MPI-M JOINT SEMINAR

# Quantum Computers now and in the near future

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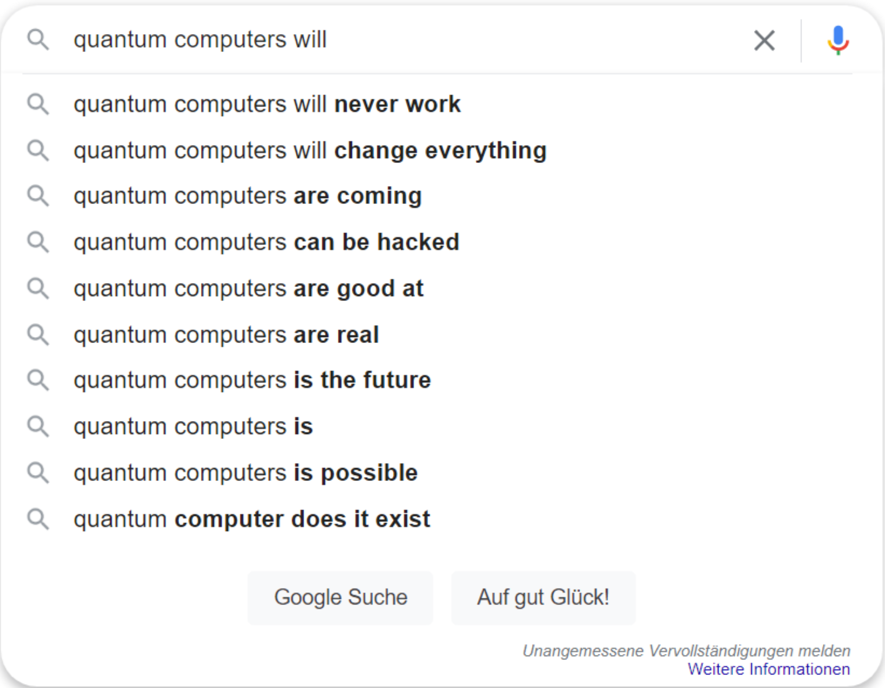
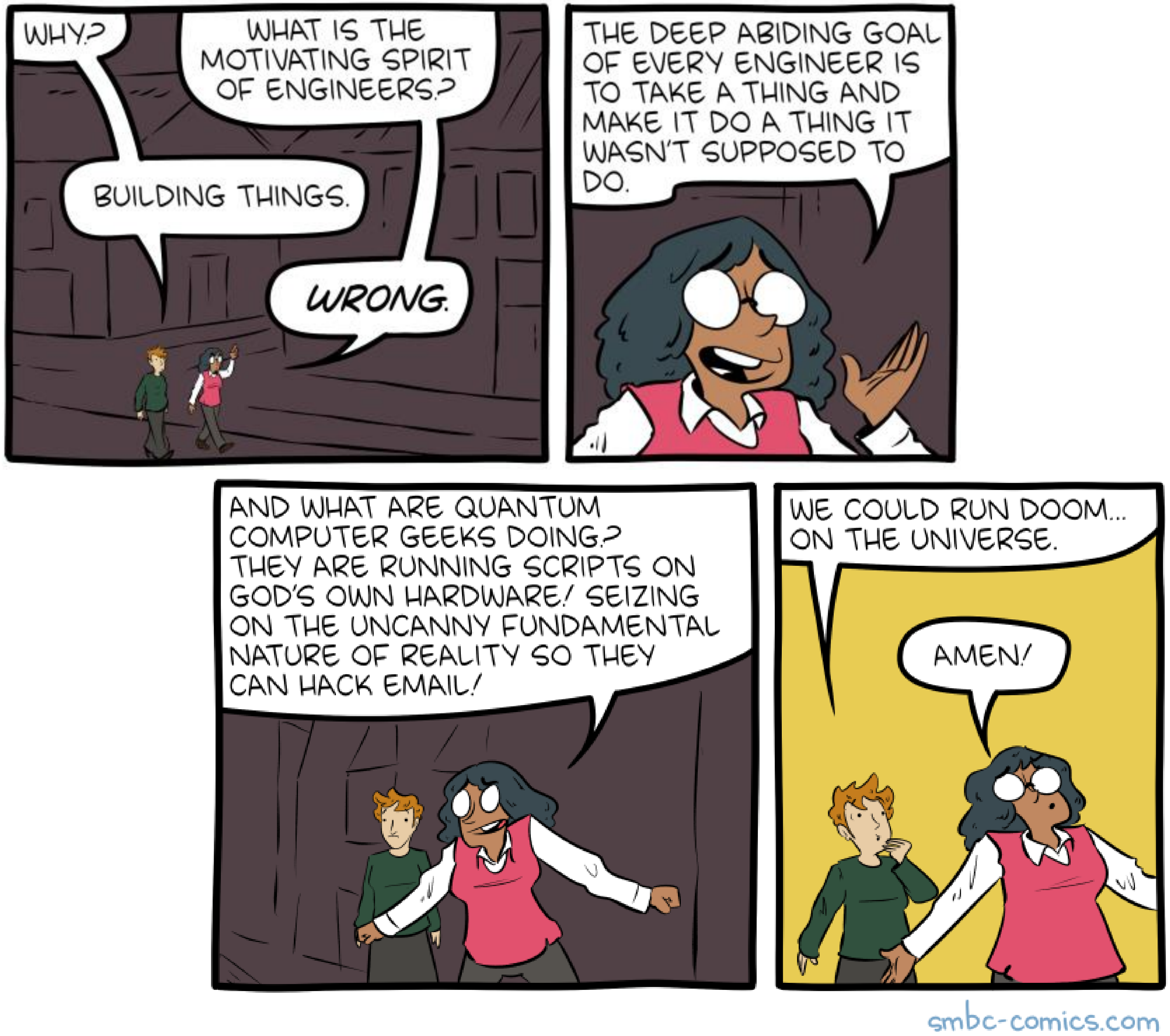
@jj_xyz


quantum computers will
quantum computers will **never work**
quantum computers will **change everything**
quantum computers **are coming**
quantum computers **can be hacked**
quantum computers **are good at**
quantum computers **are real**
quantum computers **is the future**
quantum computers **is**
quantum computers **is possible**
quantum **computer does it exist**
Google Suche
Auf gut Glück!
Unangemessene Vervollständigungen melden
Weitere Informationen

# What is a Quantum Computer?


WHY?
WHAT IS THE MOTIVATING SPIRIT OF ENGINEERS?
BUILDING THINGS.
WRONG.
THE DEEP ABIDING GOAL OF EVERY ENGINEER IS TO TAKE A THING AND MAKE IT DO A THING IT WASN'T SUPPOSED TO DO.
AND WHAT ARE QUANTUM COMPUTER GEEKS DOING? THEY ARE RUNNING SCRIPTS ON GOD'S OWN HARDWARE! SEIZING ON THE UNCANNY FUNDAMENTAL NATURE OF REALITY SO THEY CAN HACK EMAIL!
WE COULD RUN DOOM... ON THE UNIVERSE.
AMEN!
smbc-comics.com

# Quantum Hype

**A Quantum Advantage in**

ers Will
telligence,
ig Data

21. JULI 2021 | PRESS RELEASES

Quantum Computing Set to Transform Multiple Industries,
Create Up to $8
Estimates Show

Investors and Corporat
Coming in Last Three Y

OPINION

**Quantum computing has a hype problem**

Quantum computing startups are all the rage, but it's unclear if they'll be able to produce anything of use in the near future.

By Sankar Das Sarma    March 28, 2022

OP

**Quantum Computing Will Be An Asset To Curb Climate Change**

By James Dargan    December 26, 2021

e

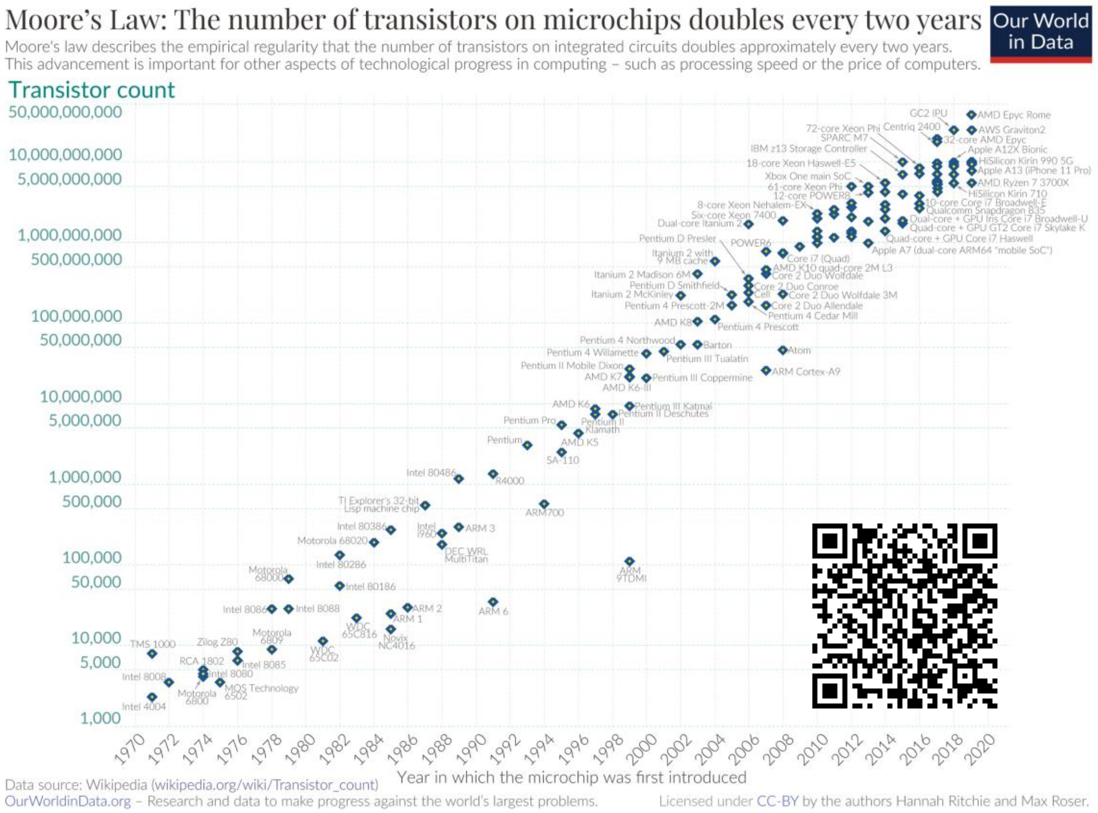
ve Systems gave free access to its
ting service to COVID-19
researchers—here's what they plan to do with it

BY MARK ANDERSON | 10 APR 2020 | 3 MIN READ |

# Why the Hype?

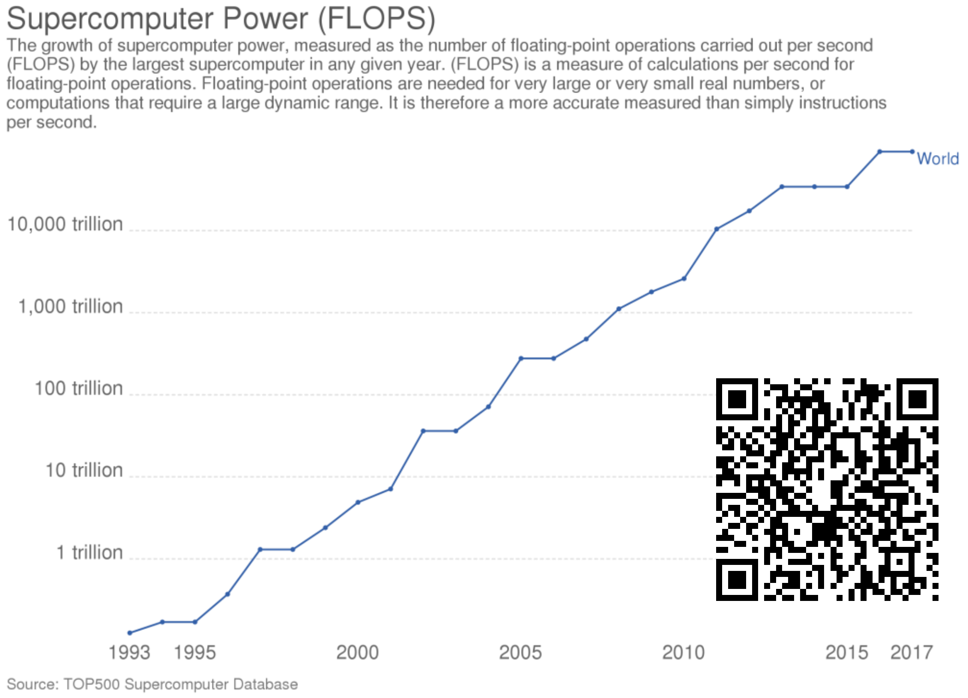
- **„Quantum“** makes everything sound advanced
- Increasing success in actually constructing quantum computers
- Achievement of „quantum supremacy“

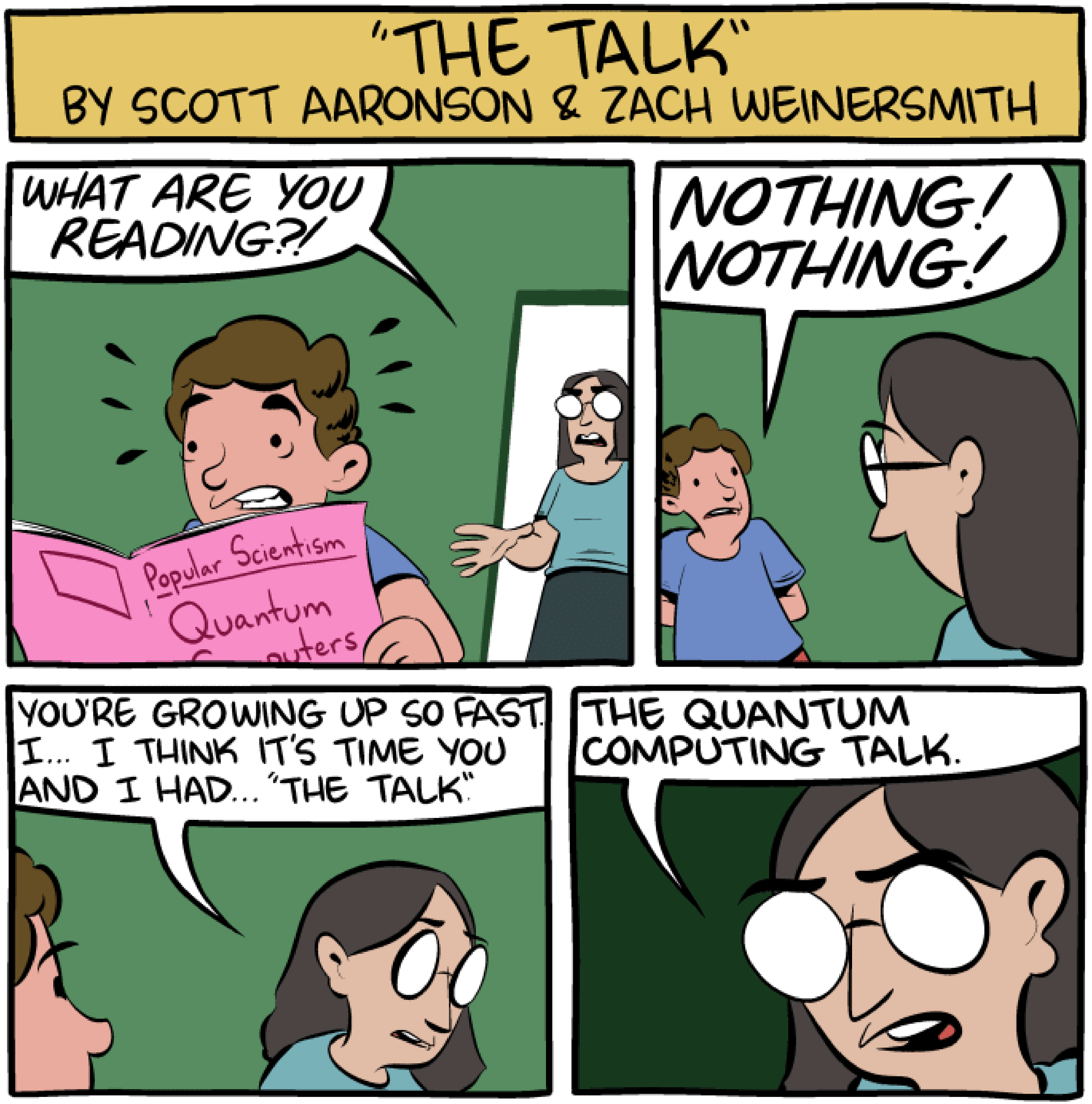
# Quantum and HPC Motivation




Moore's law can't be sustained indefinitely because of physical barriers to transistor miniaturization

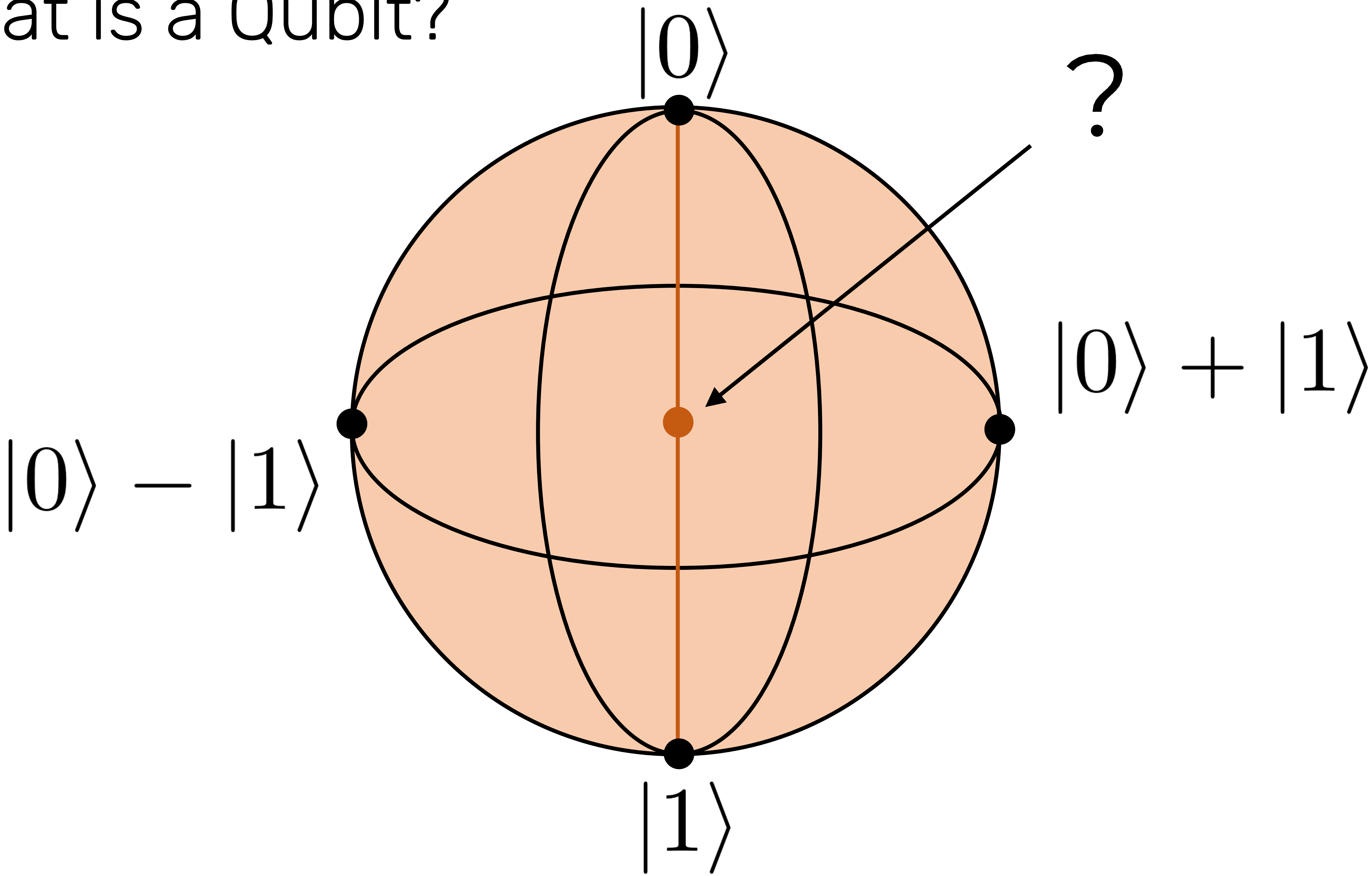
➜ Need for new approaches!



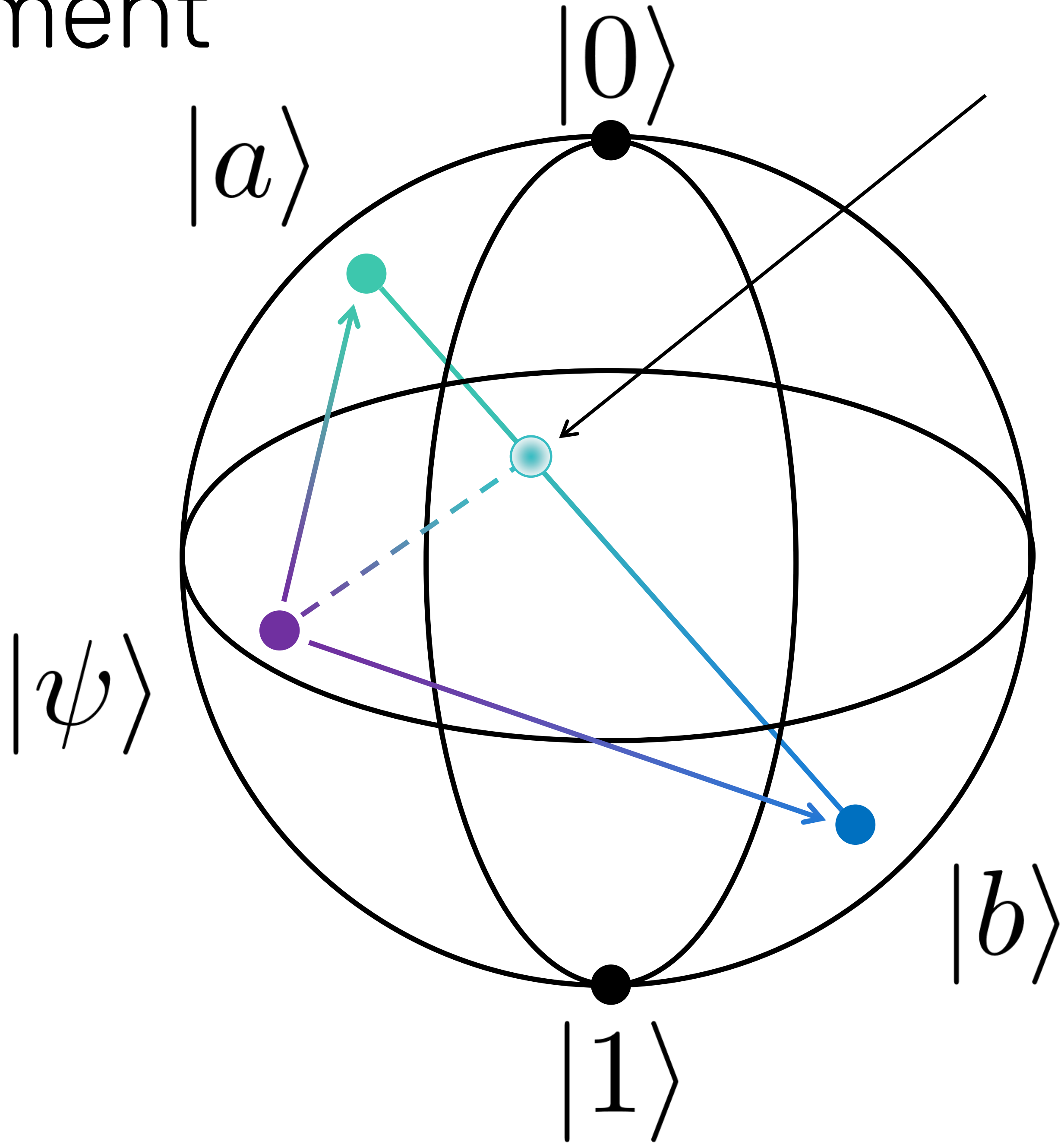

"THE TALK"
BY SCOTT AARONSON & ZACH WEINERSMITH
WHAT ARE YOU READING?!
Popular Scientism
Quantum
NOTHING! NOTHING!
YOU'RE GROWING UP SO FAST. I... I THINK IT'S TIME YOU AND I HAD... "THE TALK."
THE QUANTUM COMPUTING TALK.

# Quantum Intuition

# What is a Qubit?



# Measurement




Measurement statistics, here a : b = 2 : 1

# Important Properties of Qubits

- No measurement without disturbance
- No copying of qubits
- True randomness

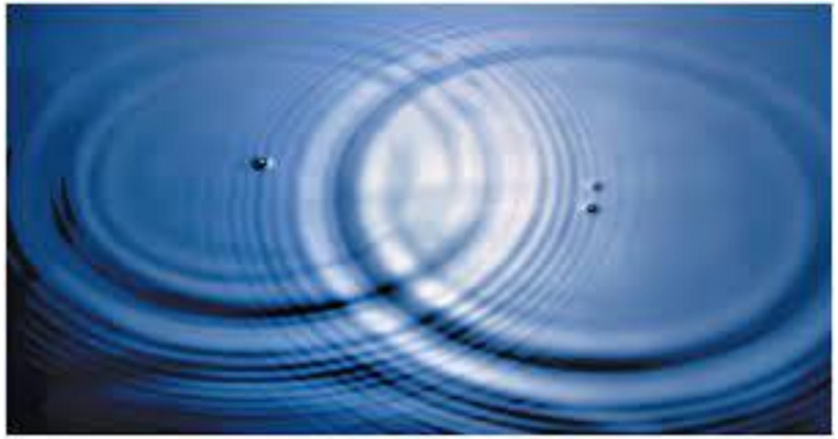
- A qubit **cannot** store more than one classical bit

# Quantum Computing

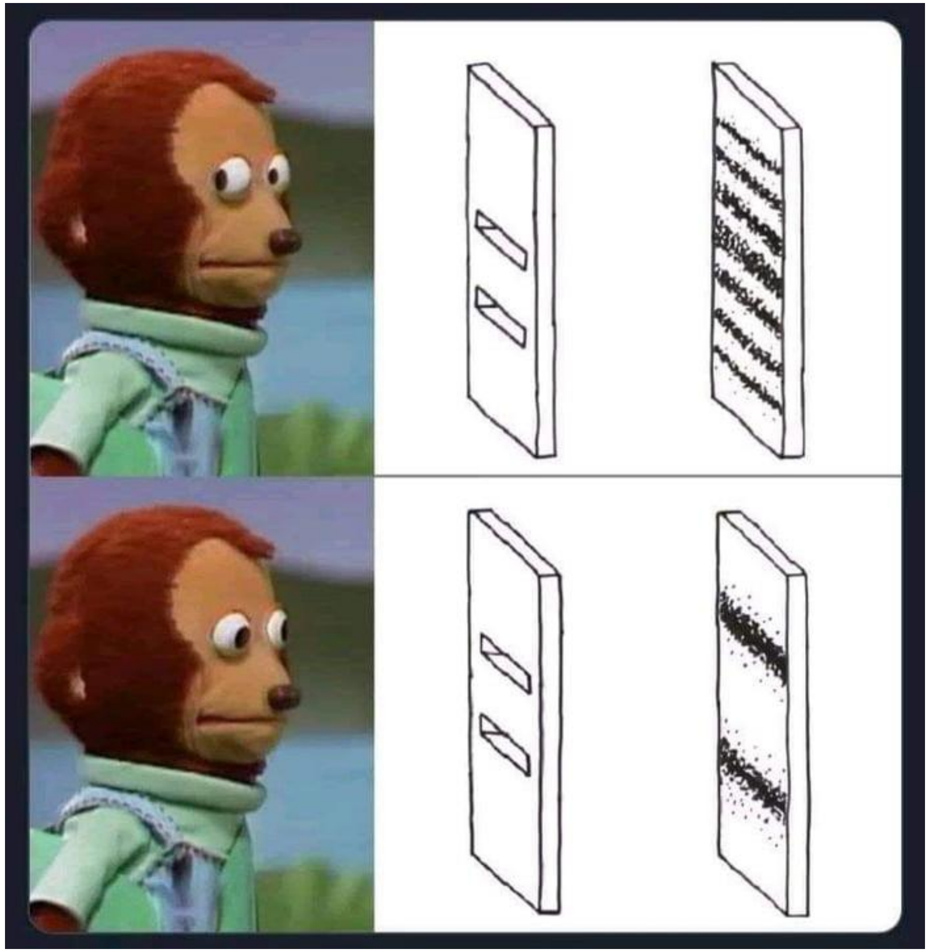
=

Use quantum effects like **superposition**, **interference** and **entanglement** to process qubits

# Interference





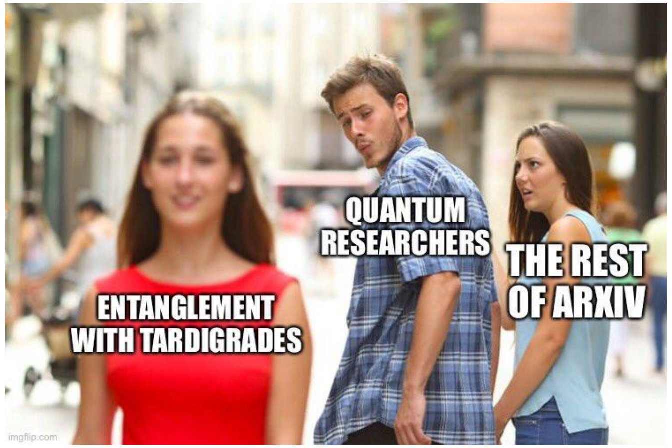


Interference is a wave phenomenon that can be exploited in computations

# Entanglement

Qubits can show non-local (and thus non-classical) correlations when measured

No entanglement = computation is completely classical!

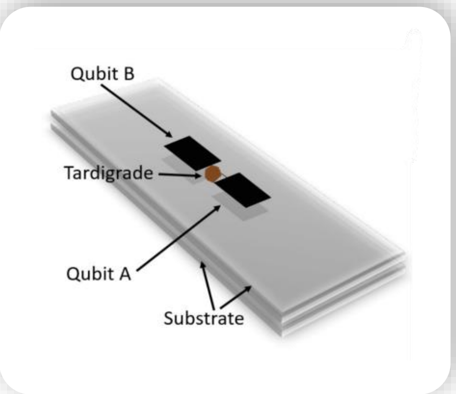


# Entanglement

## Entanglement between superconducting qubits and a tardigrade

K. S. Lee,[1] Y. P. Tan,[1] L. H. Nguyen,[1] R. P. Budoyo,[2] K. H. Park,[2] C. Hufnagel,[2] Y. S. Yap,[3,2] N. Møbjerg,[4] V. Vedral,[5,2,6] T. Paterek,[7] and R. Dumke[1,2]

[1] *School of Physical and Mathematical Sciences, Nanyang Technological University, Singapore*
[2] *Centre for Quantum Technologies, National University of Singapore, Singapore*
[3] *Faculty of Science and Centre for Sustainable Nanomaterials (CSNano), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*
[4] *Department of Biology, University of Copenhagen, Denmark*
[5] *Department of Physics, University of Oxford, United Kingdom*
[6] *Department of Physics, National University of Singapore, Singapore*
[7] *Institute of Theoretical Physics and Astrophysics, University of Gdańsk, Poland*



# Quantum Computing Facts

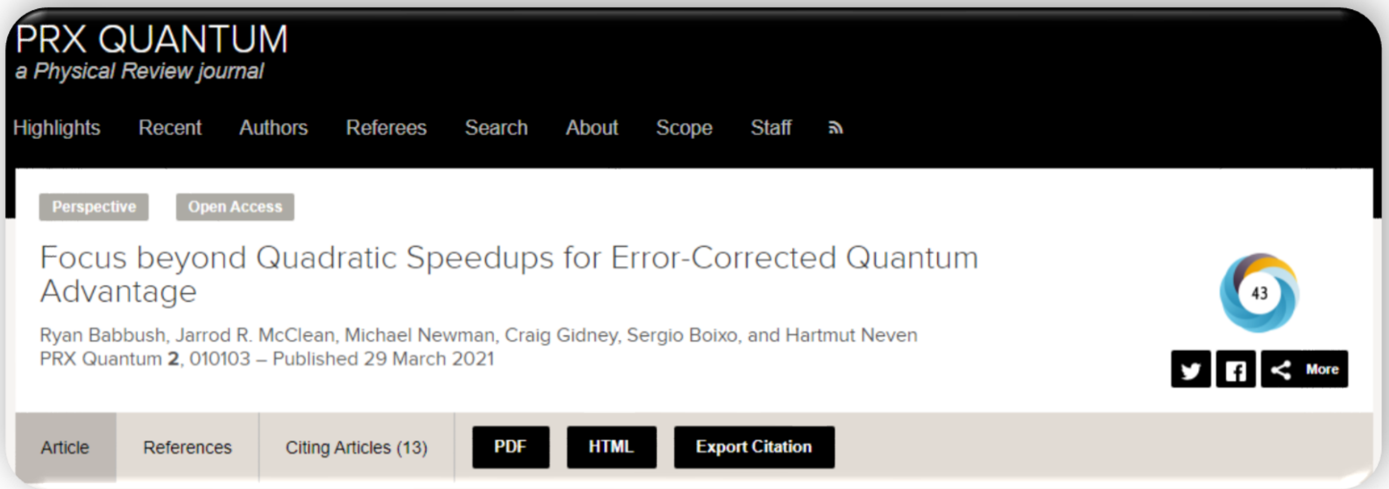
# A quantum computer is ...

... a faster computer

... a highly specialized tool suitable for very specific problems

# The Facts

Generic **quadratic** speedup for unstructured problems via Grover's algorithm



# The Facts

**Suspected exponential** speedup for Factoring via Shor's algorithm


⟨⟩uantum the open journal for quantum science

PAPERS PERSPECTIVES

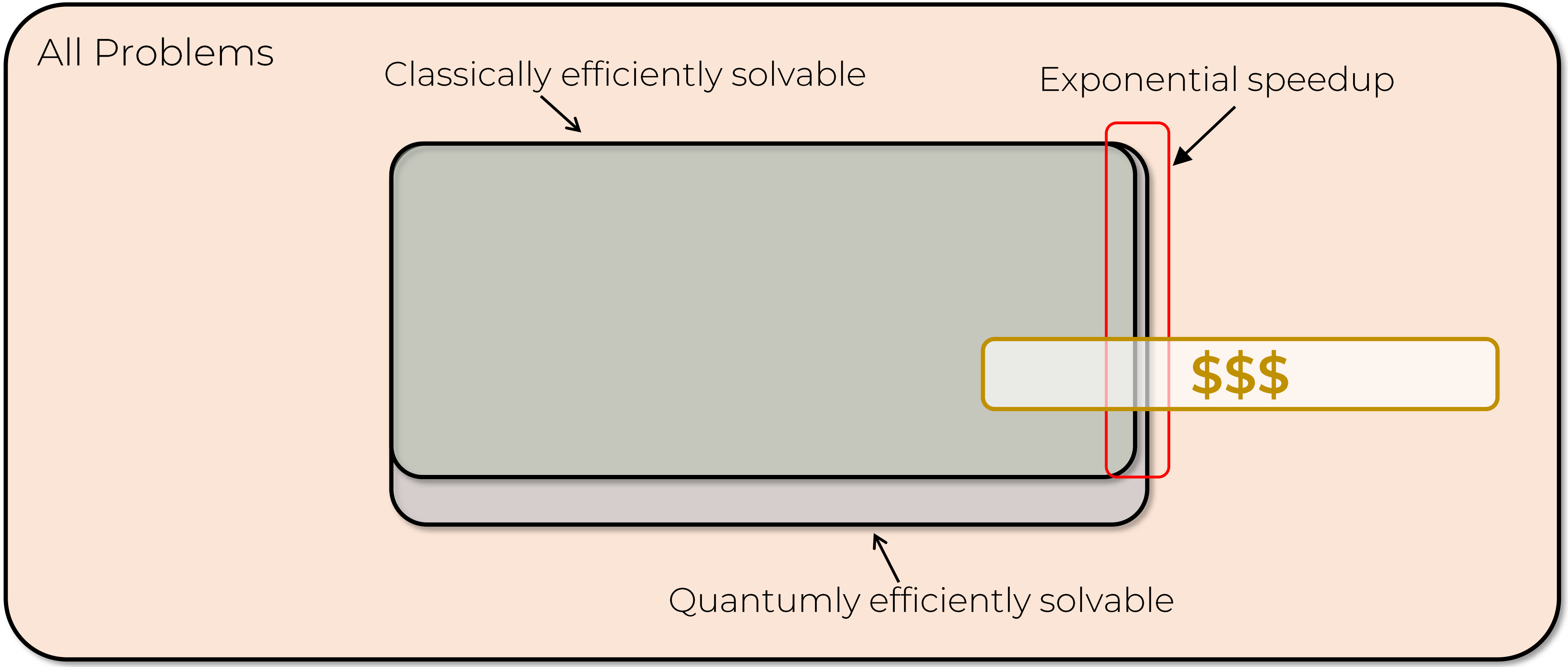
How to factor 2048 bit RSA integers in 8 hours using 20 million noisy qubits

Craig Gidney[1] and Martin Ekerå[2,3]

[1]Google Inc., Santa Barbara, California 93117, USA
[2]KTH Royal Institute of Technology, SE-100 44 Stockholm, Sweden
[3]Swedish NCSA, Swedish Armed Forces, SE-107 85 Stockholm, Sweden

# The Facts

Quantum computing only provides strong advantages for highly specialized problems!



Quantum computers are not faster because they can perform all possible calculations in parallel

# Status Quo

Not a
quantum computer

# Biggest Obstacle: Noise

Unwanted interactions with the environment disturb quantum effects and introduce *noise*

**nature physics**

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nature > nature physics > articles > article

Article | Published: 13 December 2021

**Resolving catastrophic error bursts from cosmic rays in large arrays of superconducting qubits**

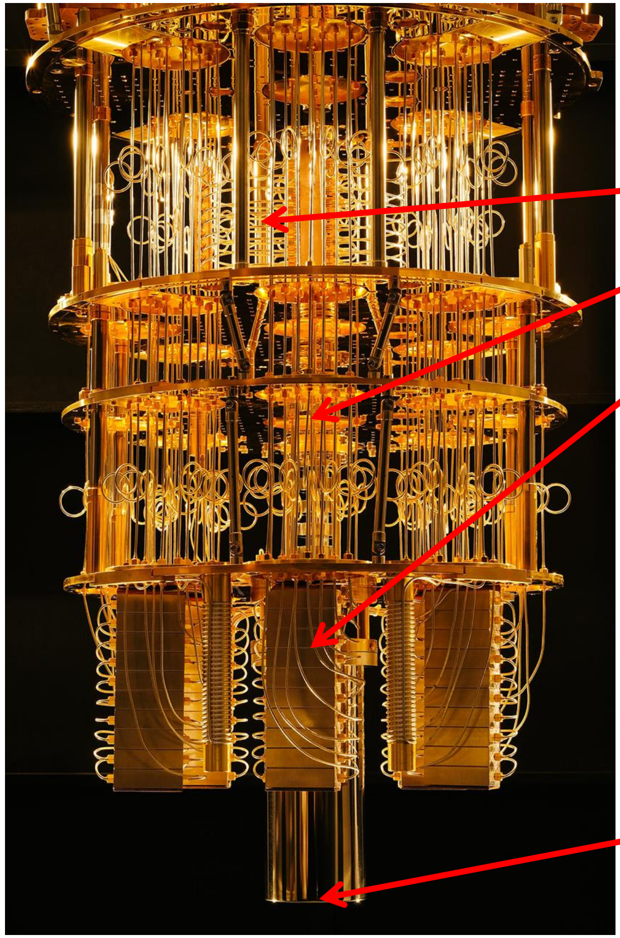
Matt McEwen, Lara Faoro, ... Rami Barends + Show authors

*Nature Physics* **18**, 107–111 (2022) | Cite this article

**2935** Accesses | **6** Citations | **116** Altmetric | Metrics

# Current Quantum Computers


*Really* cold fridge

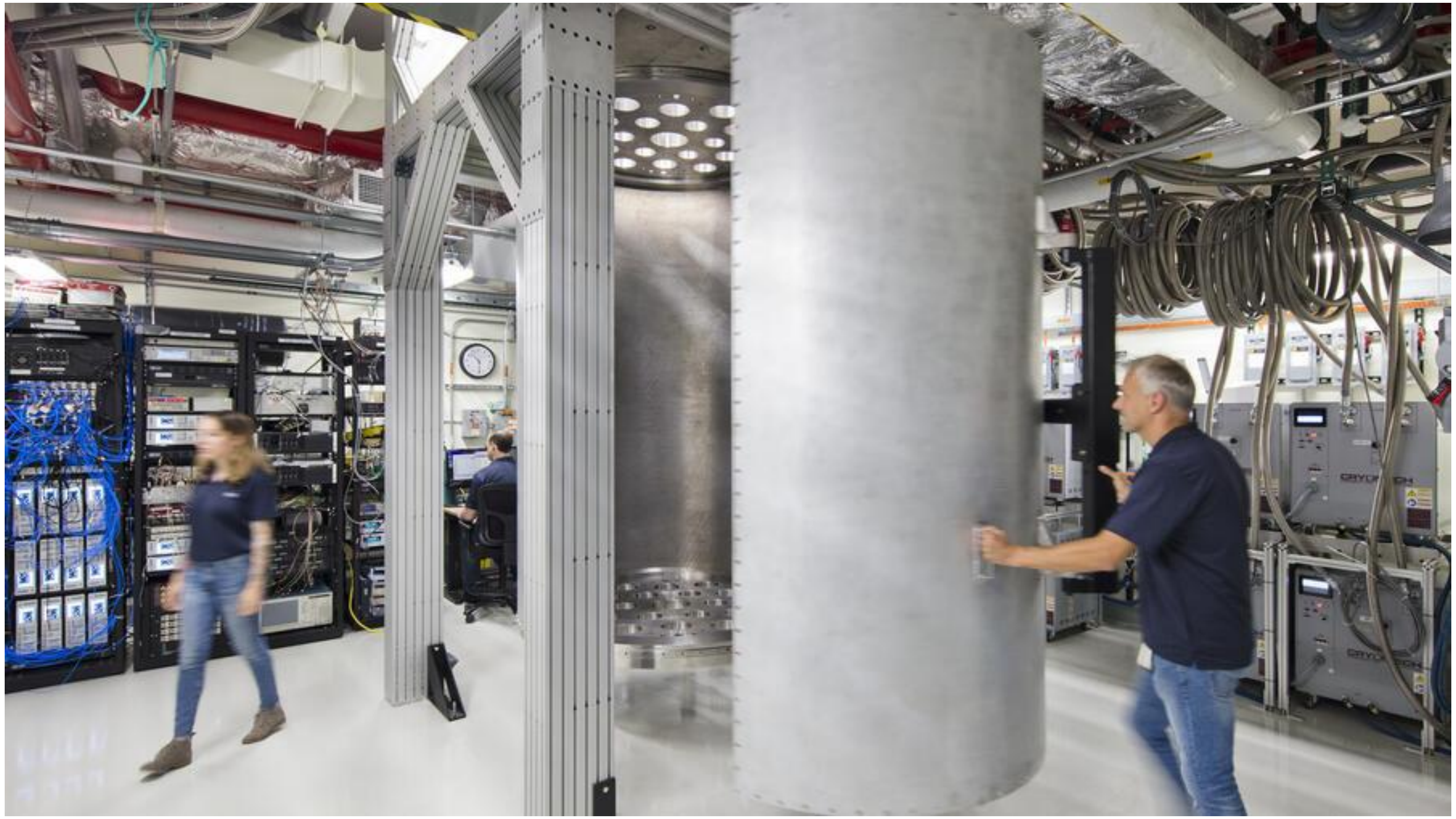


Input/Output wiring

Actual chip

Photos: IBM

# Scaling Up



Really large really cold fridge

Photo: IBM

# Also Many Other Approaches

Quantum computers based on

- Photons
- Lasers
- Trapped Ions
- Trapped Neutral Atoms
- Electrons on Helium
- Semiconductors
- … and many more

**Remember:**

# Hard Facts

- Current quantum computers have between 2 and 250 qubits of varying quality
- Quantum operations can usually only be conducted between neighboring qubits
- Qubits are relatively noisy and quantum operations not reliable

# Quantum Error Correction

We need to correct errors in order to salvage our quantum computations

- Need to encode computation redudantly
- This causes overheads in the number of qubits
- Also causes stronger hardware requirements
- First experiments have already been performed!


Quantum
the open journal for quantum science
PAPERS PERSPECTIVES

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[3]Swedish NCSA, Swedish Armed Forces, SE-107 85 Stockholm, Sweden

# Useful Applications Without Error Correction?

- Can noisy quantum devices still be useful?
- Yes, for very contrived problems
- Completely open for practically relevant problems

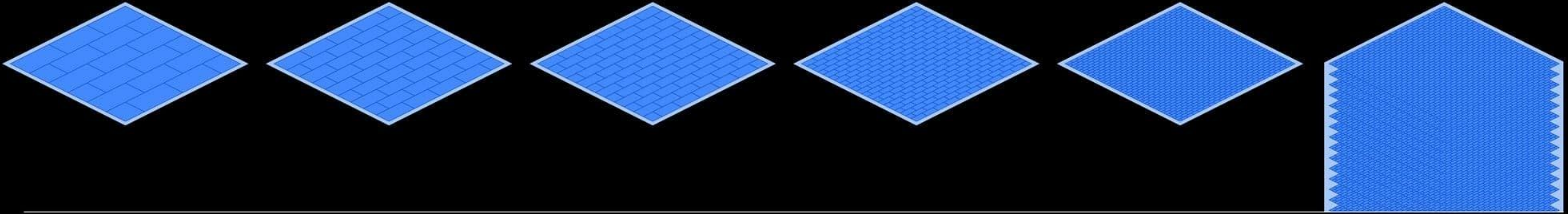
# The Future

# Scaling IBM Quantum technology

IBM

IBM Q System One (Released) — (In development) — Next family of IBM Quantum systems

| 2019 | 2020 | 2021 | 2022 | 2023 | and beyond |
|---|---|---|---|---|---|
| 27 qubits | 65 qubits | 127 qubits | 433 qubits | 1,121 qubits | Path to 1 million qubits and beyond |
| *Falcon* | *Hummingbird* | *Eagle* | *Osprey* | *Condor* | *Large scale systems* |



| Key advancement | Key advancement | Key advancement | Key advancement | Key advancement | Key advancement |
|---|---|---|---|---|---|
| Optimized lattice | Scalable readout | Novel packaging and controls | Miniaturization of components | Integration | Build new infrastructure, quantum error correction |


Roadmap For Growth & Market Leadership
Better Optimization
Chemistry
Materials
Faster Optimization
Machine Learning
Algorithmic Qubits1
1200
1000
800
600
400
200
0
22
25
29
35
64 2
256 2
384 3
1024 3
2021
2022
2023
2024
2025
2026
2027
2028
Phase I
Phase II
Phase III
Note Prepared on the basis of certain technical, market, competitive and other assumptions to be subsequently described in further detail, and which may not be satisfied. As a result, these projections are subject to a high degree of uncertainty and may not be achieved within the time-frames described or at all.
Note Market inflection points are estimated based on alignment of IonQ technical roadmap with publicly documented quantum research problems in each market
1 Algorithmic qubit number defined as the effective number of qubits for typical algorithms, limited by the 2Q fidelity
2 Employs 16:1 error-correction encoding
3 Employs 32:1 error-correction encoding
27

Source: IonQ

# PsiQuantum is building 'first useful quantum computer'

Sep 16 2021 - De Tijd

Quantum computers can help us regulate the climate, make new medicines and solve the energy problem. Australian Jeremy O'Brien hopes to create 'the first useful quantum computer' by the end of the decade with his company PsiQuantum.

Read More →

Source: PsiQ

# Judging Quantum Advantage

Quantum advantage can come in many flavors:

- Solving problems faster
- Solving problems cheaper
- Solving problems using less energy

Depending how advantages are judged, they can materialize sooner or later

# Likely Outcome

- Quantum computers will be used as accelerators, like GPUs
- Access through the qloud (no kidding) or data-center integration
- First applications in quantum-native problems

- **Timeline until large-scale impact hard to predict**

# Summary

# Summary

- Quantum computing is weird and hard to explain, popular explanations are often oversimplified and misleading
- Quantum computers are not faster computers but very specialized tools that only help for very specific problems
- Quantum computers will likely be used as accelerators
- Time to practical advantage is hard to predict, relies on breakthroughs in quantum computer engineering
- Adoption in HPC is even farther away

# Thank you for your attention!

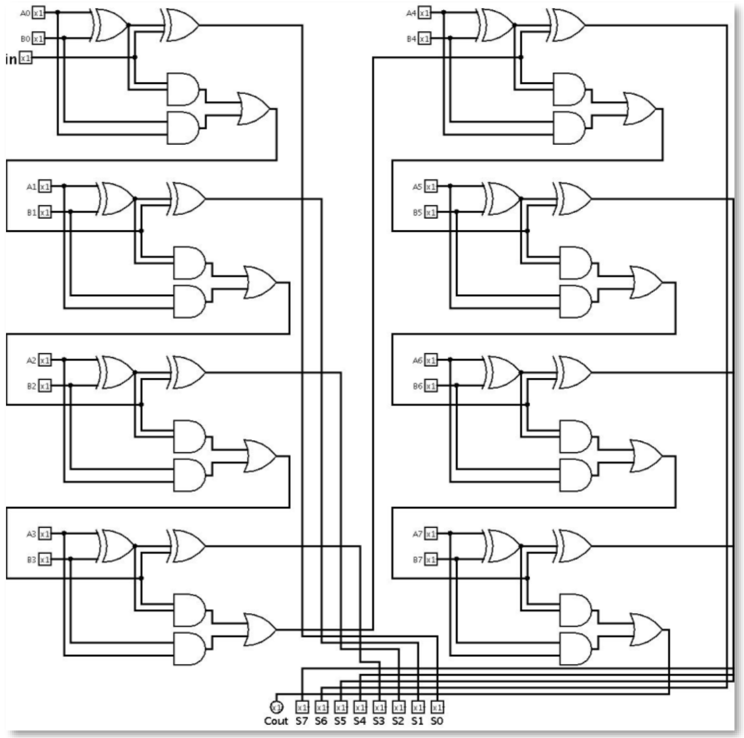
Slides

# Superposition and Computation

```python
def reset(self):
    super().reset()

    self._state = None
    self._probs = None

def _qureg_context(self):
    return QuregContext(self.num_wires)

def _init_state_vector(self, state, context):
    state = reorder_state(state)
    pqc.cheat.initStateFromAmps()(
        context.qureg, reals=np.real(state), i
    )

def _extract_information(self, context):
    self._state = reorder_state(pqc.cheat.getS
    self._probs = np.abs(self._state) ** 2
```

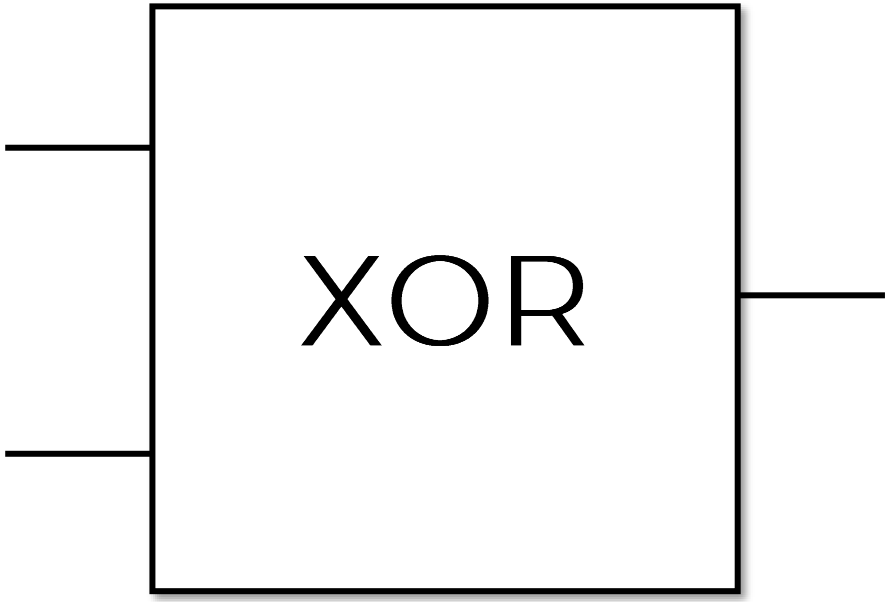
3,14

```asm
  mov eax,1
  mov ebx,1  ;  will store answer
 dtoa  sum , eax
 output resultLbl , sum
 dtoa sum ,ebx
 output  resultLbl ,sum
 mov ecx ,5
_for:
    mov edx , eax
add edx , ebx
dtoa sum ,edx
output  resultLbl ,sum
mov  eax ,ebx
mov  ebx ,edx
dec ecx
cmp ecx , 0
jne _for
mov eax , 0
ret
```




01000000100100011110101110000011

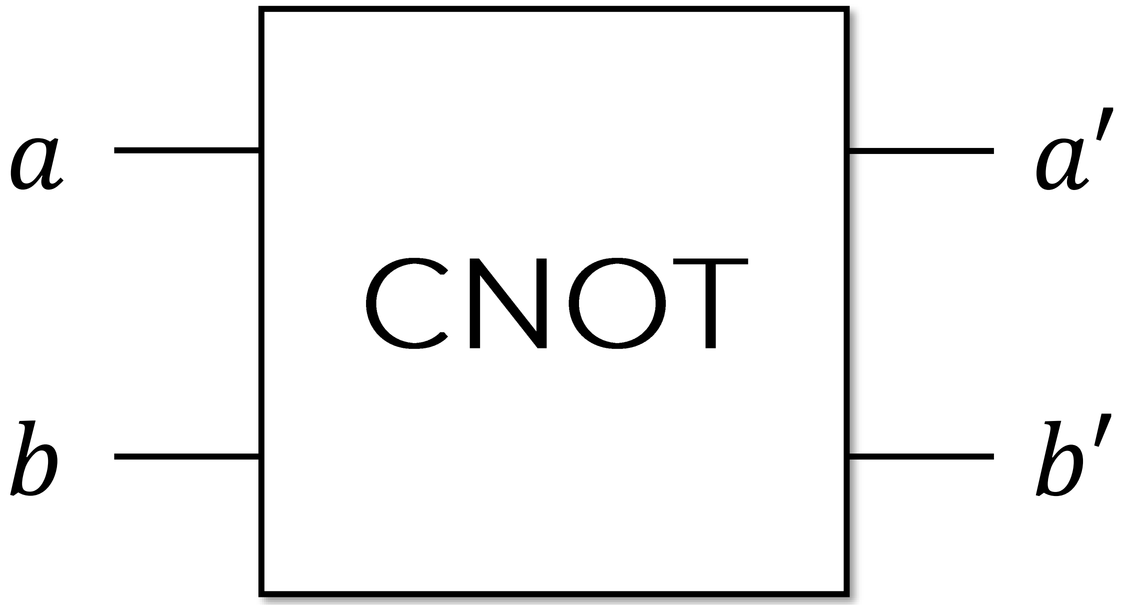
# Logic Gates




| | | |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

*Exklusive Or:*
1 if exactly one of the inputs is 1.

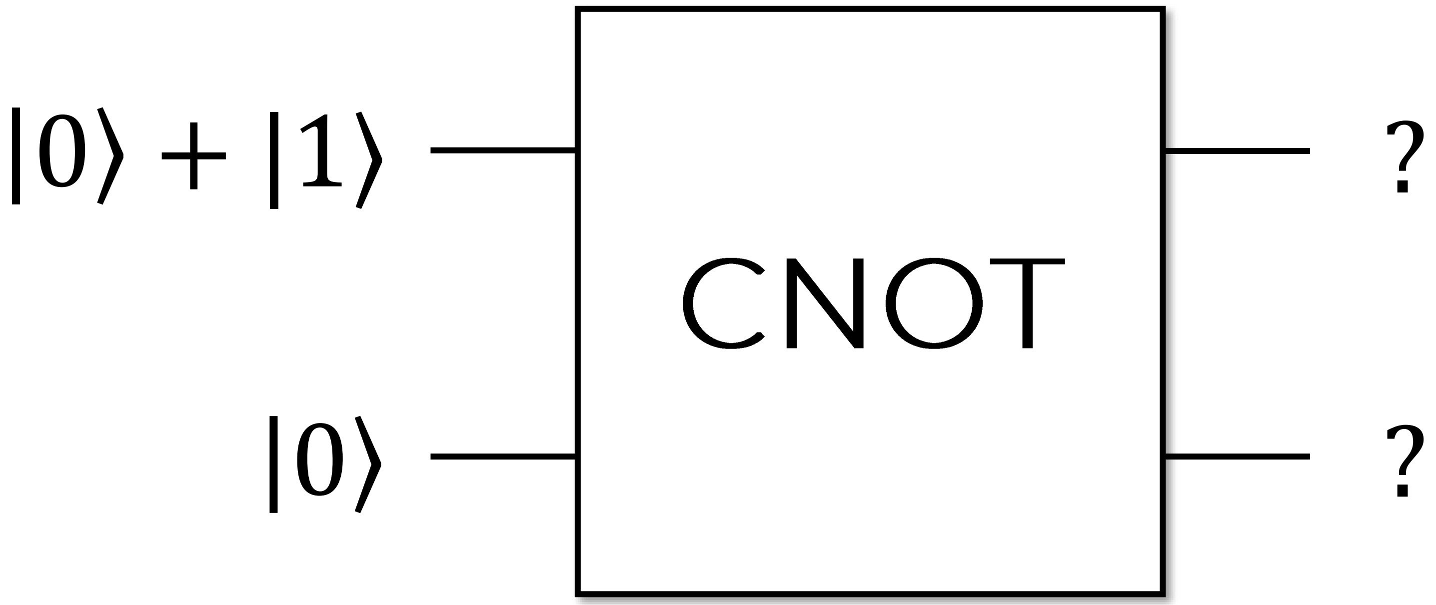
# Quantum Gates




| $a$ | $b$ | $a'$ | $b'$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 1 | 1 |
| 1 | 1 | 1 | 0 |

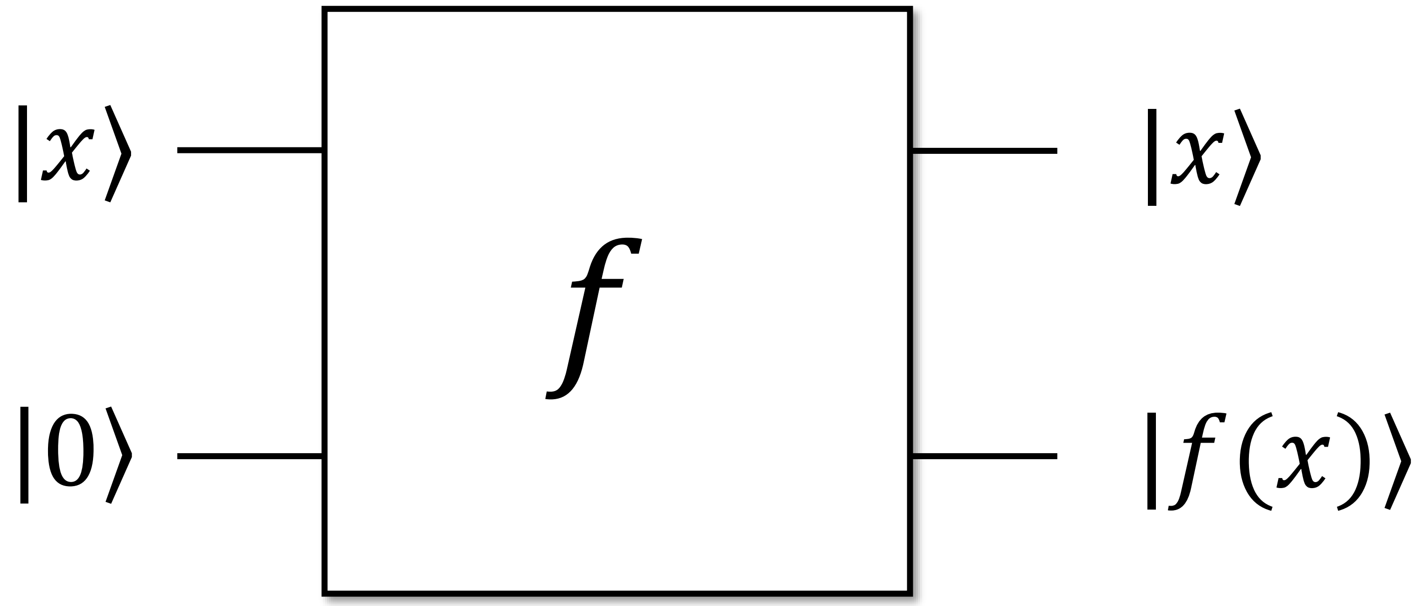
*Controlled NOT:*
Change bit $b$ if $a = 1$, else do nothing

# Quantum Gates and Superposition




$$|0\rangle_a|0\rangle_b + |1\rangle_a|0\rangle_b \longrightarrow |0\rangle_a|0\rangle_b + |1\rangle_a|1\rangle_b$$

# Quantum Parallelism




$$|x_1\rangle|0\rangle + |x_2\rangle|0\rangle + \cdots + |x_n\rangle|0\rangle$$

$$\mapsto |x_1\rangle|f(x_1)\rangle + |x_2\rangle|f(x_2)\rangle + \cdots + |x_n\rangle|f(x_n)\rangle$$