Scalability of Quantum Hardware

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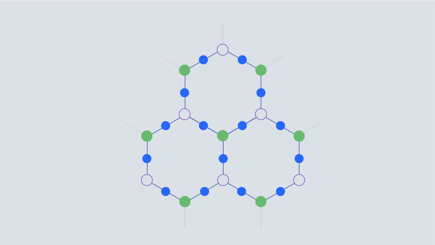
Quantum Computer Scaling

Increasing the number of qubits to allow for more complex calculations, reducing the error in the qubits

Examples of Large Quantum Computers

- IBM Eagle: 127 Qubits $\longrightarrow$ Cleveland Clinic and freely avaliable on IBM Quantum
- IBM Osprey: 433 Qubits $\longrightarrow$Announced 2022, not fully released
- IBM Condor: 1,121 Qubits $\longrightarrow$Announced 2023, not fully released
- Atom: 1,125 Qubits $\longrightarrow$Announced 2023
- IBM Heron: 156 Qubits
  - Faster than Condor, even with fewer qubits (high performance quantum computer)
  - First computer on IBM Quantum System Two (modular quantum computing!)

Why 127 Qubits? Heavy Hex Lattice



* Decreases errors from neighboring qubits, each qubit is connected to 2-3 others

Scale?

- How many bits can be encoded in 1,121 qubits?
- Convert that to terabytes...
  - Multiply by 1.12e-13
- So what is the problem?

Physical vs. Logical Qubits

- Physical qubits are the number of qubits physically built on the chip (IBM Eagle as 127 physical qubits)
- Logical qubits are groupings of qubits which function as a single qubit but in such a way that noise and error are minimized
  - NISQ Computing $\longrightarrow$ Fault-Tolerant Quantum Computing
- Number of physical qubits needed to create a logical qubit varies, but reduces the compuing power significantly

Realistic Quantum Computing Power

- Breaking a 2048 bit RSA encryption requires 20,000,000 physical qubits in the NISQ era (best case with an optimized algorithm)

Quantum Volume

- Single number that measures a quantum computer's overall performance
  - Number of qubits is a factor, but so are errors, connectivity, etc.
- Larger volume means the computer can handle larger algorithms
- Example: IBM Falcon; 27 qubits, 512 quantum volume

Issues with Scalability

- Quantum Errors
- Quantum Error Correction
- Interconnectivity Challenges
- Cooling and Control Systems

Quantum Errors And Quantum Error Correction

- More qubits, more control systems, more room for error to be introduced into the system
- Logical qubits are made from many physical qubits and gates $\longrightarrow$ room for extra noise

Interconnectivity Challenges; Cooling and Control Systems

- All quantum computers need to operator at super cold temperatures
  - Most need to operate at the milliKelvin - microKelvin range
- Adding more qubits means adding more control systems that need to be cool
- Each new qubit needs an several systems to control and measure it, space on chips is limited.

Improvements for Quantum Scaling

- Possible Research Avenues for Improvement
  - Qubit Design
  - Advances in Error Correction Techniques
  - Quantum Architecture Optimization
    - Readout multiplexing: do not need control and readout electronics for every qubit