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CHIME Cheat Sheet – April 2, 2024
Quantum Computing

Background

In the early 1900s, an entirely new science known as Quantum Mechanics was introduced to the physics field. Quantum Mechanics describes the behavior of atoms and fundamental particles such as electrons and photons. This scientific breakthrough helped later introduce the idea of merging quantum mechanics with information theory, known as Quantum Computing. Quantum computing uses specialized technology that utilizes quantum mechanics to solve complex problems that classical and supercomputers are unable to solve. While the idea of quantum computing first arose in the 1970s it wasn't until the 1980s that it started to gain some traction. This was partially attributed to the efforts of American theoretical physicist, Richard Feynman, who advocated for the establishment of quantum computing through works such as Simulating Physics with Computers and Quantum Mechanical Computers.

According to *Quantum Computing: A New Era of Computing*, in 1998, the first experimental demonstration of a quantum algorithm was reported. A working 2-qubit Nuclear Magnetic Resonance (NMR) quantum computer was used by Johnathan A. Jones and Michele Mosca at Oxford University. Shortly after, Isaac L. Chuang at IBM's Almaden Research Center and Mark Kubinec at the University of California, Berkley, also achieved this milestone. The number of quantum computers is increasing, with IBM having more than 20 available. This technology has the potential to impact the life around us including addressing security needs, healthcare, the internet and more. According to one consulting firm, "quantum has the promise to help solve some of the world's toughest challenges – in the areas of supply chain and logistics optimization, fraud detection, materials and drug discovery, climate challenges, and much more." This highlights the transformative capability of quantum computing in tackling critical issues. Specifically for healthcare, quantum has the potential to revolutionize various aspects of diagnosis, treatment, and data security.

How It Works

In a traditional digital computer, the information is encoded in the form of bits with each bit equaling to "0" or "1." These bits are used for data and processing. Similarly, quantum computers make calculations using quantum bits or qubits. Unlike traditional computers, qubits do not have to be a binary 1 or 0. Qubits can:

- Be probabilistic and exist in superposition states – this allows them to perform more than one calculation at once and can be both 1 and 0 at the same time. One example offered by Microsoft explains that when there are two classical bits there can be four possible states (00, 01, 10, and 11). With two qubits, however, they can represent any combination of these four states.
- Involve entangled particles – Caltech uses a dance metaphor to explain this concept stating, "When two particles, such as a pair of photons or electrons, become entangled, they remain connected even when separated by vast distances. In the same way that a ballet or tango emerges from individual dancers, entanglement arises from the connection between particles."

An easier way to conceptualize quantum computing is through an example involving distances, given by Sean Ong, a physicist and engineer by training. It revolves around determining the fastest way to get from point A to point B. For instance, if you try to map a distance by plugging in the destination using a traditional map device, the map will try different routes one at a time to figure out the route that takes the least amount of time, whereas a quantum device will be able to input all the routes at the same time to figure out the quickest option. This takes data processing to another level which is why quantum computing is considered a revolutionary technology.

Legislation

There have been bills introduced regarding quantum computing, the most recent being the National Quantum Initiative Reauthorization Act, which was created to reauthorize the National Quantum Initiative. Other bills that have previously been introduced include the Post Quantum Cybersecurity Standards Act to advance the rapid deployment of post quantum cybersecurity standards across the United States economy and the Leveraging Quantum Computing Act to provide an enhanced use of quantum computing. The introduction of legislation is the first step toward quantum related regulations and government implementation.

Federal Funding

The U.S. government is often a leader in next generation technology. The National Defense Authorization Act (NDAA) is a piece of legislation passed annually to fund our nation's defense priorities and infrastructure. Most recently, the Fiscal Year (FY) 2024 NDAA has allocated funding to the Department of Defense (DOD) regarding quantum technologies. This included a pilot program on near term quantum computing applications. The FY 2023 NDAA also includes several provisions and funding related to quantum computing. For instance, it directs the National Science Foundation to award higher education grants to support research on distributed ledger technologies which includes studying "implications of quantum computing on applications of distributed ledger technologies, including long-term protection of sensitive information (such as medical or digital property), and techniques to address them." It also authorized $20 million for the Defense Advance Research Project Agency's (D-ARPA) utility scale quantum computing activities.

In addition to the funding included in the annual defense funding bills, the President has requested $1.9 billion for critical and emerging technologies like biotechnology, quantum information sciences, high-speed computing, and artificial intelligence (AI) and machine learning in the FY 2025 budget for the Department of Energy (DOE). This investment is intended to strengthen U.S. leadership in science and technology, supporting DOE's national security mission. Last August, the DOE also announced $24 million in funding for three collaborative projects in quantum network research. These projects include collaborative research efforts on a heterogeneous, full-stack approach in codesigning scalable quantum networks, developing the architecture and protocols for a performance-integrated scalable quantum internet, and developing hyper-entanglement-based networking and error noise-robust correction techniques for developing advanced quantum networks for science discovery. The Department of Commerce (DOC) also has plans for funding to help spur innovation. Through the Tech Hubs Program, which was enacted as part of the CHIPS and Science Act of 2022, DOC will choose 31 tech hubs that will be eligible to receive a piece of the $500 million allocated to the program. The tech hub industries selected will range from autonomous systems, quantum computing, clean energy, semiconductors and more.

Challenges

Although quantum computing is regarded as a revolutionary technology, its complexity presents numerous challenges. The first one being qubit decoherence, which is when small disturbances make quantum bits lose their quantum properties. Additional challenges include error correction, scalability, hardware development, classical computer interfaces, standards and protocols, trained talent, and overall expense. Addressing these challenges is crucial for unlocking the full potential of quantum computing in diverse applications.

Quantum in Healthcare

Quantum computing can be significantly advantageous within the healthcare industry. It has the potential to enhance healthcare systems by being able to revolutionize computing in healthcare tasks such as drug discovery, personalized medicine, DNA sequencing, medical imaging, and operational optimization. The Cleveland Clinic has taken the lead in implementing quantum computing into their healthcare systems. They worked with IBM to become the first healthcare system to install a quantum computer specifically for healthcare research. The discovery accelerator used at the Cleveland Clinic converges classical computing, quantum computing and AI. By leveraging these capabilities using the discovery accelerator, the clinic has several projects underway related to screening and optimizing drugs targeted to specific proteins, improving a prediction model for cardiovascular risk and employing AI to search genome sequencing findings and large drug-target databases.