Quantum Technologies: Areas of Improvement or How not to Slide into Quantum Winter

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Abstract. This paper discusses key issues and highlighted topics in recent quantum computing development in connection with different perspectives opportunities and challenges, with particular focus on computational fluid dynamics related research solving partial different equations. It is noted that the current approach is combine quantum computer and high-performance computer in a data centre. It addresses the possible ways to cope with the opportunities and challenges, namely information security, funding, labor shortage, as well as diversity.

1. Introduction

Quantum world opens a grand new perspective for computing. Due to the four unique character features namely quantitation, superposition, decoherence, and entanglement, the quantum physis seems to a bit strange, however offers a huge potential computational capacity. Quantum computing is fundamentally different from classic computers, instead of operating binary bits, quantum computer uses a quantum bit (Qbit). Quantum is not new as it was already almost a century ago introduced [1]. For the classical High-Performance Computing (HPC), the Moore's law is approaching its limit since the atom has its physical size, therefore quantum computing has recently attracted remarkable attention, with putting the hope that quantum computing will be disruptive and the next big thing of mankind, see Figure 1 for the brief history of computers.

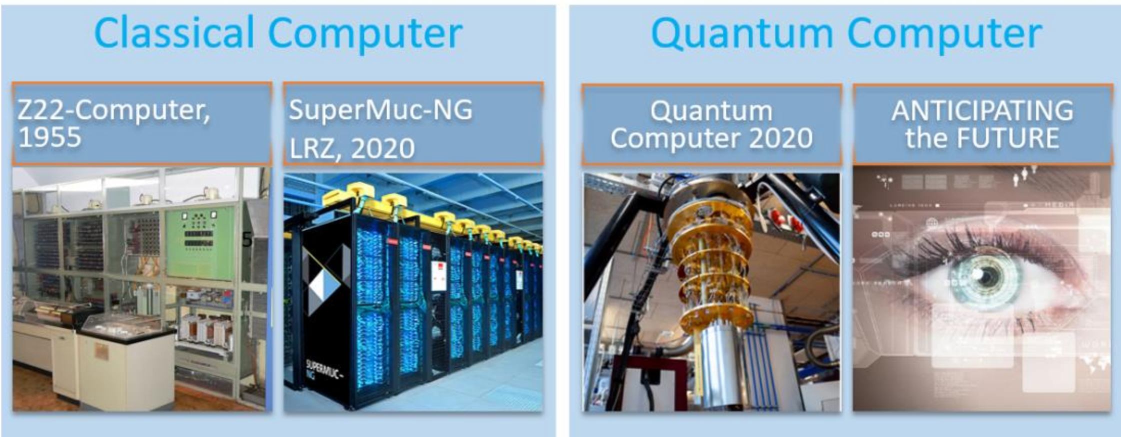

Figure 1. Z22-computer in year of 1955, supercomputer and quantum computer in year of 2020

2. Quantum reality check

As the evolution in Figure 2 shows, there are three phases since quantum was introduced namely foundation, from theory to praxis, commercialization. Quantum computing is an interdisciplinary field covers computer science, physics, chemistry, engineering, biology, pharma as well as social sciences. The world is dreaming that quantum computing may solve at least these applications exponentially faster than classical computers typically in the following areas:

- Chemistry: New catalysts, batteries
- Materials: Designing new materials
- Medical: Drug design, protein folding
- Financial: Portfolio management, options pricing, risk analysis
- Travel and Logistics: Shipping, routing, disruption management

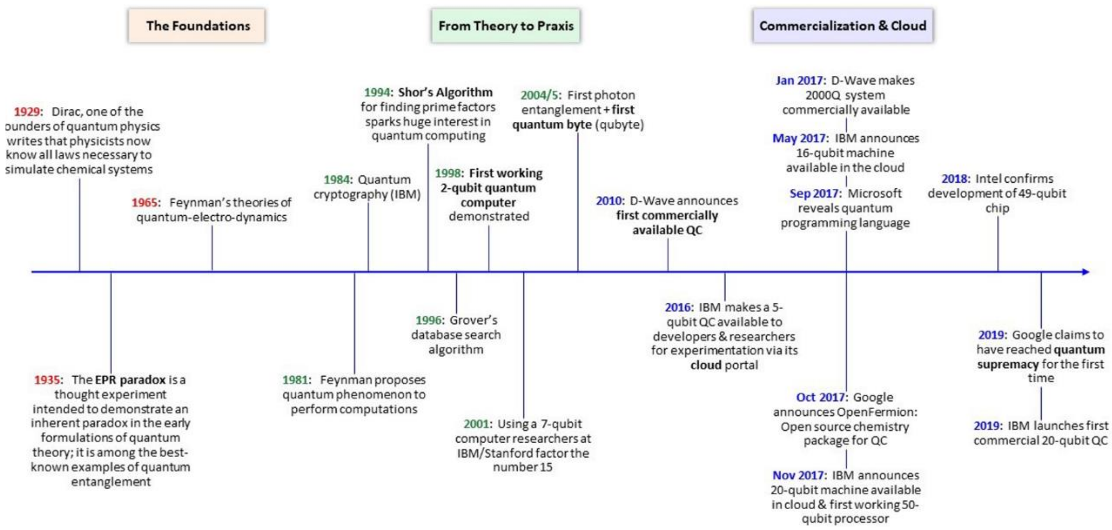

Figure 2. History and evolution of quantum

2.1. An example: computational fluid dynamics with quantum system

Recently the research activities using quantum computing are being carried out all over the world. Fluid dynamics is here taken as an example to understand the transport phenomena of fluid mechanics, e.g. water and air the most common fluids dealt with in everyday life. Three fundamental approaches define the study and analysis of engineering systems: theory, experiment and computing. An example of three fundamental approaches used in the study and analysis of engineering systems based on liquid sloshing, to investigate so named Bell-Plesset Instability in Figure 3 [2-4].

Since the ability generate simulations is limited by computing power, quantum computing, with its enormous computational capacity, is likely to benefit predictions based on computational fluid dynamics (CFD). Quantum computing opens a new perspective for CFD and current CFD algorithms based on different macroscopic or microscopic scales need to be translated into a quantum system.

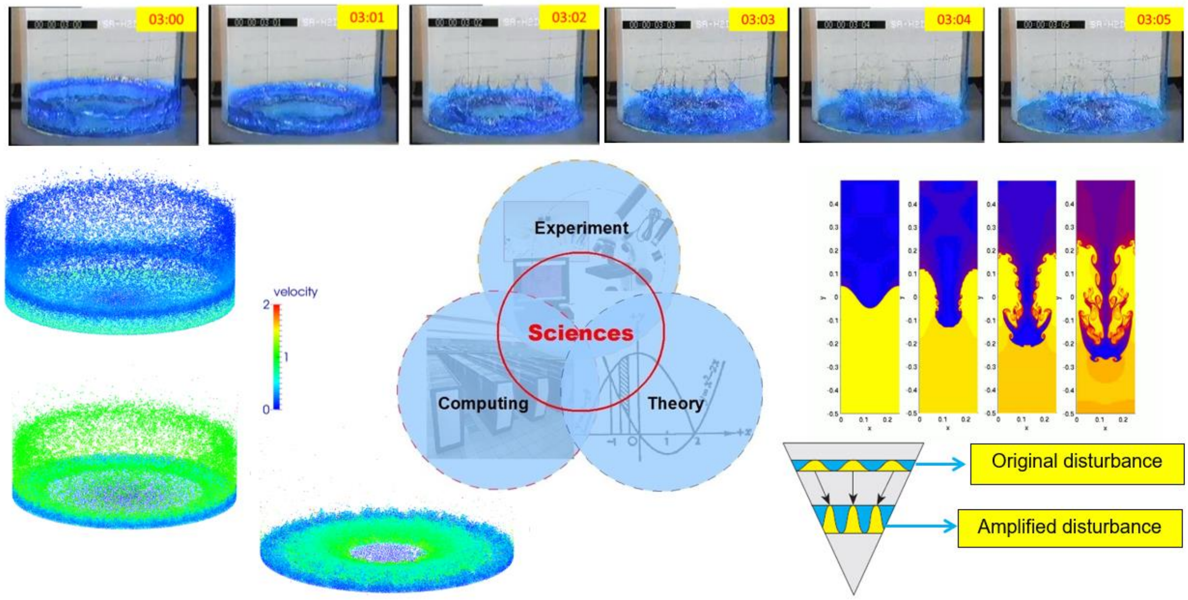

Figure 3. SPH (Smoothed Particle Hydrodynamics) simulation, experiment, and theory analysis [2-4]

The research group of the authors have therefore started with e.g. the implementation of Lattice Boltzmann Method using Intel quantum Software Development Kit (SDK) [5]. One mesoscopic approach has been applied to solve the Lattice Boltzmann equation as in Figure 4 shows. Starting the simplest transport phenomena as a starting point, the preliminary quantum simulation results have been validated with the analytical solution and the classical numerical simulation. This novel approach of using quantum computing to simulate fluid could potentially impact meteorology, materials, energy, and pharmacology.

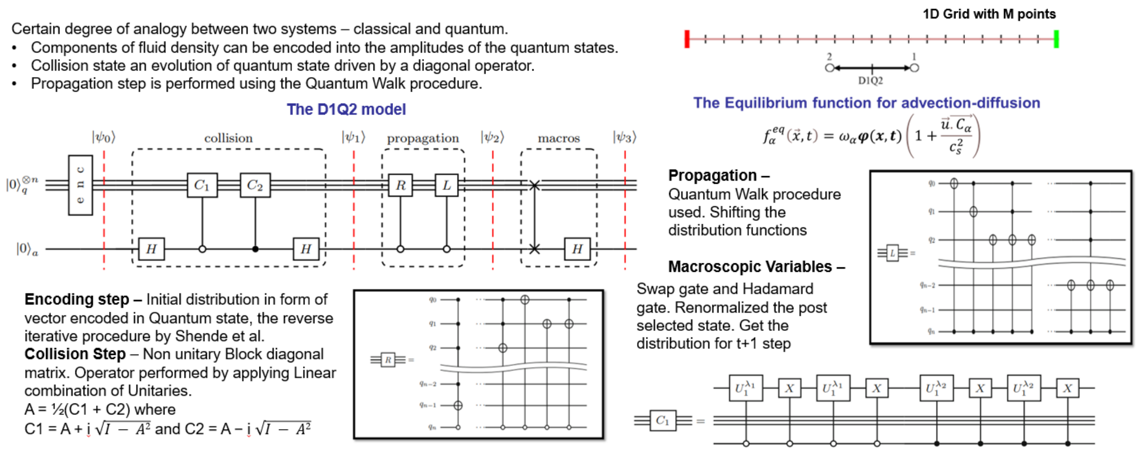

Figure 4. Demonstration of the quantum Lattice Boltzmann method [5,6]

2.2. Quantum co-processor: quantum computer doesn't currently replace traditional HPC

With 50 Qubits, the proof of quantum computing concept can be provided that the computational power already exceeds supercomputers, and it offers learning test bed for quantum "system". With 1000 Qubits, some small problems can be reasonably solved with limited error, e.g. for the chemistry and materials design, optimization for transportation and energy e.g. wind park etc. With 1 Million Qubits the cryptography and machine learning are expected to be realized. There are different Qubits approaches such as superconducting loops, trapped ions, silicon quantum dots, topological Qubits and diamond vacancies [7].

It is needed to come back to reality. We assume that quantum computers will augment, but not replace classical computers. This is because they are relatively poor at arithmetic algorithms and because they demand special, very strict cooling to shield the fragile qubits from thermal and electrical interference. The noise or de-noise problem has been enlarged and became determined to the results of quantum computing. As in Figure 5 indicated, left one is relating the problem size and the computational resources, for a comparison of traditional algorithm and quantum algorithm. At the current stage both advantages could be combined, hence in the right picture shows that, quantum computers will be put as co-processors/accelerators into classical HPC data center and clouds.

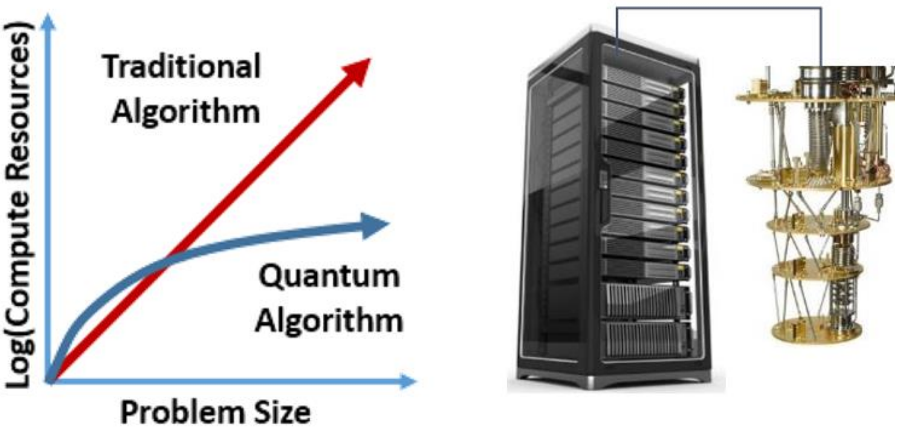

Figure 5. Combination of quantum computer and HPC

Research oriented HPC centers together with universities are therefore the best partners in order to figure out about quantum applications. For instance, Germany and Europe have a strong HPC Ecosystem (e.g. LRZ Munich, CERN, Research center Jülich) and Intel is well connected to these HPC customers. It makes sense that Germany and Europe play a leading role to conduct research in collaborations with these centers.

3. Challenges with different perspectives

3.1. Technical challenges including information security

As a completely new kind of computer, the architecture for quantum computing has been different level changes from the bottom to the top namely from the quantum chip to the application algorithms as in Figure 6 listed. There are five major challenges:

- New execution model
- Error mitigation and resilience
- Scalability
- Interconnect complexity
- Qubit device design

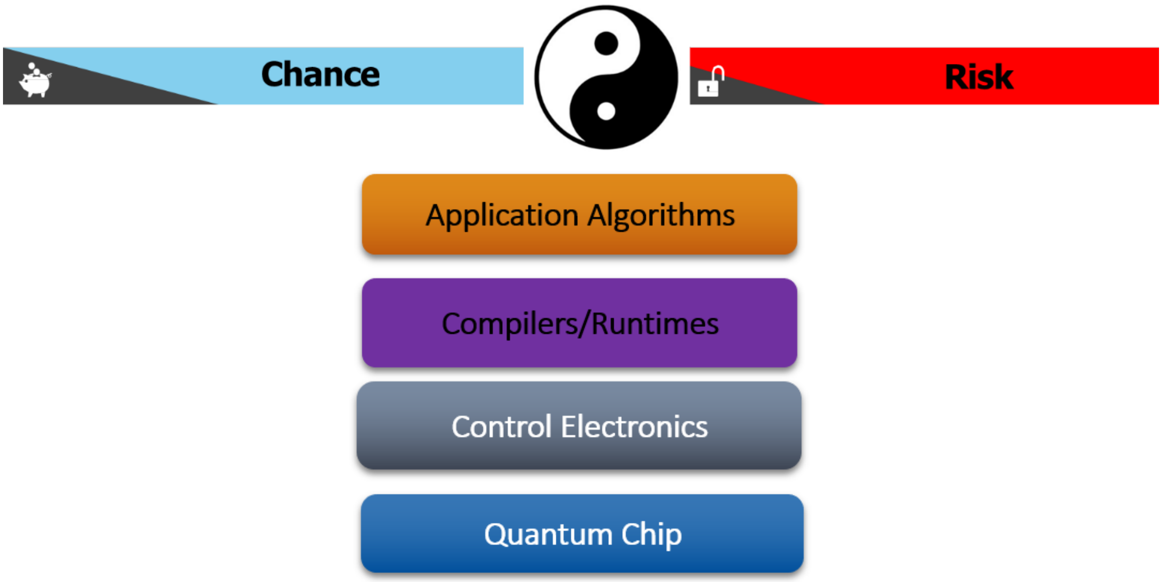

Figure 6. Architecture of a completely new kind computer

It is true that when the chance comes, the risk usually accompanies. For instance, quantum computing could be able to calculate the optimization with solving planning and scheduling problems for the transport sectors e.g. the trains, planes, ships in the harbor etc. However, the quantum computing also opens the door of e.g. cyber-attack, increasing IT infrastructure penetration and networking, not mentioning that nowadays encryptions would be unusable only in a few years.

3.2. Skilled labor problem

As an interdisciplinary new area, the qualified and skilled labor are highly needed in the day-to-day growing job market. From Figure 7 one can see the number of job posting clearly outstrips the qualified talent from one OECD report [8]. From one analysis from McKinsey & Company [9], the European Union has the highest concentration of quantum technology talent. For instance, to meet the high demanding of labor, growing continuously since its founding in 1994, Deggendorf Institute of Technology has recently launched its new master program High Performance Computing/Quantum Computing (HPC/QC) that is to our knowledge the first master program in Europe combining HPC and QC, and has attracted many international students.

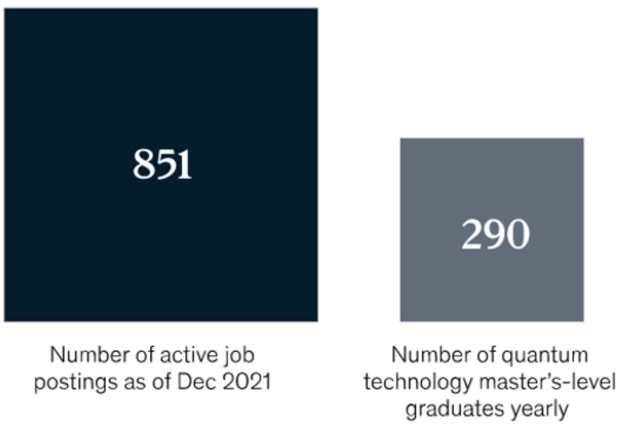

Figure 7. Gap between job market and qualified labor force [8]

4. How do we manage?

4.1. Funding

Figure 8 gives an overview of the recent years investment concerning quantum technology. While the United States and Canada have been market leaders for the last decade, China and the European Union are determined to catch up and have announced significant public funding. Chinese researchers made a claim to quantum supremacy (for a boson-sampling problem) in December 2020, and local research is expected to yield more breakthrough results backed by government funding [10].

- Quantum computing funding $3 billion total since 2001.
- Start-up funding and investment activity in 2021 surpassed $1.4 billion—more than twice that of 2020, though the rate of new quantum technology start-up creation has slowed over a longer three-year time frame.
- Quantum technology funding moved toward established start-ups, nearly 90 percent of funding is now directed at companies in next rounds of funding.
- Activity in China is accelerating due to reported large government investment (estimated at $15.3 billion), more than double what EU governments are investing ($7.2 billion) and more than eight times that of US government investments ($1.9 billion).
- China increased its quantum technology patent activity across all technologies and has originated more than half of all quantum technology patents globally.

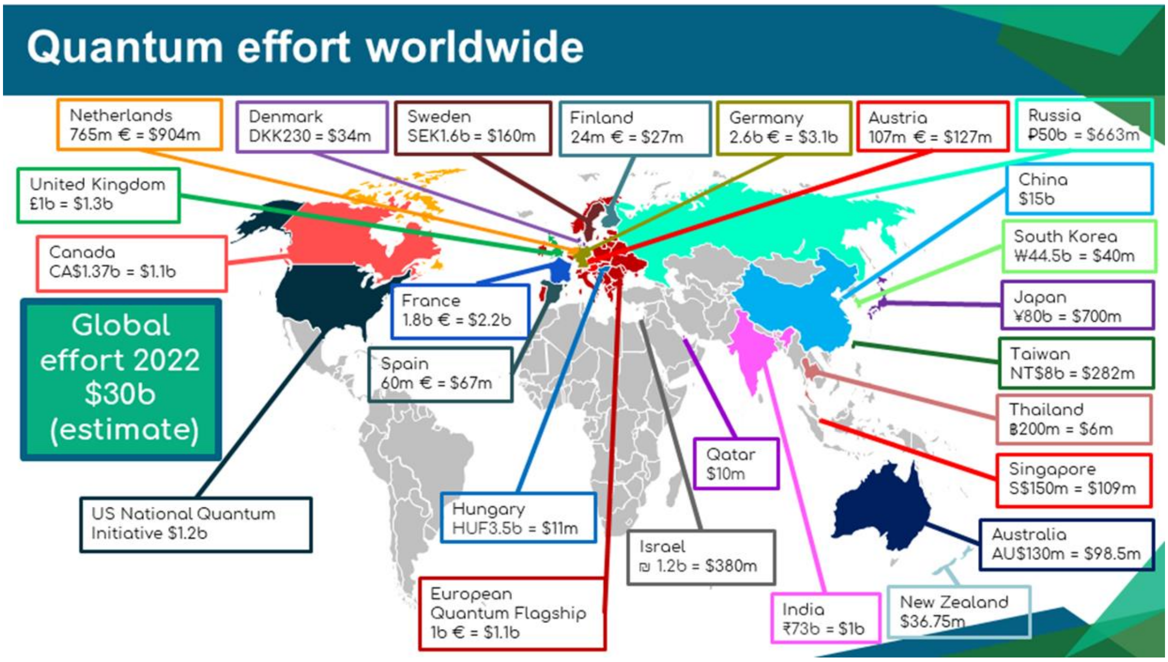

Figure 8. Quantum investment worldwide [10]

4.2. Diversity

Similarly for any development and research for high-tech, the diversity drives creativity and innovation. Scientific progress relies on problem solving and collaboration. Groups composed of people with diverse experiences and areas of expertise tend to be more creative and innovative. Every culture, every nationality, every single person sees the world in a different way and has different knowledge, perspectives, and points of view. Diversity allows for specialization and focus, drives exchange across fields and outside comfort zones. Organizations that promote diversity and inclusion are happier and more productive, a more diverse team is more likely to outperform a more homogenous team.

5. Conclusion

Even the longest march begins with the first step. This short paper could hopefully provide a quick introduction and overview of the status quo for quantum computing, which is surely the calculation tool in future for the scientific supercomputing in physics and engineering field.

Acknowledgement

The authors appreciate the efforts and supports from Intel Labs, as well as funding within the framework of Intel Mindshare Curriculum Program.

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