Information Society Technologies Advisory Group
Working Group

"Grand Challenges in the Evolution of the Information Society"

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Contents

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1. Executive Summary

In preparation for the European Union's 7^{th} Framework Programme for research and technological development, the European Commission asked the IST Working Group on Grand Challenges to assess the future of IST technologies and their influence on European society. The group's aims were to identify grand challenges in information and communication technology (ICT), the pursuit of which will stimulate research and development in key areas and help the European Union to achieve its social and economic goals. The Working Group has followed its conviction that research and development should be a resource for technology innovations that lead directly to significant benefits for European economy and society.

In our view, the Internet and today's global networks of mobile communication technologies presage an era in which IST will be dominated by complex, integrated IT systems. Europe's strength is the design, engineering and deployment of large-scale integrated IT solutions. The major challenge for research and development will lie in learning how to design and manage complex, networked systems comprising thousands heterogeneous components, while ensuring that these systems bring benefits to European Society. At the same time, the boundaries of ICT research are now rapidly expanding and prospects for further growth are also increasingly relying upon cross-fertilisation of ICTs with many other scientific disciplines, in particular material-, bio- and the life sciences. Our grand challenges aim to achieve these goals by furthering the seamless integration of diverse ICT technologies with upcoming advances in other relevant disciplines. We have sought to identify visionary projects leading to "concrete pictures of the future", focusing 8-10 years in the future, that will demand interdisciplinary research and engineering in many key areas and that exemplify application domains of particular promise for growth in Europe.

We believe that the greatest technological progress arises from projects having clear and specific goals, the achievement of which is easily recognisable. Concrete projects – such as putting a man on the moon or sequencing the human genome – generate natural milestones, and provide strong incentives for technological advancement. We have tried to follow this principle in identifying our grand challenges, which we describe briefly below.

An Overview of the Grand Challenges

1. **The 100% Safe Car**: Roadway accidents entail enormous human suffering and burden European society with tremendous economic costs. Hence, we envision projects with ICT systems leading the realisation of the 100% safe automobile for eliminating traffic fatalities almost completely.

2. **The Multilingual Companion**: With the enlargement to 25 Member States, the EU faces a new multi-lingual challenge. We envision grand projects to defeat the communication barrier between member states by developing a powerful "multi-lingual companion" that will make multilingual and cross-lingual information access and communication virtually automatic.

3. **The Service Robot Companion**: As the European population ages, spiralling health-related costs will place an immense burden on European economies. We envision the development of flexible home-care service robots, which will help people to care for themselves, improve their comfort of living and likely entertain them.

4. **The Self-Monitoring and Self-Repairing Computer**: System failures are extremely costly and all too frequent in today's complex ICT systems. We envision a grand challenge to develop self-monitoring and self-repairing computing systems that will demonstrate the principle of software systems with greatly improved reliability.

5. **The Internet Police Agent**: To reap the full benefits of the Internet, we must maintain its further development and counter criminal and anti-social activities (SPAM, viruses, worms, fraud, etc.). We envision projects to develop an automated "police agent" that will be a socially beneficial force within the Internet environment.

6. **The Disease and Treatment Simulator**: We envision the development of a computational platform for simulating the function of a concrete disease. This simulator will enable medicines to be tested without putting people at risk, and will accelerate research into damaging diseases such as heart disease and cancer.

7. **The Augmented Personal Memory**: The ICT revolution will make it possible to store virtually every image, film or television program you have ever seen, every conversation you have ever had or book you have read. We envision a project that will make it possible for people to create, preserve, sort and retrieve their own personal vast storehouse of the past, in the form of a personalised digital life diary and augmented memory assistant.

8. **The Pervasive Communication Jacket**: Most objects in the house, at work or in public spaces will soon carry wireless communications technology. We envision a communications "jacket" that will enable the individual of tomorrow to exploit these information resources in a natural and beneficial way.

9. **The Personal Everywhere Visualiser**: Visualisation is key for people to exploit the information revolution. A grand challenge is to develop a convenient personal and mobile visualisation system that will work anywhere and with minimal fuss, thereby enhancing our ability to harness tomorrow's ICT capabilities.

10. **The Ultra-light Aerial Transport Agent**: We envision an unmanned aerial transport agent for "small scale" logistics – for the transport of small packages and products from point to point, monitoring of crime, and helping in search and rescue operations.

11. **The Intelligent Retail Store**: We envision projects to realise the "intelligent retail store" – a store in which emerging ICT technologies are integrated in a way that brings more information, and efficiency to both retailers and their customers alike.

In the following pages, this report offers a more detailed description of these grand challenges and the motivation that lies behind them. We also describe the scientific goals to which they are directed in the context of European research in ICT, and the social and economic issues they are designed to address.

2. Introduction

Technology exerts a decisive influence over the course of human history. From gunpowder to the steam engine, from electricity and nuclear power through electronics and biotechnology, nations that have harnessed natural forces through technology have prospered, leaving others behind. Over the past three decades, the explosion in information technology has demonstrated this point again. Driven by terrific advances in electronics, the revolution in information and communications technology has spread powerful computing devices across the globe, created the unprecedented information resources of the Internet and World Wide Web, and transformed global communications through flexible e-mail and mobile telephone services. This explosive increase in our ability to gather, store and process information has stimulated sweeping social changes, altering the way we do our work and linking people together more closely than ever before. The Internet has already revolutionized the relationships between businesses and their customers, as well as the way businesses manage their supply chains and internal communications and processes. Indeed, modern information technology has altered the very nature of the global economy, which increasingly thrives on the creation and provision of knowledge-based products and services, rather than the production of material goods. In every case, nations involved in this revolution – primarily in the west, but also in Japan and Southeast Asia – have advanced far beyond their competitors. In today's world, technological innovation lights the way to prosperity.

In the coming decades, computers and communications technology will become immeasurably more powerful still, while also growing cheaper. In the United States, for example, a number of projects already envision the "one-dollar" computer. If information technology continues to develop as it has – and the available science suggests that it will – then a "second wave" of new products and capabilities will transform society again. The next transformation will, however, involve more than mere increased power and device sophistication. We will see a proliferation of devices based on novel physics and engineering – electronics based, for example, in plastic and other organic materials. We will see one of the oldest information technologies – paper – being replaced by electronic rivals that share its advantages (affordability and ease of use) but bring others as well (word processing, links to World Wide Web, etc). We will go beyond miniature electronics to micro-machinery, and to devices that assemble and possibly even design themselves. The next generation of devices will also exploit insights from molecular and systems biology, among other sciences, to become more "intelligent", and to bring perception, learning and reasoning into their routine functions.

Most significantly, however, information technology is set to experience a massive and unprecedented increase in systems complexity, as developers strive to integrate a vast spectrum of diverse technologies and "intelligent devices by the billions" into connected networks. In tomorrow's world, the environment will brim with pervasive sensors and other devices. Communications traffic will increase enormously as these devices share information in order to carry out the "housekeeping" chores of an information-centric world. The Internet will be everywhere, and will be a vastly deeper and more powerful environment than we know today, with multiple layers and inhabited by a population of intelligent software agents aiming to support its health and efficient function. The information society of tomorrow will be, first and foremost, a networked society, with individuals and businesses always linked into a global web of technology, and an economy founded on a seamless environment of networked information resources. These networks will aim to provide socially beneficial functions – from monitoring individual health to supporting global enterprise – with efficiency and resilience.

This second wave of information technology has immediate implications for the social and economic future of Europe. At the European Council in Lisbon in March 2000, heads of member states agreed that the European Union should aim to create…

…the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion.

Achieving these goals will, of course, require concerted government action at many levels, but it is increasingly clear that a sustainable knowledge-based economy cannot be realized without strategic investment for the research and development of information and communications technology.

Historically, it has been virtually impossible to predict what will be the greatest payoffs from investment in technological development. New technologies enable us not only to do the things we have done before more quickly and efficiently, but to do entirely new kinds of things; for this reason, technology creates entirely new industries and new areas of science. Firms such as Nokia, SAP and Vodafone, major drivers of the European economy today, emerged directly from the information revolution of the 1990s. Further advances in information technology will fuel the continued development of these and other information-based industries that are already central to the health of the overall European economy. The next generation of information technology will provide the infrastructure to integrate European businesses into a more efficient and competitive economic web; more importantly, it will also lead to entirely new industries that will dominate tomorrow's economy by providing products and services that do not exist today.

ICT will also contribute to the achievement of a broad range of other social goals. In today's networked and information-centric world, individuals, businesses and governments face novel kinds of risks. With the global economy now far more integrated than it has ever been, for example, chains of economic cause and effect reach across the world with disconcerting speed, exposing individuals, firms, and governments to a new kind of "interdependence risk" — to the possibility that events quite far away can undermine the activities on which their security and prosperity depend. While information technology cannot provide security on is own, it will play an important part in the design of security solutions. ICT also offers novel and potentially powerful tools for dealing with other societal risks, such as that associated with healthcare, a looming threat for Europe in view of projected demographic changes. With a few decades, nearly half the European population will be of retirement age, placing a great burden on the European economy. We have only begun to explore the potential for information technologies to augment the abilities of elderly to care for themselves, and also to help in the caring for the ill and handicapped.

On a more general note, of course, there is no question that ICT will also become increasingly essential to the continued advancement of basic science, be it in the design and manufacture of advanced materials, in tackling the vast complexity presented by the human genome, and, more generally, in gaining insight into complex, multi-component systems ranging from global climate to marine ecosystems, not to mention human society itself. The next century's science will depend on ICT just as the last century's depended on mathematics.

These are only a few of the areas in which ICT development will play a determining role in Europe's future. Consequently, it is clear that the European Union and its member states must take decisive steps now to ensure that levels of investment in ICT research and development match its importance to society. The next wave of information technology will not arrive on its own, or simply as a result from "momentum" already established over the past three decades.

Unfortunately, there is no guarantee that Europe will meet this challenge and manage to remain globally competitive in the most important areas of ICT. In fact, if recent investment trends in research and development continue, it is very likely that the European Union will fall increasingly behind the United States and Asia, while facing stiff and potentially catastrophic competition from developing nations, especially India and China.

Data collected by the OECD indicates that European nations are now lagging far behind the US and Asia in overall investment in ICT research and development.[1] This is true in overall terms, on a per capita basis, or if judged as a ratio of GDP. In year 2003, for example, US investment in research and development in ICT (telecommunications, hardware, software and multimedia) was estimated at 69 B$ (0.65 of GDP), which compares with the European figure of 28 B$ (0.27 of GDP). This is a difference of 40 B$! This amount increased by 50% in six years, and such a huge discrepancy cannot be found in any other sector (automotive, aeronautics, pharmacy or chemistry). The reason may be found both in the fact that public funding in the US is twic as large (11.7 B$) as in the EU (5.1 B$), and also that the ratio of private/public funding is 7.1 for US and only 5.2 for the EU. If Europe is to compete successfully in the global economy over the coming decades, it will have to double public funding and also achieve a significant increase in private sector investment. Current levels of investment in ICT will not stimulate the sustained level of innovation required for European success in the coming decades.

As one specific example, Asia is set to introduce so-called "4th generation" technology for wireless communications in 2008. For the European ICT industry, this is a very serious threat. At the moment, Europe remains strong in the wireless communication markets based on the success of Ericsson, Nokia, Alcatel and Siemens. But as technology advances to the next era, this strong position could be easily eroded. Last autumn, the IT ministers of China, Japan and South Korea discussed Asian leadership in this next generation of technology. This commitment is reflected by heavy investments in ICT research and development in these countries, on the part of both individual companies and governments. These three countries are making a serious and concerted bid to take over the lead in wireless communications technology and to roll this technology out over the world markets. This is a looming threat to the strong position enjoyed by Europe today.

This competitive challenge and others like it take on additional significance in the contemporary environment of international business and trade. Many manufacturing industries have already migrated to developing nations in search of cheaper labour. As white-collar and high technology jobs also move into countries such as China and India, these nations will become increasingly competitive. Given the high level of investment these countries have made in basic education, their economies are evolving very rapidly and will soon pose a serious threat to the advantage in technical "know how" that the west has enjoyed for many years. If the European economy is to thrive in the coming decades, it will do so not on the basis of heavy manufacturing, agriculture or even the "older" information technologies, which will continue to move into developing nations. To maintain a healthy economy and high quality of life, Europe has little choice but to remain at the forefront in the development and exploitation of information technology, and to play an instrumental role in bringing this "second wave" of ICT complexity from the research laboratory into the real world.

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[1] *Research and Development in Information Science and Technology in Large Industrialized Countries.* Study carried out for the Conseil Strategique des Technologies des l'Information by the Groupement Francais de l'Industrie de l'Information. December 2002.
http://www.csti.pm.gouv.fr/uk/etudes/Synthese_GB_EtudeR&D_Octobre2003.pdf

Apart from these economic issues, an issue of European sovereignty is also emerging. Europe is investing large efforts to guarantee the integrity of information and communications, while, in the meantime, the basic technologies and products are being fully mastered by non-EU companies who can report to their own administrations.

In conclusion, Europe will need greatly increased funding in ICT R&D from both public and private sources if it is to meet its economic and social objectives. But funding alone is not sufficient. To derive the greatest social benefit from its investment, the European Union also needs a strategic plan that will address the most immediate and formidable roadblocks in ICT. To help with this crucial task of planning and foresight, the ISTAG Working Group on Grand Challenges has identified eleven visionary projects in future information technology in combination with other relevant disciplines, the pursuit of which will bring broad social and economic benefits to European nations. Throughout its work, the working group has followed its belief that research and development in information technology is not an end in itself, but should aim to increase productivity and to address important social challenges.

IST Working Group on Grand Challenges: Vision and Aims

The aims of the IST Working Group on Grand Challenges were as follows:

- to identify major grand challenges in information and communication technology relevant to future society;

- to explore the scientific, economic and social importance of these grand challenges, as well as the potential legal and ethical implications of their realisation;

- to identify the principal scientific and technological research directions that will be instrumental in pursuing these grand challenges;

- to make a preliminary assessment of Europe's competitive standing relative to the US and Asia in the science and technology associated with each of these grand challenges.

At the outset, it is important to clarify what is meant by a "grand challenge". In the view of the ISTAG Working Group, a grand challenge in IST should be a visionary project that will demand basic and application-oriented research and engineering in many key areas of computer science, from hardware to software and beyond. Each grand challenge should have a very concrete and specific goal, focusing 10 years in future; it should be centred around "pictures of the future" and lie at the edge of "what might be possible", so as to challenge researchers to reach well beyond current capabilities. The working group strongly believes that the principle difficulty in building the next generation of ICT will lie not with individual devices, but in learning how to design and manage the coordination of networks of many technologies and many devices. Consequently, a suitable grand challenge must require the seamless integration of many diverse technologies, and strive to create functioning networks that help people to improve their lives. This is a highly interdisciplinary challenge, which cannot be met by computer science alone, but will require the coherent efforts of many scientific areas including biology and the life sciences, social science, materials science, chemistry, physics and mathematics.

In identifying our grand challenges, we have also tried to keep in mind the near-term evolution of ICT, both within FP6 over the past three to four years, and continuing into FP7 in the near future. It is important, we believe, that the grand challenges fit efficiently into the current trajectory of European ICT research and development, so as to maximize their value for society. ICT over the past 3-4 years has focused principally on rolling out ever more sophisticated mobile and wireless ICT technology, which increasingly permeates all aspects of everyday life. We are coming to depend ever more on computers and communications networks. As individual devices have become smaller and more powerful, they have increasingly been linked together within complex networks. This trend will clearly continue in the next 7-10 years. However, we also foresee two other major trends in the near future that will change the face of ICT.

The distinct processes of communication and computation are being linked together within miniature artifacts and objects, “smart” devices that are embedded or “hidden” in the environment and communicate with each other. Because these artifacts have computational capabilities, their linked communications will underlie the creation of distributed and self-regulating systems that are adapted to human needs. These semi-intelligent and highly adaptive networks will augment the physical environment with new properties, enhancing its interaction with people, while keeping the underlying system out of sight. Functions will only be revealed "on demand”. We expect – indeed, it seems virtually certain – that these new network resources will, especially in combination, stimulate a new generation of personalised applications and services. Such "cooperating smart artifacts" will boost the creation of new ambient environments that are tailored to individual needs.

If computation underlies the first technological revolution of our time, then biology underlies the second. Modern technology of molecular biology has completely transformed our ability to both understand and engineer biological function at the micro-level. We are learning that the best way for engineered systems to accomplish highly sophisticated tasks is to become more biological. Over the next decade, ICTs will be moving closer to biology and the life sciences, and ICT artifacts will increasingly involve and exploit the properties of living material, e.g., in the form of wet-interfaces. Not only will biotechnology be brought into ICT, however, in the design and manufacture of novel sensors or in new computing processes, but ICT will also flow back into the biological world. This will be most clear in medicine, but also in realistic efforts to develop implementations of "human augmentation" – the ICT-based enhancement of human characteristics.

These two trends will, of course, amplify one another. Out of the collision between complex networks of increasingly sophisticated devices and the mingling of living and non-living ICT technologies, we anticipate, in particular, a progressive entangling of virtual and real information and data. This will permit the creation of new sorts of mixed reality environments for all sorts of challenging applications. Over the next decade, it seems clear that the frontier between the real and the virtual will dissolve, with tremendous consequences for the way we do science and business, and also live our daily lives. We have aimed to take these specific trends into account in identifying our grand challenges.

Most importantly, however, a suitable grand challenge in IST must address issues with direct relevance to European economic competitiveness and social well-being. It is clear that research is only the beginning of the process of innovation. To provide real benefits, research has to lead through development to tangible innovative products and services with social and economic consequences. This is another motivating factor for our Grand Challenges: they must promise direct payoffs in the form of specific and highly practical technical capabilities, as well as new businesses and even industries. To help the European Union meet is Lisbon objectives, the ISTAG Working Group has also sought grand challenges in specific technological areas in which Europe has a real chance to exploit its existing expertise. A Grand Challenge in an area where Europe lacks the expertise or industrial capacity may be useful, but would not make optimal use of research funding and energy.

With this practical focus in mind, the group has aimed to identify a small number of concrete goals that will stimulate strategic research and development. In our experience, highly specific and well-defined goals generate natural milestones, and provide strong incentives for focused efforts to achieve them. In addition, in projects involving many disciplines – as each of our grand challenges does – the existence of an ultimate and highly visible goal provides strong incentives for cooperative exchange between researchers and teams in distinct areas, exchange which may not take place naturally in its absence. We also believe that concrete projects are most productive in terms of generating technological "spin-offs." Such spin-offs cannot ordinarily be targeted beforehand, but emerge through the concerted and integrated effort toward another specific goal. Hence, it is our firm belief that the greatest progress, both scientific and economic, arises from projects that have very concrete goals, the achievement of which is easily recognizable (such as putting a man on the moon, or sequencing the human genome).

Finally, we believe that an effective grand challenge must be formulated so that progress can be measured in an unambiguous way. Researchers must have clear benchmarks by which to judge their success or failure in taking steps toward the ultimate goal. These benchmarks represent the logical scaffolding of the scientific process, as they allow an unambiguous test of ideas and techniques tried so far. In this way, benchmarks help researchers to reject ideas that are not working, and to try alternative methods, before getting bogged down or wandering aimlessly in fruitless directions.

To summarize, we have taken the following as a precise set of criteria for any grand challenge:

- Must be visionary, looking 10 years into the future, and demand basic research and engineering in many areas of computer science, from hardware to software and beyond.
- Must demand the seamless integration of diverse technologies.
- Must promise tangible payoffs in the form of new technical capabilities and new businesses that would help the EU to exploit its existing expertise so as to meet the social and economic goals of the Lisbon objectives.
- Must focus on highly concrete goals and involve clear benchmarks and measures for progress towards those goals.

Working Methods

To identify a set of grand challenges meeting these criteria, the ISTAG Work Group has exploited the substantial expertise of the ISTAG members and consulted other relevant experts in both industry and academia. To ensure that the Working Group would not overlook any potentially important scientific and technological areas, we have also carried out an exhaustive study of existing foresight studies and technology roadmaps developed worldwide. These include studies carried out by national governments, both within the European Union and in the United States, Japan, South Korea and elsewhere, as well as initiatives of private companies with global technological standing such as Siemens and Thales. Further detail on these studies follows later in this report.

This report details the eleven Grand Challenges that were identified by the Working Group as being best suited to stimulate European advancement in information society technologies. These grand challenges are by no means intended to represent an exhaustive list, but rather a starting point to which others can be added in the future. The Executive Summary offers an overview of these Grand Challenges. What follows here is a more detailed look at the technical and scientific challenges of each project, its projected social and economic consequences, and the likely beneficial spin-offs that will result in the near term. The report also summarizes the other technology foresight studies to which we have referred in identifying our own grand challenges. Finally, the report offers brief summary and conclusions for the Working Group's overall study.

Before describing each of our grand challenges in detail, it is important to emphasize that we do not intend our list to be exhaustive. Rather, we have offered a strategic "first assessment" of some of the most important challenges, fully expecting that others will be added in the future. It may be worth mentioning, however, that we have excluded some grand challenges from our list for specific reasons. Applied research in physics, for example, is vigorously pursuing the challenge of bringing so-called "quantum computation" into reality. We certainly believe that quantum computing is an exciting and important challenge, with enormous potential ramifications for the future, both in scientific and economic terms. We have tried to identify challenges, however, where we believe significant progress can be achieved in the next decade, leading to immediate social and economic benefits. Quantum computing appears to us to require a longer time for development in a way that will lead to tangible social benefits, and we have therefore not included it in our list. A number of other challenges were excluded for similar reasons.

3. Research Challenges and Societal Innovation Implied by the Grand Challenges

The grand challenges identified here address key technological challenges in ICT for the foreseeable future. By addressing these technologies, these grand challenges will contribute directly to achieving the broad social and economic goals of the European Union. Below we offer two tables indicating visually how these challenges relate, first, to the specific technological issues, and second, to Europe's broader social goals.

The grand challenges described in this report promise to go beyond what is initially possible, and require development of understanding, methodologies, techniques, and tools unknown at the start of the research. In Fig. 1, we relate the proposed grand challenges to eight areas for research challenges, which we cluster into two groups:

1) Advanced ICT Models and Technologies
    - Cognitive Technologies
    - Human Interfaces
    - Distributed Ambient Computing
    - Advanced Knowledge Management

2) Innovative ICT Methods and Infrastructures
    - Software-Intensive System Development
    - Systems Modelling and Simluation
    - Next Generation Communication Technologies
    - Nano-electronics, Architectures and Sensing.

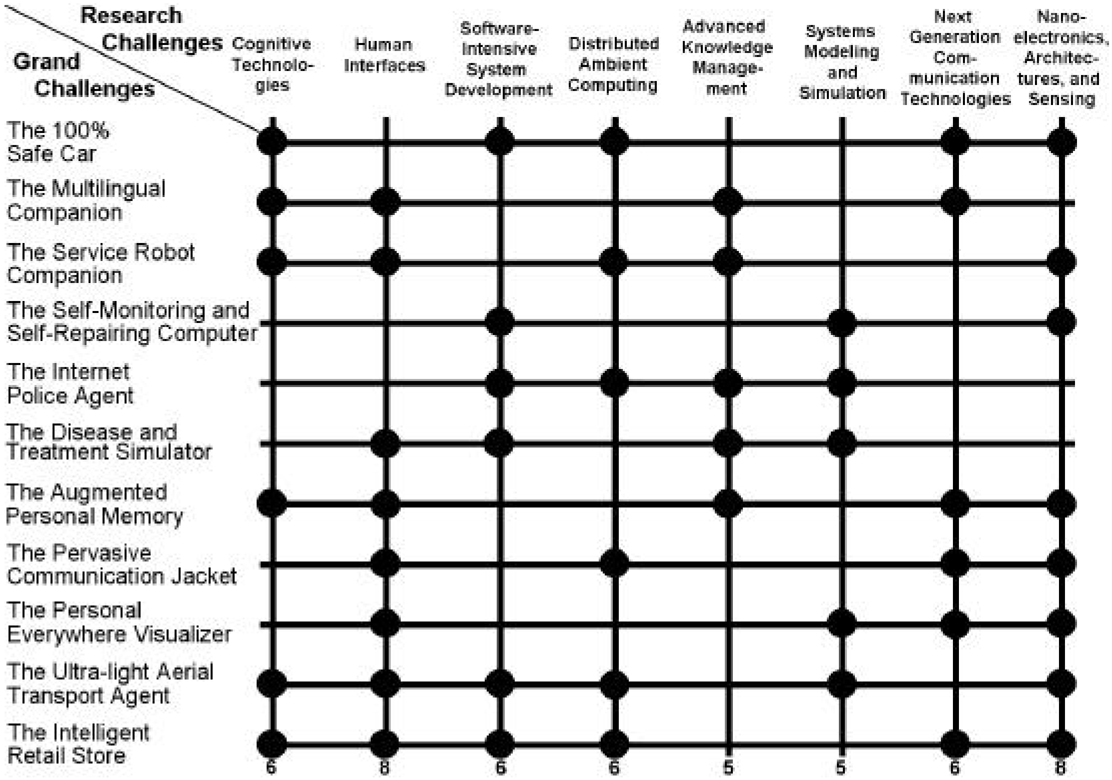


Figure 1 Relating the Grand Challenges to Research Challenges

Fig. 2 shows how the grand challenges are related to complex socio-economic challenges that the European Union is facing today:

- accelerating economic growth and job creation by new value and services
- dealing with health care in an aging society

Trust, security and privacy in ubiquitous mobile communication networks are the top ICT priorities for the European population. Thus, we show in Fig. 2 how the grand challenges are related to the societal innovations that address these concerns.

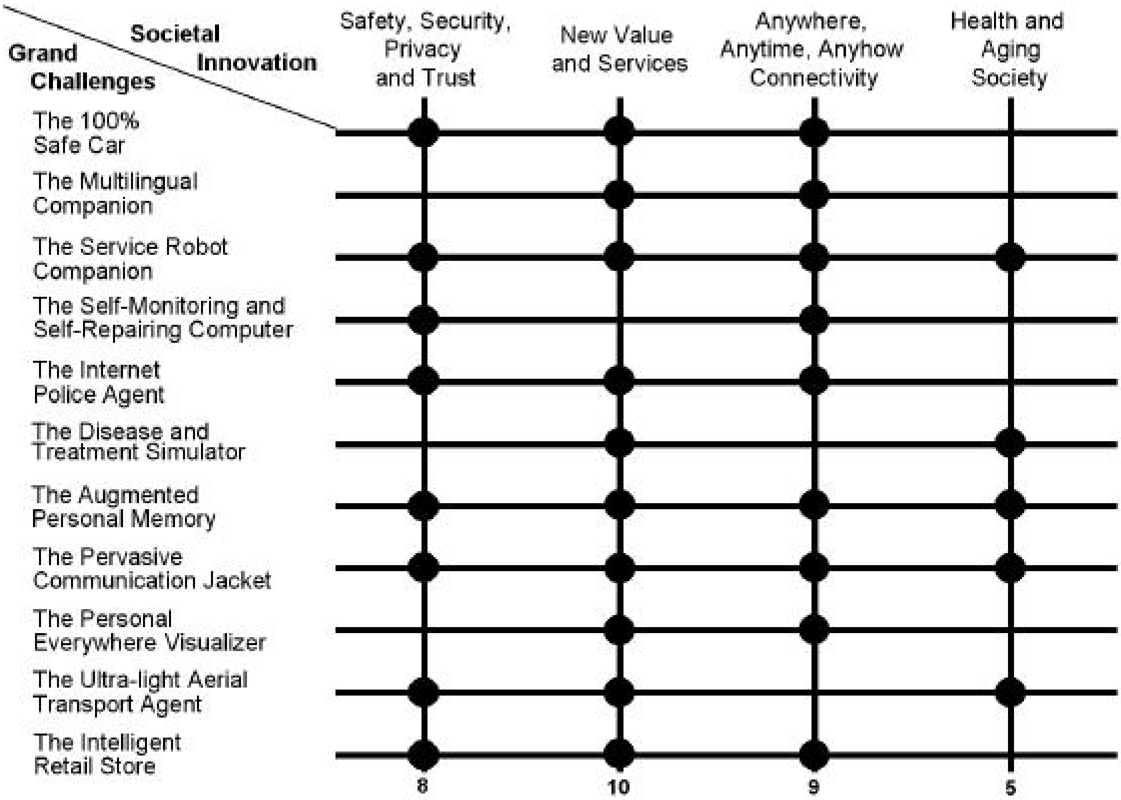
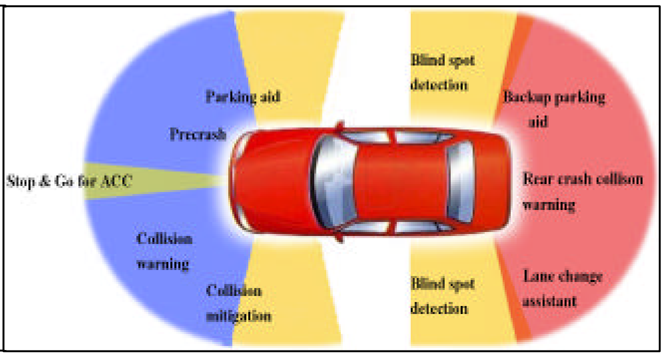


Figure 2 Relating the Grand Challenges to Societal Innovations

4. The Grand Challenges – in Detail

In the following pages, we describe in more detail the eleven Grand Challenges that were identified by the Working Group as best suited to stimulating European advancement in information society technologies, and in helping Europe to make real progress toward the Lisbon objectives. In each case, we have aimed to lay out the specific technical and scientific challenges involved, and the important social and economic benefits likely to emerge from research and development success. We have also tried to identify the likely spin-offs that will result in the near term, and have made an assessment of the current standing of European skills and capabilities in comparison with other nations, especially the United States and in Asia.

GRAND CHALLENGE #1



1. The 100% Safe Car

The vision and its potential benefits

In recent years, automobile manufacturers have made driving safer, with technologies such as airbags and automatic anti-skid braking. But the cost to human society is still very high in terms of avoidable human suffering. In Europe, automobile accidents continue to cause about 120 000 deaths and 2.5 million injuries each year, with one in three deaths involving persons under 25 years of age. Economic costs associated with traffic accidents are also considerable: an estimated 2.5–3.0% of the GDP in EU Member States.

We have become so used to the daily reality of automobile accidents that it is hard to imagine a world in which they were eliminated. But with better technology, a great many of these accidents can be avoided. There are already about 10 million automated navigation systems in use on the world's roads, with this number set to explode in the near future. Tens of millions of automobiles will soon be equipped with IT facilities including the Internet and vehicle tracking systems. Also becoming more numerous are a variety of safety-oriented systems that brake the car automatically (if it comes too close to another vehicle) or that monitor road conditions and warn drivers of hazards or vehicles in the blind spot. The dream of the 100% safe car is to eliminate traffic fatalities almost completely. We envision this goal to be achieved not through any crude “hardening” of the vehicle shell, so as to withstand impact, but in a more intelligent and flexible framework based on next-generation communications technology.

A central limiting factor in driving safety is the ability of the human driver to see and respond to developing threats on the roads. Drivers have limited vision, limited speed of response, and make mistakes. To achieve safe driving will require technology can overcome these limitations, augmenting human capabilities. Current devices to aid drivers are not as good as the driver – cannot see as far in advance, for example. Safe driving will require an ability to go well beyond the drivers’ capabilities, to let them see farther, both in space and time. The challenge is to do this by exploiting wireless and web-based technology to link vehicles to one another and to other devices on the roadway. Known as “telematics” or on-board “embedded” systems, this technology would have to be both precise and durable to provide direct assistance to drivers facing obstacles and difficult road conditions. This technology would be most powerful if it permits the flexible passing of information between cars travelling in the same direction and even to oncoming vehicles. The idea is that each car senses only other cars nearby, but signals can be relayed from one to another and so travel significant distances, around corners, etc. Drivers can benefit from others’ experiences.

A system such as this should work efficiently and rapidly without the driver needing to be aware. Some of the things this might achieve – warning drivers of icy or oily road 2 km ahead, of oncoming vehicles (so not a good idea to overtake), road works in 500 m ahead. Or telling a driver that the car coming from the right has right-of-way. This would be achieved by communications between cars and between local infrastructure and cars. They give reminders of traffic signs, lights, interpret these signs in foreign countries.

Determined pursuit of the 100% safe car will undoubtedly lead to a variety of spin-offs. It will, after all, require the development of seamless navigation aides. It is necessary to have excellent knowledge of automobile location and its relationship to other nearby objects. A fully working technology of this sort will also lead naturally to products such as full navigational aides, good for both driving and walking, perhaps even inside a building to which someone has driven. This is a concrete long term scenario.

Technical, social and ethical challenges

Within the automotive industry, innovations are increasingly based on electronics and software. Indeed, experts estimate that 80-90% of all future innovations will be achieved through these technologies. In general, these innovations aim to improve the safety of vehicles and the comfort of passengers, while also reducing fuel consumption and emissions. The development of better software will clearly be crucial to the achievement of a visionary goal such as accident-free driving. Automotive software faces special challenges because of a confluence of demands. Software is distributed and embedded, has to operate in real-time, and must be faultess because it is safety critical. We also face an explosion in system complexity. The current S-class of Mercedes Benz depends on more than 50 controllers, 600,000 lines of code, and three different bus systems for supporting the electronics. The system also has to cope with more than 600 distinct signals. With some many systems entangled with one another and in continual communication, the potential for malfunction naturally increases.

A major challenge, therefore, is to conceive a design method that will provide for a 100% guarantee of safety critical properties. A *design for dependability* that allows for *predictable* properties has to involve a closed chain of validation and verification. It must represent intermediate results of the model-driven design process with a precise and uniquely determined meaning. Formal methods provide a scientific foundation for software engineering of a kind that has been common in other areas, such as mechanical engineering, for many years.

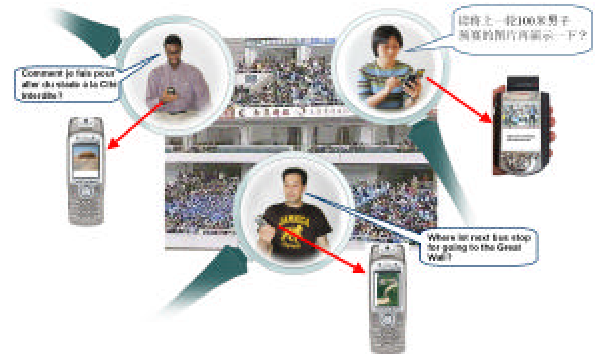
However, unlike the restricted use of formal techniques that prevails today, we must develop a method that addressesa vast range of engineering issues, from the real-time requirements for collision avoidance to efficient implementations running on layered architectures. We face the challenge of finding engineering methods that provide the necessary rigour for an entire chain of development. This is a special challenge when applied to embedded systems grouped together in ad hoc networks of other cars and facilities which exhibit autonomous behaviour that is not under the control of the driver.

Of course, manufacturers also face a variety of technological challenges which arise from the tight physical demands of operation. An air-bag controller, for example, will work correctly only if it reacts within a very small and precisely defined period of time.

EU standing relative to others

For several years, European automobile manufacturers have been world leaders in terms of technology for safety. European companies were first to introduce important technologies such as airbag controls, active distance controls, anti-slip control and electronic stability programs. Another outstanding European achievement is the “teleaid” technology, which initiates an automated emergency call in case of an accident detected by the airbag control.

European manufacturers also have name recognition on which to build. Several European automotive brands such as Volvo, Mercedes and BMW have established worldwide reputations as leaders in high quality and advanced safety features.

GRAND CHALLENGE #2	

2. The Multilingual Companion

The vision and its potential benefits

The European Union faces a serious linguistic challenge, and the problem will become even more poignant with the enlargement to 25 member states. In forging an effective and durable union, member nations must preserve their culture, and, therefore, their language, in administrative, commercial, cultural, educational and casual activities. They must also have access to important EU documents in their own language, and be able to communicate with the other EU states. The difficulties inherent in communication between member states have political, cultural and economic consequences, which the activities of the European Commission itself demonstrate very clearly. With 15 countries and 11 languages, translations must be carried out between some 55 distinct language pairs. With the arrival of the new member states, this number has been increased by a factor of four. The Commission employs some 1170 translators who, in 2001, translated more than 1.3 million pages of text. The European Parliament already spends 30% of its budget (300 M€) each year to address the multilingualism issue, which will only grow in importance. Some official texts related to the 10 new member states will only be available for some languages in 2007, and it is reported that some officials communicate only through facial expressions during formal dinners.

Computer assistance offers a visionary approach to meeting this multi-lingual challenge. We envision a multi-lingual companion that would make translation virtually automatic. The companion will be a handy and powerful resource for enhanced communication that would rapidly carry out a diverse range of activities. Imagine two or more individuals, each speaking normally in their own distinct language, in a quiet meeting room, a hallway or a restaurant, with a small portable device making it easy for each person to understand the others. A device of this sort would exploit all clues available – gestures, emotions, and so on – to automatically recognize speech in any European language. It would rapidly and accurately render translations in text and in speech in any other European language desired. Hence, it could be used to take voice dictation, immediately generating text in any number of languages, thereby streamlining the connection between humans and computers. The companion would be extremely useful for disseminating the minutes of meetings to many countries simultaneously, to each in its own language. To be more powerful, the companion would also need to have full multi-media capabilities and access to the World Wide Web (through telephones and other devices nearby). Augmented with computer vision abilities, it would also be able to translate important signs and notices, thereby aiding both human-to-human and human-to-machine communications.

Aside from the special relevance of a multi-lingual companion to the European Union and its tasks, such a device would also have many repercussions elsewhere, especially for business, tourism and education. In the past decade, corporations have established a global reach far beyond anything in the past. To carry out their activities effectively, they have a great need for rapid and accurate translation that can help individuals communicate within the time span of a single meeting. These tasks, at present, require valuable individuals with multi-lingual skills who are often in extremely short supply. A computer resource would greatly spur economic activity between European states by making transactions more immediate, less costly and by lowering the risks associated with misunderstanding.

In the area of tourism, of course, it is barely necessary to point out the potential benefits of a multi-lingual companion. It would spur tourism not only between European Union nations but also between European states and many other nations in the world.

Technical, social and ethical challenges

This grand challenge requires progress in a vast range of technologies related to language and communication. These include speech recognition, generation and summarization, speaker, gender and language recognition, language and text understanding, dialog handling, audio processing, non-verbal communications processing (emotions, context-sensitive information), written information processing (OCR, handwritten recognition, document handling, real scene analysis), multimedia information extraction and retrieval (including radio and television broadcast), and broadband mobile communication.

Speech recognition is an extraordinarily difficult problem, the focus of a major research efforts for several decades. While the past decade has seen very significant progress, resulting in an increasing number of useful products and services, important problems remain, especially in coping with the natural variability of human speech and speaking environments. Getting a computer to recognize human speech effectively is still a major problem. This issue will have to be addressed with a problem-based approach, by making recourse to evolutionary strategies, based on the improvement of the training and decoding algorithms and on larger amounts of data, and to new paradigms and disruptive approaches. All results will need to be integrated into complete systems and be thoroughly evaluated.

But recognition is only part of the problem. The derivation of meaning from language requires other perceptual and cognitive processes – the understanding of grammar, for example. We will need to make significant strides in understanding the perceptual and cognitive factors that affect language acquisition and comprehension. Indeed, language goes to the heart of what the human brain does well. Reproducing this facility will require a greater interaction between cognitive and computer science.

We also face a choice between using language pairs, or one or several "pivot" languages, i.e. of finding the most efficient way to provide language translation services for more than 20 languages.

Social issues are related firstly to the need to allow European citizens to express themselves in their native languages, while also allowing them to communicate efficiently with each other. Another dimension is the support it could bring to facilitate the communication of non-European immigrants, and finally to help Europeans when visiting non-European foreign countries. Development of the technologies for the multi-lingual companion would also give Europe a very strong position in addressing other non-European languages, and increase its share of the international language technology market.

EU standing relative to others

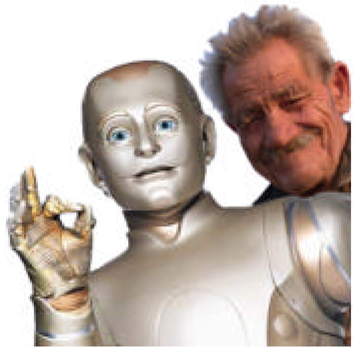
A weakness of Europe – the inherent difficulty of communications among its diverse citizenry – can be turned into a strength. The European community has a strong incentive for solving the multi-lingual challenge, an incentive that is lacking elsewhere.

The problem is very different in the United States, for example, apart from the American-Spanish issues which recently induced the US administration to alter slightly its monolingual policy. Many people worldwide tend to understand English, while very few Americans understand foreign languages. In view of the recent dramatic events, and aiming to address this issue, the US has developed a large effort on multi-lingual language processing (translation and cross-lingual information retrieval), while also developing Business Intelligence tools based on Language Technologies.

European research is also of very high quality in this area and well organised, with many laboratories in various countries, including the new member states.

However, European industry is not in a similar situation. Many large European companies (France Telecom, Thomson, Philips, Alcatel) decreased their efforts in this area, while IBM and Microsoft show at the same time state-of-the-art research, multi-lingual international presence and business capabilities. Several European SMEs are starting to become strong and may well flourish with the foreseen development of the markets. These include, among others, A Capella, Telisma, Voice Objects, Linguatec, Xtramind, Sympalog and Vecsys.

GRAND CHALLENGE #3



3. The Service Robot Companion

The vision and its potential benefits

With few exceptions, European nations have declining birth rates and increasing life expectancies. As of year 2000, roughly one in every five adults was over age 64. In the coming decades, this ratio is expected to increase markedly to nearly one in two, and half of the adult population will come to be of retirement age. With the growth in the elderly population, health related costs will undoubtedly explode, doubling about every decade, and placing difficult burdens on EU economies, and on the social and health services within each nation as they try to cope with this vast swelling of the elderly population. In principle, this demographic challenge can be addressed by two mechanisms. The first is to enable individuals to work longer (possibly in a broad sense of the word "work"), while the second is to reduce the human effort required to care for each elderly person. European nations will presumably have to take both steps, and it is notable that both point to the use of innovative technologies for facilitating the activities of elderly persons. The same goes for people with disabilities, where technology can be enlisted to help persons with light handicaps to carry out active and fulfilling work, and to provide new ways to care for and aid persons with more serious handicaps.

In addition to productivity-oriented considerations, of course, there is also a strong humanistic justification for improving the quality of life of elderly and handicapped persons. The elderly and chronically ill face particular difficulties in performing many ordinary, routine tasks that were easy in earlier life (preparing food, dressing themselves, cleaning, washing dishes). They find it more difficult to remember faces and appointments. Clearly, we should aim, where possible, to put new technology into service to help people live better lives in their later years.

We encourage a challenging project that aims to provide flexible service robots for the elderly, robots that would not necessarily do things *for* people, but would extend and enhance the individuals own ability to perform crucial tasks. From a physical point of view, aging naturally involves a loss of both physical and mental dexterity. A great deal of research in medicine aims at mitigating the suffering involved with these natural problems through drugs and exercises, yet technology clearly has an important role to play as well. Service robots could take care of household chores – loading the dishwasher, dialing the telephone, pouring and helping an individual to drink a glass of milk. They might also engage in more delicate and adaptive acts of helping, such as automatically adjusting a person's hearing aid to suit the volume of a television programme. In addition, service robots should help elderly and other incapacitated individuals not only with simple physical chores, but with their mental tasks as well, helping the individual to recall appointments, to recognize the voice of a neighbour or relative, or to keep track of bills that need paying. A robot might also help individuals to identify faces which they can no recognize. The ultimate aim of the robot is to enable people to do what they want to do, and to enhance human-human communication.

Robotic technology provides mechanisms for countering the loss of physical capabilities that typically afflicts the elderly. Taken together, a team of service robots would effectively provide an enhanced “habitat” for the elderly or disabled. Robotic aids can provide ways for individuals to move around (with an “intelligent” wheelchair, for example) or can accomplish important functions automatically (with an automatic vacuum cleaner). Robots involving medical technology, finally, might be used to diagnose emerging health problems in early stages, thereby simplifying treatment, or to provide “on-the-spot” advice about appropriate therapies or ongoing monitoring to ensure that a medication is working as intended.

The development of such robots, and their effective integration into a helpful environment, may go a long way to improving the quality of life for elderly and disabled, reducing European health care costs, as well as stimulating the emergence of new industries.

Technical, social and ethical challenges

The problems involved in developing a flexible service robot are unlike those encountered in building industrial robots. Whereas industrial robots often do the same task repeatedly, a service robot will face a widely varying set of tasks. Hence, the robot cannot be "pre-programmed" in any simple way. On the other hand, these robots would not have to be completely autonomous – they should instead enhance and complement the abilities of the user, filling in only where necessary. This will naturally simplify their design.

A successful robot will rely heavily on visual information, as only this can offer the complexity and depth of detail required to enable the robot to function in unknown environments. Machine processing and recognition of visual clues is therefore a major point of emphasis.

It is imperative that these robots be made easy to use, and easily adaptable. The user, for example, should be able to make changes in the robot operation, rather than requiring some specialist programmer. This will require advances in software engineering and robotic control, as well as in speech recognition. Increasingly, human speech will be used to control various devices and services. This makes for convenient human control, but it is essential that persons feel free to speak normally, in both vocabulary and syntax. This will be especially important for the elderly, for whom it is particularly difficult to learn the special handling properties of new devices.

From another point of view, the technical challenges in the development of service robots involve not only specific constituent subsystems, but their integration into a coherent whole – an environment that functions as an effective system. The technological goal is to provide an enhanced environment, something that is *interactive* and provides for good communication with the inhabitant. The systems integration side of the challenge will be particularly concerned with modeling and with the communication between the human user and the system. Modeling is important since high quality services with a high degree of integration and uniformity requires the system to maintain a good model of the inhabitant and his or her (or visitors’) actions.

With regard to social and ethical issues, some of the system facilities just described will require a trade-off between different societal values – in particular, the personal integrity of the individual may come in conflict with the concern for their physical and psychological well-being. One kind of integrity problem will arise if the inhabitant reacts psychologically to the notion of being supervised continuously by, for example, health-monitoring service robots. It is well known that depression, passivity and a certain paranoia comes along with high age, and it is easy to see how health monitoring systems might resonate with those developments.

Another, broader integrity problem arises if the IT systems that enable convenient communications with others become loaded with sensitive personal information that is not adequately protected. For example, speech recognition systems become able to understand and remember large parts of what a person says, this accumulated information should be routinely safeguarded.

EU standing relative to others

European research is very strong in several of the constituent technologies that are needed for service-robot systems. The market for industrial robots has grown significantly over the past decade, and, in expertise and experience, Europe and the United States are rapidly catching up to Japan. The European reseach area is particularly strong also in cognitive technologies of the type required to make service robots especially useful for the elderly and disabled.

In addition, the strong position of welfare policies in several European nations is an important asset, as it has promoted long awareness of the special needs of the elderly and handicapped. The strong position of EU governments in the management of healthcare should also ensure ample opportunities for testing and development of robot-service systems through practical trials. Indeed, a number of research projects are already being performed on various aspects of the vision described here.

GRAND CHALLENGE #4

4. The Self-Repairing and Self-Monitoring Computer

The vision and its potential benefits

In the past two decades, computational power has increased by a factor of 10,000. Even a handheld organizer of today has more power than a desktop computer of the mid 1980s. Increasingly, however, it has been recognized that the continued advance of ICT systems faces a "software crisis", as failures have become routine as software has grown more complex and powerful. On the World Wide Web, one frequently finds encounter sites that are down; laptops and desktops not infrequently seize up during operations; cell phones require frequent rebooting. For individuals, these failures are annoying; for businesses and other large-scale enterprises, they can be very costly. To take one example, software failures at the Denver airport's automated baggage handling system delayed the airport's opening and incurred costs of US$1.1 million per day. More generally, it has been estimated (by NIST) that that American economy loses more than $60 billion each year due to software bugs. According to the same study, 80% of software development costs of a typical project are spent on identifying and fixing defects.

Designed properly, functioning properly, software should be an integration platform, an enabler that brings together the capabilities of many other technologies. The ultimate goal of software is to increase the efficiency of the collaboration between people and systems, to guarantee the security of a system, and give people the ability to exploit all assets that should be available to them. At the moment, however, we simply do not know how to develop good software, and both individuals and corporations continue to spend more on maintenance, repairs and operations than they do on hardware and software put together. The root of the problem is that science and engineering for software simply has not advanced in the same way as it has for hardware.

It is absolutely crucial for Europe's industry to overcome this problem and to master the development of software. To stimulate progress toward this goal, and to move toward an era of more reliable software, we envision a grand challenge that would demonstrate the operation of a "self-repairing" computing system – a computational system in which the software is designed to detect and correct failures by itself. To achieve such a system, we expect a variety of ideas and approaches to contribute. Some of these ideas are working toward truly "error free" software. Others accept that computer crashes may be impossible to eliminate entirely, and look to designing systems that recover rapidly when problems do occur. Integrating these and other avenues of research, this project will result in a broad strategy for developing software with greatly improved reliability – a technology that lets programmers write software that is better, more powerful, bug free, and that can be done faster and easier. In some cases, it should be possible to certify that software is completely bug-free.

The achievement of this goal will have important consequences in virtually all areas of modern ICT. It will hopefully lead to the automated development of some software, leading to greater reliability. It will also allow developers to produce intelligent software that can manage complex large-scale critical situations. The vision of self-healing software systems will also contribute to improvements in dependability and security, in protecting critical infrastructures, airports, harbours, mass transport, etc. Potentially, ideas and initiatives that would lead to more reliable software and better ways to develop it may also have important spin offs. They may suggest ways to bring the same self-repairing strategy to other engineering environments, perhaps even to the design and management of human systems, in business organizations, for example.

Technical, social and ethical challenges

The fundamental issues involved in reliable software development are writing code, finding bugs, and certifying that programs can be trusted. Of these, finding bugs is currently the absolute bottleneck, and we need better ways to do this.

We also require better ways to certify software. At the moment, certificates only establish the origin of a software component, not that it is definitely bug free. Moreover, the software community needs to overcome an excessive focus on "bugs," and recognize that faultless software goes beyond debugging. Users want to be sure that the software is actually doing what it is supposed to be doing. This is true certification. Bug free code always gives output, but not necessarily the right output. Using theorems to prove that software is reliable, it is now possible to go from toy problems to real problems.

An important challenge in moving toward this goal will be to establish standard benchmarks for software reliability. When reliability can be measured clearly, and this information is public, it offers incentives to developers to improve their products.

We must also try to move toward some standardization of software architectures. This is good for openness and interoperability

Another point to consider: Eliminating bugs and achieving perfect software is not the only way forward. The costs associated with failures also reflect the amount of time a system is down. This can be addressed not only by having fewer failures but in enabling the system to be re-booted very quickly.

We also need to study the human factors that contribute to computer failures. It is frequently overlooked that a major source of failure is mistakes made by human operators (in running complex web sites, for example). Such failures can only be reduced in frequency by managing the nature of the interaction between people and computers.

EU standing relative to others

EU is strong on web-based software. We have a good chance to compete internationally in software. A few companies are already competing with Microsoft. We need to stimulate more.

If we could develop something approaching truly error free software, this would be a momentous development and give the EU a great competitive advantage. Most industry is software industry. In software development, the EU has a potentially huge advantage, and momentum from the open-source movement, but competitors are catching up.

GRAND CHALLENGE #5	

5. The Internet Police Agent

The vision and its potential benefits

“Trust and security,” in the words of European Commissioner Erkki Liikanen, “are crucial components in the information society.” Trust is a resource for social cooperation; security a condition for its enduring existence. A focus on these issues will be required if we are to realize the most promising benefits of the information society.

In particular, the Internet has been one of the most surprising technological developments of the past two decades. It has revolutionised the way we communicate, and the technologies and services of the Internet and the World Wide Web that it supports have created the largest information resource in world history. Most people in developed or developing countries have at least one electronic email address; in much of the world, it is at least possible to connect to the Web. The growth of this resource shows no signs of slowing, having doubled in size every year for more than a decade.
But the Internet also has problems. Originally, the culture of the Internet was decidedly open, stressing the free and unrestricted sharing of information. This culture suited the first Internet users, especially in the defense and the scientific communities. But now that the Internet has spread globally, to all areas of society and throughout business, its ongoing evolution has raised a host of divisive questions related to the proper treatment of intellectual property rights, the authorization of information usage, and other legal and social issues. At the same time, this new technological resource has inevitably been infected with opportunistic and anti-social forces – we now have an Internet crime wave. The Internet has become a “lawless realm”, afflicted by a number of “negative” aspects:

- The seemingly unstoppable increase in “spam” email, which occupies a large fraction of all Internet resources;
- Identity theft, and associated crime;
- E-mail viruses and worms, which spread mainly through the personal use of the Internet;
- Dangerous or unauthorized access to information.

To prevent these unhealthy developments from destroying the usefulness of the Internet, we envision a project to demonstrate an “automated internet police,” which would have several main duties:

- To guarantee the authentic identity of both web sites and individuals who visit them;
- To filter information on web sites in an effective way that makes them both safe and accessible;
- To alert Internet users and protect them from dangers of which they might be unaware;
- To come to the aid of Internet users in distress, and to communicate public information about best practices;
- To report suspect organizations or individuals to proper bodies who might pursue legal action.

A police agent on the Internet might also help to protect privacy and anonymity (through the use of cryptography, for example), to make economic transactions safe and transparent, or to help establish and protect ownership of intellectual property. We believe that users will only trust systems if they feel that they are “in control”. Hence, the aim of the police agent would be to give the user an intelligent and informed agent, a computational resource that can help them make informed decisions. The development of some resource of this kind seems absolutely essential, especially in view of the inevitable increase in Internet complexity in the future.

Technical, social and ethical challenges

A number of technical advances will be required to realize the Internet Police Agent and to achieve better Internet security.

Authentication: Today, authentication of users mainly works through passwords. For some critical transactions, digital identity cards with embedded microprocessors provide excellent security, but this solution is too costly to be widely used. In the near future, biometric techniques – based on fingerprint, iris or face recognition – represent a promising track toward better authentication, but existing technology lacks adequate dependability for large-scale operations.

Identification (computers): In a mobile and pervasive environment, previously unknown computing devices will constantly penetrate locally available networks. Depending on the character of the network, effective mechanisms will be required that enable on- or offline verification of the penetrating systems and processes.

Encryption: For government and business communications (within fixed, mobile or wireless networks), network/IT and communication systems demand failsafe security. Not only does the information infrastructure require protection, from threats ranging from student hackers to sophisticated criminal organizations, but so does the information being passed. Pressing issues will involve the development of cryptographical techniques that can be adjusted or adapt themselves to a dynamically changing environment, responding to failures in power supply, to the availability of infrastructure based on public key technology or the varying abilities and trustworthiness of communication partners.

Security Policies: Technologies offering "fine-grained" access to content exist but are not yet compatible to dynamic connections and organizations. Technologies will be required that adjust themselves to evolving settings and responsibilities. Mechanisms will also be required to control the good conduct of trusted devices and to facilitate countermeasures in case of abuse.

From a social point of view, it will be important to identify the best way an Internet agent could be implemented. Would the Internet Police Agent be best conceived as an artificially intelligent "helper", always available to the user? It might detect viruses, offer wisdom on Internet sites and advise users on the potential for trouble, while racing to the aid of those who have discovered trouble. Alternatively, should it be more like an already existing body, such as the Internet Content Rating Association, which is an international, independent organization that empowers the public, especially parents, to make informed decisions about electronic media by means of the open and objective labeling of content? It will be crucially important to consider in detail the most socially beneficial form for the Internet Police Agent.

Another issue is privacy. Work on Privacy is being managed as part of W3C's (World Wide Web Consortium) Technology and Society domain. W3C is jointly working in the area of privacy with a variety of Member organizations and institutions, and a number of Invited Experts from the USA, Europe, and Asia. W3C has become an intermediary and communication platform between the industry and data commissioners and is finding viable solutions for privacy on the Web.

The **PICS**™ specification enables labels (metadata) to be associated with Internet content. It was originally designed to help parents and teachers control what children access on the Internet, but it also facilitates other uses for labels, including code signing and privacy. The PICS platform is one on which other rating services and filtering software have been built.

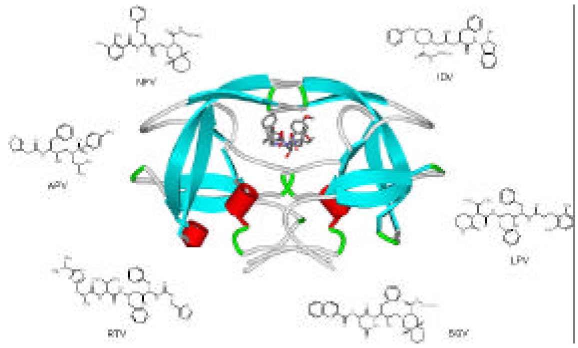
The Platform for Privacy Preferences Project (P3P), developed by the World Wide Web Consortium, is emerging as an industry standard providing a simple, automated way for users to gain more control over the use of personal information on Web sites they visit. At its most basic level, P3P is a standardized set of multiple-choice questions, covering all the major aspects of a Web site's privacy policies.

The work already done by W3C has to be enlarged and carried on with the new constraints.

EU standing relative to others

Europe has played and will play a key role in the definition of the standardization of Internet and the World Wide Web, thanks to its active participation through the participation of ERCIM to the W3C. We have in Europe very good skills in term of mathematics, leading to top specialists in cryptology. On the other hand, the issue on the safety on Internet is one of the key issues raised by the European Commission.

GRAND CHALLENGE #6



6. The Disease and Treatment Simulator

The vision and its potential benefits

When researchers announced a rough draft of the human genome in February 2001, they drew the curtain closed on an era of molecular biology that was centered primarily on the discovery of the structures and functions of single genes and proteins. Although much remains to be done in this way, biologists now face a more difficult challenge to move beyond single molecules and to bring within comprehension the workings of the complex biochemical pathways that underlie higher-level features of organismic physiology. A living cell is a dynamic and ever-changing system comprised of not only genes, but hundreds of thousands of proteins and innumerable small molecules, all interacting with one another in ways not solely specified by the genes.

The field of systems biology aims at understanding and simulating the cell, as a whole. This field is still in its infancy, not so much because we do not have the computing frameworks. In fact, simulations software, notably of metabolic processes within the cell is quite far advanced, to date. In contrast we are missing vital data, notably on the distribution of proteins and metabolites within the cell and on the kinetics of enzymatic reactions and protein-protein binding processes. Getting at these data is a challenge for biology that can be compared to that of sequencing the human genome.

Here, we do not aim at simulating a cell in its totality, rather, we aim at focusing our modeling and simulation enterprise to the context of concrete diseases. In contrast to systems biology, this is a more application-driven approach. We forego the need of collecting large amounts of data for a holistic simulation and focus on the parts of the system that have proven to be disease-relevant. On the other hand, our bioinformatics disease model goes beyond the single cell and has to incorporate inter-cellular events, such as the interaction between an infectious agent (like a virus) and its host cell or the intercellular events composing an immune response to an infection.

In contrast to basic systems biology models that, at least initially, can be based on a rather unified software framework of solvers of differential equations, say, the disease model we envision has to be much more inhomogeneous, because it involves events on very different time and space scales. Intercellular interactions have to be modeled on a different level from the metabolic events inside a cell. Gene regulation events are on a different scale yet. Therefore modeling disease processes and the response to be expected from drug treatment requires a substantial amount of informatics modeling work.

As a consequence, the disease and treatment model has to be targeted to one or a limited set of concrete disease. We suggest certain types of cancer (e.g. colon cancer) or a few concrete infectious diseases for this purpose. (HIV is a relevant example.) The challenge will not be to make a general disease simulator. We regard this latter problem as so hard as to be infeasible. While the underlying simulation machinery of a disease and treatment model can be more generally applicable, its concrete realization for a given disease requires modeling work that is particular to that disease.

It goes without saying that such a project can only be successful when it is carried out in close interaction between biologists, medical experts and bioinformaticians/computer scientists.

As a consequence, a project along these lines would stimulate vast communication and collaboration between otherwise diverse fields. The challenges of molecular biology have already stimulated such interdisciplinary focus; in particular, the field of bioinformatics – which has brought biologists into intimate contact with computer scientists and other information specialists – has experienced rapid growth in the past ten years, and this is expected to continue. Moving well beyond the study of individual molecules and families of molecules, the field is taking off to analyze and model biochemical interactions networks and expand cover continually subsystems of the cell.

This project will pose many challenging problems to researchers, but also promises more than scientific insight. Indeed, the links to biotechnology, pharmaceutics and medicine are strong and direct. A disease model would make testing of drugs possible in silico and, if it is implemented in an appropriate fashion, allow to incorporate increasingly complex side effects. In contrast to existing bioinformatics developments that have targeted mostly the pharmaceutical industry, this development would address the whole medical sector, from diagnostics to treatment Thus, it would emanate to a substantial part of the European health sector. This process is already happening: We expect, microarrays to be widespread in doctor's practices for diagnosis within the next five to ten years. Also, for certain diseases (HIV) the personalized administration of drug treatment suggested by computer-based methods is in the stage of clinical evaluation.

Medical application is inevitable. Also, the disease and treatment model will interface directly with other projects of human benefit, such as the physiome project (www.physiome.org)and the modeling of whole organs.

At another level, the disease and treatment model is a challenging interdisciplinary problem that would offer benefits to many other areas as well. In essence, the bioinformatics challenges required to attack the problem deal with unstructured data that stem from naturally evolving phenomena that are not subject to the rational approach of design imposed by the human engineer. Informatics methodology has a problem with such structures to this day, in particular in dealing with the analysis of scenes, computational linguistics, analysis of financial data and processes, geo-informatics, and analysis of evolving structures in software design and on the Internet and World WideWeb. For example, how to make gathering information easier? Solve these problems in biology, we will perhaps also learn how to ask an open domain question, and get an answer, rather than searching through lots of documents, etc.

Bioinformatics is a very visible and extremely challenging application area for developing these kinds of methods. Any advance in this field has a high potential for cross-fertilizing with these other disciplines.

Technical, social and ethical challenges

In pursuing the vision of the disease and treatment model, we face a number of distinct technical challenges:

- Developing methods for the effective linking, interoperation and maintenance of biological data. We must learn how to bring together heterogeneous and often inconsistent data from a variety of sources, and to draw from this data a most consistent record. We will also need to develop effective ways to store this data and to discover and eliminate mistakes within it.

- Developing better methods for visualizing biological data. This is not so much drawing molecules, but rendering patterns in other highly complex (high dimensional) data more easily accessible to human perception. This problem reaches, of course, well beyond biology to all of statistics, but bio-informatics offers a powerful motivation for tackling it.

- Increasing the reliability of bio-informatics predictions, which are now extremely unreliable. Biologists have inaccurate models of nature and analyze them with *ad hoc* procedures that yield only rough results. We need to devise more consistent methods and learn how to measure the level of our success, giving each biological prediction a confidence value. Few bio-informatics procedures today can do this – but this is necessary to stimulate measurable progress.

- Providing more appropriate models for biological processes within the cell.

- Providing the computing power necessary to perform the most computationally intensive analyses and simulations. Grid computing may be crucial here.

We face a social scientific problem as well. Bioinformatics is the use of informatics technology to help biologists, but progress cannot be achieved without the collaboration of the separate communities. We need biologists AND informaticians. How can these communities be joined effectively? The interdisciplinary nature of this field makes it difficult to support, yet this is where support is most needed. Bioinformatics in the long run needs the development of new methods, but these are unlikely to emerge if projects are rated exclusively on their potential short-term biological output.

EU standing relative to others

Classical systems biology seeks to understand the behaviour of specific cells. It is a major focus of research worldwide, with most projects studying unicellular organisms such as bacteria or yeast. In Germany, research has also been concentrated on liver cells. Also, ongoing European projects are studying the managenment of antiviral drug resistance, dealing mainly with hepatitis B and C and the flu virus. But there has been no emphasis so far on the software modeling tools. What distinguishes the grand challenge described above from this ongoing work is its focus not on specific cells but on the integrated modeling of specific diseases, which may find their origin at the multi-cellular level, or in cellular sub-systems. This is a unique and potentially very valuable approach.

Europe has a long history and proven expertise in pharmaceutical research. In this area it is closely matched by research in the United States, but is far ahead of Asia. Modern genomics is driven by bioinformatics, which has been the focus of a major effort to launch new curricula for bioinformatics at top European universities over the past decade. For this reason, Europe has a very strong standing in the design of complex bioinformatic algorithms. In combination with the capabilities of the European pharamaceutical industry, this bioinformatics expertise provides a strong and highly competitive starting point for attacking this grand challenge.

GRAND CHALLENGE #7

7. The Augmented Personal Memory

The vision and its potential benefits

For centuries, people have recorded bits and pieces of their lives with photographs, scraps of paper, letters and books, in stories and in their own memories. The revolution in electronics, information and communications technology promises to take our ability to store and retrieve our experiences and memories into an entirely new area – in which virtually every image, film or television program you have ever seen, every conversation you have ever had, every book you have read, or web page visited, will automatically be available for later recall. With the right technology, individuals in the future will be able at any instant to sort through this vast treasure-trove, conjuring up a conversation held forty years ago with their father, the face of a childhood friend, recalling a note scribbled in a business meeting, or a significant paragraph read but now all but forgotten from last week's newspaper. The value of such recordings will likely be beyond what we might imagine. Already, people stored shoeboxes of old photos, letters and so forth, and see these as some of their most valuable possessions – the things they would save from a burning house.

This is the dream of what might be called a personal "auto-biographer". Within a few years, information storage technology will have made drives that can store a life's worth of information affordable to ordinary people. We will be storing everything: information from calendars, contacts, photographs, conversations, music, videos, notes, email. The Autobiographer will automatically gather and record telephone calls, the individual's location, and will be linked to biological signals, monitoring and recording health. Unlike photos that you need to sort and keep in a safe place, letters or papers you organize in files and so on, the Autobiographer will be distributed, communicating at all times with the other devices in the environment, with the World Wide Web, and with the Autobiographers of other individuals.

To be useful, this device – and the network of other devices with which it will work – will be easy to use. Computer files and filing cabinets demand a hierarchical style of storage; the Autobiographer will not demand its user to categorize anything, but will store the information automatically, adding links to other data to which it might naturally be related. Later, this natural web of information will be searched on demand. You will be able to ask the Autobiographer a question, and to find specific pieces of information, much as we do now with the World Wide Web. Hence, making this search work will require overcoming difficult issues of the organization of databases and in effective search technologies and strategies. On the World Wide Web we already face information overload. The available information is growing exponentially, most of it is useless for any particular purpose, and the useful bits are exceedingly difficult to extract. The Autobiographer will bring these issues into particular focus, and success on the project will naturally spill over into many similar problems of the information age, such as building better ways to search the web.

Technical, social and ethical challenges

The Autobiographer project faces many technical challenges:

- the development of powerful and flexible sensors that can capture as much information as possible, including accurate physical locations;

- designing the system to work flexibly with real people taking their behaviour patterns into account;

- finding ways to organize and extract information from the vast databases that will arise.

Searches cannot be based only on text – unless audio and video images are automatically stored with textual annotation. Automatic annotation of images and other non-textual information may be crucial in making an augmented memory system useful, helping users to recall and identify the meaning of images, for example, or in making information available and meaningful to descendents, for whom it will have extraordinary value.

Another relevant area that may play a significant role is computer visualization for identifying meaningful patterns within large data sets. The task of retrieving the information you want may be greatly aided by appropriate visualization methods.

Along with technical issues, the Autobiographer brings to light a variety of social concerns and problems. If such a system accumulates images, perhaps most will come from the outside – taken by devices in the house, for example. It might be argued that a house should remember what happens in it. But for this to be acceptable, the system would require tight security, and may currently be impractical. Yet, the system would also offer pervasive observation that protects people in the house. There will be a great deal of concern over this problem, as well as with civil liberties and the potential for government abuse. In this regarding, it is notable that the DARPA "Life Log" project has been cancelled (as of early February), for undisclosed reasons.[2]

Is it morally defensible to supervise people, without their approval, even for their own benefit? An Autobiographer could be used to help the elderly or disabled, but how many people would

[2] The project was facing significant criticism because of worries over "Big Brother" scenarios, where governments would use the technology to snoop on oblivious individuals.

accept this? What affect would it have on social relations – on, say, the willingness of people to visit a place or person where an Autobiographer is in operation?

Related to the issue of privacy is the problem of making personal information available only to the right person. The Internet is currently based on the IP protocol, where every user has an address. In contrast, it might be possible to improve privacy by abandoning this scheme in favour of one that tracks and uses the physical location of a person. This is a challenge, but some projects are already moving toward this.

In general, we should expect an Autobiographer to support common (possibly unstated) social conventions, rather than to ignore or subvert them. For example, a recorded conversation should be owned, in some sense, by all the participants – not just the person who chose to record it. Such measures will prove crucial in the acceptance of this technology.

EU standing relative to others

Europe has a long tradition in research on user modelling, which is one of the key enabling technologies for this grand challenge. European researchers are leaders in developing coherent and unified methods for the digital representation of individual human knowledge, experiences, beliefs, emotions, intents and abilities. In addition, Europe is a leader in mobile internet technologies and ambient intelligence, which are prerequisites to realizing personal augmented memories.

In Europe, the SPECTER project (http://www.dfki.de/specter/) is already working on a personal assistant that keeps track of its user's actions and affective states. It creates a personal journal which, together with a user model learned on the basis of it, supports the generation of context-appropriate recommendations and actions. Research on SPECTER is being sponsored by the German Federal Ministry for Education and Research.

In the US, the MyDay Personal Data Capture System is being funded by DARPA. The goal of MyDay is the development of a very low cost wearable data capture system to support the "physical" data stream acquisition on a person as they experience their daily life. The physical data stream, as a minimum, includes visual, audio, and geolocation information. MyLifeBits is a project at Microsoft’s Bay Area Research Center Media Presence Group (http://research.microsoft.com/barc/mediapresence/MyLifeBits.aspx) and deals with a lifetime store of everything. It is the fulfillment of Vannevar Bush's 1945 Memex vision including full-text search, text and audio annotations, and hyperlinks.

GRAND CHALLENGE #8

8. The Pervasive Communication Jacket

The vision and its potential benefits

Economic, social and technological trends are moving toward greater mobility. In banking, and in Internet and telephone use, people increasingly expect high speed and multimedia capabilities. The world now plays host to some 12 billion microprocessors, and in the near future, an increasing number of objects – from automobiles to books, from houses to hairbrushes – will carry both communications and computational technology. Devices will become far smaller and more powerful, and will fade invisibly into the environment. On the basis of wireless technologies, these devices will communicate with one another – your laptop sending information (maps, addresses etc.) to your car, devices inside the house communicating with your watch (reminding you of appointments). The information technology environment will become pervasive – everywhere and always on.

Hence, a major challenge will be to enable individuals to communicate easily and effortlessly with this ambient environment, and to harness its available information and computing facilities effectively – in other words, to give them a form of “augmented cognition”. We want to ICT infrastructures to evolve into a global communications and information utility formed from billions of interconnected components. To do so, individuals will need an efficient way to interact with all these devices, and to exploit their information resources.

The pervasive communication jacket will meet these aims. It will not necessarily be a jacket *per se*, but perhaps a kind of wearable lining that could be stitched easily into many kinds of clothing. It would be with the user at all times, carrying out communication and sensing tasks of many kinds. The jacket could use bio-sensors to monitor the health of its wearer – an employee in a hazardous environment, for example. It would be the constant companion of the businessman, recording conversations, ideas, notes, making telephony easy and putting the user in constant links with the information resources of the World Wide Web. Equipped with low-power bio-sensors, the jacket may also help to bring down medical costs for European nations.

By 2010, it is likely that mobile data services will be in full operation, helping individuals to find shops, restaurants, hospitals and so on. There will be wireless infotainment in homes, all workflows in companies will be based in internet/intranet, etc. Services will also be adaptive – detecting signals from the user and tuning services to his or her likely needs and interests. One major problem to be faced by this vision of augmented cognition, as conceived in the past, is that it requires a dense and expensive infrastructure. The pervasive communication jacket will help to solve this problem, as the user will effectively provide a mobile infrastructure.

In addition, mobile communication is a base technology for other disciplines and industries. In the coming decade, we anticipate a new generation of products in the European textile and fashion industry (pervasive communication jackets), new safety products including bio-sensors, new industries to produce these sensors, and a new branch of the healthcare industry that will incorporate new technologies in traditional medical facilities. Hence, a strong European position in mobile communication will boost other markets and will provide new business opportunities.

Technical, social and ethical challenges

The big problem to be faced is achieving the effective integration of many different communication technologies, and doing so in a way that does not burden the user. He or she may use a personal journal to store or retrieve information. The journal should learn the user's habits, and become more efficient and useful in the future. Meanwhile, the jacket's devices should be filtering and extracting useful information from the environment, feeding this to the user when appropriate. It should point out new services that the user did not know were available, and make recommendations based on its estimate of the user's intentions and state of mind. And all of this should be done in a way that is "personalizable" so that each user can have the system function in the best way.

Achieving these goals will require pervasive radio communications (i.e. a operating 4th generation mobile communications infrastructure). It will be a challenge to enable many distinct kinds of networks to interact efficiently. At the moment, for example, data transmission cannot cope with high speeds in cars or on high-speed trains or planes. A train has to possess its own moving internal wireless LAN. How can this be linked to the rest of the network? The goal is to get many distinct networks to talk and work together, achieving seamless roaming, mobile wireless networks. Unfortunately, existing data-communication protocols were designed for fixed line technology, and struggle with mobility. Hence, we envisage the development of new protocols that are optimized for wireless mobile networks, an which take advantage of the technological know-how of the European mobile communications industry. Networks in this "post-IP" era should evolve perpetually, establishing and then breaking contact with one another as individuals move about. This will be true for wide-area cellular networks, wireless local area networks, networks of sensors and control mechanisms in machinery, doors, etc., moving networks (within trains and planes), networks within the home and networks of devices around the body (personal area networks).

We will also need better antenna technologies and ways to encode information in radio signals. We need to extend coverage, reduce interference, improve system capacity and increase accuracy of location-based services. Another important advance would be powerless mobile terminals, which would use light, radiation, body heat or the kinetic energy of human motion as the energy source rather than batteries.

In addition, we must learn to deal efficiently with the available radio spectrum. This is a politically charged issue, as companies have paid a lot for spectrum. The principal challenge may be to devise an effective form of spectrum sharing.

Other challenges are linked to the diversification of the value chain – mobile users will have different provider companies, service providers, content providers, infrastructure providers. There are many issues to be settled: for example, how to bundle all these different services offered to the individual, and who will be the single business partner of the customer when many services get involved?

We will also need open standards and platforms for business to take off. Technologically, some of this is not so hard. Bit rates, for example, are already today high enough for machine-to-machine communication.

In a world of pervasive communications, there are, of course, many security concerns. Can other people listen in? We are talking about the total recording of personal and other sensitive information. The key for social acceptance is to discuss the concerns early enough and to develop reliable safety/trust technologies. The technology and its applications must be developed in the midst of an ongoing discussion about social concerns.

Concerning infrastructure in a pervasive communication environment, it is not realistic to provide a sufficient number of base stations to deal with the traffic. Hence, self-organizing cellular networks and multi-hop infrastructure will be required to reduce the number of base station sites.

EU standing relative to others

There are two main paths defining the 4th generation of mobile networks. Existing cellular systems can go broadband and packet-oriented; alternatively, the Internet can go mobile and real-time. The former path is being pursued by Europe and driven heavily by Asia. The latter path is pursued mainly by the United States. At the moment, Europe still has a good position with companies like Alcatel, Ericsson, Nokia and Siemens concerning the GSM and UMTS-markets. However, due to the strong position of Qualcomm as the holder of essential patents, Europe has already lost shares in the UMTS market to the US. Concerning systems beyond 3G, we face major competition from Asia, which is set to introduce 4th generation technology before 2010.

Asian leadership in “next generation” mobile systems is reflected by heavy research and development investments. In Japan, DoCoMo employs several hundred researchers in mobile communications and has already gained the leading position. They have been running a 4G field-trial in Tokyo since summer 2003. In South Korea, the (semi-) state research organisation ETRI has roughly 150 researchers focused on 4G-technology and there is a government-funded program to develop the high-performance wireless Internet. ETRI is also sponsored by Samsung and LG. In China, the 8.6.3-program (comparable to a European Framework Programme) involves a huge 4G-activity bringing together many universities and international companies. In addition, the Chinese Ministry of Science and Technology (MOST) has founded a "Shanghai research center for wireless communication" where they are pulling together roughly 80 leading experts to work towards essential IPRs in the field.

Summarizing, China, Japan and South Korea are planning to take over the lead with regard to technology, IPRs and standardisation for 4G and to roll out this technology over the world markets. Europe has to face this challenge by fostering investments in R & D and to come up with a standardization strategy – otherwise, Europe will lose the race toward 4th generation mobile systems.

GRAND CHALLENGE #9	

9. The Personal Everywhere Visualiser

Vision and Potential Benefits

Our information society is facing a continuing growth of data at exponential rates. Very often, however, we are getting overloaded with useless data and it is notoriously hard to extract the information relevant to us. This information overload dramatically affects many aspects of our professional and private life. Some relief is provided by a variety of methods for interactive visualization and display, which offer a far more effective way to access, process and filter information. These methods, however, require high-resolution computer screens or sophisticated immersive projection technology to fully unfold their potential, which makes them impracticable for mobile use. In a highly mobile society, such as the unified Europe, personal and professional success will depend tremendously on instant availability and visualization of salient information. Such interactive information display has to be accessible everywhere and at all times, and must adapt to the individual user's needs and demands. We believe that recent advances in information and communication technology, in particular mobile, wireless communication and advanced display, provide enabling technologies to meet this challenge.

We envision the *Personal Everywhere Visualizer*, PEV, a mobile, handheld device combining high-resolution and ultra-lightweight projection technology with high-speed wireless communication, advanced graphics, and sophisticated visualization. Linking to the web and other large data repositories, such a device will allow us to access and display salient information with great convenience and flexibility. Realistic graphics along with intelligent information filtering will narrow down the complexity of queried information, "tuning" it to the perceptual capabilities of the human brain. Equipped with novel interaction metaphors, the device will offer fast, intuitive, and instant access to information. The Personal Everywhere Visualizer (PEV) will comprise hardware for display, capture, and communication, as well as software for realistic graphics, visualization, animation, image understanding, and multimodal interaction. Having the size of a Personal Digital Assistant (PDA), the device will be readily available to generate instant display, augmented reality, and immersive communication scenarios for a wide range of applications including tele-presence, tele-learning, product management, mobile office environments, medical applications, retail scenarios, homecare of elders and entertainment.

For instance, a mobile user will employ the PEV to create a tele-presence experience. The built-in projection optics will generate an instant, high-quality display and visualize a remote communication partner with high quality on an arbitrary surface. At the same time, high-resolution video of the user and its environment will be captured by the device and transmitted to the remote site. In such a scenario, the PEV will constitute an enabling technology for instant presence and collaboration.

In a mobile virtual office scenario, the PEV will create an augmented reality office environment by overlaying synthetic imagery onto a real scene. The user will have full access to all relevant information and documents as if he was in his physical office, while advanced retrieval and visualization methods will support efficient search and document processing. Novel, multimodal interaction metaphors will allow him to interact with his virtual mobile office. In idle mode, the PEV could continuously acquire and refine information about the actual environment to optimize display quality.

Another potential application is in medicine. Not only would the PEV be utilized for instant communication and diagnosis by remotely located experts, but it could also be used for instant display of salient medical information about the patient. For instance, a surgeon might utilize the PEV in the operating room to overlay high-quality X-ray images or other information onto the patient's body. Likewise, real-time image capture would be used to acquire patient data on the fly.

A further potential application is the intelligent retail store. Here, the PEV could be utilized by customers to identify products and to optimize the shopping experience. For example, the handheld PEV of a customer would overlay high-quality projection onto retail shelves thus creating an augmented reality scenario. The PEV could display information about products, for example, and enable customers to interact with it.

Similarly, the PEVs potential for augmented reality could be harvested for tele-learning. For instance, museum visitors connect their PEVs to the museum database. On demand, the PEV would display background information onto any art object or nearby wall. This information could be customized to the visitor's knowledge and preferences.

Technical, Social, and Ethical Challenges

The creation of such a device requires powerful information and communication technology. A large number of fundamental research questions have to be addressed in the fields of computer graphics, computer vision, visualization, animation, imaging, multimodal interfaces, display technology, and mobile communications. For instance, we will have to investigate advanced display technology, such as digital light processors (DLPs), auto-stereoscopic displays, laser displays, holographic displays, and the like. Of research interest are also combinations of intelligent projection technology with 3D dynamic shape and appearance acquisition. Various types of miniature cameras and other sensors must be combined and studied.

Novel methods have to be developed to render and visualize abstract information and to composite them into real environments. In particular, the interaction between rendering and data capture must be investigated. High-quality light simulation and light source estimation are further issues. Research must be devoted to information representation, coding and compression of information, decentralized storage, and streaming. We foresee that the PEV will eventually let the human computer interface disappear. To this end, we have to pursue fundamental research in multimodal interaction. Other important research issues include system software, application programming, intelligent data mining, as well as perceptual and usability studies. The PEV will allow users conveniently to adapt the presented information to their individual needs. This requires extensive research in authoring tools. For automatic methods recent advances in machine learning bear great potential.

Such technology raises serious social challenges regarding privacy and security. A highly personalized device will surely contain private user data and it will store significant information about the user's behavior, attitudes, and preferences. From the early stage of development, the design of such a system has to put emphasis on security and privacy. Improper use of a large-scale instant display might unintentionally reveal private information to surrounding people. Intelligent spatial awareness of the PEV combined with smart encryption technologies could remedy these problems.

EU standing relative to others

The PEV would draw upon Europe's strength in mobile and wireless information and communication technologies. There have been major investments in the deployment of high-speed wireless communication networks in many European countries, UMTS for instance. In addition, European industries have been leading in industrial optics and in laser technology and there is a tremendous industrial experience in laser and holographic projection systems.

The vision also exploits Europe's strength in computer graphics and visualization technology, image capture and understanding, multimodal interaction, and human computer interface technology.

There are currently several major research initiatives in Europe related to virtual and augmented reality technology and presence, partly in the European Union 6th Framework Programme for RTD. The envisioned device would harvest the knowledge and experience resulting from these efforts.

GRAND CHALLENGE #10

10. The Ultra-light Aerial Transport Agent

The vision and its potential benefits

You are a doctor who has happened upon a serious accident on a busy motorway. You need medical supplies from a local hospital, and it is only two kilometers away. On your mobile phone you have requested the supplies, and they have been sent out. But to no avail – in the prevailing traffic, they will never arrive in time.

You are an engineer managing a large construction site for a major hydroelectric dam. A small part has failed in a crucial piece of machinery, bringing work to a halt. Workers and equipment stand idle, while a replacement part is only fifteen kilometers away. Unfortunately, in your remote location, it will take nearly three hours for the part to reach you.

These scenarios and many others like them illustrate an important and costly gap in modern transportation technology. Their solution requires little more than the ability to move small parcels over distances of a few kilometers, promptly, and irrespective of traffic and barriers of natural terrain. Currently, however, such a technology does not exist. To address this inadequacy, we propose the development of small, autonomous aerial transport agents, semi-intelligent and flexible in their operation, which would perform the above tasks rapidly and cost effectively. The uses of such agents would by no means be restricted to accidents or disasters. We believe that small aerial transport agents will offer immense potential benefit, not only in terms of convenience for individuals, but for business, law enforcement, scientific research and public health.

As the incessant traffic of bicycle- and automobile-based couriers in every major city attests, the demand for rapid and inexpensive transport of small objects is immense. At the moment, a fuel-thirsty van weighing several tons is often the preferred mechanism for moving a letter from one side of a city to another. Aside from the burden this places on traffic, this solution is obviously inefficient. An efficient vehicle for moving a small parcel shouldn't weight much more than the parcel itself. Fuel-efficient aerial transport agents would significantly decrease the wasteful burden of urban traffic. This technology could have enormous economic value. At the moment, available airspace is used very selectively. Low altitude airspace is not used by ordinary commercial air traffic, but could be exploited effectively by autonomous, unmanned vehicles. This would lead to a much more efficient use of available space, while significantly decreasing traffic on the ground.

The ultra-light aerial transport agent would be much more than a remote controlled aircraft. It would resemble a flying robotic agent that would be able to cooperate with other agents to achieve a variety of socially-beneficial tasks. As mentioned above, these agents, especially through coordinated action in adaptable networks, would make a major contribution to "small scale" logistics. Businesses could move light-weight products – and in the future, perhaps even people – from point to point. This would decrease small scale delivery costs. In connection with e-business, in particular, this would be a major boost to economic activity, as physical transportation costs represent a large fraction of many e-business transactions (delivery of books, fast food, etc.)

But logistics is only the beginning of a world of applications. Eighteen years after the nuclear accident at the Chernobyl reactor, the immediate area is still too dangerous to be investigated and monitored effectively by human engineers. Aerial robots would have made such monitoring routine even in the days just after the accident. From experimentation close to active volcanoes to detailed tracking of animal populations, ultra-light aerial agents would open new avenues for scientific research. In public health applications, they could routinely monitor air pollution, or gather specific weather data on the immediate command of a meterologist – data that might be crucial to improving a forecast.

On another level, aerial agents of this type would be extremely useful for law enforcement. They could be employed in dangerous search and rescue operations, for monitoring areas of high crime, or for patrolling international borders.

Technical, social and ethical challenges

An ultralight aerial transport agent that can perform missions of the type described above must combine flexibility and reliability: flexibility so that it can handle many types of jobs and deal adequately with many kinds of situations that arise along the way, and reliability so that it does not endanger persons or property below it or around it. Its development is therefore primarily a question of new information and communication technology that will provide adaptive, faultless performance. Other technologies will also be needed, of course, especially for the aircraft design, in relation to electromechanical control and energy supply. The minimisation of noise is also a challenge when designing unmanned aerial vehicles (UAVs). This suggests the use of platforms such as vertical take off and landing airplanes, rather than helicopters or blimps.

UAVs will require both low and high autonomy. Low autonomy is a question of control engineering and conventional software engineering, for building a system that can take off, perform maneuvers and land automatically. High autonomy requires the UAV to contain a detailed model of its environment and of itself, as a necessary prerequisite for the required flexibility.

The transport agent will also need to be equipped with an adequate user interface, so that a user can specify destinations and appointed tasks using speech input, and possibly a display screen for pointing out intermediate or final destinations.

Finally, conceptual modelling and knowledge representation are of central importance for this challenge, since they form the basis for intelligent navigation and task planning. The conceptual models must be closely integrated with solutions to other problems involving sensors, vehicle control, geographical information systems and natural language dialogue, to mention just a few.

The most obvious social issue of UAVs is safety. Conventional air traffic of today is regulated by a very sophisticated system of safety measures, and the civilian safety administrations are obviously going to be involved in the development and use of unmanned aerial vehicles. Strict authentication of UAVs will also be necessary in order to prevent their use for criminal or even terrorist activities.

Unmanned “watchdog” UAVs may also be the most effective way of protecting sensitive installations against attacks by hostile aerial (or other) autonomous vehicles.

EU standing relative to others

Research in the European Union matches or exceeds in sophistication that of our main competitors in several of the key technologies that are required for unmanned aerial transport agents, including description logistics, artificial intelligence planning, computer vision, and relevant aspects of automatic control and dialogue technology. The development of UAVs also puts high demands on the “systems technology”, that is, on the ability to construct a complex system from its parts. Several European labs are world leaders in this area (e.g., the University of Bundeswehr in Munich, the LAAS laboratory in Toulouse, and the University of Linkoeping).

With respect to the physical design of unmanned aerial vehicles, the USA is investing very large resources into the development of such systems for military purposes, whereas the corresponding efforts in a few EU countries have started later and have a more moderate size.

Finally, with respect to high autonomy in a UAV, the EU has one major project – the WITAS project in Linkoeping – that has demonstrated high autonomy in a UAV system in actual flights that well surpassed what has been developed and demonstrated elsewhere.

In summary, therefore, the EU has a number of laboratories that together represent the best competence in the world (equal to or better than elsewhere) both in the specialized technologies that are needed and I the ability for systems building and integration for this kind of system.

GRAND CHALLENGE #11

11. The Intelligent Retail Store

The vision and its potential benefits

The development of the barcode changed the face of the retail industry. From the experience of the individual shopper at the check out, to the greater ease of basic business functions such as inventory and supply-chain management, the barcode and associated reading technology have stimulated sweeping changes in the way Europeans shop. These technologies, however, do not begin to hint at the changes set to come. The emergence of pervasive communications devices will link retailers with their suppliers and customers in new ways, with tremendous consequences for the retail world. This challenge addresses key business factors that will drive competitive differentiation in the global retail industry: smarter selling, smarter shopping and smarter in-store operations. Retailers can differentiate themselves from their competitors by exploiting ICT technologies, for better understanding of their customers' wishes, and to improving their ability to deliver a satisfying business service.

We envision a store in which innovative ICT technologies have been integrated in a way that brings greater efficiency to both retailers and their customers alike. Manufacturers are already beginning to put RFID chips in products of all kinds, from electronics devices to articles of clothing. This technology makes it possible for shoppers with the right mobile terminal to ask direct questions of inanimate objects: where or when were you made? Do you contain potential allergens? Based on advanced speech and language technologies, spoken dialogues with products will enhance the shopping experience. The intelligent retail store will be based on a network of systems, some carried by individual shoppers, others embedded in articles for sale or in the shopping environment, that work together seamlessly to give shoppers and retail companies greater communications and practical information awareness.

In the intelligent retail store, shoppers will carry in their cart a “smart shopping assistant” – a compact system that can compare products automatically or receive suggestions for alternative products, even ideas for dinner, for gifts, or for local activities to do after shopping. It would give advice – if requested – for healthy eating, while also giving the retail firm – if the user permits – better information about his or her behaviour and preferences. A mobile multi-modal terminal mounted on a shopping cart would display all sorts of personalized information in real-time, showing a shopper their location in relation to products they might want to buy (a great resource for locating those hard-to-find items). Based on high-precision indoor navigation, the system would easily guide the customer to the product shelves that carry the items on his electronic shopping list. In addition, based on advanced plan recognition and user modelling technologies, the smart shopping assistant might recognize the plan behind a customer’s shopping behaviour and help them to locate ingredients for a special dish or to assemble various components for an appliance. In this way, cross-selling and up-selling recommendations would be generated on the fly. The shopping assistant, recognizing that the customer is picking up the usual ingredients for lasagna, may recommend an Italian red wine from Tuscany – a wine similar to one the customer enjoyed some time before but has since forgotten. Such services make sure that shoppers get the best value.

At another level, this technology will also allow shop management to track their inventory more effectively, making it easier to manage supply and demand. Wireless and mobility applications will empower store managers to make informed and timely decisions. Spin-off benefits would also include fraud detection at the checkout stand and intelligent staff scheduling based on customer traffic analysis. Smart shelves will alert staff when the shop's shelves are getting empty or packed products are past their sell-by date.

Finally, advanced ICT technologies will attract shoppers even outside the store. In a virtual shopping window, a life-like character serving as an artificial sales agent can catch the attention of passers-by. If they decide to enter the store, the virtual sales agent will be “transported” automatically to the mobile terminal of the shopper and guide him through the shop. Another added-value service might provide a spatial alarm, informing a shopper whenever he or she passes a shop that offers a desired product. Such location-based services ensure that shoppers don’t forget to buy important items or have to make long detours at the end of their shopping tour.

In conclusion, advanced ICT retailing solutions will enhance store operations, worker productivity and shopper satisfaction.

Technical, social and ethical challenges

To realize the intelligent retail store, a number of deep technical problems must be addressed, primarily in the fields of mobile and cognitive technologies, human interfaces, and distributed ambient computing. At the outset, the technology must be made “invisible” to the customer. When people shop they talk between themselves and act normally; the communications network of the intelligent retail store must not interfere. It should also work naturally for those people running the retail store.

At the same time, the mobile systems carried by individual shoppers should be easily "programmable," so individuals can adapt them to their own needs. It will be crucial to develop authoring and machine learning tools to make this easy.

There is also one serious social issue to be faced concerning individual privacy. Technologically, it is becoming possible to put RFID tags in virtually all objects, including clothing, shoes, credit cards, books, etc. An individual will therefore carry around a set of identifying labels on their person. These labels can be used for beneficial ends, such as learning a person's behaviour to serve them more efficiently, but they might also be used to spy on people, and to track their whereabouts. For this reason, the technology of the intelligent retail store raises serious privacy issues that must be addressed early on in development. It may, for example, be necessary to give individuals an easy way to disable RFID tags after leaving the smart-shopping environment. The popularity of today's supermarket loyalty cards shows that shoppers are more willing to surrender privacy if they get something in exchange and are aware of the risks of giving that information. Already today, these loyalty cards allow stores to build up a detailed profile of each customer's shopping habits, in exchange for discounts or cash vouchers.

EU standing relative to others

Few industries match retailing for cut-throat competition. Jostling for the attention of consumers, European retailers are working hard to fine-tune their store formats, logistics, and services based on advanced ICT technologies. Most of the top 25 retailers such as Carrefour (France), Metro (Germany), ITM Entreprises (France), Tesco (UK) , Royal Ahold (Netherlands), Rewe (Germany) and Aldi (Germany) have saturated their home markets. These retailers have few opportunities to open new stores, and therefore must either improve the performance of existing stores or go elsewhere. Europe's integration process creates an opportunity to obtain new efficiencies from pan-European operations, which will spur further cross-border acquisitions within Europe. Although American retailers tend to be the biggest (Wal-Mart is leading), European retailers tend to be the most cosmopolitan. Asia is less visible in the retail industry: Ito-Yokado, although Japan's largest retail player, is the world's 16th largest retailer. Today innovation is seen as key to growth in European retail industry.

The Metro Group, the world's fourth largest trading and retailing company, has achieved an early demonstration of an intelligent future store. Metro has a powerful presence not only in Germany, but also in 28 countries around the world with more than 2,300 locations and with a work force of almost 240,000 employees. A supermarket of the German Extra sales division located in Rheinberg, North-Rhine Westphalia, is serving as a demonstration and evaluation centre (see www.future-store.org). In this future store, the application and acceptance of advanced ICT technologies in retailing is tested thoroughly under realistic conditions in large-scale field trials. Jointly with SAP, Wincor Nixdorf , Feig Electronic as well as numerous other companies, Metro is using the Extra Future Store in Rheinberg as both a living technology laboratory and a model for the future of global retailing. It serves world wide as the industry's showplace for radio frequency (RFID) product tagging technology, where remote product tracking technologies are being tested on live consumers in a real store environment.

Europe can exploit its strengths in mobile ICT technologies, advanced user modelling, plan recognition technologies, adaptive multi-modal presentation generation, as well as multi-agent-based supply-chain management and logistics, to boost its retail industries in the global competition.

5. Technology Foresight Resources

In identifying a set of grand challenges, the ISTAG working group has drawn on the broad expertise of its members, but has also taken note of a variety of technology foresight activities that have been carried out by national governments and private enterprises. These independent resources have reinforced our own conclusions regarding the most pressing challenges in IST for the coming decade and beyond. The specific resources that we have consulted are listed below:

Government Studies

European Union

Institute for Prospective Technological Studies (IPTS), Thematic Network on Foresight on Information Society Technologies (FISTERA), Foresight studies (http://fistera.jrc.es/)

European Robotics Research Network (EURON), Roadmap on Robotics Research (www.euron.org)

Neuro-IT Network of Excellence Roadmap (www.neuro-IT.net)

A Dependability Roadmap for the Information Society in Europe, IST project 2001-37533 AMSD (http://www.am-sd.org/)

Foresight in the UK (http://www.foresight.gov.uk/)

Grand Challenges for Computing, sponsored by the UK Computing Research Committee, with support from EPSRC and NeSC (National e-Science Centre) (http://www.nesc.ac.uk/esi/events/Grand_Challenges/proposals/index.html)

Chips for Everything - The House of Lords (UK) (http://www.parliament.the-stationery-office.co.uk/pa/ld200304/ldselect/ldsctech/15/15.pdf)

The Vision Book by DG Information Society – European Commission. (http://europa.eu.int/information_society/topics/research/visionbook/index_en.htm)

Research and Development in Information Science and Technology in Large Industrialized Countries. Study carried out for the Conseil Strategique des Technologies des l'Information by the Groupement Francais de l'Industrie de l'Information. http://www.csti.pm.gouv.fr/uk/etudes/Synthese_GB_EtudeR&D_Octobre2003.pdf

Swiss National Centres of Competences in Research (NCCR). http://www.snf.ch/downloads/nccr_profile_en_01.pdf

Foresight study of the Spanish Information Society. *Aprovechar la Oportunidad de la Sociedad de la Informacion en Espana.* Recomendaciones de la Comision Especial de Estudio para al Desarrollo de la Sociedad de la Informacion. http://www.cdsi.es/documentos/informe_final_cdsi.pdf

United States

Converging Technologies for Improving Human Performance (Nanotechnology, Biotechnology, Information Technology and Cognitive Science)
(http://wtec.org/ConvergingTechnologies/).
Also, the NBIC 2004 Conference (http://www.infocastinc.com/NBIC/nbic.asp)

Grand Challenges in Computer Science and Engineering, US initiative by the Computing Research Association (CRA), (http://www.cra.org/reports/gc.systems.pdf)

Fundamentals of Computer Science – Challenges and Opportunities, 2001-2003, sponsored by National Science Foundation (still ongoing, see
http://www4.nas.edu/cp.nsf/Projects+_by+_PIN/CSTB-L-99-09-A?OpenDocument)

National Science Foundation: Challenges in Theoretical Computer Science,
http://www.research.att.com/~dsj/nsflist.html

The International Technology Roadmap for Semiconductors, Roadmap on Emerging Research Devices,
(http://public/itrs.net, http://public.itrs.net/Files/2003ITRS/ERD2003.pdf)

Canada

Science and Technology Foresight Pilot Project: Bio-Systemics Synthesis, STFPP Research Report # 4 (http://2100.org/Nanos/biosystemics-canada.pdf)

Technology Foresight Pilot Project GEOSTRATEGICS – Canadian Interdepartmental Science and Technology Foresight Pilot Project: Synthesis Report Geostrategics
(http://www.moyak.com/researcher/nrc/Geostrategics.pdf)

White Paper: Synergy between Medical Informatics and Bio-informatics: Facilitating Genomic Medicine for Future Healthcare (Project IST 2001-35024)

Japan

The 7th Technology Foresight, National Institute of Science and Technology Policy (NISTEP)
(http://www.nistep.go.jp/)

Korea

Technology Roadmaps and National R&D initiatives in Korea,
http://www.nistep.go.jp/IC/ic030227/pdf/s5-1.pdf,
http://www.nistep.go.jp/IC/ic030227/pdf/p5-1.pdf

Non-Governmental Foresight Studies

W. Wahlster and C. Weyrich (eds.), *Forschen für die Internet-Gesellschaft: Trends, Technologien, Anwendungen*. http://w4.siemens.de/ct/internet-trends. Report by Feldafing Circle on megatrends in information technology, supported by BDI and FhG (2002).

Pictures of the Future. This is the Siemens magazine for research and innovation, published quarterly. http://www.siemens.com/pof.

H.-J. Bullinger (ed.), *Trendbarometer Technik*. Hanser, Munich (2004).

R. Wilhelm (Ed.), *Informatics: 10 Years Back, 10 Years Ahead.* Lecture Notes in Computer Science 2000, Springer-Verlag, Berlin (2001).

Le plan stratégique de l'INRIA pour la période 2003 – 2007. http://www.inria.fr/inria/strategie/

6. Conclusions

The IST Working Group has identified eleven grand challenges. We emphasize that the real value in each case lies not in the realization of a specific device or in the advancement of any one key technology, but in the broad social and economic benefits likely to result. These grand projects are designed to make the next generation of ICT technology contribute most effectively to European efforts to achieve economic growth and social cohesion. They are designed to stimulate and to help establish new industries that will dominate tomorrow's economy by providing products and services that do not exist today. These grand challenges will help Europe to remain globally competitive in the most important areas of ICT, even in the face of increasingly strong challenges from the United States and Asia.

As we have already argued, the highly focused nature of the grand challenges – their organization around very specific, concrete objectives – is instrumental to their success. Challenges of this kind stir a spirit of determination and research drive that is otherwise not easily achieved. While it is not a matter for the working group to determine the mechanism by which the European Commission may eventually fund these projects, it is worth mentioning that the character of these challenges requires, in our view, carefully crafted funding instruments. Each of these challenges will require effective collaboration between distinct and otherwise unrelated disciplines, ranging from physics and computer science to social science and biology. Funding instruments must provide mechanisms to ensure that disciplinary sub-groups have strong incentives to stick to the original specific goal, and to take it seriously. Suitable instruments should also permit the redirection of research funds during the project, so as to enable researchers to capitalize on unexpected developments during the work. In addition, we believe that the grand challenges will be most effectively pursued if the European Commission can set up several such projects in parallel to compete with one another.