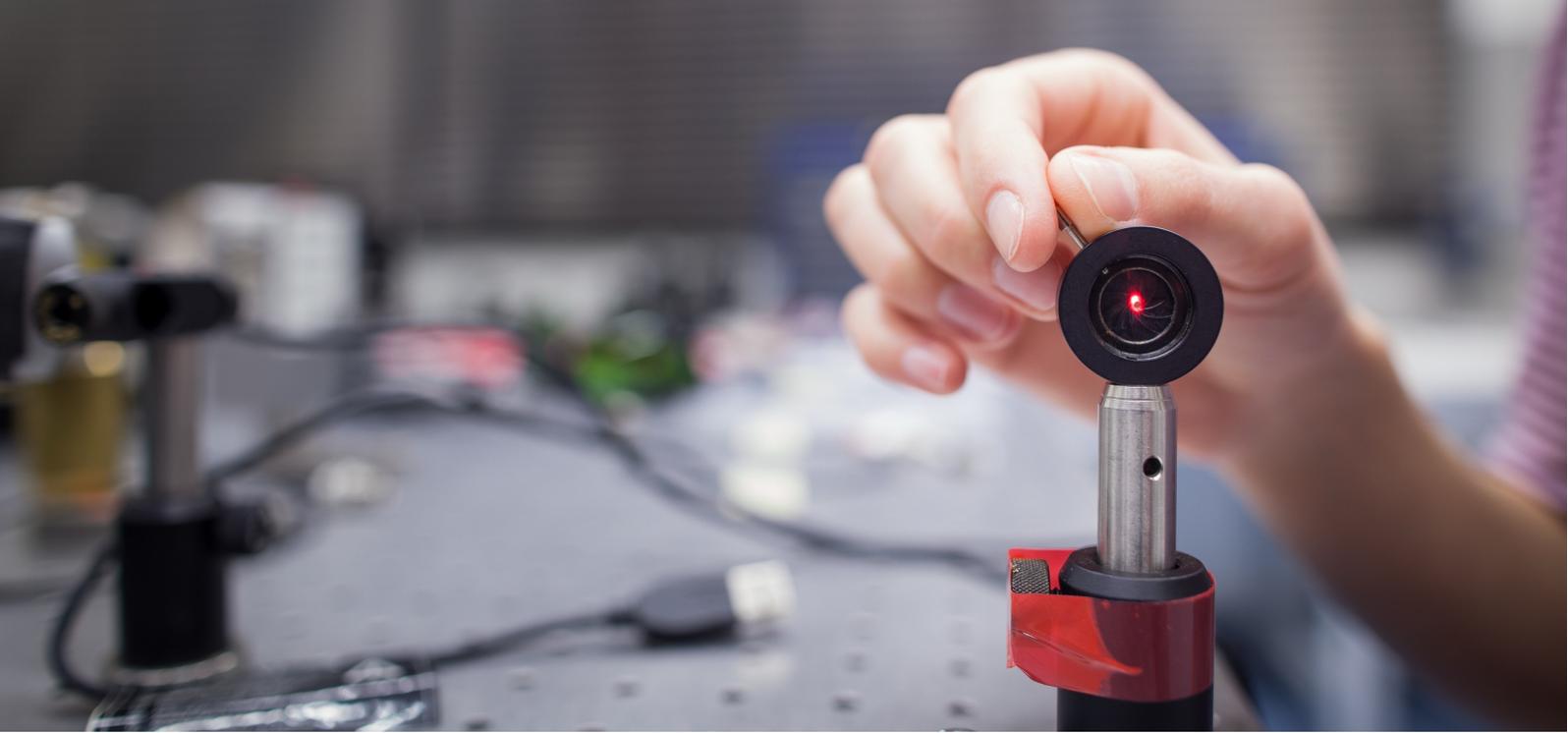




Revolutionising genomic sequencing through quantum computing

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Introduction

Advancements in science and innovation are only possible when an idea is given due recognition. Though implementing these ideas might seem difficult, it isn't entirely impossible. The possibility of building quantum computers is one such idea, which has become increasingly relevant in this globally evolving technological landscape.

Quantum computing is the new way of performing computation based on the principles of quantum physics. Unlike traditional computers which use bits, the smallest unit of information represented using 0 or 1, quantum computers use quantum bits or qubits. Qubits introduce a different behaviour to computation by using superposition—meaning they can exist as both 0 and 1 simultaneously—rather than being restricted to just one state. Entanglement is another property of quantum computing where qubits are linked in a way that the state of one qubit immediately affects the state of another. Quantum computing, using both superposition and entanglement, can potentially solve certain complex problems far more efficiently than even the fastest classical supercomputer.

Understanding how traditional and quantum computing differ is key to fully appreciate the potential of quantum computing technologies. Traditional computing involves transistors which either be a 0 or a 1 and its capacity is linearly proportional to the number of transistors. Quantum computing, on the other hand, involves qubits which can be both 0 and 1 at the same time and its capacity increases exponentially with the number of qubits. Additionally, qubits are extremely fragile and sensitive to the environment due to which quantum computers need a temperature close to absolute zero (-273.15°C) in order to function. Because of this, error rates in quantum computers are quite high. Traditional computers operate well in room temperatures keeping the low error rates.

Just like how a light bulb is not a more powerful candle, a quantum computer, contrary to popular belief, is not just a more powerful, faster, regular computer. It's an entirely different concept of computing, built on principles that do not exist in the classical world, designed to tackle a completely different set of problems. "The quantum tortoise and the classical hare: a simple framework for understanding which problems quantum computing will accelerate (and which it won't)", ¹ proposes an evaluation framework using which organisations can assess whether to use quantum computing to solve certain problems. The key insight of this framework is that quantum computing can seldom offer advantages for most small or medium-sized business problems. It can, however, be of importance for large-scale business problems with exponential algorithmic complexity and those that need to process massive datasets.

One such problem is genome sequencing. The rapid expansion of genomic data presents substantial computational challenges in the bioinformatics sector. Traditional methods struggle to meet the increasing demand for speed, accuracy, and efficiency. Genomic information is essential for human health. It is central to studying personalised medicine and early disease detection. But due to its large volume, even the fastest systems require hours or even days to read a complete DNA sequence.

¹ <https://mitsloan.mit.edu/press/will-quantum-computing-be-better-your-business>

Genome sequencing: The quantum way

Genome sequencing relies on breaking the DNA into multiple fragments, reading those fragments, and then reconstructing the sequence using algorithms such as dynamic programming, graph-based assembly, and heuristic searches. DNA consists of four nucleotide bases: adenine (A), cytosine (C), guanine (G), and thymine (T). These bases pair with one another in specific combinations—A with T and G with C. The human genome typically contains around 3 billion base pairs² and processing this volume of data requires enormous amounts of memory, and time.

Even though next-generation sequencing has improved speed and cost, classical computing still cannot fully overcome the underlying mathematical explosion of possibilities inherent in genetics.

Quantum computing, by leveraging superposition and entanglement, can evaluate multiple genetic possibilities simultaneously, carrying out certain genomic tasks more efficiently. One major advantage of using quantum computing is sequence alignment. Classical computers compare DNA fragments sequentially, which becomes time consuming as datasets grow. Quantum algorithms, on the other hand, can search and match sequences more efficiently—particularly for large and pollution-level genomes. Quantum computers are also better suited to uncover complex patterns, improving variant detection and genetic association studies.

Some of the algorithms that quantum computers use are:



Ultra-fast sequence alignment:

Algorithms such as Grover's search and Quantum Approximate Optimization Algorithm (QAOA) can accelerate matching and alignment tasks. Problems that scale quadratically or exponentially on classical machines can be solved more efficiently with quantum speedups.



Handling population-scale genomic datasets:

Quantum systems can analyse massive, multidimensional datasets more efficiently. This makes it possible to process millions of genomes in ways classical systems cannot.



Superior variant detection:

Quantum-enhanced machine learning can identify rare mutations, structural variants, and complex patterns in DNA more sensitively than current classical models.

² <https://www.indiatoday.in/science/story/human-genome-fully-sequenced-gene-editing-dna-chromosomes-medicine-1932311-2022-04-01>

Benefits of using quantum computing for genome sequencing

Quantum computing can solve numerous complex problems in molecular biology like drug discovery, structural simulations, protein folding, and genome assembly. The healthcare industry, to this day, faces challenges due to massive datasets, molecular complexity, and long computational cycles. Experts believe that quantum computing could provide a solution to these problems. Quantum computers can explore numerous possibilities simultaneously due to the principles of superposition and entanglement. These principles are helpful in addressing challenges in protein folding, genome sequencing analysis, and molecular interaction modelling.³

Processing vast genomic data becomes exponentially fast—taking minutes not hours, as it previously did. Quantum computing excels at pattern recognition, identification of genetic variants, and protein folding predictions with unmatched precision. These capabilities give the healthcare sector deeper insights into genetic disease prediction, accelerate drug discovery, and make personalised and precision medicine more accessible and effective.

From an economic standpoint, faster analysis reduces computational time, energy usage, and dependencies on large-scale computers, therefore lowering operational costs. In medicine, quicker genomic insights enable earlier diagnosis and more targeted treatments, reducing trial-and-error approaches. In the pharmaceutical industry, quantum-accelerated genomic analysis can shorten drug discovery timelines and R&D expenses.

As technology matures, these efficiencies will make large-scale genome sequencing more affordable and accessible, delivering greater value than classical computing for complex genomic problems.



³ <https://www.analyticsinsight.net/healthcare/are-quantum-computers-the-future-in-healthcare-or-just-a-hype>

Conclusion

Quantum computing is still in its early stages, but the pace of advancement is remarkable. Google aims for a million qubits by 2030, while companies like Rigetti, Honeywell, Microsoft, and PsiQuantum are shaping the emerging quantum ecosystem. The quantum computing market, projected to grow from \$928.8 million today to \$6.5 billion by 2030, reflects accelerating commercial interest⁴

However, challenges remain—qubit fragility, extreme cooling requirements, high error rates, and a global talent shortage. We are currently in the Noisy Intermediate Scale Quantum (NISQ) era, where quantum computers exist but remain noisy and limited. This means that the current quantum computers operate on qubits that are highly sensitive to the environment. Slight change in temperatures or electromagnetic radiation can cause a qubit to lose its quantum information, thereby causing errors. Nevertheless, hybrid quantum–classical systems and quantum cloud services are making the technology increasingly accessible. Quantum computing may not replace classical computing, but for genomics—the study of one of nature’s most complex systems—it offers transformative potential. The problems are significant, but the benefits are extraordinary.



⁴ <https://www.fortunebusinessinsights.com/quantum-computing-market-104855>



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