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QUANTUM COMPUTING FOR HEALTHCARE APPLICATIONS

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ABSTRACT

In recent years, scientists have been working on something called quantum computing, which can do calculations in a completely different way than regular computers. It's become really interesting to both researchers and companies. But, we don't yet know all the ways quantum computing can help in healthcare. It looks at how quantum computing can make healthcare better. It looks at things like finding new medicines, personalizing treatments, reading DNA, making medical pictures, and organizing how healthcare works.We looked at lots of research papers and sorted them into different categories, like what they talk about, what they need to work, how they keep information safe, and what still needs to be figured out. This helps everyone, whether they're new to quantum computing or experts, understand what's happening in this area of healthcare. It also helps them see where there might be chances for new ideas and what problems still need solving when using quantum computing in healthcare.Using quantum computing in healthcare could change how we do medical research, diagnosis, and treatment. This chapter looks at how quantum computing might help in healthcare. It might make complex simulations faster, improve how we develop drugs, make medical images better, and make personalized medicine more advanced. The chapter also talks about the good things and challenges of using quantum computing in healthcare. It discusses things like how powerful the computer is, how we make algorithms, and how we keep information safe. This chapter shows how using quantum computing in healthcare could make healthcare better and bring new ideas to medicine.

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INTRODUCTION

The main reason we choose quantum computing instead of regular computing is that quantum computers can look at all the information at once. Regular computers can only look at one thing at a time. This means quantum computers are better at predicting things and doing it faster. When it comes to a patient's health, predicting and doing it quickly is very important. We use the information from the healthcare industry and what worked before for similar patients to give suggestions to the doctor about what to do for the patient. The connection between quantum computing and healthcare is like a brand-new, super-advanced technology. It could make a huge difference in how we do medicine. Quantum computing uses special science rules, and it has the power to change healthcare in ways we couldn't even imagine before. This new technology can help us solve really hard problems in healthcare, like finding new medicines, understanding genes, and making healthcare work better. As we look into how quantum computing can help in healthcare, we see that it can bring new answers, speed up our research, and change how we do healthcare in a big way. In this exploration, we'll learn the basic ideas of quantum computing, why it's better than regular computing, and how it can change healthcare to make it more accurate, faster, and personalized for each patient.

In simpler terms, quantum computing can lead to better, faster, and more personalized healthcare, and it's an exciting area of technology that holds a lot of promise for the future.

What is a qubit?

Qubits are like the building blocks of a quantum computer. They're a bit like regular bits or transistors that we use in regular computers. But, there's something special about qubits. They use a weird thing called "superposition," which means they can be in multiple states at once. It's a bit like flipping a coin. When you flip a coin, it's either heads or tails when it lands, but while it's in the air, it could be either one. In a quantum computer, qubits do calculations by playing with these multiple possibilities before giving a final answer. They don't decide if they're a "0" or a "1" until we need to know. It's a bit like changing how a coin falls while it's still in the air – it could be heads or tails. This flexibility of qubits is what makes quantum computers so powerful and different from regular computers.

Types of Quantum Computers

Quantum Annealer: This is the least powerful and most limited type of quantum computing. It's the easiest to make, but it can only do one thing. Also, most scientists agree that it doesn't have any advantage over regular computing.

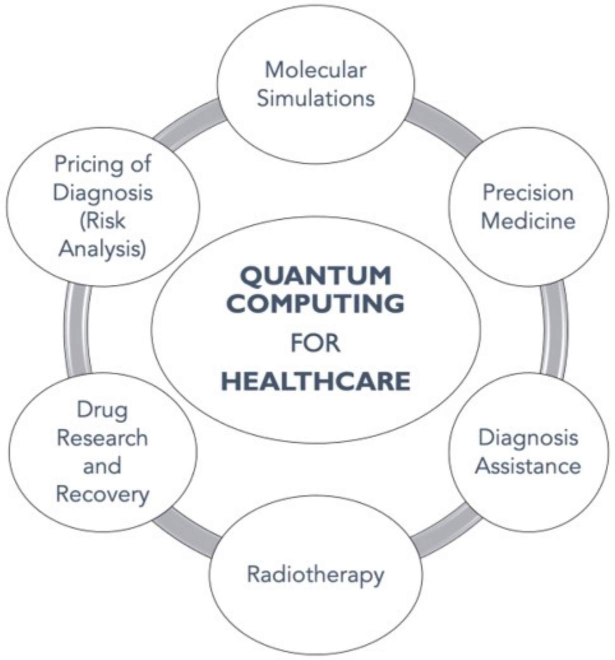

Figure 1. Quantum Computing for Healthcare

Analog Quantum: Analog quantum computers can simulate complex quantum interactions better than regular devices or a mix of them. They might have about 50-100 qubits. Plus, they're faster than regular computers and can do more calculations.

Universal Quantum: This kind of quantum computer is the most powerful and versatile, but it's also the toughest to create. It comes with many technical difficulties. Additionally, experts believe this machine will have over 100,000 physical qubits.

How Does Quantum Computing Work?

A quantum computer has important parts:
An area that comprises qubits or quantum bits (the basic unit of information in quantum computing).

- It has a place with qubits (special bits for quantum computing).
- It can send signals to qubits.
- It also uses a regular computer to run programs and give commands.

"Quantum computing, combined with AI, is changing many parts of healthcare and medicine. This includes things like medical pictures, finding out what's wrong with a patient, and making personalized treatments. It's also helping with drug research. Quantum computing could have a big impact and might solve many problems in this field."

1. Quantum Computing Applications

Material Science

1. Quantum computing can help simulate how molecules and materials behave, which is useful for fields like materials science and drug discovery.
2. Big companies like Google, IBM, Microsoft, and Intel have their own teams working on quantum computing to solve important problems.
3. Not only big companies but smaller ones and startups are also getting into quantum computing.
4. Regular computers struggle with complex molecular interactions, but quantum computers can handle them better. For example, they can help chemical and petroleum companies develop new products faster.
5. IBM's quantum computers, which are available to the public, were used to study chemicals like lithium hydride and beryllium hydride for the chemical and petroleum industries. This might help create better catalysts and surfactants.
6. ExxonMobil is using quantum computing to develop new energy and manufacturing technologies. They see potential in improving power grids, making more accurate environmental models, and discovering new materials for capturing carbon more efficiently.

Quantum Computing in Finance: Quantum computing should make financial planning better, which means it can help guess what might happen in the stock market and make sure risks are under control. In January 2023, some quantum computing companies and a big bank in France, CréditAgricole, said they finished a 1.5-year study. They looked at how quantum-like techniques could help figure out the value of financial stuff and how risky loans are. In a news release, the companies talked about some papers that give more information about their work. They also did two tests in their study, one on figuring out financial stuff and another on predicting when loans might be risky. They found that using quantum-like techniques made the computer much faster and need less memory. This means they can use it for real-world problems like valuing financial things. Even with just 50 qubits, it worked really well, and they think it will be even better with 300 qubits, which they should have by 2024. The authors say they created the first computer program that uses both quantum and regular techniques to predict when someone's credit rating might go down.

Quantum Computing Application in Machine Learning (ml): Using quantum computing can make machine learning algorithms better, which means they can make predictions faster and more accurately. The blog post mentioned that Quantum Machine Learning (QML) brings together quantum computing and a less-known area called quantum sensing. It's expected that for some problems, quantum computers will be much better than regular computers, but we need more qubits and better error correction in quantum computing to make it happen. Even though there are many tough challenges for quantum computing to be useful, thatthe Quantum Machine Learning (QML) showed its first big advantage in this experiment. They also said that when you use a limited number of examples from quantum computing, regular computers can't beat it, even if they have unlimited resources. Until now, this method has only been tested in a controlled experiment, where the researchers created the quantum state themselves and acted like they didn't know what it was. To use these methods for real experiments, we need to improve current quantum sensor technology and find ways to accurately move quantum states to a quantum computer. However, the fact that today's quantum computers can already process this data and gain a significant learning advantage is a good sign for the future of quantum machine learning.

Quantum Computing Applied to natural Language Processing (nlp): Another area where quantum computing can be applied is to enhance Natural Language Processing (NLP) and speech recognition, making communication more accurate and efficient. A practical example of this is the release of the first quantum natural language processing (QNLP) toolkit and library by Cambridge Quantum Computing (CQC) in October 2021. Now, with this toolkit, QNLP applications like automated dialogue, text mining, language translation, text-to-speech, language generation, and bioinformatics can be developed more quickly. We're exploring the special abilities of quantum computing for making significant discoveries. Our latest project in Quantum Natural Language Processing (QNLP) with researchers from shown that, even at this early stage, QNLP techniques can produce results for sentence classification that are comparable to traditional methods. However, we understand that the infrastructure for quantum computing needs to improve before these techniques can be used commercially. Importantly, we see that the QNLP approach can lead to explainable AI, which means more accurate and accountable intelligence, a crucial factor in the field of medicine. The opportunity to get practical experience in the experimental side of QNLP. This area is new and significant in making NLP work on actual quantum computers.

Quantum computing applied to optimize tasks: Lastly, quantum computing can find success in areas like logistics and manufacturing, where it's believed to perform complex optimization tasks much faster than traditional computers. An example of quantum computing helping with optimization comes from the Latin American startup Quantum-South. This Uruguay-based company shared a post on its website in June 2022, titled "Enhancing Cargo Loading Plans with Quantum Annealers." It explains how they used quantum annealers via Amazon Braket in a hybrid approach to optimize cargo in the lower compartments of passenger aircraft, leading to improvements in cargo loading plans. The advanced use of this solution could better organize the mix of passengers, weight, and cargo on busy flights, based on their initial trial results. Additionally, it will allow for increased process efficiency, reducing the amount of time required for analysis and optimization. Additionally, Quantum-South reports that IAG Cargo, part of International Airlines Group (IAG), has tested the solution. It may significantly improve workload efficiency because the current optimization process only covers some flights, while the solution could optimize the entire cargo carrier network. "IAG Cargo is always seeking innovative ways to make its processes more efficient," explained Angel Cabeza, IAG Cargo's Head of Technology Change. He also mentioned, "We're eager to proceed with further phases to confirm the positive outcomes we've observed." Dr. Rafael Sotelo, Co-Founder & President of Quantum-South, shared, "We started by closely studying the current IAG Cargo process at Adolfo Suárez Madrid–Barajas Airport in Spain." He added, "Our teams collaborated to integrate operational data into our algorithms and tailored two use cases to create a unique solution that fits IAG Cargo's specific needs." In simpler terms, IAG Cargo is excited about improving their processes, and Quantum-South worked closely with them to create a custom solution after studying how things currently work at one of their airports. They are now moving ahead to confirm the positive results.

Ensuring the Security of Quantum Computing in Healthcare

Security in healthcare applications is crucial because they deal with people's lives. However, healthcare faces a challenge because its systems are often separate, which makes it hard to share data and make progress. Chuck Brooks, a cybersecurity expert and chair of the Quantum Security Alliance, suggests that we need to collaborate better between academia, industry, researchers, and governments to ensure security. Security in quantum computing is also very important. It can significantly boost computing power, which could threaten current cryptographic methods. While cryptography has been the foundation of healthcare information security, quantum computing combines classical cryptography with quantum mechanics to offer strong security for healthcare communication. Quantum cryptography is based on the laws of physics and is commercially available. Overall, there are various security technologies that can help improve healthcare information security.

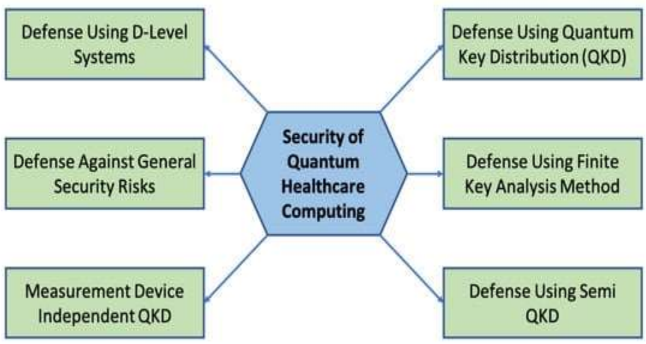

Figure 2. Classification of important technologies to secure the processing of healthcare information with quantum computing

Quantum Computing Applications in Healthcare: Quantum computing is great for heavy-duty healthcare tasks, especially in the Internet of Things (IoT) world of digital healthcare. It's like having super-powerful computers that can do amazing things. For example, it can help with medical devices connected to the Internet or cloud. This super-computing power can lead to big discoveries in healthcare. Switching from regular computers to quantum ones can help a lot in healthcare research. It's like going from a slow car to a super-fast one. It can make tasks like studying proteins, figuring out how drugs and molecules fit together, and even testing new medicines much quicker. One cool thing is that quantum computers can do DNA sequencing incredibly fast, which could make personalized medicine a reality. Quantum computers are really good for doing complex healthcare tasks, especially when it comes to connected medical devices like sensors that are linked to the Internet or the cloud. These powerful computers can also help make big breakthroughs in healthcare research. For example, they can speed up things like studying how proteins fold, figuring out how molecules like drugs fit together, and testing how well molecules bind together. Here are a few examples of what quantum computers can do in healthcare, like quickly reading DNA to personalize medicine.

Supersonic drug design: The first and most important step in making new medicines is comparing molecules. Regular computers can compare lots of them, but they can't handle really big molecules. So, Quantum Computing can step in and compare larger molecules. This means we can make more progress in developing medicines and finding cures for different diseases. Furthermore, Quantum Computing allows healthcare experts to simulate complex interactions between molecules at a very tiny level. This is a big deal for medical research and finding new medicines. Soon, experts will be able to simulate all 20,000 proteins in the human genome and understand how they work. They'll also be able to simulate how these proteins interact with both existing and new drugs. The old way of making medicines through long and expensive clinical trials is no longer the only option. Scientists and pharmaceutical companies are now trying different methods like using artificial intelligence, human organs-on-chips, or in silico trials to speed up the process and make drug discovery and development less costly. For instance, it relies on supercomputers to search for potential therapies in a vast database of molecular structures. One of its powerful tools, AtomNet, checks over 100 million compounds daily. In 2015, Atomwise conducted a virtual search to find existing safe medicines that could be adapted to treat Ebola. Remarkably, they identified two potential drugs in less than a day, a process that typically takes months. In another case, InSilico Medicine made news by revealing that their smart algorithm helped them develop a new drug candidate in just 46 days.

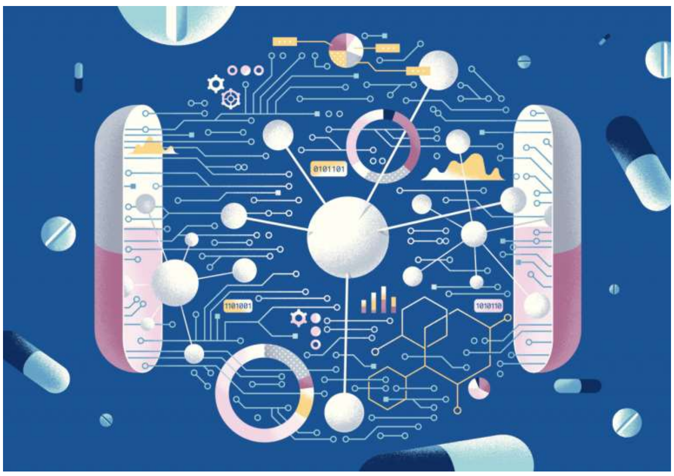

Figure 3. Supersonic drug design

Reaching the age of in silico clinical trials: In silico clinical trials mean using computer simulations instead of people, animals, or cells to test therapies or drugs. Quantum computing can greatly improve these simulations, allowing for detailed 'virtual humans' and complex models like HumMod, which mimics various body functions. This could lead to 'live' trials with virtual patients, customized by the testers, making trials faster, better, and more complete. We might soon see new drugs on the market just weeks after their discovery.

Figure 4. Clinical trials

Sequencing and analysing DNA full speed: In the past 20 years, genetics and genomics have undergone significant transformations. It once took over 15 years and billions of dollars to decode the human DNA during the Human Genome Project, which began in 1990 and presented its final results in 2006. However, today, there are over 2,000 genetic tests available for various human conditions, and you can even order them online through direct-to-consumer genetic testing companies. These tests allow individuals to discover their genetic disease risks and aid healthcare providers in diagnosing illnesses.

Figure 5. Sequencing and analysing DNA full speed

In less than 10 years, the technical conditions, time, and cost of genome sequencing have improved by a factor of 1 million. However, we think there's still room for a significant revolution in this field. Quantum computing has the potential to push this revolution forward. It could enable faster genome sequencing and more thorough analysis of the entire genome. Quantum computers could also provide more reliable predictions by considering even more information than traditional computers, and they could integrate all genomic data into health records. Quantum computing could eliminate uncertainties in genomics and genetics, leading to improved health for everyone.

Making patients truly the point of care: Currently, we are able to measure a gazillion of health data about ourselves – but we know that it's still not that widespread. In the future, health sensors, wearables, and tiny medical gadgets could send zettabytes of data about patients into the cloud. Just as a comparison: while in 2013, the amount of digital data encompassed 4.4 zettabytes, by 2025 the digital universe – the information we create and copy annually – is predicted to reach 175 zettabytes, or 175 trillion gigabytes (!). Quantum computers will be able to make sense of these huge amounts of data, including bits and pieces of health information. Moreover, surveillance of patients through connected sensory systems might render physical hospitals useless – and truly make patients the point of care. Quantum computing could ensure the 'home front' for smoothly running these systems.

Arriving at the perfect decision support system: We have long surpassed the era when the accumulated knowledge of medical professionals could 'reside' in one professor's head. It's just too much. On Pubmed, there are 34 million papers. If a single doctor could only read 3-4 studies of their field of interest per week, they could not finish it in a lifetime and meanwhile, millions of new studies would come out. That has already been a problem for a while, thus IBM created a supercomputer and its algorithm, IBM Watson, to sift through millions of studies in a second – although there is some uncertainty about what will happen to these initiatives after the sale of Watson. Quantum computing would take that to a whole new level and even augment it with special skills. What if such computers could offer perfect decision support for doctors? They could skim through all the studies at once, they could find correlations and causations that the human eye would never find, and it might stumble upon diagnoses or treatment options that the human doctor could have never figured out by themselves. At the very endpoint of this development, quantum computers could create an elevated version of PubMed, where information would reside in the system but not in the traditional written form, but in qubits of data as no one except the computer would 'read' the studies anymore.

Figure 6. Perfect decision support system

Creating the safest medical data systems ever: In her TED talk, ShohiniGhose mentioned the use of quantum uncertainty for encryption as one of the most probable applications of quantum computing. She believes it could be used for creating private keys for encrypting messages sent from one location to another – so that hackers could not copy the key perfectly due to quantum uncertainty.

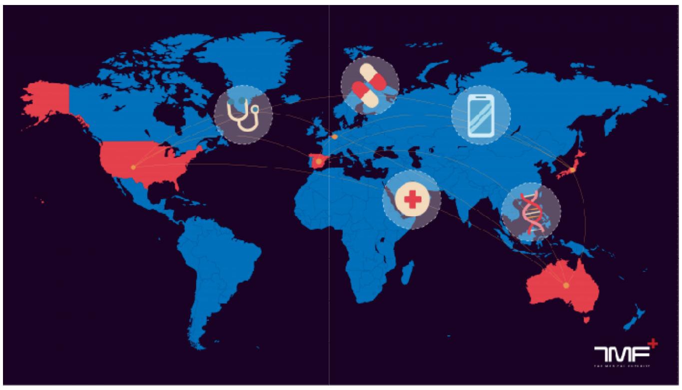

Figure 7. Creating the safest medical data systems ever

They would have to break the laws of quantum physics to hack such keys. Imagine that level of security with regards to sensitive medical information: electronic health records, genetic and genomic data, or any other private information that the health system generates about our bodies. There are already some examples. In January 2018, a joint China-Austria team showed that communication between continents with quantum encryption was possible. The latest breakthrough achieved by this group consists of combining quantum communication from the Micius satellite with the fiber-optic network in Beijing. It is the first practical proof that the technology that allows networks to use quantum encryption is already available. Quantum computing has indeed amazing potential – in theory. However, we still have to wait a lot until any of this can be applied in real life, so this is rather science fiction at the moment. Plus, another problem with quantum computing is that very few people know what it means and understand its workings completely.

Radiotherapy: Radiotherapy is a widely-used treatment for cancer. Moreover, it uses radiation helps destroy cancerous cells or cease them from multiplying. It is also crucial to devise a radiation plan to reduce the damage to healthy tissues and body parts. It also deals with complex optimization problems with thousands of variables. Therefore, reaching the optimal radiation plan needs multiple simulations until an optimal solution is acquired. Hence, with quantum computing the range of possibilities that are considered between each simulation is broad. As a result, it allows healthcare professionals to execute numerous simulations simultaneously and develop an optimal plan.

Healthcare Data: Patients want to secure and safeguard their medical and healthcare data. Hence, it is pivotal to examine and assess all the techniques of hacking. For example, ID Quantique is a firm that uses components of quantum mechanics to secure data. Therefore, using quantum entanglement is one of the more practical applications and quantum cryptography safeguards the data.

Genomics: Genomics refers to the study of complete genetic components of an organism. That is to say, it incorporates, recombinant DNA, DNA sequencing methods, and bioinformatics. Moreover, it requires sequencing, assembling, and analyzing of the structures and functions of genomes. Further, the latest techniques involve dividing the DNA into small components. It also includes the search for certain types of biomarkers and any disease-related mutations. As a result, this comes down to two major repercussions that need addressing. Firstly, the process is too time-consuming. Secondly, it becomes slower with only manual operations involve. Hence, traditional computers are not dynamic enough for the tasks. Therefore, Quantum Computing is the right way to go forward as it has more computational power and storage capacity. Moreover, the outcomes will be more accurate to help provide correct diagnoses and personalized medications. Further, it will enable professionals to create a database of genomes to discover unknown biomarkers and mutations. It will also revolutionize the treatment by considering various factors like environment or lifestyle.

Improving Imaging Solutions: Quantum Imaging devices help create highly accurate images that enable the visualization of single molecules. Further, Machine Learning and Quantum Computing help physicians and professionals to interpret the results. Moreover, machine learning helps identify abnormalities in the body and quantum computing provides the interpretation of the results and its treatments. Although, traditional MRIs help detect areas of light and dark, and the radiologist needs to evaluate them. Hence, quantum imaging tools help differentiate among tissue types to enable more precise imaging.

What is Quantum Computing and Why is it Different than Our Current Computer Technology?

Quantum computing is a revolutionary concept in digital data processing based on the fundamental principles by which nature operates, i.e. quantum mechanics. With advancements in physics in the early 20th century, methods of observation and purity of materials reached the level at which some quantum phenomena became detectable.

Figure 8. Technology of Quantum Computing

The best example of this is a regular transistor present in ever y modern computer or device. It operates by directing large clouds of carriers of electrical current using engineered materials and quantum-based principles (band structure, localized states, etc.). They produce behavior unusual for naturally found materials – an ability to precisely control current with current, or current via light, or light via current. Recently, miniaturization of transistors, detectors, and, at the same time, access to extremely low temperatures (such as −273C) have opened the possibility to operate, observe, and, most importantly, isolate individual particles with their inherently quantum properties. These properties are one reason the desktop or laptop computers we use have little resemblance to quantum computers. Even though theoretically established for over 100 years, these properties have only recently been observed and verified over a wide range of particles and systems. While being nonsense in our daily experience, quantum mechanics has already led to dramatic advances in a few specific areas in medicine (e.g., MRI, laser surgery) with potential to revolutionize medical research and clinical care.3 Because modern computers have largely saturated computational power and no longer grow exponentially as occurred in the last century, quantum computing, if realized, is the most promising technology for major advancements in processes currently beyond the reach of existing computing power.

2. ***Quantum Algorithms for Cognitive Healthcare:*** The healthcare industry is experiencing an explosion of data and at the same time the cost of healthcare is rising. Cognitive computing in healthcare is using big data in conjunction with advanced machine learning and supercomputers/cloud services to help doctors detect diseases earlier, improve therapeutic outcomes and ultimately reduce the cost of care. In this project Siemens Healthineers and UCL investigate the use of quantum machine learning algorithms to improve cognitive computing in healthcare.

3.

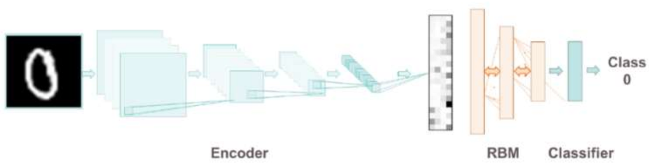

Figure 9. Cognitive Healthcare

Algorithms running on quantum processors have the potential to perform extremely fast calculations to solve problems that are computationally intractable with classical computers. This offer significant potential when extracting meaningful, decision level information from medical images.

Image Classification with Quantum Pre-training and Auto-encoders: Computer vision has a wide range of applications from medical image analysis to robotics. Over the past few years, the field has been transformed by machine learning and stands to benefit from potential advances in quantum computing. The main challenge for processing images on current and near-term quantum devices is the size of the data such devices can process. Images can be large, multidimensional and have multiple color channels. Current machine learning approaches to computer vision that exploit quantum resources require a significant amount of manual pre-processing of the images in order to be able to fit them onto the device. This paper proposes a framework to address the problem of processing large scale data on small quantum devices. This framework does not require any dataset specific processing or information and works on large, grayscale and RGB images. Furthermore, it is capable of scaling to larger quantum hardware architectures as they become available. In the proposed approach, a classical autoencoder is trained to compress the image data to a size that can be loaded onto a quantum device. Then, a Restricted Boltzmann Machine (RBM) is trained on the D-Wave device using the compressed data, and the weights from the RBM are then used to initialize a neural network for image classification. Results are demonstrated on two MNIST datasets and two medical imaging datasets.

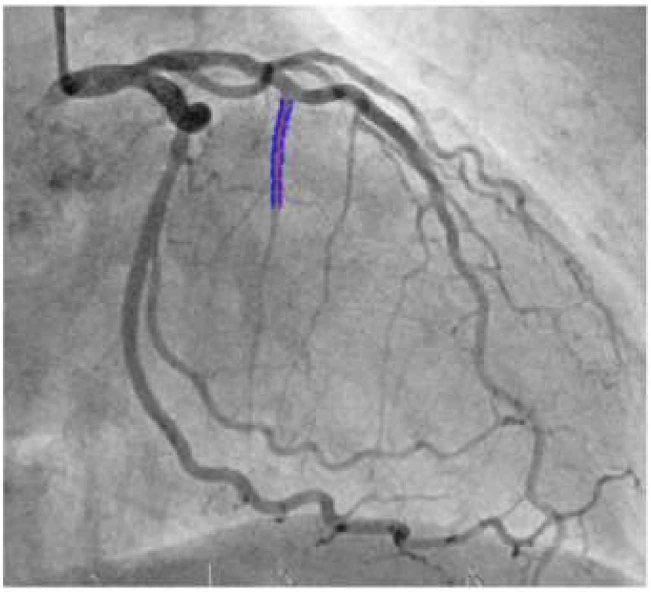

Figure 10. Image Classification with Quantum Pre-training and Auto-encoders

Graph Cut Segmentation Methods Revisited with a Quantum Algorithm: Quantum computers take advantage of inherently quantum mechanical features to process information. These devices can offer polynomial, or even exponential speed-ups to conventional, classical computers. We attempt to show the possibility of practical, near-term computer vision applications for such devices. In particular, we look at solving the task of image segmentation with a quantum algorithm.

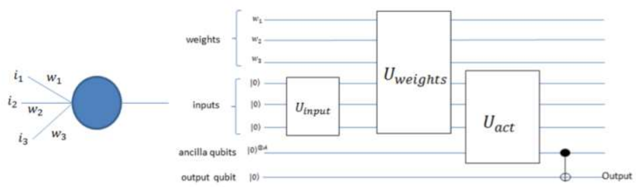

Figure 11. Graph Cut Segmentation Methods

Our approach is based on the graph cut methods of maxflow min-cut and normalized cuts. These graph cuts are solved using the near-term quantum algorithm of QAOA.We present encouraging results on artificial datasets, as well as small-scale medical images.

Training and Meta-Training Binary Neural Networks with Quantum Computing: Quantum computers promise significant advantages over classical computers for a number of different applications. We show that the complete loss function landscape of a neural network can be represented as the quantum state output by a quantum computer. We demonstrate this explicitly for a binary neural network and, further, show how a quantum computer can train the network by manipulating this state using a well-known algorithm known as quantum amplitude amplification. We further show that with minor adaptation, this method can also represent the meta-loss landscape of a number of neural network architectures simultaneously. We search for this meta-loss landscape with the same method to simultaneously train and design a binary neural network.

Binary Classification on Gate Quantum Computing: Small-scale quantum computational devices are currently available, and a universal quantum computer is forecast to be built within the next decade. It is thus important to understand both the impact and potential applications of the technology. The IBM Quantum experience allows users to experiment with a 5 qubit quantum chip using their online web platform. In this work, a binary classifier is considered which can be run on the IBM quantum device, and apply it to medical data for the prediction of dementia.

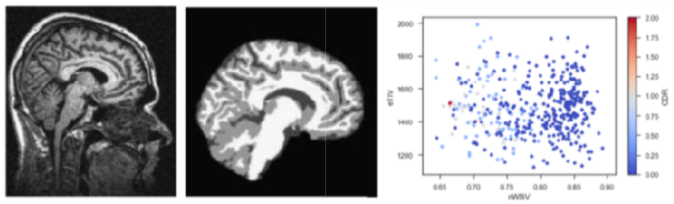

Figure 12. Binary Classification on Gate Quantum Computing

CONCLUSION

Classical computing works by processing bits, or 0s and 1s representing electrical signals of on and off. Quantum computing employs a very different technique for information processing. It uses qubits, which can exist as both a 1 and 0 at the same time, and uses the properties of subatomic particles in quantum physics such as interference, entanglement, and superposition to extend computational capabilities to hitherto unprecedented levels. The efficacy of quantum computing for important verticals such as healthcare where quantum computing can enable important breakthroughs in the development of life-saving drugs, performing quick DNA sequencing, detecting diseases in early stages, and performing other compute-intensive healthcare related tasks is not yet fully explored. Furthermore, implementations of quantum computing for healthcare scenarios such as these have their own unique set of requirements. Unfortunately, existing literature that address all of these dimensions is largely unstructured. This research is intended to be the first systematic analysis of the capabilities of quantum computing in enhancing healthcare systems. Quantum computing has revolutionized traditional computational systems by bringing unimaginable speed, efficiency, and reliability. These key features of quantum computing can be leveraged to develop computationally efficient healthcare applications. To this end, we, in this paper, provide a comprehensive survey of the existing literature focused on leveraging quantum computing for the development of healthcare solutions. Specifically, we discussed different potential healthcare applications that can be benefited from quantum computing. In addition, we elaborated upon the key requirements for the development of quantum-computing-empowered healthcare applications and provided a taxonomy of existing quantum computing architectures for healthcare systems. Furthermore, we also discussed different security aspects for the use of quantum computing in healthcare applications and discussed different quantum technologies that can ensure the security of such applications. Finally, we discussed current challenges, their causes, and future research directions where quantum computing could provide immense benefits. This is a novel study which underlines all the key areas of quantum computing implications in the healthcare paradigm and can provide a one-stop solution to the research community interested in utilizing and analyzing different prospects of quantum computing in various healthcare applications.

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