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SURVEY OF THE MAJOR TRENDS AND ISSUES OF RESEARCH AND INNOVATION IN COMMON APPLICATIONS OF ICT

Introduction

The first electronic computer, called Z3, was created by a German engineer in 1941. Almost concurrently, American engineers conceptualized and built a computer called Electronic Numerical Integrator and Computer (ENIAC), which was based on electron tubes and had its debut in 1943. These early computing machines opened a new era of digital data processing, which has had enormous impacts in all fields of production, business and social life. In retrospect, the dominant way of organizing computer systems changed practically in every ten years (Figure 1). At the end of the 1970s, cheap single-chip microprocessors were introduced. They facilitated the development of personal computers (PCs), which in turn extended the decentralization to the point where practically each and every human can have a self-contained personal computer. The 1990s saw the adoption of the Internet as an infrastructure for transferring data between computers regardless of their location on the planet, and the propagation of the world-wide-web as an astonishingly fertile new medium for sharing of information and conducting business. A new field of research and development interests, called ubiquitous computing, emerged in the late 1980s and rapidly proliferated after the mid-1990s. Although the affordances of personal computing have not yet been fully utilized, ubiquitous computing is already opening the door for a new type of systems, services, and applications.

In our days, application of information and communication technology (ICT) is being governed by a couple of interweaving trends, such as proliferation of wireless communication, virtual reality, embedded sensor networks, adaptive cooperating computing, non-deterministic networking, and artificial intelligence. Recent advances in communication technologies, which are showcased by smart phones, Internet pads, and PDAs, make us believe that mobile devices with wideband internet access and increasing computing capabilities will soon overtake personal computers as the information appliance of choice in the daily life. At the same time, the computing infrastructure is moving off from the model of self-standing computer workspace, upon which exclusively computing functions are carried out, to a cooperative cluster of distributed computing entities, which are able to provide such a high level computing power for professional applications and immediacy in communications that has never been experienced previously.

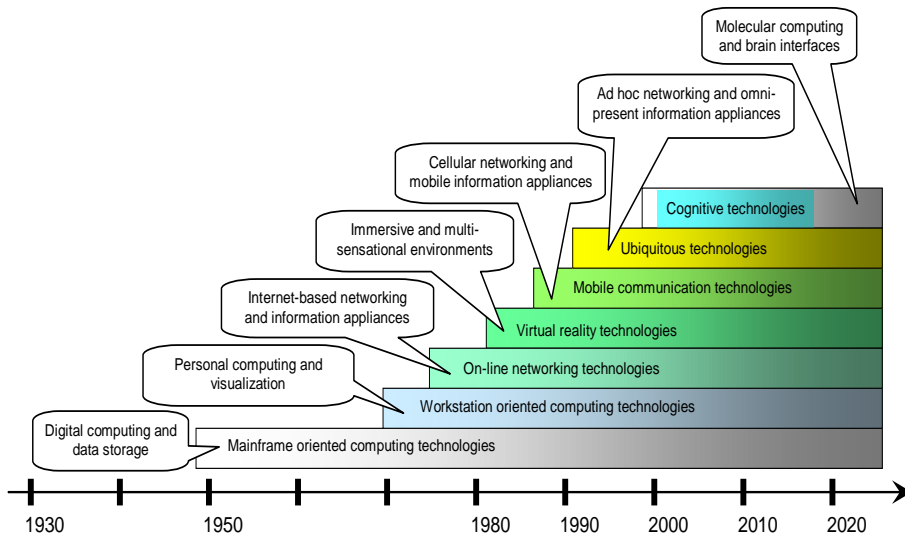


Figure 1 Advancement of computing technologies

Cloud computing is a form of location independent computing, whereby shared, loosely coupled, and volatile servers provide resources, software, and data to computers and other devices on demand. It is a natural and widespread adoption of virtualization, service-oriented architecture, and utility computing. Grid computing is another form of distributed and parallel computing, whereby a 'super virtual computer' is composed of a cluster of networked computers acting in concert to perform very large tasks. A cloud, or a grid, serves as a platform or infrastructure that not only enables execution of tasks (services, applications etc.) by automatically putting resources into use according to actual requirements, but also manages ensuring the reliability of execution according to pre-defined operational quality parameters. It operates in an elastic fashion to allow both upward and downward scalability of resources and data. These open systems are nowadays considered to be the real high-performance computing (HPC) solutions, rather than the standalone supercomputers. The abovementioned service-oriented computing solutions will involve computing techniques that operate on software-as-a-service. When embedded in everyday products, the anywhere and anytime present sensing and communication capabilities will allow establishing an Internet of Things, following the analogy of Internet of Data. The second-generation World Wide Web, called semantic web, is foreseen as one of the most important resources to create intelligent and 'knowing' devices and services. The semantics oriented information processing will make data understandable for computers. These trends are accompanied by the consolidation of visual computing, ranging from computer graphics to render screen images into 3D models that can also be animated, to holographic scientific visualizations of real-world objects that can normally not be seen, such as the shapes of molecules and cells, air and fluid dynamics, and weather and disaster patterns.

It should be noted that the rapid proliferation of ICT, on the one side, and the existence of a large social inertia, on the other side, lend themselves to some sort of

cognitive tension, and raise not only many issues and questions, but also friction and resistance [1]. This paper summarizes the largest and most influential megatrends (referred to as challenges below), and elaborates on the related technological and societal issues.

Challenge One: Living in the information universe

Driven by both foundational and operative research, as well as by the interest of practically all sectors of the productive industries and administration, information and communication technology (ICT) is flourishing and keeping not only industrial production and business changing, but also our everyday life. Due to the fast and self-triggered pace of ICT development, there is a strong technology push situation, which favors to the formation of the information society [4]. The information society is a social order in which the creation, distribution, diffusion, use, integration and manipulation of information is a significant industrial, economic, political, and cultural activity. It is often referred to as network society to describe several different phenomena caused by the spread of networked, digital information and communications technologies in the context of social, political, economic and cultural changes. The knowledge economy is seen as an economic counterpart of the information society whereby wealth is created through the economic exploitation of knowledge and knowledge-intensive processes. The information society radically changes the relationships of individuals and business entities to the tangible world and to each other. ICT concurrently creates new employment opportunities and eliminates the needs for certain traditional workplaces. Advanced societies are converting themselves from a knowledge economy to an innovation economy in order to maintain the highest possible level of sustainable well-being.

Modern ICT enables building and maintaining social networks, which are now the fastest growing Internet sites, allowing flexible access to millions of people and offering both social and business benefits. Social networks are virtual communities organized around a range of special interest groups. There are two major social (but also personal) challenges rooted in the information society. They are known as information threshold and information overload. Information threshold means that, in our modern era, not having enough information may create a detrimental situation, facilitate the development of the digital divide, and lead to exclusion (Figure 2). The digital divide refers to the gap between people with effective access to digital and information systems, and those with very limited or no access at all. The concept of a knowledge divide is used to describe the gap in living conditions between those who can find, manage and process information or knowledge, and those who are impaired in this process. Information overload refers to the difficulty a person may have at coping with in the presence of too much information (e.g. flood of e-mails) and building an understanding to make proper decisions. The amount of data that we collect and store on a society level doubles every eighteen months. Difficult to imagine, but it means that in the next two years we will collect more data than that existed ever before in the past. The collection and storage of this data continually challenges the capacities that we have to store data, as well as the capacities that we have to process it – therefore knowledge should be extract from it.



Figure 2 End-of-life of computers (Source: New York Times Company)

Two state-of-the-art features of current ICT are its unprecedented large scale and its unavoidable complexity. Establishing ICT mega-systems needs new empirical research insights, as well as implementation and maintaining methodologies. Most universities have difficulties with doing research work on the large-scale systems because they are generally not available for empirical studies and interventional experiments. There is also a serious disincentive to invent new and much better systems as a consequence of the existence of powerful entrenched de facto standards, such as Intel microprocessor architecture, URL, TCP/IP and Windows. ICT research and development strategies play a major role in providing responses to societal challenges, such as the sustainable societies/economies, ageing population, sustainable health and social care, inclusion, security, and education. Notwithstanding, new governmental policies are also needed to drive economic and societal development for the coming decades.

Challenge Two: Approaching the physical limits

As forecasted by Moore's law, the number of transistors in a processor chip is doubled every one and half years and getting to the range of one billion [2]. While the physical sizes and the instruction execution times are continuously decreasing, the storage capacity of the background storage devices of personal computers is measured in giga-bytes, of servers in tera-bytes, and of large information technological centers in peta-bytes. Billions of computers are connected through the Internet, and it is already rather difficult to estimate the total amount of aggregated and processed data. However, a negative implication of Moore's Law is obsolescence. The improvements of technologies can be significant enough to rapidly render existing computing technologies obsolete. In a situation where ecological sustainability is paramount, and in which material scarcity and energy insufficiency dominate, survivability of hardware and/or data are of high importance. The current short lifetime and performance increase of computing capacities must be considered from the aspects of both rapid obsolescence and sustainability [3].

It has been observed that the pace of miniaturization has slightly slowed in the past years, and will most probably further decelerate in the following years. The primary reason is that electronics technologies are approaching the point where digital circuits and steady state components will be of the size of a few atoms only. Traditional microscopic circuitry etched in silicon wafers is running into a wall of overheating by 2015. New technologies, possibly not involving transistors at all, may be required for further miniaturization. Software processing and data management are also expected to change. As formulated by Wirth's law, the successive generations of computer software acquire enough bloat to offset the performance gains predicted by Moore's Law. In simple words, despite the gains in computational performance, most of the currently developed complex software applications can perform the same task just at a reduced speed.

At the beginning of 2000s, the idea of natural sub-atomic particles-based computing emerged with the objective to process digital data and information more efficiently by controlled physical, chemical and/or organic processes, and to replace current integrated-circuit technology. We can foresee that, probably within twenty years, the circuits on a microprocessor can be measured only on atomic scale. In addition, the difference between atoms and bits will disappear. Consequently, the logical next step is to create quantum computers, which will harness the power of atoms and molecules in performing processing and memory tasks. Quantum computers have the potential to perform certain calculations significantly faster than any silicon-based computer. Sustainable nanotechnologies and biotechnologies will be the key determinants of their future success.

Challenge Three: Propagation of cyber-physical systems

The intensive merging of physical systems and ICT is also taking place and lends itself to manifestation of the paradigm of cyber-physical systems (CPS). They rapidly penetrate into the product innovation and service provisioning practice [5]. CPSs are functionally and technologically open systems with some hallmark characteristics: (i) information processing capability is in every physical component, (ii) system components are networked at multiple levels and extreme scales, (iii) functional elements are coupled logically and physically, (iv) complex manifestation at multiple temporal and spatial scales, (v) dynamically changing system boundaries, structure reorganizing, and reconfiguring capability, (vi) high degrees of automation by means of information aggregation, reasoning and closed-loop controls at many scales, and (vii) unconventional computational and physical substrates (nano-mechanical, biological, chemical, etc.).

The cyber and physical sub-systems are tightly integrated at all scales and levels in CPSs. The cyber sub-system is responsible for computation, communication, and control, and it is discrete, logical and switched. The physical sub-system incorporates natural and human-made components governed by the laws of physics and operating in continuous time. According to the current scientific stances, next-generation (molecular and bio-computing-based) CPSs might have reproductive intelligence. As is today, CPSs are designed and built up based on stratified (multi-layer) platforms that amalgamate network, hardware, software, firmware and mindware layer components. Complex CPSs

may manifest as hierarchically smart systems, incorporating multiple layers of networked smart entities. These entities play the role of nodes in the network, and take care of massive-scale information processing and communication, as well as of functional adaptation in contexts.

Over the last decades, macro-, meso-, and micro-mechatronics technologies offered themselves for the implementation of the first generation of cyber-physical systems. Near-future cyber-physical systems will go beyond the embodiment and control principles of current multi-scale mechatronics-based systems. Their nodes can be volatile, will be steered by different objectives, and perform autonomous execution within one holistic collective system. This is a major difference to existing collective systems (e.g. systems of swarm intelligence), in which the units typically serve a common purpose without any selfishness. In order to implement an agent type functioning, the nodes should be able to make decisions in real time, resolve conflicts, and achieve long term stability. Furthermore, they should be able to reason based on partial, noisy, out-of-date, and inaccurate information. Intelligent agents may learn knowledge to achieve their goals.

Ubiquitous computing and intelligent agent technologies have come to open up new perspectives [6]. Usually, an agent is regarded as both a physical and an abstract entity. The way in which intelligent software agents residing in a multi-agent system interact and cooperate with one another to achieve a common goal is similar to the way that professional humans collaborate with each other to carry out projects. Distributed in the network environment, each agent can independently act on itself and the environment, manipulate part of the environment, and react to the changes in the environment. More importantly, through communication and cooperation with other agents, they can perform mutual work to complete the entire task.

Challenge Four: Ubiquitous computing

As the third wave of information processing, ubiquitous computing (UC) facilitates the integration of computing power into everyday products, devices and environments in such a way that they can offer optimal support to the daily life activities of humans. There is no dedication in the sense that many devices in an environment can collectively accommodate one or more humans around. Research in UC is inspired by two grand challenges, namely by humane computing and integrative cooperation [7]. Due to the fact that humans are mobile and their personal devices and on-body devices are portable, UC is generally thought of as a class of mobile technologies. But in addition to human-device interaction and mobile computing, a fully-fledged implementation of UC involves many more technological constituents, such as networked intelligent sensors, agent technology, data transmitters, and sensation generators.

Forms of UC can be numeric or symbolic calculation, signal sensing, search space exploration, signal transmission, networking, and signal conversion. Depending on what aspect of the ubiquitous operation receives emphasis, ubiquitous computing is also referred to as omnipresent computing, calm technology, smart computing, pervasive computing, ambient intelligence, and green computer technology. These terms have a resembling meaning from a functional and a technological point of view, but somewhat different system behavior concepts are hiding behind them. If ubiquitous computing is

about equipping everyday things in the real world with information processing power, it also means a seamless integration of information and knowledge into artifacts, environments and organs [8]. The societal objective of UC is an optimal support of humans in their daily life activities in a personal, unattended, and remote manner.

Ubiquitous computing-based systems are omnipresent in terms of the exploitation of functional affordances in space (all-pervading), they are permanently ready for operation in time (alert), and characterized by small sizes, functional shapes, and low energy consumption (viable). Fulfillment of operation and problem solving are based on a collective of entities (cooperative), the entities may be incorporated in host artifacts/environments (embedded), and carry out smart reasoning and adaptive information processing based on information sensing, mining and communication (smart). The networked entities can be highly heterogeneous (computers, robots, agents, devices, biological entities, etc.) and fractal. Ubiquitous systems (artifacts and services) interact with the user typically in the cognitive domain (proactive), and show a remarkable history, situation, scenario, user, environment, and context awareness (situated). The elements may have autonomy in terms of their own different (potentially conflicting) objectives, individual properties, decision making, and actions in context [9]. Based on elicitation of context, ubiquitous systems can perceive the constituents of the environment within a span of space and time; comprehend the meaning of their status, and project the status information onto the operation of the system elements in the near future. Ubiquitous systems are dynamic and the elements can be entering or leaving the collective at any time (fluid boundaries). A sub-class of ubiquitous systems are effective on a short distance, that is, inside a human body or an artifact (implanted), on the human body or an artifact (wearable), or between a person and the directly surrounding environment (ambient). Another sub-class can work in a medium range, as fixed or ad-hoc networked cluster of entities.

Challenge Five: Through smartness towards intelligence

For the time being, we do not have any model of working intelligence than that has been formed by nature in humans. Therefore, in the context of implementation of intelligent computing solutions the starting point is human intelligence. Artificial intelligence research aims at partial, ultimately a fully-fledged, reproduction of human intelligence in artificial systems. In addition to making logical inference and relying on knowledge, the reproduced intelligence should have features such as: (i) to choose to either ignore or focus attention, (ii) form, comprehend and remember ideas, (iii) understand and handle abstract concepts, (iv) implement vague reasoning and learn from experience, (v) adapt to new uncertain situations and guide behavior, (vi) use knowledge to manipulate things and environment, and (vii) utter and communicate thoughts. Implementation of inferential reasoning is addressed as a good guess heuristics to observations (based on logic, statistics, etc.), or by interpolating the next logical step in an intuited pattern. The abovementioned other features are much more intangible and complex, which explains why artificial intelligence research is still in its infancy.

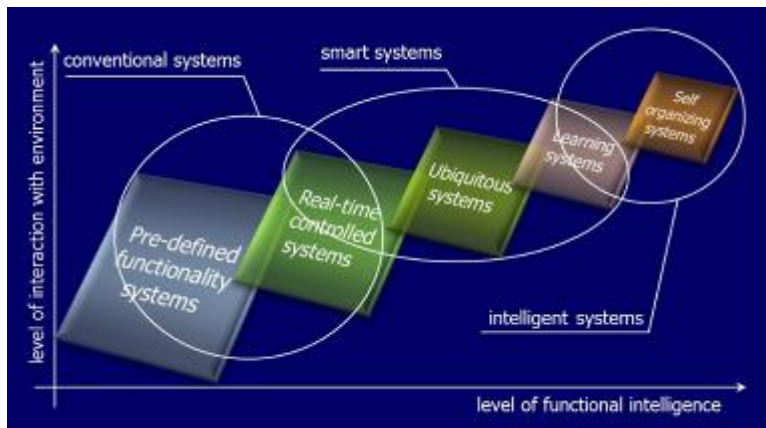


Figure 3 Positioning smart systems

As far as embedding artificial intelligence in artifactual systems is concerned, the current strategy is to strive for only a limited subset of human intelligence that has been called system smartness (Figure 3). Increasing levels of system smartness, such as programmed performing, structural adaptation, sensing, inferring, learning, anticipating and self-organizing have been defined. The two major issues have been how to endow artifacts with higher levels of system smartness (intelligence), and how to deal with building artifacts which evolve into creatures that evoke their own intelligence (i.e. are equipped with emergent machine intelligence).

Smartness is much more than just a bunch of built in functionalities. Smart systems should be capable to implement situated decision making, autonomous operation, and self-supervision [10]. They are supposed to be able to perform, adapt, sense, infer, and learn at a reasonably high level, and interpret external and internal sensory information and goals. They have to be able to distinguish objects and their properties, and to determine spatial, functional and temporal relationships of objects [11]. Smart systems should autonomously develop a set of action plans for a set of goals and relationships, evaluate the developed plans, and select the plan that proved to be best suited for achieving the goals. During execution they should monitor the environment to determine if its changes require changes to the plan or other goals [12]. They are also supposed to show openness towards the working environment and the circumstances of operation, and share relevant information with the other relevant entities [13]. Scientists agree that implementation (regeneration) of human intelligence is the largest challenge for human intelligence. As mentioned above, there is no model to use for implementation of intelligent artifacts other than that is offered by the human brain [14]. Technology-based replication of the elements, structure and operation of the human brain is just simply a too complex task. It has to be also mentioned that artificial regeneration of human intelligence by human would lead to an absurd ontological existence situation.

Challenge Sixth: Brain interfacing technologies

Brain-computer interfaces (BCI) create a novel communication channel from the brain to an output device bypassing the conventional motor output pathways of nerves and muscles [15]. Behind the idea and technologies of BCI is the observation that the activities of the human brain can be recorded based on the generated bioelectric currents in the respective region of the brain (Figure 4). For instance, any thought of moving, rotating and imagination of three-dimensional objects activates certain parts of the brain. BCIs are functionally different from neuroprosthetics, whose objective is typically to connect any part of the central nervous system (e.g. peripheral nerves) to an electromechanical actuator device. BCIs usually connect the brain with a computer system. In other words, BCI represents a narrower class of systems that interface with the human nervous system. Invasive, partially invasive, and non-invasive BCIs are the three fundamental types of BCIs that have been studied so far. Non-invasive interfaces (NII) are based on neuroimaging technologies, which have already been used to power muscle implants and restore partial movement of limbs. Although NIIs are easy to wear, they produce poor signal resolution because the skull dampens signals, and blurs and disperses the electromagnetic waves created by the neurons. Therefore, their fidelity is still not sufficient to capture the actions of individual neurons, and to precisely locate the domain of the brain that created them.



Figure 4 Entry-level brain-computer interface

A BCI is a continuously alert device that monitors the brain's activity and translates a person's intention into digital control information for actions [16]. Most of the non-invasive brain interfaces use electroencephalography (EEG) to detect brain's electric signals. The sensing device is susceptible to noise and extensive training required before users can work with this technology. Self-regulation of the brain may lead to stronger signals that can be used as a binary signal to provide control information for a computer. EEG uses electrical signals, but neural activity also produces other types of signals that could be used in a BCI, such as magnetic and metabolic. Magnetic activity can be

recorded with magnetoencephalography (MEG), while metabolic activity (reflected in changes in blood flow and the blood oxygenation level) can be observed with multi-functional magnetic resonance imaging (MRI), positron emission tomography (PET), and high-resolution optical imaging (HOI) [17]. As for now, the best average information transfer rates for experienced subjects and well-tuned BCI systems are relatively low, around 25 bit/min, which roughly three characters per minute.

At this moment, the application opportunities of BCI systems are hardly known. Typically, their application is considered as alternative of human-machine interfaces, such as the use of the brain electrical activity to directly control the movement of robots. Beside these, there have been some other prospective applications explored. One of the new fields of application is the use of brain-computer interfaces in the space environment, where astronauts are subject to extreme conditions and could greatly benefit from direct mental tele-operation of external semi-automatic manipulators. As an example, mental commands could be sent to transmitters and actuators without any output/latency delays, which is not the case with manual control in microgravity conditions.

Challenge Seven: Lack of multi-scale informatics

Information exists in systems on multiple spatial and time scales, and manifests in different forms and substances. This difference also means that there are barriers in terms of information transfer and transformation among systems ranging from particle systems through biological systems and created technical systems to galactic systems. Multi-scale informatics (MSI) is supposed to have the potential to capture information and information flows, and interconnect these systems physically, syntactically, semantically and operatively. In other words, MSI is to lend itself to an integral manifestation of information theory, technology and application over multiple, functionally interrelated natural and artificial systems, no matter if they feature mega, macro, meso, micro or nano physical sizes and operation times.

Though the need for MSI has been recognized and a growing demand for it is building up, neither the theories nor the technologies are really known. The technological basis of MSI is a collaborative informatics infrastructure (CII) that manages multi-scale information manifestations and enables cross-scale information flows. For different physical phenomena dominate system dynamics at these different scales, a variety of information models and processing forms should be implemented according to the different regimes. Ultimately, MSI needs to be able to pass information from one scale (such as human brain) to the next (such as cooperative engineered systems) in a consistent, validated, and timely manner. The scientific challenge of MSI originates in that information spans more than nine orders of magnitude in length scales and practically the same number of meaning ranges (Figure 5).

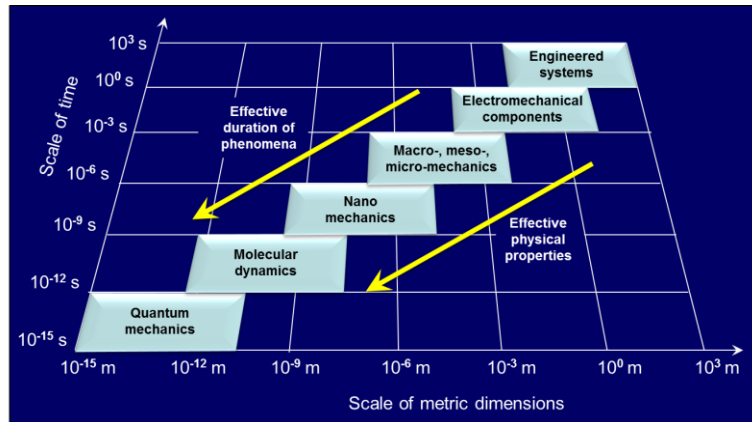


Figure 5 Operation fields of multi-scale informatics

One of the major bottlenecks in multi-scale research today is in the passing of information from one level to the next in a consistent, validated, and timely manner. From the aspect of human processing of multi-scale information, the primary challenges are the inherent heterogeneity and complexity. Copying with multi-scale information requires increased conceptual abstraction, data reduction, and robust models of information extraction. The emerging vision for meeting these requirements is the ‘knowledge grid,’ which incorporates advances being made by semantic web, non-deterministic informatics, collaborative networks, and grid communities. Effective use of knowledge grids will also require iterative approaches and cultural changes, involving long-term collaborations of domain information researchers to fully realize the potential of cross-scale, systems-oriented informatics.

Challenge Eight: Uncertainties of quantum computing

Quantum computing is the result of the interaction of information science and quantum physics. It is supposed to remove those technical (space and time) limitations that traditional steady-state information processing technology is facing. As the fourth stream of computing, this technology is based on a radically different way of representing information (Figure 6) [18]. The information is represented by quantum bits (qubits), which are tiny quantum mechanical two-state systems. A system of n qubits represents 2^n possible states and it is possible for a physical system (say, an electron) to be in all its particular states (or, configuration of its properties) simultaneously. When measured, it gives results consistent with having been partly in each of the possible configurations. The calculating power of a quantum computer grows exponentially with the number of qubits, because it dissociates memory and processing power. Researchers claim that a quantum computer of several hundred qubits would be able to encode a quantity of information equal to the number of atoms in the universe.

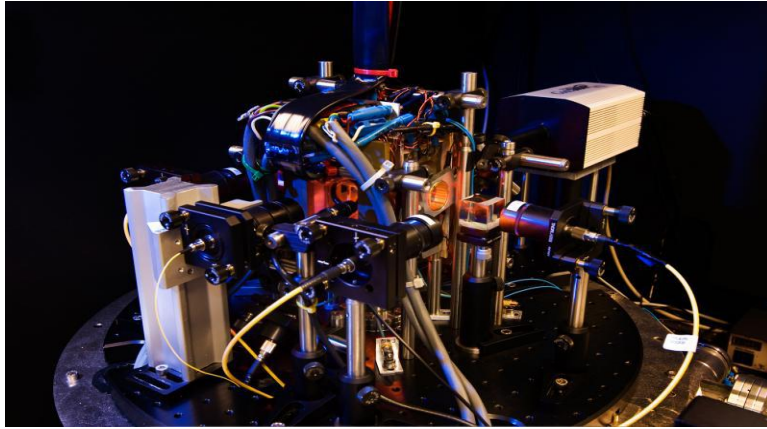


Figure 6 Quantum computer as it looks today

To be capable to represent binary digits that form the basis of digital computing, a quantum computer can be implemented using particles with two opposite spin states (spin up, spin down). Scientists have already built simple quantum computers that can perform certain calculations, but a practical quantum computer is still years away. They utilize the fundamental principle of quantum mechanics, which is known as quantum superposition. Superposition of qubits is controlled by nuclear magnetic resonance (NMR). Usually, liquid crystals are used to prevent decoherence (uncontrolled interaction between qubits). There are many potential technological solutions to trap ions and atoms for transferring qubits. While the uncertainty intrinsic to the physical phenomena has been studied with great efforts, the uncertainties associated with the implementation have not yet been addressed from all aspects. For example, a ‘quantum calculation’ is in fact a series of measurements. One measurement positions the processor to initiate the possible entry values. Another initiates a quantum circuit that ‘makes the calculation’, and a third retrieves the result. Calculating is thus a matter of measuring – an unthinkable idea in the classical world. Quantum data processing overturns the theories on which today’s information sciences are based. Current research in this field is making many more discoveries and supposed to bring in surprisingly novel ideas. A challenge that quantum communication is facing lies in the difficulty of transmitting the particles and their quantum states, that is, entangled particles, over long distances.

Challenge Nine: Utilization in lifelong learning

With the advent of cloud computing and ad-hoc wireless networking, educational applications are gradually leaving the standalone desktop computers and increasingly moving onto server farms accessible through the Internet [19]. The implications of this trend for education systems are huge. Inside and outside the classroom environments, the principle of one-to-one computing (OOC) is becoming more and more accepted. OOC creates universal access to learning technologies and provides information appliance to

every learner. Not only in the highly developed societies, but also in the developing ones, they will make cheaper information appliances and easier access available. This gives space for more extensive and mobile and ubiquitous learning approaches, which seems to be indispensable for both on-demand learning and lifelong learning. The challenge will be to providing the ubiquitous connectivity to access information residing in the cloud. To support ubiquitous learning, new contents availing methodologies are introduced and applied, such as contents managements systems (CMS), learning object repositories (LOR), and virtual mentor service (VMS) are offered. These technological solutions effectively support peer to peer, self-paced, and deeper learning. CMSs allow editing, appending, or other customization of study materials for specific purposes and according to the needs of courses, to exactly suit the style and pace of the courses. Educator- and learner-related online portfolios allow finding the best match among them.

As ubiquitous computing-enabled smart systems proliferate, they will more and more penetrate into education as autonomous smart tutoring systems, which are able to do affective diagnostics and (brain, bio, text, and image) signal analysis to deepen into learners' beliefs, judgments, reasoning, etc., recognize speech and analyze voice, and seamlessly interact with individual trainees or groups of learners [20]. These systems, which manifest as portable applications, will be able to provide a semi-automatic coaching assistance, comprehend the context of learning, understand the emotional states of learners, derive statistical information about their progress, and generate questions and drills for learners. It has been found that massively multi-player and other online game experience is extremely important in education because (serious) games offer an opportunity for active participation, increased social interaction, freeing built in incentives, and creating civic engagements among learners.

Computer-based electronic learning (e-learning) technologies are helpful to explore the prior knowledge, learning style, and learning gaps of the students, and to make the education more adapted to the strongest and to the weakest learners, than just to the assumed average middle. E-learning goes together with the redefinition of learning spaces, and converts them to virtual classrooms or cyber-studios. In these, the educators play a different role. The 'front of knowledge' role typical in classroom education is being transformed to an instructional manager role, guiding the learners through individualized learning pathways, creating collaborative learning opportunities, identifying relevant learning resources, and providing technological insight and support. On the other hand, some already argued that there is the danger that there will be an increased inability to adapt socially with the shift to more individualized learning, especially in the formative year,.

Some concluding remarks

The authors of the book 'The world's 20 greatest unsolved problems' identified, among others, the creation of the universe, the mystery of the dark matter, a consistent quantum theory of gravity, the mechanism of mass formation, the unification of the basic forces, the emergence of life, consciousness, and manipulation of nanostructures as representatives of the largest intellectual and technological hurdles [21]. I think we are not making a big mistake if we consider the pile of issues associated with information, communication, and computing science and technologies as the 21st greatest unsolved

problem for the 21st century. From both theoretical and practical perspectives, this is at least as mysterious and as challenging for current and future science and technology as the abovementioned ones.

In addition to sketching the general orientation of the major trends and the underpinning technological advancements, this paper also intended to deal with the practical implications and the personal factors of second generation ICT. Obviously, much less topics could be involved in the discussion than actually exists. Many important ones, such as interoperability of complex ICT systems (in particular, that of smart systems), increased specialization of software industry, cyber knowledge security and growth of cyber fraud, development of e-science, the relationship of the declining traditional media and the growing online substitutes, and the thread of cyber-attacks and wars would have deserved attention and at least a brief analysis. However, it was not possible due to the large amount of related information and the space limitations within this extended paper. Nevertheless, this paper tried to point at some major issues, such as importance of critical systems thinking, linking the technological affordances to solving societal problems, need and opportunities of creating smart systems, fostering creativity by multi-disciplinary fusion of knowledge, handling systems complexities in development and usage, consideration of social and human aspects in promoting pervasive technologies, and saturation in the perceptive and cognitive domains of human beings. The related tasks cannot be overestimated.

The development of informatics, the ICT industry as a whole, and the need of the society for ICT resources can be regarded as an inevitability. From this perspective, no radical and unforeseen changes in technological, economic and societal arrangement can be expected. Computing resources are becoming less visible, and they appear in miniature forms/sizes, and often embedded in other artifacts. Their price, power consumption and ecological impact of computing devices are continuously decreasing. Everyday objects are becoming smart and capable to communicate in context and collectively act even under unforeseen circumstances. These are indicators of the economic, social and ecological sustainability of ICT. On the other hand, there are many uncertainties concerning the mentioned grand challenges, especially their interaction on shorter and longer scales. Since they are transforming the natural world and created world very fast, living together with these grand challenges needs more attention. It tends to become a common opinion that ICT is not about knowledge, technologies, solutions and products any more, but about society, people, inclusion and experiences. In this context, education has a mandate and a huge number of tasks. Assumed that technological progress is the main driver of human well-being and economic growth, is our current education capable to prepare individuals for the even more technology-dominated world of the near future?

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