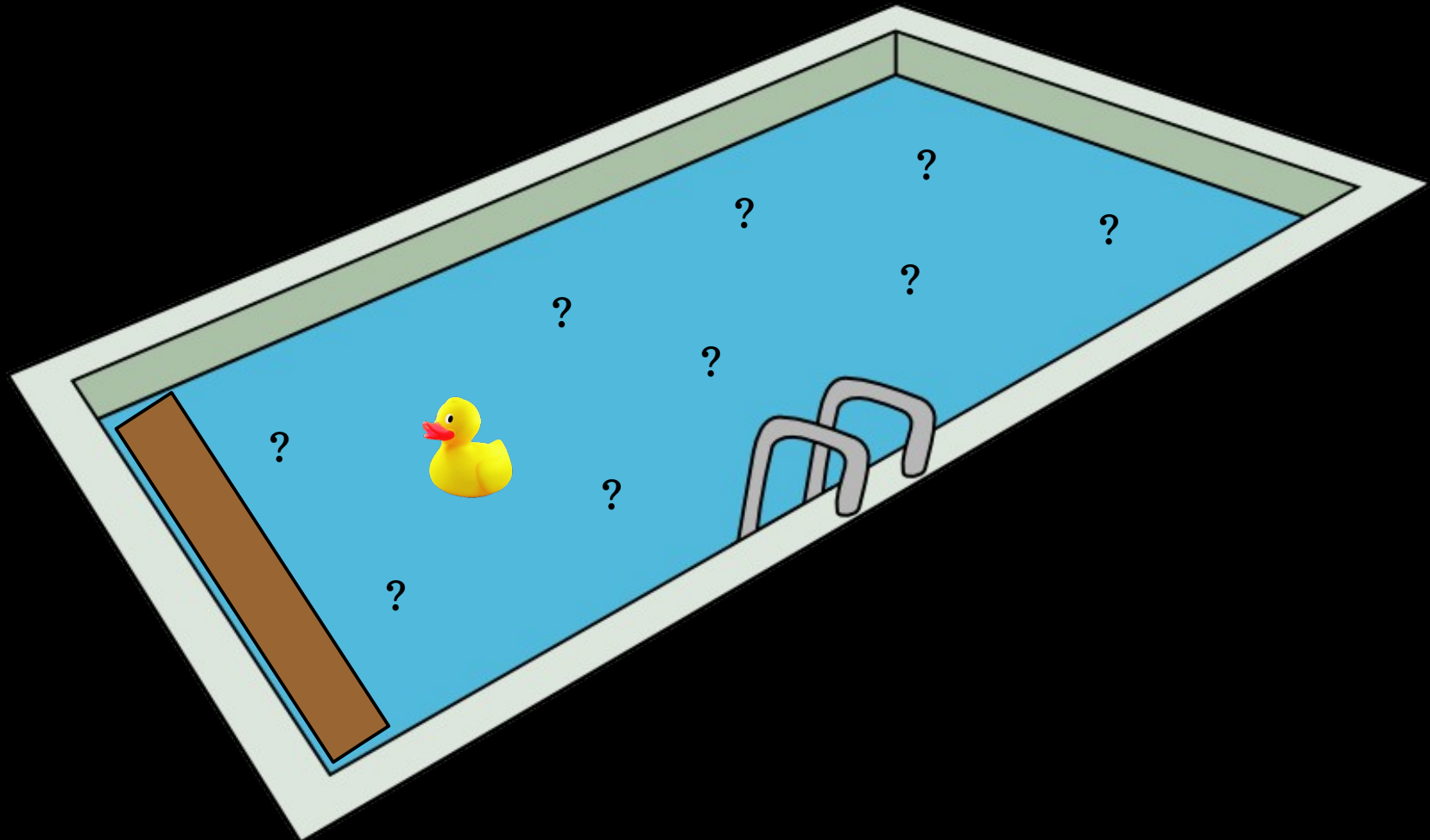
Quantum search



Quantum search



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