9. The Future of Computing and Accelerating Discovery - A Perspective for Switzerland

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Summary

The Future of Computing is envisioned as the synergistic combination of advanced computing concepts that natively interweaves classical computing, artificial intelligence and quantum computing.

It will accelerate discovery to address scientific, business and societal problems and allow us to take a global approach to tackle the planet's most pressing challenges. Recent experience around the impacts of COVID-19 underscores the importance of quickly empowering society to anticipate and mitigate disruptive events at a global scale.

A Change of Pace

Most technological advances of modern society over the past 60 years have been rooted in the progress of computing. Switzerland holds a pioneering role as early adopter of computing technology, as ETH Zurich was the first institute in Europe to work with a digital computer called Z4 around 1950. While the Z4 was an electromechanical computer, meaning it used moving relays to perform computations, the advent of microprocessors based on large-scale integrated circuits (ICs) with transistors laid the foundation for what was to become an exceptional story of technical advances. The doubling of the density of transistors on chips every two years became known as Moore's Law, with Dennard scaling providing its physical underpinning. Today's availability of laptops, mobile phones and internet applications are all results of several decades of this exponential growth of computing power, starting in the mid-1960s. More recently, continuation along this convenient roadmap for the semiconductor and computing industries has become challenged by both physics and economics. The benefits of Moore's Law have become more marginalized with each new microprocessor generation, which has significant business implications and the question on the minds of most technologists today remains – is one of the key productivity engines of modern society coming to a halt?

Most CEOs are not much concerned about Moore's Law nowadays. In terms of computing, industries are seeking to leverage ever-growing troves of data by applying artificial intelligence (AI) to extract actionable insights. While Switzerland has long been at the forefront of research in AI, an analysis of challenges and recommendations for AI has only been published at the Federal level in December 2019 by the Swiss Secretariat for Education, Research and Innovation (SERI). Looking ahead, a disruptive form of computation is looming on the horizon: quantum computing. Both AI and quantum computing have performance roadmaps in their own right, so it may be natural to assume that such technologies could be the societal growth engines of the future. However, this is only part of the story, and the implications are indeed much broader, in a vision we at IBM Research call the *Future of Computing.*

Bits, Neurons and Qubits

To explain the contrasts between the different technologies and capabilities of classical computing, AI and quantum computing, we examine their fundamental building blocks.

Classical computers are based on the binary bit, which can assume a well-defined state of either zero or one. Business workloads like transactions and data storage can be handled by extremely reliable and robust systems built in this way. Large-scale mathematical and logical computations can be executed incredibly fast by modern microprocessors and large amounts of data can be stored in the memory in our computers and phones thanks to the developments described by Moore's Law.

In contrast, AI is built on the concept of the neuron, inspired by neuroscience and the workings of our brain. In neuromorphic computing, AI is implemented in hardware by using memory devices to perform both, computation and information storage, thus mimicking the synaptic connections in the brain. This eliminates the movement of data between computational units and memory and results in much more energy-efficient systems. Neural networks can be trained to map an input, such as a picture of a handwritten digit, to the desired output, such the number the digit represents. The applications of AI are today mostly in a first phase, called Narrow AI, in which models are trained to learn single, specialized tasks, like personalized recommendation engines or speech recognition. We are now in the phase of Broad AI, which is AI that can learn more generally and scale across different disciplines to successfully combine learning and reasoning. One such example from IBM Research Europe is an AI technology that detects cracks in a bridge using photographs from drones.

For quantum computing, the fundamental building block is the quantum bit, or qubit. Compared to classical computers where the doubling of bits essentially results in a doubling of performance, the performance of an ideal quantum computer doubles when just one additional qubit is added. The performance of real quantum systems is best measured using the quantum volume metric, which has been shown to double annually in an exponential fashion that is reminiscent of the scaling of semiconductor technology according to Moore's Law. It is predicted that quantum computers will be able to answer technologically relevant questions that are intractable for classical computers within this decade. Notably, quantum computers are particularly well suited to solve particular classes of problems, such as describing the structures of molecules or risk modeling in finance.

This brief excursion into the world of bits, neurons and qubits illustrates different technological paradigms. In the Future of Computing, however, key business and industry applications will become transformed through the synergistic combination of these paradigms, and how they are delivered and consumed.

The Democratization of Computing

Enterprises have seen a fundamental shift in the provisioning of computing resources through the emergence of cloud computing. Traditionally, a key advantage of cloud has been the pay-as-you-go model, permitting businesses to access computing, storage and database resources flexibly and dynamically. Today, businesses can also access AI services over the cloud, with AI stacks permitting the development, scaling and deployment of AI applications to unlock business value. With the abstraction of AI services in so-called low-code and no-code environments, and the adoption of tools allowing businesses to access those services across multiple clouds, we are witnessing a democratization of AI which provides unprecedented access to analytics capabilities to extract real-time insights from big and small data.

Since May 2016 it's also possible to access quantum computers via the cloud. The IBM Quantum Experience has put the most advanced quantum computing systems into the hands of developers, researchers, academic and enterprise users. Anyone with an internet connection is today able to run a quantum experiment and explore new algorithms for quantum finance, chemistry, and protein folding, among others. An open-source quantum computing software development framework called Qiskit has been made available for developers to leverage quantum processors in research, education and business. Earlier this year, the Fraunhofer-Gesellschaft, one of Europe's leading organizations for applied research, announced plans to establish a national competence network for quantum computing and the installation of an IBM Q System One quantum computer in Germany – the first of its kind in Europe.

It is time for enterprises to think of the cloud not only as a convenient business model for economic provisioning of bits, but also as a key enabling technology to access cutting-edge computing capabilities such as neurons and qubits as a service. The cloud, and more specifically the hybrid cloud, which connects a company's private cloud services and third-party public clouds into a common infrastructure, will be the vehicle of choice for delivering the Future of Computing.

Accelerating Discovery and the Role of Switzerland

The emphasis of the Future of Computing lies in the realm of accelerating discovery. In contrast to the automation of logical workflows handled well by today's classical computing infrastructure, discovery involves the combination of large amounts of data with advanced reasoning. Consider the example of scientific discovery of new materials. The cumulative body of materials research provides a vast knowledge base to inform new developments, but the complexity of gathering, interpreting, evaluating and inferring from this knowledge is a daunting task. In addition, knowledge gaps need to be identified and filled in by practical experimentation or computer simulations. Overall, the scientific discovery process today is akin to an art in which serendipity plays an unneglectable role, and it is therefore an inherently risky undertaking for many enterprises despite being a key driver of innovation and societal advancement.

The acceleration of discovery through the convergence of bits, neurons and qubits will drive a resurgence of the scientific method to enable rational decision-making for the most complex challenges. A framework which interweaves classical computing, AI and quantum computing, serving as a collaborative assistant and advisor to humans to ingest knowledge and present insights, will alleviate the burden of complexity in the discovery process and allow us to apply our human intuition and intelligence in the development, exploration and testing of hypotheses. The result is a fundamental transformation of the discovery process by accelerating it and reducing the time-to-market from 10 years to 1 year for innovative solutions ranging from materials to finance to life science.

We argue that Switzerland is well-positioned to lead in the development and application of the core technologies that underpin the Future of Computing. Scientific discovery is deeply encoded in Switzerland's DNA, and with its renowned research institutions and high standard of living it is no coincidence that international tech giants are running research from here. Another important attribute of Switzerland is its dedication to data security and compliance, which encourages Swiss companies to seek out cloud services supporting local storage of personal data. Against this backdrop, Switzerland is remarkably well suited to unify key technical, societal and economic strengths under one umbrella to once again become an early adopter, this time for the Future of Computing.

Addressing Global Challenges – Responding to COVID-19

Recent experience around the impacts of COVID-19 underscores the importance of quickly empowering society to anticipate and mitigate disruptive events at a global scale. Exceptional coordination has for instance been demonstrated in bringing together supercomputing resources in the US under the COVID-19 High Performance Computing Consortium and making them available for COVID-19 research in areas such as bioinformatics, epidemiology and molecular modeling. Sharing of insights and validation of results across global teams is a key component of coordinated scientific efforts to mitigate COVID-19.

This collaborative, knowledge-sharing approach to discovery is also a decisive characteristic of IBM Research's Future of Computing vision. Within a timespan of two weeks, two of the building blocks of our Future of Computing effort were trained on COVID-19 and made available to the public as cloud services. One of the building blocks is the Deep Search service developed at IBM Research Europe, which enables scalable, customizable and domain-specific information extraction and search. It was used to create a COVID-19 knowledge graph that within a week was queried by hundreds of users across the scientific community via a web browser to structure the rapidly growing body of scientific knowledge related to the novel disease[1)].

The second building block is a novel AI generative framework developed at IBM T.J. Watson Research Center, which is capable of creating and screening novel molecular structures aimed at specific biological targets. The technology was applied to three COVID-19 targets to generate candidate antiviral molecules, the structures of which have been shared via a cloud-based tool that allows exploration and down-selection of the molecules[2)]. Ultimately, the goal is to accelerate the process of identifying promising new drug candidates for coronavirus and potential similar, new outbreaks.

These recent actions exemplify the agility with which the frameworks underpinning the future of discovery can be applied to new challenges, and they outline the underlying global approach to accelerated problem-solving that builds upon collaborative knowledge sharing, interweaving of synergistic computing technologies including classical bits, neurons and qubits, and a cloud-based access model providing ample opportunities for research, innovation and business transformation in Switzerland and globally.

1) https://ds-covid19.res.ibm.com/

2) https://covid19-mol.mybluemix.net/

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