Integration of High Performance Computing and Quantum Computing

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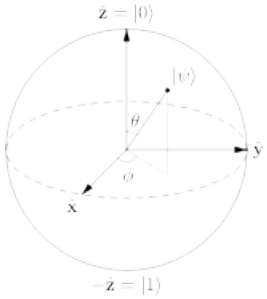
Why Quantum?

- **Fundamentally changes what is computable**
  - **For some problems you need a quantum computer**
    - **Noted by Feynman in 1982**
  - **Some of what was previously intractable is with QC tractable**
    - **Chemistry, optimization, …**
- **Moore's Law is ending**
  - **Quantum computing can help in continuing to increase performance**
  - **QC compute power can scale exponentially with the number of devices**
- **Quantum computing is radically different from "classical" computing**
  - **Thinking fresh and new is necessary**
  - **Can lead to new "classical" algorithms**

Basics



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- Bloch Sphere, graphical representation of the possible states of a qubit
- The state is a superposition of both |0> and |1>
- Superposition can and is exploited in algorithms
- Measurements return the binary state in other words a qubit becomes a bit

- Each measurement get one sample; Multiple samples are needed for full solutions
  - Statistical post-processing is needed

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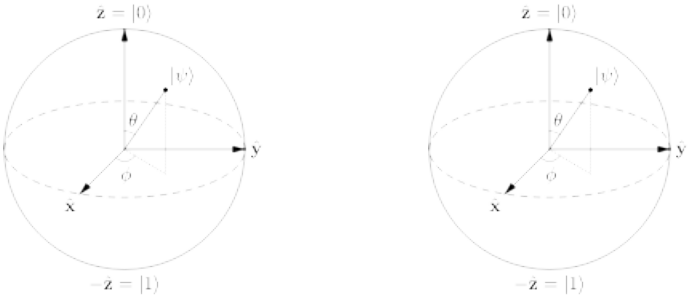

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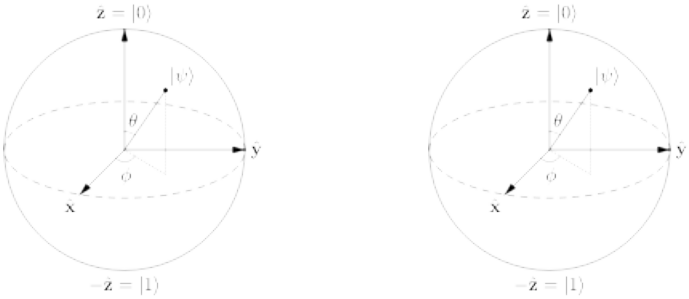

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- Multiple qubits can be combined, entangled
- N qubits means 2^N states; This is the strength of quantum computers
- Algorithms should target exponential problems
- The exact theoretical computational power of quantum computers is debated

- Current systems are NISQ, Noisy Intermediate-Scale Quantum, computers
- Few qubits; Lots of noise; Needs calibration; Can only “run programs” for a very limited time

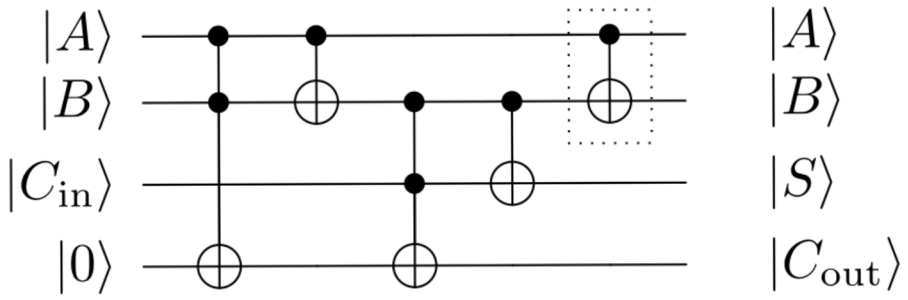
Quantum simulator of physical system

- A quantum system is needed to efficiently simulate a quantum system
  - Noted by Feynman in 1982
- “Lets build an experiment where we use quantum effects to understand another system”
  - Leveraging the intristic quantum nature of quantum computers
- Use the quantum computer as an accelerator for quantum effects!

Types of Quantum Computers

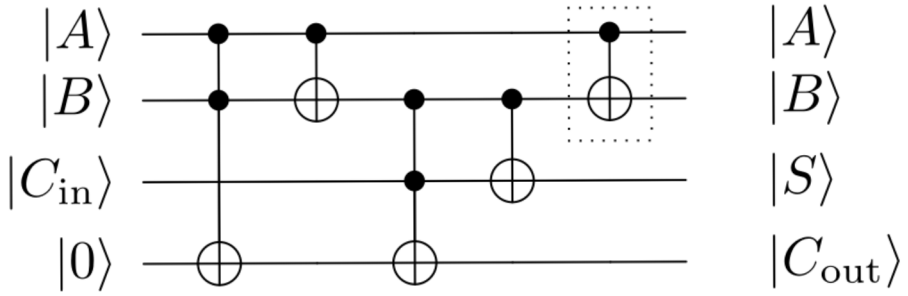
- Many different types of quantum computers exists
  - Simulators
  - Annealers
  - Gate model computers
- All types require a classical host

Quantum Gate Model Systems



- More general quantum computers consists of quantum logic gates forming quantum algorithms
  - Above a quantum full adder

Quantum Emulators



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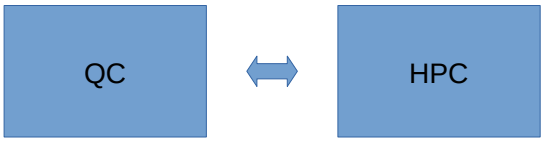
- Quantum algorithms can be emulated in software
  - Though very computationally and memory demanding
- Many quantum emulators exists, too many to be discussed in a short presentation
  - Many algorithm representations exists too
- Software emulators scale to about 34+ qubits; 50 qubits require 16 petabytes of memory

QC and HPC Interplay



- QC is first used as an accelerator of key HPC algorithms

The Challenge

HPC + QC + ? = Success!

- **Open question: How to integrate quantum devices into classical systems.**

- **Software? Programming models? Compilers?**
- **Workflows?**
- **System software? Tools?**
- **Hardware / Software co-design, classical and quantum**
- **Computer architecture?**
- **Hardware integration?**

HPCQC.org

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