The Future Begins Here
Quantum Computing: A Scalable, Systems Approach
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A Reality Check

- If we had tens of thousands of qubits today... what could we do with quantum computing?
- Hint: What applications could you run on a computer with just a processor?
Quantum Computing: Key Concepts

Superposition
- Classical Physics: Heads OR Tails
- Quantum Physics: Heads AND Tails

Entanglement
- N Quantum Bits or Qubits = $2^N$ States
- 1) 2) 3) 4)

Fragility
- Observation or noise causes loss of information
Changing the World

TIME

“Quantum Will Change Everything”  Feb 16, 2014

Climate Modeling

Travel & Logistics

Cryptography

Drug Design

Financial Modeling
Key system challenges for Quantum Practicality

- New execution model
- Error mitigation & resilience
- Scalability
- Interconnect complexity
- Qubit device design
Qubit Control Processor

- Feeds correct instructions to run algorithm
- Sends info about what pulses to generate/timing
- Generates the pulses to manipulate the qubits

Quantum Runtime

- instruction
- instruction

Qubit Control Processor

- Micro-ops
- Micro-ops

Control Electronics
Quantum Compiler

Compiler takes algorithm and maps & schedules to qubits
Qubit Mapping & Scheduling

3 x 3 square grid – independent control

Logical Schedule

- Hadamard q0
- Move q1, I0
- ControlledZ q1, q0
- Move q1, M1
- SWAP q1, q0
- Move q2, I1
- ControlledZ q2, q1
- Move q2, M2
Noise-Resilient Quantum Algorithms

- Hybrid quantum-classical algorithms are noise-resilient
- Full computer system needs to have hybrid quantum-classical versatility
Materials Design - Application Area

- High-value, real-world use case for quantum computing
- Complex materials simulations - intractable for classical computers
- Workload to understand scaling, resilience and assess performance

High Temperature Superconductivity
Impact of Connectivity on Algorithm Performance

Qubit Connectivity

- Linear
- Ladder
- Grid

Increasing Difficulty to Build

Quantum Fourier Transform

Problem Size (Qubits)

Fidelity

Holmes et al, Quantum Sci Tech 5 (2020), 025009
**Putting it All Together**

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*Q-NEXT brings together nearly 100 world-class researchers from three national laboratories, 10 universities and 10 leading U.S. technology companies with the single goal of developing the science and technology to control and distribute quantum information.*
Summary

- Quantum computers promise dramatic increase in performance
- Intel research focus:
  - Scalability to thousands to millions of qubits
  - All layers of the compute stack
  - Workload-driven co-design
  - Useful Applications
- Quantum Practicality: Large scale, commercial quantum computing
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