Major Challenges in Ambient Intelligence*

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Abstract: Despite recent (and upcoming!) turbulence, Information Society continues to develop and the world's economy continues to go increasingly digital. This process is fuelled by the exponential pace of growth of the underlying Information and Communication Technologies (ICTs).

Today, ICTs are steadily intruding all aspects of our life, in all sectors. But the so-called *digital revolution* has barely begun and will continue to foster changes for decades to come. Indeed, recent studies show that the pace of technological advance in ICTs will continue to gallop throughout the next decade at least and will soon enable – among others – an environment of ***ambient intelligence***, with computing and storage capacity embedded in most physical objects in our surroundings and with everything linked together through seamless broadband communication networks spanning from the home to the global level. At the same time, several other complementary disruptive technologies are also emerging based on advances on sensor, software, knowledge and cognition technologies: a new generation of intuitive and natural human computer interfaces and a new family of intelligent systems that will remove the complexity of building large-scale, interactive and inter-communicating systems.

As ICTs will progressively become a *ubiquitous utility*, they will change, for better or worse, almost every aspect of our life – economic, political, cultural, private and social. Although the underlying business models are still to emerge, the enabling of Ambient Intelligence will generate huge business opportunities for capturing new markets, or extending existing ones. But investment in digital technologies alone will not suffice. It must be complemented by investment in specialised knowledge, in human capital and digital skills. At the same time, the widespread diffusion of ICTs in society creates complex organisational, social and ethical challenges for which we must prepare ourselves.

This paper briefly reviews the recent progress in major ICTs and discusses the main technology as well as business, educational and social challenges that lie ahead us for creating, living and working in future ambient intelligent environments.

Keywords: Information Society, Ambient Intelligence, pervasive computing and networking, nanotechnologies, communication networks, human-computer interfaces, knowledge technologies, education and digital skills, technology and people.

1. The Early Days of the Information Society

A great deal has happened during the last decade of the development of the Information Society. Just a short 10 years ago, when we were discussing the Internet and the potential Web, they were still little more than 'toys' for researchers. Within just a few years, the Internet and the web have expanded all over the world at a breakneck pace. They created a collective exhilaration about the unlimited prospects of a new borderless networked world and produced the dot-com exuberance. Today, despite the dot-com boom and bust, severe business and financial hurdles and ongoing recession, compounded by other recent dramatic events (terrorism, war, ...), the reality remains that the world's economy continues to go, however turbulently, digital.

This digitalisation of the economy, reflecting also our transition to the Information Society, has however barely begun and the last 10 years could well be the first 10 of the next 100. As the Internet and the Web, broadband communications and more broadly Information and Communication technology (ICT) are becoming increasingly ubiquitous, they steadily continue to intrude in all sectors and to progressively transform every aspect of our life – private, social, economic, political and cultural. The new phase we are entering will also see a composite revolution as ICTs integrate with biotechnology and the life sciences as a whole.

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* **Disclaimer**: The opinions expressed in this paper are those of the author and do not necessarily reflect the views of the European Commission.

2. Exponential Technology Advances

Recent scientific trends confirm that the pace of technological advance will continue to gallop for at least another decade under the so-called *exponential laws* (e.g. Moore's Law), with computing, communication and storage capabilities doubling every 18, 6 & 9 months respectively.

Whilst technology is advancing exponentially, applications and services follow much quicker than ever before, but they are developing in a step-wise fashion, in the shape of a series of alternating jumps and plateaux. The jumps are caused by the advent of disruptive technologies. Their cusps provide huge business opportunities for capturing new markets or extending existing ones through the development and deployment of whole new families of innovative products, applications and services. History shows that so far there has been a clear advantage to the first comers and that those who wait for the plateaux find only monopolised or commoditised marketplaces.

The PC, enabled by the advent of the microprocessor was such a jump, which changed radically the world of computing, and its applications. Another "miniaturisation", that of laser technologies, widened the pipes and enabled the Internet as we know it. A new plateau thus emerged, that of networked computing.

The plateau that is to be coming next is brought about by a new vision. It can be attributed again to a kind of miniaturisation, that of sensors and actuators and to recent advances in embedded software. Their combination, communication and interaction is rapidly bringing us toward the so-called ***pervasive computing and networking era*** and will allow us to create an environment of ***ambient intelligence***. The main technology building blocks that are underneath this new environment of ambient intelligence are presented in what follows.

2.1. Computing and Storage Technologies

Based on Moore's law, according to which the number of transistors on chip is doubling every 18 months, the top-down miniaturisation progress of CMOS technology shows no signs of slowing down since almost forty year now. Latest findings show that it will continue to race ahead for at least 15 more years, boosted by intensive R&D efforts and new knowledge in materials, equipment, process, packaging and design methods. Within the coming decade, we may thus be able to produce on an industrial scale devices containing 10 billion transistors on one chip performing 100 billion operations per second. Before, we will have though to overcome some huge technical challenges including mastering thermal and other effects at the atomic level and an unprecedented complexity in design.

Alternatively, breakthroughs are also expected from nanotechnologies exploring new computing devices from the "bottom-up" direction, through assembly of molecules or even atoms into stable structures (molecular electronics) or through exploiting quantum effects (quantum computing).

Similarly dramatic advances have also occurred in storage capacity over the last 25 years. Progress in storage technologies is also expected to continue at a similar unabated pace. In a decade from now, we could have 1 Terabyte of data in one square-inch portable devices.

2.2. Seamless Communication Networks

Before the end of this decade, seamless broadband communication networks will be spanning from the personal area to the regional and global area. This will be made possible by meshing all sorts of different communication networks, whether these are fixed telephony networks, fixed wireless networks, 3rd or higher generation mobile networks, wireless PANs and LANs, satellites or whatsoever. The recent surge of WiFi technologies is yet another phenomenon coming in from the "edges" to conquer.

The integration of fixed and mobile, all-IP, communication infrastructures and their interconnection and interoperability will permit the seamless roaming of data and services from anywhere at anytime. Information and services will become accessible through a multitude of different devices and platforms (TVs, PCs, laptops, PDAs, mobile phones as well as their coming future hybrid information appliances). This in its turn will contribute to opening up demand for a whole new generation of broadband applications and services.

2.3. Anthropocentric Interfaces

A new generation of intuitive and natural human computer interfaces, anthropocentric interfaces, is under preparation, which will greatly increase the usability of systems and enhance/substitute for our senses. It is based on integration of recent advances in computer vision and speech recognition systems and other sensory and multimodal interfaces. The coming of these essentially invisible interfaces will also signal the possibility of computers, at least as we know them today, to *disappear* and to be integrated in our clothes, furniture, cars etc., or to be absorbed into the network.

At the same time, successive waves of innovative high-quality, displays and visualisation technologies will lead us from today's pocket-size digital assistants, laptops & TV-screens to the emergence of tomorrow's wearable and foldable displays and to future wall-size home display systems.

2.4. Intelligent Systems and Environments

They are enabled by computing embedded in any/every physical object in our surroundings and with everything linked together through seamless communication networks. Indeed, with the current pace of technology development, networked ICT devices consisting of a new generation of sensors & actuators as well as tags and identifiers, will soon be small, powerful and cheap enough to be embedded and implanted into everything, from everyday objects and artefacts to our clothes (wearables) and even within us (bio-implants), recording, processing and transmitting real time data of any kind. Technology will also enable soon locating people and objects with a good resolution.

Context-aware and *proactive systems* will then be required for serving, in a most natural and intuitive way, people who are living and interacting in such environments. Such systems will understand and self-adapt to changing situations and contexts; invisibly manage themselves and available networked entities and resources; and, proactively undertake some speculative or anticipatory actions. Their aim will be to hide the overall system complexity, preserve human attention by delivering us only information which is rich with meanings and contexts and provide stable functionality whenever requested. They will become our *personal agents*, seamlessly adapting to our preferences, catering for personalised and tailored use and augmenting our mental and memory capacity.

Furthermore, with the enhancement and extension of our senses and our physical capabilities through augmented and mixed reality and through moving personal autonomous robotic assistants, the geographic reach of our environment becomes unbounded. The possibilities then will be only limited by our imagination.

2.5. Software and Knowledge Technologies

A new generation of *software and knowledge technologies* will be binding everything together from the nano- to the tera-scale, and removing the complexity of building open, intelligent computing and communication systems, as well as their collective behaviour and their co-operative interactions with people.

At the nanometer-scale, we will soon hit the complexity limits in chip design because of the exponential growth of interconnections between chip components. Nanosystems are not only becoming more complex but they need to be designed in shorter time. Disruptive software technologies are needed for increasing the productivity of next generation chip design.

At the other end of the spectrum, systems are being built with increasing number of computing and communication capabilities. They are open, unbound, dynamic and endowed with some intelligence. We will soon need to master their complexity, provide them with learning and gracefully evolving capabilities as well as with self-diagnosis, self-repair, self-adaptation and self-organisation capabilities. Designing, controlling or even only modelling and monitoring the behaviour of such systems are fundamental challenges to address.

Within this decade, pervasive computing and networking systems will probably come of age. There will then be a radical shift in challenges: from demonstrating their concept to integrating them into existing infrastructure; to designing and building composable and proactive (mainly software-based) architectures; and, to designing, creating and delivering to people personalised mass-scale ubiquitous applications and services on thousands of different devices.

Finally, today, there are about 500 million PCs deployed over the world, which are connected to the Internet. Another 5-10 billion embedded processors are also potentially capable of communicating and interacting with each other. Recent advances in distributed software technologies and in peer-to-peer networking permitted to begin tapping to all this computing power by having *the network become the computer*, in the sense of ***grids***. Large distributed computing architectures and supporting frameworks are needed for enabling the interconnection and inter-working of the most advanced computing systems on the global network while coping with communication delays and network and node failures and, ultimately, for creating a computing and data grid with properties similar to the electricity grid.

In addition to the above, a number of other essential **disruptive software and knowledge technologies** that will be needed to realise the vision of Ambient Intelligence include mainly the following:

Content and Knowledge management, dealing with the creation, acquisition, management and production of content, the management of huge databases, the development of *semantic-enabled systems and services* (incl. the "semantic web") and efficient data representation and handling.

So-called *cognition technologies*, perception and vision technologies and the new generation of *artificial intelligence,* for developing systems that understand and interact dynamically with their environment and that are sensitive to context changing.

2.6. Security Technologies

Digital security has been growing in importance for years as more aspects of business and personal life have come to depend on computers. In the coming years, with computing and networking capabilities being integrated almost in every object we will be using, we would like to live without worrying at every step about security, ownership, privacy and individual rights. Developing future computing and networking ubiquitous utility infrastructures which are *"trusted and confident"* and guarantee anywhere-anytime secure services will be key challenges.

2.7. Future Technologies for extending Human Performances

At the same time, ICTs are increasingly playing a major role in combination with other sciences: e.g., in proteomics where the next performance landmark could well be the ab initio simulation of protein folding in real time, 20msec, rather than in the current 40 months.

In fact, more and more often, new and innovative ideas stem from the intersection of different science and technology fields. Examples include physics, chemistry or biochemistry for the nanometer or quantum devices; computer science, sociology and even economics for the tera-scale applications; design, architecture, educational and cognitive sciences for the human-computer interfaces; neuro- and cognitive sciences for new IT systems and technologies, etc.

Looking further ahead, the just started integration of ICTs with upcoming advances in bio- and life-sciences combinations are bound to be at the origin of the next revolution in medicine and more generally in biology and in related life-sciences applications.

3. Technology and Business

What will be the economic impact of Ambient Intelligence? Most pointedly, who will make money out of it, with which business models and which partners, if any?

On the one hand there will be those that supply the technology and on the other there will be those who use the technology to create new products and services. A number of business-model scenarios are already emerging for the latter, larger, group. The revenue models include: *stand-alone models* built upon the embedding of intelligence into a new range of communicating personal devices; *access models* concerned with providing widely distributed and low-price device networks and services; *intersectorial e-consortia models* based on new groups of multidisciplinary and multisectoral collaborative business networks and strategic alliances for the design and deployment of new families of multi-channel innovative applications and services.

The shift to Ambient Intelligence will in addition require that companies focus on their key assets: their human capital and intellectual property and their customer and business relations.

4. Education and Skills

To translate the technology advances into new applications and services, we need a generation of people acquiring skills, which are not yet readily available from, or easily provided by, existing education systems.

The first adjustment needed is to extend the basics, be that either as a scientist or as a citizen in the information society, to include the skills needed for digital literacy.

The next is to provide the scientists of the 21st century, whatever their field, with the broader portfolio of skills needed: skills for handling the micro- & nano-world and for controlling the tera-world (that of large, complex systems) and skills from the underpinning domains of cognition and computation.

Furthermore, as we are entering the world of continuous learning and training, one has to question what will happen. Can universities, as we know them today, remain the sole and exclusive portrayers of professional training? Certainly, universities should and will remain the keepers of truth and beauty, and at the core of scientific research. But as far as professional and vocational training are concerned, there seem to be many other actors – the private sector and commercial services – that come, using the technologies themselves, to play a role.

5. Technology and People

Information revolution and the subsequent emergence of the Information Society are still at their infancy. While the power of ICTs looks set to continue to grow exponentially and their price to fall, how fast they will be introduced and which changes they will bring to the society, for better or worse, is still highly uncertain. In some areas, these changes may be marginal but in most, they will be profound and unprecedented.

Let's consider for the moment some of the positive effects that the penetration of ICTs may have on society. ICTs have the potential to improve our living and working conditions; empower the individual and offer us more choice and convenience; deliver better health care and other social and public services, improve access to information, education and knowledge, as well as to cultural and leisure opportunities; enable higher interactivity and networking between people, businesses and governments; further support community building and foster dialogues across boundaries; stimulate economic growth and productivity and create new economic prospects and jobs.

In some areas, changes are already visible (e.g., person-to-person communications through electronic mail, cellular phones or peer-to-peer exchanges, mobility and teleworking, telebanking, e-commerce, online public services, interactive gaming and digital entertainment, virtual communities, etc), while in others, they are yet to come. At the same time these changes already pose several new challenges: usability and social inclusion (digital divide), copyright/ownership and public goods, privacy and accessibility, freedom and security, creative diversity versus destructive prevalence, open markets versus walled gardens, just to mention a few.

But as ICTs will continue to develop exponentially and progressively become a ***ubiquitous utility***, like electricity, they will change almost every aspect of our lives. They may empower us, but at the same time, they may also harass us and change us for better and worse. By themselves, technologies carry no angels or devils. They are just our new shovels and tools in the emerging Information Society. Which of these changes they bring will finally be for good or ill is yet impossible to predict, because it will depend on how technologies will be applied and how they will be used and this will be a matter of personal, social as well as political choice.

In all circumstances, technologies and the change they bring will pose multiple novel social, organisational and ethical challenges and the decisions to be taken will be difficult, controversial and may be even divisive. In any case, we will need to better prepare ourselves for the coming changes and better understand and evaluate their consequences and their social / societal impact by deploying for example massive field based quasi-experiments (ethnographies). Most importantly, we will need to re-conciliate between ourselves and develop a closer interaction between technologists and humanists as well as sociologists, policy makers and others, while keeping at the epicentre of our activities and minds *the human dimensions* and the values that we cherish or we choose to preserve.