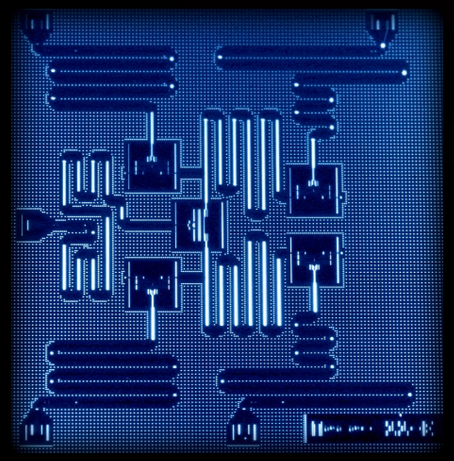


ZOLTÁN ZIMBORÁS

CURRENT STATUS OF QUANTUM COMPUTING

GPU DAY 2020
October 20, 2020

WIGNER HUNQUTECH

QHUNGARY

News about Quantum Computing in WIRED

May 16, 2013

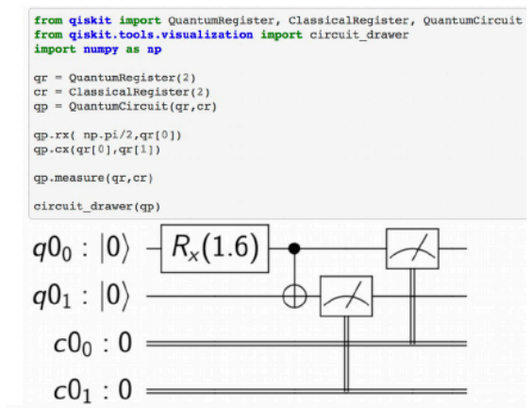
Google, NASA Open New Lab to Kick Tires on Quantum Computer

February 19, 2018

The Ongoing Battle Between Quantum and Classical Computers

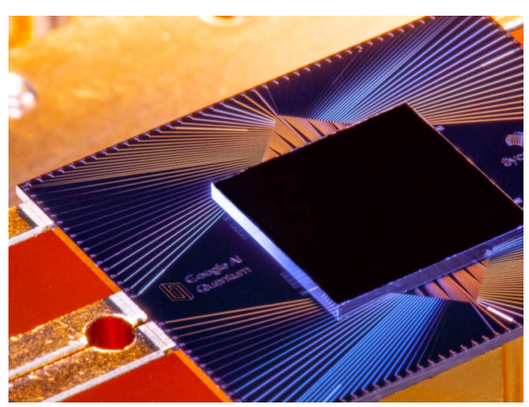
April 11, 2019

IBM, Microsoft Is Taking Quantum Computers to the Cloud



October 21, 2019

IBM Says Google's Quantum Leap Was a Quantum Flop



Even politicians now often talk about Quantum Computing

IBM Deutschland ✓
@IBMDeutschland
Follow

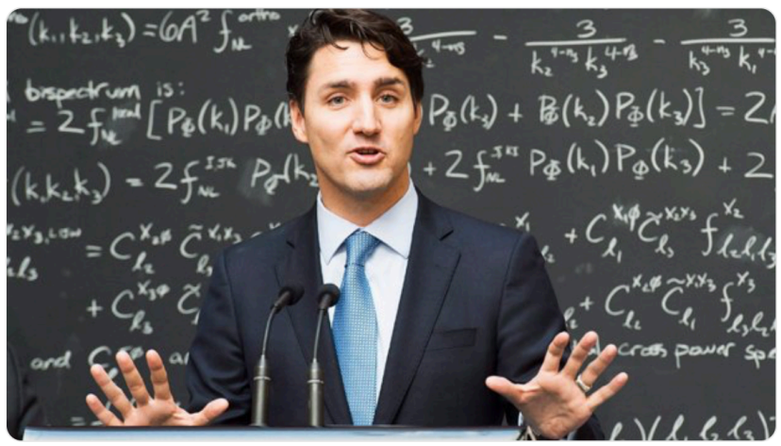
Getting quantum-ready with Angela Merkel, Chancellor of Germany #digitalgipfel19! Learn more about our collaboration with Fraunhofer to advance quantum computing #IBMQ here: newsroom.ibm.com/2019-09-10-IBM…
@regsprecher @IBMpolicy @IBMEuropepolicy @ibmdeutschland @Fraunhofer

Ivanka Trump ✓
@IvankaTrump
Follow

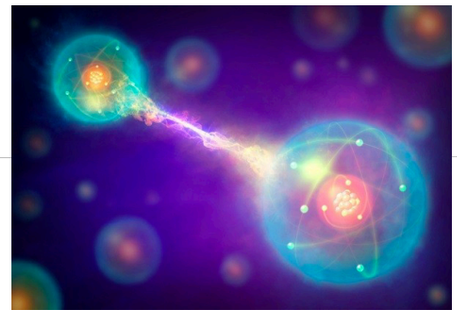
It's official! 💥 The US has achieved quantum supremacy!
In a collaboration between the Trump Admin, @Google and UC Santa Barbara, quantum computer Sycamore has completed a calculation in 3 min 20 sec that would take about 10,000 years for a classical comp.

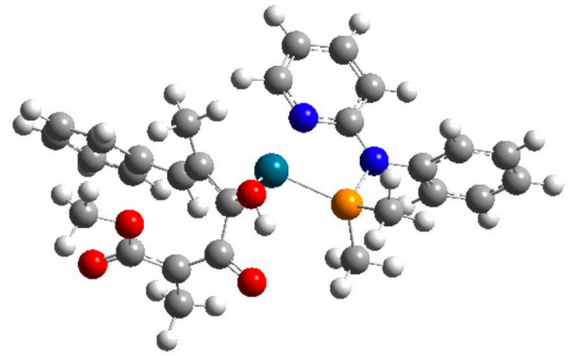
5:47 AM - 23 Oct 2019

Trudeau breaks into impromptu quantum computing lesson during Q&A with reporters in Waterloo cp24.com/news/trudeau-b…



The structure of this talk

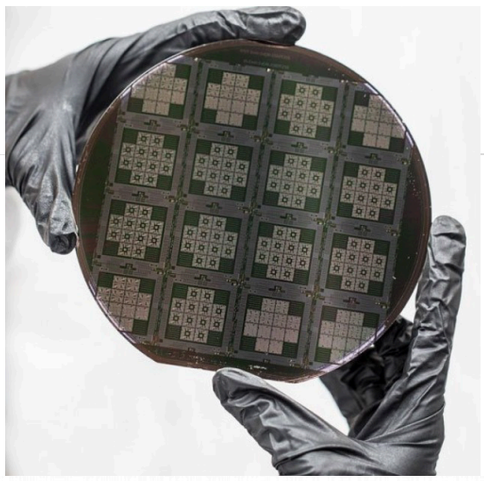




What is a Quantum Computer?

What is a Quantum Computer good for?

What is the current stage of Quantum Computing?



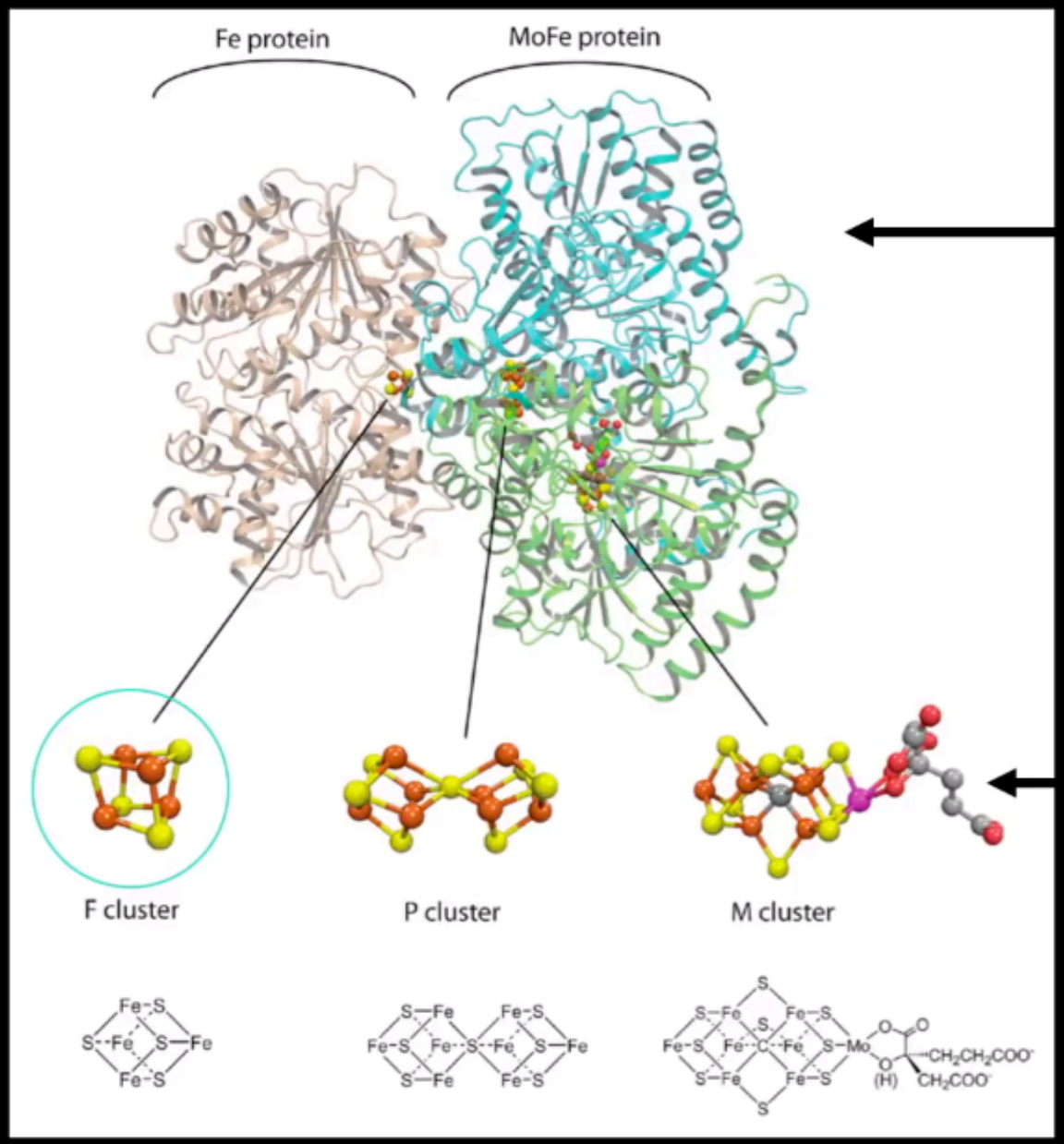
How to nurture collaboration between different fields of Science and Technology?

The involvement of Hungary in QC.

HUNQUTECH

QUANTUM PHYSICS AND QUANTUM CHEMISTRY: INTRINSICALLY HARD PROBLEMS

Simulating this cluster is at the limit of classical computers



Nitrogenase enzyme involved in N_2 to NH_4 reaction

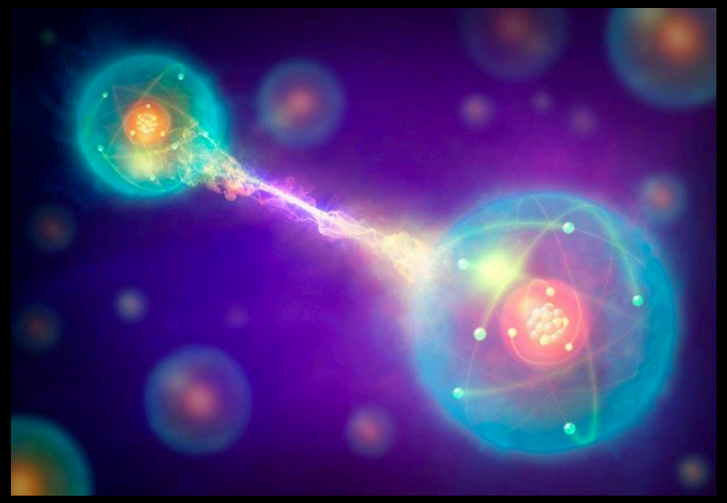
These regions are involved in different reaction stages

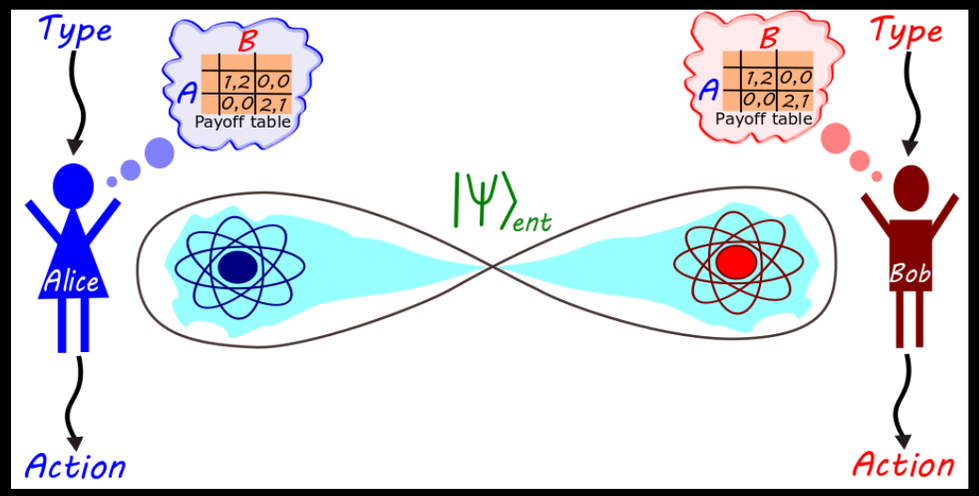
Iron sulfide clusters (Fe_xS_y) of different sizes.

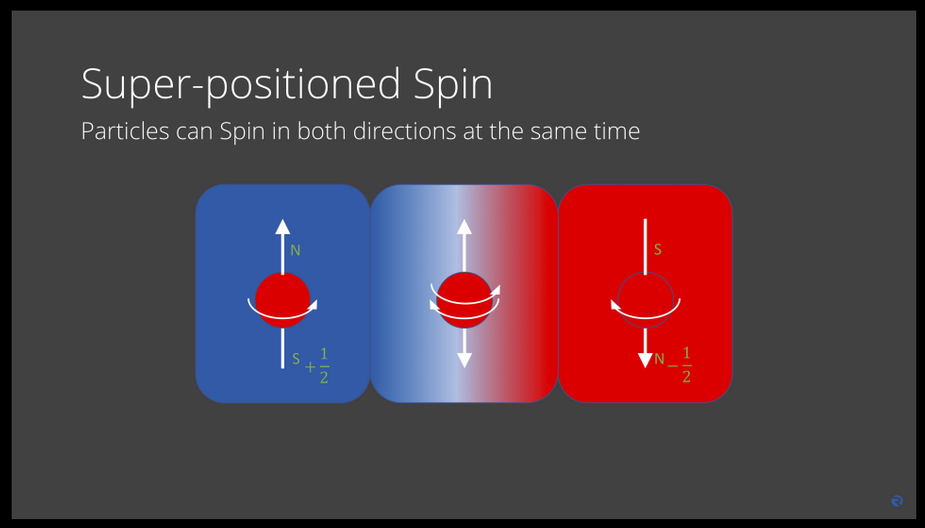
Chem. Rev., **2014**, *114* (8), pp 4041–4062
DOI: 10.1021/cr400641x

QUANTUM PHYSICS AND QUANTUM CHEMISTRY: INTRINSICALLY HARD PROBLEMS

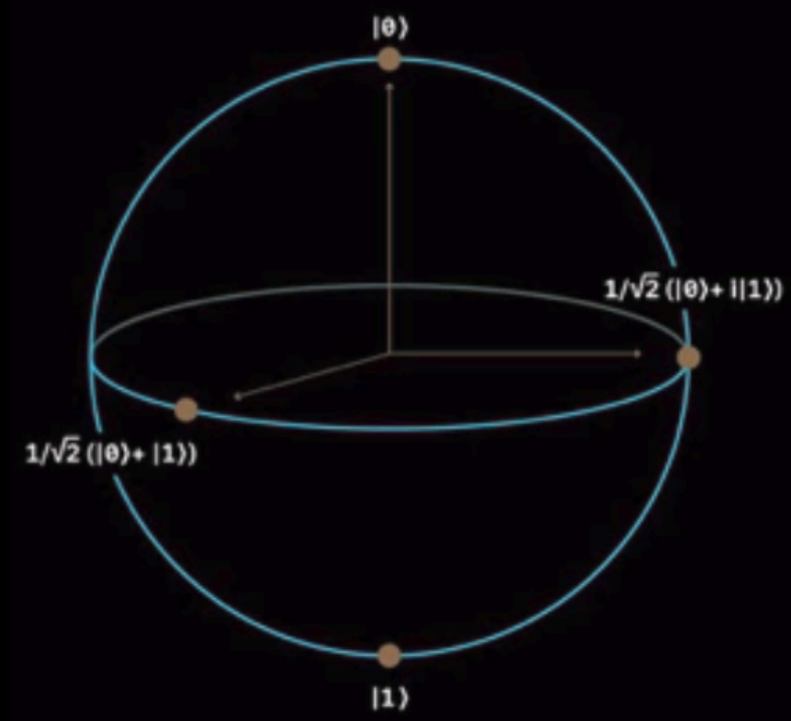
THE REASON: QUANTUM ENTANGLEMENT AND THE PRINCIPLE OF SUPERPOSITION



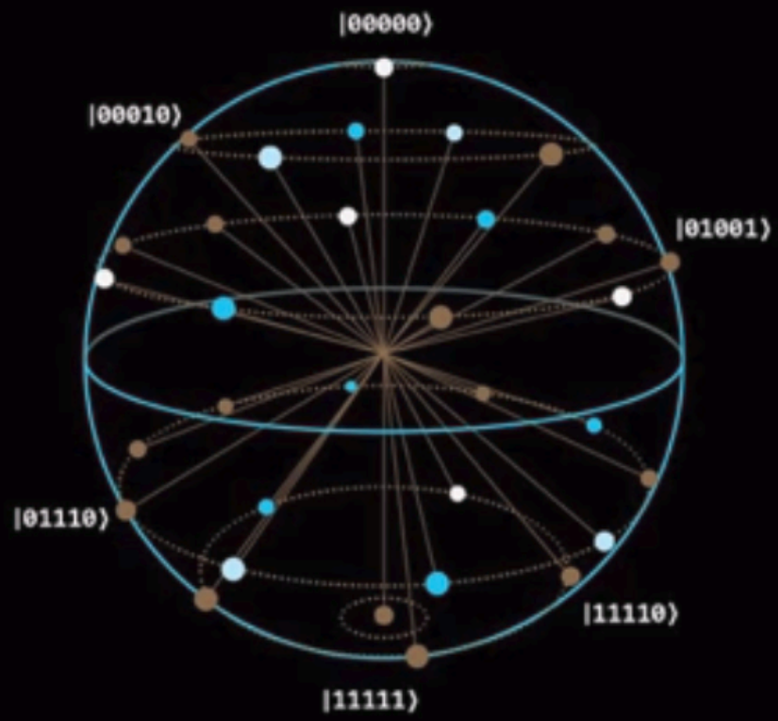




THE EXPONENTIAL STATE SPACE OF QUANTUM MECHANICS



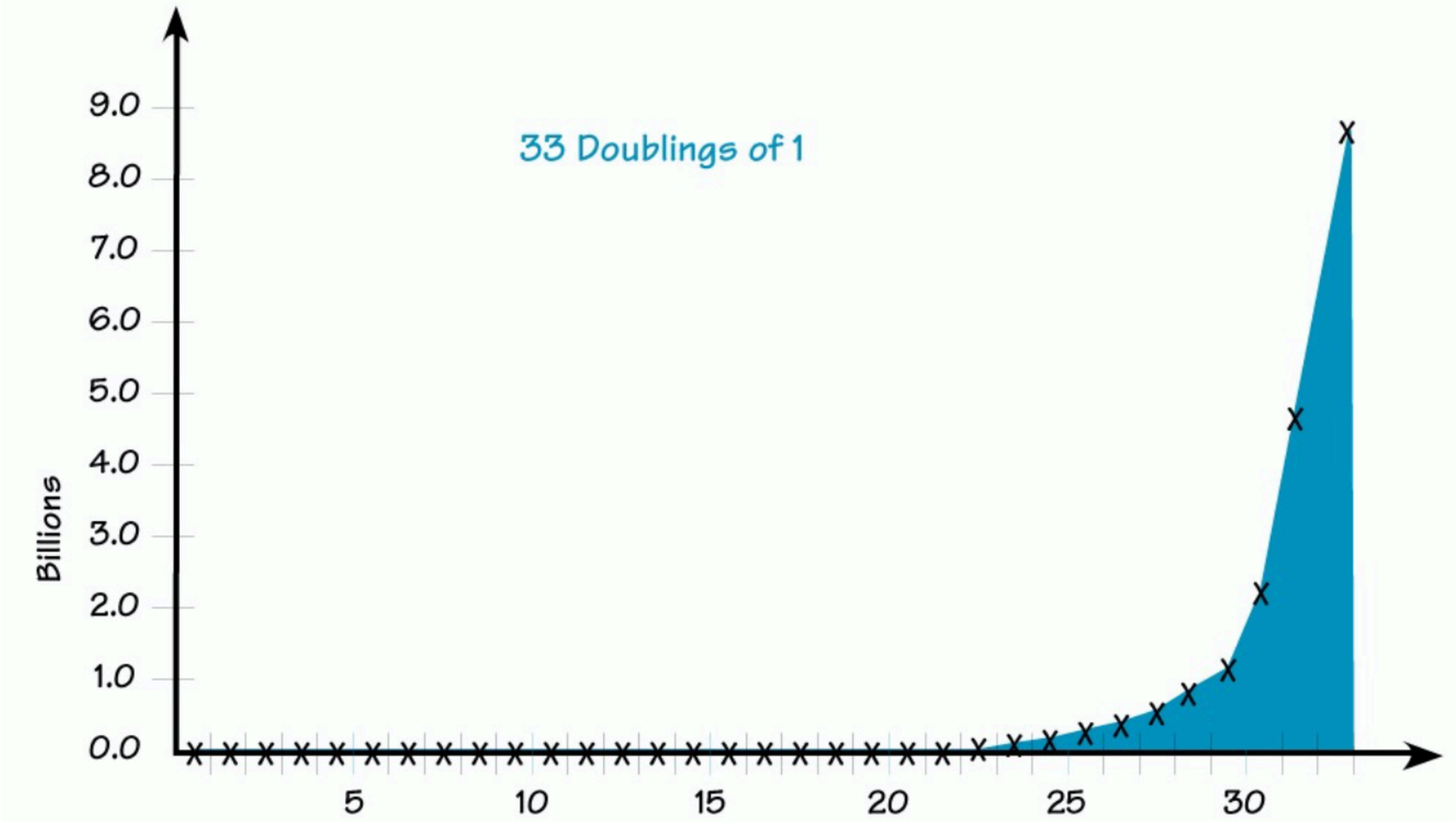
BLOCH SPHERE (1 QUBIT)



QSPHERE (5 QUBITS)

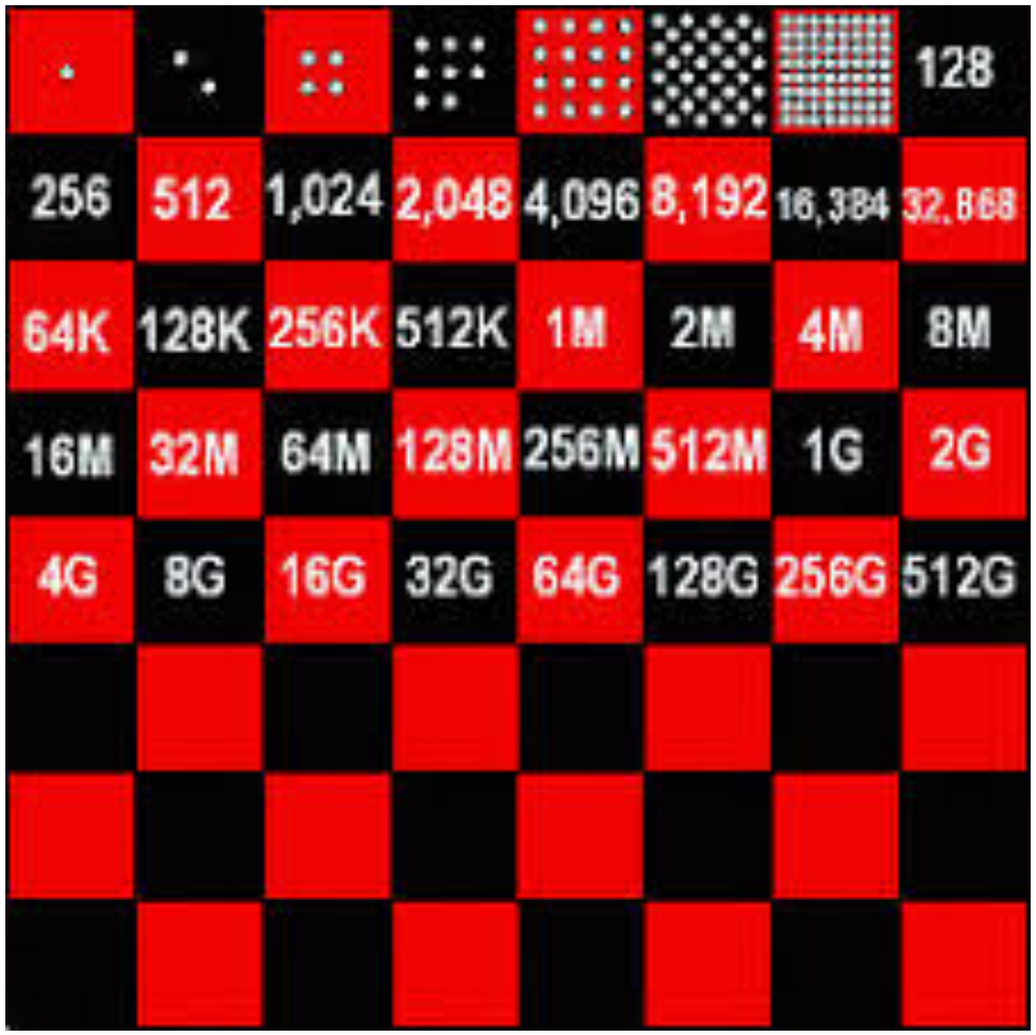
Quantum states

The exponential wall

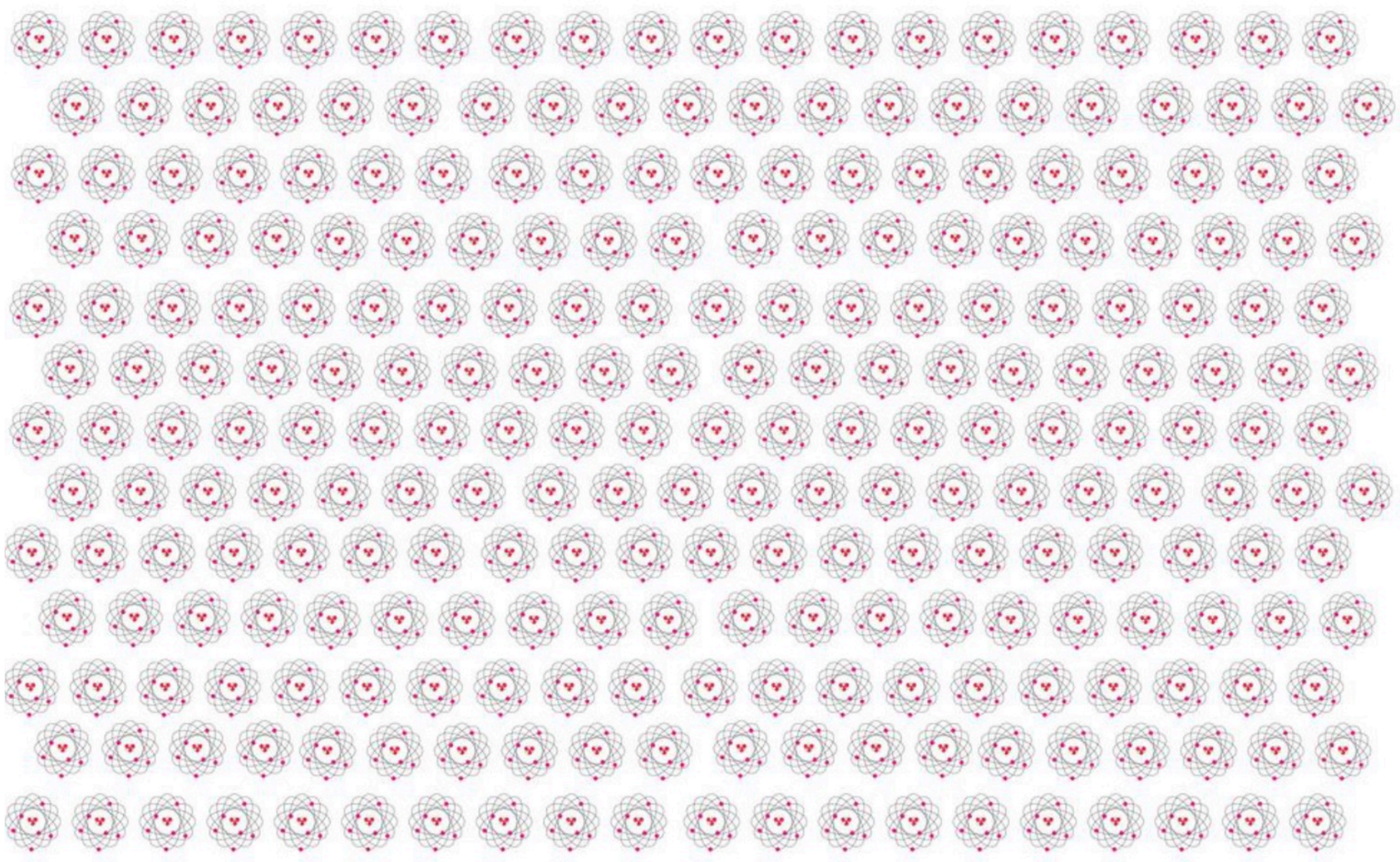


Exponentials and the legend about the inventor of chess

Exponentials and the legend about the inventor of chess



Exponentials and the difficulty in simulating Quantum Physics



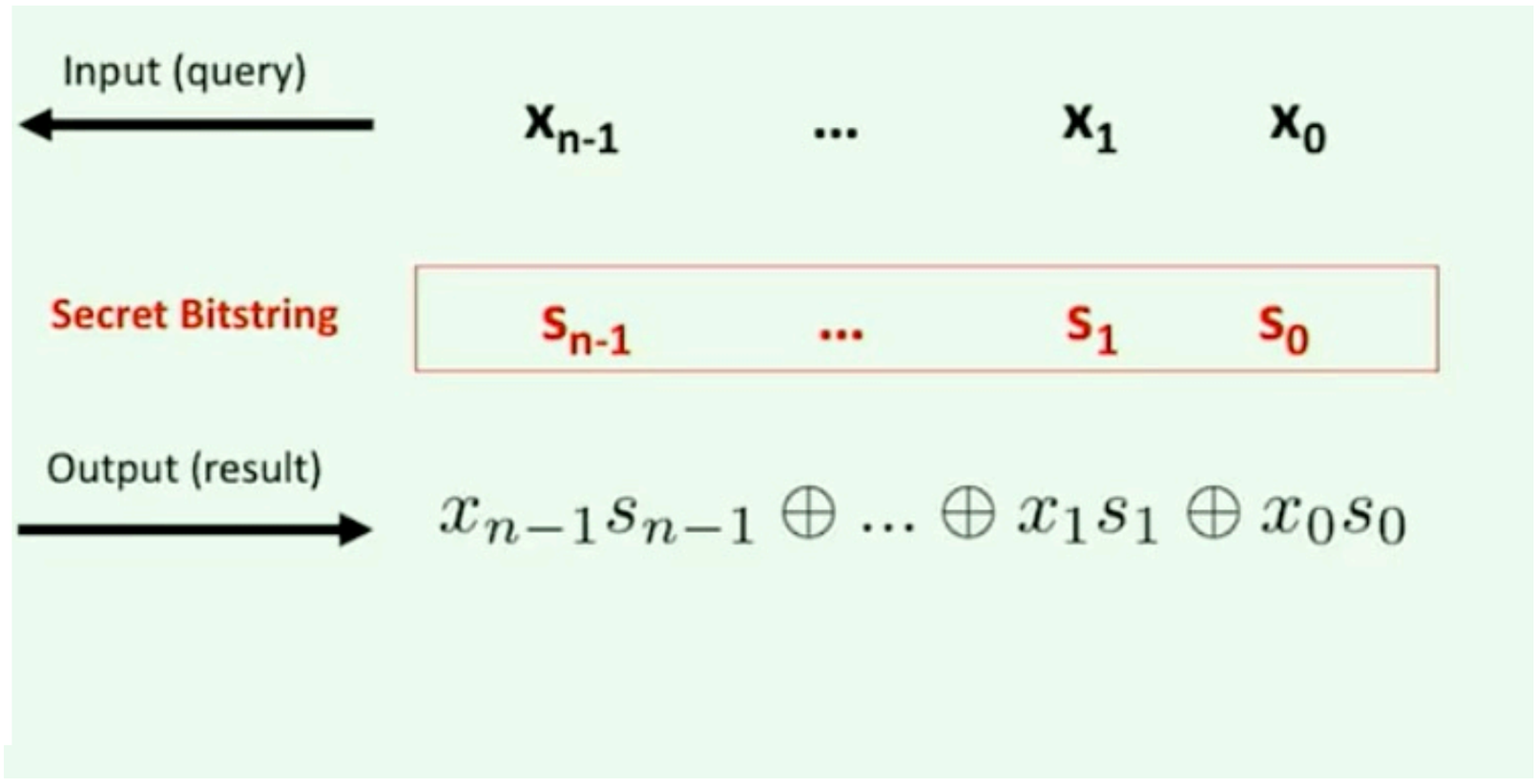
No classical computer ever could store a generic quantum state of 200 qubits.

"HOW CAN YOU SIMULATE THE QUANTUM MECHANICS? (....) CAN YOU DO IT WITH A NEW TYPE OF COMPUTER - A QUANTUM COMPUTER? IT IS NOT A TURING MACHINE BUT A MACHINE OF DIFFERENT KIND."
(R. FEYNMAN)

Surprise: also classical problems can be solved by Quantum Computers

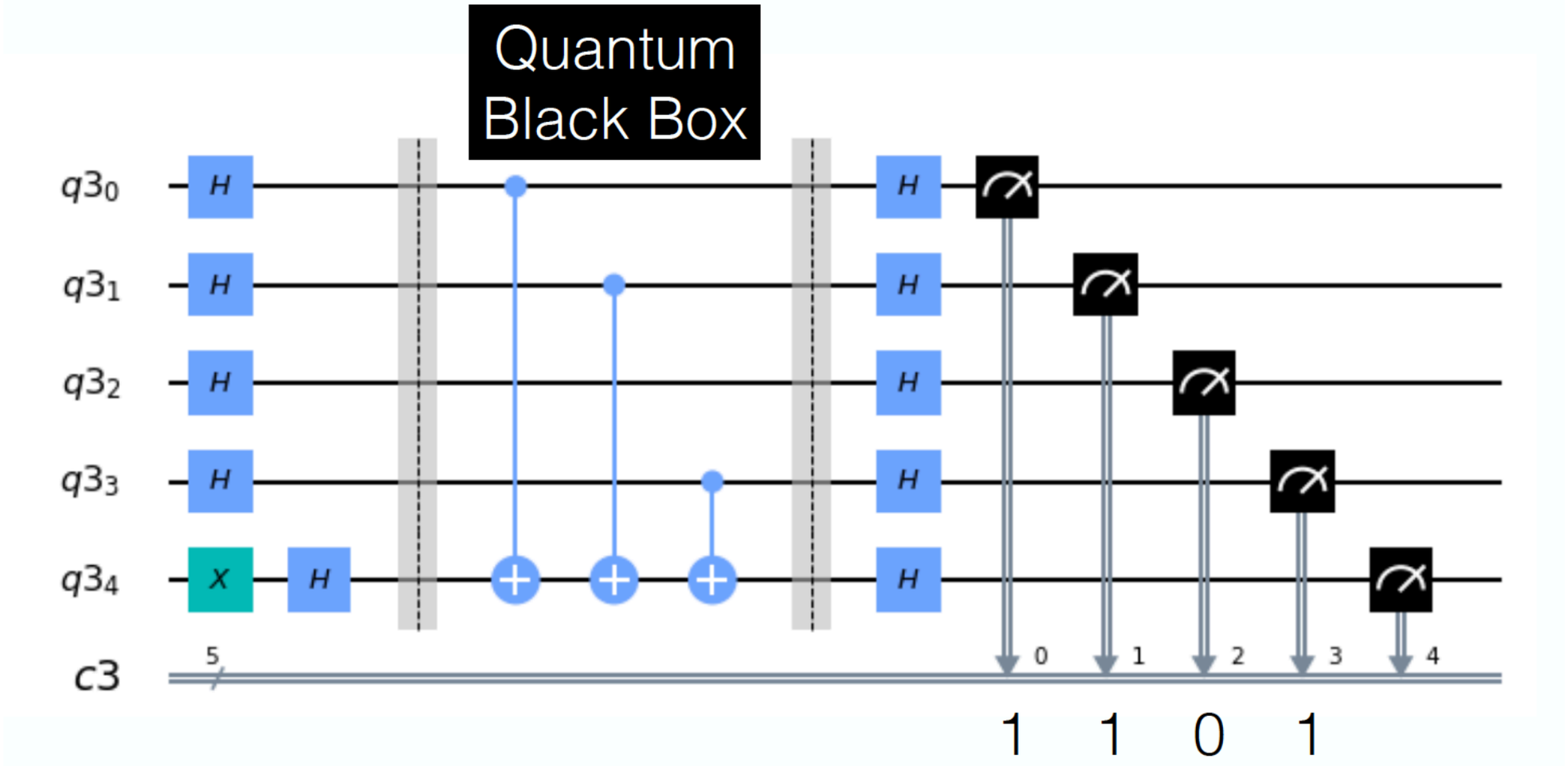
The Bernstein-Vazirani Problem

Black Box



How many queries do we need to determine the secret bit string?

The Bernstein-Vazirani Algorithm



See lecture of András

Shor’s algorithm (1994)

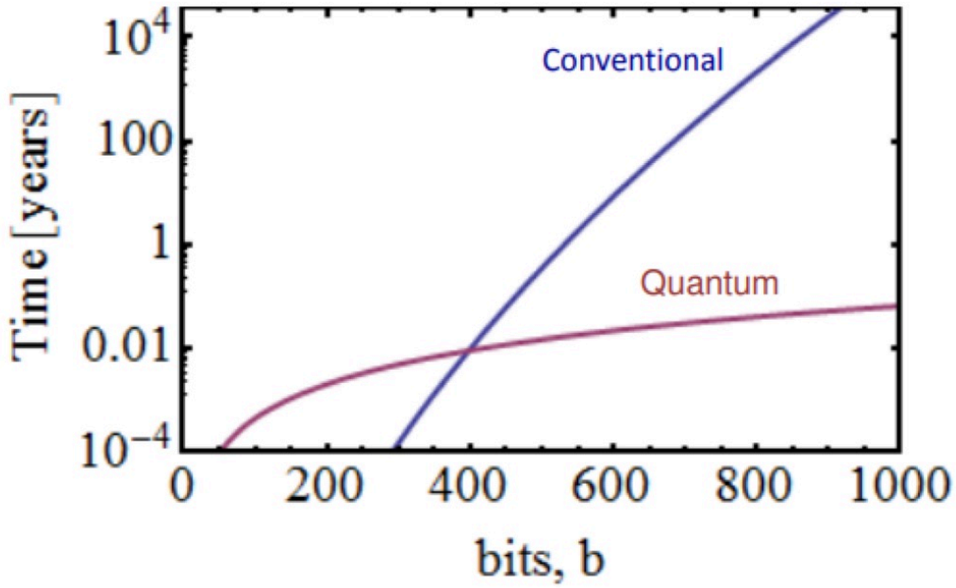
Peter Shor

Shor's algorithm is a quantum algorithm for factoring a number N in $O(n^3)$ time, named after Peter Shor.

Factor a number into primes:

M = p * q

How long will it take ? (t)



Source: http://www.ibm.com/

<u>Classical</u>

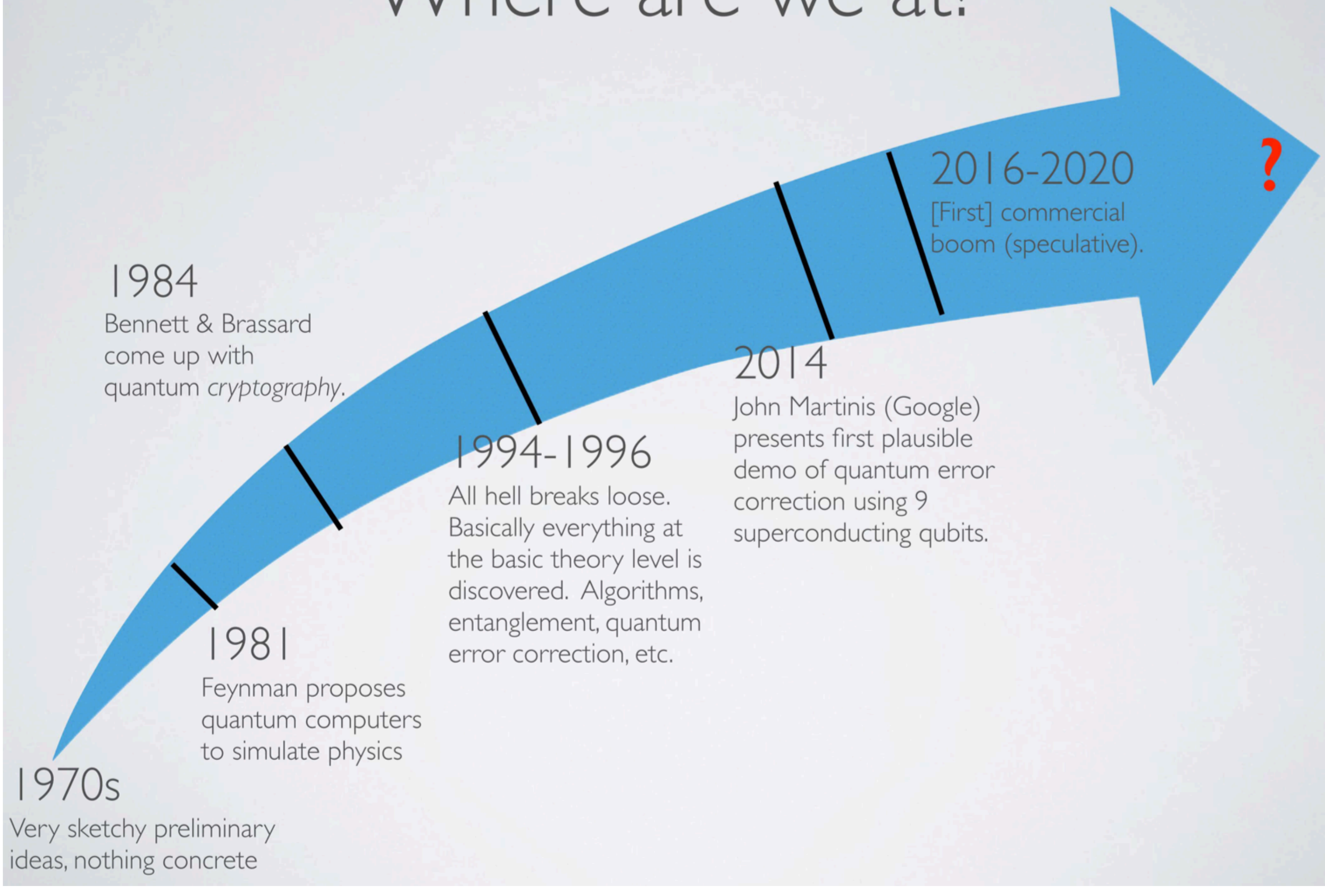
$t \sim O(2^{n^{(1/2)}})$

<u>Quantum</u>

$t \sim O(n^3)$

What is the current stage of Quantum Computing?

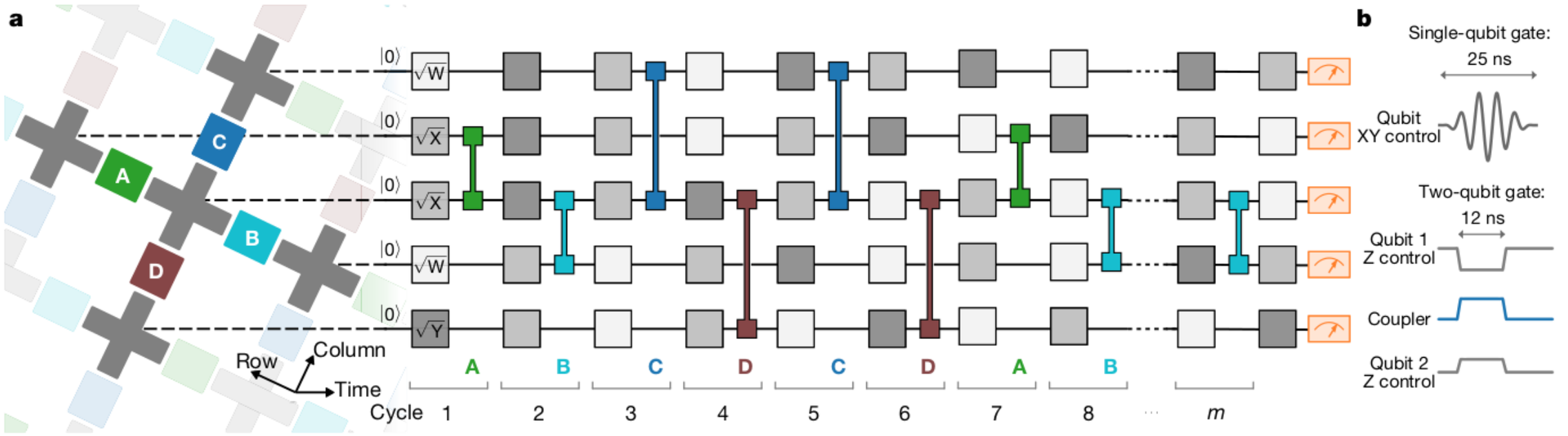
Where are we at?



Potential QC Technologies

Qubit Type	Coherence	Scalability	Control
Superconducting			
Electrical Quantum Dots			
Trapped Ions			
Neutral Atoms			
Diamond Defect Centers			
Topological (Majorana fermions)			
Photonic			
Liquid NMR			

Quantum supremacy test: sample a random quantum circuit



53 qubits, 20 layers

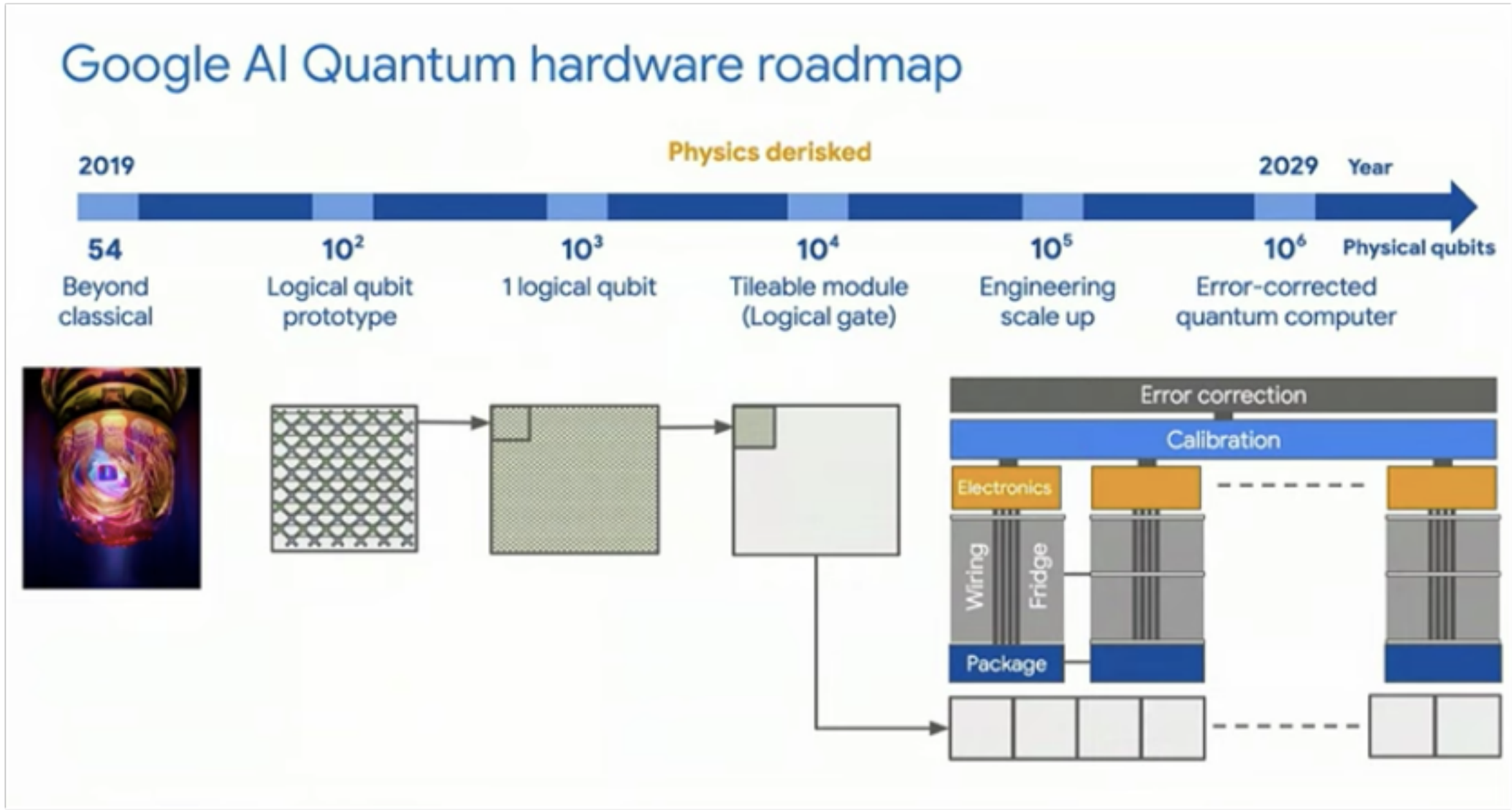
Start with all qubits 0 → run circuit → measure all qubits

3 million samples, expected fidelity 0.1%: 600 seconds

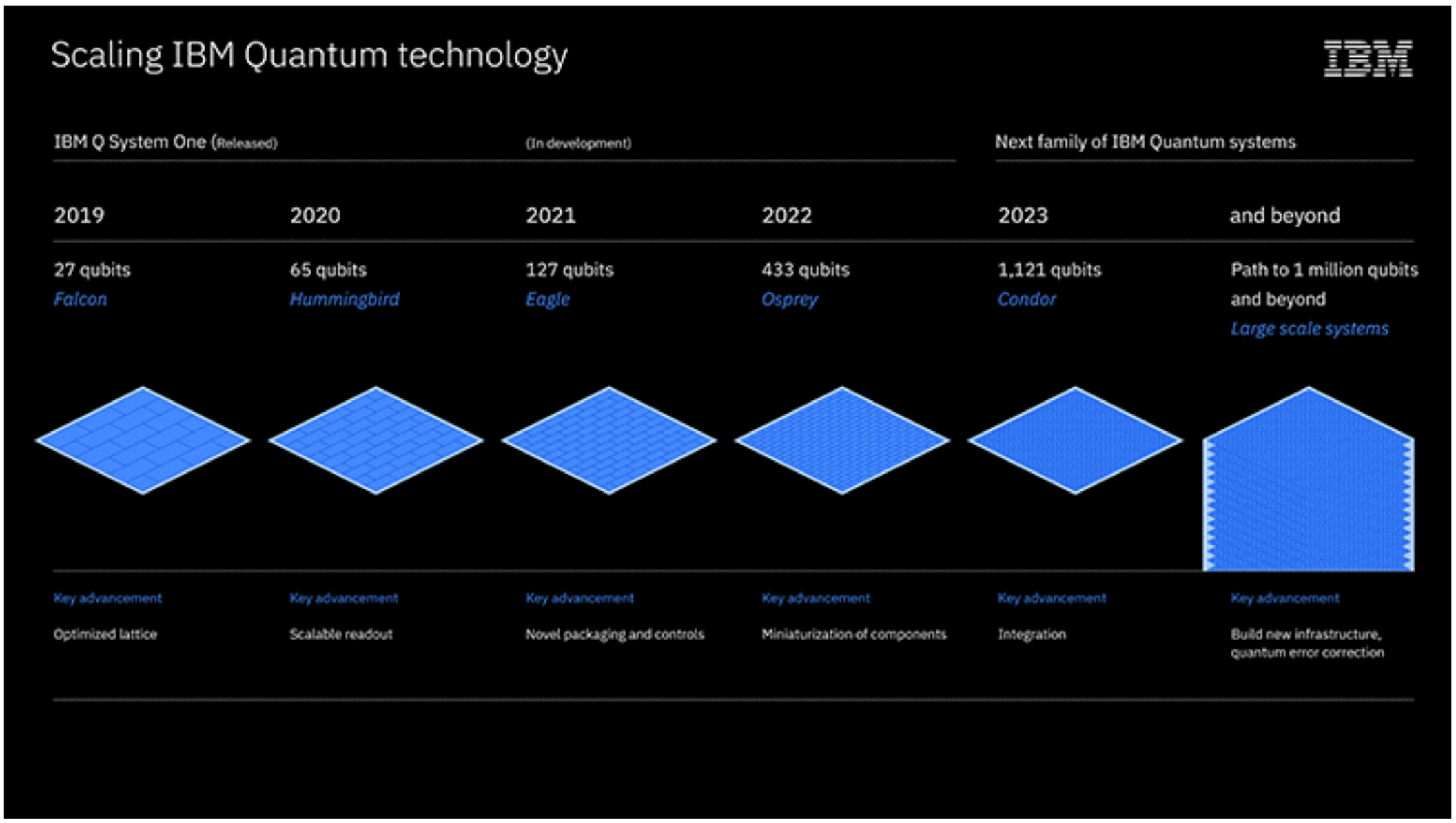
Best classical simulator: Schrodinger-Feynman algorithm, Google Cloud servers: 10000 years

IBM suggests: maybe 2.5 days?

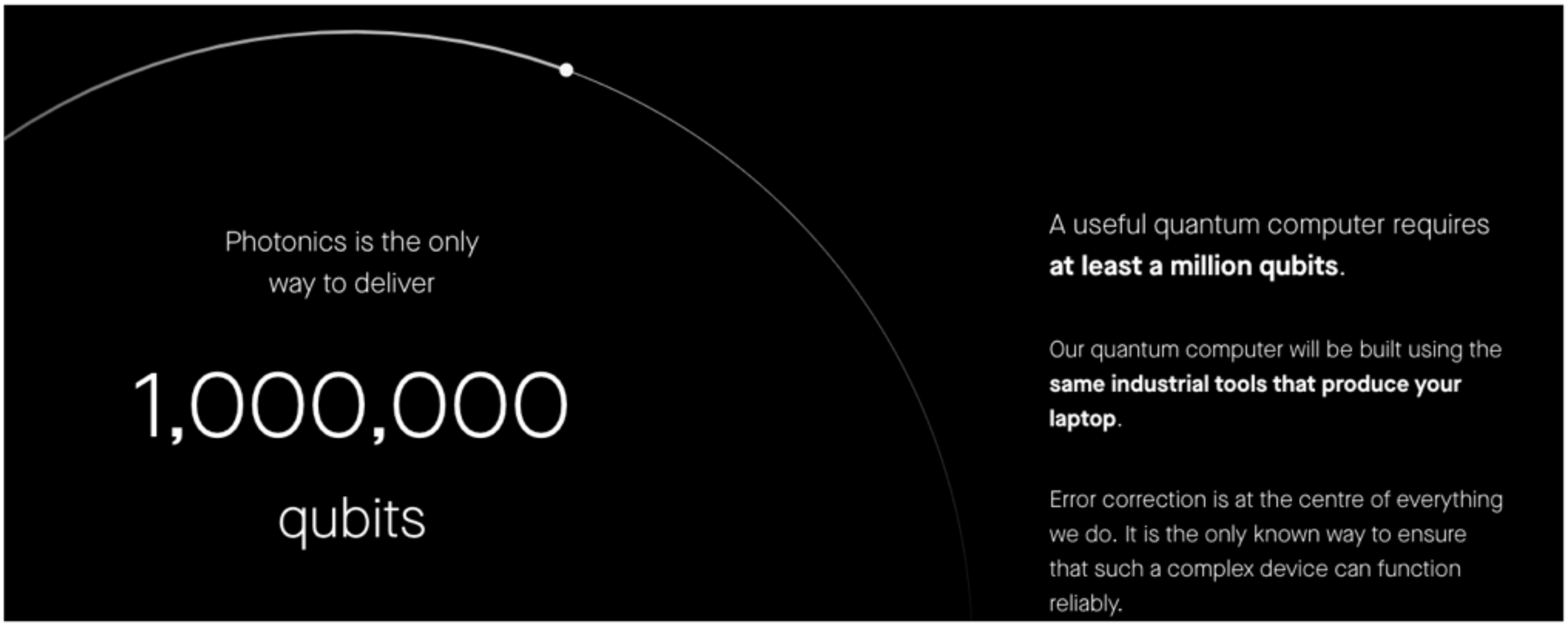
Google’s Roadmap



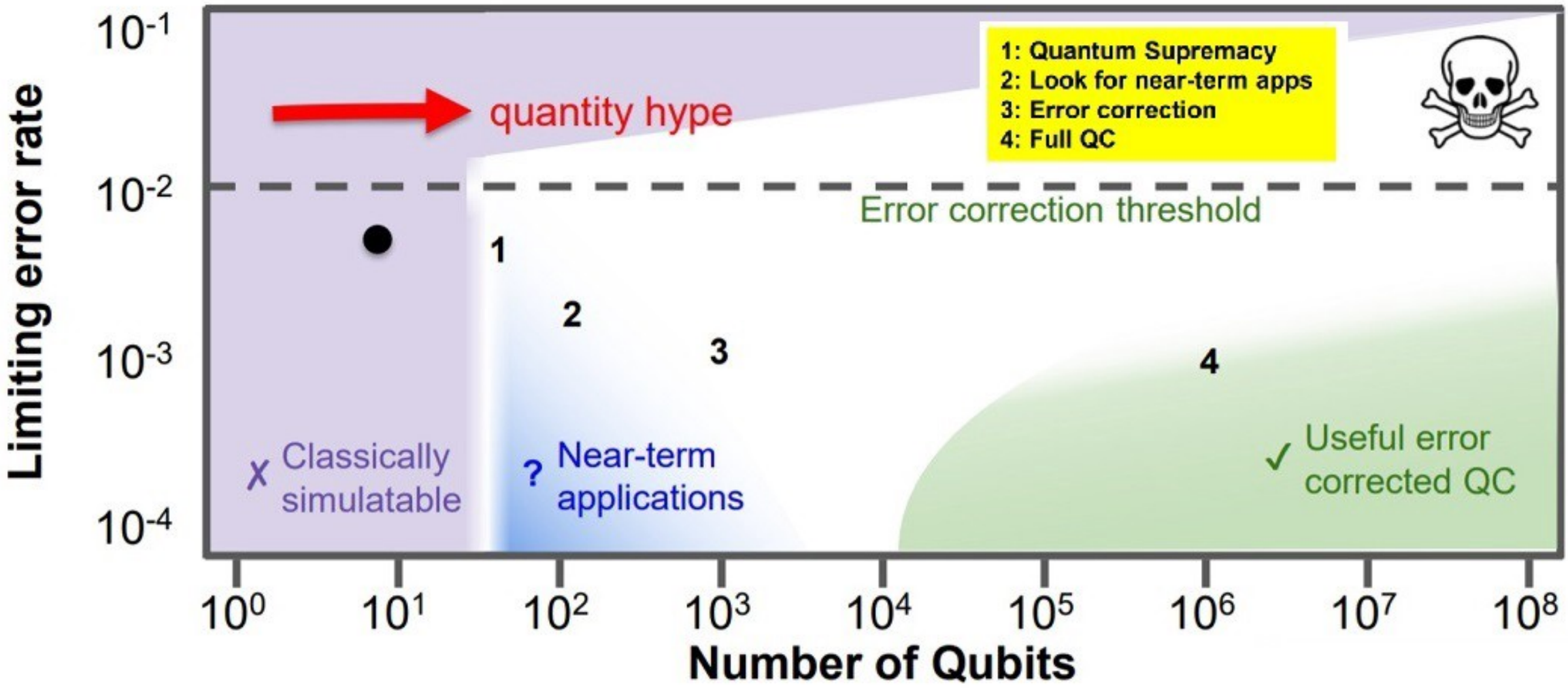
IBM’s Roadmap



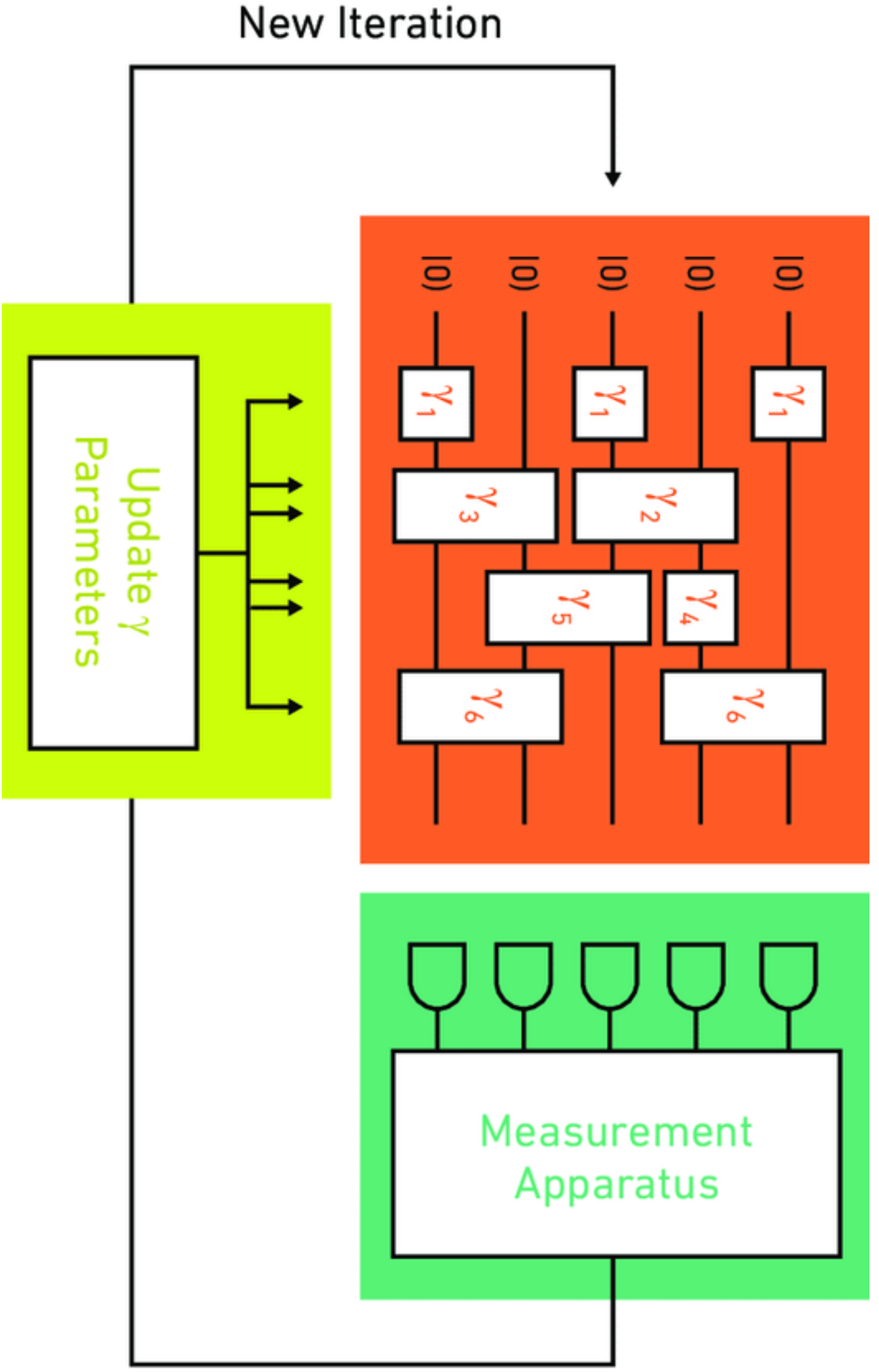
PsiQuantum's Plan



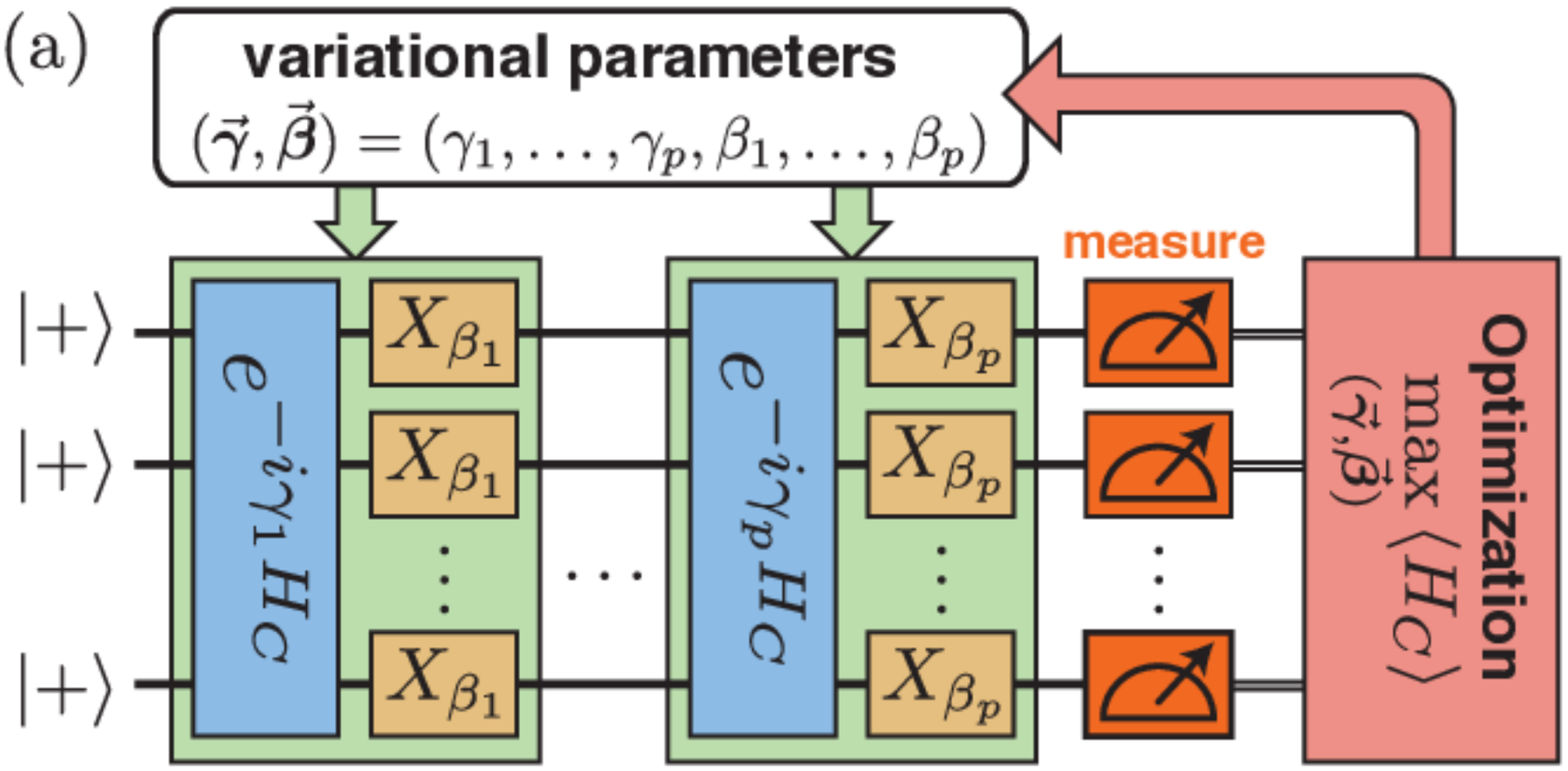
Noisy Intermediate-Scale Quantum (NISQ) Era



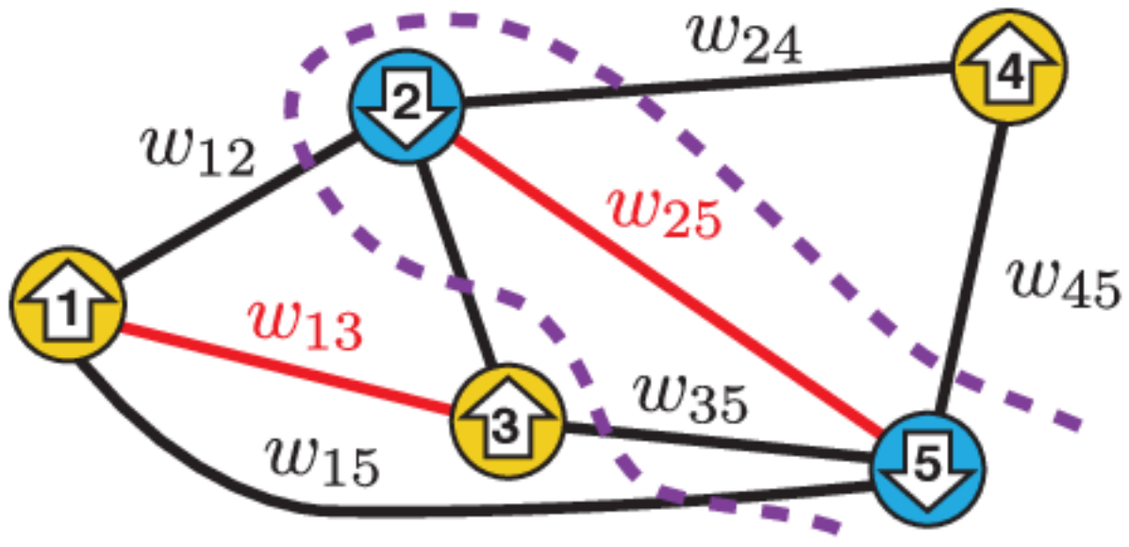
NISQ Era Quantum Algorithms


New Iteration
Update γ Parameters
|0⟩
|0⟩
|0⟩
|0⟩
|0⟩
γ_1
γ_1
γ_1
γ_3
γ_2
γ_5
γ_4
γ_6
γ_6
Measurement Apparatus

(a)


variational parameters
$(\vec{\gamma}, \vec{\beta}) = (\gamma_1, \ldots, \gamma_p, \beta_1, \ldots, \beta_p)$
measure
$|+\rangle$
$|+\rangle$
$|+\rangle$
$e^{-i\gamma_1 H_C}$
X_{β_1}
$e^{-i\gamma_p H_C}$
X_{β_p}
Optimization
$\max_{(\vec{\gamma},\vec{\beta})} \langle H_C \rangle$

(b)

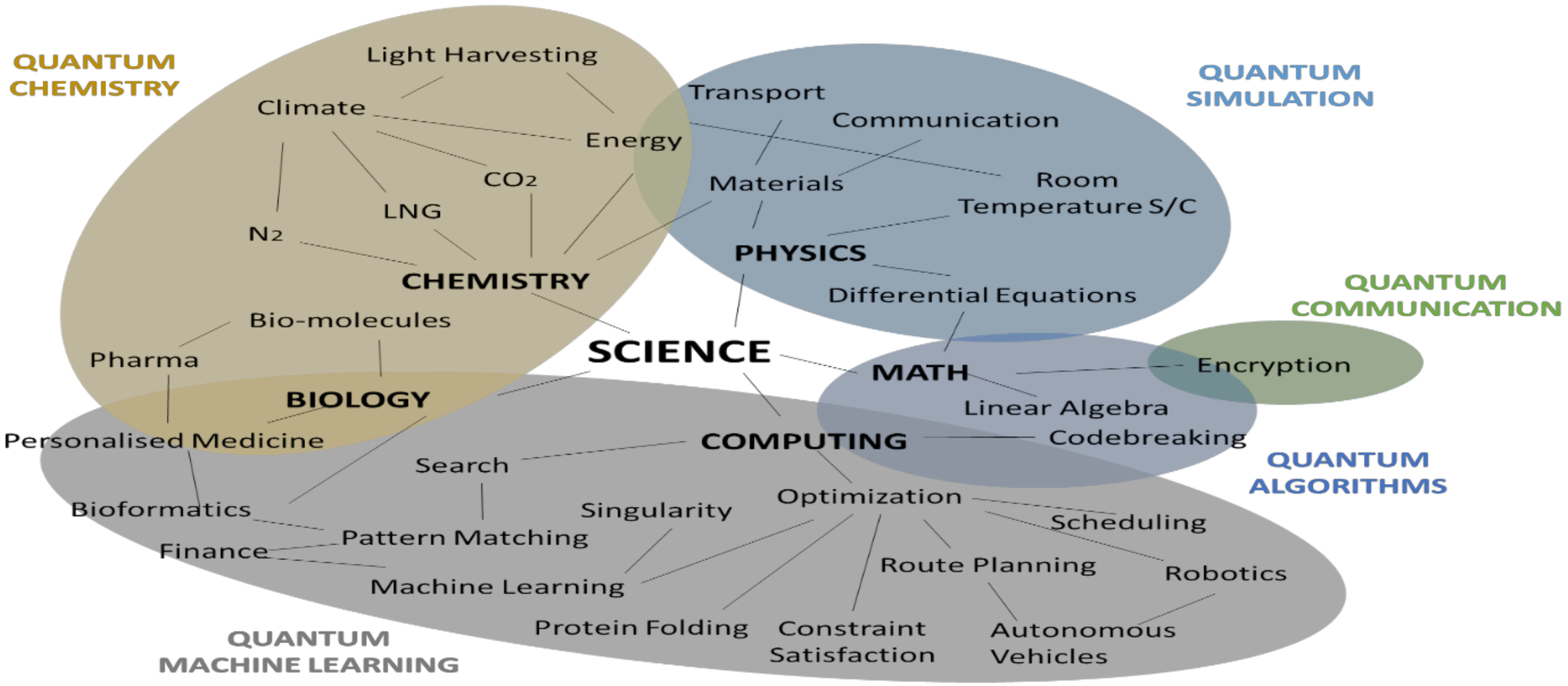

w_{12}
w_{24}
w_{25}
w_{45}
w_{13}
w_{35}
w_{15}
1
2
3
4
5

- Quantum Chemistry, Quantum Physics

- Optimization, Machine Learning

- Factoring

- Future ideas???


QUANTUM CHEMISTRY
Light Harvesting
Climate
Energy
CO2
LNG
N2
CHEMISTRY
Bio-molecules
Pharma
BIOLOGY
Personalised Medicine
Bioformatics
Finance
Pattern Matching
Search
Singularity
Machine Learning
QUANTUM MACHINE LEARNING
Protein Folding
Constraint Satisfaction
Optimization
Route Planning
Scheduling
Robotics
Autonomous Vehicles
QUANTUM ALGORITHMS
COMPUTING
SCIENCE
MATH
Linear Algebra
Codebreaking
Encryption
QUANTUM COMMUNICATION
Differential Equations
PHYSICS
Materials
Transport
Communication
Room Temperature S/C
QUANTUM SIMULATION

Moore’s Law

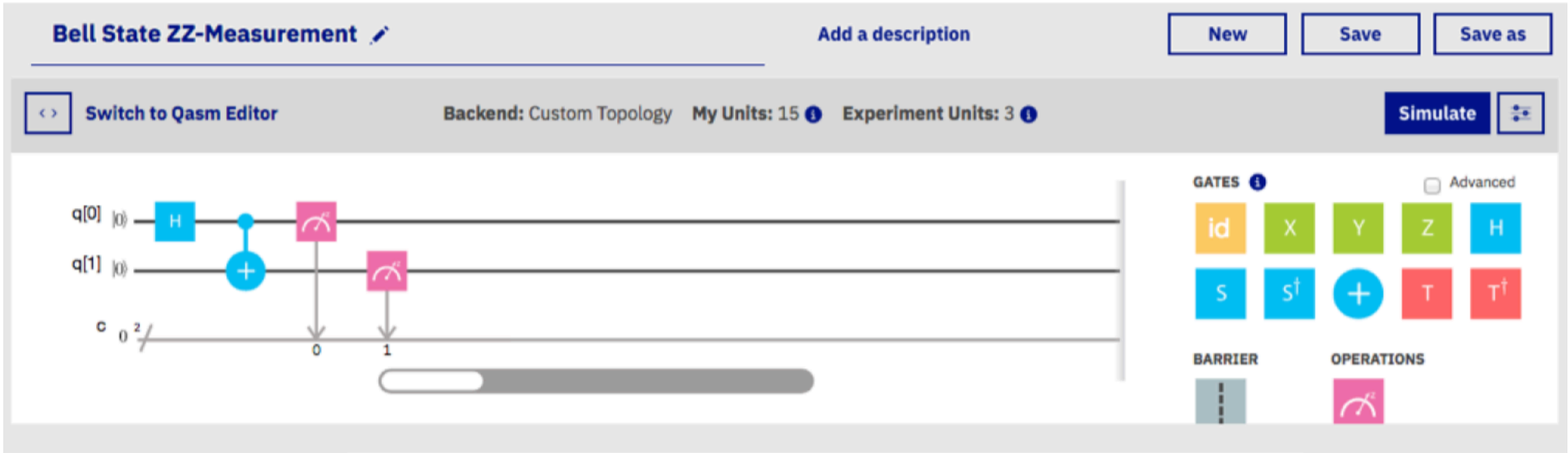

Physical gate length
(nanometers)
25
20
15
10
5
0
2013
2015
2017
2019
2021
2023
2024
2025
2027
2028
2030
Year
2013 Report
2015 Report
Moore’s law
is slowing…
Confidential © 2016 Arm Limited
arm

Online Accessible Programable Quantum Computers

- Multinational Companies & Start Ups

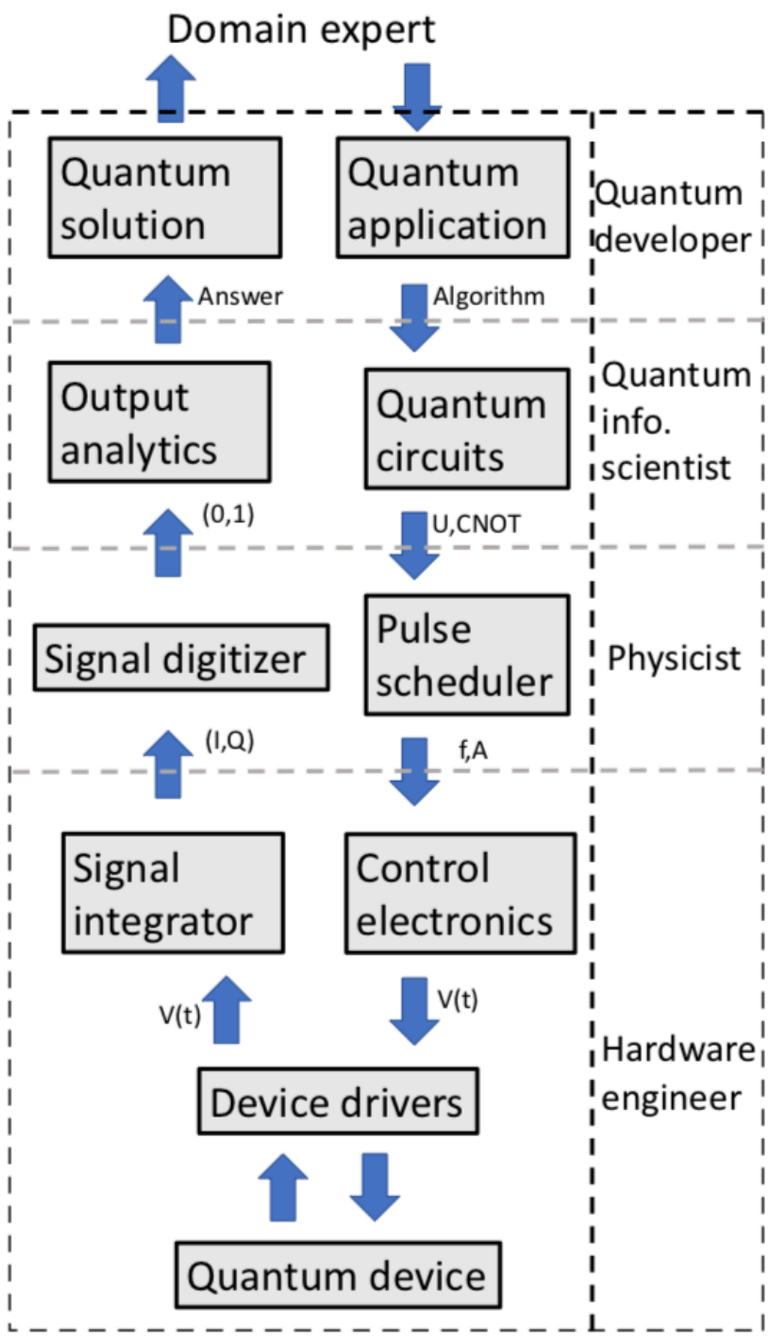
- Very good entry point for virtually everyone

There is a handy python environment for quantum programming




```
from qiskit import QuantumProgram
qp = QuantumProgram()
qr = qp.create_quantum_register('qr', 2)
cr = qp.create_classical_register('cr', 2)
qc = qp.create_circuit('Bell', [qr], [cr])
qc.h(qr[0])
qc.cx(qr[0], qr[1])
qc.measure(qr[0], cr[0])
qc.measure(qr[1], cr[1])
result = qp.execute('Bell')
print(result.get_counts('Bell'))
```

Nurturing Collaboration across Disciplines

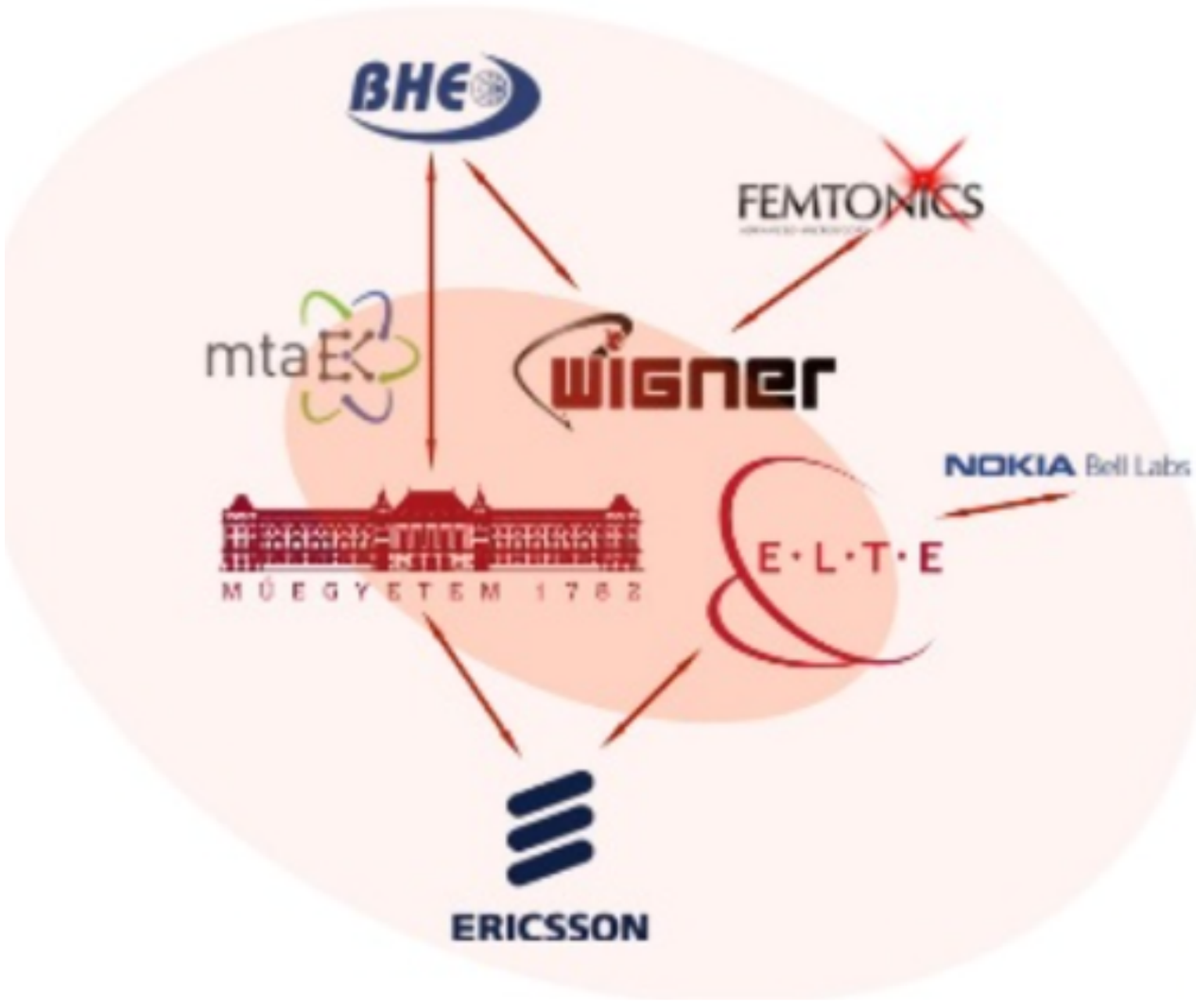


Welcome to Q2B

HunQuTech
Hungarian Quantum Technology Programme

About the Hungarian QT community

- Physics is traditionally a strong discipline in Hungary
- c.c. 100 researchers have QT related activity
  - including groups from previous excellence programs (ERC Starting Grant, Momentum Program of the Hungarian Academy of Sciences)
  - refocussing current activity toward quantum technologies
  - connecting to all pillars of the QT Flagship (**communication**, computation, simulation, sensing) is possible + fundamentals
- Photonics: strategic direction in R&D politics (c.f. ELI@Szeged)
  - strong development is expected in photonic-based quantum communication and in quantum light-matter interaction (memory, repeater, single photon sources)



HunQuTech Partners

Reminder of tomorrow's satellite event Quantum Programming Miniworkshop

https://sites.google.com/view/qhungary

13:00 - Zoltán Zimborás (Wigner/BME): Introduction, QWorld, QHungary

13:10 - Ákos Budai, András Pályi (BME): Quantum Computing in Practice- with demonstration: programming IBM's quantum computers through the cloud

14:15 - Coffee break - free discussion

14:30 - János Asbóth (BME/Wigner): Quantum Supremacy

15:05 - András Gilyén (Caltech): Quantum-Inspired Classical Algorithms