qLearn Week 10: Quantum Error Correction

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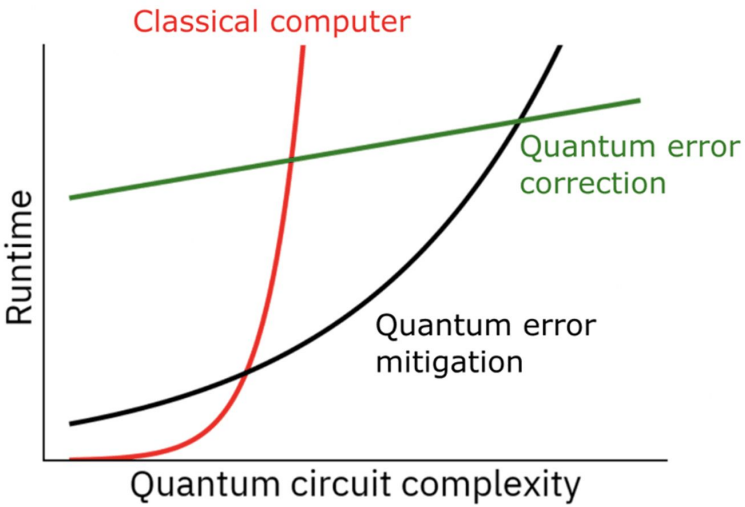
Classical Computing Errors

- ‘Bit-Flip errors’
- Methods of fixing, limiting, preventing
    - Checksum
    - RF shielding on computer boards

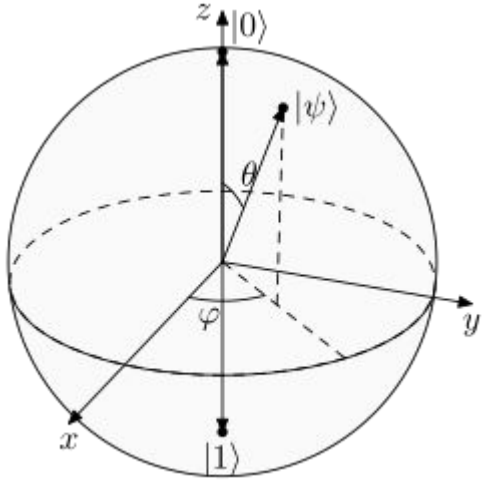
Dealing with Quantum Errors

- Error Suppression
  - Steps taken before an algorithm is run to **prevent** an error from occurring
- Error Mitigation
  - Uses outputs after an algorithm is run to reduce or eliminate the adverse effects of noise in results
- Error Correction
  - ‘Fixing’ errors mid-computation



Types of Errors

- Bit Flip (X error)
- Phase Flip (Z error)
- Amplitude Damping/Relaxation
- Phase Damping/Dephasing
- Depolarizing Noise



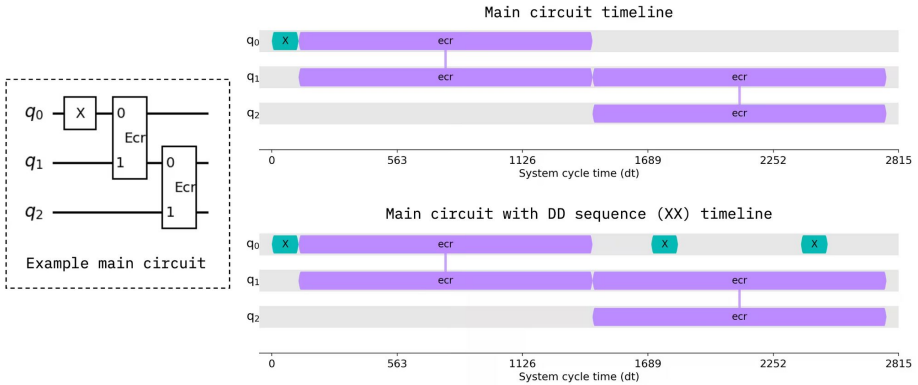
Hardware-Specific

- Trapped-Ion: E-field surface noise, Mag-Field fluctuations, ion motion instabilities
- Photonics: Photon-shot noise, Dark Current noise

How can we ‘fix’ these errors?

Error Suppression Strategies

- Transpilation-Based methods -> reducing operations & optimizes circuits
- Dynamical Decoupling: flips idle qubits to isolate from environmental noise and prevents decoherence (mainly in superconducting hardware)
- Pulse Shaping/Optimization: redefine the machine language abstraction of circuits to increase operation robustness against errors



Error Mitigation Strategies

- Zero-Noise Extrapolation
  - Run circuit normally -> noisy output
  - Artificially inflate noise (added gates)
  - Run again with more noise
  - Repeat to fit a curve and mathematically extrapolate to ‘zero noise’
- Readout Error Mitigation -> ‘calibrating hardware’
  - Measure many known states
  - Keep track of misread measurements
  - Adjust final probabilities accordingly
  - Note: only applies to readout (ie. measurement) errors
- Probabilistic Error Cancellation -> ‘correcting a biased coin’
  - Experimentally learn *noise model* (ask me what this is!) of hardware
  - Apply inverted noise gates and run circuits
  - Combine results to statistically cancel out noise

Error Correction Strategies

- Surface Codes
  - Popular error correcting strategy
  - Measures ‘commuting parity checks’ (stabilizers) without measuring data
  - Cannot measure same type of error on same ‘plaquette’
- Color Codes
  - Newer error correcting strategy
  - Can measure multiple error types