COST Foresight 2030

Harnessing the Digital Revolution

Technical Report:
COST Foresight 2030 Workshop 1 – 3 April 2009

COST Foresight 2030

A New Society in the Making:
A COST Interdisciplinary Strategic Initiative in the Wake of the Digital Revolution

Summary

From innovation triggered by user virtual communities to remote surgery and new financial instruments, the creative power of individuals is being fostered at proportions previously unseen. The main driver enabling such a pace of innovation, scientific progress, and user adoption is the Digital Revolution. One consequence is that interrelationships between science, technology and society are increasing in complexity and harder to understand.

COST Foresight 2030 is an initiative encompassing a set of events designed to explore a multi-disciplinary vision for a future permeated and shaped by the Digital Revolution. The first of such events is this brain-storming workshop on Computer and Communication Sciences and Technologies (CCST), whose objective is to identify key technologies available by year 2030 in terms of Devices, Systems and Services and the corresponding benefits for Individuals, Society and the World. The outcomes of this workshop will serve as the basis for experts in other scientific areas to envision how challenges in their respective disciplines will be tackled when such technologies are available.

COST Foresight 2030 will subsequently encompass events presenting long-term, CCST-enabled perspectives in the following selected fields: Life Enhancement, Energy, Food Security, Natural Resources Management and Organisation of European Society. These sectors of knowledge and innovation play fundamental roles in human life and are going to be highly influenced by CCST.

The outcomes of the COST Foresight 2030, in the form of Proceedings and policy recommendations, will be a valuable tool for policy makers, industry, researchers, consultants and strategy managers alike.

Overview and Timeframe of Events

Advisory Group Meeting, 4 December 2008

The format of the different workshops and list of participants were decided by the Advisory Group. This group is made up of eight members who are aware of the state-of-the-art in the fields of CCST, life enhancement, energy, food security, natural resources management and society.

Strategic Workshop: Computer and Communication Sciences and Technologies, 1 to 3 April 2009

This first workshop included about 20 experts in the field of Information and Communication Technologies (ICT) as well as Computer and Communication Sciences and Technologies (CCST). The aim of this workshop was to set the scene by presenting state-of-the-art and future technologies to be developed by 2030 in these fields. The outputs of this workshop are going to serve as input to the next workshops in the series.

Four Parallel Strategic Workshops: Energy, Food Security, Natural Resources Management and Life Enhancement, 30 June to 2 July 2009

Based on the outcome of the first workshop, the experts in the four fields of interest will submit position papers. They will describe the expected developments in various areas affected by progress in CCST. Each three-day workshop will involve about 20 experts and the participants will be split into three working groups, counting six to seven people each. All workshops should end with a plenary session that summarises the main ideas.

Since the selected fields are closely linked, the rapporteurs from each working group will get together to discuss for an additional half day. This interdisciplinary session will serve to exchange major findings and compare results achieved in the different fields. A discussion on a common topic from different perspectives will also help identify key open points. The results of these workshops will serve as a basis for the activities of the final workshop in the series.

Strategic Workshop Societal Organisation, 7 to 9 October 2009

Based on the conclusions from the previous five workshops, about 20 experts will try to envisage the society of 2030, especially focusing on future cities, health, education, business, and impact on human behaviour.

Wrap up Meeting, January 2010

A committee made up of one rapporteur from each of the six workshops will analyse the various conclusions and elaborate this information to prepare for the final conference event.

International Dissemination Conference, June 2010

The international conference will be a major dissemination event. It will last for three days and will involve experts from academia, industry and policy making. It will serve to gather all major outcomes of the six workshops and present them to the members of the society at large.

For more information on this initiative, please visit www.cost.esf.org/events

Technical Report:
COST Foresight 2030 Workshop
1 – 3 April 2009

Join Joe in 2030

Joe will be 82 in 2030. A large portion of his body will be artificial – not just hips and heart but kidneys, eyes and ears. His mobile phone will be distributed in the eyeglasses, pen, palmtop, and belt, while his personal terabyte memory (PTBM) is implanted in one of his artificial limbs. One of Joe's favourite places is the Parador de Baiona in Spain, so he is planning to walk around that castle wall an April evening.

As friends arrive and check in to the luxury hotel, the icons inside Joe's eyeglasses change colour. Looking over the northern wall down to the waves crashing on the rocks below, Joe says "Hi, Fernando" to his icon. From the lobby 20 seconds later via peer-to-peer voicemail, Fernando says "Hi, Joe. How are you? Shall we meet on the terrace for a beer?" On the inside of Fernando's eyeglasses is a map that shows him where Joe is. Their entire conversation has occurred via their wearable wireless information appliances and the cognitive Parador, securely and without the larger cloud networks.

As they walk towards the bar, the waitress sees that they are coming for a beer so the cognitive-bar shows her and them that they ordered the local draft beer when they met there six years earlier. They agree, "Yes, the local brew again" and it's waiting for them at their table, with the right little bit of Joe's medication offsetting alcohol interaction with his other medications. Their wives join them a few minutes later, guided by the cognitive Parador. Joe's PTBM reminds him of Fernando's wife and kids' names and proper pronunciation learned in 2024 so that Joe's age does not interfere with social graces.

The cognitive Parador with its cognitive bar is just part of the societal cloud environment of trustable cognitive spaces. Joe's voice, his personal electronics and his body parts – original and artificial as well as their individual histories – make him unique. Post-quantum biometric cryptography has replaced RSA security and has completely done away with bank account hacking, replacing passwords with megabit time-tagged crypto-keys that decay to useless random bits if not promptly used as intended.

No one except Lynne, Joe's wife of 70 years, can access his full personal information space. They have no secrets. However, the information shared with the travel agent, European immigration, the US tax authority, and Fernando is limited until Joe gives his permission. As they talk in the April evening 2030, they share with Fernando and his wife how much they enjoy the Lakeside Inn in Mt. Dora, Florida in the US. When Joe mentions the inn, its picture appears between their local ad hoc secure personal information spaces, retrieved from his own videos in the US. When they talk about the menu, it pops up from the inn's website, retrieval cued via voice recognition in Spanish with user-context sensitive case-based reasoning, projected inside their eyeglasses as if hovering in the air. When Fernando says his son Ramon would like the inn, the data moves wirelessly and wired across the globe via the global network (running open source software) to Ramon in an airplane over the Pacific, random bits intelligible only to Ramon, Fernando and Joe.

We’re talking about a revolution…

This scenario may seem far-fetched today, but such rapid advances in information and communications technologies (ICT) are not only possible, but inevitable, by 2030. ICT is already present in every aspect of our lives. In 2009, ICT devices ranging from Grid-connected supercomputers to tiny RFIDs (radio frequency information devices) affect already almost every human activity. The progress of ICT is accelerating at a dizzying pace, as predicated by Ray Kurzweil’s 2001 essay, “The Law of Accelerating Returns”*.* In this essay*,* the inventor and futurist postulates that all technological progress follows an exponential growth.

Already, as an economic sector, ICT represents 7% of world GDP and grew by 12% in 2007. The sector employs more than 15 million people in OECD (Organisation for Economic Cooperation and Development) countries alone with worldwide revenues in excess of US$ 3.8 trillion. The Digital Revolution holds much promise – the challenge lies in how to shape this revolution.

The *COST Foresight 2030 Workshop: Harnessing the Digital Revolution* took place in Bruges from 1 to 3 April 2009 brought together 20 ICT leading scientists, researchers and industry representatives from around the world to debate the effects of technology on our lives in 21 years time and to start to answer some of society’s defining questions and challenges as the Digital Revolution unfolds.

The objectives of the workshop were to identify emerging technologies and scientific developments in the field of ICT, pick out mega-trends and the corresponding drivers, attempt to predict which technologies and related applications will be available by 2030, and suggest directions for future research priorities.

The workshop focused on 2030 because just as today’s ICT bear little resemblance to the IT technologies of 20 years ago, the next 21 years will usher in even more dramatic changes. The year 2030 was chosen because the ICT-based applications and services that will be available to us then will look just as amazing to us as the Blackberry or Nokia E71 would have looked in 1990. Just 20 years ago, Internet was in its infancy and GSM phones did not exist.

Which revolutionary technologies will prevail by 2030?

Since the invention of the integrated circuit, the number of transistors that can be placed inexpensively on an integrated circuit has increased exponentially. This is the essence of “Moore’s law” – and it appears to be set to continue for the next 21 years. Moreover, in the future, it is expected storage capacity to go down to the molecule level and processing being boosted by quantum computing.

The semiconductor industry maintains that multiple technical options exist for the next 10 to 15 years. The industry also reports that semiconductor technology, which is based on CMOS (complementary metal oxide semiconductor), is expected to hit a wall by 2020. However, beyond-CMOS research is well underway, particularly in the area of nanotechnology. The result will be a continuing exponential increase in computing power.

Massive increases in processing capabilities of computers and further miniaturisation of circuits and devices will result in the development of services that today would be considered closer to science fiction than reality. However, participants did not discount “out of the blue” technology advances that could change all of our preconceptions.

During the workshop, participants broke into working groups to explore future ICT application scenarios related to Individuals, Society and the World. They also analysed current trends and future requirements in of the areas of Devices, Systems and Software & Services. In each working group, participants were asked to think outside the box and imagine a society that is very different from today.

They were also asked to identify likely success areas where technologies and applications will develop rapidly to meet individual or societal needs.

Devices in 2030 – smaller, faster, smarter

Processors invisible to human eye

Low-cost printed electronics will form the production basis for processors and sensors of all types, with the CMOS (complementary metal oxide semiconductor) roadmap running through nanowire FETs (field-effect transistors) to carbon nanotubes, then on to molecular electronics and quantum computing. Non-volatile memory will become increasingly important and will need to become totally non-volatile, that is, with memory able to store data permanently without the need for a power source.

Microprocessors, already the size of a grain of rice, will reduce even further in size as nanoprocessor production technologies come to fruition, opening up the likelihood that individual microprocessors will no longer be visible to the human eye. As devices continue to shrink to the size of basic biological units such as cells, nano-sized sensors will bring new possibilities.

With such miniaturisation, the health sector as an example will benefit from new capabilities such as in-vitro diagnostics. Almost all areas of human activity will benefit from greater capabilities and innovation, as device technologies and processing power combined offer ever-greater opportunities for decentralised processing and decision-making. For example, primary care responsibilities could transfer very effectively from large central hospitals to local surgeries or the home environment.

As semiconductor production technologies advance into the realms of nanotechnology, electronics-focused R&D will deliver new breakthroughs in materials and systems, offering new solutions in application areas such as energy by providing new component building blocks for that sector. For example, photovoltaic devices will become much more efficient at harnessing the sun's energy, and other more efficient or sustainable methods will emerge to draw and store energy.

In 2030 the brain-on-chip will be available as brain processing approaches and capabilities created in silicon become a reality. The level of brain processing in a single chip may remain within the 1 billion neurons range. Further evolution will advance through connectivity in a cloud-like environment. These developments will usher in many challenges in maintaining a dynamically evolving connectivity infrastructure to support brain-like processing. Developing this connectivity infrastructure will open up many new opportunities for innovation.

Tiny sensors everywhere

Among the key points that emerged in discussions on device technologies and in all other working groups was that micro-miniature sensors will be the enabler for many diverse applications, from environmental monitoring through human health to determining the temperature of the earth's core.

By 2030, tiny sensors will be fully integrated into a huge range of products, providing the monitoring data fundamental to almost all automated processing. These sensors, many of them invisible to the human eye, will form the foundations on which 2030's technological support and knowledge capabilities are built.

In the home, intelligent, cognitive aids will become commonplace as sensor technologies are incorporated into more and more everyday products. Intelligent, cognitive aids will proliferate and become commonplace as production costs drop and user acceptance grows. Homes might become classified as either "fully smart" or "partially smart". This would distinguish newly-built houses with sensors embedded into every single device and system, all of which are cognitive and able to interact, from older houses offering a mix of traditional and smart areas.

In the workplace, expect the growth of teleconferencing using intelligent avatars capable of standing in for people who cannot attend meetings. Increasing use of tiny, portable ICT-based expert systems will support individual decision-making in the office, on the production floor, in hospitals and in agriculture management in the fields. Because of multiple and simultaneous technological advances, work will become increasingly linked to education and training.

Several participants pointed to the potential for Europe to take the lead in developing sensor technologies.

Human health – eHealth to become a key application area

Human health will have emerged as a key area, due to pressure for better healthcare from governments, health organisations and individuals. ICT-based progress in this area will likely garner maximum user acceptance. Inexpensive, tiny and reliable biosensors will provide the basic monitoring and measurement data for advanced, patient-focused healthcare services.

Much of the basic patient data that will feed into eHealth systems will be gained from body-monitoring sensors that enable real time metabolonics. Sensors will be worn anywhere on the body, swallowed (disposable) or implanted. They will be ubiquitous – in the home, the office or in the doctor's surgery, where sensors will be scanning a patient's physical state as he/she arrives for a consultation. These sensors will be able to continuously check body functions such as blood pressure, heartbeat, lung function, blood alcohol levels, concentrations of drugs in the bloodstream and an individual's emotional state.

Participants discussed the potential of a 'smart toilet' as a concept for daily monitoring of changes in body fluids using for example a build-in urine analyser. Together with a blood pressure monitor and a set of scales to measure body fat and weight, an individual will be able to measure and collect the data about his/her current health status.. The results will be transferred to a home network and integrated into a person's confidential medical file. (Prototypes for intelligent toilet systems have already been developed, but they have not been widely commercialised.)

Most participants believed that the DNA Biochip will be available by 2030. Such a chip will contain all possible data about an individual's genetic makeup. It could resemble a credit card or be implanted directly inside the human body. However, the use of the DNA Biochip raises serious ethical concerns, thereby creating new business opportunities to find solutions to address issues such as privacy and security.

Participants debated the All Body Simulator concept – the idea that a particular eHealth system might be able to simulate every single function of the human body. They considered it an attractive idea, but agreed that such all-embracing monitoring and simulation technology would not be achievable by 2030.

Massive data flows

Because tiny sensors will be ubiquitous, massive data streams will be flowing backwards and forwards. A multitude of sensors in everything – from satellites, human beings, and businesses, to institutions and governments – will be communicating with each other to provide raw data for multitudes of processing and reasoning applications. In many cases, the data will be multidimensional.

For example, technical advances in wireless sensor networks will provide the ability in 2030 to monitor the climate, weather events and ocean dynamics to a far greater extent and penetration than today. Combined with greater computational power, these increased data flows will enable the building of richer climate models, allowing for simulations of the effects of various human interventions into climatic conditions.

Such massive data flows will open up myriad opportunities for innovation in software and services to manage ever-increasingly complex systems.

Systems in 2030 – a cognitive globally aware network

Today's computing and communication systems are likely to be unrecognisable by 2030. More powerful computing systems will include super-computer-on-chip type applications, with greater connectivity between such processing systems as wired and wireless networks expand.

Several technologies in the systems area have a high likelihood of success and a significant impact on society. Internet-linked sensors in the workplace will make the use of IP (Internet Protocol) communications ubiquitous, for example, to automatically control lighting, heating, ventilation and access.

A key challenge will be to manage the complexity of the systems that will drive 2030's digital world. Opportunities will arise as researchers and the private sector work together to develop the necessary tools to effectively manage this complexity.

A global network resource

Another likely success scenario is the concept of the "cognitive globally aware network". This scenario was widely acknowledged by participants as having the greatest likelihood of becoming a reality by 2030. Today, cognitive networks use self-configuration capacity to respond and dynamically adopt operational and context changes.

Tomorrow's cognitive globally aware network will collect and organise information and knowledge from sources across the world. This network will be universally responsive to the needs and demands of individual users, while optimising overall network performance. People will access the network and interact with their offices, files and their personal responsibilities in both physical and virtual worlds.

The technological requirements underpinning this cognitive globally aware network are expected to come from a direct evolution of current trends. Internet access will be all-pervasive thanks to wide availability of low-cost broadband (wired or wireless) for all users. New business and economic models will combine an open, secure and reliable network and service infrastructure with free competition on the Internet-based services market. Knowledge creation and sharing will aim almost exclusively at an online target market, with public opinion wooed via opinion-based portals that have a proven reputation.

Communication methods will be dramatically different. The network will integrate real and virtual worlds. People could visit distant friends and colleagues in the form of high-definition avatars, able to appear and interact as real persons. This raises both technological challenges and questions concerning social legitimacy.

The network's communications abilities will be secondary to its ability to act as a kind of universal wiki, the ultimate knowledge resource, with the ability to answer any question on any subject. A multitude of local decision support applications tailored to both group and individual needs will rely on this global resource, the planet's ultimate knowledge base.

In business, software developers and engineering consultants will be able to run simulations that gather data from both physical and virtual environments within that global research database. For example, individuals may also use sub-sections of the global network's resources to help manage their energy consumption and facilitate the sale of surplus or on-site generated energy back to the grid.

A simulation element will be commonplace in almost all research fields, from condensed matter to engineering, from biology to medicine, thereby helping researchers to showcase innovation or leadership in a particular field. In the process, research initiatives will have to address the migration of scientific and engineering fields from classical experimental and theoretical knowledge to simulation-based research.

Human-machine interfaces (HMI) advancing

Local and personal memory storage in the terabyte range will be available in devices, mobile phones and other HMI terminals, in cars, televisions and even within artificial limbs. Seamless access to local and personal memory storage as well as the virtual storage within global networks will change the way we look at the world and interact with it.

It will become more difficult to determine what is local and what remote; what is a product and what a service; and who is the provider. Similarly, display and projection technologies will have evolved to match our eye and brain resolutions (8 Mpixel and 20 Mpixel respectively), making the distinction between the real and the virtual increasingly difficult to discern.

Potential direct brain-to-computer or computer-to-brain interfaces may be able to augment or even bypass the normal human sensory communication pathways. This would allow far more efficient communication with machines, for example, by developing new senses, as well as communication with other human beings. Directly implanted devices are the obvious interface method. However, non-invasive approaches may also be possible by 2030.

Decision-support systems help eliminate doubt

Real-time monitoring and communication capabilities will make possible decision-support systems that will remove much of the doubt in human decision-making, especially in high-stress environments and scenarios. For example, fire-fighters will know just how extreme the temperature is for a fire on the other side of a solid wall and will have advice on how to deal with it. Workers at the international space station will have advice on the correct procedures for assembling a vital piece of machinery.

Decision support will prevail in the healthcare sector. Personalised, patient-focused healthcare was forecast to be achievable on a mass-market scale. eHealth systems will advance enormously by 2030, benefiting from cheap, widespread micro-miniature sensors, as well as massive processing power.

Natural-language processing capability is considered another key objective. Finally overcoming the speech-to-text obstacle will simplify the human-machine interface (HMI), and will make the keyboard-input process redundant. However, participants doubted that the “Babelfish” dream – a device implanted directly inside the human ear that enables universal language translation – could be achieved by 2030.

Software & Services in 2030 – managing information

Innovation in systems and products will become even more global as the importance of international markets increasingly takes over from regional or local markets. Participants generally agreed that the globalisation of innovation is even more likely. Consider that around 60,000 applications have been developed worldwide for Facebook over the past 4-5 years. At the same time, more than 20,000 applications have been developed for the iPhone in the last year alone.

Information becomes easier to find

With global networks providing the kind of “universal wiki” that informs on every possible subject, efficient methods of labelling and categorising information will be all-important. As a result, automatic semantic annotation of text using algorithms is likely to become omnipresent by 2030.

Today, semantic annotation of text and documents is a labour-intensive process, with existing automated annotation models still subject to high error levels. By 2030, the kind of computing power available will provide the opportunity for technological breakthroughs that will enable radically new applications and markets to be created.

Such methods will allow the public to easily access millions of news items, stories, reports, and documents in every field of human endeavour. Semantic annotation of text, functioning automatically and on a large scale, will enable researchers – both human and machine – to move beyond simply finding web pages to using tools capable of accessing and organising information on complex topics.

Evolving product design, development and production

Software languages are likely to undergo a revolution. They will be both understandable and usable by non-experts, enabling them to manage software and services development and adaptation. Business analysts will be able to translate customers' needs directly into development solutions. Service providers will be able to meet customers’ evolving demands by adapting existing solutions on-the-fly to new or changing requirements.

However, a huge amount of standardisation in protocols and standards will be necessary. Open standards will become even more important than they are now, and protocols for service level communications will converge. Shared ontology and knowledge bases will be fundamental to enabling semantic interoperability between services. These knowledge bases will also be the foundation for information sharing between humans and machines.

Engineers will make increasing use of virtual-reality simulation to develop new software applications. Automated development and verification tools are already taking over many of the more onerous and repetitive tasks of software development. The development process will certainly evolve into increasingly abstractive engineering techniques that are platform free.

By 2030, many products will be built in automated factories by virtual manufacturers and shipped directly to the consumer. Products will evolve and advance as a direct response to customer feedback. Individual consumers will be able to propose new functionality, and producers will be able to rapidly modify product updates for the global market.

Today’s budding “prosumerism” – or customer centricity – will surely continue with the rapid proliferation of ICT, combined with education, informed consumerism and networks. “Prosumers” benefit from being in control of their lives and are proactive – they call the shots on important issues. They seek out tips and clues from all sources, but are not slaves to lifestyle gurus or brands. They pick, mix and assemble their lifestyles to meet their own needs.

3D printing will move beyond rapid prototyping, which will drive the potential for customisation on a massive scale. With such enhanced possibilities for the customisation and design of products, the nature of product development, manufacture and distribution will change fundamentally. Stock control processes are likely to change also, making use of advanced modelling and prediction algorithms to optimise production and supply chains.

The advent of virtual products will open up a new frontier for innovative technologies. New technologies will allow all real artefacts to have a digital counterpart. (However, the interaction between real and digital artefacts will be impossible.) Digital artefacts will become a part of everyday life as everyone has access to everything around the world.

This will create opportunities for Europe in the area of cultural diversity, with the potential of new jobs in fields such as cultural heritage and developing new business models.

HMI to integrate into our surroundings

Human-machine interfaces will be found in everyday items, such as eyeglasses, pens, palmtops, clothing or even trouser belts. Because enormous amounts of memory (by today's standards) in the terabyte range will be available, the locations of HMI may become more imaginative. For example, memory could be implanted inside the human body, within an artificial limb or an elbow joint replacement.

Wearable physiological devices will almost certainly have a role to play. Brain stimulation technologies may be used to expand our senses in some very specific applications, for example, in the areas of security or military. At the same time, direct brain stimulation could become very important for certain medical applications. New membranes will be created for information exchange control, enabling people to create their own reality bubbles, which will be enabled by augmented or mixed reality.

The boundaries between different realms of technology are likely to blur as technologies converge and the human-machine interface evolves far beyond the archetypal fixed screen and keyboard. Novel input/output devices, able to interpret inputs as different as spoken language, gesture, tone of voice or emotional state will become available.

These HMI will enable people to control how they see the universe – and how the universe sees them.

The learning machine

A key point that emerged in the discussions was that there will be a revolutionary change in the way people interact with technology in 2030. By that time, self-learning ICT will enable software systems and services and the machines that they control to adapt to human inconsistencies, rather than vice versa.

Self-adaptation and self-evolution for software and services, and thus for intelligent products, will become a standard requirement that will reduce the load on software developers. Intelligent machines will be able to program themselves by using a set of adaptation rules that are part of their "genetic" make-up. The task of the engineers will be to refine the adaptation rules that enable these machines to self-adapt.

These self-learning systems will be able to be "taught" by non-expert users to a much wider extent than today. Such capabilities will bring new risks as well as new benefits. Ethical considerations and the question, "But should we do that?" will need to be addressed and will demand standards from public authorities and solutions from the private sector.

The move from machine-focused HMI to human-focused HMI will represent a radical shift in emphasis in the way we use technology. Many more individuals will be able to exploit the benefits of modern ICT-based services. The elderly and young children will use intelligent aids in ways that they cannot do now. For example, new software services could even allow the mentally challenged to exploit technology to help them overcome the challenges of daily life.

With semantic labels embedded into devices, the data from such devices will integrate with the speech, actions and even thoughts of users. Information links will be carried out wirelessly, so that homes, workplaces and regular public transport services will become cognitive, knowing users and adjusting the local environment to their personal needs.

Combined advances in digital micro-systems, software, Artificial Intelligence and machine reasoning will allow the construction of intelligent robots, with artificial personality and self-consciousness-like behaviour. These robots will populate homes and workplaces. New legislation will be necessary because of the ubiquity of such person-like machines.

At the same time, the issue of trust in technology-based systems and services will rise in importance. Isaac Asimov's Three Laws of Robotics[1] will be relevant in the case of human-like servants or labourers. But other areas will be of equal importance. For example, security considerations for preventing identity theft will drive extensive innovation on issues of data retention and privacy.

Virtual reality becomes widely used

Large-scale, reality-based role-play in the virtual world will be used by everyone. Virtual reality scenarios began in the online games industry in the late 20th century, but by 2030 such scenarios will have spread to education, industry, training and a host of similar applications.

3D virtual-world platforms will be based on open standards, cheap and easy to develop and distribute, and have built-in payment infrastructures allowing module developers to charge for goods and services. They will also be simple to install, configure and set up for the end user.

Pervasive computing that better anticipates users' needs and gives a personalized, adaptive user experience will blur the boundaries between physical and virtual realities. Real-world experiences augmented with additional information from virtual equivalents could well become the norm, thus transforming communication, cooperation and even simulation.

The connotation of mobility itself will change. As real-world travel becomes increasingly expensive, virtual space will gain in importance. People's virtual networks and identities will become an "always-on" part of their everyday identity. In mixed virtual/physical reality environments users will not be able to tell if they are interacting with a human being or a digital persona.

When a greater reliance on virtual reality blurs real and virtual boundaries online, the public's need to trust that space grows in importance. If someone's information space is hacked or corrupted, their confidence in the global network is shaken. Trust, and the security to underpin that trust, will be all-important in the networked reality of 2030.

Blurring of boundaries in the virtual world will spill over into the real world. Some individuals already spend more of their time online than they do in the physical world – a situation regarded as unhealthy. Many more people will find themselves in this situation, giving rise to a potential new field of medical casework addressing "excessive disconnection" from reality.

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[1] Asimov's three fundamental rules first appeared in the story "Runaround" in *I Robot* (1950). 1. A robot may not injure a human being or through inaction allow a human being to come to harm. 2. A robot must obey the orders given it by human beings except where such orders would conflict with the first law. 3. A robot must protect its own existence as long as such protection does not conflict with the first or second laws.

Yet, attitudes regarding physical space are likely to change even among so-called "balanced" individuals. The notion of "place" as in place of birth or residence may become more fluid. Early casualties may be identification with a particular nation-state as the place of birth and first loyalty. Citizenship itself may come into question, as tele-presence and teleportation enables people to impose their own geographical limits.

Personal information spaces all-important

Individual personal information spaces in the virtual world will become even more important than they are today. Current applications such as Facebook and Twitter will evolve into personal information spaces that are trusted, using technologies such as biometric cryptology and post-quantum cryptography to ensure security for the individual's online identity.

These trusted information areas will store almost every single item of information about an individual, with that individual's full consent and trust that only he/she has access to that information. Limited access to specific data areas by third parties will only be granted under strict controls.

Personal information spaces could morph into tele-presence technologies – with a virtual-reality agent authorised by your personal space to attend meetings and act on your behalf. A tele-presence portal in the home or within walking distance will be possible by 2030. Such portals would greatly facilitate the all-important "face" communication for those too far away or unable to travel easily for real-world meetings.

Tele-presence technology is available today, but making it widely available is still a very costly proposition. Participants agreed that the ultimate goal of functioning teleportation systems is probably unachievable by 2030. However, the possibility of achieving functioning virtual teleportation systems is more realistic by that date. The only point at issue is the likely level of sophistication of such systems.

The Individual Life Footprint (ILF)

Another key concept that may emerge by 2030 is an "individual life footprint" (ILF), a continuous, real-time measurement of an individual's impact or "footprint" on the environment. Leading up to 2030, a growing recognition of the importance of sustainability and personal responsibility will increase social pressure on individuals to minimise their environmental footprint. In 2030 and beyond, this pressure will intensify – imagine being rebuked by Facebook friends for a public ILF score that has risen above 8.5 out of 10.

In this scenario, as the concept of environmental responsibility becomes mainstream thinking, individuals will face strong social pressures and probably financial incentives to optimise the way they use scarce planetary resources. New markets will arise, enabling individuals to trade ILF debits and credits similar to emissions trading in today's carbon markets.

Conclusions

In summary, the ICT-based applications and services that will be available to us in 2030 will look just as amazing to us as handheld computers would have looked back in 1990. Increasingly, they are also defining our environment, as they serve to improve telecom infrastructures, buildings, roads and vehicles, ships and planes, shops and warehouses, manufacturing and supply chains, hospitals and medicine.

Throughout all discussions and debates, eHealth emerged repeatedly – and with near-unanimous agreement from the participants – as one of the areas which would harness the rapid progress in the ICT domain, and especially benefit the ageing population of Europe. In this respect, defining standards is key. Standard setting will remain a critical area of involvement for industry and policymakers, whether for patient data, machine-learning algorithms to support diagnostics or sophisticated modelling of the human body. Moreover, in this context, privacy, security and trust issues will become paramount.

By 2030, we will witness the coming of age of technologies for fluent brain-computer and computer-mediated brain-to-brain interaction – known as hyper-interaction. We will be able to regulate how we "see" the universe – and how the universe sees us. Users will be accustomed to blurring virtual experiences with reality. Brain-to-brain communication will be possible as will "real" feeling experiences through the use of digital media to create simulated reality. Efficient brain-to-computer and computer-to-brain interfaces will increase or bypass natural sensorial communication pathways.

Web 2.0 has helped to communicate, share information and collaborate on the World Wide Web. Web 2.0 is also transforming the economy and empowering consumers. By 2030, this transformation will be driven by "prosumers" – proactive consumers who will demand products designed specifically for them. By 2030, many products will be built in automated factories by virtual manufacturers and shipped directly to such prosumers. Products will evolve and advance as a direct response to customer feedback. New technologies will allow all real artefacts to have a digital counterpart. As a result, digital artefacts will become part of our daily lives as everybody will have access to everything around the world. The forthcoming 2.0 economy will open up endless possibilities for creative individuals – and SMEs – to excel in the global marketplace.

In the future, increasingly larger amounts of data will be collected from sensors around the globe involved in automated monitoring tasks, like minimising pollution, optimising transport, preventing impending disasters, tracking the healthcare of individuals, operating homes, running businesses and many other applications that are unimaginable today. Computing the carbon footprint will be something of the past, as interconnected monitoring systems will calculate a comprehensive individual life footprint that takes into account most individual factors that impact sustainable living and promote responsible decision-making.

Preparing for this data deluge will open up opportunities for complex data management systems as we grapple with the challenge of how to manage this information, including storage, aggregating, searching, filtering, trusting and certification. This calls for technologies that will automatically enrich information with semantics. But also, those used for cooperative tools that aggregate, organise and increase information. Today, semantic annotation is in its infancy, allowing for shallow analysis. By 2030, this field will be highly sophisticated, enabling deep analysis that, when merged with simulation, will lead to unprecedented predictive power.

Global connectivity – being wired to the world and to each other – will be a way of life in 2030. Connectivity will be affordable and will open up new horizons as our notion of geography shifts. The new global network will allow multilingual and multicultural interaction, made possible by new technological developments allowing for automatic translation and natural language processing. With this shift to a global network will come a notable shift in human social behaviour as we are able to interact with others regardless of distance or language. Some predict this new geography will change our notion of citizenship, ushering in more flexible concepts such as "liquid citizenship".

Underscoring these developments will be the concept of global sustainability. In fact, by allowing us to better manage the Earth's natural resources, ICT can facilitate the transition towards a sustainable future with a more environmentally-friendly way of living that includes sustainable economic development and participative global governance.

Enabling these visions is the fact that the experts agreed that Moore's Law will continue to apply in the semiconductor industry, certainly until 2020 and, with some technological twists, beyond that. One consequence is that the processing power of computers in 2030 will be at least four orders of magnitude larger than today.

Finally, such an exponential technological growth, typical of ICT, is already being witnessed in other areas, like genomics and services. In most cases it is nurtured by multidisciplinary undertakings that apply computational thinking from Computer Science to other disciplines, fostering what is known as "industrial-scale science". This opens a new era of laboratory work, departing from ad-hoc linear experiments towards automated parallel production chains of experiments that can be described in structured, formal languages and that can be run by less experienced people with the help of appropriate computer interfaces.

COST Foresight 2030 workshops – what's next?

Shifting social patterns and demographics will require new models for organising European society. This will usher in new challenges that Europe may – or may not – be ready to meet. The strategic brainstorming workshop in Bruges held 1 to 3 April laid the foundation for a second workshop to be held 30 June to 2 July 2009, where participants will discuss how the Digital Revolution will affect four major areas of society: energy, food security, natural resources management and life enhancement.

A third workshop, from 7 to 9 October 2009, will attempt to define society in 2030, focusing on future cities, health, education, business and the impact of ICT on human behaviour. A wrap-up workshop will be held in January 2010 and an international dissemination conference is planned for June 2010.

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The workshop gathered experts in the field of Computer and Communication Sciences and Technologies:

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- Dieter Fellner, TU Darmstadt, DE
- José-Luis Fernandez-Villacañas Martín, European Commission, BE
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- Andre Hagehülsmann, Microsoft, DE
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About COST

COST is an intergovernmental European framework for international cooperation between nationally funded research activities. COST creates scientific networks and enables scientists to collaborate in a wide spectrum of activities in research and technology. COST Activities are administered by the COST Office.

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