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Review Article

Computing for Science, Engineering and Society: Challenges, Requirement, and Strategic Roadmap

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Executive Summary

Computing, communication, and technology have not only made an amazing progress in the past couple of decades but also made a huge impact on the evolution of science and society. During the last half-century, we can broadly say that the pace and direction of this evolution is due to the rapid growth in theoretical and technological advancements in Computer Science (hardware and software), networks, electronics, photonics — each one catalyzing the other's growth and thus reducing their costs and in turn their accessibility. In fact, some of the outcomes were a result of funding from NSF, DARPA (USA), and advancements realized at Bell Labs, AT&T, IBM, Xerox, SRI, *et al*. One of the most striking observations since the beginning of the century has been that the pace and growth is largely dictated by the market[1]. Some of the important characteristic observations are:

1. There is an information avalanche as the digital universe is expanding at a rapid rate. It is estimated that by year 2020, the digital data produced will exceed 40 zettabytes. This corresponds to saying for every human there is approximately 5200 gigabytes of data[2].

2. Disruptive, efficient infrastructures have shrunk the world making it possible to produce and consume regardless of the location. This, in fact, is showing a tendency of huge growth; thus evolution of society will be dictated by the people and social communities who are able to coalesce in a very short time and make their presence and influence felt.

   In these days, with the availability of massive computations, there has been successful attempts to shift *parts of decision phase of applications, that had been the forte of humans, to machines*. This is often referred to as AI/Machine Learning in various glorious terms in the media. Thus, the machines are not necessarily just number crunchers but also decision makers. It is important to note that the compound annual growth rate (CAGR) of investment in such applications is more than 47 billion USD. This naturally reflects the need to invest in such massive computing infrastructures that would drive innovations and discoveries.

3. Blockchain and the distributed ledger technology have been making inroads in finance and governance for transparency, efficiency and trust management.

4. Another very significant point to be noted is that scaling up of scientific discovery has become dependent on the computing power both in theory (paradigms) and practice (applications).

5. Even disjoint areas of science and technology are influencing one another, for instance photonics, quantum mechanics, smart-grid, CRISPR, containment of communicable disease outbreaks through social networks (on GPS).

6. Apart from the foundational areas of Computer Science including ICT, some of the recent works on cognitive computing have shown an enormous potential for healthcare, education. Keeping these fallouts in mind, there is a need

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[1]IEEE COMSOC 2020 Report, June 2012.

[2]Zhiwei Xu and Guojie Li, Computing for the Masses, Communications of the ACM, 54, 10, pp. 129-137

to consider how ICT can accelerate human decision making, creativity, and innovation, etc., in a variety of scenarios of health and other impactful societal applications.

7. Power of computing lies in its open-endedness and its understanding rather than constraining it. Thus, there is a dire need to find ways by which cooperation, collaboration, synergy, and consilience be provided on a platform that provides momentum to science and engineering discoveries and innovations. Such a need becomes amply clear when we look at the scenario of *precision medicine* that has become possible only due to the cooperative work of doctors, patients, biomedical researchers, engineers, and computer scientists.

Thus, policymakers need to strategize policies for investment in ICT for a spectrum of purposes ranging from societal needs to science discoveries, keeping in mind at least a few crucial facts like:

1. A number of main crises that are facing the world, environmental pollution, scarcity of basic resources (like water and food), energy (in terms of availability and cost) shall matter.

2. The proliferation of Internet of Things along with the underlying sensors, and converging data standards are all combining to provide new possibilities for the physical management and the socio-economic development of cities. For instance, in the context of smart cities, it is necessary to keep in mind[3] : *Technologies influence patterns of behavior. Digital and mobile technologies are making the connections between service providers and users, tighter, faster, more personal, and more comprehensive. Sharing-economic business models are emerging that enable more efficient use of physical assets, such as cars or real estate, and provide new sources of income to city residents.*

3. Forecasting the future of ICT is hard and risky due to dramatic changes in technology and limitless challenges to innovation. In fact, it is only a small fraction of the innovations that truly disrupt the state of the art. Some are not practical or cost-effective, some are ahead of their time, and some simply do not have a market. There are numerous examples of superior technologies that were never adopted because others arrived on time or fared better in the market.

4. There is a significant digital divide: developing countries with a shortage of technology and education are still "technology dependent", but developed countries are already market driven, with technology having become a commodity, and with expectations covering more than just technology. Industry and institutions have broadened their interest and now focus very much on meeting market needs.

Keeping the above rationale in view, the report is only an attempt to better understand the impact of the disruptions the disciplines and technologies may lead to. Such an understanding enables us in arriving at strategies for ICT investment to promote innovations[4] in science, technology and societal applications, to meet the spectrum of requirements and aspirations of the country. **It is necessary to keep in mind that while the country is a giant in software, it has a long way to gain that level of supremacy in hardware and products/systems. Such a reality makes it necessary for the country to get supremacy in building and evolving complex intelligent systems that could have an impact on society and science**. Needless to say that the overall strategy for serious innovations for scientific and technological discoveries/inventions require a thorough re-organization of higher education keeping in view the role of ICT. The report provides a broad overview to cater to an effective ICT investment for innovations for research, higher education, and societal applications.

The important broad takeaways are:

1. Initiate and invest in strategic computing centers to promote scalable science discoveries keeping in view the expected requirements rather than just the raw power.

[3]Technologies and the Future of Cities, Feb 2016, https://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST_cities_report_final_3_2016.pdf

[4]The country that wants to out-compete must out-compute (Suzy Tichenor, June 2007)

2. Establish scalable strategic centers for cyber security (including big data analytics, blockchain/ crypto-currencies, etc.), e-governance, public infrastructures, etc.

3. Invest in innovative approaches for network and system design that would promote scalable architectures leading to large scale systems research.

4. Invest in adapting quality human resource developments by architecting computational thinking in science and engineering disciplines.

5. Invest in a strong research above threshold/ critical strength in core computing disciplines that include frontier areas, including Deep Learning (AI), cognitive computing, quantum computing, blockchain applications that have demonstrated potential of societal impact, that could be game changers in the years to come. In fact, the recent leap into quantum computing processors (IBM, Google, Intel), or neuromorphic chips from HP needs to be kept in mind, to address the needs of building strong computing infrastrtures for pushing innovations and inventions for science and engineering as well as societal applications.

6. The most important aspect is to monitor progress with constructive feedback through independent evaluations.