CSCI 4140
Overview of Applications of Quantum Computers

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Introduction

- It’s still very early, but we are beginning to see applications of quantum computing
- Universal quantum computer are still too small for many applications
- Special purpose quantum computers, such as D-Wave and Xanadu can support some real applications
- Start by examining some useful techniques and then move onto some promising application areas

Linear Algebra

- Linear algebra is the basis for many useful applications
- Already seen quantum phase estimation that can compute eigenvalues
- There are other algorithms for eigenvalues that are more robust
- There are algorithms for solving systems of linear equations
- Many of these algorithms require larger quantum computers to be truly practical, but that could be the case in a few years

Random Numbers and Random Walks

- On classical computers we have pseudo random numbers, they aren’t truly random and can be predicted
- This is a possible security hole for techniques that require truly random numbers
- We can easily use quantum computers to generate real random numbers
- A Hadamard gate on a single qubit produces a completely random bit when measured
- Combine multiple bits to get purely random numbers

Random Numbers and Random Walks

- A random walk is when a random decision is used to select the next direction of motion
- This can be done in a 2D or 3D space, used to model certain physical phenomena
- It can also be done on graphs, which edge to follow in the next step
- Can represent a computer network by a graph, walk the graph, and the edges with the highest number of visits are the weak points of the network
- Used in network design and distributed processing algorithms

Optimization

- A very important problem, and hard to solve
- Good optimization algorithms can save huge amounts, D-Wave has made a business out of this
- Proper scheduling of deliveries and transportation can be a major cost saver when many vehicles are involved
- Several optimization algorithms have been developed for quantum computers
- Will become more important as the computers scale

Logic

- Mathematical logic is used extensively in a number of fields, software engineering, computer design, databases, etc.
- Problem: one of the classical hard to solve problems, for useful logics there are no efficient classical algorithms
- Quantum algorithms for some of these problems are appearing
- Have potential to be a game changer, make applications that are currently impossible computationally feasible

Graph Algorithms

- Xanadu's optical quantum computer shows that certain graph theory problems can be efficiently solved on a quantum computer
- Many important applications could be improved with quantum algorithms in this area
- Example: network routing, existing algorithms are mainly heuristics, solving the problem completely is too difficult
- Some scheduling problems fall into this class as well

Chemistry

- Chemistry relies heavily on quantum mechanics
- On a classical computer these computations are hard to impossible, even for small atoms and chemicals
- Since quantum computing is based on quantum mechanics, it’s a natural for these problems
- Can directly simulate the quantum mechanical problem, no need to translate it for a classical computer
- Could be used to improve drug design

Finance

- Honeywell sold its first quantum computer to a financial intuition
- Many financial problems require extensive computations, a number of financial institutions use super computers
- Small differences can mean a lot in large financial transactions
- Arbitrage: stocks can trade on multiple exchanges in different countries, small movements in stock price or exchange rates could produce a profit making opportunity
- These situations last for a very short period of time, usually less than a second, so you need to move very quickly

Finance

- Asset allocation: given a fixed amount of money how can it be invested to get the maximum return with the least risk
- A large number of alternatives, many different investments and many combinations, need to consider all the potential risks
- Pricing: how do you price a new security? Consider the possible return on investment and potential risks
- This involves some very complicated mathematics and significant computational problems

Optimization

- This is important to many industries, this is why D-Wave is in business
- They sell quantum computers and time on their own machines to companies with optimization problems
- Things like optimizing factory schedules, transportation routes, transport schedules
- Making a small change in a process could mean a significant cost savings

Machine Learning

- Machine learning is a hot topic, combine it with quantum computing!
- There has been some early work applying quantum computing to machine learning
- A lot of this is theoretical, but beginning to see implementations
- The ability to explore multiple solutions in parallel seems to be a big advantage
- Again, need to wait for bigger machines to see if this is practical

Summary

- As quantum computing becomes more popular beginning to see more practical algorithms
- Areas with significant computational problems can benefit from this
- Could change what we think is feasible to compute, create new applications that were thought to be impossible
- Getting the tools into as many hands as possible is key to making progress in this area