QUANTUM COMPUTING FOR DIGITAL TRANSFORMATION OF COMPLEX BUSINESS OPERATIONS

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Introduction

Exploration, innovation, speed, quality, scalability, agility, efficiency, and effectiveness always remained the collective mantra for human civilisation right from ancient days. Originally meeting needs for living life and fighting out existential threats used to be the driving force and motivator for discovering new sources of energy, food, shelter, and other consumables. Gradually, ease of living life and finding/crafting new goods for consumption, expansion, diversification, entertainment etc. evolved as the drivers for exploration and discovery. Mankind started becoming creative and thus explorations for new started yielding inventions and creative value creations. They also learnt the process of creative destruction to make room for new and 'innovention' for moving ahead through the path of making life better and affable.

This process never stopped as *charaiveti* or long endless journey towards self-realization evolved as the new addition to the mantra making life meaningful. People started moving through the accelerated process of civilisation. Here the word self-realisation is not being used from spiritual perspective but to mean self-actualisation. Two forces led the innovative mind for making the world a better place to live with ease and satisfaction. But satisfaction continued to remain unsatiable.

The eternal yearning for knowing why things happen in specific ways they happen and as being observed in nature was the first one. The foremost example of this is Newton's discovery of laws of gravity, the principles of visible light, and laws of motion. And the second one is self-actualisation by doing something that can remove sufferings of mankind. Plenty of inventions and discoveries in medical science are testimonies of these. The recent one is creation LED bulbs to minimis electricity and thus reduce carbon emission and also save cost.

Image Source: *https://www.cnet.com/tech/computing/ibm-new-53-qubit-quantum-computer-is-its-biggest-yet/*

Human civilisation witnessed several revolutions and hundreds of evolutions in the homogeneous fields of development. The process received accelerated pace right from the first industrial revolution commencing from 1780s for mechanisation powered by water and steam. The second revolution came in 1870s when mass production started with electrification of industries. But speed, control systems and qualitative perfection simultaneously with higher volumes still eluded mankind. Scientists continued with cerebral research to achieve more. The third industrial revolution, which started around 1970 was essentially driven by advanced computer science and technology. In this Industry 4.0 era computing technology has further advanced and moving towards commercialisation of Quantum Computing, which is the subject matter of this paper.

Objective

Quantum computers and quantum computing is an emerging field in the broad arena of information and communication technology with borrowed knowledge and application technique from the domain of quantum physics. It has started evolving at a slow but steady pace. Most of the developments so far are in the form of experimentation and pilot projects. Keeping these features in view the objective of this paper is dissemination of first-hand knowledge and information about quantum computing. Efforts would be made to briefly discuss the changes from classical computing systems to quantum computing systems without getting into technological matters. Efforts would be made to also share some outlines of the applications of quantum computing that are gradually revving up for benefits of industry trade and commerce.

Evolution of Computers and Computing Systems

The unsatiated desire of mankind to create and contribute something new for society was the crucible for the third revolution which started around 1970 with many more evolutions in both hardware and software for computing. Since then, computers and electronic control systems started being adopted for automation of industrial units and official desk top jobs. After this automation by computerisation became a global movement. This was further accelerated by advancements in communication technologies which made computers and handheld devices mobile. Research and development continued and presently quantum computing is on the verge of being adopted for commercial use by handling voluminous tasks.

In the article of October 2022 on Web3.0[1] under this column, the author has briefly written about the path through which the process of communication evolved from ancient days to present day Web3.0 for computerised communication. Similarly computing technology has also evolved from the first computer to present day quantum computing. The mechanically run analytical engine, or the popularly known difference engine, of Charles Babbage, on which he worked up to 1871, is regarded as the first ever computer of the world. Ideas for many subsequent complex electronic designs for modern computing machines are borrowed from it. However, the idea for programming of a modern computing machine has been borrowed from the Punch Cards[2] for making textile weaving patterns of Joseph-Marie Jacquard (1820), a French weaver and merchant.

Readers would be keen to know more about the history of evolution of computers, including laptop and palmtop computers like iPad and phones. The chronicle published by Computer History Museum[3] containing evolution of computers from 1937 to 2015 would be a good read for them. Balmer Lawrie group of Kolkata used to operate computers for writing financial books of accounts in which data used to be inserted through punched cards. The computing machines used to be almost as tall as the room ceiling. The author confirms these two having seen in 1980s during his employment period with that group.

Punch card used to be the system for data entry in many organisations before data punching system was adopted using electronic devices to generate off-line inputs for computerised processing of data. Later tape drives came for storing both punched and processed data. Experimentation for directly providing inputs to computers from a keyboard started experimented from around 1951at MIT but perhaps was put to successful commercial use quite later.

Genesis of Quantum Computing

Oxford Dictionary defines the word 'quantum' as "*a discreet quantity of energy proportional in magnitude to the frequency of the radiation it represents*" and 'computing' as "*the use or operation of computers.*" The former definition was borrowed from scientific domain. In common parlance if these two words are combined Quantum Computing (QC) can simply be defined as that system which uses the 'Quantum Theory' the original knowledge for which belongs to the domain of Physics as a subject. Therefore, QC is a product that emerged from combination of multiple knowledge dawn from the domains of Physics, Mathematics and Computer Science.

Quantum mechanics was developed in various stages during years between 1900 to 1925. However, this paradigm shift in computing technology, inspired by quantum theory, was first ideated in 1980 by Richard Feynman, considered to be the father of quantum computing. He was very ably supported by Yuri Ivanovich Manin, a Russian mathematician who could integrate theoretical physics with mathematical logic. Paul Anthony Benioff, an American physicist also contributed through his cerebral research on quantum information theory.

Classical computers generally

perform using the principles of Boolean Algebra. Computer scientists explain that classical computers work with three or seven mode logic gate principle. Readers are aware that using this principle such computers, including laptops and smart phones, process data in exclusive binary state at any time consisting of 0 meaning off/false or 1 on/true. For this each computer has a processing circuit with large number of transistors and capacitors. The whole system has limitations of processing speed and quickly switching from one state to the other for performing functions dictated by the users, albeit that speed is also overwhelming.

The fundamental unit of remembrance or memory in a Quantum Computer is a 'Quantum Bit' or a 'Qubit'. A quantum bit is a basic unit of information which is used for performing multifaceted quantum algorithms. It is created from a quantum system like an electron or photon. "*The foundational core of quantum computing is to store information in quantum states of matter and to use quantum gate operations to compute on that information, by harnessing and learning to "program" quantum interference".*[4] The findings from a random reading by the author reveal that while *" ..... a classical computer needs eight bits to represent any number from 0 to 255, a quantum computer would be able to represent every number tween 0 to 255 at the same time."* However, computer scientists can confirm this claim as the objective of this paper is not to deal with technicalities of QC.

Quantum Computers - Ideation and Developments

It took quite a lot of time since ideation by Richard Feynman for an actual quantum computer to see the light of day. Tireless and intensive research efforts of scientists in Universities of Berkley, MIT, Oxford, Stanford, etc., as well as IBM meet with success in developing a few 2 Qubit Quantum Computer. The journey continued to be a bit slow. In 2007 came the first 28 Qubit computer for field application from the stable of a startup called D-Wave of Canada.

Source: https://thequantuminsider.com/2020/03/31/d-wave-offers-free-quantum-cloud-access-for-covid-19-projects/

Their efforts continued to further increase the processing speed. D-Wave as a startup was magnanimous enough to provide access to their cloud computing system, powered by QC, for all project work that were performed for Covid-19 Pandemic. Scientists and research look for the services of a supercomputer, being a computer with high level performance as compared to general ones, when they work with voluminous data for complex calculations with many variables. At times supercomputers also fail to serve their purpose the way they want. Quantum Computers (QCs) are designed to serve such requirements for computing at gigantic scale with lightning speed because those can function faster than a classical computer by a hundred to thousand times. The user's device of a QC system is about the present size of a computer, but the main processing unit is quite large.

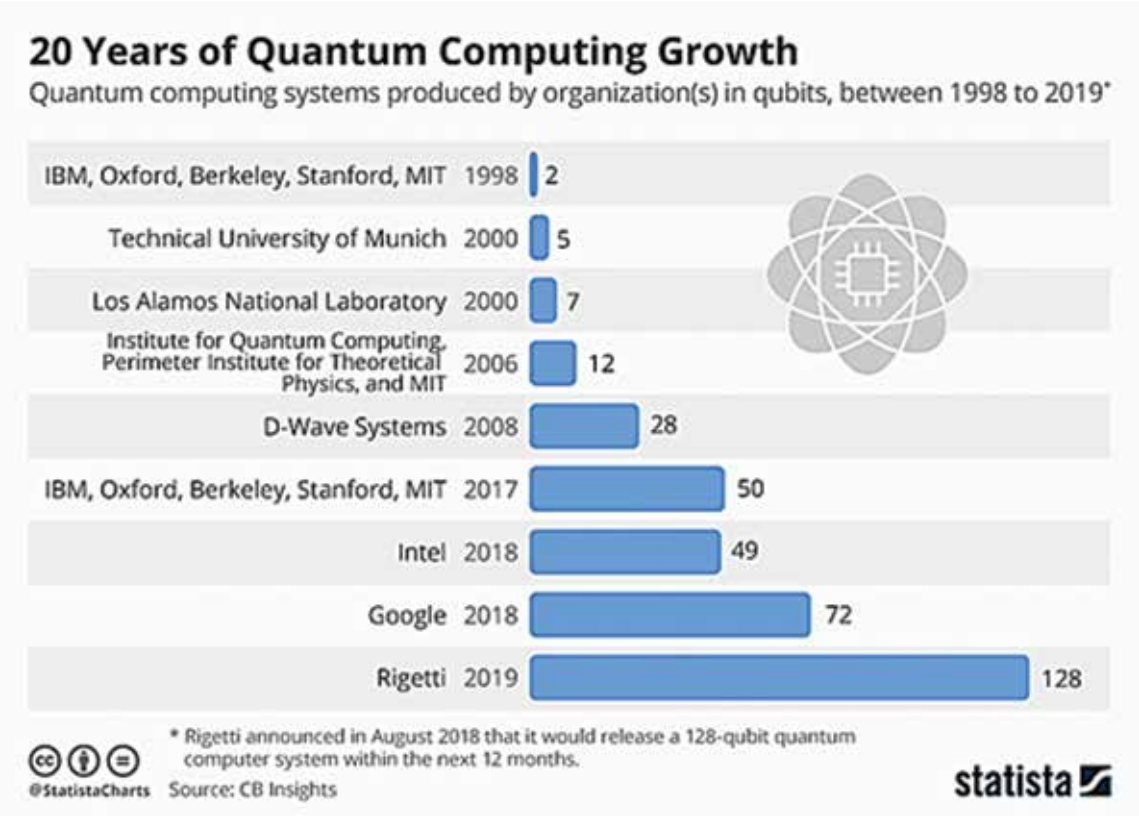
According to IBM[5] *"Quantum computers are elegant machines, smaller and requiring less energy than supercomputers. An IBM Quantum processor is a wafer not much bigger than the one found in a laptop. And a quantum hardware system is about the size of a car, made up mostly of cooling systems to keep the superconducting processor at its ultra-cold operational temperature. ..... Our quantum processors need to be very cold – about a hundredth of a degree above absolute zero. To achieve this, we use super-cooled super fluids to create superconductors*."

QCs are very powerful but very difficult to build as can be observed from the time it took to come to a reasonable scale of applications since 1980s when it was ideated. Quantum computing received quantum leap when digital giants started working for commercialisation of QCs. Incidentally global players like IBM, InonQ, Google and Rigetti, allows people to access their QCs for performing research work. IBM has also started selling QCs. Nitin Dahad, the European correspondent of EE Times, [6] reported in March 2020 that "*An IBM Q System One quantum computer will be installed in an IBM computer center near Stuttgart in early 2021," The said quantum computer was scheduled to be operational from early 2021. The following is a picture of the main processing system of that quantum computer.*

Source: https://www.eetimes.eu/first-ibm-quantum-computer-to-be-installed-in-europe-in-early-2021/

IBM has entered into a collaboration agreement for this with Fraunhofer-Gesellschaft of Germany Their objective is to provide companies and dedicated research organisations in the geographical region of European Union access to the powerful technology of QC. Those organisations are expected to conduct research on probable application cases and develop multidimensional strategies for and with quantum computing in complete compliance with European laws and GDPR.

QCs have still not been commercialised to such an extent that common people can use it. Hence the number of units built so far is also not very large. The following graphic of the globally renowned statistical organisation Statista provides an account of QCs produced by global giants during a period of 20 years from 1998 to 2019. It accounts for about 353 QCs by 8 groups of organisations including those who collaborated with research laboratories of various Universities.



Source: https://www.weforum.org/agenda/2019/10/quantum-computers-next-frontier-classical-google-ibm-nasa-supremacy/ and https://www.statista.com/chart/17896/quantum-computing-developments/

However, whether the course for commercialisation of QCs would take in foreseeable future is still not clear. This can be observed from the conclusion of Advait Deshpande in his research paper of October 2022[7]. He has concluded that, *"Perceived ROI in quantum computing and its potential to disrupt the current classical digital-computing landscape has intensified competition amongst the so-called big tech companies and selected high-performing start-ups to deliver a functional quantum computer. This makes it challenging to realistically assess available quantum-computing capabilities and to distinguish the hype from market realities."*

Applications of Quantum Computing

Readers by now must have understood that QCs are gargantuanly powerful and can process data using complex algorithms at lightning speed. The authors research collectively reveals that its phenomenal power would prove to be a game changer for equally giant digital players in creating applications for digital transformation and solving problems for business in which decision-making needs prior analyses of hugely huge data with large number of variables and complex business issues. This will also reduce business risks and uncertainties in functional management by more accurate predictive analysis drawing lessons and patterns from the past using enormous volume of data.

The following can be possible broad categories of applications in BFSI sector for which the incredible

power of QC can be used. All these would create enormous impacts at the marketplace and enhance profit and profitability of business entities and other users:

- High frequency trading at stock exchanges for executing quantitative buy-sell strategies simultaneously with controlling and monitoring of risks, and portfolio optimisation,
- Quick detection of indicators of fraud to facilitate proactive management of fraud risks,
- Clustering of ostensibly disparate sets of assets for identifying behavioural patterns in respect of performance of those assets, customers' sentiment with the objective profit optimisation and risk aversion,
- Development of complex quantum algorithms for improved efficiency in cases of:
  - Insured risk management and premium pricing in varying geographic and demographic conditions and settlement of claims,
  - Lending decisions with varying degrees of credit rating, collaterals, and liquidity profiles of borrowers,
- Management of information security systems by quantum-proofing and applications of advanced next generation algorithms for cryptography to safeguard of confidential data of customers.

According to the author one of the possible business use cases could be route-traffic optimisation for shipping and marine freight container service providers who must maximise, optimise, or minimise, as appropriate, the following:

- Optimise utilisation of hundreds of ships and thousands of marine freight containers ferrying over thousands of ports across the world,
- Minimisation of customers' expenditure for containers and marine freight by optimisation of timing for positioning of ships and containers at various global seaports and dry-ports in a manner that optimises distance for carriage,
- Minimise unproductive movements of empty containers and partly loaded ships,
- Minimise waiting time for customers to ship out their merchandise from ports of loading,
- Optimise, based on availability of berths and unloading/ loading facilities at ports, time taken for unloading of cargo at the port of destination and again reloading for carriage of next customers' cargo to the next destination, etc.

Readers would be benefitted by referring to Cem Dilmegani's updated research paper[8]. He has quoted top twenty use cases and applications of quantum computing. He has also provided details of applications and names of organisations which have already started using quantum computing facility or at various stages of pilot research before commercial applications.

According to a research report published by Mckinsey[9] in December 2021 the global business ecosystem has started showing growing symptoms for applications of QCs for commercial purposes. The report contains by way of exhibits exhaustive information covering:

- Startups working on QC projects and funding for those with spike to USD 1.7 Bln. between 2020-21
- Maturity of hardware and software for QC projects for various types of industries,
- Industry use cases and predicted values at stake between 2035-2030, etc.

In this paper they have quoted the report published by Statista regarding country-wise commitment of funding from public sources for research in the emerging field of quantum computing. It reveals that top five commitments (Nos, are in USD Billion) are from China - 15, European Union - 7.2, USA - 1.3 and India and Japan - 1.00 each. They are followed by Russia - 0.7, Canada - 0.6 and Israel - 0.5. All these committed numbers provide silver lining of assurances for bright future of digital transformation with quantum computing.

Information from India on QC

The newspaper 'Mint' published from Mumbai has reported on November 26, 2022, that Tata Consultancy Services (TCS)[10] has created a laboratory for quantum computing on Amazon Web Services. Their corporate customers would be able to use this virtual R&D environment powered by Amazon Bracket. According to the report TCS has said that *"..... it will combine its "deep domain knowledge" and tech expertise with the power of qubits or quantum bits to help customers build solutions for risk evaluation, secure communication ecosystems, and predict customer behavior*".

In the report of Statista, as mentioned above, India stands as one of the five countries where public funding has been committed to the extent of USD 1 Bln. for conducting research and development activities related to hardware and software for quantum computing. According to a report published in IndiaAI[11] the following is an illustrative list of Indian institutions which have commenced research and development activities in larger

domain of quantum computers and computing:

- Initiatives on Quantum Technologies by Indian Institute of Science (IQT@IISC),
- IIT, Jodhpur has set up a Quantum Information and Computation Group,
- IIT Madras has set up a Centre for Quantum Information Communication and Computing, and
- Tata Institute of Fundamental Research has set up a Quantum Measurement and Control Laboratory.

One can, therefore, hope for India emerging as one of the top players in this emerging field of quantum computing and derive benefits for its circa 140 Bln, citizens.

Conclusion

Readers by now must have appreciated that quantum computing with quantum computers is continuing to be an emerging field for both hardware and software. Implementation of 5G in telecommunication arena would work as an enabler and booster for this field. The author would consider that this paper has reasonably served its objective if readers can get first-hand knowledge and information about quantum computing and its applications as contemplated so far. The author would like to write more about this field as the course of research, development and applications for digital transformation with quantum computing continues. MA

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