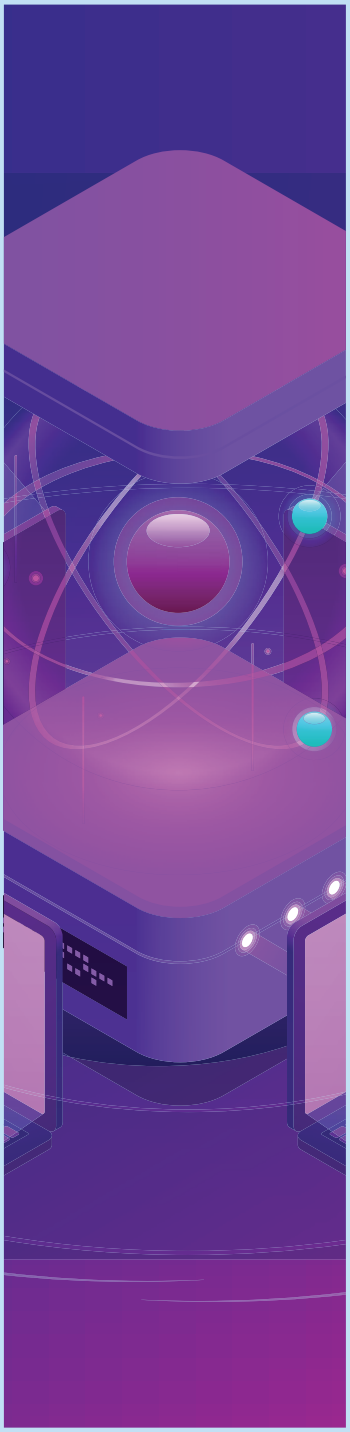
VIEW POINT



QUANTUM WINTER A REALITY OR MYTH?

Abstract

Is Quantum winter a reality or myth? It has been the focal point of recent trends in quantum computing and quantum-inspired solutions. This POV briefly touches upon the events of AI winter and discusses if quantum will suffer the same fate. Not just quantum computing, but why is quantum physics so important? Does it hold the key to everything? Can it solve the mysteries of the origin of the universe? Quantum mechanics and string theory are two leading theories that can explain the universe better than most. But they all are only theories. Quantum computing in recent years has become a little more than just a theory with the invention of QPU (Quanutm processing units) & Quanutm inspired solutions. Few are still skeptical about QC's exponential computation capacity and solving decades-old millennium-priced problems in just a blink of an eye.

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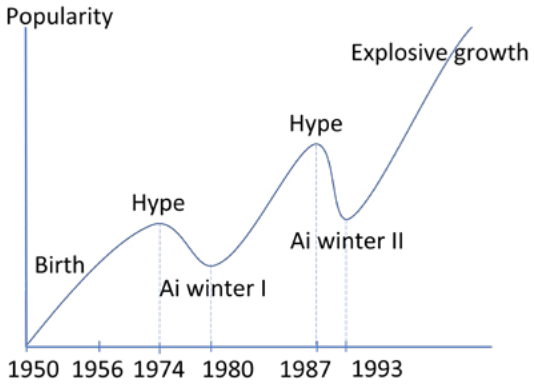
Quantum Winter?

Alan Turing [1950] asked the question - Can machines think? The concept of 'thinking' is difficult to define, so he asked a simple question, whether a machine could imitate a human being, and this came to be known as the "Turing Test". It led to a series of inventions, finally leading to AI as we know it today. The word "Q winter" is derived from AI winter. The funding and interest in AI were declining during the winter period. This term was coined from the likeness to the concept behind nuclear winter. Several hype cycles took place in this field, followed by disappointment, criticism, and funding cuts, and further followed by renewed interest years or decades later when people began to realize the significance. Quantum is also facing some criticism and doubts, and hence some say that the Quantum winter is coming.

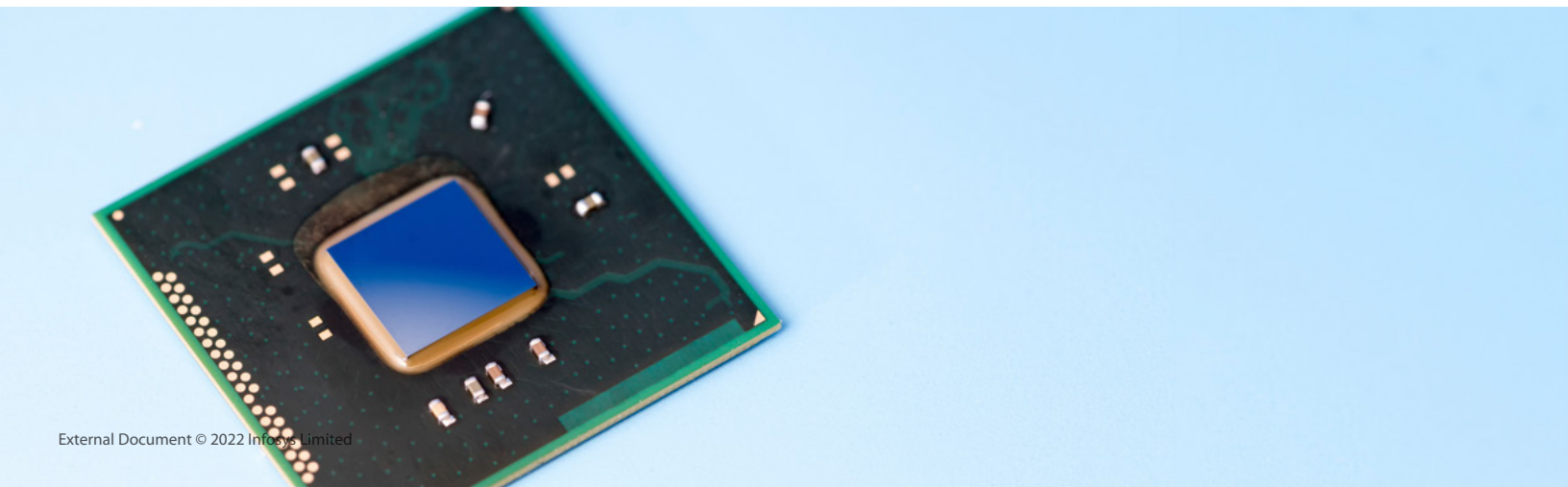
AI Winter Brief Timeline



(Source - https://www.actuaries.digital/2018/09/05/history-of-ai-winters/)

Artificial Intelligence Failed and is Just a Hype

Hype is prevalent in every emerging technology, and such was the case with steam engines and planes. Back in the old days, people thought humans could not breach the speed limit of 50 miles/hour and, if done so, their internal organs would explode. So, hype, criticism, and doubts around the new technologies are quite common. Amidst the ups and downs, AI continued to develop newer and better technologies that already have found their way into our homes in the form of smart devices. There is a silly myth that artificial intelligence (AI) has failed, but AI is all around you all the time, according to AI researcher Rodney Brooks (2002). If that was the case back in 2002, can you imagine the level of impact AI has on us today on a day-to-day basis? While writing this PoV, I asked Alexa to rap and make a shopping list for me. Even, the sentences you are reading now have been dictated by me to Microsoft Word. Imagine a computer listening to me, understanding what I am saying, and writing the same thing in English. It seems simple enough, but this in itself is a significant achievement. Humanity has taken a giant leap from just a question - 'Can machines think?' to now, machines actually thinking, learning and beating us in the game of 'Go' or 'Chess', the very humans who created them. Then what are AI winter and Quantum winter? Let's understand the reason why the AI winter started, how it ended, what caused it and see if it is the same with quantum computing.



The Downfall of AI *(AI Winter the Beginning)*

The word "Artificial intelligence" was coined at a summer research workshop at Dartmouth College in 1956, and it was then that AI and AI research as a separate field was officially born. A collective of prime minds in this space like John McCarthy, Marvin Minsky, Claude Shannon, and Norbert Wiener suggested that - Machines can simulate intelligence if they are programmed, such that they can precisely imitate human intelligence by virtue of machine learning. It provided a realistic road map for subsequent research in AI. Taking inspiration from the 1940's advances in the field of neuroscience, Frank Rosenblatt 1957 created the perceptron, a simple neural network with only one layer of neurons connecting inputs to outputs with adjustable weights, which was a very crude representation of the neurons in the brain in the form of computing code. Even the sophisticated computers available then were too slow to handle the computation requirements of the cutting-edge perceptron, so he built an ingenious machine that was purpose-built for perceptron and could differentiate between shapes and English letters. Then there was an increase in funding. But in the '50s and early '60s, the progress stalled.

The period from 1967 to 1976 was a quiet decade with very little progress. Bar-Hillel showed that machine translation was not feasible. According to him, it was "utterly chimerical and hardly deserves any further discussion." Later Minsky and Papert 1969 proved that only linear problems could be solved, but non-linear problems could not be solved and hence caused a downfall of AI. Thus, interest was lost, no further funding was provided, and no major corporations extended a helping hand, as very few at the time understood the significance of what was being developed. So subsequent few years were considered the first AI winter.

AI Winter: The Conclusion

It took almost 17 years until backpropagation came to light, which revolutionized AI forever (later, a new fact came to light stating that the backpropagation was discovered way before even Rosenblatt came up with the artificial neural network). It brought a ray of hope for AI to be practically implemented to solve real-world problems. This article is just from the point of view of Rosenblatt and the subsequent events that took place in the development of AI and neural networks today because it forms the basis of most AI applications like image recognition, self-driving cars, etc. The brief history of AI is already discussed in the short blog featuring the same debate with a comprehensive AI history covering not only neural networks but almost all the events of AI. AI winter partly was caused because the computation power of the computer that existed back then was not enough, and at the same time, many people believed AI to be just a hype in the scientific community. The current scenario for quantum is somewhat similar to what AI was going through. The field is under criticism from industry experts and scientists, but now, due to the rise of social media and the internet, more and more companies aiming for quantum supremacy Q winter might not be coming anytime soon. However, let us not get ahead of ourselves and get the discussion back to AI winter. I believe that

AI winter came partly due to the absence of access to the latest technologies and partly because very few believed in it, and even fewer among them pursued it no matter what. These few brave men and women changed the technology world as we know it because AI is everywhere today.

Not only computer programming but nowadays, every other school and college is teaching artificial intelligence and data science. If such facilities had been available then, someone like me would have written an article on how AI winter is just a myth. Enough hearsay, and let us get down to the facts. How did AI winter end? Some believe that it ended with the invention of backpropagation, and there was a rise in interest in the field, but later, another AI winter happened. There were many reasons, but it was mainly due to the nonavailability of high-end computers because AI is a computation-hungry beast. It requires a huge computational power, and even today, one cannot simulate or run industry-level problems on a regular laptop. One would need high-end GPUs and CPUs, or some people would directly use cloud services. So, it is believed to have ended somewhere in the period of the mid to late '90s when computers were more powerful and capable of handling AI computations, and many industries ceased this chance to fill the technological void of machine intelligence with AI-powered products. That was when AI research started getting a lot of funding. Even large companies started building AI-ready components and incorporated AI to the point that no one could differentiate if certain things that machines did were hardcoded or were AI. Such examples would be Google Search Engine and Netflix video recommendations (both were launched around the same time in 1998 and 1997, respectively, and no one knows whether they migrated to AI or were built from scratch on AI). Nick Bostrom said, "a lot of cutting-edge AI has filtered into general applications, often without being called AI because once something becomes useful enough and common enough, it's not labeled AI anymore." At the same time, some vendors are labeling their products and software as "Self-learning", "Machine learning-enabled", or "Powered by AI", etc., to sell their product even if it does not have any AI components or software. It is unsure if this is to sell their products or forestall another AI winter. Food for Thought.

Quantum Tunnel

Now that we have a brief understanding of AI winter, we can get down the path of quantum.

Before quantum computers were invented, in the period of mid to late 80s and early 90s, most computer engineers and scientists believed that binary/classical computing was the ultimate invention. Everyone was sure that they should be able to compute everything that is computable in the universe, from basic arithmetic to rocket science. Moreover, Moore's law was popularized and tried to predict the advances in computational power of CC – Classical Computers. CCs could not necessarily do everything efficiently, though. Let us say you wanted to understand something like the universe's origin or perform a task like studying the behavior of atoms or molecules. When you enter the realm of atomic and subatomic particles that form the basic building blocks of everything, even the mere classical computers trying to unravel these mysteries, the CCs begin to falter. It is because science or physics becomes spooky (Search "Spooky Action at a distance" for more information). This realm is ruled by quantum mechanics and its phenomenon such as entanglement, superposition, coherence, etc. Calculating these states becomes an exponentially increasing problem with the increase in complexity. Finally, these supreme classical computers reached their limits giving rise to a new breed of superheroes called the quantum computers that were steady challengers to the previously unbeaten hero, the classical computer. A quantum computer can deal with particles under study by superposing and entangling its own quantum bits (Qubits). For example, 1 Qubit can hold 2 classic bits of information, 2 Qubits can hold 4, and 3 can hold 6, and so it grows exponentially. For instance, we need just 40 entangled qubits to model a problem state that requires 1 trillion classical bits to model the same problem. If quantum computers are so powerful, why is there a debate about the Quantum Winter? It might be due to the below facts:

Challenges

- Quality of Qubits – The current generation quantum computers are noisy and inaccurate.
- This current generation's noisy quantum computers are outperformed by supercomputers, quantum simulators and quantum inspired optimizers.
- Error correction in quantum computing is a difficult task.
- The scalability of quantum computers is limited by current technology. QPU-powered laptops are still decades away.
- At the very least, generating a qubit and holding it to a steady state itself is a big challenge.
- On top of the above challenge, quantum computers need to maintain the state of entanglement, coherence, and other necessary properties of qubits for calculations, and this proves to be a Herculean task.

- Some quantum computers need a cryogenic apparatus to maintain their temperature precisely above absolute zero. With the current scenario of power outages and energy crises, this would not be very feasible.
- Even if it were feasible, the most challenging hurdle is that we cannot store the system state or pause in-between calculations, switch off, go and grab a cup of coffee, come back and resume. If done so, we need to start all over again because of the no-cloning theorem and decoherence. Additionally, these calculations sometimes take hours and days to compute.

There are several other reasons still under debate, which some feel are the barriers that need to be overcome to commercialize the power of quantum computers. Until we achieve that, we should curb this hype about quantum computers and focus on real-world problems like global warming, hunger and poverty, financial frauds, bankruptcy, trading inefficiencies, etc., to ensure a growing world economy and prosperity for all. One more debate is if we do not allow such wide spread of Q-tech or any other growing technology, there would hardly be any progress. Mindshare of knowledge and continuous efforts to progress can empower global minds to collaborate and elevate the technology landscape to its fullest potential. If we say no to every technology below the TRL threshold (Technology Readiness Level), technological advancement will be stalled for humanity and science in general. The Infosys Quantum Center of Excellence has use cases built on quantum computing for tackling world problems like carbon capture and sequestration, financial fraud detection, malware classification, optimal route planning, portfolio optimization, credit risk analysis, and more.

Quantum computing aside, the fact of the matter is that an ordinary calculator can beat a quantum computer if given a simple mathematical calculation for both. But would we really use a quantum computer for calculating 1+7? Moreover, some say QC's can be commercially viable only if we reach at least 1,000,000 qubits. At the same time, are 1 million qubits really required or can we make do with superior quality 1,000 or 10,000 Qubits. The question remains to be answered.

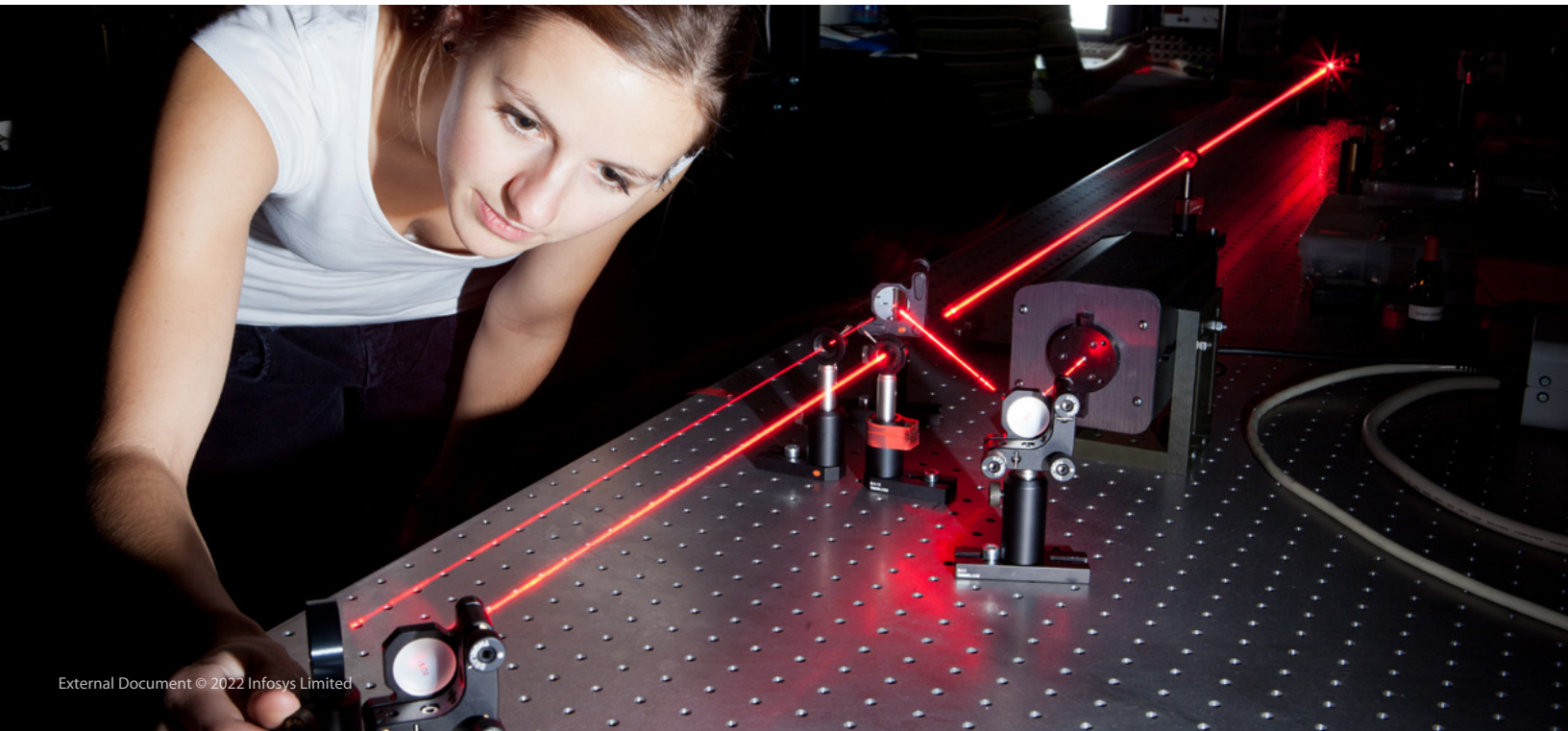
Let's see if Q can solve some of the above challenges

- [sciencedaily] Research advances noise-cancelling for quantum computers
- [scitechdaily] Quantum Computing in Silicon Hits 99% Accuracy
- [zdnet] Q-CTRL touts error-correction methods boost quantum algorithm success by 1000 times
- [news.microsoft] Microsoft Azure reveals a key breakthrough toward scaling QC
- [sciencealert] Scientists can now Measure a Mechanical Quantum System Without Destroying It
- [wired] Euler's 243-Year-Old 'Impossible' Puzzle Gets a Quantum Solution

Hopefully, the above points must answer all the doubts that have surrounded quantum challenges, and dedicated efforts around the globe are continuously taking quantum computing to newer heights. The above points are not the final solutions in proving Q technology for scalability, reliability, etc. But surely, this indicates that there is enough industry-backed momentum to catapult it through TRL for commercial application. Below mentioned points are some of the astonishing facts and recent breakthroughs in the field of quantum computing.

Recent Breakthroughs in Quantum Computing

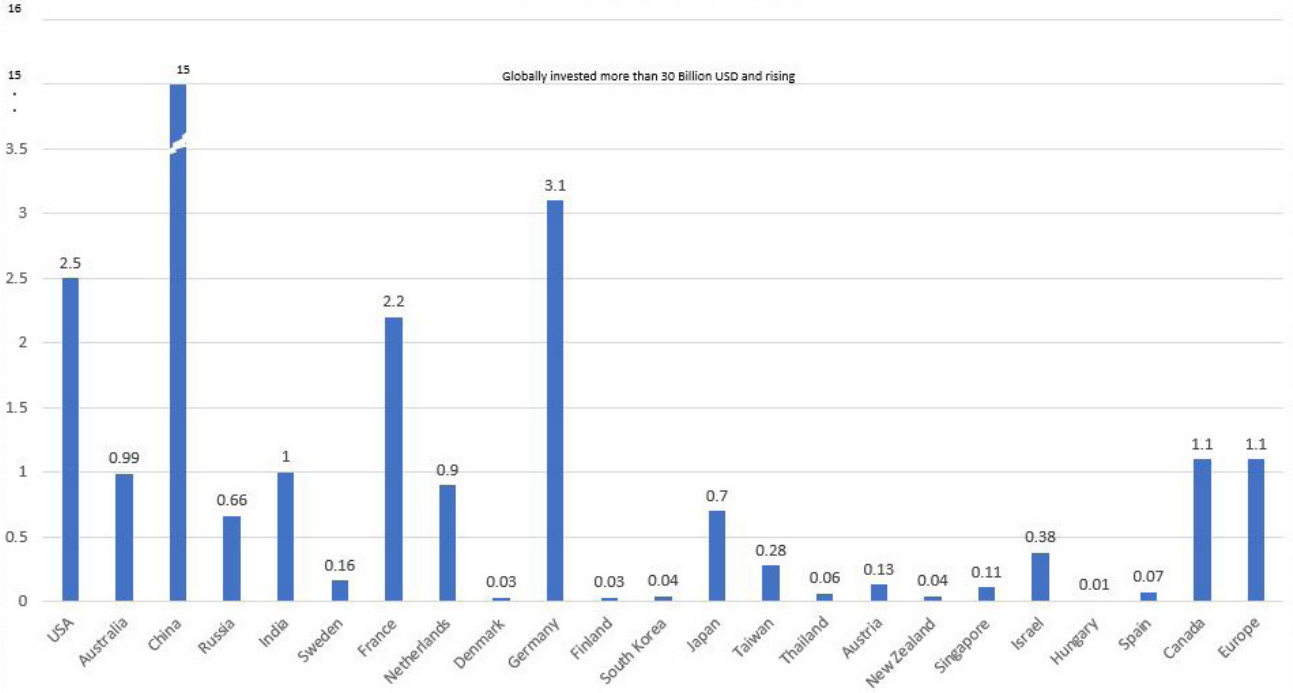
- [ndtv] Indian Army Sets Up New Quantum computing Lab, Artificial Intelligence Centre
- [economictimes] India and Finland work out a plan to set up a virtual network center on QC
- [IonQ] IonQ Takes Quantum Computing Public with $2 Billion Deal
- [Rigetti] Rigetti, a Quantum computing company also goes public with a $1.5B valuation
- [computerworld Apr'19] GTN discovers new drugs with machine learning and quantum physics
- [volkswagen-newsroom Oct'19] Volkswagen optimizes traffic flow with QC
- [gruppotim.it Feb'20] TIM is the first operator in Europe to use quantum computing live on its mobile networks (4.5G and 5G)
- [caixabank Apr'20] Caixa Bank becomes the first Spanish bank to develop a risk classification model using QC
- [newsroom.ibm Mar'21] Cleveland Clinic, IBM launch 10-year quantum computing partnership
- [qcware Apr'21] Goldman Sachs is claiming a quantum computing breakthrough, designing algorithms it says could be used on hardware that may be available in as little as five years
- [Insidequantumtechnology Jun'21] Huawei's HiQ Cloud Service Platform Includes Qc Simulator and Q Programming
- [Citibank Sept'21] Citi joins $25 million round in quantum pioneer QC Ware
- [eon Sept'21] E.ON allies with IBM Quantum to Advance Energy Transition Goals
- [fortune.com Jan'21] Roche taps into quantum computing software for Alzheimer's disease research
- [prnewswire.com Jan'22] Menten AI Partners with Xanadu to Develop Quantum Machine Learning for Protein-Based Drug Discovery
- [hyundai Jan'22] Hyundai Motor partners with IonQ for battery development and object detection
- [prnewswire Jan'22] Quantum computing Application Sees Real World Success at Pier 300 at The Port of Los Angeles
- [Samsung April'22] The Galaxy Quantum 3 mobile phone has been revealed in South Korea. The smartphone will be available for pre-order from April 22 to April 25, 2022. Galaxy Quantum 1 and 2 are already available in the market



Putting Things into Perspective

Those new to the quantum field must be surprised by the above facts. There is so much happening in quantum, yet we are unaware. Furthermore, a point to be noted is these are not just some POCs or trials but are real-world impacting events. And this is just the tip of the iceberg. Can you even imagine a smartphone that already has quantum technology in it?

- As per the article "Quantum Leaps in Quantum Computing?" by Charles Q. Choi on Dec1, 2017, in principle, a 300-qubit quantum computer could perform more calculations at once than the number of atoms in the observable universe.
- Chinese quantum computer, Jiuzhang, Gaussian Boson Sampling detected a maximum of 76 photons in 1 test and an average of 43. The time taken was 200 seconds compared to 2.5 billion years by the fastest Chinese supercomputer, suggesting that a quantum computer can perform that task 100 trillion times quicker.
- "We estimate that the sampling task finished by Zuchongzhi quantum computer in about 1.2 hours will take the most powerful supercomputer at least eight years." Yulin Wu et. al. report in their paper "Strong Quantum Computational Advantage Using a Superconducting Quantum Processor".
- Google boasts that its quantum computer can solve a problem that was classified as "infeasible" in under 200 seconds. For which a standard computer would require 10,000 years to find a solution.
- Global Q Technology Market Report 2020 highlights that this market will reach $21.6 billion by 2025.
- Global investment in quantum technology has already crossed $30 billion and still rising.



Overview of Global Funding in Quantum Technologies(Source - https://qureca.com/overview-on-quantum-initiatives-worldwide-update-2022/)

The current generation of quantum computers is just the 1st generation quantum computers. Imagine what would they be able to do after a few years. Below are some of the companies that are involved in building quantum computers:

Type of Quantum Computer	Superconducting QC	Trapped ION QC	Neutral/Cold Atom QC	Laser / Light	Photonic QC	Silicon Spin QC
Companies / Institutes	IBM Q, Google, Rigetti, Dwave, Seeqc, Alibaba, IQM, OQC	Honeywell, IONQ, Quantinuum, AQT, Oxford	Cold Quanta, PASQAL, QuEra, Atom computing	Vescent, NKT, QANT, Toptica, Ligentec	Quanfluence, PsiQ, Xanadu, PsiQuantum, QC82, ORCA	Intel, photonic, equal1, quantum motion

These are some service providers, clients, and educational institutions in the field of quantum:

Software Service	Infosys, Fujitsu, NVIDIA, Atos, Huawei, 1Qbit, QCWARE, NQCG, HQS, ZAPATA, CLASSIQ, ParityQC, menten.AI, Qubit, Terra Quantum, Keysight, QuantFi, ProteinQure, Multiverse computing, HQS, QCTRL
Cloud Services	Aws, Google, Azure, IBM, Dwave, Fujitsu
Major Clients	Volkswagen, Bank of America, J.P.Morgan, Wells Fargo, Odyssey, AstraZeneca, GSK, Denso, Johnson electronic, Goldman sachs, Airbus, Merck, OTI, BMW
Education	MIT, Stanford, IIT, IBM, classiq, Google, Dwave, Oxford, Intel, Coursera, Udemy, Qpiai, edx, NPTEL, Pennylane, Czech TU, Buffalo Uni, Delaware Uni, MISIS, UCL, ETH Zurich

Conclusion

Let us, for a second, divert our attention toward what gave rise to quantum computers. The answer is quantum physics or quantum mechanics. Since the discovery of the Higgs Boson in 2012 (that discovery by itself took decades and decades of collaboration, funding, and ultimately belief), no substantial breakthrough in the area of physics has taken place that can unify all theories or explain everything. I believe that "the rate of discovery is directly proportional to the size of the object under study". You may quote me if someone else has not already said it before. Therefore, for the same reason, we cannot call it winter. Earlier, scientists thought classical physics had explained everything, and nothing was left. Of course, they had not looked close enough at that time. If we look closely at fundamental particles like subatomic particles and some large objects like black holes, our science begins to fall apart. Until now, all the fields of science, be it physics, biology, chemistry, etc., were only trying to understand the behaviors we could see with our naked eyes. Due to the same factor, every other person came up with theories and postulates to explain it. However, nowadays, almost everything obvious we can see and feel has been explained, making us look even further deeper within. And that's when things start getting difficult because you need high-end equipment, months and years of study, only to understand its nature and properties. Take cancer, for example, we have not been able to find a cure, and it's been around for ages, and we have not been able to eradicate most diseases, even the ones like the common cold and fever. Furthermore, we have not been able to find a replacement for plastic and its undegradable property.

Quantum computing, while being massively computationally powerful, at the same time has a lot of wrinkles to iron out. Recollecting my thoughts from 'AI Winter the Conclusion', AI winter might be because of a lack of modern facilities like the internet, social media, widespread education of cutting-edge technology, cloud computing, and large corporations did not believe in it at the time. Nowadays, many universities are giving quantum computing courses, and there are many online courses for quantum computers and quantum processors available on the cloud at a very affordable price. Large corporations and many startups have worked on quantum technology for a few years, and many countries globally have invested in quantum technology at an overall investment crossing $30 billion and rising. Anyone can choose to buy stocks of companies doing research in quantum computing. Are the scales balanced enough for us to compare this with AI winter or nuclear winter and conclusively say that quantum winter is coming?

AI winter was a phase of no breakthroughs with investments and interest lost in the field but is it the same with quantum? From all the points discussed in this article, do you believe quantum winter is coming? or has it already arrived, and we have not noticed it because we are so overwhelmed by the quantum technology that we are blind to it.

Food for Thought.

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About the Authors

Adarsh V Katagihallimath

Adarsh enjoys his role as Senior Associate Consultant with Infosys Centre for Emerging Technologies. He is part of the Quantum Centre of Excellence and works on tackling classically unsolvable problems with Quantum computing, Quantum-inspired solutions and Artificial Intelligence.

Contributors

Vijayaraghavan Varadharajan

Dr. Vijayaraghavan Varadharajan is a Principal Research Scientist doing research in the field of Quantum Computing, XAI, FoW, Security Analytics, Cloud security, Security assessment, Authentication and Privacy protection. He also focuses on Emerging technology & Business opportunity identification, Incubation and Venture assessment for Investments. He is working with universities and seeing how academic research can help in solving real-time Industrial problems. Vijay has 6 granted US patents and filed many US and Indian patents in key technology areas. He has published 50+ research papers in international journals & conferences.

Aseem Rajvanshi

Aseem Rajvanshi is an Associate Consultant working in iCETS. His main objective revolves around researching various industries for trends and emerging technologies like Quantum Computing, AI, etc., and preparing thought leadership articles. He completed his MBA in Data Science & Data Analytics from SCIT, Pune.

Write to quantumcomputing@infosys.com to know more on Infosys Quantum Center of Excellence.

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To know more, please reach out to iCETS@infosys.com.

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