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DEPARTMENT OF INFORMATION TECHNOLOGY

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Quantum Computing

INTRODUCTION

- **Quantum computing is an area of computer science that uses the principles of quantum theory. Quantum theory explains the behavior of energy and material on the atomic and a sub-atomic levels.**

- **Quantum computing uses subatomic particles, such as electrons or photons. Quantum bits, or qubits, allow these particles to exist in more than one state (i.e., 1 and 0) at the same time.**

- **Quantum computing is a cutting-edge field of computer science and physics that aims to leverage the principles of quantum mechanics to perform computations.**

- **Traditional computers use bits to represent data, which can be either 0 or 1, and process information using binary logic gates**.

- **Quantum computers, on the other hand, use quantum bits, or qubits, which can exist in a superposition of states, representing 0, 1, or both simultaneously.**
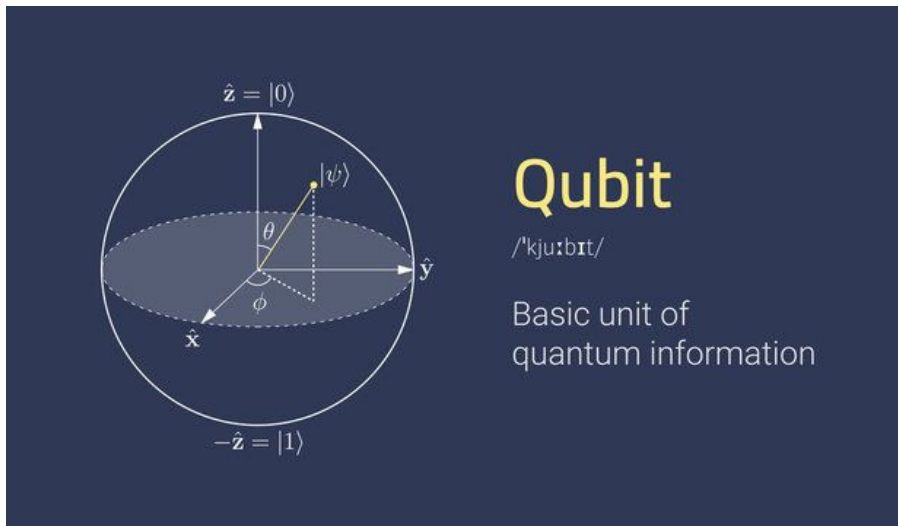
- **The unique properties of qubits, such as superposition and entanglement, enable quantum computers to perform certain types of calculations exponentially faster than classical computers for specific problems.**
- **This potential for exponential speedup in solving certain algorithms has attracted significant interest and investment from researchers, governments, and private companies.**

KEY PRINCIPLES OF QUANTUM COMPUTING

Superposition:	A qubit can exist in multiple states (0, 1, or any combination of both) simultaneously until it is measured, unlike classical bits, which are in a definite state.
Entanglement:	When qubits become entangled, the state of one qubit is dependent on the state of another, regardless of the distance between them. This property allows for highly correlated quantum states and plays a crucial role in quantum computing.
Quantum gates:	Quantum gates are the building blocks of quantum circuits, much like classical logic gates in traditional computers. They manipulate qubits and perform quantum operations like superposition, entanglement, and interference.
Quantum parallelism:	Quantum algorithms can exploit superposition to evaluate multiple possibilities simultaneously, which is one of the reasons for the potential speedup over classical computers for specific tasks.

WHY DO WE NEED QUANTUM COMPUTERS?

- **When scientists and engineers encounter difficult problems, they turn to super computers. If a supercomputer gets stumped, that's probably because the big classical machine was asked to solve a problem with a high degree of complexity. When classical computers fail, it's often due to complexity.**
- **Complex problems are problems with lots of variables interacting in complicated ways. Modeling the behavior of individual atoms in a molecule is a complex problem, because of all the different electrons interacting with one another.**
- **Identifying subtle patterns of fraud in financial transactions or new physics in a supercollider are also complex problems. There are some complex problems that we do not know how to solve with classical computers at any scale.**
- **The real world runs on quantum physics. Computers that make calculations using the quantum states of quantum bits should in many situations be our best tools for understanding it.**

Fig 1: IBM, Cleveland Clinic Install World's First Quantum Computer for Health Care Research

CHALLENGES FOR QUANTUM COMPUTING

Decoherence:	**Quantum states are highly sensitive to their environment, and interactions with the external world can cause qubits to lose their coherence and collapse into classical states. Maintaining coherence and minimizing errors is a major challenge in building practical quantum computers.**
Quantum error correction:	**Errors are inevitable in quantum computing due to noise and decoherence. Developing robust quantum error correction techniques is essential to ensure the reliability of quantum computations.**
Scalability:	**Building larger quantum systems with more qubits is a significant engineering challenge. As the number of qubits increases, so does the complexity of managing them and avoiding errors.**
Noise and fidelity:	**Quantum computations are prone to errors caused by noise in quantum hardware. High fidelity in quantum operations is crucial for reliable quantum computing.**

IMPORTANT MILESTONES IN THE HISTORY OF QUANTUM COMPUTING

1905:	**Albert Einstein explains the photoelectric effect—shining light on certain materials can function to release electrons from the material—and suggests that light itself consists of individual quantum particles or photons.**
1924:	**The term *quantum mechanics* is first used in a paper by Max Born.**
1925:	**Werner Heisenberg, Max Born, and Pascual Jordan formulate matrix mechanics, the first conceptually autonomous and logically consistent formulation of quantum mechanics.**
1930:	**Paul Dirac publishes *The Principles of Quantum Mechanics*, textbook that has become a standard reference book that is still used today.**
1993:	**The first paper describing the idea of quantum teleportation is published.**
1996:	**Lov Grover of Bell Laboratories invents the quantum database search algorithm.**
2002:	**The first version of the Quantum Computation Roadmap, a living document involving key quantum computing researchers, published.**

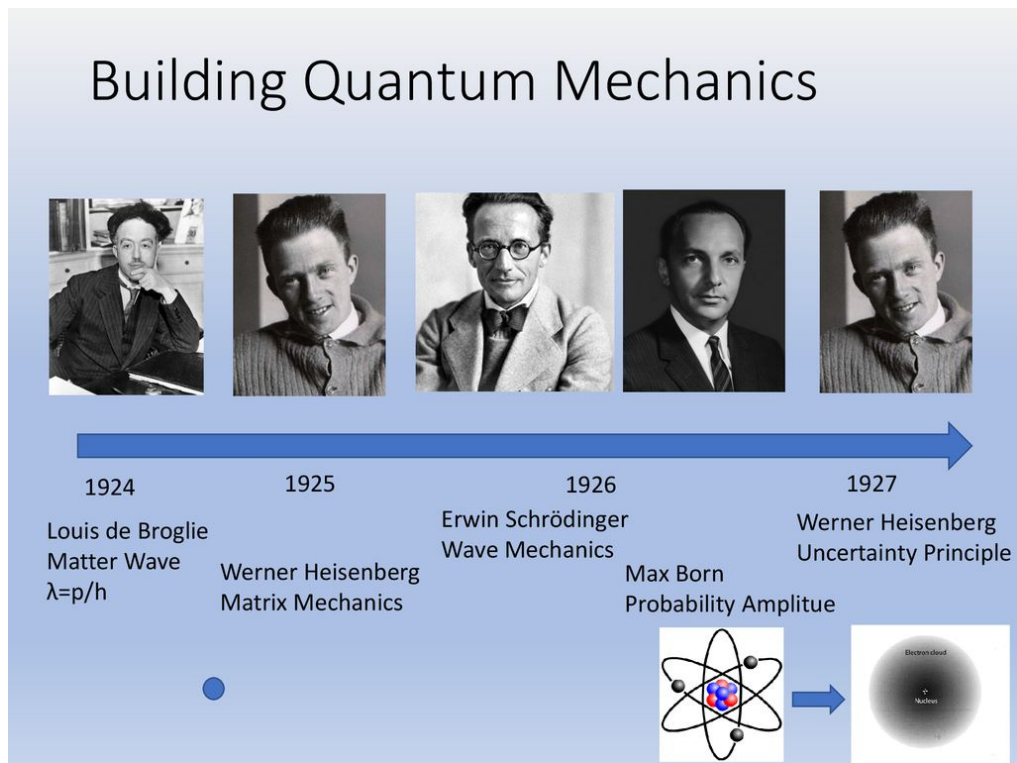| 2011:	The first commercially available quantum computer is offered by D-Wave Systems.

Fig 2: TIMELINE OF QUANTUM COMPUTING

QUANTUM COMPUTER VS CLASSICAL COMPUTER

- **Quantum computers have a more basic structure than classical computers. They have no memory or processor. All a quantum computer uses is a set of superconducting qubits.**

- **Quantum computers and classical computers process information differently. A quantum computer uses qubits to run multidimensional quantum algorithms. Their processing power increases exponentially as qubits are added.**

- **A classical processor uses bits to operate various programs. Their power increases linearly as more bits are added. Classical computers have much**

less computing power. Classical computers are best for everyday tasks and have low error rates.

- Quantum computers are ideal for a higher level of task, e.g., running simulations, analyzing data (such as for chemical or drug trials), creating energy-efficient batteries. They can also have high error rates.

- Classical computers don't need extra-special care. They may use a basic internal fan to keep from overheating. Quantum processors need to be protected from the slightest vibrations and must be kept extremely cold. Super-cooled super fluids must be used for that purpose.
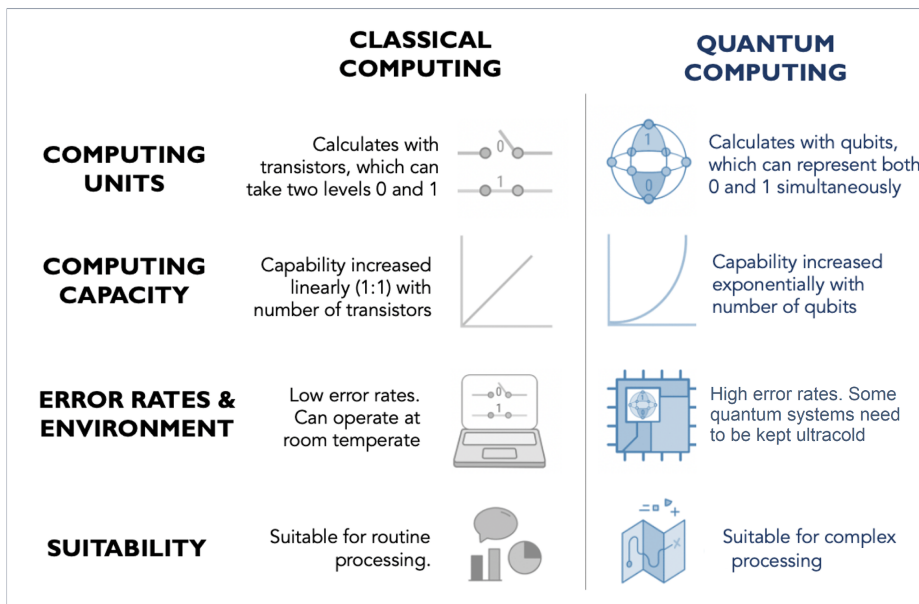

	CLASSICAL COMPUTING	QUANTUM COMPUTING
COMPUTING UNITS	Calculates with transistors, which can take two levels 0 and 1	Calculates with qubits, which can represent both 0 and 1 simultaneously
COMPUTING CAPACITY	Capability increased linearly (1:1) with number of transistors	Capability increased exponentially with number of qubits
ERROR RATES & ENVIRONMENT	Low error rates. Can operate at room temperate	High error rates. Some quantum systems need to be kept ultracold
SUITABILITY	Suitable for routine processing.	Suitable for complex processing

Fig 3: CLASSICAL COMPUTING VS QUANTUM COMPUTING

CONCLUSION

- Quantum computing holds immense promise and potential to revolutionize various fields in science, technology, and industry.

- As quantum computing continues to evolve, it will likely have a profound impact on society, transforming the way we approach scientific research, data analysis, problem-solving, and information security. However, its full potential may take years or even decades to realize as researchers work

towards overcoming the current technological barriers and discovering novel applications.

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