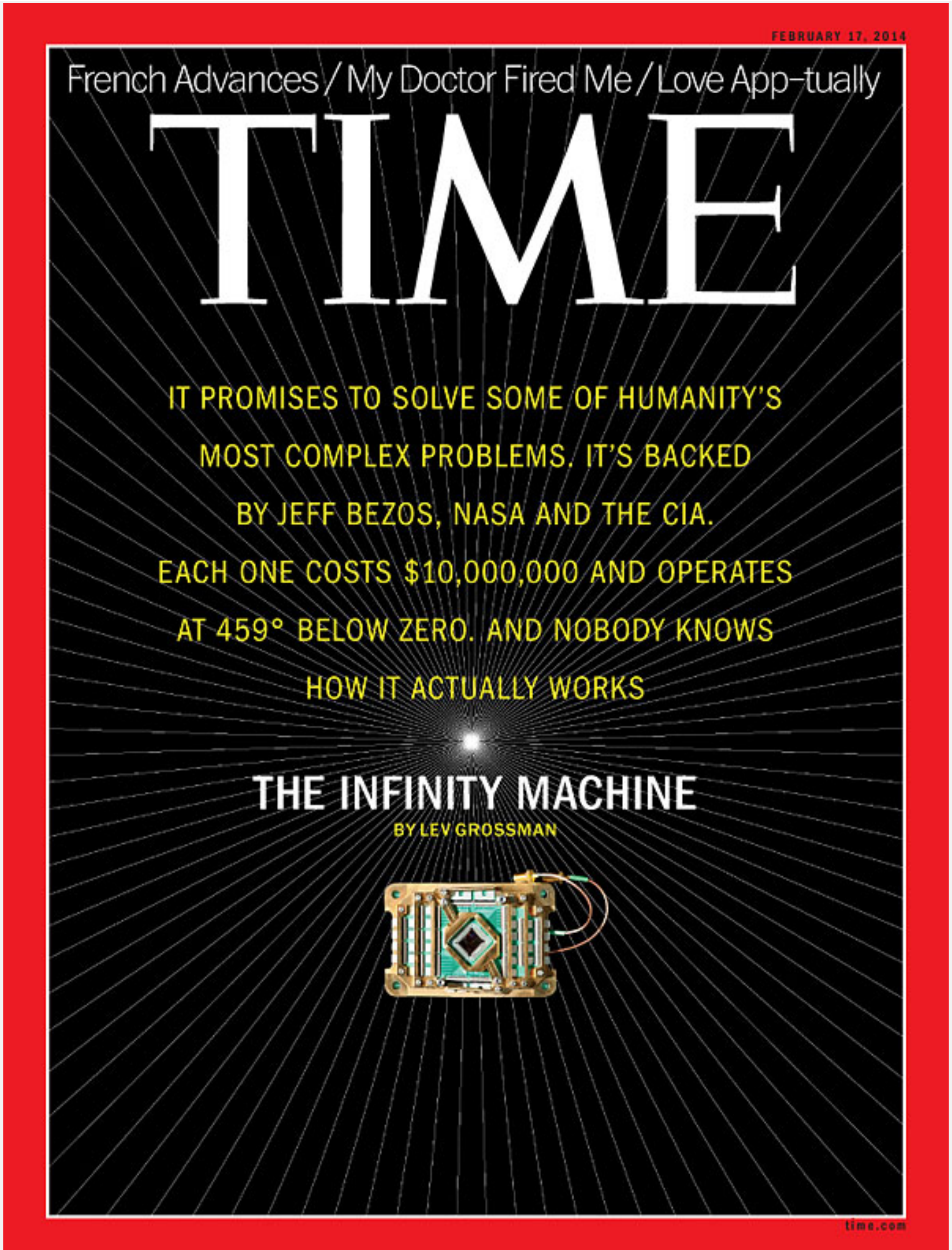
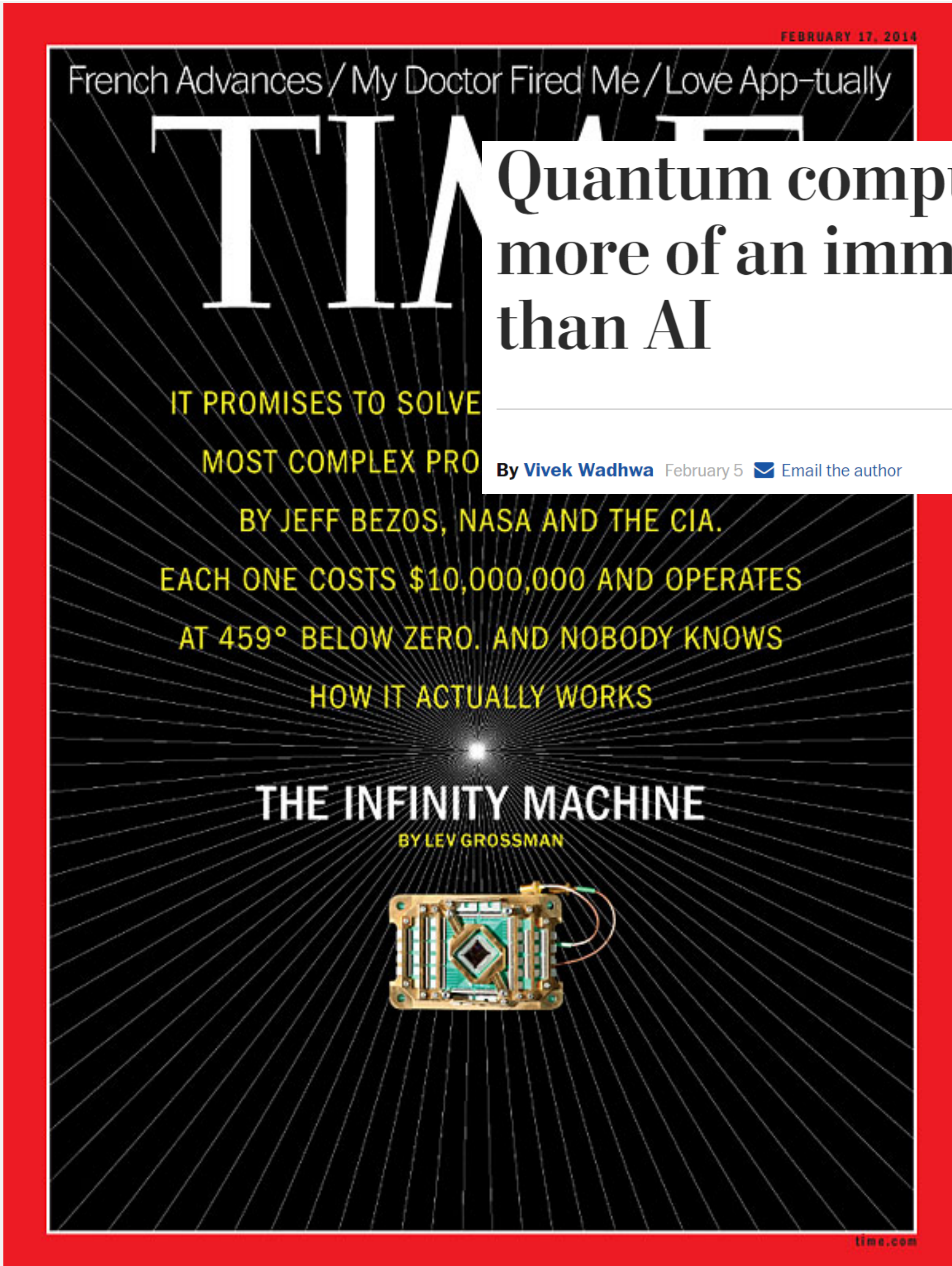
# Infinity Machines: Will Quantum Computers Live up to the Hype?

**Shelby Kimmel – Computer Science**

**Paul Hess – Physics**

Middlebury

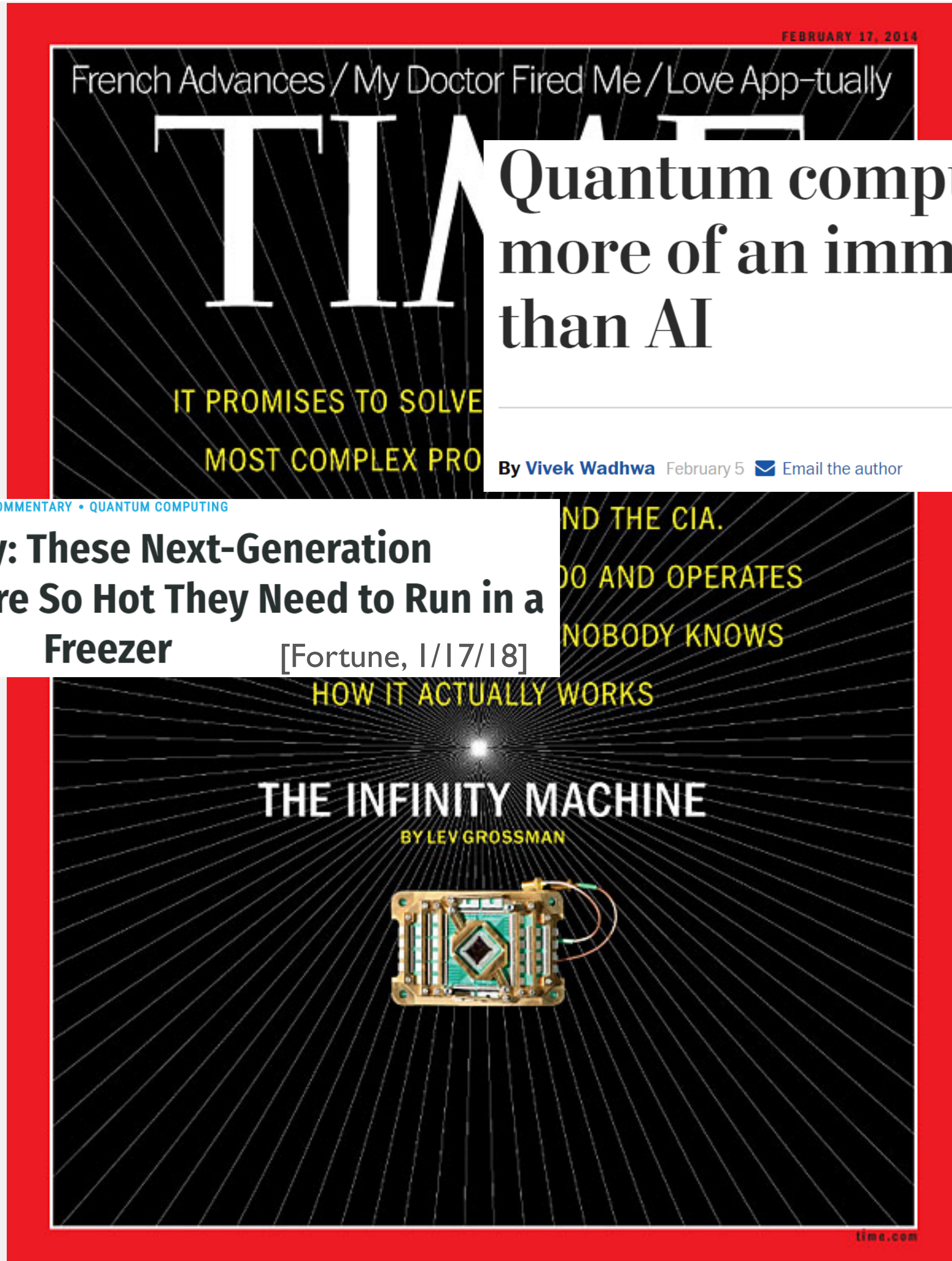

FEBRUARY 17, 2014
French Advances / My Doctor Fired Me / Love App-tually
TIME
IT PROMISES TO SOLVE SOME OF HUMANITY'S MOST COMPLEX PROBLEMS. IT'S BACKED BY JEFF BEZOS, NASA AND THE CIA. EACH ONE COSTS $10,000,000 AND OPERATES AT 459° BELOW ZERO. AND NOBODY KNOWS HOW IT ACTUALLY WORKS
THE INFINITY MACHINE
BY LEV GROSSMAN
time.com




# Quantum computers may be more of an imminent threat than AI

By **Vivek Wadhwa** February 5 Email the author

[Washington Post]

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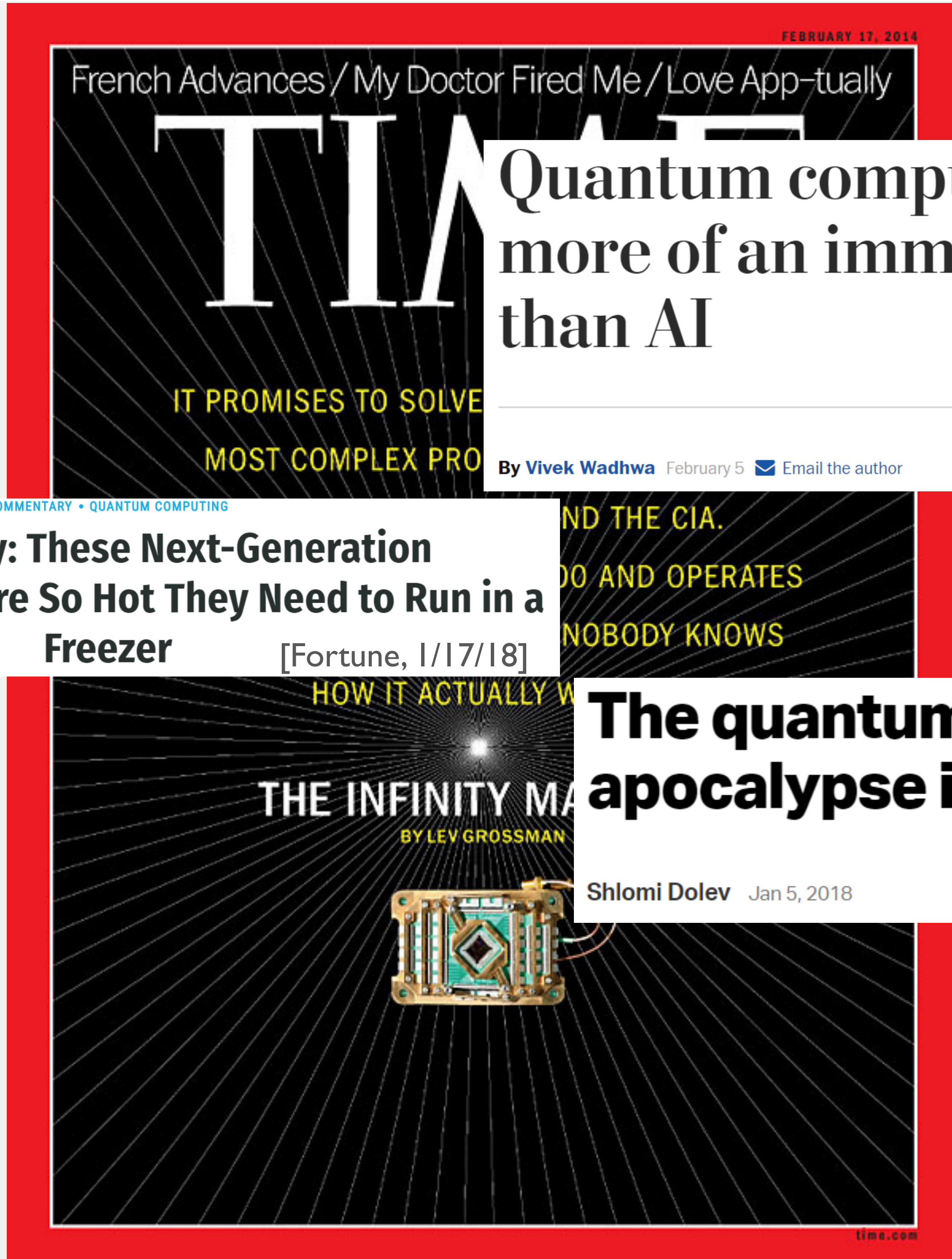
COMMENTARY • QUANTUM COMPUTING

## Commentary: These Next-Generation Supercomputers Are So Hot They Need to Run in a Freezer

[Fortune, 1/17/18]

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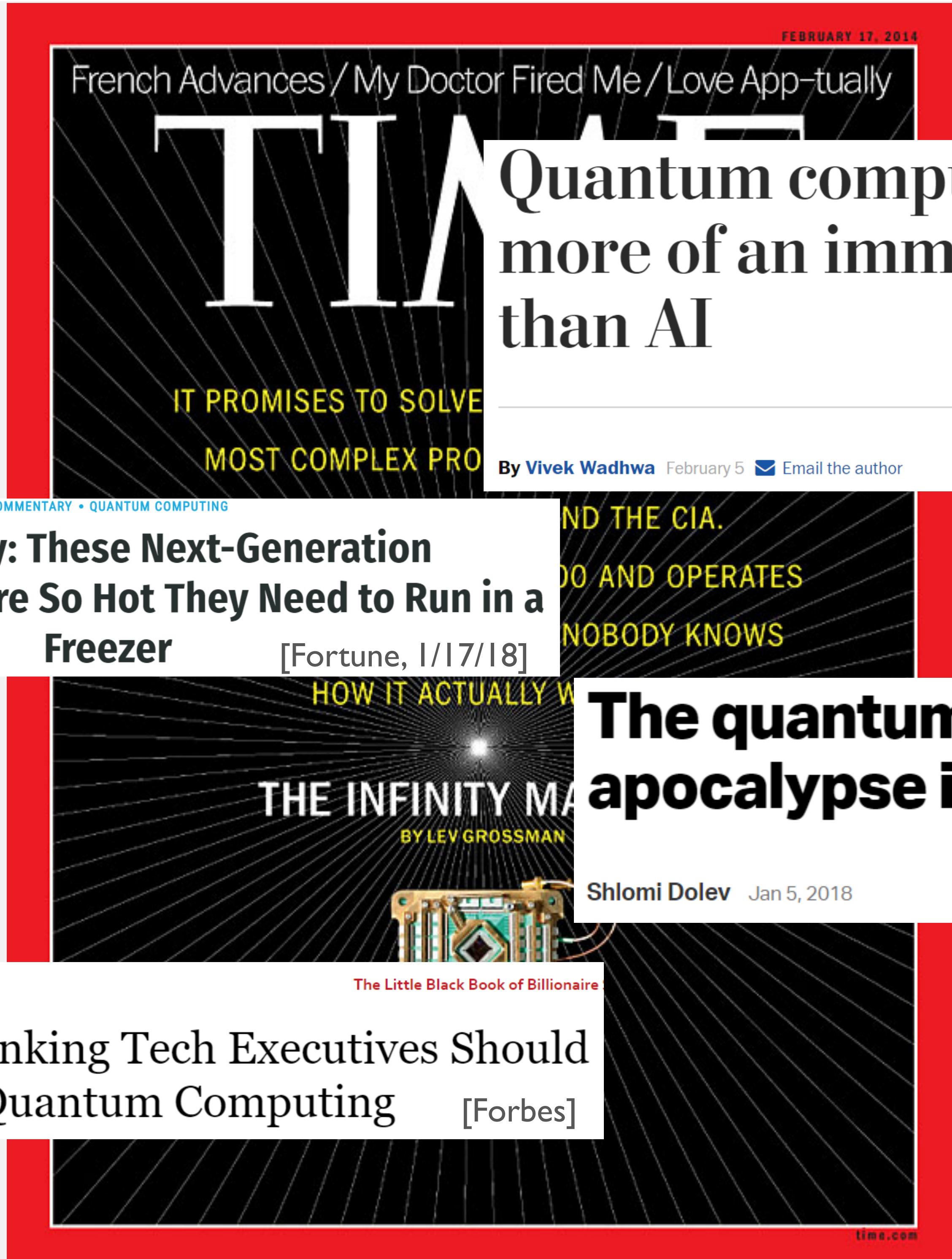


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MAR 1, 2018 @ 07:00 AM 1,141

The Little Black Book of Billionaire

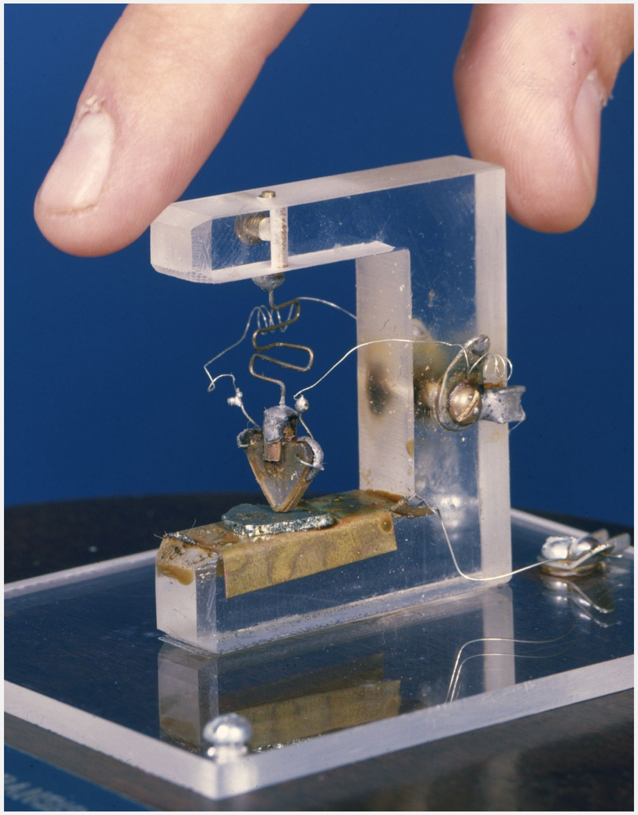
## Why Forward-Thinking Tech Executives Should Keep An Eye On Quantum Computing

[Forbes]

# Is the hype real?

- Why are people so excited about quantum computing?
- Are they infinity machines?
- Are quantum computers imminent?

# Limits on current computers



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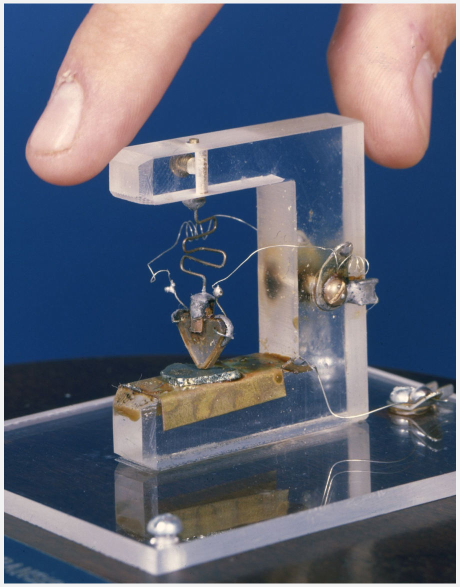
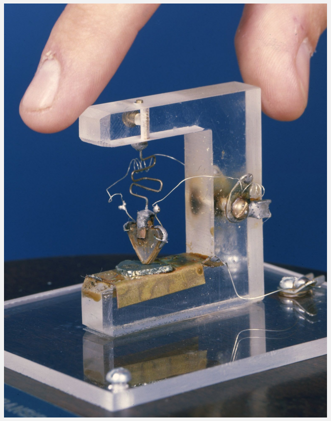


+2 years

# Limits on current computers



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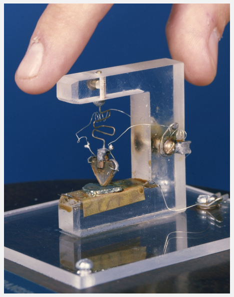

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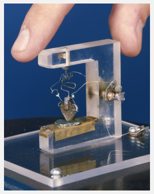
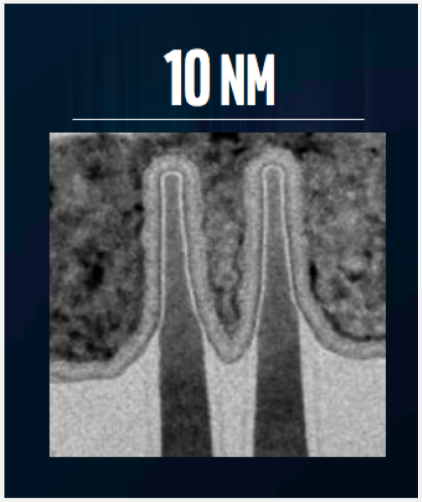
# Limits on current computers



+2 years

# Limits on current computers

Moore's Law:
exponential increase in transistors per chip



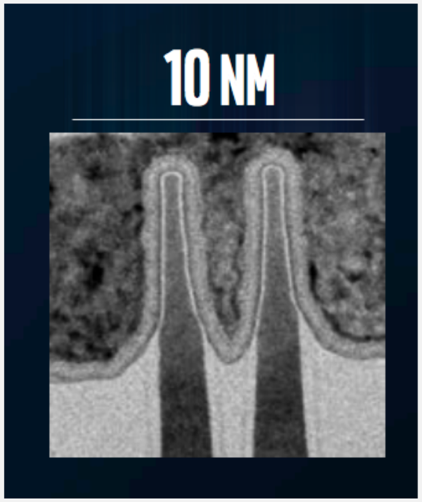
Intel

Today

# Limits on current computers

10 nm:

- Human hair is several thousand times thicker
- 20 atoms across



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When you get down to the size of atoms, quantum effects appear.

# Limits on current computers

10 nm:

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- 20 atoms across

When you get down to the size of atoms, quantum effects appear.

It's not a bug; it's a feature!

# Quantum Computing

Using quantum effects, can solve some problems ***much*** faster

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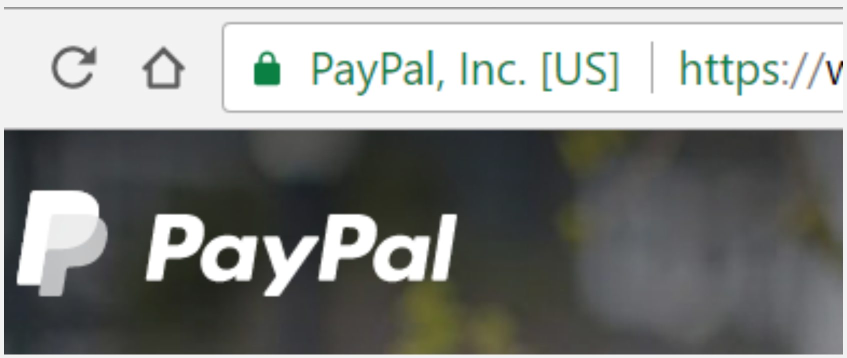
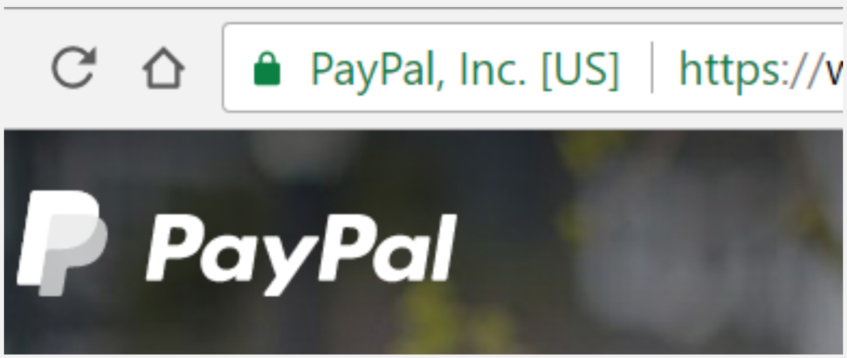
- 


Break public key cryptosystems

# Quantum Computing

Using quantum effects, can solve some problems ***much*** faster

- 


  Break public key cryptosystems

- 


  WorldArtsMe

  Find new chemical processes

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# Quantum Computing

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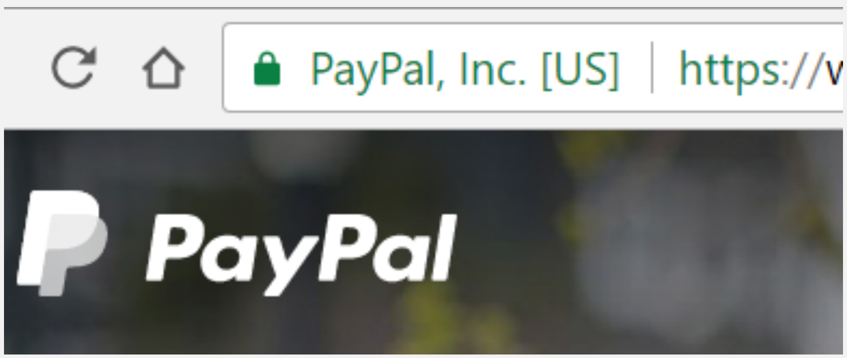
- 


  Break public key cryptosystems

- 

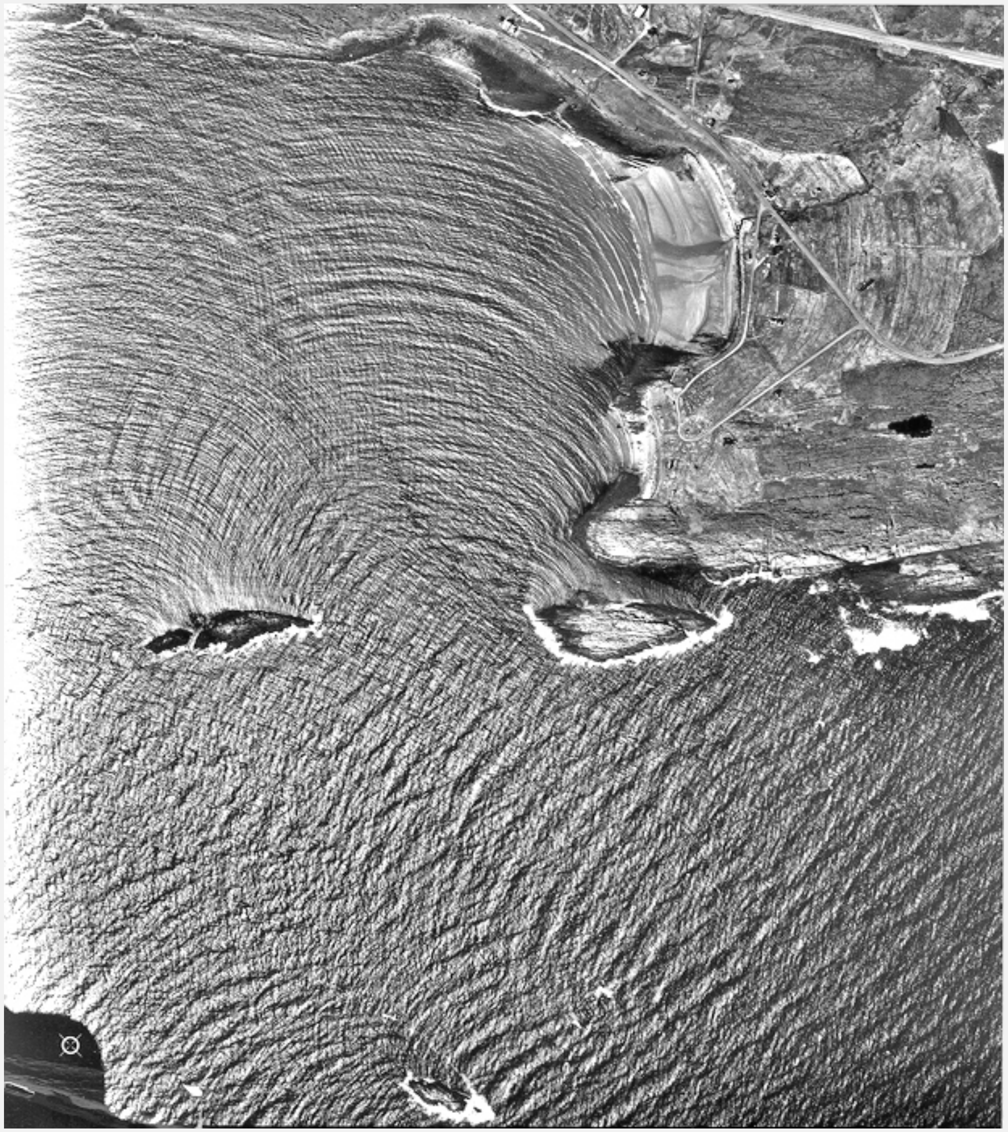

  WorldArtsMe

  Find new chemical processes

- Other problems?

# Metaphor for quantum computer

- Quantum computation is like interaction of waves, islands, and shore



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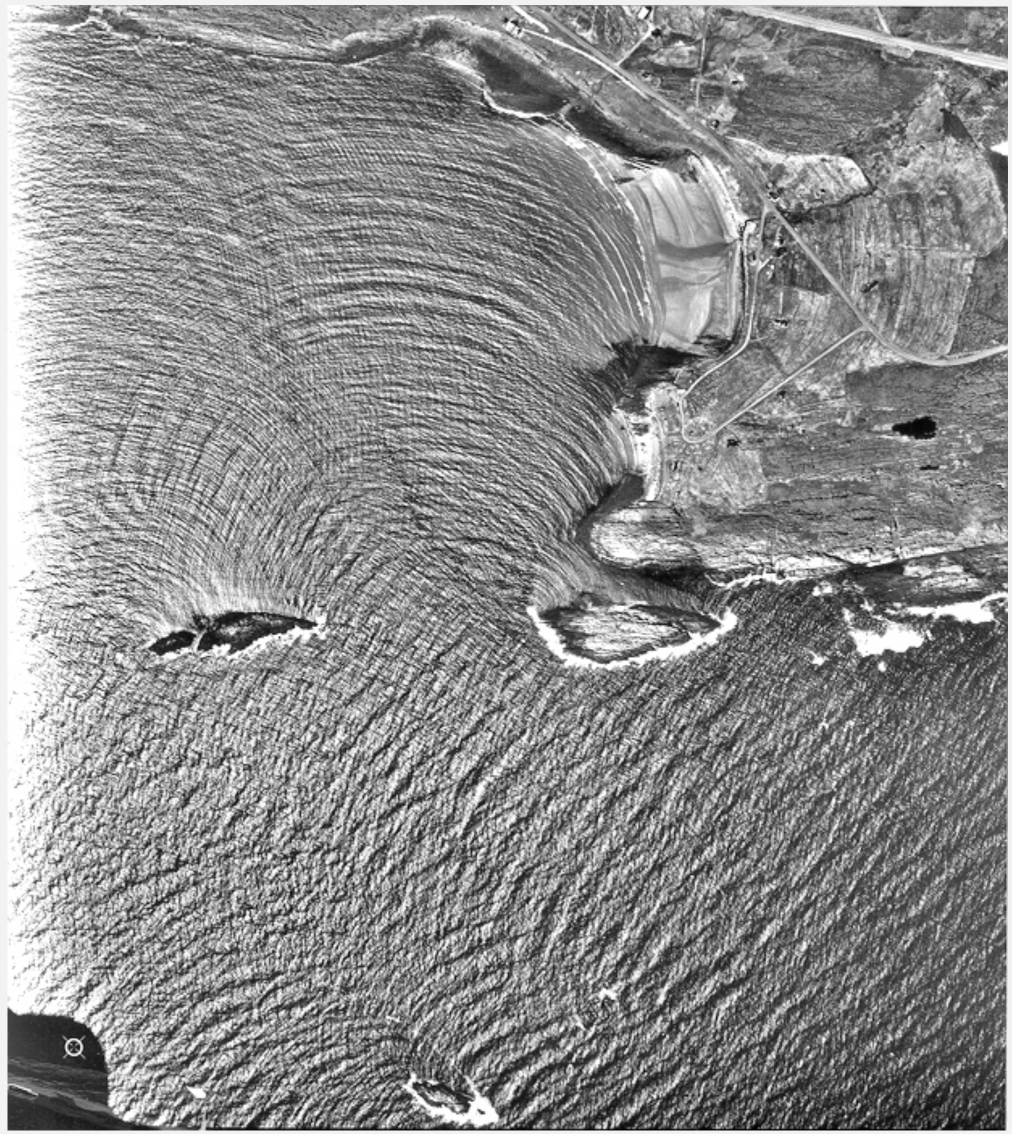
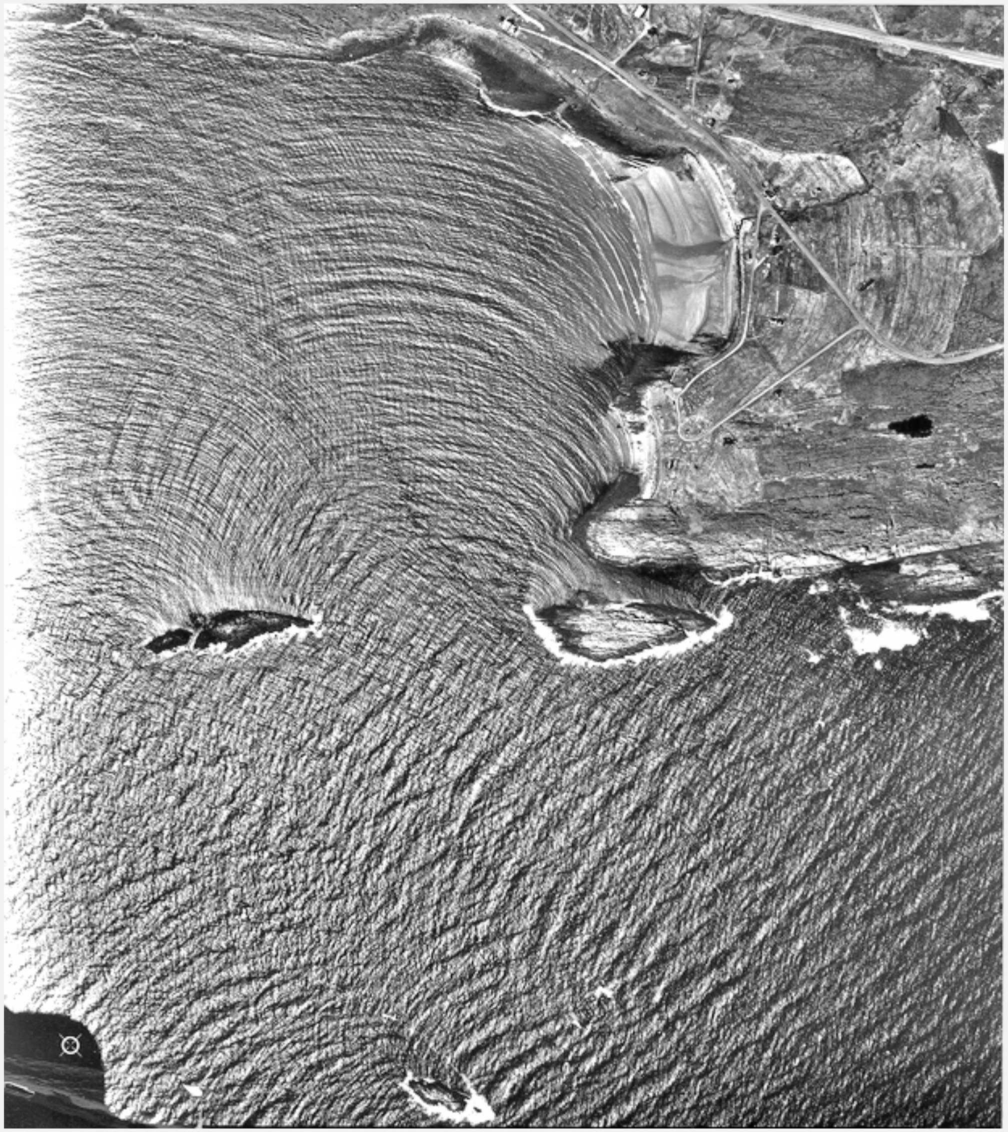


# Metaphor for quantum computer

- Quantum computation is like interaction of waves, islands, and shore
- I can control islands and shoreline
- Output of computation is location of a large wave



# Quantum Advantage

Quantum computers seem really helpful for some problems but not others.

WHY?

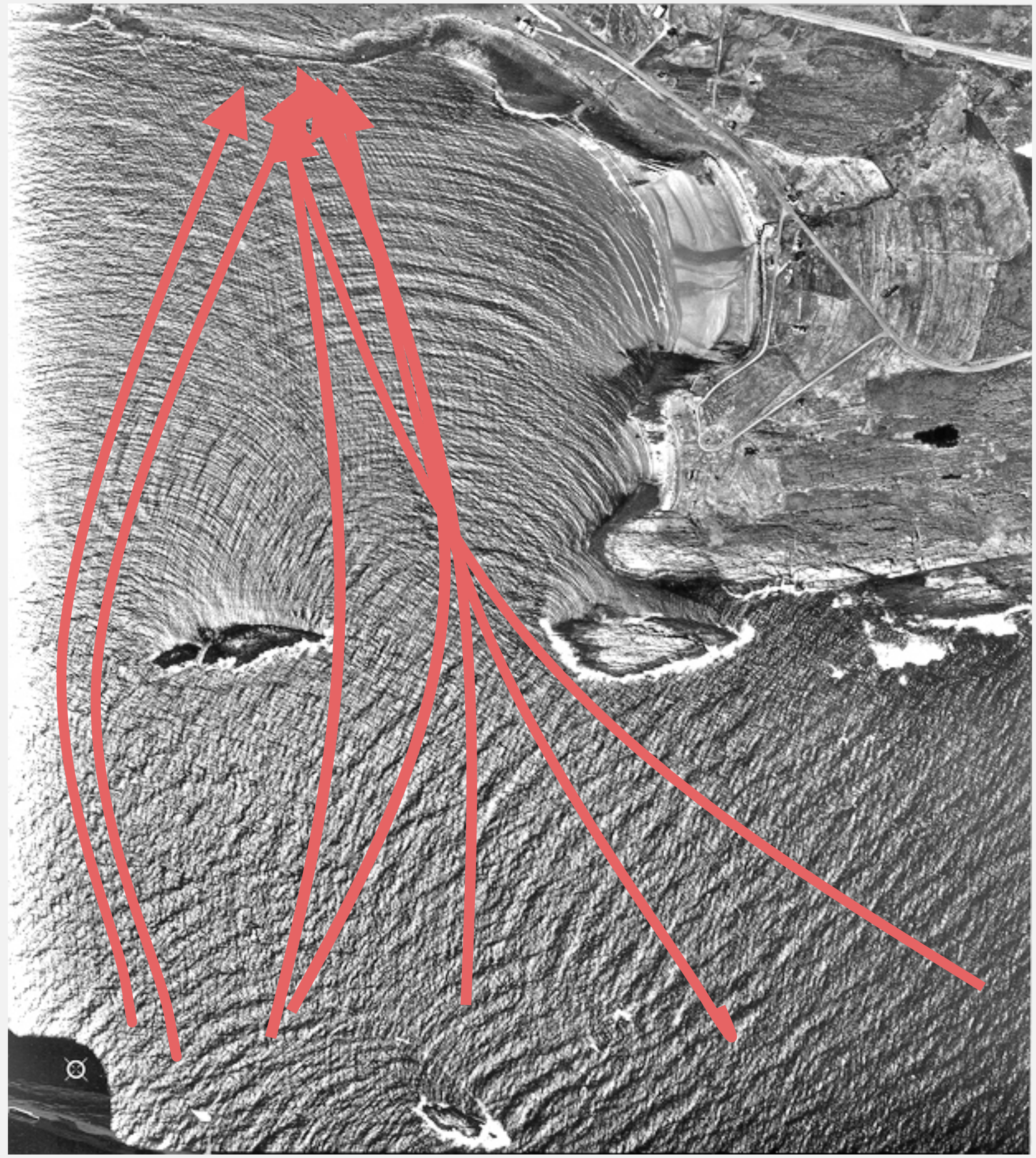
- Superposition
- Interference

# Quantum Advantage

- Superposition – "can be in many states at once"

# Quantum Advantage

- Superposition: waves explore many paths through the environment, hit all the points on the shore



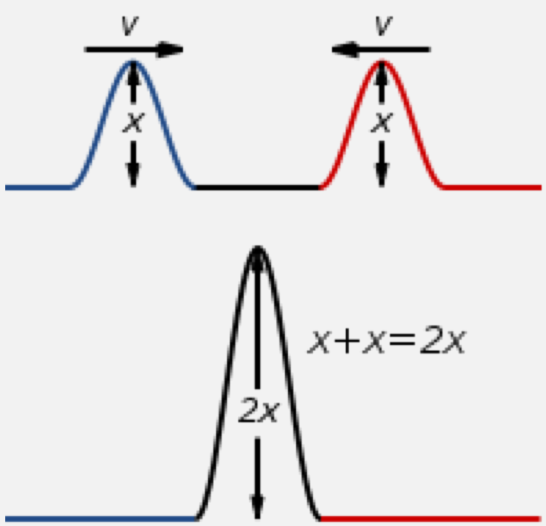
# Quantum Advantage

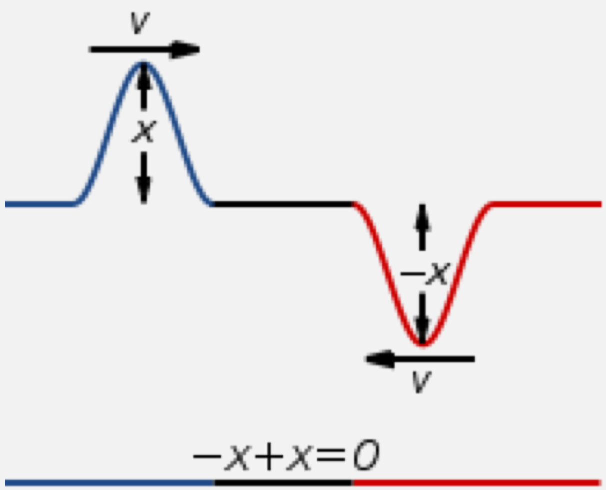
What gives quantum computers their power?
Why is this power helpful for some problems, but not helpful for others?

- Superposition – "can be in many states at once"
- Interference

# Quantum Advantage

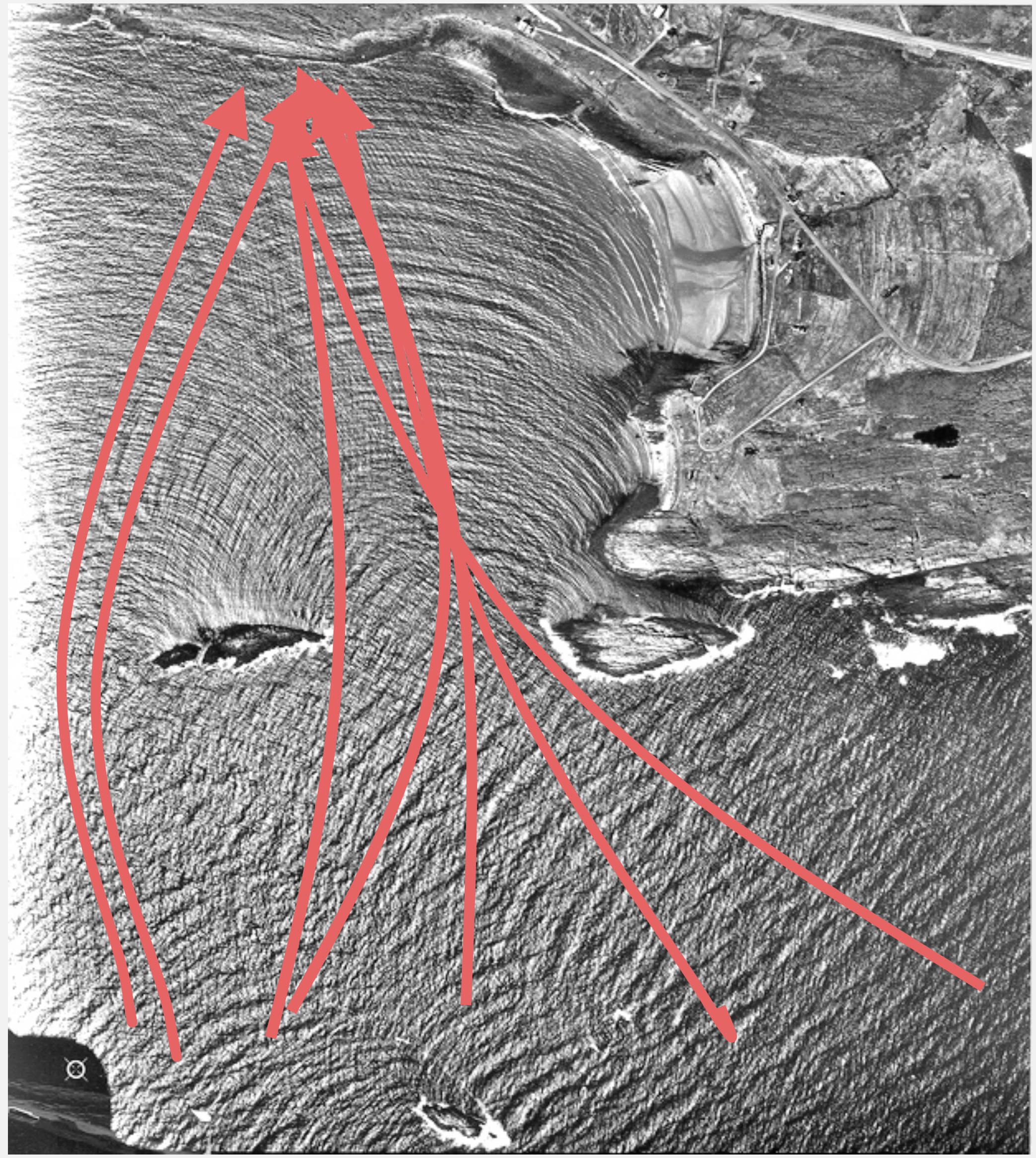
- Interference



# Quantum Advantage

- Interference: waves travel from different paths. If in sync when get to shore, get big wave, if out of of sync, get no wave.



# Quantum Advantage

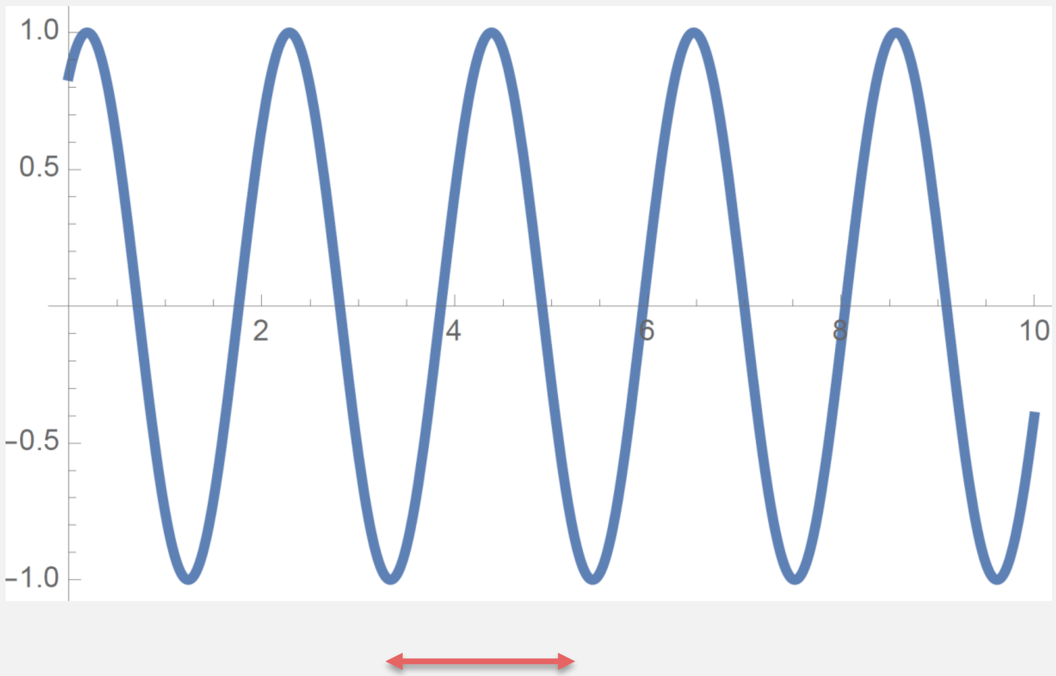
What gives quantum computers their power?
Why is this power helpful for some problems, but not helpful for others?

- Superposition – “can be in many states at once”
- Interference – “cancel the bad, enforce the good”

# Quantum Advantage

- Some problems have structure that helps build up interference fast:

What is the period of a periodic function?

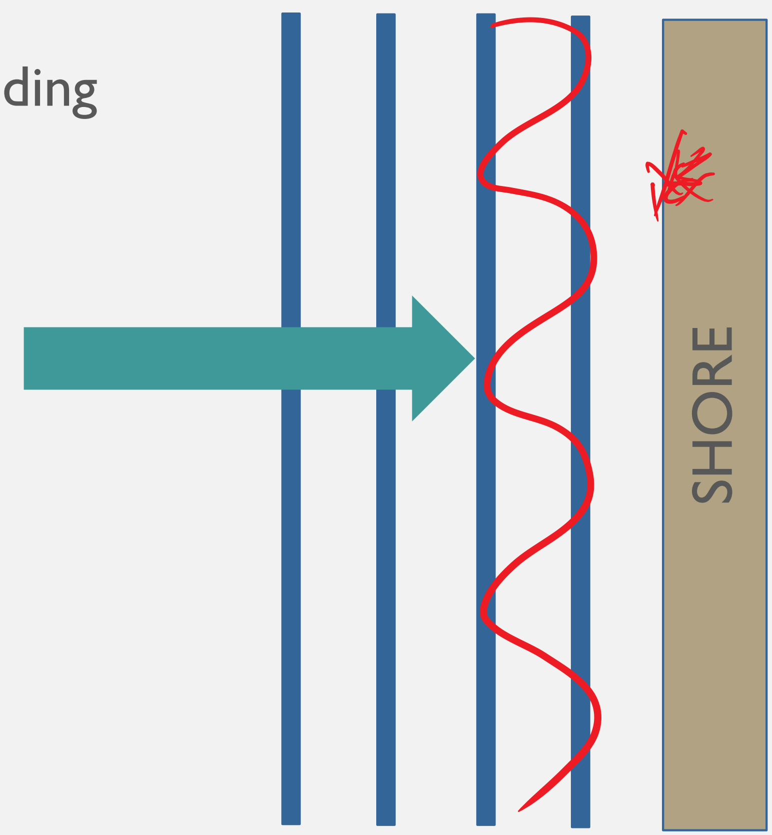


# Quantum Advantage

- Some problems have structure that helps build up interference fast:

Period Finding

Ocean



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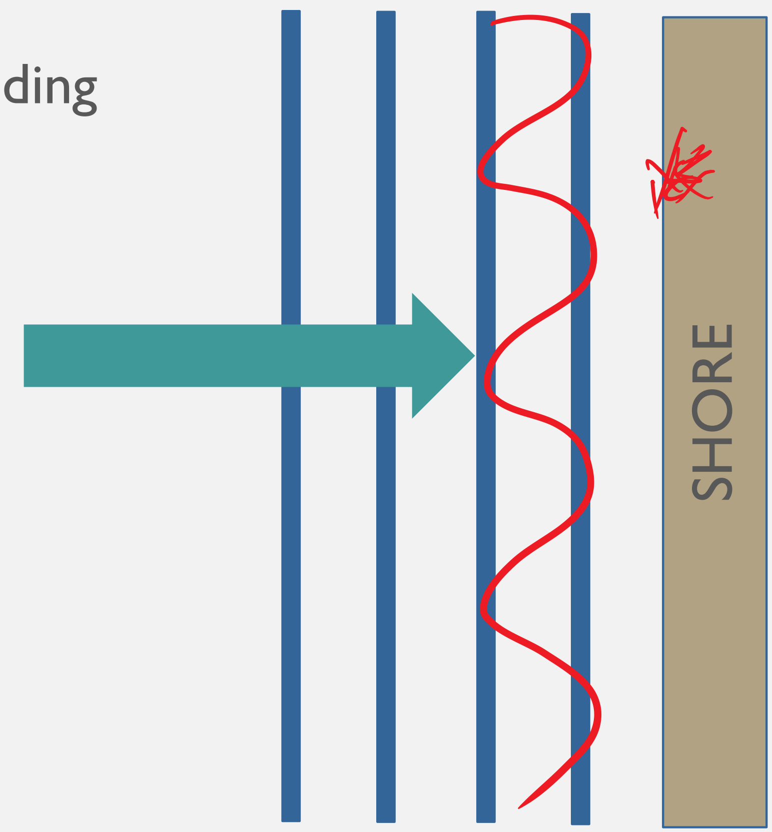



Quantum computers can find the period of a function exponentially faster than regular computers

Used to break cryptosystems

# Quantum Advantage

- Other problems have very little structure, need more time to build up interference

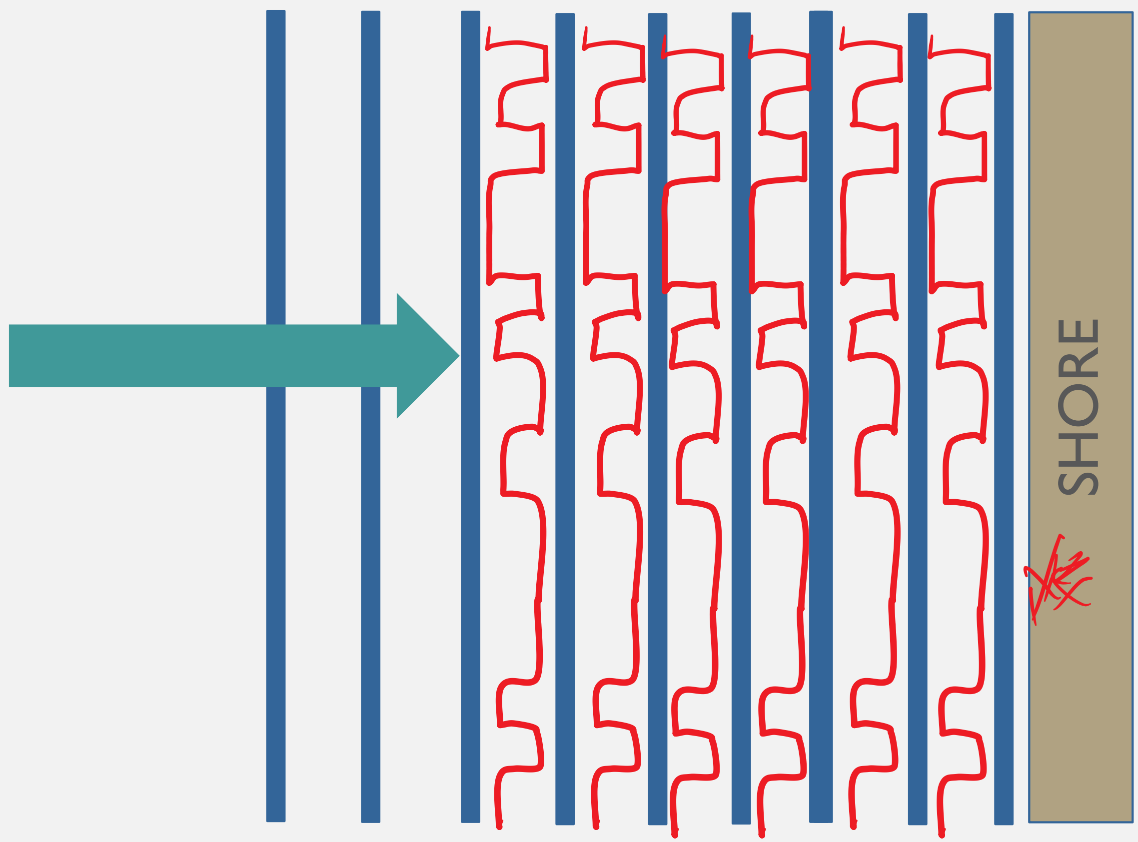
Parity: Even or odd number of 1's

$011010101110$ (seven $1's$ → odd parity)
$011010001110$ (six $1's$ → even parity)

# Quantum Advantage

- Other problems have very little structure, need more time to build up interference

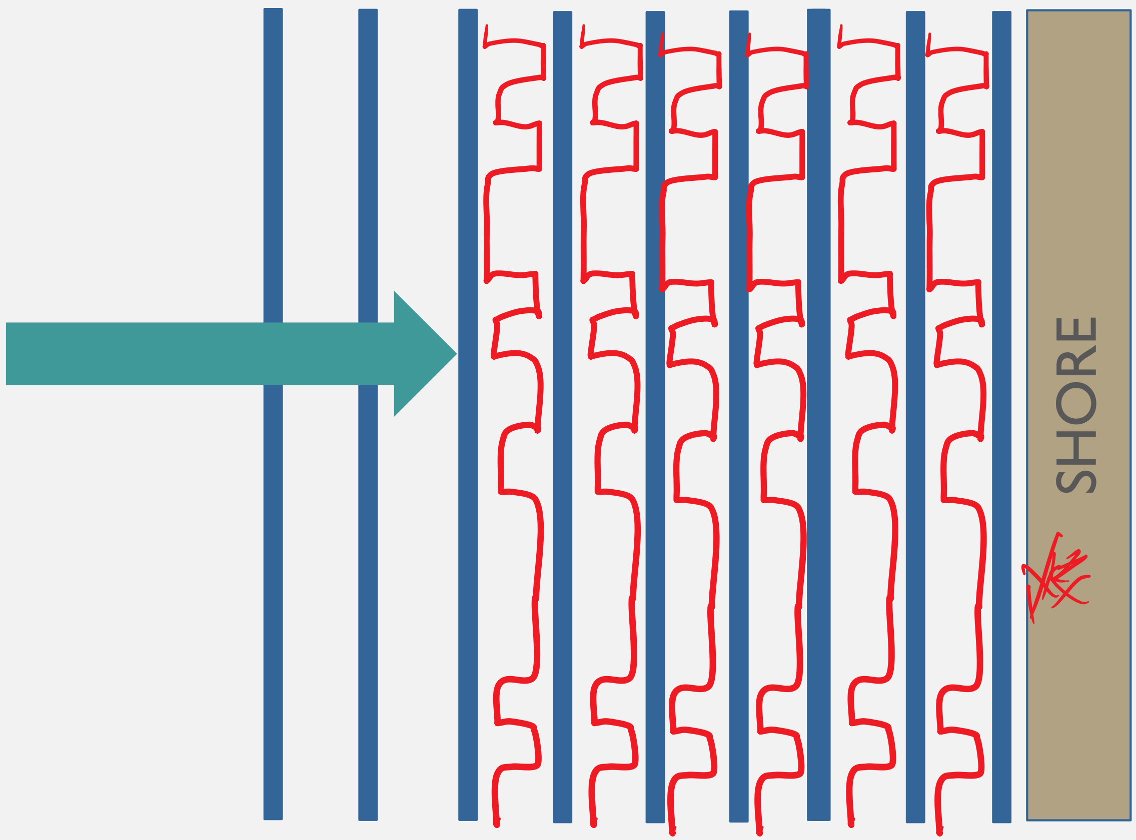
Parity



# Quantum Advantage

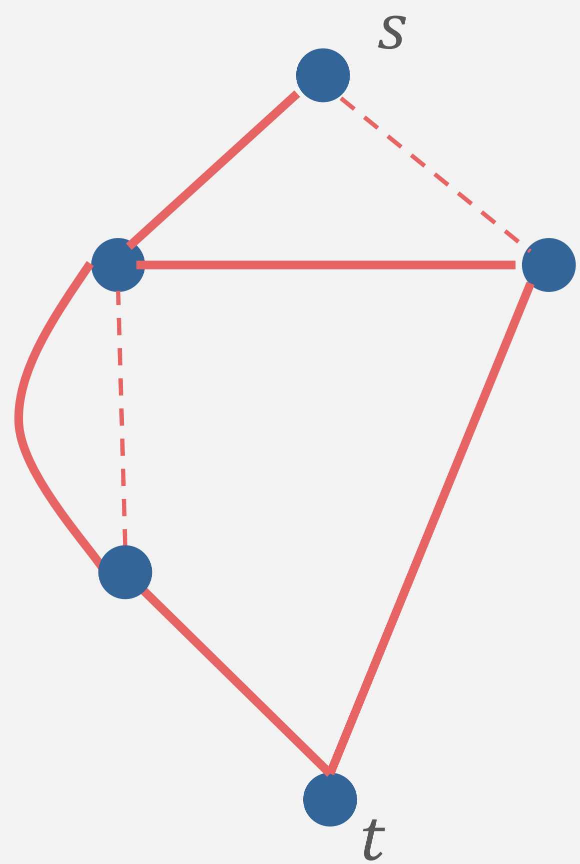
- Other problems have very little structure, need more time to build up interference

Parity:
No quantum advantage



# Quantum Advantage for $st$-connectivity

$\boldsymbol{st-connectivity}$:
is there a path from $s$ to $t$?



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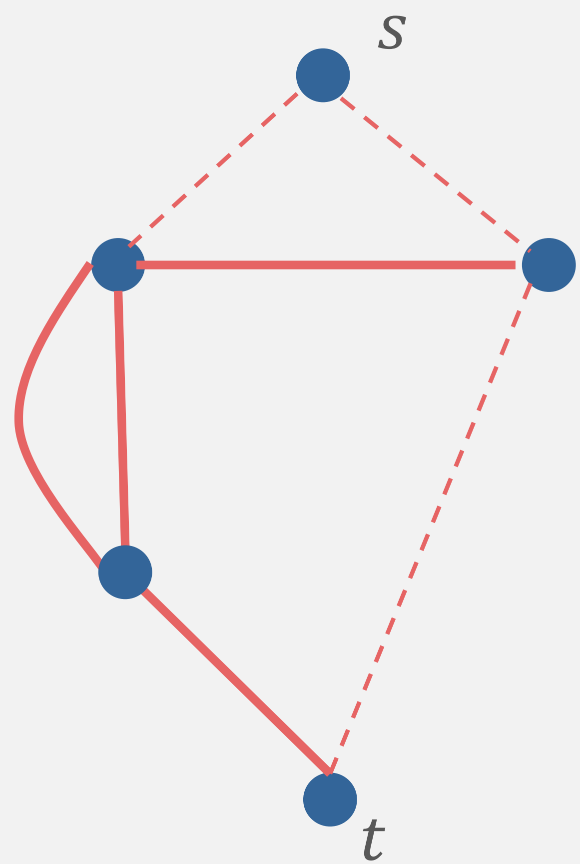
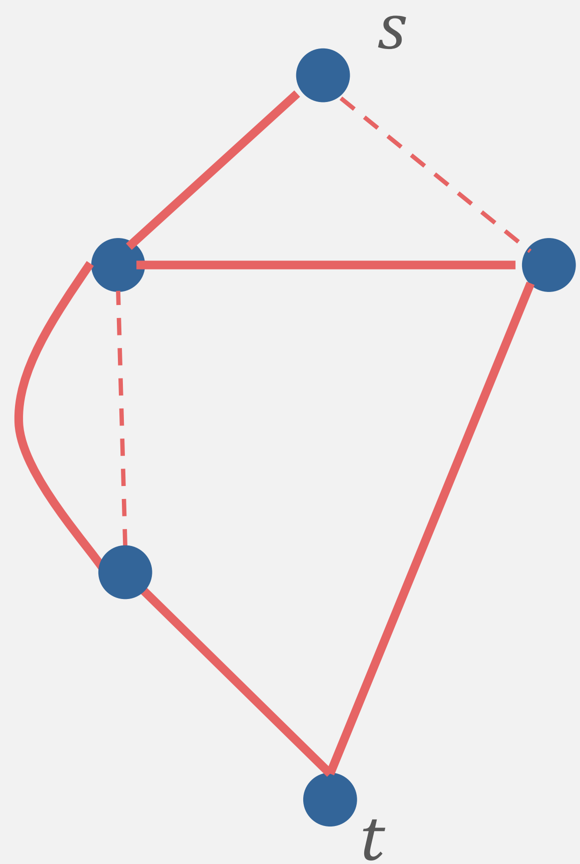


# Quantum Advantage for $st$-connectivity

$\boldsymbol{st - connectivity}$:
is there a path from $s$ to $t$?

Applications:

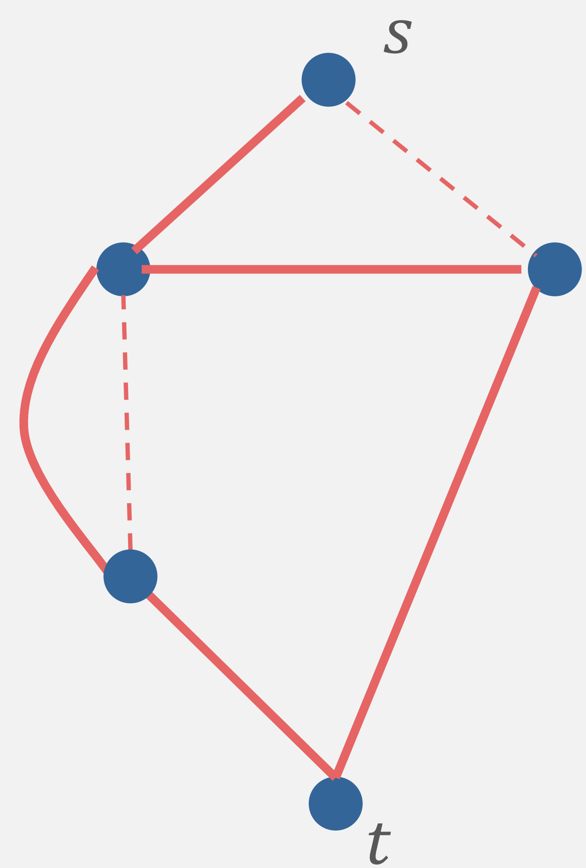
- Finding relatives
- Navigation



# Quantum Advantage for $st$-connectivity

$\boldsymbol{st - connectivity}$:
is there a path from $s$ to $t$?

What types of graphs have structure that make this problem easy to solve for quantum computers?



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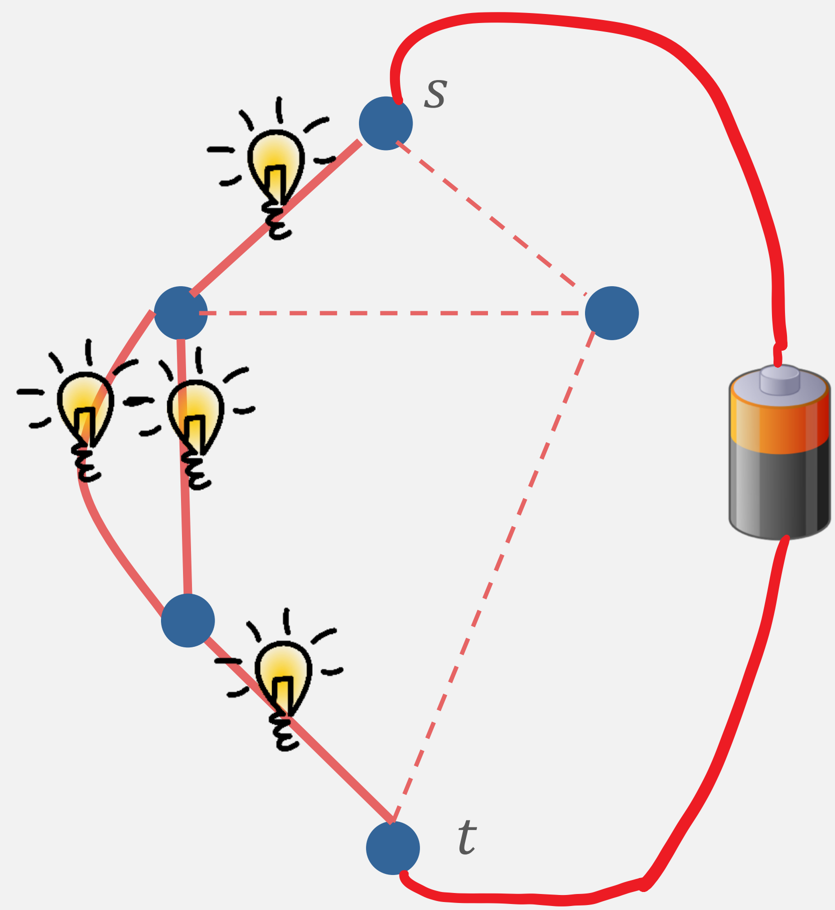
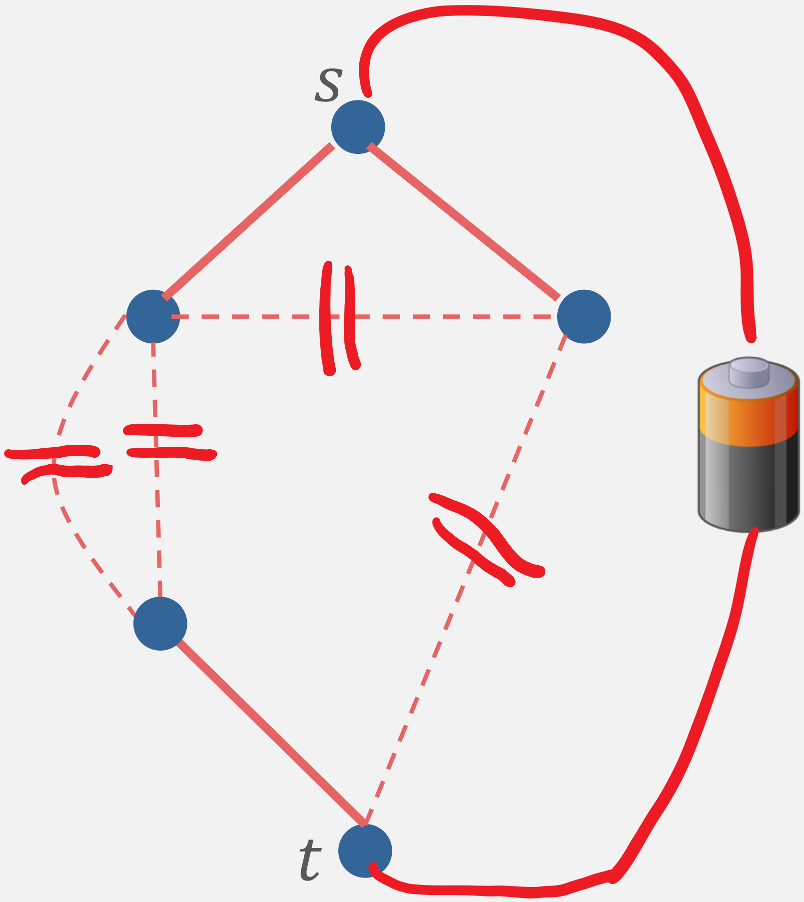
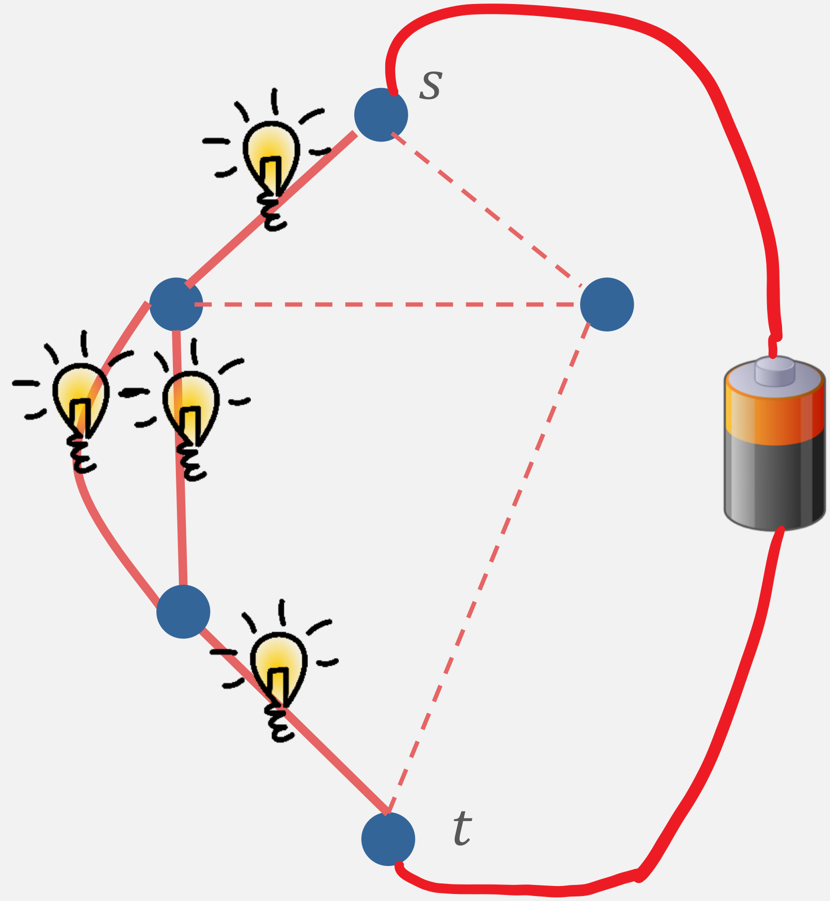



More current flow (smaller effective resistance) → easier for quantum computer to solve

# Quantum Advantage for $st$-connectivity




Less charge build-up (smaller effective capacitance) → easier for quantum computer to solve



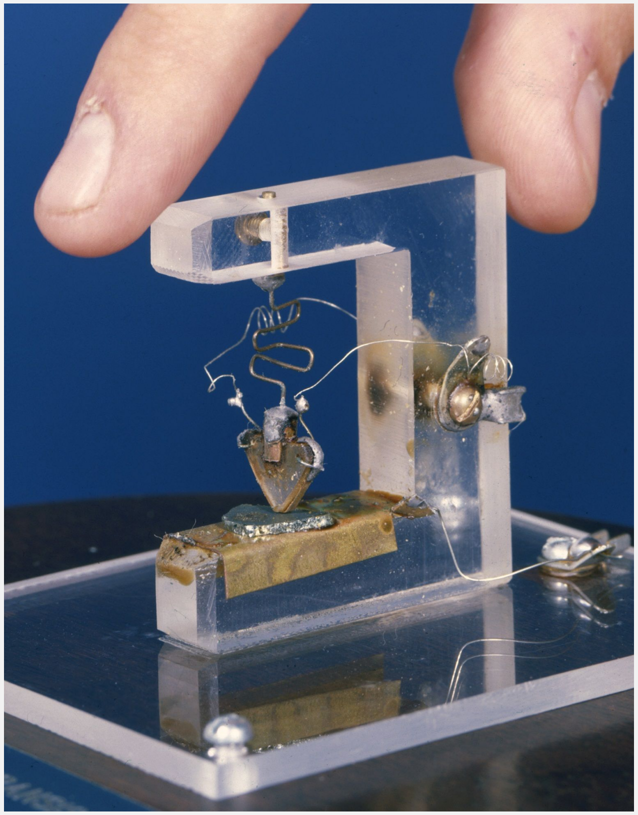

More current flow (smaller effective resistance) → easier for quantum computer to solve

# Is the hype real?

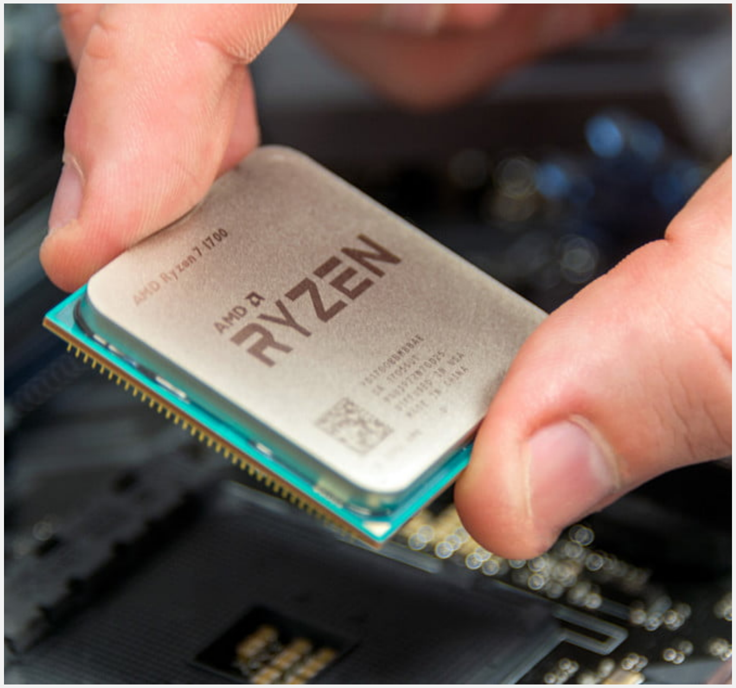
- Why are people so excited about quantum computing?
- Are they infinity machines?
- Are quantum computers imminent?

# Why Moore's Law?


The vacuum tube
(1940s-1950s)



The first transistor (replica)
1947




Modern CPU Chip
Over 4 billion transistors
(AMD Ryzen 7)

# How do we go quantum?

State 1 

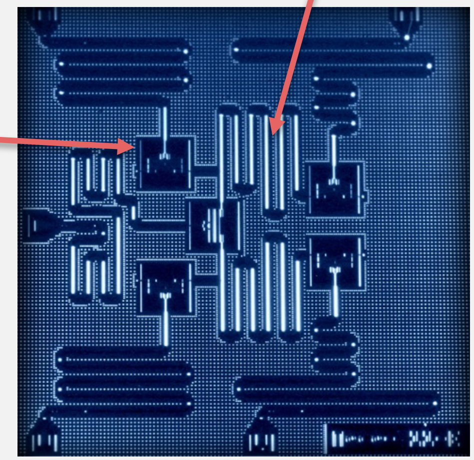
Superposition

State 0 

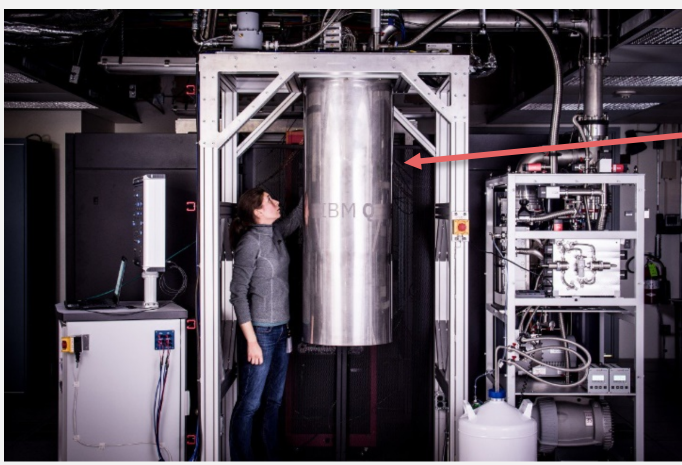
Step 1: Make or isolate a "quantum bit" (qubit)

Connecting wires

Qubit



Step 2: Wire them together to generate interference



Contains 20 qubits

Step 3: Put lots of connected qubits together

Photos: IBM Research

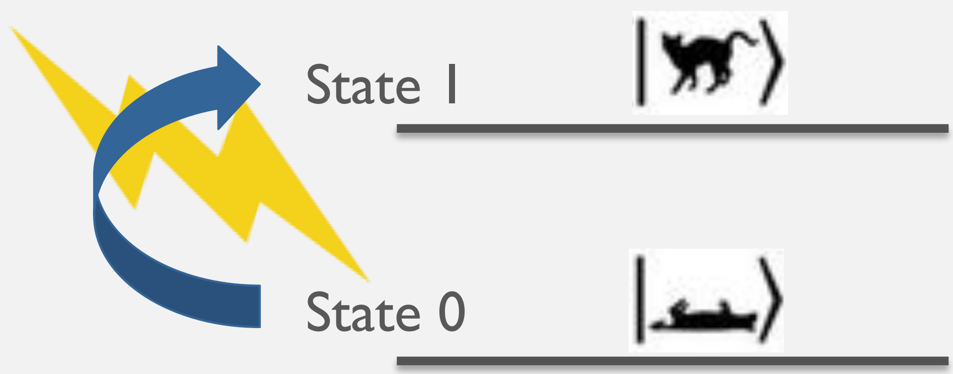
IBM Cloud Interface

Step 4: Run cleverly designed quantum algorithms

# Limitations: Cutting though the hype

Loss of Memory (Noise)

Why IBM's qubits must be refrigerated to $-459°$ F

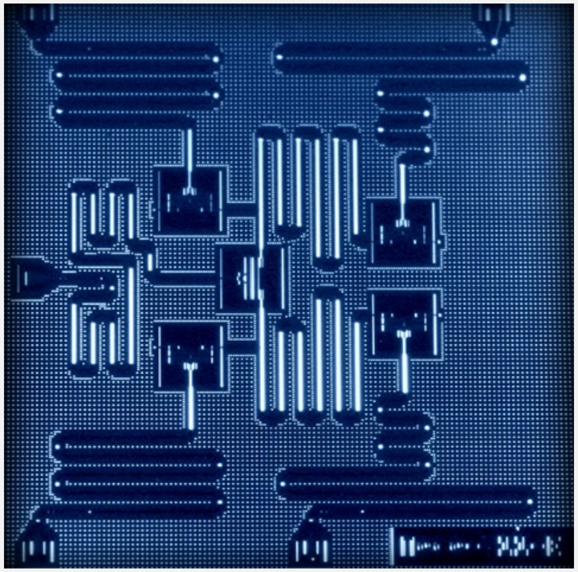



Lack of Precise Control

Qubit must be "revived" correctly 99.9% of the time

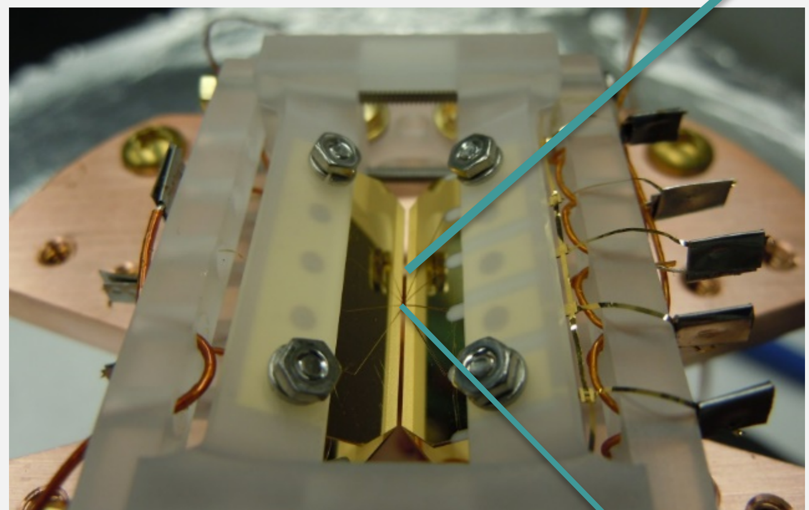
The more "9s", the better

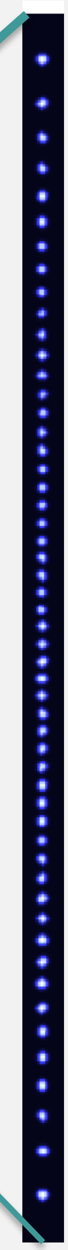
# Still searching for our transistor?



Printed Circuit Qubit

The IBM and Google approach





Levitated Atomic Ions

Both technologies have benefits and drawbacks ….

Is there another way to make progress on interesting problems using the limited machines we have now?

# Analog Computing

## Making the most with limited resources

Antikythera Mechanism
for astronomical predictions
(2nd Century B.C.E.)

Photo: Steven Fine

Tide-Predicting Machine No. 2
U.S. Coast Guard, (1912 – 1965)

PACE 16-31R – Electronic Analog Computer
for spacecraft trajectory calculations
NASA (1950s – 1970s)

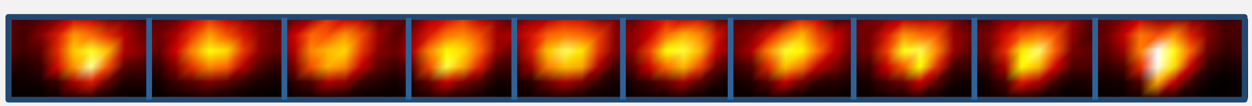
Photo: NASA

# A quantum simulator of magnetism

The physics we'd like to simulate

A chain of interacting quantum bar magnets
- Seems simple, but its behaviors are complex
- Practical applications:
    - Encodes "optimization problems"

Why go analog?
- Less fine control required
- Errors and noise have less effect

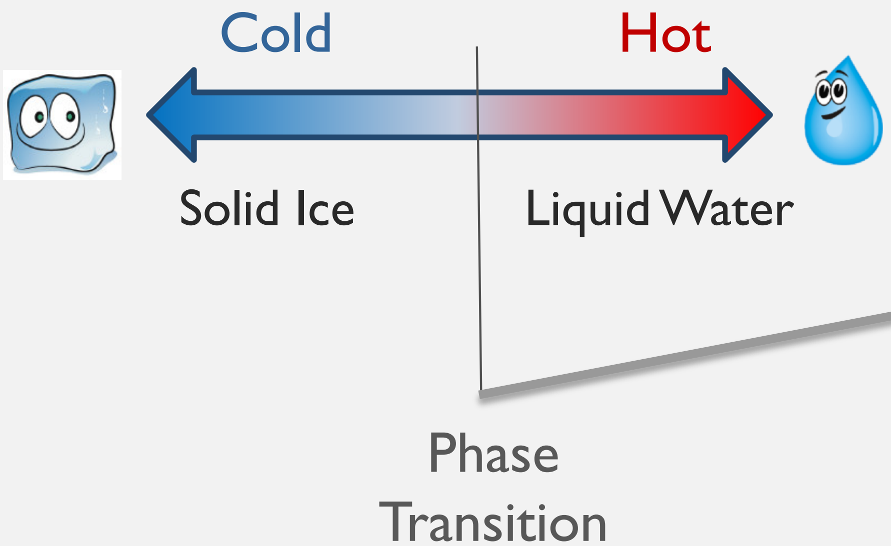


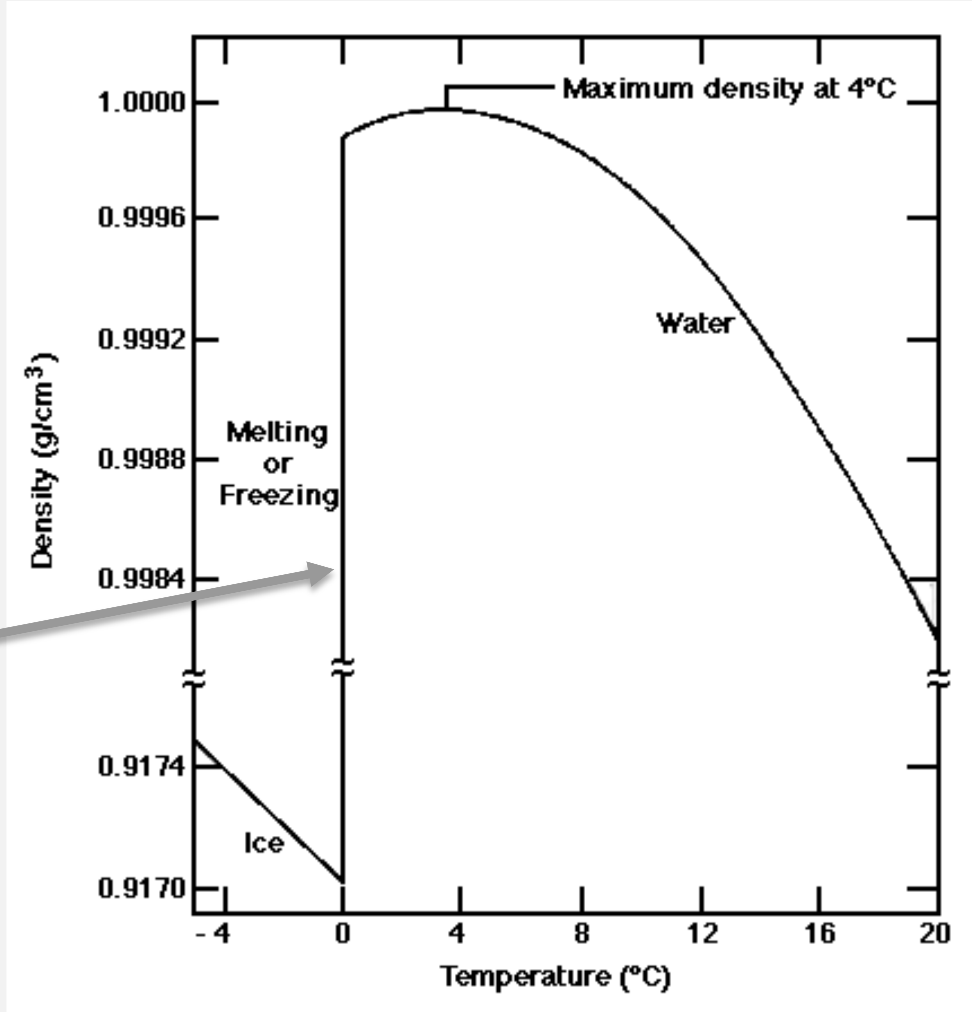
10 trapped ion quantum simulator

Simulate one quantum system with another

# Application: Detecting a phase transition

Q: At what temperature does the water melt?



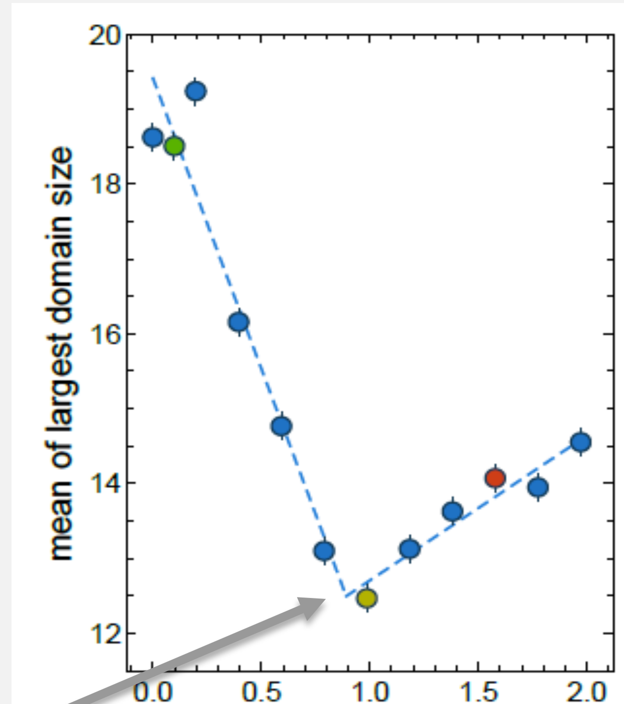
# Application: Detecting a phase transition

Q: At what magnetic field does the magnet "melt"?

Start with this magnetized state

End with this partially demagnetized state

Measure *largest domain size*




Applied magnetic field strength

Phase transition

With 53 ions, this calculation is beyond the ability of "classical computers"

# Is the hype real?

- Why are people so excited about quantum computing?

  Solve some useful problems really fast.

- Are quantum computers imminent?

  Quantum analog simulators – Yes.
  Universal quantum computers – Probably not soon.

- Are they infinity machines?

  We'll see…

# Questions?

Theory collaborators: Stacey Jeffery, Michael Jarret, Alvaro Piedrafita

Experimental Acknowledgements