Q2B

2017

A Reconfigurable Quantum Computer

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Quantum Computing for Business
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IONQ

IonQ Highlights

Full Stack Quantum Computing Company

Venture Capital Backing from NEA, Google Ventures, Amazon

Spinoff from Duke and University of Maryland

Industry Leading Team in Trapped Ions

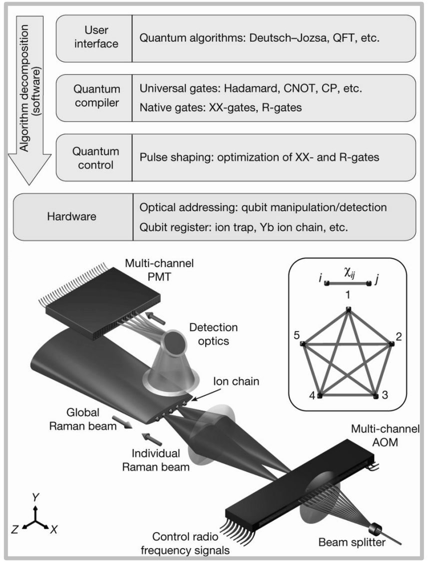
Proven Technology Operating Today with >50 Qubits

Qubits: The Challenges

- Stable, well-characterized physical system
- Ability to implement all “computing operations”
- $f(x)$ Efficient algorithm execution
- Scalable beyond individual modules

IonQ: Demonstrated Full-Stack Solution

Fully-Functional Proof-of-Concept Quantum Computer



THE WALL STREET JOURNAL.

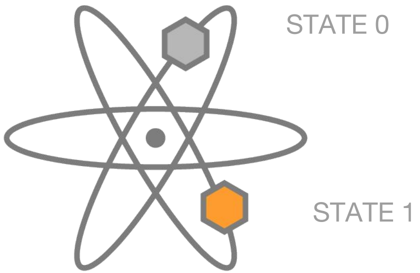
"The work represents a leap in the field of so-called quantum computers"

"The new prototype…is a step in that direction – a 'very clear demonstration of flexible programmability and universality on a single hardware platform'"

"Previous attempts have made strides toward, but haven't quite achieved, such versatility"

Ions: Nature's Qubits

Each ion stores a qubit as a simple two-state system

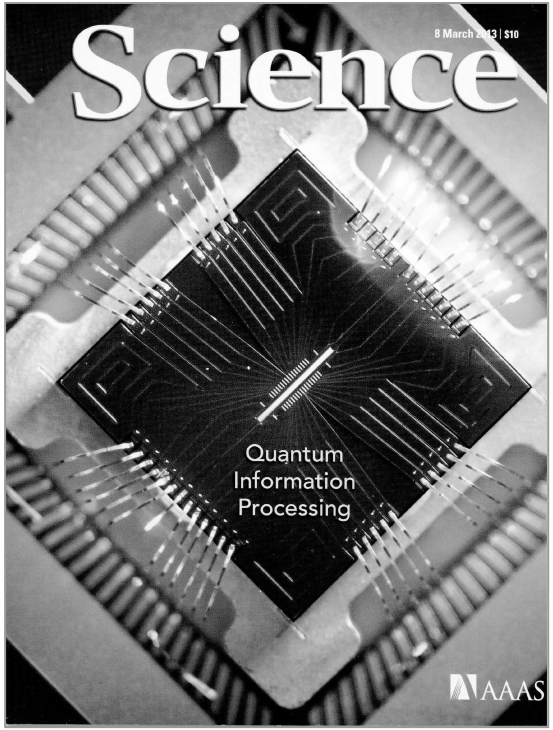


Ions make impeccable qubits

- Fundamentally quantum
- Inherently identical & immutable
- Highest demonstrated performance

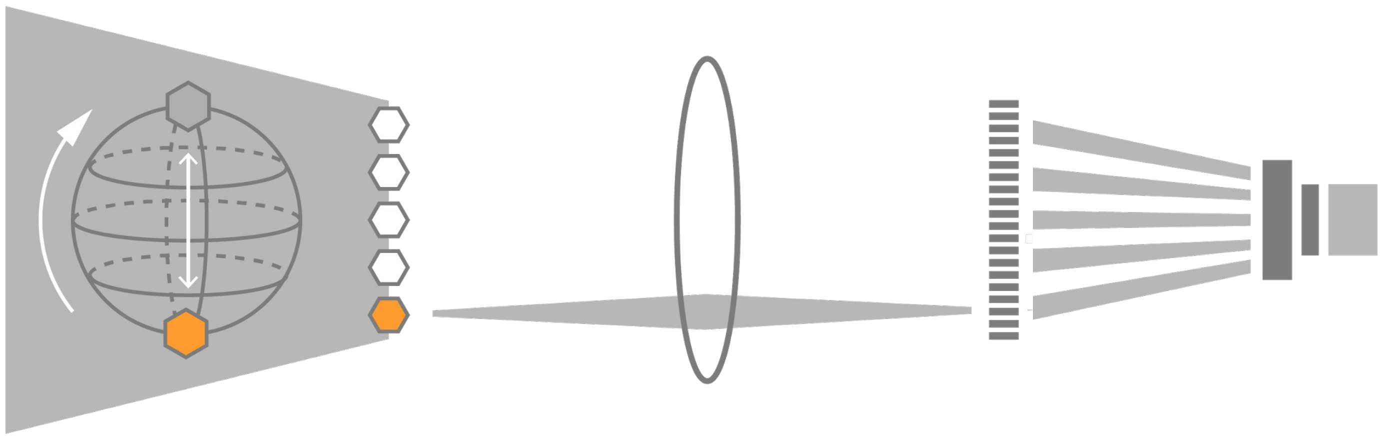
Ions are "trapped" by classical electric fields in a vacuum

- Perfect isolation using Si technology
- Programmable and reconfigurable
- At room temperature



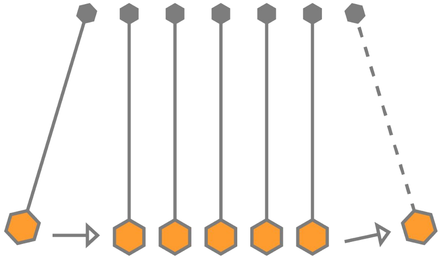
Ion Qubit Computation

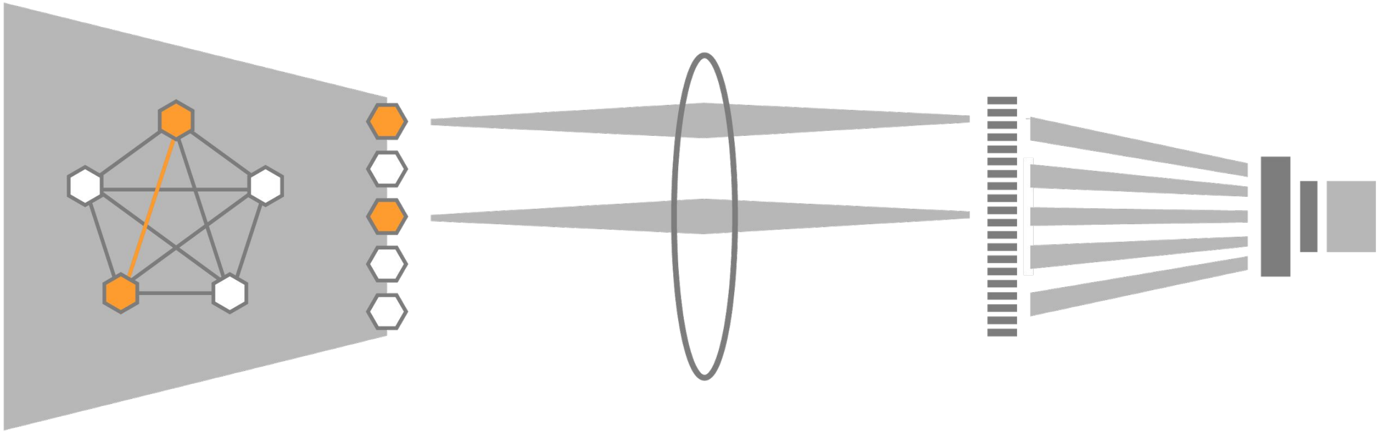
Laser beams are used to manipulate ion qubits
(i.e. prepare *any* qubit state)



Ion Qubit Computation

Laser beams can also perform logic operations between qubits (e.g. manipulating pairs of ions)





Ion Qubit Computation

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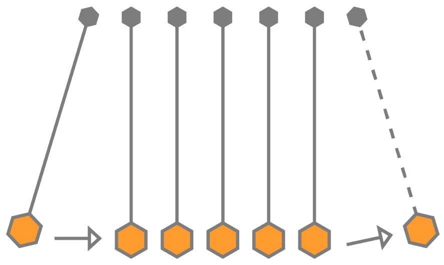
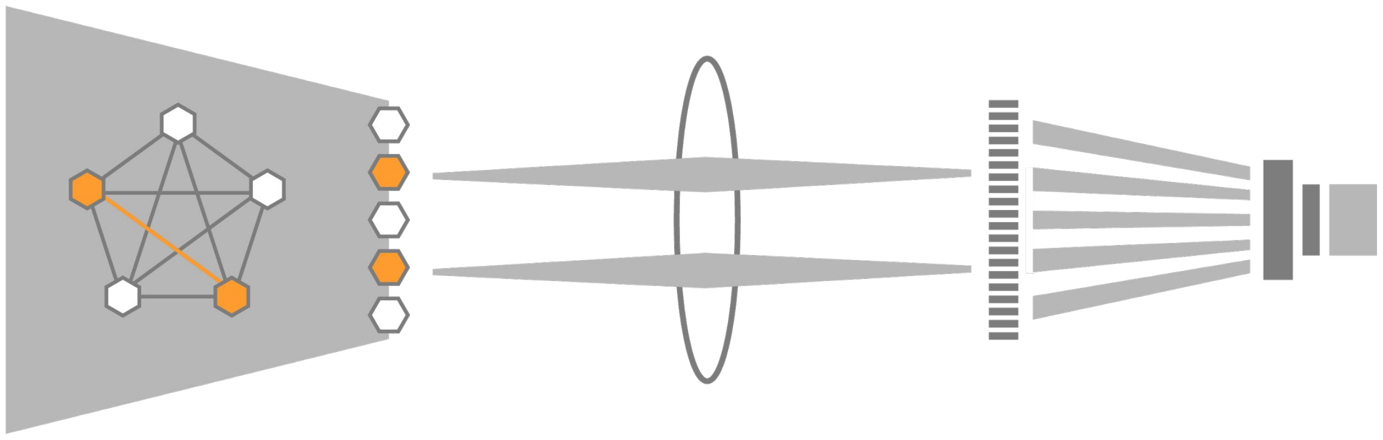
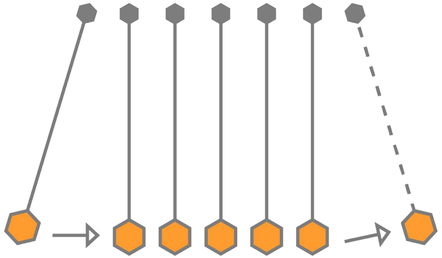
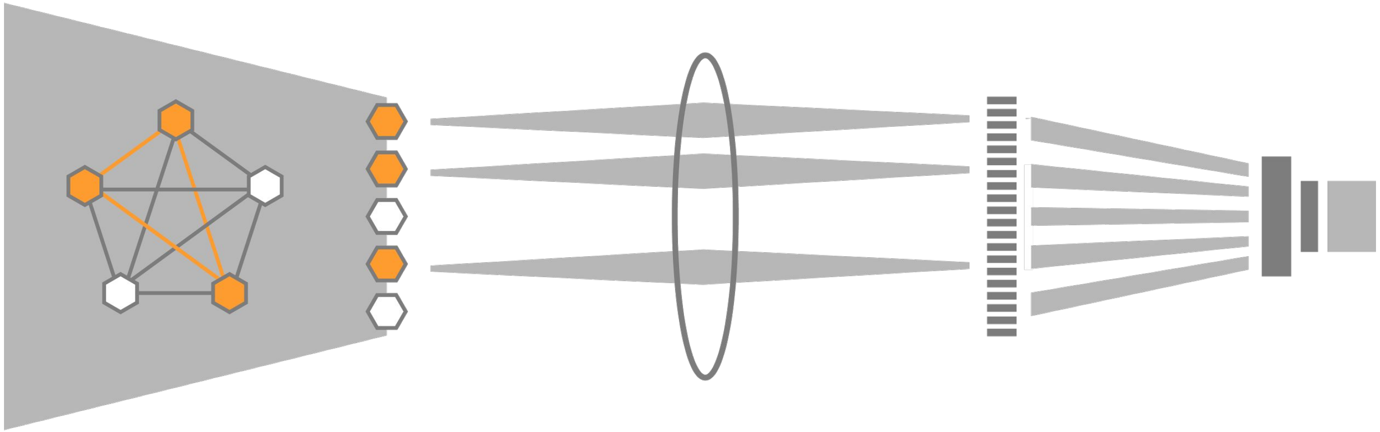




Ion Qubit Computation

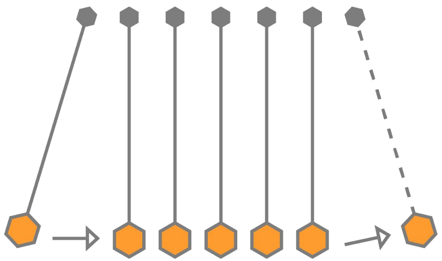
This also allows multi-qubit gates, e.g.
3-qubit gates...

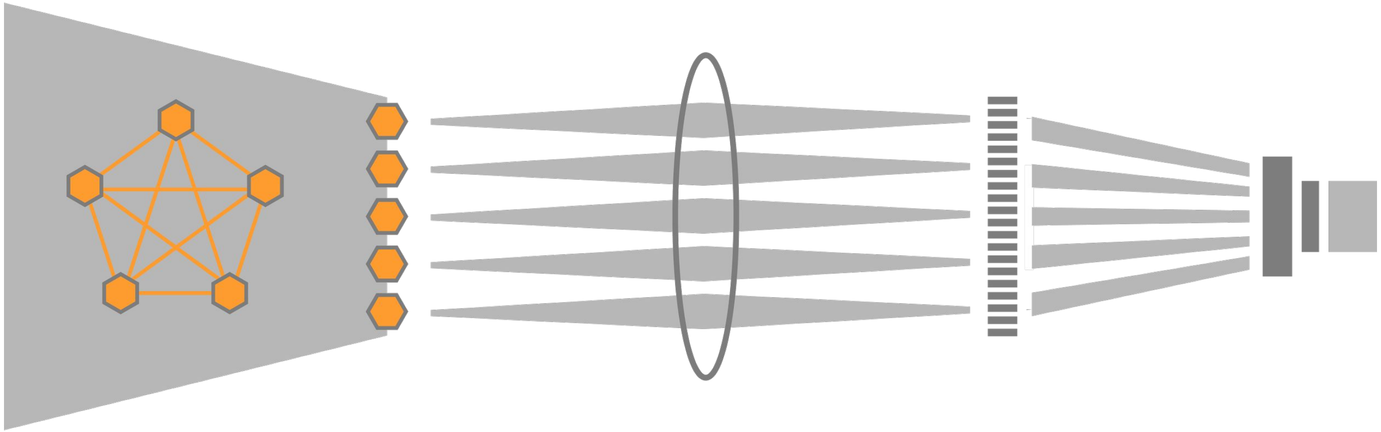




Ion Qubit Computation

...and N-qubit gates!



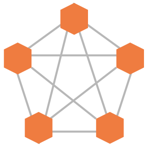


IonQ vs Alternatives

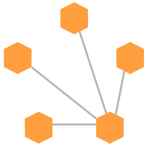
System

Connectivity

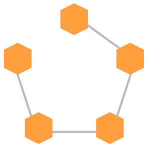
TRAPPED IONS
Fully Connected



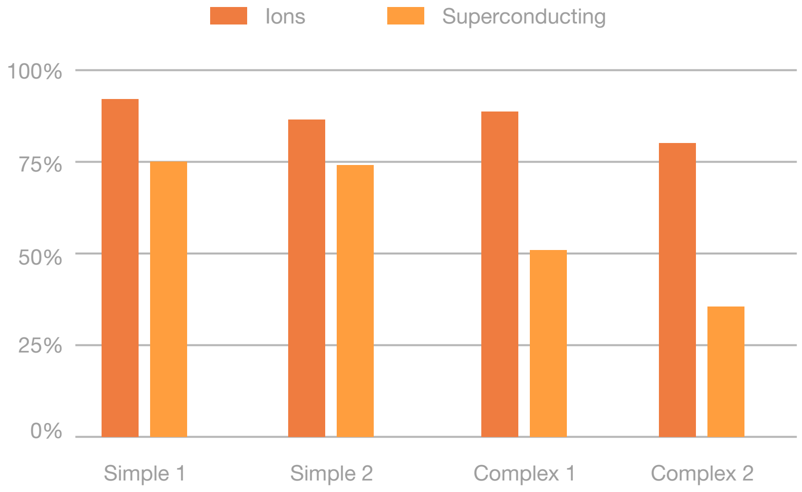
Superconducting Loops
Star Connected



Superconducting Loops
Adjacent Connected



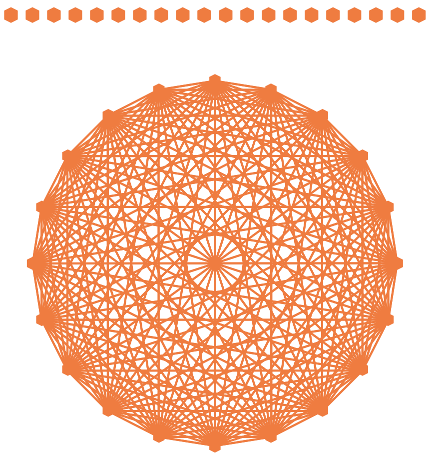
Algorithm Success Probability*

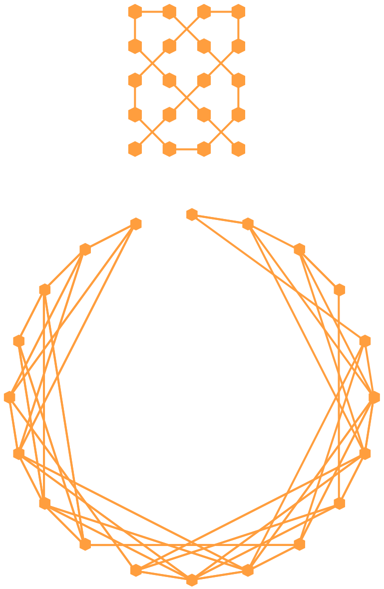


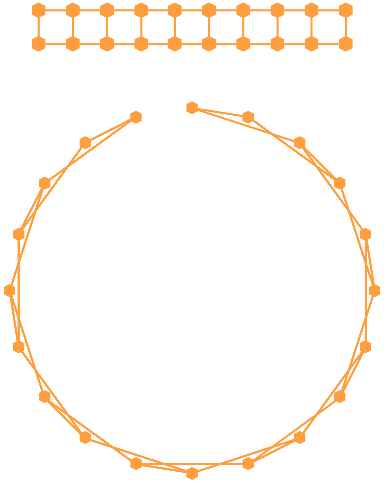
*2017 Proceedings of the National Academy of Sciences, "Experimental Comparison of Two Quantum Computing Architectures"

Connectivity Matters

Not all 20-qubit systems are created equally.







Fully Integrated System

Vertically Integrated

Software
Program,
Control, UX

- Focused development on “Quantum OS”
- Quantum-computing programing language and compiler
- Customer-optimized user interface
- Hardware control system

Hardware
Controlling
Qubits

- Fully Connected System
- High Fidelity Qubit Hardware
- Lab-scale Prototype: Today

Software Strategy

Simple | Elegant, Easy-to-use, Approachable API and SDK

Extensible | Evolving Domain-Specific Libraries

Manageable | All the Benefits of a Cloud-based Service

Powerful | Unmatched Tools, Simulation and Hardware

Flexible | Developer-first, Developer-friendly

Cloud Integrated Development Environment

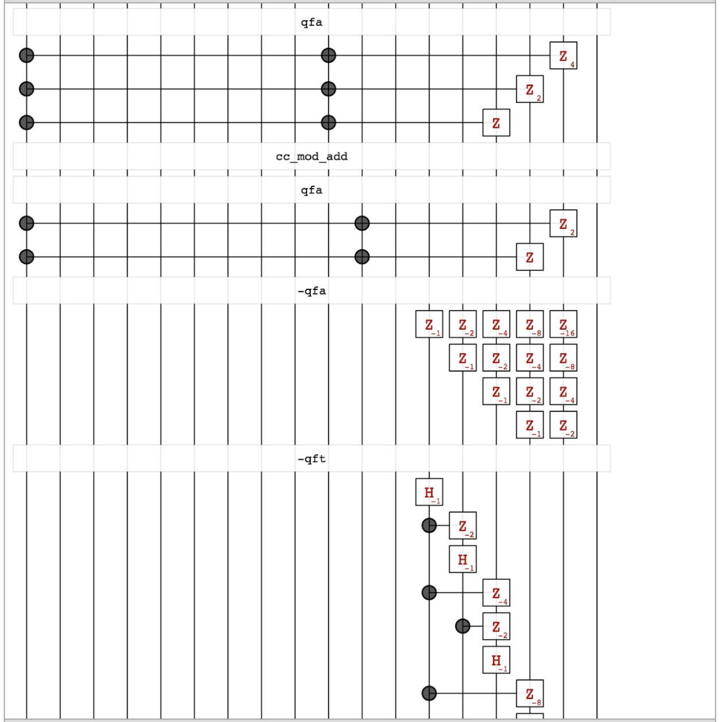
Shor's Factoring Algorithm

new edit list - +

```
set semiprime 16723
set seed 2
set L (floor(log(semiprime)/log(2)+1))
set gl_bandwidth (2*L)

label (L)

alloc reg_cont[(2*L)]
alloc reg_wkspI[(L)]
alloc reg_wkspII[(L+1)]
//alloc overflow[1]
alloc aux[1]

seq qft [register] nq bandwidth
    loop ntarg (nq-1) 0 -1
        op h register[ntarg]
        if (ntarg>0)
            loop ncont (ntarg-1) (0)
                if ((ncont-ntarg)<=bandwidth)
                    set ang (2**(ntarg-ncont))
                    op z register[ntarg] register[ncont] (ang)

seq qfa [register] nq addend bandwidth
    loop bit_add (nq-1) 0 -1
        if (floor(addend/2**bit_add)%2==1)
            loop ntarg (nq-1) (bit_add) -1
                if ((bit_add-ntarg)<=bandwidth)
                    set ang (2**(ntarg-bit_add))
                    op z register[ntarg] (ang)

seq cc_mod_add [control1] [control2] [register] nq addend bandwidth nc1 nc2
    group controls control1[nc1] control2[nc2]
    cexp  qfa controls register (nq+1) (addend) (bandwidth)
    exp  -qfa register (nq+1) (semiprime) (bandwidth)
    exp  -qft register (nq+1) (bandwidth)
    op cnot register[(nq)] aux[0]
    exp   qft register (nq+1) (bandwidth)
    cexp  qfa aux[0] register (nq+1) (semiprime) (bandwidth)
    cexp -qfa controls register (nq+1) (addend) (bandwidth)
    exp  -qft register (nq+1) (bandwidth)
```

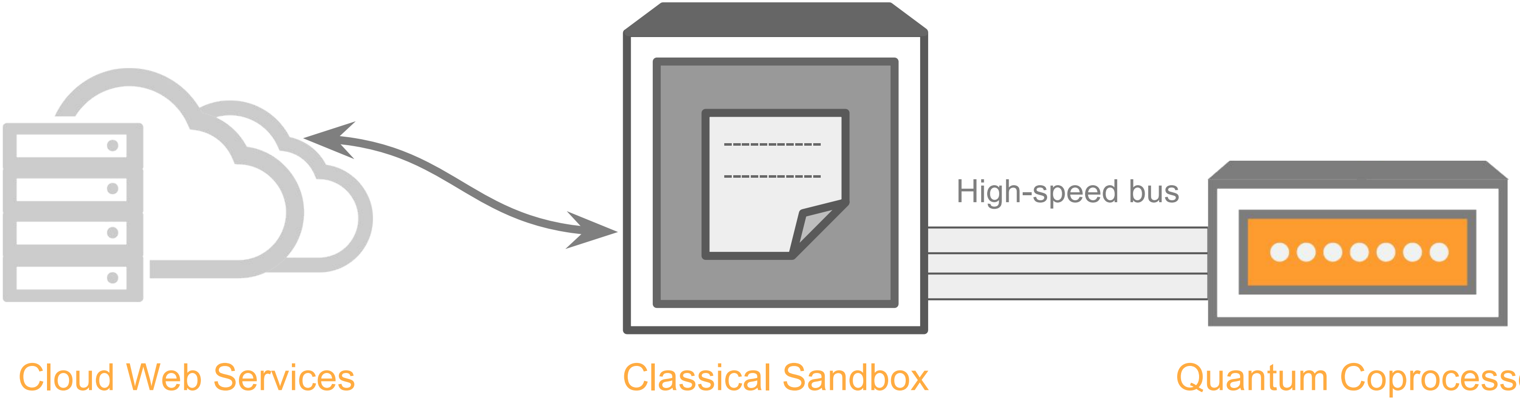
$e^{ix} = \cos x + i \sin x$

update simulate execute jobs - +



2481 1 qubit 3932 2 qubit 768 3 qubit 7181 total gates 3791 circuit depth

Hybrid Computation



Iterative programs are executed in a classical sandbox co-located with the quantum computer.

IonQ Design System

Complete System

Fully programmable, general purpose machine

Supports engaging with a broad set of potential users

Best-in-kind performance on algorithm execution

Compelling roadmap for future scalability

The Full Power of Quantum

IONQ

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