

Entry

Quantum Computing: A Concise Introduction

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Definition

Quantum computing is an emerging field in computing technology that harnesses the principles of quantum mechanics—including superposition, entanglement, and quantum tunneling—to process information in fundamentally new ways. While classical computers use bits that represent states of either 0 or 1, quantum computers use quantum bits, or qubits. Unlike classical bits, a qubit can exist in a superposition of the logical states 0 and 1 simultaneously. This property allows quantum-powered systems to perform certain complex computations much faster than classical computing systems. Quantum computing holds great potential to transform many sectors by enabling breakthroughs in quantum cryptography, information retrieval, optimization, and artificial intelligence. Through quantum algorithms such as Grover’s and Shor’s algorithms, quantum computers can significantly accelerate the speed of data searching and break encryption systems that would take classical computers billions of years to crack. While still in the relatively early stages of development, quantum computers hold considerable potential to shape our next generation of computing.

Keywords: quantum computing; qubits; quantum information processing; quantum algorithms; Grover’s algorithm; Shor’s algorithm; quantum cryptography



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1. Introduction

Quantum computing is rapidly reaching a point of transition from a theoretical curiosity to a real-world, transformative technology. The advanced computational abilities of quantum-based systems, harnessed from the unique properties of quantum mechanics, promise to dramatically shift the speed and efficiency of our systems [1]. By moving beyond the classical computing paradigm of binary digits (“bits”) that can only operate in two states (0 or 1) to qubits, which can exist in multiple states simultaneously through quantum superposition, quantum systems can solve certain computational problems much faster than classical machines [2]. This computational efficiency has wide-reaching implications for cybersecurity, information retrieval, and the optimization of artificial intelligence [3].

While quantum computing may be viewed as some distant and futuristic innovation more likely to be realized in the pages of a science fiction novel than in real-world applications, this technology already exists in some form through hardware like Google’s Willow chip [4], IBM’s superconducting quantum processors [5], IonQ’s trapped ion systems [6], and software platforms such as Qiskit [7], Google’s Cirq [8], and Microsoft’s Quantum Development Kit (QDK) [9]. While today’s quantum devices remain limited in scale and

error rates, their continued evolution reflects rapid progress toward more robust and scalable systems [10]. These developments have far-reaching implications for fields such as cryptography [11], optimization [12], agri-food [13], and materials science [14]. If costs decline and demonstrable value is shown in real-world deployments, rapid adoption is plausible. In that case, the resulting impact could be comparable to recent advances in generative artificial intelligence in late 2022/2023. A consolidated overview of the hardware platforms and software development kit (SDK) is provided in Table 1.

Table 1. Summary of Quantum Platforms and SDKs: Strengths, Limitations, and Maturity.

Category	Platform	Type	Connectivity	Strengths	Limitations	Maturity
Hardware	Google Willow [4]	Superconducting (transmon)	Planar grid and nearest-neighbor	Fast gates; advanced calibration & benchmarking pipelines	Cryogenics; crosstalk; fidelity scaling	Research & Noisy intermediate-scale quantum computing (NISQ)-class flagship devices
Hardware	IBM Quantum [5]	Superconducting (transmon)	Coupling-map topologies (planar)	Cloud access; strong toolchain	Coherence & connectivity constraints typical of superconductors	Broad device family; leading NISQ access
Hardware	IonQ [6]	Trapped ions (hyper-fine/optical)	All-to-all within a single chain	Long coherence; high single/two-qubit fidelities	Slower gates; scaling across chains needs photonic links	Commercial cloud systems; strong small to medium-circuit performance
Software	Qiskit [7]	SDK (Python)	IBM devices; providers for others; simulators	Rich transpiler; visualization; pulse-level access	IBM-centric by default	Actively maintained; wide community use
Software	Cirq [8]	SDK (Python)	Google devices and compatible simulators	Native abstractions; noise models; calibration workflows	Google-centric	Research & production tooling within Google ecosystem
Software	Microsoft QDK [9]	SDK (Q#, Python & C# interop)	Azure Quantum ecosystem; simulators; resource estimation	High-level Q# language; resource estimation; heterogeneous backend routing	Heavier tooling stack; best within Azure flow	Active tooling; growing backend support

Given the impact that this quantum technology may have, it is critical to examine how organizations and society at large may anticipate opportunities and threats that will be presented and ensure that they are left in a favorable position for the decades to come.

This entry provides an introduction to quantum computing and explains related concepts within the context of their real-world impact on our systems for current and future professionals. The implications of these innovations for society are then discussed,

including how they may impact various information systems, information retrieval, and the information, knowledge, and computing professionals. Through this analysis, the nature of quantum computing will be demystified, and the realistic disruptive potential of the technology will be highlighted.

2. Quantum Principles in Quantum Computing

Often, concepts in computing can be broken down into their most basic elements and thus be made more accessible for all to understand. The lowest level of most computing systems is the binary digit, or “bit,” the 0s and 1s that represent electrical signals and are the backbone of all information stored, manipulated, and conveyed by these systems [15]. When systems can be broken down to 0s and 1s, it is considerably easier to understand how each aspect of the system builds from that foundation. However, quantum computing does not rely on bits—rather, it utilizes unique attributes of quantum mechanics to build a machine that is much faster and more efficient than any previous-existing technology [16]. In order to understand the quantum computer, we must first have some background in quantum theory.

Quantum mechanics focuses on phenomena at atomic and subatomic scales—such as the behavior of electrons within atoms and photons, the fundamental particles of light—and explains why these particles behave in ways that defy classical intuition [17]. While classical physics can approximate the behavior of macroscopic objects, it fails to accurately describe systems at the quantum scale, where particles exhibit both wave-like and particle-like properties. For instance, electrons do not occupy fixed positions or follow precise trajectories but instead exist in probabilistic distributions described by wavefunctions. These principles are not limited to subatomic particles; quantum behavior is also critical at the atomic level and beyond, particularly in fields such as quantum chemistry, where the structure and interactions of molecules depend fundamentally on quantum effects [18]. A summary of quantum computing mechanism is depicted in Figure 1.

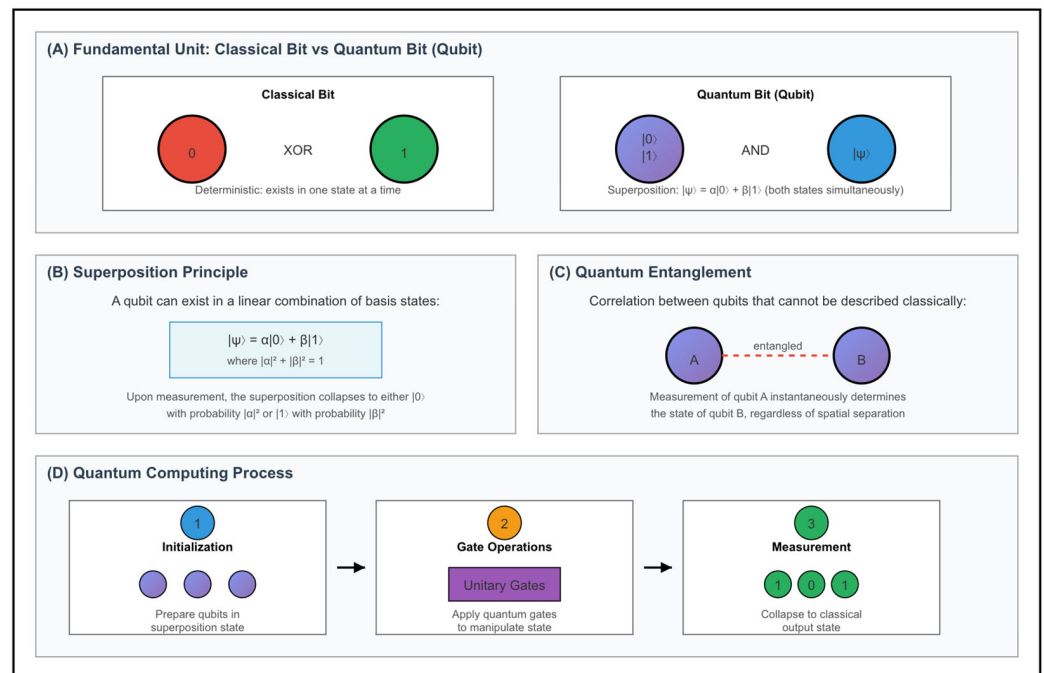


Figure 1. Fundamental principles of quantum computing.

One of the foundational postulates of quantum theory is superposition, which states that a quantum system can exist in a linear combination of multiple basis states simultaneously. In quantum computing, this means that quantum bits (qubits), unlike a classical bit that must be in state 0 or 1, can exist in a coherent combination of both states. Mathematically, the state of a qubit can be described as:

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

where $|\psi\rangle$ is the qubit’s state, $|0\rangle$ and $|1\rangle$ are the computational basis states, and α and β are complex probability amplitudes satisfying $|\alpha|^2 + |\beta|^2 = 1$. Upon measurement, the qubit collapses to one of the basis states, with probabilities determined by the squared magnitudes of the amplitudes as formalized by the Born rule [19].

It is important to note that this is not the same as the qubit being “both 0 and 1 at once” in a classical sense, nor is it simply a matter of uncertainty. Superposition reflects a uniquely quantum mechanical structure of information that enables powerful interference and computational effects, often illustrated by Schrödinger’s cat thought experiment [20].

Entanglement is another key quantum phenomenon that occurs when two or more qubits become correlated in such a way that a measurement performed on one qubit instantaneously affects the outcome probabilities of measurements on the other, regardless of the distance between them [21]. This allows quantum computers to process information in interconnected and parallel ways that classical computers cannot replicate.

To realize functional quantum computers, physical implementations of qubits must meet stringent requirements such as the DiVincenzo criteria [22]. These include the ability to initialize, coherently control, and measure qubits with high fidelity while also ensuring scalability and long coherence times. A variety of physical platforms have been developed to meet these challenges. Notably, neutral atoms in optical tweezers [23] and ion traps [24] represent macroscopic systems that support coherent qubit manipulation and entanglement, showcasing how quantum behaviors can manifest beyond the microscopic scale.

Fundamental differences in information processing for classical and quantum computers are shown in Table 2.

Table 2. Fundamental Differences Between Classical and Quantum Computing for Information Processing.

Feature	Classical Computing	Quantum Computing
Basic Unit	Bit (0 or 1)	Qubit (a coherent quantum state in superposition of basis states)
Key Phenomena	Binary Logic	Quantum gates
Processing	Sequential/Parallel	Quantum parallelism with interference-based amplitude manipulation
Example Task	Password cracking	Grover’s algorithm; Shor’s algorithm for factoring (breaking RSA (i.e., Rivest-Shamir-Adleman) encryption)
Limitations	Limited by Moore’s Law	Sensitive to decoherence

When someone observes or measures a quantum state, the superposition appears to collapse into single, definite outcomes. However, this collapse—a postulate of quantum theory—is distinct from decoherence, which is a physical process resulting from unwanted interactions between the quantum system and its environment [25]. Decoherence occurs when quantum information leaks into the environment due to thermal noise or coupling with external particles, thereby disrupting the delicate quantum state. Quantum systems

must be carefully isolated and stabilized, using specialized hardware described in the following section, to prevent decoherence and ensure meaningful computation.

To perform operations on the qubits, quantum computers utilize quantum gates, which are the quantum version of the logic gates used in classical computing. These gates manipulate qubits using unitary transformations, altering their superpositions and entanglements without collapsing the quantum state. Common quantum gates employed today include the Hadamard gate, the Pauli gates, and Controlled NOT (CNOT) gates (for quantum entanglement). These principles are foundational for making quantum computing a feasible technology rather than a hypothetical construct. The evolution of IBM quantum processing capabilities is presented in Figure 2.

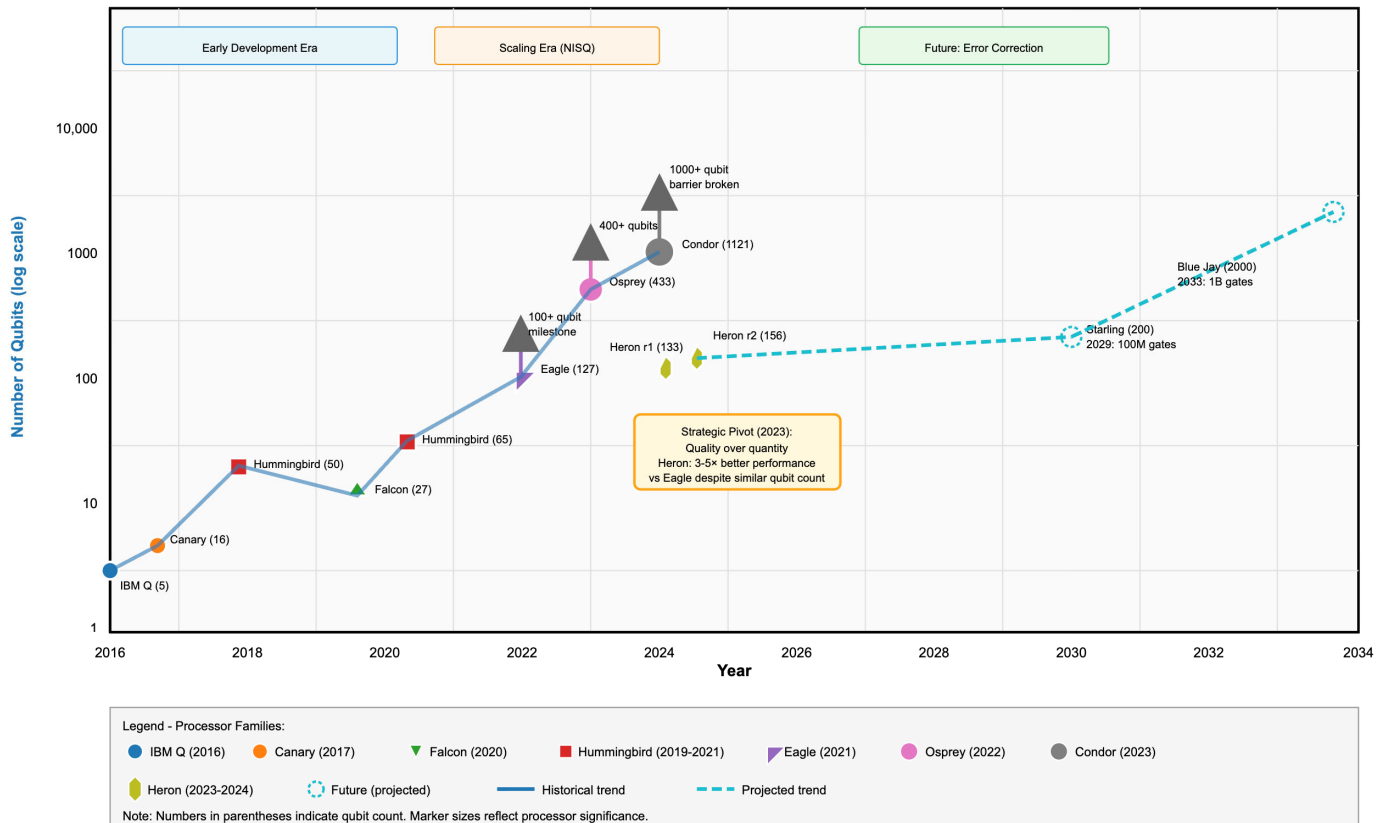


Figure 2. Evolution of IBM quantum processor qubit count from 2016 to 2033 (projected). Logarithmic scale shows exponential growth from 5 qubits (IBM Q Experience, 2016) to 1121 qubits (Condor, 2023), representing a 224-fold increase in seven years; depicted based on data from [5].

2.1. Hardware for Quantum Computing

The hardware used for quantum computing differs quite significantly from the classical computing systems in order to ensure the technology can maintain and manipulate delicate quantum states. Qubits require isolation from any noise or interference; otherwise, the quantum properties can be disrupted. Current quantum platforms include superconducting circuits, which use supercooled electrical loops controlled by microwave pulses, and trapped ions, which use lasers to manipulate atoms suspended in electromagnetic fields. Maintaining coherence and mitigating decoherence are primary challenges, motivating diverse physical implementations of qubits.

Beyond superconducting circuits and trapped ions, several promising platforms provide alternative approaches to scalable, high-fidelity quantum computing. One example is neutral atoms trapped using optical tweezers—highly focused laser beams that hold individual atoms, typically alkali metals like rubidium or cesium [26]. These atoms are precisely arranged into configurable arrays or lattices with high spatial resolution. Quantum information is encoded in the atoms' internal energy states or hyperfine levels. Controlled interactions between qubits are achieved by exciting atoms to high-energy Rydberg states, enabling strong and tunable coupling.

Another approach involves photonic qubits, where quantum information is encoded in photon properties such as polarization, time-bin, or spatial path [27]. Photons naturally travel at the speed of light and interact weakly with their environment, enabling operation at room temperature and making them ideal for long-distance quantum communication and quantum networking [28].

Additionally, nitrogen-vacancy (NV) centers in diamond represent a solid-state platform where a nitrogen atom substitutes for a carbon atom adjacent to a vacancy in the diamond lattice [29]. The electron spin associated with NV centers can be optically initialized and read out, with coherence times extending to milliseconds at room temperature. NV centers show promise for quantum sensing, communication, and small-scale quantum networks [30].

While significant progress has been made in developing quantum hardware, practical quantum computing requires overcoming fundamental challenges related to errors and noise. Quantum states are inherently fragile and susceptible to decoherence and operational imperfections, necessitating quantum error correction techniques that protect information without directly measuring qubits [31]. Error correction relies on encoding logical qubits into entangled states of multiple physical qubits, enabling the detection and correction of errors [32]. In practice, error correction incurs substantial resource overhead, as each logical qubit is encoded across many physical qubits and requires frequent syndrome extraction and decoding. Complementing this, fault tolerance ensures that quantum computations can proceed reliably even when individual components are imperfect by applying error correction throughout the computational process [33]. Designing universal quantum gate sets—the quantum analog of classical logic gates—that can be implemented fault-tolerantly is crucial to building scalable quantum computers [34]. Fault tolerance extends beyond protecting data; it constrains how gates, measurement, and feedforward are orchestrated so that failures remain correctable throughout long computations.

2.2. Quantum Algorithms

With a classical computer, in order to try to crack a ten-character code, you would have to enter one combination at a time [35]. If a code has 10 alphanumeric characters, then there are 62^{10} potential combinations (26 uppercase letters, 26 lowercase letters, and 10 numbers and ten characters in the password). This means there are 839 quintillion combinations of possibilities. Even an incredibly fast modern supercomputer, able to try 1 billion combinations per second, would take over 10,000 years on average to guess the right combination.

Grover's algorithm provides a quadratic speedup for unstructured search problems by exploiting uniquely quantum phenomena such as superposition, phase inversion, and amplitude amplification through interference [36]. This allows it to reduce the number of steps needed from 839 quintillion to about 29 billion, because Grover's algorithm provides a quadratic speedup, solving the problem in a number of steps roughly equal to the *square root* of 839 quintillion (29 billion), as shown in Figure 3.

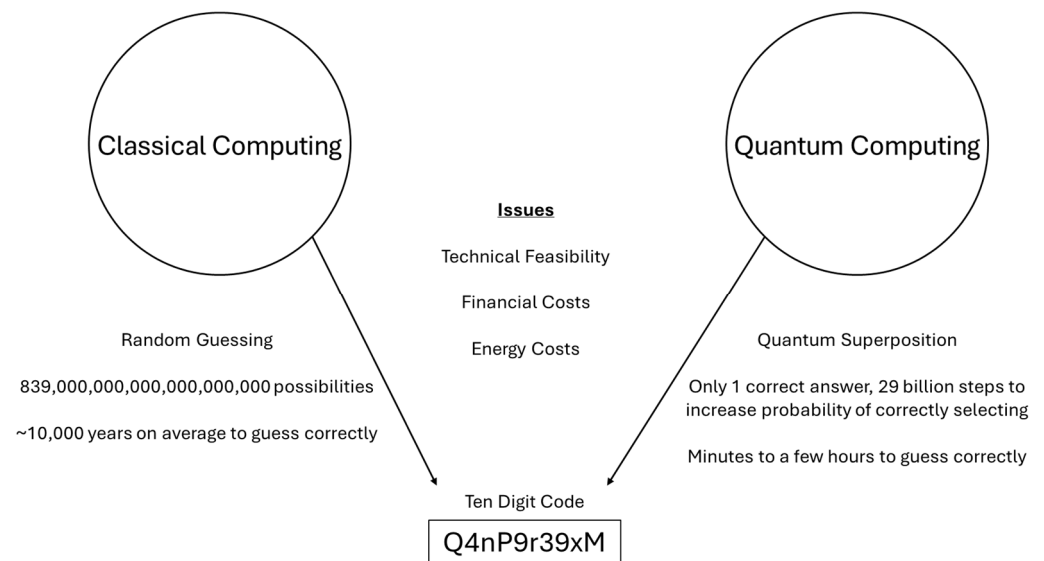


Figure 3. A Comparison of Classical and Quantum Computing.

Contrary to the popular misconception that quantum algorithms “test all combinations simultaneously,” Grover’s algorithm does not evaluate every possibility in parallel in a classical sense. Instead, it orchestrates quantum interference to increase the probability of measuring the correct result after a number of iterations proportional to the square root of the total number of possible combinations [37]. For instance, even a system that could only work at 1000 steps per second could identify the correct code in much less than one calendar year, while a more aggressive system working at 1 million steps per second could crack it in a handful of hours.

Another quantum algorithm that poses a major threat is Shor’s algorithm [38]. In modern encryption—such as RSA (Rivest–Shamir–Adleman) [39], which protects communications between systems—a key aspect to ensuring a message cannot be broken is the mathematical difficulty of factoring a very large number into its two original prime factors. The product of these two numbers—the modulus—is publicly known, but the identity of the two prime numbers is not. In RSA encryption, the number to be factored is hundreds of digits in length, and the correct pair of large prime numbers is incredibly difficult to identify using a classical computer, likely taking billions of years. However, Shor’s algorithm, operating on a quantum computer, has the ability to factor these large numbers exponentially faster [40]. Instead of checking the possibilities one by one, the algorithm uses quantum parallelism to find the factors within a few hours, which poses a significant threat to the security of RSA and similar encryption approaches.

2.3. Computational Complexity and Quantum Advantage

To rigorously assess the capabilities of quantum computing, it is essential to situate it within the framework of computational complexity theory [41], which classifies problems based on the computational resources (typically time or computational steps) required to solve them using different models of computation [42]:

- Class P (Polynomial Time) consists of problems that can be solved efficiently (i.e., in polynomial time) by a classical deterministic algorithm.
- Class NP (Nondeterministic Polynomial Time) includes problems for which proposed solutions can be verified efficiently, even if finding such solutions may not be feasible in polynomial time. One of the most prominent open questions in theoretical computer science is whether $P = NP$.

- Class BQP (Bounded-Error Quantum Polynomial Time) encompasses problems that can be solved efficiently by a quantum computer, with an error probability of less than $1/3$ for all instances (which can be reduced further via repetition) [43,44].

Quantum computers are believed to offer computational advantages primarily for problems in BQP that are not known to lie within P. A canonical example is the problem of integer factorization [45]. While classical algorithms require super-polynomial time to factor large numbers, Shor's quantum algorithm can perform this task in polynomial time—placing it in BQP. Since integer factorization is not believed to be in P, this capability illustrates the potential of quantum computing to outperform classical methods for certain classes of problems [46].

2.4. The Power of Quantum Computing

As illustrated in the examples above, quantum computing allows for more effective use of information by computers. While the data does not literally move quicker (this is determined by the speed of light and the efficiency of the physical materials that carry the signal), they can be interpreted much quicker with both a higher level of encryption (protection) and efficiency. This means that the data can be used much more efficiently, speeding up the time for large computations, simulations, or training of artificial intelligence models.

The potential of quantum computing to dramatically accelerate certain types of calculations makes it a revolutionary advancement in the field of computing. When integrated with artificial intelligence, quantum systems could tackle complex problems—such as optimization, pattern recognition, and drug discovery—much faster than classical computers [47]. This acceleration would enable AI models to analyze massive datasets and make decisions at a scale and speed previously unimaginable. While not every AI task will benefit equally from quantum enhancements, the convergence of these two technologies could reshape entire industries and redefine the boundaries of machine capabilities.

Quantum computing has the potential to advance recent innovations beyond their already revolutionary capacities. Just as individual tools like generative artificial intelligence have transformed our lives by improving how we compute and make decisions, the unification of these tools through quantum-powered systems could elevate them to entirely new levels of performance—turning today's advanced technologies into tomorrow's superpowered systems.

3. Areas of Quantum Computing's Greatest Potential Impact

3.1. Cybersecurity and Post-Quantum Cryptography

One of the greatest areas of concern with quantum computing is cybersecurity. As illustrated in the example in the prior section, quantum computing presents a major challenge for the traditional forms of encryption and access control that rely on factoring or logarithmic problems. This development leaves many of our systems in knowledge industries at high risk of attacks. In broader society, attacks may focus on military systems and financial institutions [48]. If this technology were received into the wrong hands, it could severely compromise our entire information infrastructure and cause widespread damage.

In response to quantum threats to cybersecurity, post-quantum cryptography (PQC) has been developed to ensure that cryptographic systems remain secure even against attackers with quantum computers [49]. PQC does not rely on exploiting weaknesses in quantum computers. PQC is based on mathematical problems believed to be hard for both classical and quantum algorithms to solve [50]. Lattice-based cryptography is an approach that introduces multidimensional problems and some noise into its design. Consider a lattice as a grid in multiple dimensions—like trying to find the exact point where several

invisible threads cross in a vast web. The goal is to construct a problem that is too complex for even powerful algorithms to untangle efficiently.

3.2. Information Retrieval

As discussed previously with Grover's algorithm, quantum computers have the capacity to explore extensive pools of data at a quadratically quicker rate than traditional computers. This would allow users to enter sophisticated prompts with a great deal of detail and specificity, and the quantum algorithm could parse through the text of all available documents and provide relevant resources at a near-instantaneous rate [51]. Combined with other emerging technologies like large language models, these tools could rapidly optimize metadata for resources, produce better results and better contextualize or explain those results, all at a rate that is much faster than our current retrieval systems. From the perspective of the information user, this would be a great boon and would likely cause a technological revolution similar to what was experienced with the emergence of ChatGPT. Undoubtedly, many companies are investing in developing quantum technologies right now for this very reason.

However, there are several issues with quantum information retrieval that may negatively impact information organizations like libraries as well as the information users themselves. From the perspective of libraries and librarians, it would be great to provide the most relevant information in the quickest time possible. This directly ties to Ranganathan's Five Laws of Librarianship—'save the time of the reader' and 'every reader their book'—and the service-focused orientation of the modern library [52]. However, these quantum retrieval mechanisms may operate so well that they render libraries and information professionals obsolete. The complexity of these algorithms could also make it difficult for a librarian to explain to other users or identify when and how issues arise. One opportunity that may arise, however, is a new dimension of information literacy: what to do when the information retrieved is "too perfect." When an answer seems too good, does it mean that it is biased towards a certain perspective or that certain information may have been left out?

3.3. Automation

Quantum computing could dramatically accelerate the current rate and sophistication of automation due to its ability to rapidly optimize decision making [53]. Using the same principles that allow for efficient retrieval and break encryption, it can determine the fastest or safest path to get from point A to point B, minimize the amount of energy expended by a machine, and substantially reduce the number of errors that the machine produces [12].

One of the greatest barriers to widespread adoption of quantum-enhanced automation—other than the current technical limitations of quantum computing—is the high financial and energy cost [50]. This cost will be prohibitive in many cases, especially in the short term. Quantum systems are extremely expensive to build, operate, and maintain, requiring specialized conditions such as ultra-low temperatures to function reliably. This makes them impractical for many small-scale applications like optimizing a single self-driving car. However, like most emerging technologies, their cost, size, and energy demands are expected to decrease with time, while their performance and accessibility improve, prompting large-scale adoption.

4. The Post-Quantum Future

The emergence of quantum computing will prompt a few existential questions and challenges for society and many industries. This innovation is essentially a unifier, which enhances the capabilities of many of the existing technological threats to our technological

infrastructure and the knowledge worker's role in society [54]. This presents a new challenge for professionals to redefine their role in an evolving landscape [55]. This section explores some of the *potential* impacts that quantum computing may have on technology and society. While largely theoretical at this stage, these implications are important to consider in order to better anticipate and prepare for possible future developments.

4.1. How Will Knowledge-Based Industries Evolve?

While knowledge industries are unlikely to disappear, the nature of knowledge work will shift significantly. Tasks that rely heavily on pattern recognition, summarization, indexing, or data analysis will be among the most affected by quantum-enhanced AI systems [56]. Systems capable of instantly retrieving, interpreting, and explaining complex materials in plain language may challenge traditional roles such as research analysts, technical writers, or information specialists [57].

However, this shift is better understood as a transformation rather than obsolescence. Professionals in knowledge industries will increasingly focus on high-level roles in strategy, ethics, policy, education, and systems design [58]. Their value will lie in guiding the responsible development and application of these technologies, ensuring transparency, and fostering trust in how information is generated and used. To remain relevant, knowledge workers will need to emphasize human-centered competencies that machines cannot replicate—such as contextual judgment, interpersonal communication, and ethical reasoning.

4.2. What Is the Future of Work?

The future of work as a whole has been contemplated in light of the emergence of quantum computing. The speed of quantum algorithms would theoretically produce computers that can perform many human tasks at a rate much faster than a human [59]. Theoretical improvements in computational speed and efficiency could augment AI models, possibly automating repetitive, predictive, or pattern-based tasks more effectively than before [60]. This could have implications for a broad range of professions, from white-collar knowledge work to blue-collar tasks such as assembly or transportation [61]. At the same time, new opportunities are likely to emerge. The development, maintenance, and application of quantum technologies will require specialized skills, potentially creating new job categories [62].

4.3. What Becomes of the Human Mind?

One of the more intriguing questions relating to the emergence of quantum computing is what comes of the human mind, human interactions, and human values in the light of this rapid change [63]. Though many may argue that we have already reached the point at which human cognition and critical thinking skills are at their weakest in modern history, accessibility to technology that elevates the capacity of existing AI models to deliver information and perform tasks on our behalf will exacerbate these issues. Do we risk becoming alienated from all meaning in our lives, or do we become emancipated from memorization, work, and routine that consume most of our days? This is perhaps more philosophical and of long-term concern compared to the other two issues but one that might have the greatest sustained impact on society's well-being.

Table 3 describes all the areas proposed in this entry where quantum computing may impact society—particularly within the information and knowledge domains.

Table 3. Key Areas of Quantum Computing’s Projected Impact Across Information and Knowledge Domains.

Area of Impact	Description	Potential Benefits	Challenges & Concerns
Cybersecurity & Post-Quantum Cryptography	Quantum computing threatens traditional encryption; PQC aims to resist quantum attacks using hard mathematical problems (e.g., lattice cryptography).	More secure systems in a post-quantum world.	Existing infrastructure is vulnerable; risk of cyberwarfare.
Information Retrieval	Quantum-enhanced algorithms (like Grover’s) allow faster and more relevant data search and retrieval.	Rapid, precise access to information; supports complex queries.	May reduce role of libraries; risks of bias or over-reliance on “perfect” results.
Automation	Quantum optimization can drastically improve machine learning, logistics, and robotics.	Higher efficiency, fewer errors, optimized decision-making.	High costs, energy demands, risk of job displacement.
Knowledge-Based Industries	Quantum-AI systems could perform summarization, indexing, and analysis roles.	Frees humans to focus on ethics, strategy, and creativity.	Disruption of traditional professional roles.
Future of Work	Quantum computing boosts AI productivity across sectors.	Job creation in quantum tech; increased efficiency.	Threats to repetitive and cognitive jobs in both blue- and white-collar sectors.
Human Cognition & Society	Potential impact on mental engagement, purpose, and autonomy.	May liberate humans from routine tasks.	Risks of dependence, alienation, erosion of critical thinking.

4.4. Quantum Ethics and Policy

Ethics are obviously a major concern when it comes to the capacity of quantum-powered systems. As noted in the cybersecurity section, quantum computing threatens the most popular current encryption standards such as RSA and ECC (Elliptic Curve Cryptography), which are used in virtually all critical operations like banking, healthcare, and national security. Additionally, quantum technology *may* power superintelligent artificial intelligence systems, creating major changes in society overnight. Developers and policymakers need to engage in discourse about potential disruptions created by the emergence of quantum technology to determine if certain stakeholders need privileged and early access to new quantum decryption technologies, how the emergence of superintelligent systems could be managed by companies and the government, and how to ensure these quantum tools are used responsibly and to the benefit of society [64].

The pace of innovation has accelerated rapidly in recent decades, and patterns from other emerging technologies suggest quantum computing warrants serious attention now. Many thought similar things about artificial intelligence and the applications of large language models less than five years ago, yet AI transformed multiple industries seemingly overnight [65]. Recent developments, such as Google’s Willow chip designed to solve in under five minutes problems that would take modern supercomputers over 10 septillion years to solve, emphasize how close we are to a breakthrough in quantum technologies [66].

5. Conclusions

This entry has explored the fundamental principles of quantum computing, its current state of development, and its potential applications across various domains. While quantum computing remains in its early stages with significant technical challenges to overcome—particularly in error correction and qubit stability—the trajectory of development suggests transformative impacts are on the horizon. The implications extend far beyond computing-intensive disciplines. As quantum technologies mature, they will reshape cybersecurity infrastructure, accelerate scientific discovery, and potentially enable new forms of artificial intelligence. Proactive preparation is essential: organizations must begin developing quantum-resistant security protocols, researchers should explore quantum-enhanced methodologies in their fields, and policymakers must establish ethical frameworks to govern quantum technology deployment.

With this awareness, individuals should prepare for change now in order to become leaders for the next generation of technology. The emergence of large language models was merely one step in a rapid trajectory of innovation and expansion. Future steps are likely to introduce significant shifts in practice and policy, warranting proactive preparation. Even if we are not technical experts on quantum mechanics or computing, it is important for all individuals to understand the impacts that this innovation may have on our society.

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