High Level Applications Overview

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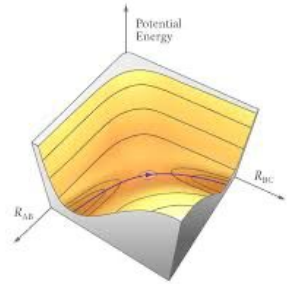
Chemistry and Materials Science

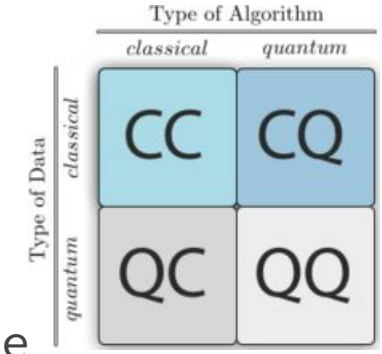
Chemistry applications



- Chemistry calculations hit a point where classical methods are no longer tractable
  - System is too large/too complex
- VQE is a common algorithm, as is QPE (Quantum Phase Estimation)
- Applications include materials discovery and drug design

Quantum Machine Learning

Applications



- Quantum-enhanced machine learning models combine classical and quantum approaches for improved optimization and data processing
  - Healthcare (medical image processing)
  - Finance (fraud detection)
- Depends on type of data and algorithm
- Quantum Neural Networks (QNN) which combines quantum mechanics and NNs

Quantum Optimization

Possible algorithms

- Quantum Approximate Optimization Algorithm (QAOA)
  - Good for combinatorial optimization problems
  - Recall that U = exp (-i H): exponentiating a Hermitian matrix gives us an unitary matrix (time evolution)

$$U(\boldsymbol{\gamma}, \boldsymbol{\alpha}) = e^{-i\alpha_n H_M} e^{-i\gamma_n H_C} \dots e^{-i\alpha_1 H_M} e^{-i\gamma_1 H_C}$$

- Quantum Unconstrained Binary Optimization (QUBO)
  - minimize a quadratic objective function over binary variables

Cryptography and Security

Algorithms

- Shor’s algorithm
  - For prime factorization
  - To factor an integer N, Shor’s algorithm needs time log N and requires quantum gates of order $O((\log N)^2 (\log \log N) (\log \log \log N))$
- Quantum Key Distribution (QKD) algorithm

Current State

Error Mitigation and Correction

- Dynamic decoupling
  - canceling out environmental noise while qubits are idle
  - Let noise accumulate in one part of the system by applying certain gates and then let it cancel out in another part of the system
- Pauli twirling
  - Insert random gates to simplify the noise
- Zero Noise Extrapolation (ZNE)
  - Add more noise! Extrapolate noise in the opposite direction
- Algorithmic properties!
  - GSE corrects all single-qubit gate errors