Introduction to Quantum Computing

How do different models of physics affect how quickly we can compute?

How would basing computation on a quantum mechanical model rather than a classical mechanical model change our notions of computing?

How quickly does nature allow us to do computation?

A quantum computer has fundamentally different way of encoding and processing information.

Just because a piece of hardware has a certain number of qubits, it is not necessarily a quantum computer. It’s the interconnection between qubits that critical.

Any computation a classical computer can do, a quantum computer can do with roughly the same efficiency.

Like classical algorithms, some quantum algorithms are inherently probabilistic and others are not.

Algorithm efficiency is often determined by heuristic means instead of by strict mathematical formula.

Superconducting quantum processors (Trapped ion, photonic quantum, electron spins, neutral atoms, topological, anyon)

Precision, speed, and generality of the control -> quantum supremacy does not mean useful quantum supremacy.

Optimization, ML, Chemistry, and Materials Simulation.

Cost function C(z), phase separation operator tied to the cost function, driver/mixing operator

AQO (Adiabatic Q Opt), QA (Quantum Annealing), QAOA

Physical demonstration of complex amplitudes polarization.

Classical state spaces combine via the Cartesian product

Quantum state spaces combine via the tensor product (exponential state space)

Eigenvalues are amplitudes and eigenvectors are state vectors

The Continuous Path Towards Quantum Advantage

Katie Pizzolato

IBM Quantum

* 2016 First 5 qubit system on the cloud
* QC have become a research tool (a great pivot for IBM?)
* User base is changing – usage differs based on the type of user
* NISQ, FTQC, Quantum Inspired
* In HPC – what is the time to solution for a problem of interest?
  + QPC – noise free
* Map interesting problems to quantum circuits; run quantum circuits faster on quantum hardware
* Thermal properties and kernel
* Noise-free estimators can be obtained from noisy quantum computers today.
* Scale, quality, speed to push the gamma down.
* 127 Eagle, 433 Osprey
* Gate fidelity, coherence
* QC can offer value before have FTQC

MAP Interesting problems to quantum circuits

Simulating nature (ansatz), mathematics & data with structure,

Find sufficiently difficult circuits -> map them to hardware (circuit knitting, embedding, **entanglement** **forging**, circuit cutting) -> HPC and classical communication between QP will allow quantum advantage to be reached faster. Intelligent orchestration with elastic computing.

Quantum kernels in industry applications – cern openlab, amgen, woodside

**Stuff in the stack that allows experimenters to focus on experiments and their results and not on the overhead. What implications does this have on the pace of innovation and progress towards the sequential deep stack and ancillary goals for industrializing quantum technology. QBLOX.**

HEPLab – Fermilab 🡪 what is the connection between HEPP and QC? Dialing down parameters to go from lots of photons to a single photon. Attacking the problem of “eliminating” quantum decoherence.

Concept of co-design 🡪 develop vertically and horizontally (what does vertical and horizontal axes mean? For example is vertical the physics stack and horizontal the controls to apply to the physics stack?

National Labs 🡨🡪 Industry 🡨🡪 Academia

Synergies to drive ancillary projects while not distracting from prim projects. What are ancillary versus primary projects?

Collaboration between Rigetti and Fermilab (how does this work at a more granular level).

Go back and check the slide containing the decoherence formula. How does other content of the presentation map to the variables in the formula?

How does research, parameters, environment, results that characterizes FermiLabs experiments in the HEPP domain change when you move to the quantum domain? How does knowledge in one domain affect the rate of gains in another domain?

**transmon**

Startup

Quantum Chemistry – quantum algorithms (background in machine learning) Consortium aimed at building end user. Quantum circuit learning. There was as many software issues as there are hardware issue. Government

**New Quantum** (spin out of Cambridge). Quantum network and interconnect $2.5 in G, ($5 / $4). End-to-end in the context of moving standards. Don’t underestimate how tough it is to spin up facilities. Peer-to-peer sharing of facilities. Aware of timeline between product, revenue, and market (15, 7, 3 years). Deep tech is a totally different animal. 40% of HPC is in networking. Is this a potential customer for Entangled Networks?

Building truly scalable QC, secure IP first in the HW domain, logistics problem on the hardware subcomponents. Too optimistic about timelines and may have promised too much (this expectation and bumps in the road is a two-way street). Promised too much, too quickly).

QBlox – Neils CEO/Founder, control electronics and software, NIST milestones, spin IP out of research (raised 8-9, grants, revenue, bootstrapped). Transition from vertically integrated companies to horizontally value chain oriented (system integrators). Larger scale error correction

Qiskit Fundamentals

Chapter 1 Quantum Circuits and Operations

Quantum programs are normally expressed with quantum circuits (class: QuantumCircuit) that contain quantum operations.