Title: Introduction to Quantinuum and TKET

Speakers: Mark Jackson
Date: October 13, 2022 - 2:00 PM

URL: https://pirsa.org/22100088

Abstract: As a recent combination of two strong global leaders in quantum computing, Honeywell Quantum Solutions and Cambridge Quantum, Quantinuum integrates quantum hardware and software, including solutions for drug discovery, materials science, finance, and other applications. Quantinuum aims to be a center of gravity for quantum computing, supporting collaboration across the ecosystem. For this we have also developed "TKET", an open-source architecture-agnostic quantum software stack and 'best in class' compiler. This enables our partners, collaborators and clients to effortlessly work across multiple platforms and tackle some of the most intriguing and important problems in quantum computing.

Bio: Dr. Mark Jackson is the Senior Quantum Evangelist at Quantinuum. He received his B.S. in Physics and Mathematics from Duke University and Ph.D. in Theoretical Physics from Columbia University. He then spent 10 years researching superstring theory and cosmology, co-authoring almost 40 technical articles. To promote the public understanding of science, he founded the science crowdfunding platform Fiat Physica and non-profit Science Partnership Fund. He is Adjunct Faculty at Singularity University and a Director of Astronomers Without Borders.

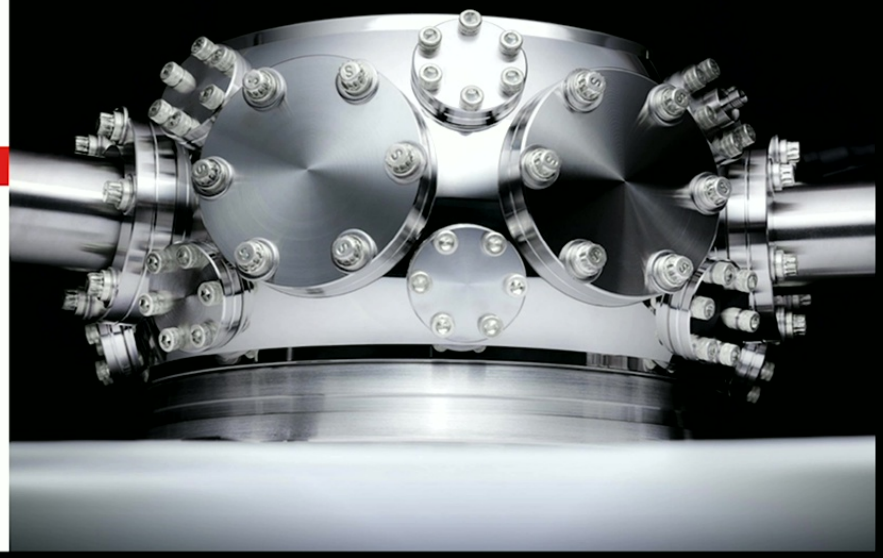
Zoom link: https://pitp.zoom.us/j/98433088425?pwd=UzgwcGpUYnBKNzJmMnQ1ZVNOdGVXZz09

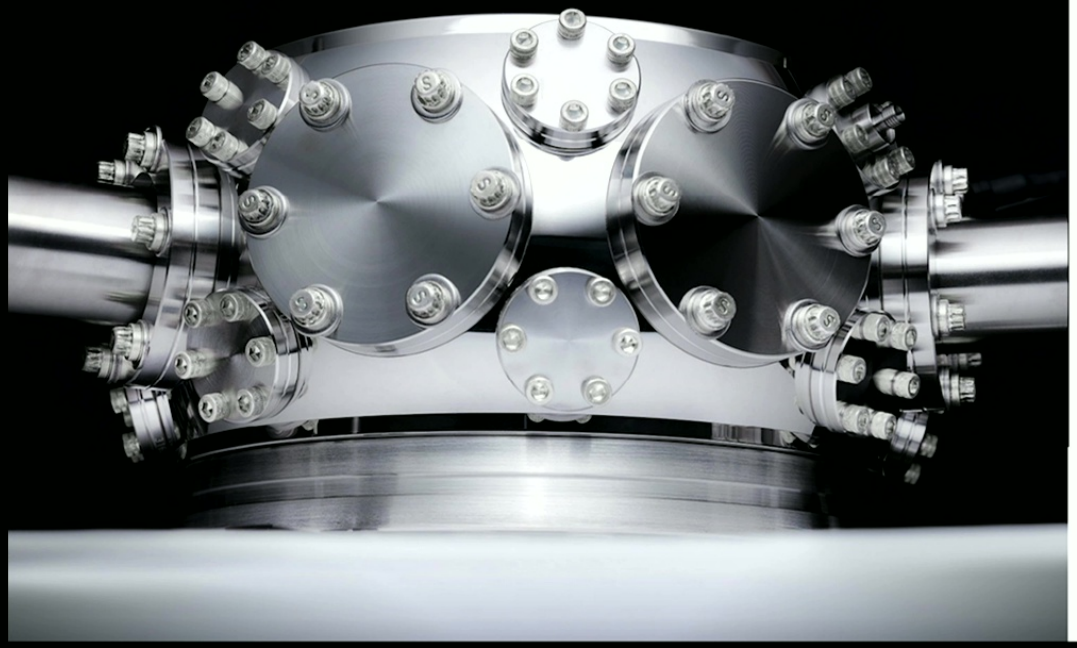
QUANTINUUM

INTRODUCTION TO QUANTINUUM

PRESENTED BY:
Dr Mark Jackson
Senior Quantum Evangelist

October 13, 2022





ABOUT QUANTINUUM

AN INTEGRATED APPROACH

Industrial Collaborators

Telcom, Finance, Pharma, Automotive, Manufacturing, Transport, Chemicals….

Cybersecurity

Quantum Origin: quantum computing-enabled cryptographic keys

Quantum Chemistry

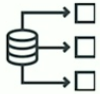
InQuanto: State-of-the-art chemistry platform for quantum computers

AI & ML

Including open-source QNLP Toolkit and Library **'LAMBEQ'**

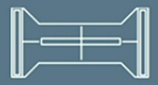
TKET

Open-source quantum software development platform



Third Party Platforms

Quantum Hardware, Simulators and Cloud Providers



H-Series

Quantum Computers

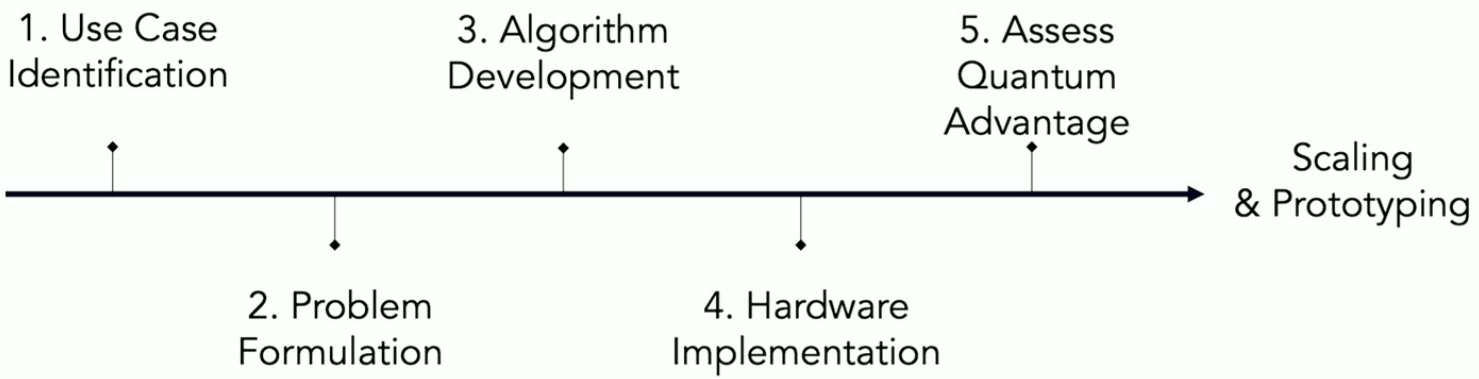
Powered by **Honeywell**

Quantinuum Products | Partner / Ecosystem Products

QUANTINUUM

CLIENT ENGAGEMENT

- R&D Collaborations
- Geared towards building tailor-made quantum computing capabilities for your unique computational problems



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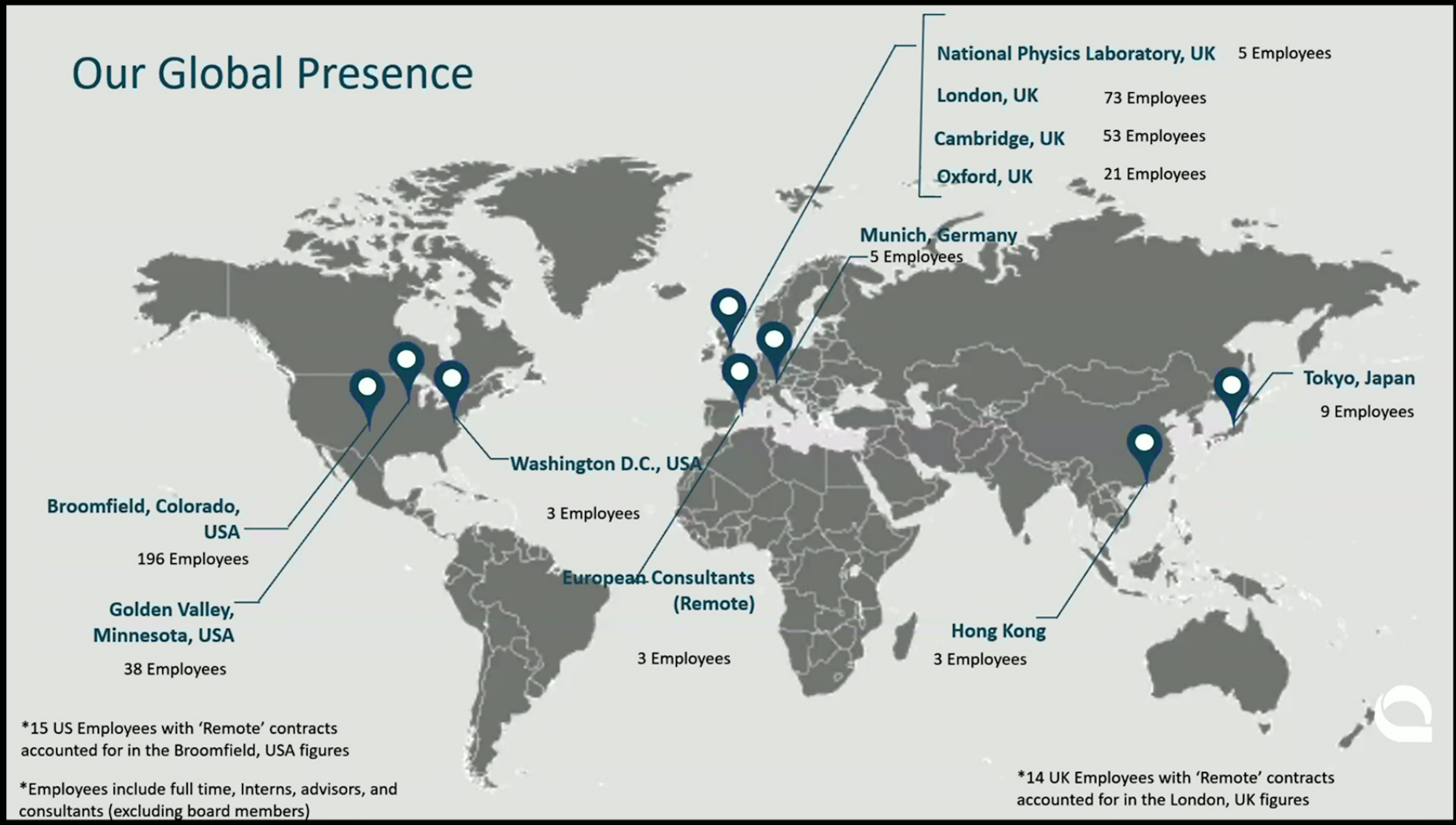
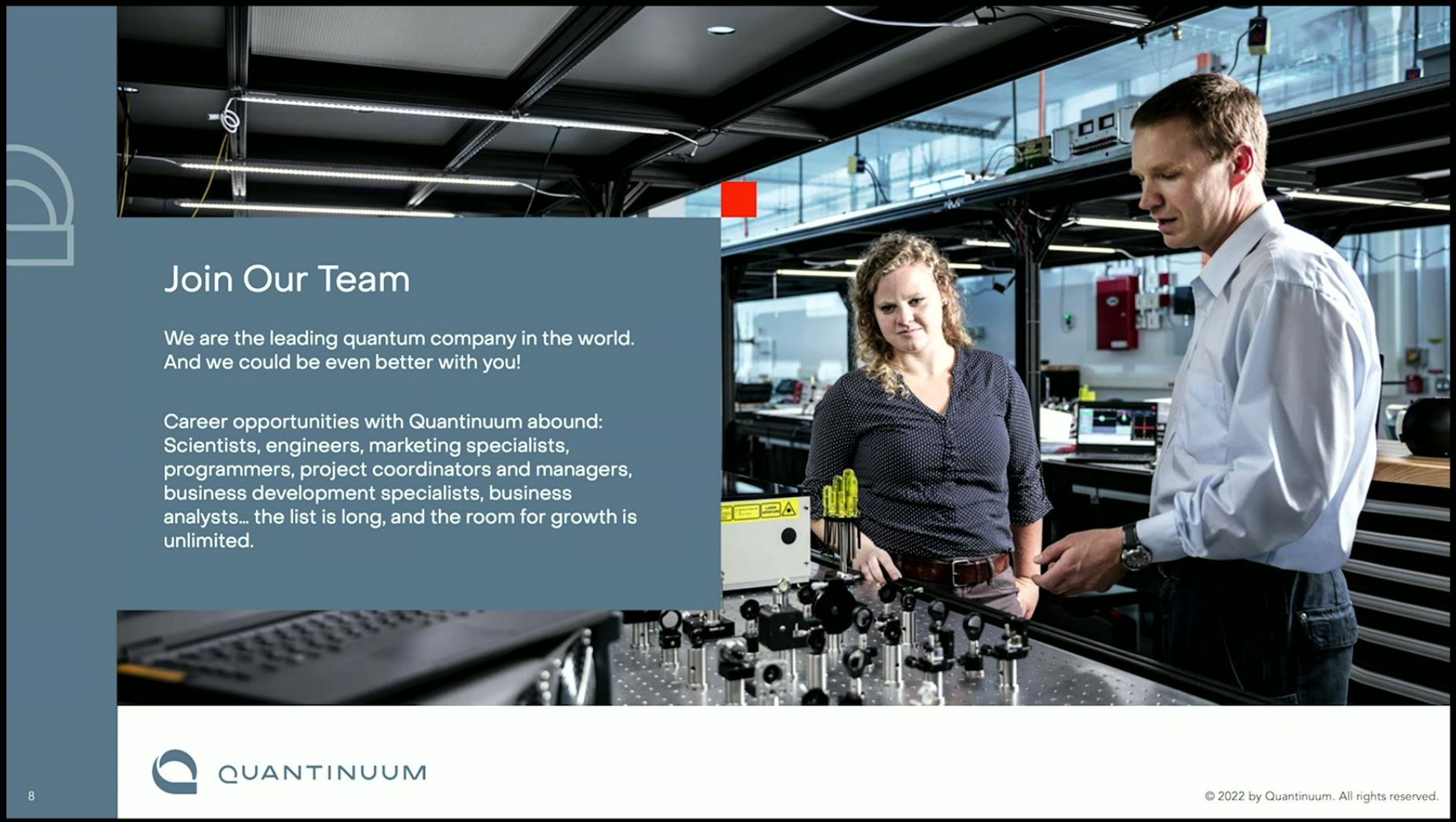

Our Global Presence
National Physics Laboratory, UK 5 Employees
London, UK 73 Employees
Cambridge, UK 53 Employees
Oxford, UK 21 Employees
Munich, Germany
5 Employees
Tokyo, Japan
9 Employees
Washington D.C., USA
3 Employees
Broomfield, Colorado, USA
196 Employees
European Consultants (Remote)
3 Employees
Golden Valley, Minnesota, USA
38 Employees
Hong Kong
3 Employees
*15 US Employees with 'Remote' contracts accounted for in the Broomfield, USA figures
*Employees include full time, Interns, advisors, and consultants (excluding board members)
*14 UK Employees with 'Remote' contracts accounted for in the London, UK figures


Join Our Team
We are the leading quantum company in the world.
And we could be even better with you!
Career opportunities with Quantinuum abound:
Scientists, engineers, marketing specialists,
programmers, project coordinators and managers,
business development specialists, business
analysts... the list is long, and the room for growth is
unlimited.
QUANTINUUM
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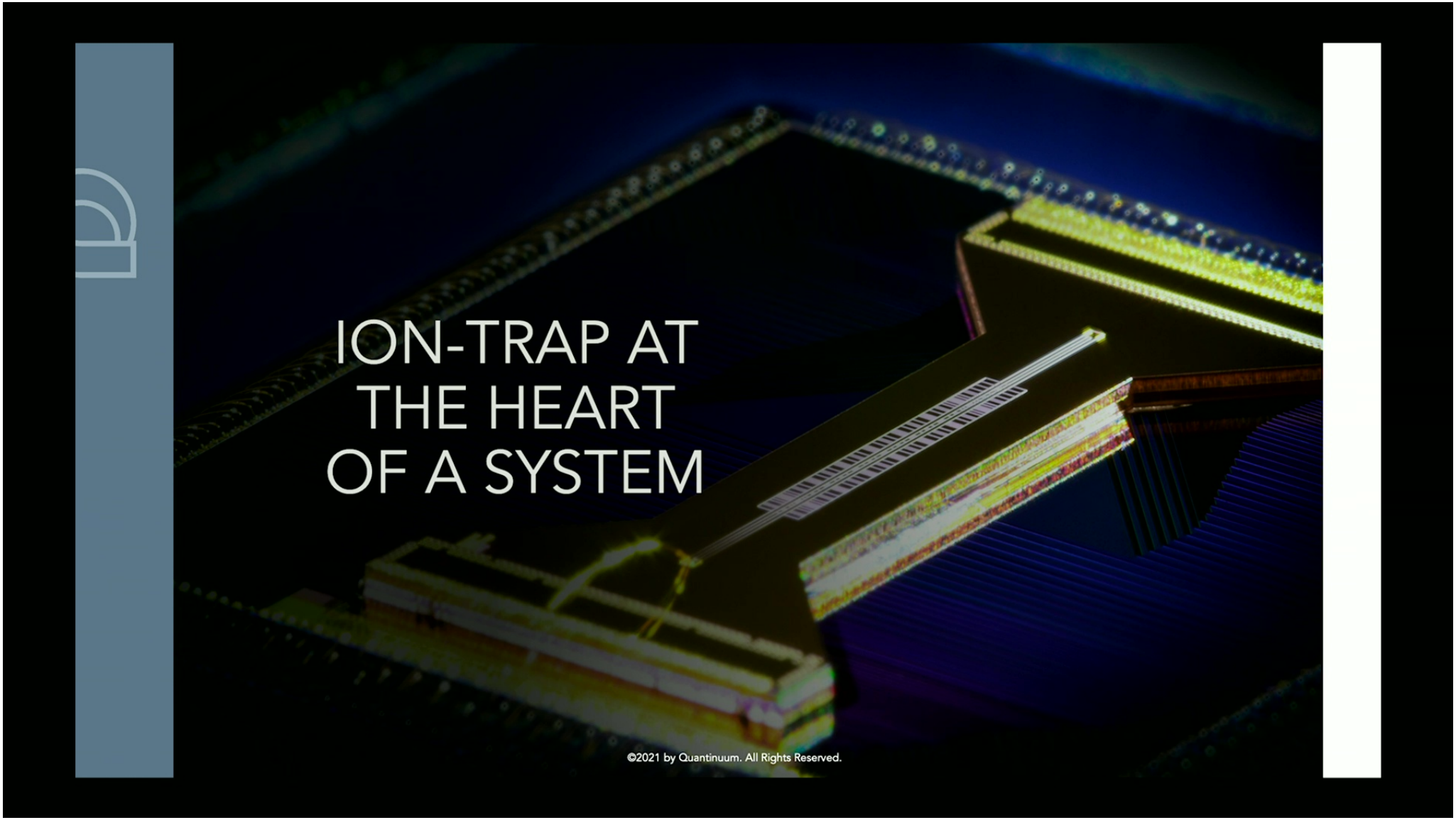
ION-TRAP AT
THE HEART
OF A SYSTEM
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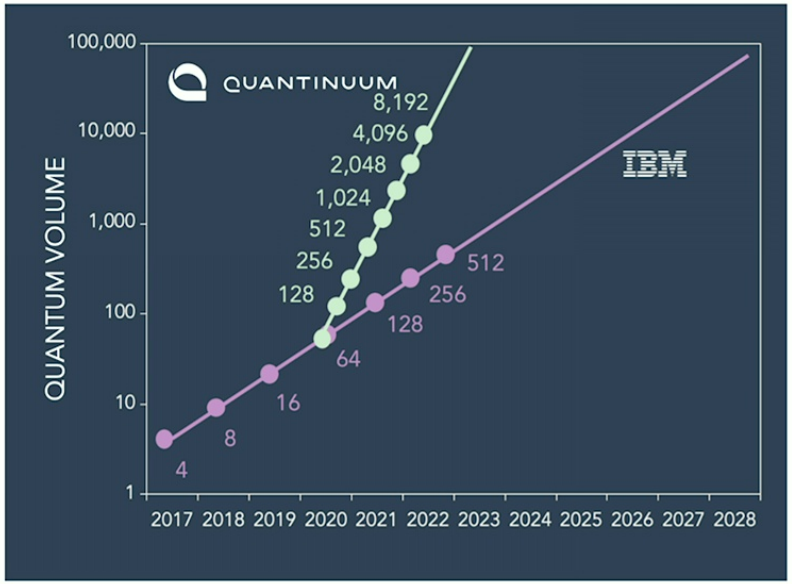
ROADMAP FOR QUANTUM HARDWARE IMPROVEMENT



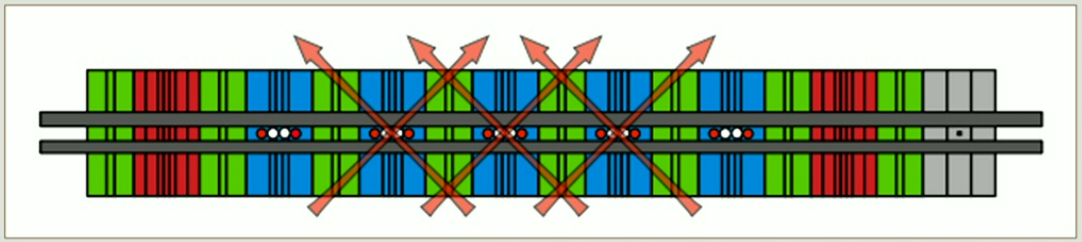
- Quantinuum has increased the Quantum Volume by a factor of 10x each year
  - This is much faster than Moore's Law, which is 2x every 18 months
- This suggests commercial applications in just 3-5 years

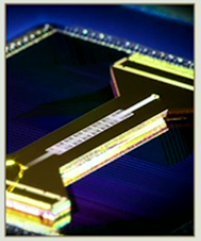
QUANTINUM

QCCD ARCHITECTURE – REALIZED IN 2020

QUANTUM CHARGE-COUPLED DEVICE DEMONSTRATED BY QUANTINUUM (2020)

ION TRAP ARCHITECTURE





ARCHITECTURE FEATURES

- Identical, high-quality qubits
- Dedicated interaction zones
- Short ion chains
- High fidelity quantum gates
- Ions transport from zone to zone

Quantum bits (qubits) are stored in the electronic states of Yb^+ ions

$^{171}Yb^+$ $|1\rangle$ $|0\rangle$ HYPERFINE QUBIT

$^{138}Ba^+$ COOLING ION

Pino, J.M., Dreiling, J.M., Figgatt, C. *et al.* Demonstration of the trapped-ion quantum CCD computer architecture. *Nature* **592,** 209–213 (2021).

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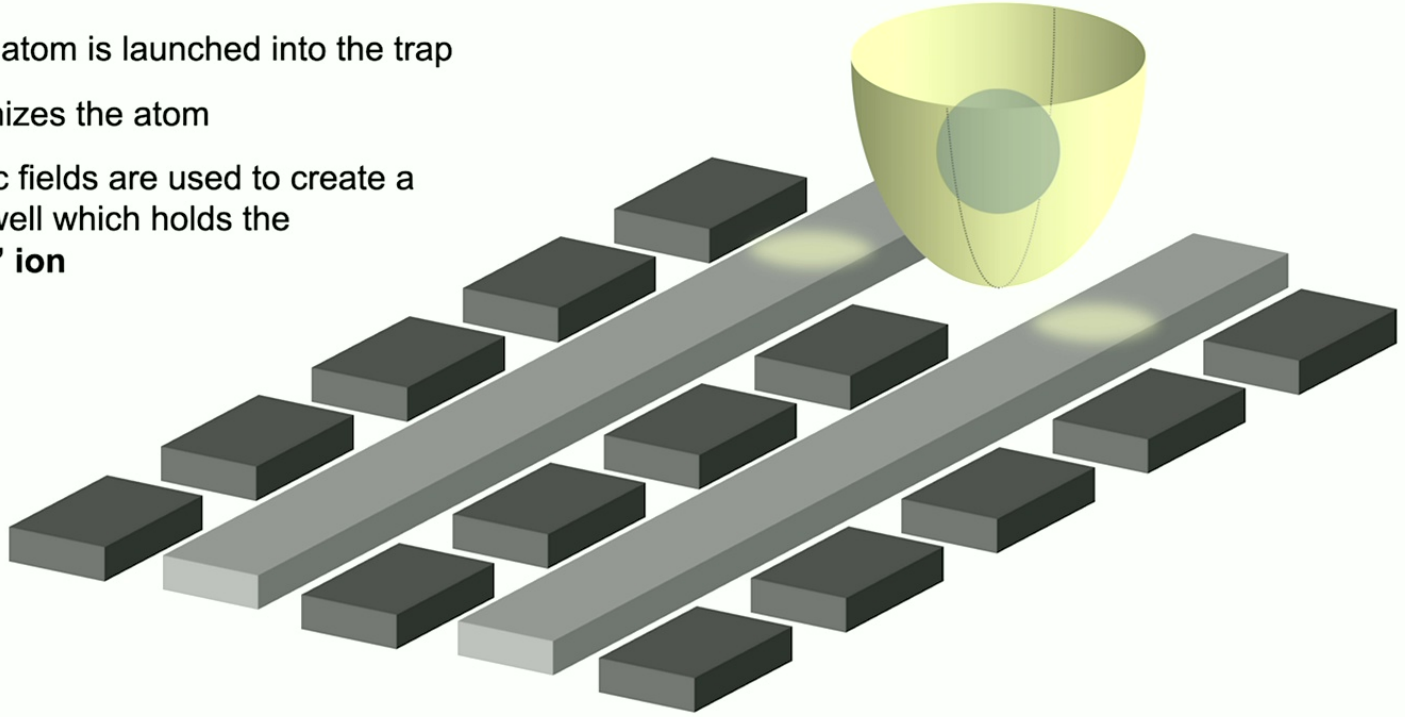
LOADING IONS

Ytterbium atom is launched into the trap

A laser ionizes the atom

RF electric fields are used to create a potential well which holds the **“trapped” ion**



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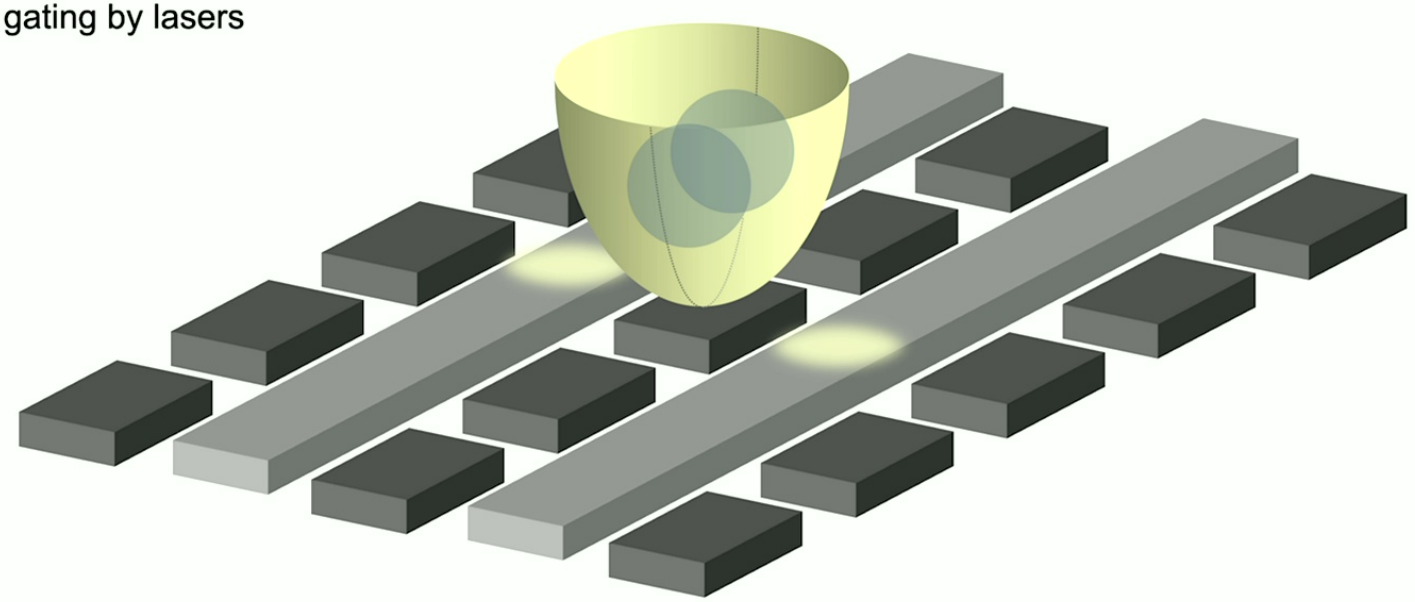
MERGE AND ENTANGLEMENT

Individual trapped ions can be merged to a single well for two-qubit gating by lasers



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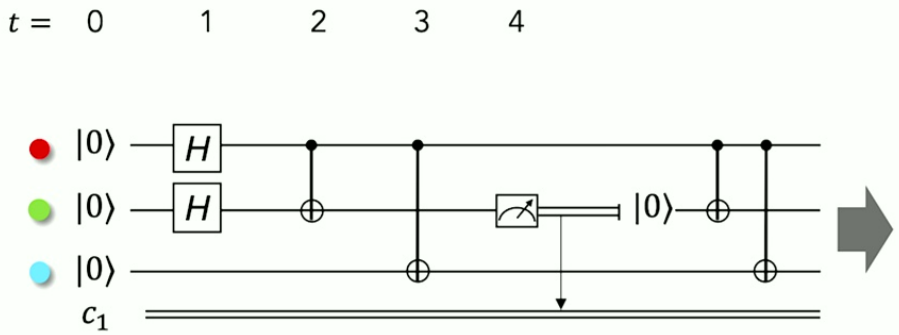
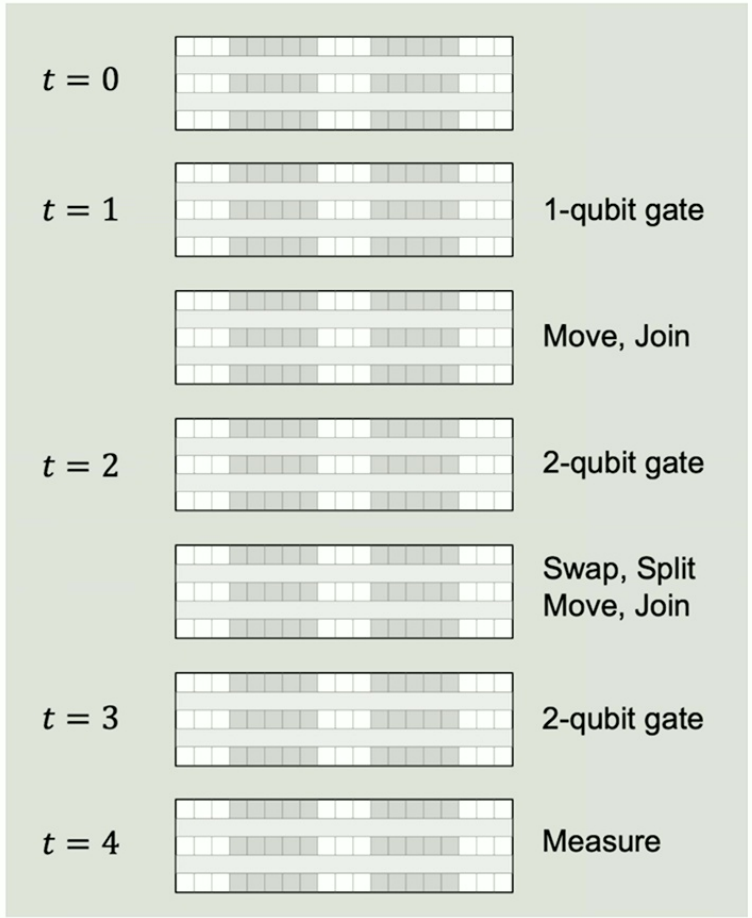
PHYSICAL IMPLEMENTATION

Quantum Circuit





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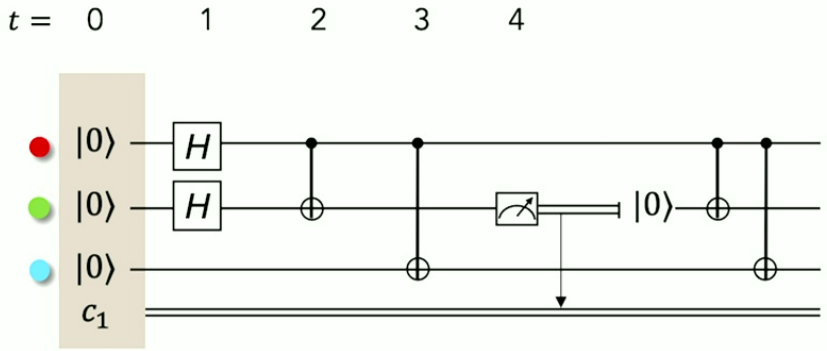
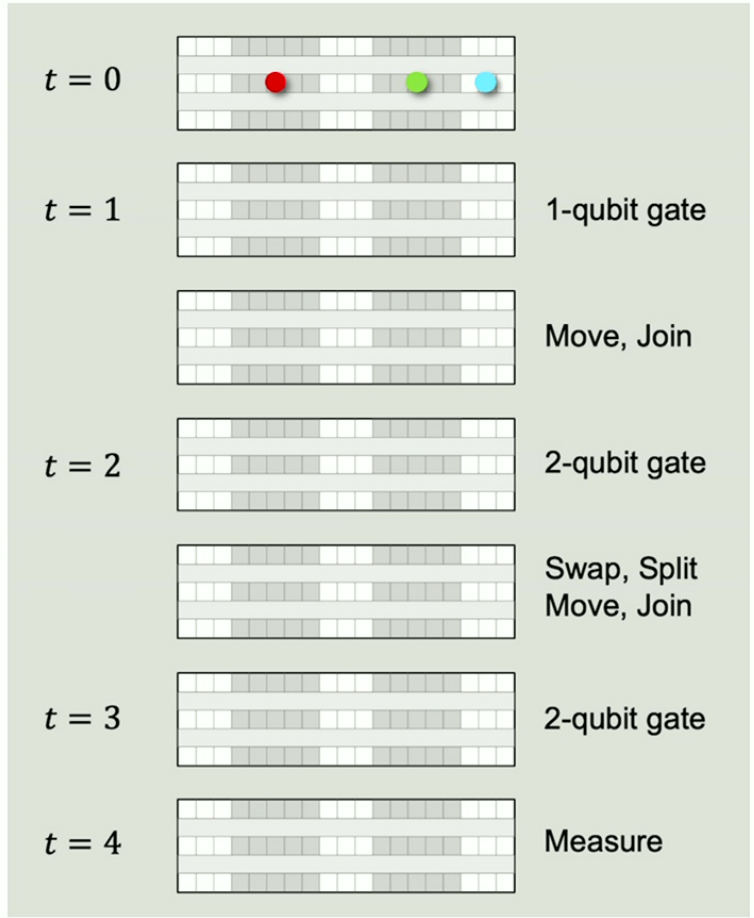
PHYSICAL IMPLEMENTATION

Quantum Circuit

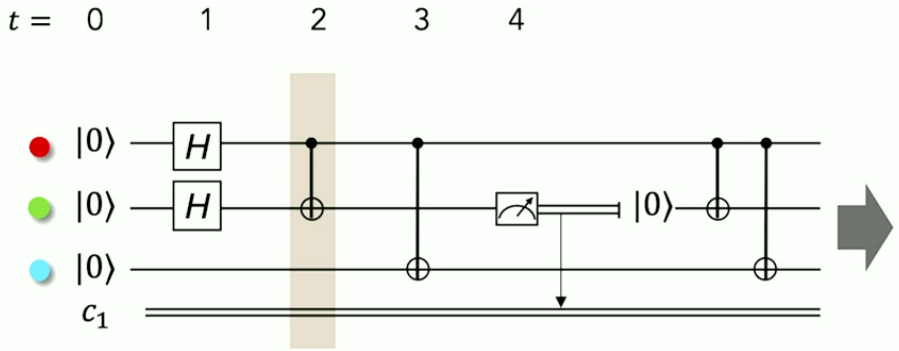


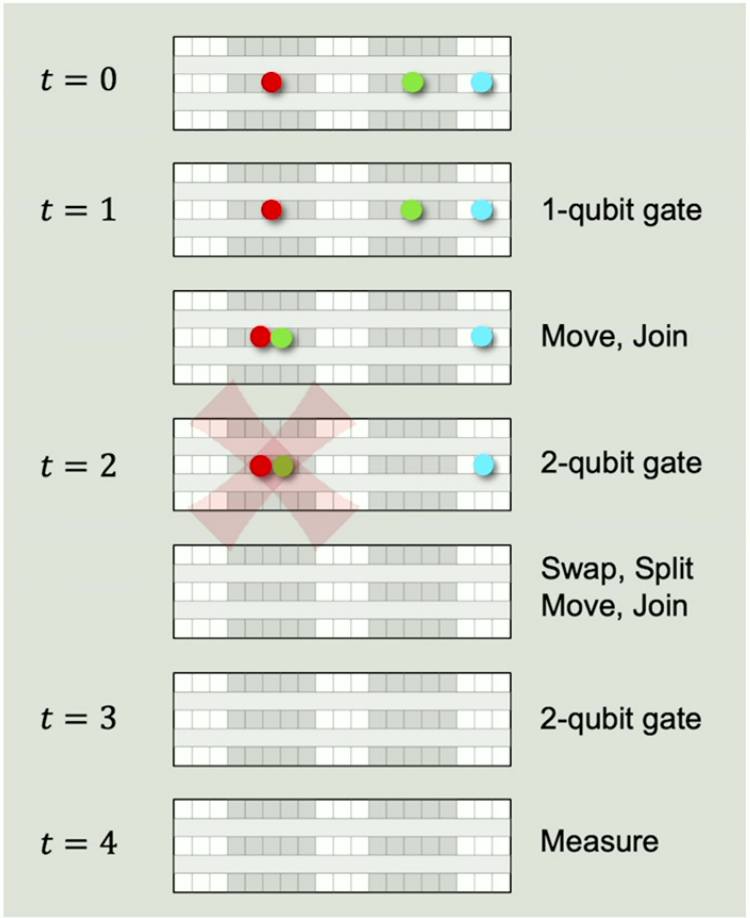


QUANTINUUM

PHYSICAL IMPLEMENTATION

Quantum Circuit





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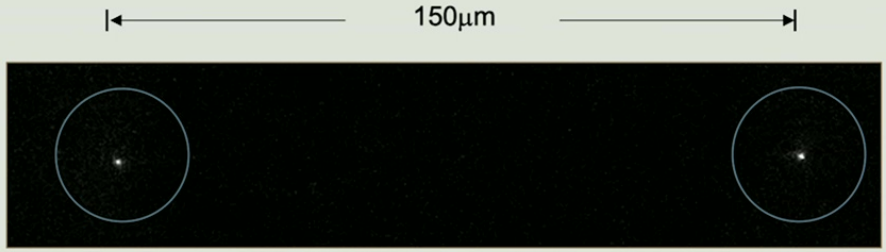
REAL-WORLD VIEW

SPLIT AND COMBINE

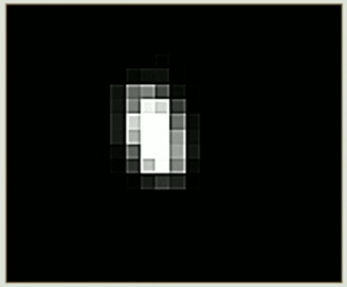
Ion is transported into the same zone

Ions are combined into a single potential well and then re-separated



SWAP

Ions are carefully manipulated to reorder positions



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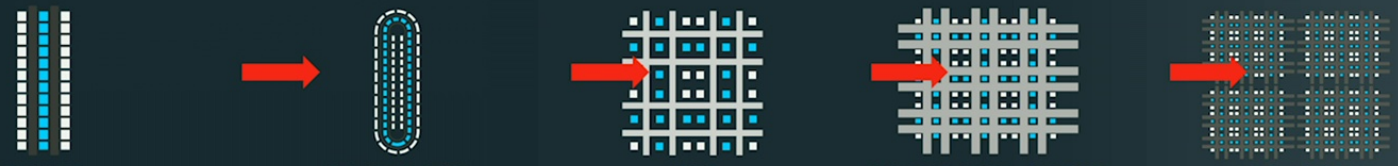
The Future of QC and What's Needed to Get There

- Proven roadmap
- Rapidly scaling computing power and accuracy
- Many key enabling technologies already demonstrated for generational upgrades

2020 — Model H1 (Q3 2020) — Model H2 (Q4 2022) — Model H3 — Model H4 — Model H5 — 2030



LINEAR	RACETRACK	GRID	INTEGRATED OPTICS	LARGE SCALE
• Highest measured quantum volume QV8192 • Real-time quantum error correction • 2Q Fidelity: ≥ 99.7% • Mid-circuit measurement • Qubit re-use • Conditional logic	Scalable Multi-Zone Quantum Operations	Scalable Control Systems	Scalable Laser Delivery	Modular Cross Ion-Trap Transport
	1st Opportunity to Demonstrate Quantum Advantage	Expanded Value Creation in Chemistry and Machine Learning	Fault Tolerant Applications Integrated into Businesses	Full-Scale Universal Fault-Tolerance

H-Series Hardware Provides a Unique Opportunity to Build & Test Industry OS

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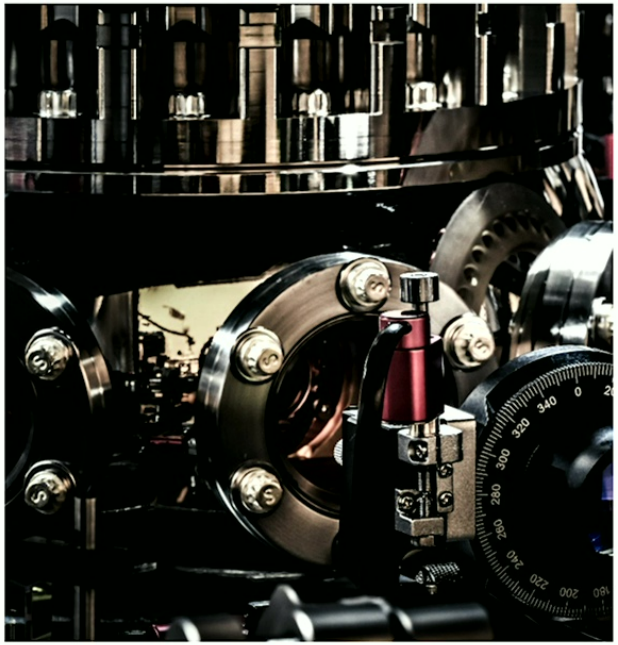
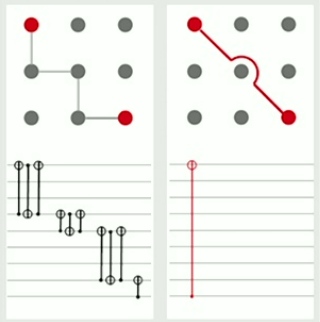
H-SERIES
QUANTUM COMPUTERS ON THE CLOUD



	MODEL H1 (2 systems)
Measured Quantum Volume	8192
Physical Qubits	20
Coherence Time (s)	≥ 3
Typical Limiting Fidelity	≥ 99.9904%

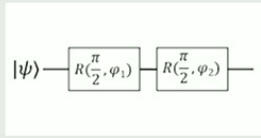
All-to-All Connectivity

Nearest Neighbor | All-to-All

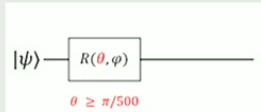


High-Resolution Rotations

Fixed amplitude systems

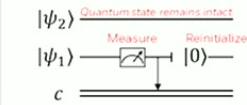


Trapped-ion system

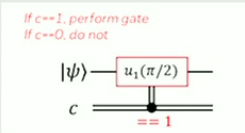


Qubit Branching and Reuse

Measurement and reuse



Conditional logic



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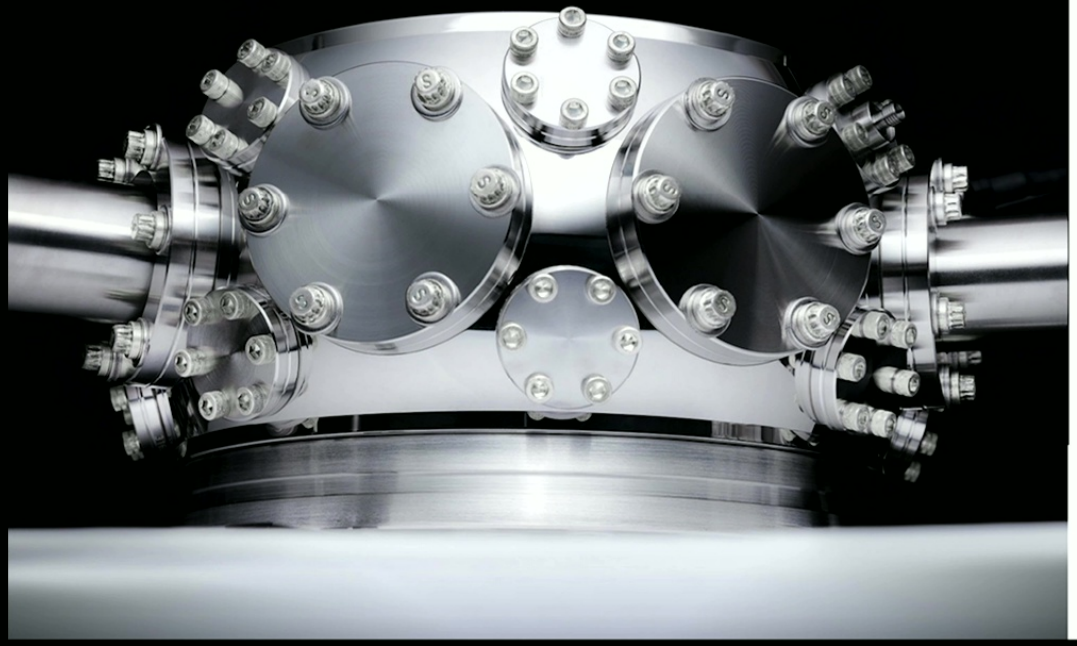
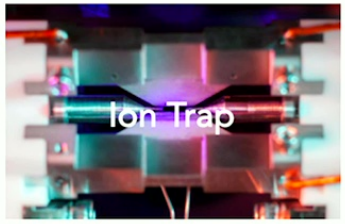
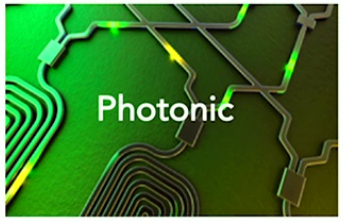


TKET

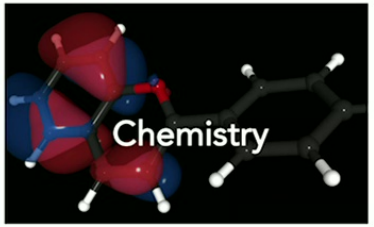
The Leading Quantum Software Development Kit

CONNECTING THE QUANTUM WORLD





(tket) CQ



578,652 downloads as of today

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AVAILABLE BACKENDS

	(tket) CQ	aws	Azure	Qiskit	Cirq
IBM	✓	✗	✗	✓	✗
Cirq Simulators	✓	✗	✗	✗	✓
D-Wave	✗	✓	✗	✗	✗
AQT	✓	✗	✗	✓	✓
Quantinuum	✓	✗	✓	✓	✗
Rigetti	✓	✓	✗	✗	✗
Microsoft QDK	✓	✗	✓	✗	✗
Quantum Circuits	✗	✗	✓	✗	✗
ProjectQ	✓	✗	✗	✗	✗
Qulacs	✓	✗	✗	✗	✗
IonQ	✓	✓	✓	✓	✓
OQC	✓	✓	✗	✗	✗

(tket) also runs on ColdQuanta and IQM

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COMPILATION TASKS

CIRCUIT OPTIMIZATION

Preserve semantics and make smaller

+

SOLVE CONSTRAINTS

Alter the form to meet the restrictions of the backend

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OPTIMIZATION: REDUCE GATE COUNT

PEEPHOLE OPTIMIZATION

Local graph rewrites

Pattern-replacement

Optimal 1q and 2q subcircuits

Commutation- and basis-invariant Clifford reduction

MACROSCOPIC OPTIMIZATION

Resynthesis

Product formula optimisation (e.g., Trotterised Pauli operators, UCCSD)

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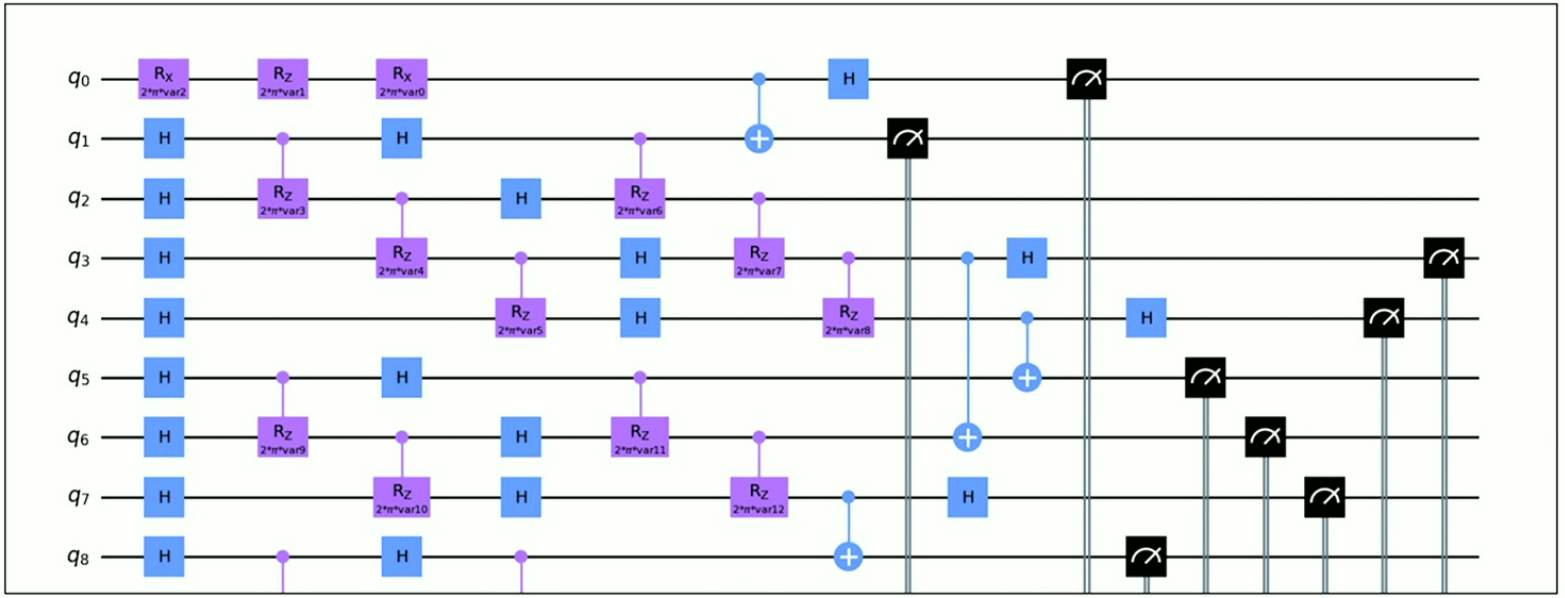
QUANTUM CIRCUITS



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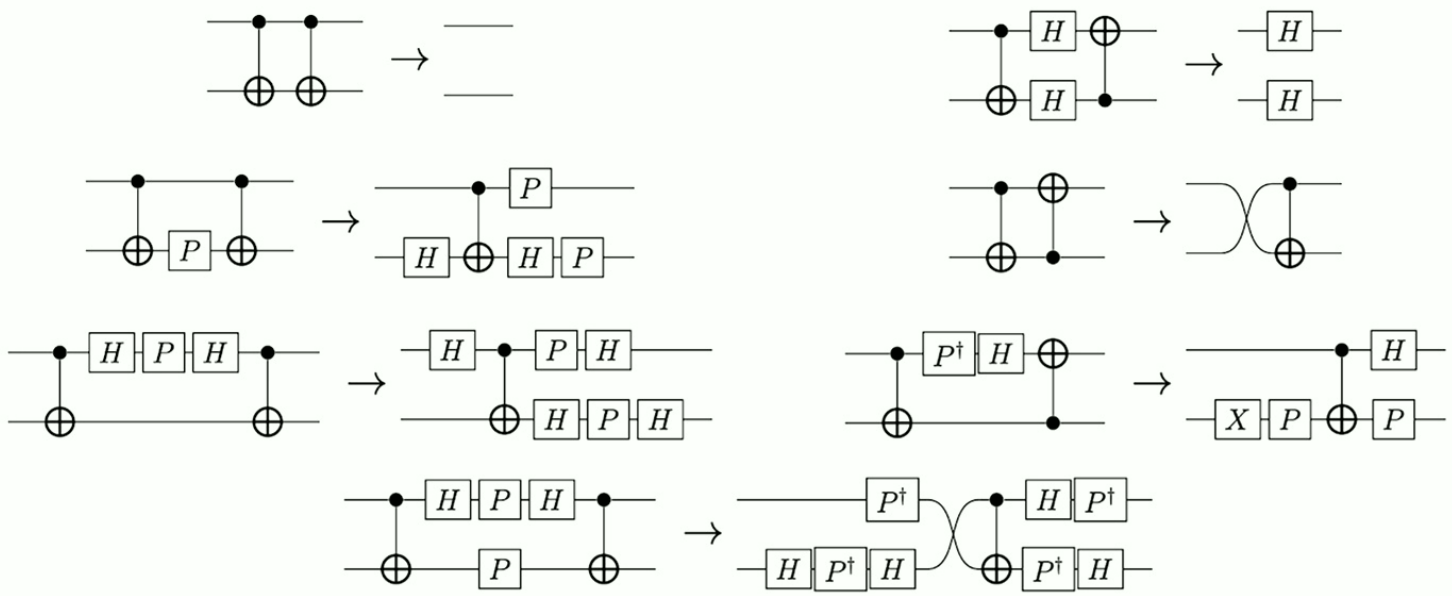
EXAMPLE CIRCUIT OPTIMIZATION



- For more technical detail see arXiv:2003.10611

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SOLVING CONSTRAINTS

QUBIT MAPPING AND ROUTING

Map logical qubits to physical and solve for connectivity constraints

TRANSLATION

Match target language/gate set

DELAYING MEASUREMENTS

Push measurements to final layer if mid-circuit measurements are not valid

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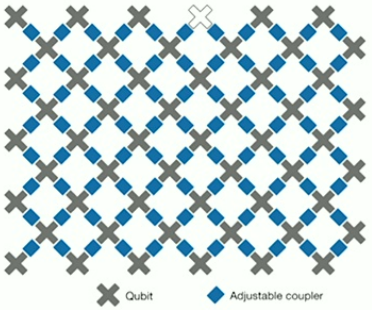
QUANTUM HARDWARE ARCHITECTURES

SYCAMORE

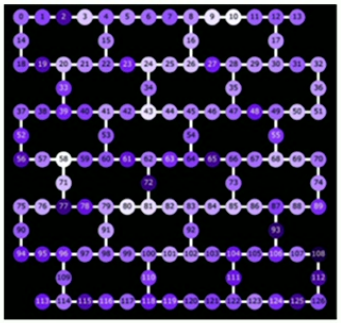
Google



Basis Gates:
CZ, PhasedX, RZ

EAGLE

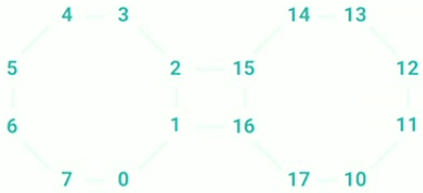
IBM



Basis Gates:
CX, ID, RZ, SX, X

ASPEN

rigetti



Basis Gates:
CZ, RX, RZ

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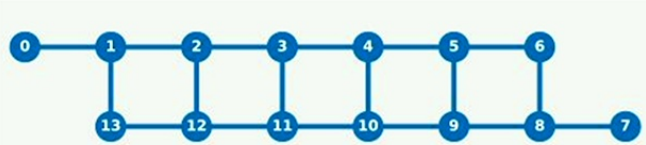
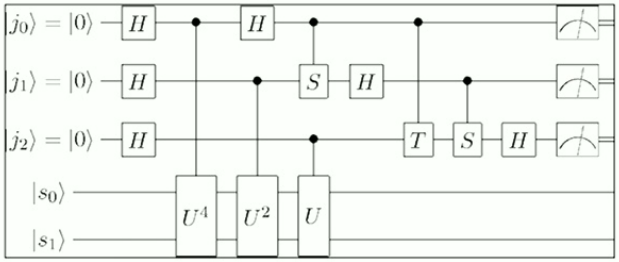
EXAMPLE ROUTING PROBLEM

IBM MELBOURNE



4 qubit coupling max

QUANTUM CIRCUIT



5 qubit coupling

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ROUTING

PROBLEM

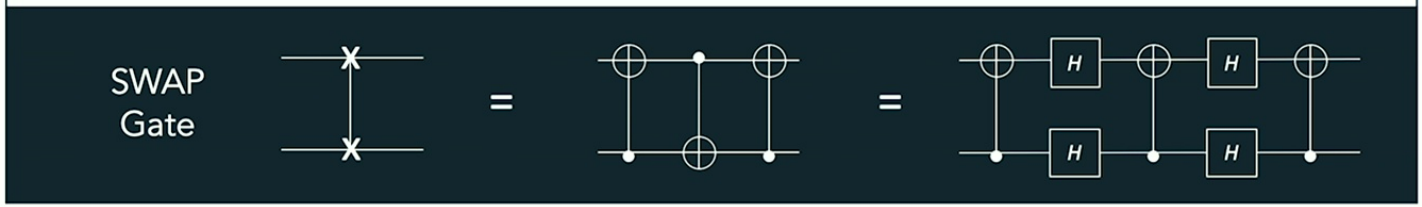
At each time step a pair of qubits need to interact but are not adjacent.

SOLUTION

Insert SWAP operations to move them closer together.

Very expensive! Need to do this optimally.

Difficult combinatorial problem — NP-hard.



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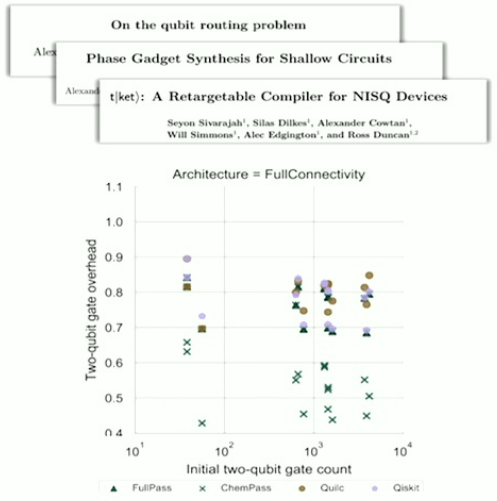
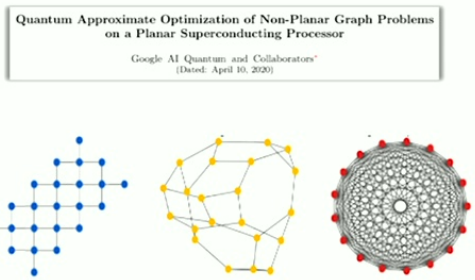
PUBLICATIONS USING TKET



TKET performance is continuously and extensively benchmarked, consistently outperforming competitors



"…the number of two qubit operations is roughly quadratically reduced"

Used by major NISQ hardware vendors to significantly boost quantum algorithm performance [see Google's latest Paper]

IBM

"Tools leveraging the Qiskit transpiler infrastructure, that refine quantum circuits for increased performance on specified devices"

CERN openlab

TKET is used by leading research institutions and corporations tackling real-world problems on NISQ devices

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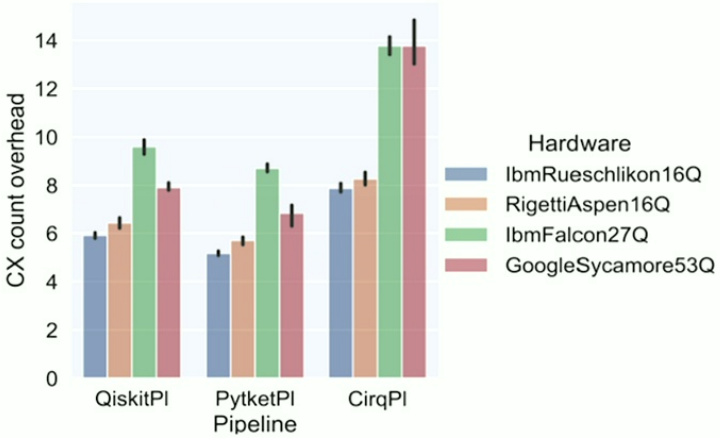
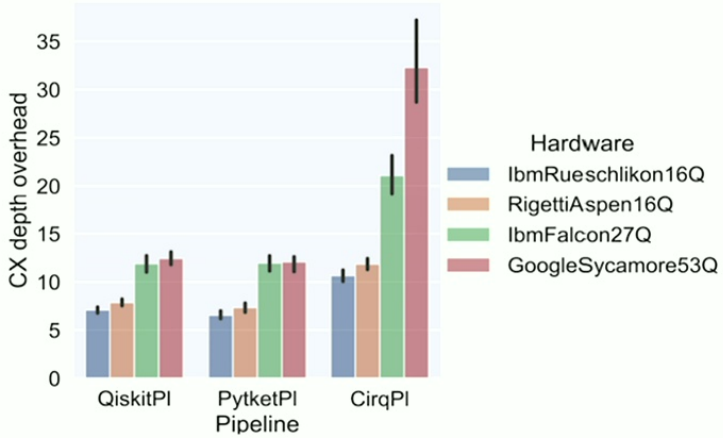
BENCHMARKS





Arline Compiler Benchmarks, March 2022,
`https://github.com/ArlineQ/arline_benchmarks`

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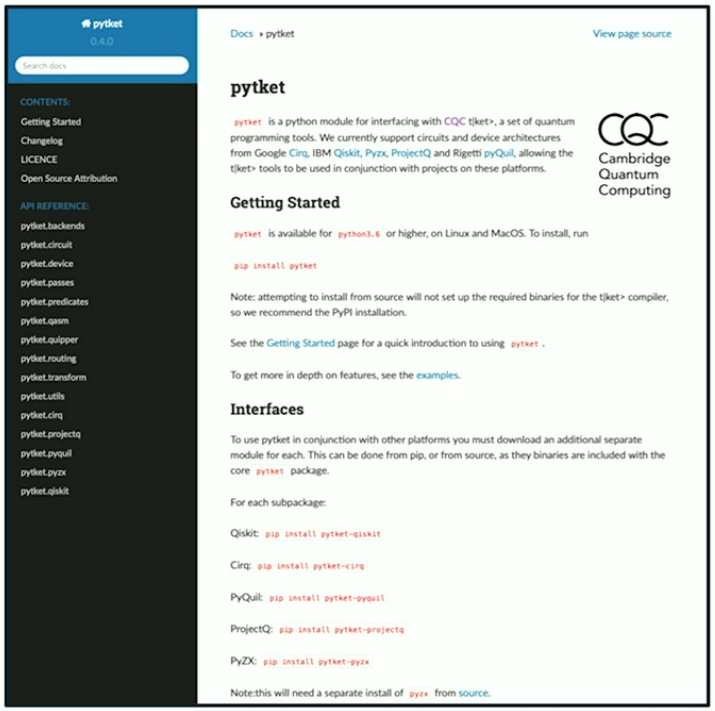
INSTALLING TKET



- Free and available at

  `https://gitub.com/CQCL/pytket`

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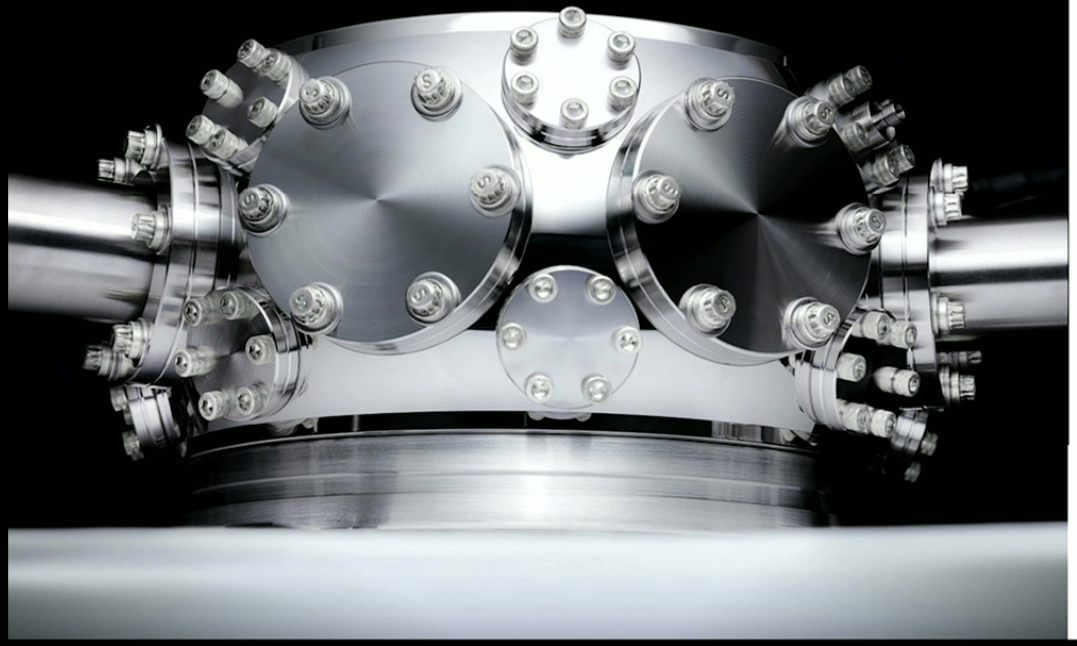


SOFTWARE

Commercially-ready Quantum Applications

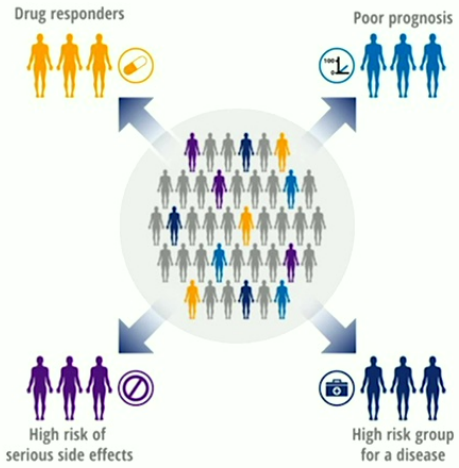
MULTI-GENE BIOMARKER DISCOVERY

Using genetic biomarkers to predict drug responses within patients

- Preclinical drug efficacy correlates poorly with real clinical outcomes, particularly in oncology.
- Predictive biomarker analysis could improve outcomes but is computationally expensive.
- CQ is developing state-of-the-art quantum machine learning methods for bioinformatics.
- The focus is on deriving insight from the analysis of genetic data to identify cancer treatment biomarkers and drive the next generation of bioinformatics.
- This will improve oncology drug efficacy predictions, and ultimately patient care and outcomes.

JSR Life Sciences

CrownBio



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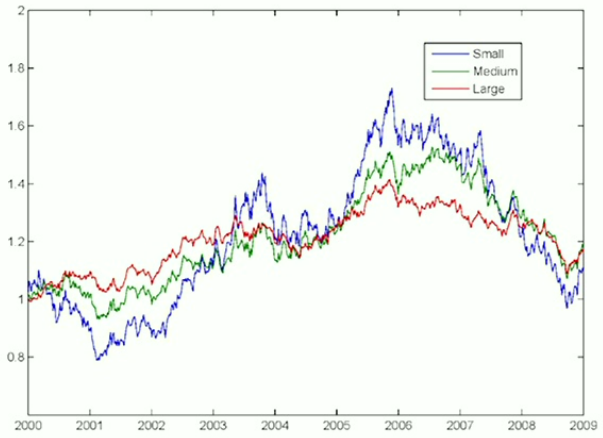
QUANTUM MACHINE LEARNING

Better models for prediction and reasoning

- Monte Carlo is nothing but a way to use randomness in order to solve a deterministic problem
- Quantum Monte Carlo is quadratically faster, as confirmed by our scientist Steven Herbert
- We have applied this toward financial forecasting, synthetic data generation, decision support system



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MANUFACTURING OPTIMIZATION

Job shop scheduling optimization for steel manufacturing

NIPPON STEEL

- Production scheduling optimization is essential to the steel industry in order to manufacture a diversified product line from a limited number of resources while minimizing equipment downtime.
- However, scheduling optimization is an NP-hard problem and classically intractable.
- CQ developed methods to efficiently express our Nippon Steel's problem and identified sources of quantum advantage. The work led to the development and implementation of a new algorithm.
- CQ also compared solver algorithm performance across different hardware architectures (ion trap, superconducting).
- The developed methods could be applied to large scale optimization tasks in the future across steel manufacturing and distribution.

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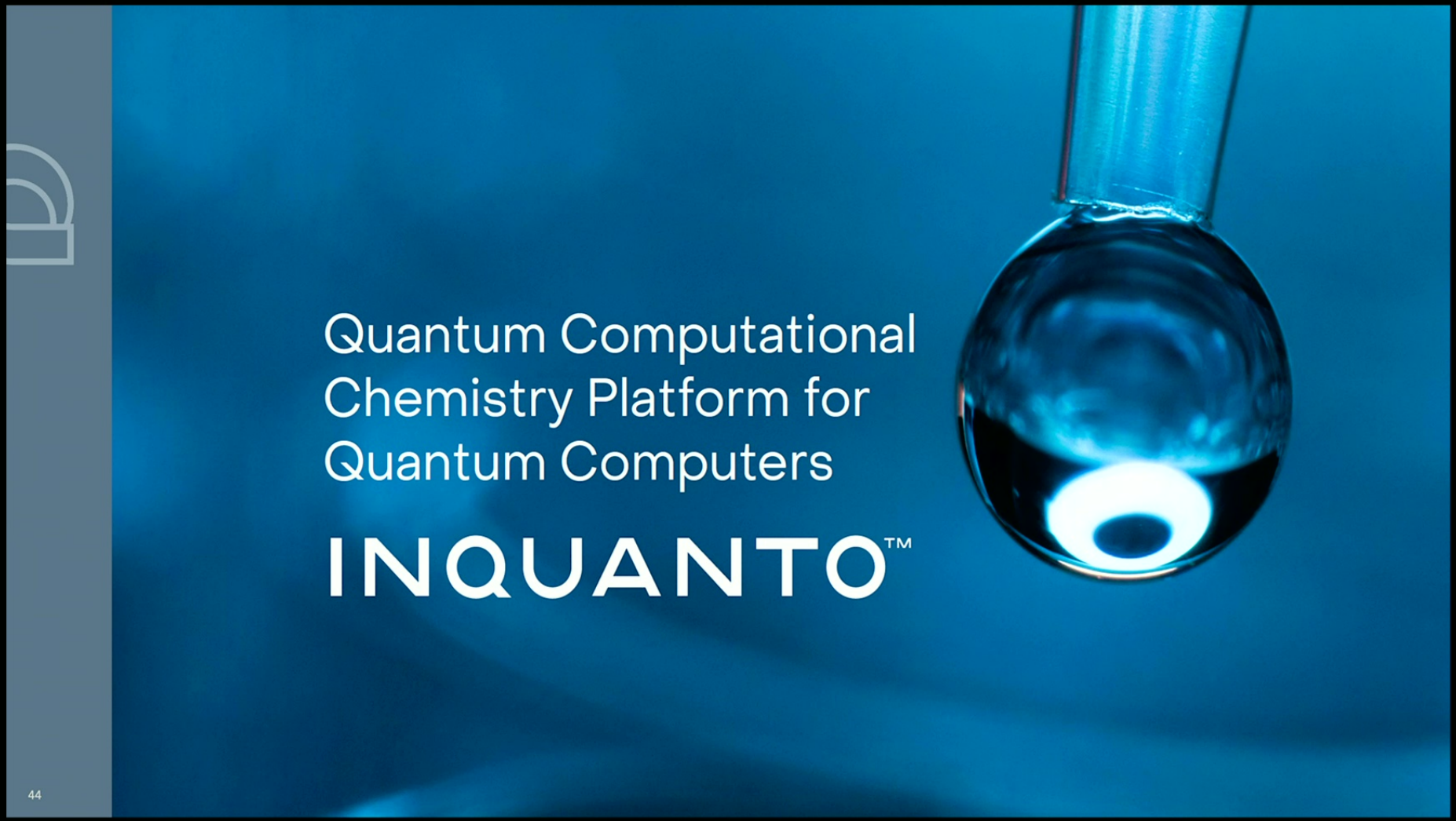
Quantum Computational
Chemistry Platform for
Quantum Computers
INQUANTO™
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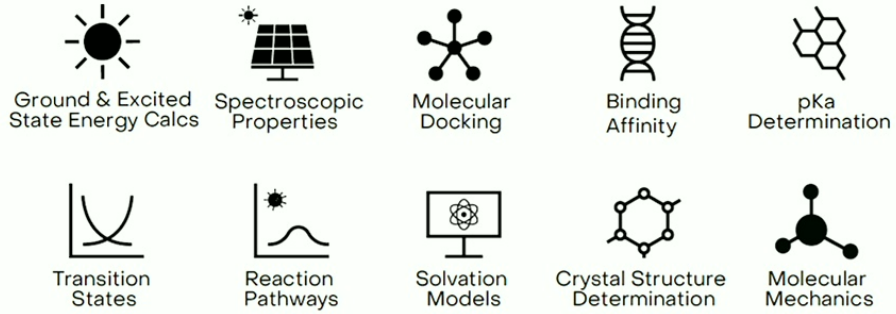
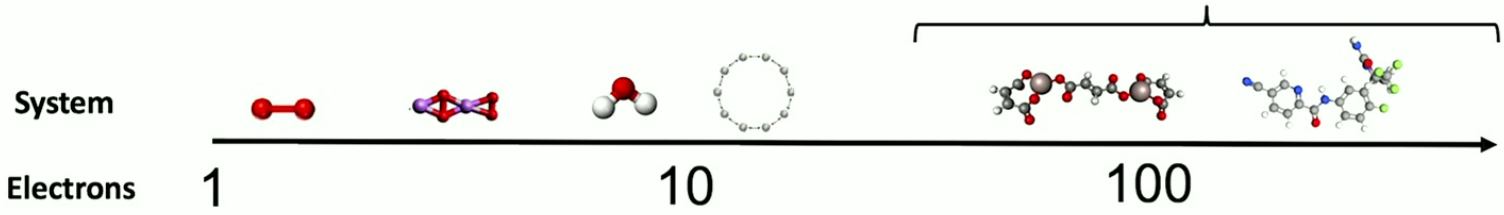
THE FIRST ENTERPRISE GRADE QUANTUM CHEMISTRY DEVELOPMENT PLATFORM



Tackle Industrially Relevant Systems Using NISQ Resources



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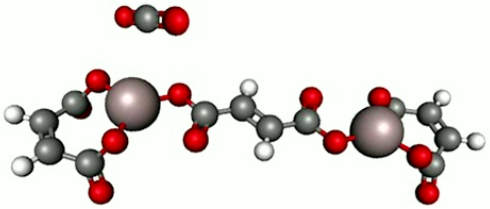
R&D COLLABORATIONS

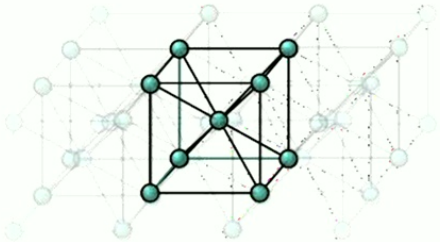
TotalEnergies



Modelling Carbon Capture On Metal Organic Frameworks

arxiv.org/pdf/2203.15546.pdf

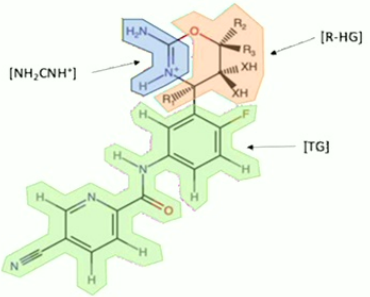
NIPPON STEEL



Modelling Iron Crystals With Novel Noise Mitigation

arxiv.org/pdf/2109.08401.pdf

Roche



Quantification of Protein-Ligand Interactions

arxiv.org/pdf/2110.08163.pdf

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CYBERSECURITY THREATS

This is especially key for organizations that have data with a value lifespan of 5+ years

Quantum computers will break RSA

"Decrypt-later" attacks have already begun

Existing keys are not quantum-proof

Organizations moving to the cloud but want BYOK

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4 GUIDING PRINCIPLES FOR KEEPING YOUR DATA SAFE

- Use perfectly unpredictable keys – Perfect Randomness
- Don't trust. Prove your keys are perfect and private – Certifiable Randomness
- Generate keys that are quantum-proof – Quantum safe algorithms
- Maintain control of the foundations used for encryption – Cloud Strategy

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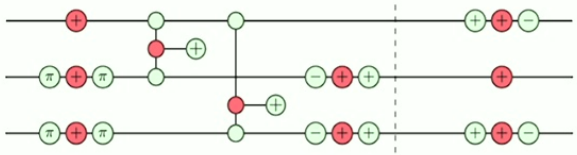
GENERATING QUANTUM-ENHANCED ENTROPY



Quantum Computer

Bell Test

Imperfect RNG

Randomness extractors

Final Output

Quantum-enhanced entropy

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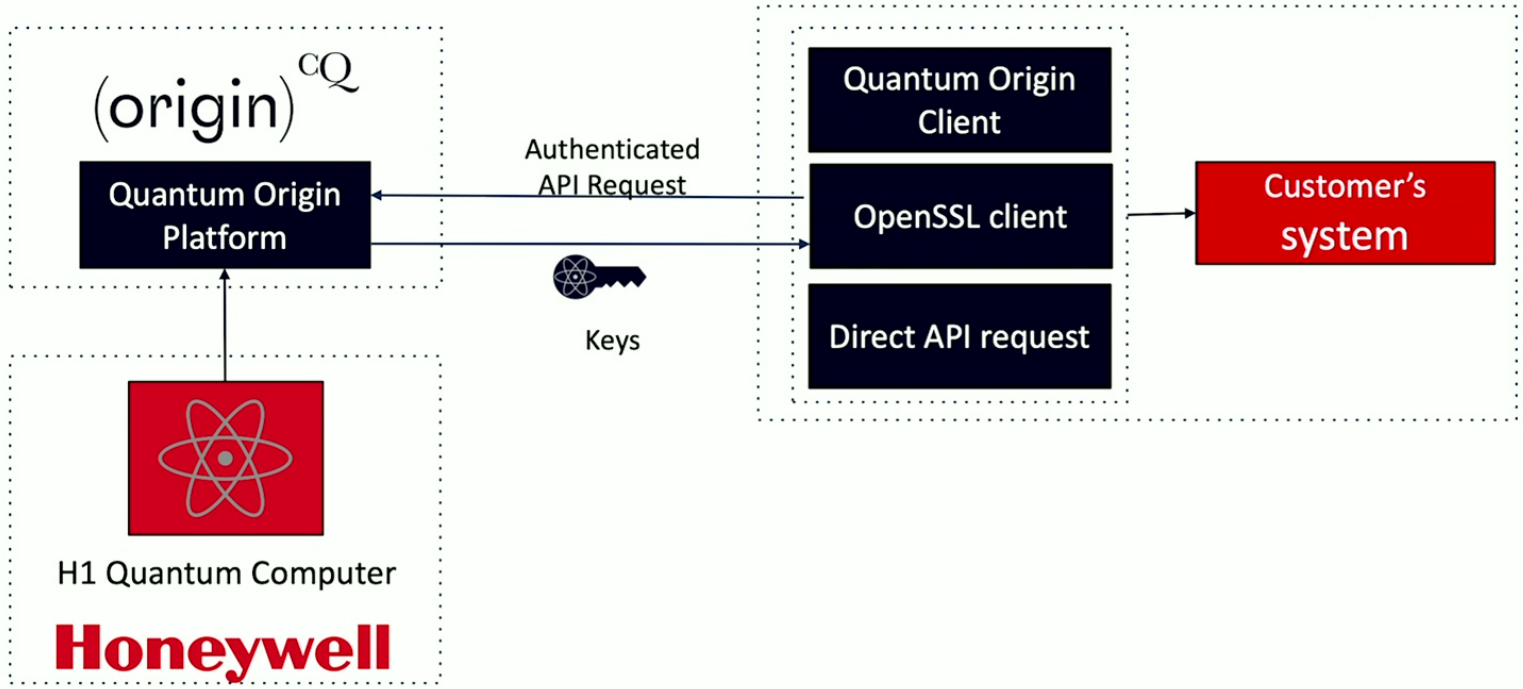
ORIGIN SYSTEM DESIGN OVERVIEW



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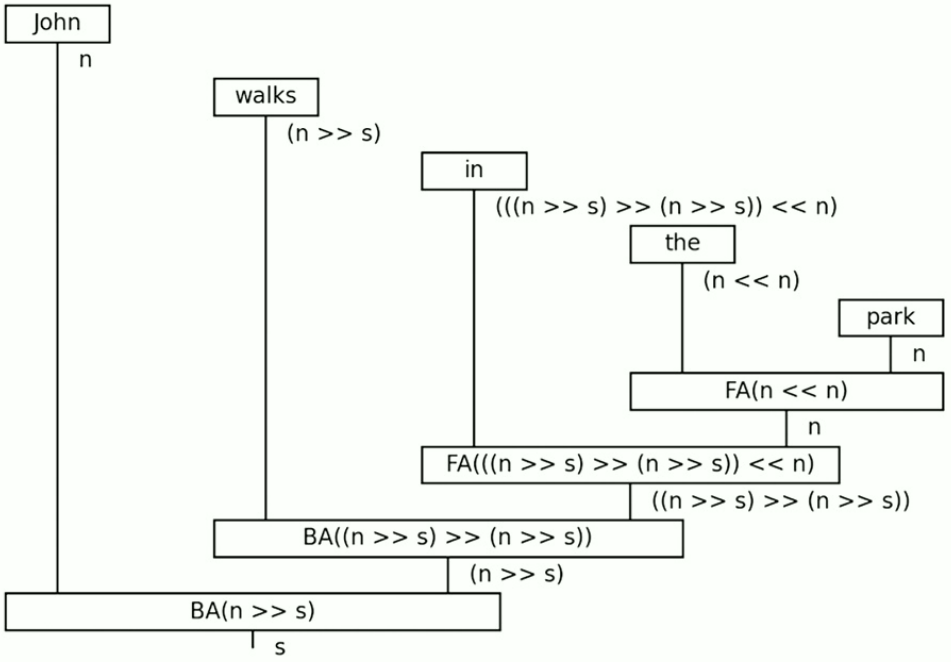
sentence → **parsing** → syntax tree → encoding → string diagram → rewriting → rewritten string diagram → parame-terisation → quantum circuit / tensor net → optimisa-tion → task-specific output



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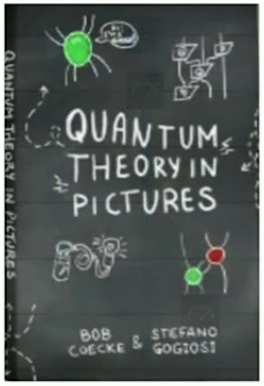
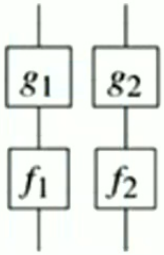
QUANTUM-**COMPOSITIONAL INTELLIGENCE**

- Quantum-compositional reasoning
- Diagrammatic reasoning
- Implications for society
- Implications for intelligent systems design



$$(g_1 \otimes g_2) \circ (f_1 \otimes f_2) = (g_1 \circ f_1) \otimes (g_2 \circ f_2)$$

versus



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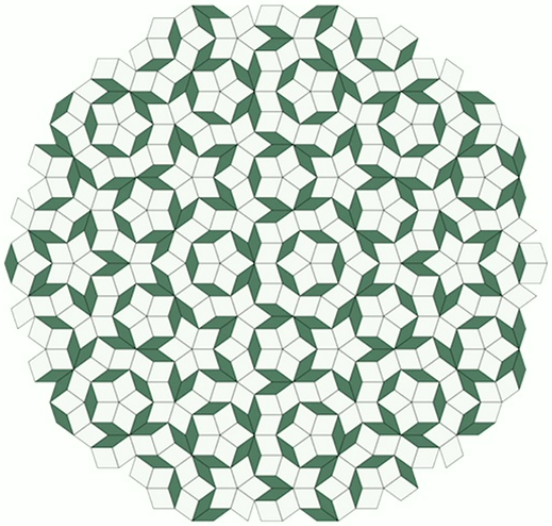
NEW PHASE OF MATTER

FLATIRON INSTITUTE

SIMONS FOUNDATION

- Strange New Phase of Matter created in Quantinuum's H1 machine acts is structured but not periodic
- By subjecting a quantum computer's qubits to quasi-rhythmic laser pulses based on the Fibonacci sequence, physicists demonstrated a way of storing quantum information that is less prone to errors
- Collaboration with Flatiron Institute's Center for Computational Quantum Physics in New York City



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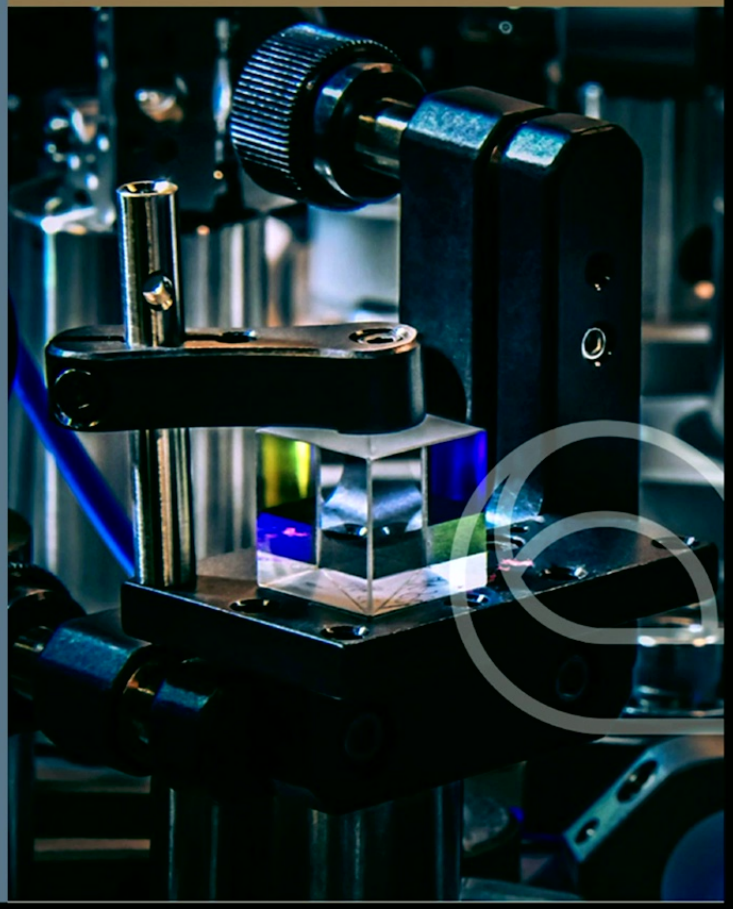

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