

Information Technology¹

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What is possible is not independent of what we believe to be possible. The possibilities of such developments in the practical world depends upon their being grasped imaginatively by the people who make the practical world work.

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¹ Available from the webpage http://www.cordis.lu/foresight/conference_2005.htm.

Executive Summary

This report reviews the challenges and opportunities for Europe especially in the field of Information Technology (IT) in view of strengthening the European Research Area (ERA). IT ranks as the most important among the key technologies because of its *dominant role in all other areas and in the convergence of technologies*. It deserves a continued special attention due to its economic and societal relevance not least for innovation. For instance, the productivity growth rate of Europe's economy is based on ICT to a degree of 50%.

The challenge for Europe is to build upon the high level of education and the ingenuity of its people in a synergetic way, to overcome the well-known systemic failures, to break up rigid organisational structures hindering innovation, and do so in harmony with its cultural, social and natural heritage. Our traditional ways of designing such a complex fabric are no longer sufficient to achieve this goal. ICT and especially Artificial Intelligence (AI) and Cognitive Science (CogSci) with their *knowledge technologies*, have the potential to support this transformational process.

The report's analysis of Europe's science and technology base and activities in IT demonstrates that substantial efforts are needed to succeed in the competition with the main competitors. Europe lags behind in comparison with the US, Japan, etc. in most factors including the number of patents, the spending levels in R&D and in education, the number of researchers, the percentage of corporate research, the low ICT employment intensity, the slow penetration of ICT and its computational paradigm in other areas (especially in social sciences and humanities), the net business profits, and many others. Europe has to increase its efforts substantially to be able to compete with the current technology leaders and competitors. Thereby we propose a so-called *awards (funding) scheme*, which would strengthen the basis of the ERA from bottom up, complementary to the current funding schemes (like FP6).

The second purpose of the report is to provide an overview of key aspects and trends of research and development (R&D) in IT. This overview in Section 4 is structured around two characteristics of IT which are, first, the need for a tight integration and immersion of IT into all facets of reality (physical, biological, psychological, and social world) and, second, the levels of abstraction which have evolved during IT's development. The overview produces a great variety of detailed perspectives for the technological development in all subfields of IT.

Two general visions are considered most important. One, in accordance with the first characteristic, is the integration of *intelligent* systems within the natural, human, but also technical sphere. This is why AI, virtual reality, (multimodal) Human/Computer Interface (HCI), humanoid robotics and, generally, the coupling and reconciliation of the real with the virtual are considered top issues for R&D in the coming years. This vision is about to transform virtually every other domain (S&T, engineering, design, development, and production, business, government and administration, and many more discussed in detail). The other vision is the transformation of software production into a scientific discipline, incorporating also new computational paradigms and leading to a high degree of *automation* as well as to an increasing autonomy, robustness and tolerance of systems.

In view of these two visions the report proposes four major challenge problems: the Automation of Programming based on descriptively specified system and environment models; the development of humanoid robots on the basis of bionic and CogSci principles; the development of an Integrated Hybrid Public Transportation System and of a Semantic Law Support System.

The major findings of the report's political, economic and technical analyses are summarized in two tables presented in Section 5.

0. Introduction

A High Level Expert Group on “Key Technologies for Europe” (*KeyTech* for short) was set up by the European Commission, Directorate-General for Research, Directorate K (“Knowledge-based economy and society”), Unit K2 (“Science & Technology Foresight”). The task of the group consists in preparing a report on emerging science and technology trends in fifteen broad research domains and the implications for EU and Member States research policies. As a basis for this report each of the experts was charged to prepare a thematic profile on his/her domain of expertise. The present report provides this profile for the domain of Information Technology (IT).

The format of the present report follows the one suggested along with the mandate and can be seen from the five section headings in the table of contents. That is we start in Section 1 with a description of the socio-economic challenge for Europe in the domain of IT. Thereby we point out the central relevance of IT for virtually all other domains and discuss several general directions in which Europe could undertake major efforts to meet the great challenge of matching the leading position of its global rivals in this domain. Section 2 expands on this general analysis and provides some hard and unpleasant facts without ignoring some positive signs giving rise to some cautious optimism. Unfortunately the given frame in time and space did not allow to provide an in-depth analysis of the strengths, weaknesses, opportunities and threats (SWOT) of IT in a way which would be satisfactory from a scientist’s point of view and which – except for more casual studies – can also *not* be found in the literature.

Section 3 is devoted to EU’s activities in IT. We present a proposal for complementing the current funding policy with a bottom-up policy, termed *awards scheme*. It aims at strengthening the conditions of a larger number of selected excellent researchers and developers in public institutions as well as in industry. It would compensate an inherent structural weakness in comparison with the US. Apart from that we discuss previous programmes of the Commission and their effects on Europe’s standing in IT from a global perspective and have a short look at the activities of the member states.

The main part of the present report may be found in Section 4 in which we take a closer look at the domain and its prospects from a technical perspective. As a prerequisite we first structure the field in a coherent and systematic way in order to avoid ending up with rather arbitrary lists of the kind to be found in similar reports, eg. in (Compañó et al. 2004, p.68f). Our way of structuring is based on two principles, namely the embedding of IT systems in reality and the standard layers of abstraction used in IT and reaching from its applications at the top level down to the physical level. The entire section offers a rich variety of long-term challenges, visions and technological opportunities. It ends with a list of challenge problems which are recommended for special attention in future framework programmes of the EU (such as FP7).

The report ends with a concluding section, which summarizes the main findings and presents a SWOT matrix, and with the list of references. Altogether the report is based on the material contained in a variety of previous reports and studies listed in the references, including one edited by the author (Bibel et al. 2004). It tries to achieve a synopsis of these earlier studies. In addition the systematic structuring of the domain has led to insights which suggest a balance of weights on different subdomains which occasionally may differ from that in earlier reports.

A report of the given length can of course not pretend to cover IT comprehensively at any level of detail although it does cover a truly wide range and a great many of scientific and technological issues. Only at the highest level of abstraction we hope to have treated the most

important parts. In its more detailed passages the selections out of the infinitely many possibilities have been made more in an exemplary way. Note that the area of communication is explicitly not included since there is a parallel report on Communication Technology (CT). Since IT is so closely related with CT that usually both are treated together as ICT we could not avoid to often take the ICT view and also briefly touch upon CT explicitly (within Subsection 4.9). Also the report is technology oriented. It neither treats the more critical aspects of such technologies nor their impacts on individuals, groups, the society as a whole, and the environment. For both of these issues we refer to (Bibel et al. 2004) where they are discussed at great length. In this respect the report is focussing truly on IT and not on the wider Information Society Technology (IST).

The material presented here reflects nine general trends to be observed in the current technological evolution. A fundamental trend is the *convergence* of sciences and technologies (Nordmann 2004) which is closely correlated with the pervasion of IT through all other sciences and technologies, especially with the role of knowledge in IT – from programmed to managed to meta-knowledge – (Bibel et al. 2004, Section 4.1), as is further expanded in Subsection 4.6. One therefore now also speaks of Converging Technologies (CTeks) which are mainly based on Nano-, Bio-, Info- and Cogno- (NBIC) Technologies (Roco et al. 2002). *Miniaturization* (and higher degree of – vertical – integration) characterizes the second (related) trend. Chips, memories, computers, sensors, and many other devices are getting ever smaller, in fact so small that they may sort of disappear into the environment and become invisible for the eye (as discussed in Subsection 4.7). Connected with this trend is the ongoing *distribution* of collaborating devices (also termed ubiquitous computing) as a further trend. Similarly the *distribution* of problem solving (eg. in the form of distributed or grid computing) is a trend ongoing since the beginning of the IT age (see Subsection 4.9). As systems become ever more complex the level of *autonomy* is increasing without compromising transparency. Another general trend is the continuous *migration* from analogue to digital, from fixed to mobile, and from voice/text to multimedia equipment, regardless of physical location of the equipment. While computation so far has been realized mainly on the basis of CMOS technology, we are now experiencing the new trend of exploiting an ever greater *variety* of physical, chemical, biological, etc. phenomena for use in computational processes (see Subsection 4.11). Another general trend consists in an ever closer *coupling* of the real and the virtual, a topic discussed in detail in Subsection 4.7. The final trend demonstrates a phenomenological *approximation* (or reconciliation) of the virtual to the real which is quite a different aspect (see Subsection 4.4). For instance systems exhibit an ever more intelligent behaviour (see Subsection 4.3). In the conclusions we will mention further, more technical trends.

1. The Socio-Economic Challenge for Europe

Europe boasts of many attractions: rich inheritance, cultural diversity, social coherence, moderate climate, fertile soil and natural beauties. There are however a number of indications which give rise to serious concerns about Europe's future: economic competitiveness with serious competitors in place or rising at the horizon (like China), ageing and shrinking societies with severe consequences for the national social benefits and health systems, rising levels of unemployment, rising levels of state debts, lack of political leadership in reforming outdated and inadequate structures, rising costs in resources which Europe has to import.

Overcoming these fundamental problems and maximising the quality of life of its population in a sustainable way is the undisputable goal for Europe, as it is for any other

region in the world. Major factors thereby are Europe's economic competitiveness, in order to favorably influence its trade balance and accordingly increase its wealth, and its flexibility to adapt to the rapid changes in the global environment in its widest sense. Both competitiveness and flexibility heavily depend on the scientific-technological innovative capacity in the European Research Area (ERA). The challenge therefore consists in increasing this capacity to a level which compares well with that of its competitors.

The potential for a competitive performance of Europe is enormous. The number of highly educated people with great talents traditionally compares well with any other area in the world. Many fruitful ideas have their origins in Europe. But there is a systemic failure in exploiting this potential to a degree which would allow Europe to excel in competition with the rest of the world in economic terms. According to the European Innovation Scoreboard (EIS) published by the European Communities each year the EU lags the US in seven out of ten indicators measuring economic success (EC 2002b). This is not the place to analyze the reasons for this failure in any detail which has been done in many other studies.

Information technology (IT) is an example for this failure. Beginning with the invention of the modern computer by Konrad Zuse in the early forties many fundamental ideas, on which the evolution of IT was based in the past sixty years, had their origins in Europe. But Europe took too long to grasp IT's opportunities. In consequence, except for a few sectors within IT where Europe excels, the core technology is driven by the US, Japan, and others, with many negative consequences for the European technological leadership and economy. The difficulties to cope with the fundamental problems mentioned at the outset might have a lot to do with these consequences.

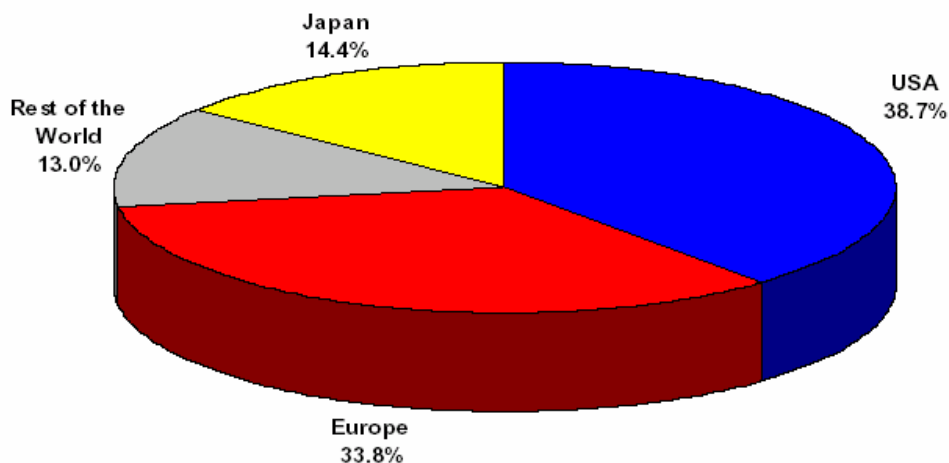
Among the key technologies IT is of particular importance for its inherent cross-disciplinary and cross-sectoral nature. ICT is revolutionising the functioning of the economy and society, and is generating new ways of producing, trading and communicating. There is no other science or technology nor any sector in the society which could do without IT; ie. IT is essential for all of them. ICT has become the Union's second most important sector of the economy, with an annual market of 600plus B€ (billion Euros) and employing more than 2 million persons in Europe, a number that is steadily rising. The productivity growth rate of Europe's economy is based on ICT to a degree of 50% (Verheugen 2005). In the US the degree is even 60% as pointed out by Commissioner Viviane Reding for IST. For instance, 90% of all innovations in the automobil industry are driven by ICT (Computer Zeitung Nr. 9, 28.2.05, p.2). Similarly, ICT is revolutionizing the life sciences; for instance, just the small sector of information systems for hospitals in this large area is expected to double by 2010 to a volume of over 6 B\$ according to a study by Frost&Sullivan. Lacking behind in IT means lacking behind in everything while leadership in ICT supports general leadership. It is therefore a great challenge for Europe to catch up with the rest of the world in core areas of IT. If this could be achieved many other problems could be solved much easier as well.

Although this challenge is not easy to attain there are great opportunities which have to be grasped. First of all can Europe build on its strengths in some areas within the software and communications technology such as the cell phone, mobile/wireless processing technology, integrated business platforms, applications software and ICT services (Compañó et al. 2004, p.68f). Also, "Europe is eighteen months ahead of the United States in the introduction of grid technology" (Rifkin 2004, p.47). Second, the technological development in IT is still characterized by disruptions through novel inventions. Such disruptions are expected both for future computer hardware as well as for the software production process (see Section 4). So for any player there remains a realistic chance to overtake previous leaders. According to the Lisbon strategy Europe is now determined to seize its chances.

One of the reasons behind the above-mentioned systemic failure is the tendency to hinder activities of motivated individuals or groups (by a host of regulations, rigid structures, etc.) rather than supporting activities in a synergetic cooperation and a friendly competition. This tendency has led to fragmented activities and structures in all sectors. The EU's member states are governed by 25 varying legislative, regulatory, educational, financial and patents systems blocking many attempts for fruitful cooperation. In fact there are many more of these systems since for instance in federal Germany each of its 16 states has its own system. Europeans must rather learn to pull together. This is ever more important as market structure is changing into a network commerce in a globalized economy (Rifkin 2004, Ch.8) where cooperation building on trust and synergy are essential features. It is also important as innovations in IT (as in other areas) ever more depend on the knowhow in more than one discipline, ie. the are of the nature of converging sciences and technologies (Nordmann 2004). The intellectual capacity and scientific basis in the individual disciplines is excellent. So what is needed is an openness towards innovations outside of the beaten tracks, a rational management of the necessary means for exploring new ideas, of collaboration without heavy overhead, of direct transfer of novel techniques to industry, business, administration and governance, and of norms, standardizations, and generally a political climate which support the synergy of creativity.

The techniques used in IT to cope with the complexity of its systems are in fact a model for what had to be done to realize such a rational management (see Section 4.6 for more details). In so far IT is more than a cross-sectoral technology in the above sense; its methods actually carry the potential to revolutionize also classical disciplines like the social sciences.

Worldwide IT market by region, 2005



Source: EITO in cooperation with IDC

Market value 2005: 917 billion Euro

Europe must also generate a climate in the public debate which is more favorable towards adapting new technologies with a potential for supporting sustainable development. This includes the need for a higher esteem for all actors involved in the educational, scientific and technological cluster resulting also in appropriate infrastructures and salaries. Successful scientists must become heroes *before* they leave the country or die (as it happened to Einstein and Zuse in their homeland and to too many others).

One way to improve the image of science and technology (S&T) consists in the pursuit of challenge projects which aim at improving core social needs such as public transport or preventive medical technology (Bibel et al. 2004). Therefore Europe has to structure its funding policy in such a way that the development converges towards improvements of the situation of the population as individuals as well as groups or societies within a sustainable environment.

2. Europe's Science and Technology Base in IT

There is an empirical rule saying that an economy draws the more out of a new technology the earlier it enters the race well prepared. As mentioned in the previous section Europe has wasted too much time before it recognized the central importance of IT. To understand this importance just note the enormous size of the ICT market which includes ICT equipment, software products, IT services, and telecoms carrier services. In 2005 it is estimated at 2,044 B€ (billion Euro) worldwide with a share of 620 B€ in the EU. The share of the IT worldmarket is 917 B€ (the rest contributed by telecommunications) with the regional distribution shown in the picture on the page 6. The ICT market with a growth rate of 4.3% still continues to rise considerably faster than the GDP.

Given IT's role in virtually all other sectors, as pointed out in the previous section, this altogether explains an essential part of Europe's technological and economic problems. Of course our situation is not hopeless and there are many encouraging signs, but it is certainly not as good as the Lisbon strategy anticipated by this point in time and as some politicians might want it appear. Let us have a look at some hard facts.

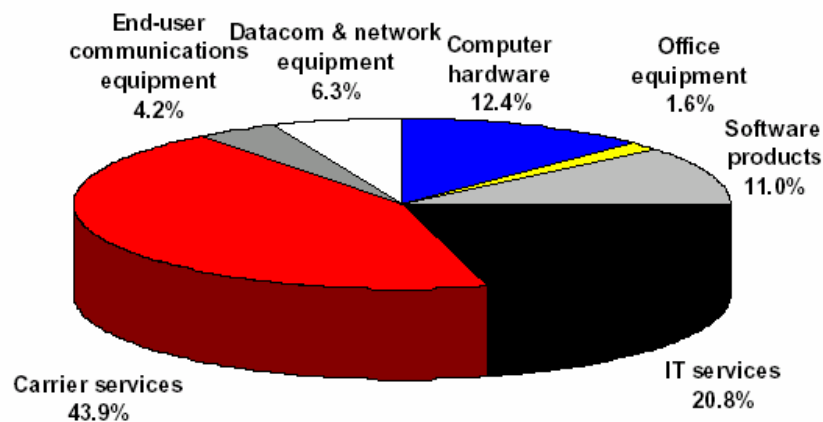
Europe globally is a relatively small player in competing for the important semiconductor or integrated circuits (IC) world market which 2004 featured record sales of 213 B\$; at any rate the European-based production in this area is not apart with its consumption and with its industrial weight. It is expected that in 2005 China's IC market will become the largest regional IC market in the world with a volume of 34,3 B\$ (<http://www.icinsights.com>). The company Intel reports a record revenue of 34.2 B\$ for 2004 (<http://www.intel.com>). The lesson behind these two figures: only the powerful players can take advantage of a rapidly growing worldmarket. The picture on the next page shows the market structure for Western Europe.

No European company is among the top ten companies ranked according to the number of US patents launched in 2004. The best European company is Bosch ranking 16th, far behind the world-leader IBM which holds 40,000 patents. Generally, European countries lodge only 9% of the patents registered at the American Patent Office (APO) compared with 21% for Japan and 57% for the US. Even at the European Patent Office (EPO) Europe with a share of 36% is just level pegging with the US (EC 2002a). In 2003, Japan had the highest number of triadic patents per million population (93) followed by the US (53) and the EU (31).

According to (Compañó et al. 2004, p.45) the ratio of information society technology (IST) related patents in relation with all patents filed at the European Patent Office in 1999 for the European Union is more than ten percent below that for the US. Korea and Japan are doing even significantly better than the US (let alone Europe) in this respect. Only Finland, the Netherlands and Ireland are better than the US, three countries which, most likely as a consequence, have demonstrated extraordinary economic strength in comparison with the EU on average.

Finland is a model for demonstrating how much investment in education and an emphasis on IT can change matters to the positive; its IST patent rate excels at 60%. On the negative side Germany is a model for demonstrating the consequences of adhering too long to traditional sectors and ignoring key sectors for too long: its share in world production of the automobile industry amounts to 23% (if mergers are taken into account) while in IT it plays an inferior role. Its current economic struggle (notwithstanding the costs of reunion) has a lot to do with these particular facts.

Western European ICT market structure, 2004



Source: EITO in cooperation with IDC

Market value 2004: 594 billion Euro

The *patent rate* just discussed is one classical benchmark for measuring performance. Another one is the *spending level* in research and development (R&D). Adjusted for inflation, the US today spends 38% more on R&D (in all sectors) than it did in 1991 while in Germany this growth rate over the same period is only 14.5%. In 2003, R&D intensity (ie. share of GDP) in the EU amounted to 1.93%, well below the US (2.59%) and Japanese (3.15%) intensities, but still above China (1.31%). The rate of growth of EU's R&D intensity (+0.7% per year between 2000 and 2003) is close to stagnation and far from sufficient to reach the 3%

objective in 2010: if this trend remains unchanged, EU's R&D intensity will be only about 2.20% in 2010. If current trends for both China (with annual growth rates in R&D intensity around 10% since 1997) and EU-25 hold on in the coming years, China will have caught up with the EU by 2010.

It is the overall target that two-thirds of R&D expenditure are financed by the business sector. In 2002, the business sector financed 55.6% of domestic R&D expenditure in the EU, compared to 63.1% in the US and 73.9% in Japan. This share decreased at a rate of 0.6% per year in the year between 2000 and 2003 so that the target is most unlikely to be reached by 2010. Considering just the public R&D expenditure it rose in the period 1998–2004 in the US by 40.3%, in Japan 27.3%, in UK 27.7%, and in Germany only 3.9%. The average growth rate for ICT R&D investment in the EU in the period 1997–2001 is only 4%. For ICT the R&D rate in the US is three times the one of Germany.

These general figures are reflected in innovational areas like the nanotechnology. For instance the US has launched the National Nanotechnology Initiative (NNI) which is supported by public funds amounting to 774 M\$ in 2003 and 847 M\$ in 2004 while Japan invested 650 M\$ already in 2002 in this area (BMBF 2004). In 2005 the worldwide investment in nanotechnology research exceeds 3 B\$. In comparison the EU has allocated 1,300 M€ within FP6 for this area which breaks down to 325 M€ per year. These figures must of course be complemented by the investments at the national level.

The figures for the educational sector are similarly insufficient. While the EU is producing more S&E graduates than the US and Japan, the overall funding of tertiary education as a percentage of GDP is lower in the EU than in the US and women remain under-represented. Generally, in the EU member states research policy is typically considered a “soft topic” in contrast to hard topics like economic, foreign or military policy. Not so in the US. In the recent “Project 2020” of the National Intelligence Council which analyses the most important factors of global developments, research policy ranks among the most important factors (Frankfurter Allgemeine Zeitung 39, 2005, p.44). It warns that in 2020 the leading research institutions could be those in China. Already now India and China invest huge sums in basic research in the areas of nano-, material, bio-, and info-technologies. This is the basis on which both could become leaders in key technologies with enormous (negative) consequences also for Europe and even the US. Even a country like South Korea is spending the substantial amount of 654M\$ of public money in 2005 on basic research. In other words, emerging economies like China and India will not remain just suppliers of cheap mass products but is or soon will be competing also in the high-quality and high-technology products and services sector of the economy.

In the field of computer science and technology, already today the best research and higher education institutes in China compete well with those in the US, including Beijing University (Beijing), Tsinghua University (Beijing), Hongkong University of Science and Technology, Fudan University (Shanghai), the Institute of Computing Technology and the Institute of Software within the Academia Sinica (Beijing), Nanjing University (Nanjing), Microsoft Research Asia (Beijing), Jiaotong University (Shanghai), Harbin University of Technology, and others. The Indian Institutes of Technology (IIT) are of similarly high quality in IT as well as in other subjects. In India this has already lead to an international leadership of a number of its software companies.

The number of researchers in Europe compares badly with that of its competitors. In 1997 it had 5.28 researchers (in Full-Time Equivalents) per thousand labour force (in 1999 5.4, in 2001 5.7, in 2003 5.4) compared to more than 7 (9.0 in 2003) in the US and more than 8 (10.1 in 2003) in Japan. Within the EU again Finland excels with the figure 10.62 (EC 2002a).

These figures are reflected in the number of publications. In 2003, the US led with 809 scientific publications per million population, followed by Europe with 639, and Japan with 569.

A typical European feature is the fact that only slightly less than half (49.0% in 2003) of its researchers are in business enterprises while the comparable figures are 80.5% in the US and 67.9% in Japan. This strict separation of the research and business sectors causes a substantial delay in the transfer of research results into products.

Given these trends it is no more a surprise that in the period 1900–1920 90% of all nobel prizes went to Europe compared to only 25% in the last 20 years to mention another indicator. Europe is nearly absent in prizes awarding IT pioneers (Kyoto prize, Turing award, etc.). And the trends indicate that we are still on the downhill side.

As we said at the outset of this section there is no reason to be utterly pessimistic. Higher education in Europe still produces a great number of highly qualified people in IT and other key technologies. Yet, still a too high percentage of the very best are lost by “brain drain”, mainly to the US (Compañó et al. 2004, p.40). And given the efforts of Europe’s competitors the situation could become truly serious unless Europe’s strategy will prove successful.

Also, as already mentioned in the previous section, European industry has succeeded in capturing important markets and niches in ICT (eg. in mobile/wireless communication systems, business and applications software, microsystems and embedded systems, grid technology) in which some major European companies such as Siemens, SAP, Nokia, DaimlerChrysler, Bosch, ARM, BT etc. are playing leading roles. The area of nanoimprint lithography (NIL) discussed in more detail in Section 4.11 allows the strong European chemical industry to excel in a particularly promising area.

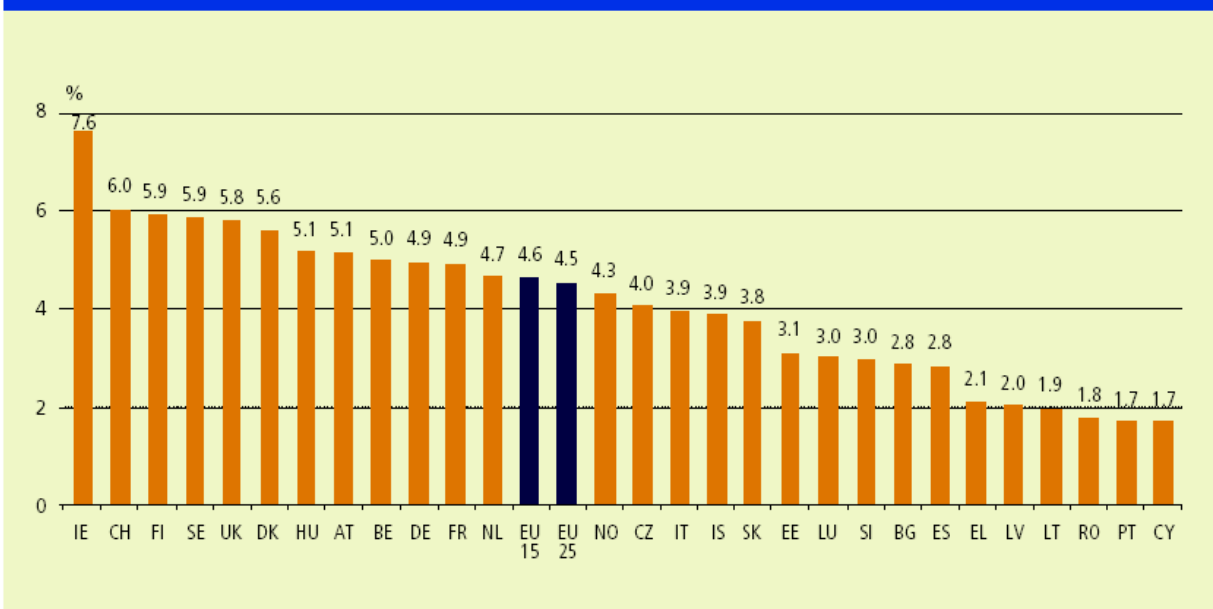
An important factor in innovation, which is crucial for such successes, is the close collaboration of researchers with industry for accelerating the knowledge transfer. The Fraunhofer Gesellschaft with over 2500 R&D workers, the second largest research organization in Europe in the field of information technology, may be seen as a role model for this kind of successfully connecting industry and scientific research. It is also promising that the EC on 11 March 2005 adopted a European Charter for Researchers and a Code of Conduct that aim at providing researchers with long-term careers and at improving their employment and working conditions.

As a further positive aspect the EU’s new member states (NMS) provide a great potential due to the high educational level of its people, their high motivation, and the lack of rigid structures holding back some of the old members. Especially Hungary is doing very well in the ICT sector. The table on the following page shows the ICT employment intensity for European states in 2002 measured as the number of jobs in ICT sectors as a proportion of the total workforce (Stimpson 2004).

As these figures show ICT employment is an important factor but still a relatively small one. Much more important for economic success is the transformation that ICT brings about in other sectors. The degree of this transformation is especially low in NMS which is the most important reason for their lagging behind in economic development.

The degree of this transformation in the entire EU is particularly far behind in the service sector which is technologically underdeveloped in Europe. For instance, although about 70% of all working people are in the service sector, it is far behind in terms of export: in Germany only 14% of all exports fall into this category compared with 30% in the US. This enormous difference suggests a lack of competitiveness in this sector. This assessment is supported by the fact that R&D in Europe still focusses on the manufacturing industries sector although the

service sector has a much greater potential in the future. In fact a detailed analysis of general and IT related figures reveals that most of the EU-US R&D gap stems from the combined effect of low R&D intensities and sizes of the services sector and ICT manufacturing. Also the productivity growth problem in the EU compared to the US is mainly located in the ICT-using services sector and to a lesser extent in the ICT-producing manufacturing industries. For this reason we will come back to the importance of ICT for the service sector in Section 4.6.



3. Activities of EU in Information Technology

The European Commission has established a policy of supporting research and development within a policy framework which, as far as the major funding resources are concerned, might be characterized as follows. It asks experts from all sectors, disciplines and member states for their advice concerning the areas in R&D worthy of financial support in terms of the likely effects on Europe’s prosperity in a very general sense. On the basis of this input framework programmes are designed, discussed with the experts and with the member states and refined as a result of these interactions. Then the programmes are approved by the council. On the basis of such programmes the Commission calls for project proposals and with the help of experts selects from these the best ones worth to be supported. The projects are surveyed again by experts and controlled by the Commission on the basis of reports.

While this seems to be a fair and rational process, it is not an optimal one. It involves a heavy overhead in monitoring on various levels, the project-partnerships are often superficially established to conform with the requirements, and the progress in technological means is by far not exhausted in realizing the pursued goals.

The ideal would be to combine the strengths available in the European R&D community with rationally elaborated perspectives of future development. Such a combination would require an elaborate and upto-date database of European researchers and developers and their achievements including their publications and patents along with a solid comparative evaluation of these data. On the basis of such an evaluation the best candidates could be selected and additionally ranked according to the perspectives. On the basis of such a rational

ranking the funding of their research and collaborations, without any strings attached except for monitoring the results, would be more effective than the time consuming – especially for the researchers and developers – procedure under the current scheme. In particular it would spare the researchers and developers the enormous amounts of time spent in preparing (successful and failing) project proposals, progress reports, and so forth, which to a large extent is time lost for truly creative research and development. In fact it is likely that the real geniuses of the Einstein kind are never successful in the present system and therefore are not supported the way they should.

Let me call this proposed scheme the *awards scheme* since awards are typically given following such a procedure. However most awards are given to a very few selected and outstanding researchers or developers in public institutions or in companies. The proposal here however aims at a relatively large number of smart people, groups and innovative companies. An example of an awards scheme of this kind was successfully undertaken by the (privately initiated) Canadian Institute for Advance Research which even payed salaries to selected university professors freeing them from many time-consuming and non-creative duties otherwise leaving them in their usual environment.

The funding process envisioned in this proposal would of course be revolutionary in the sense of asking the regulatory agencies to approach the researcher and developer rather than the other way around as under the present scheme. It is still difficult for any public agency to realize the ideal of acting in service of the citizen in the true sense. In fact most of the legislature adopts a somehow opposed view of public institutions which is that of a regulatory and monitoring entity. So the revolution would in fact have to start with legislature.

The proposal is meant to *complement* the current policy, not to substitute it altogether. Larger projects, technology platforms and initiatives, exchange programmes, especially those supporting young researchers, of course, all have their values and cannot be replaced by incoherently organized individual bottom-up activities. But it would compensate a weakness in Europe which, in contrast to the US, features a certain inflexibility in its institutions and companies; they prove unable to give specially talented persons, especially young ones, the appropriate support for the development of their creativity. Excellence can grow only bottom-up. Because of this fact support must also go to the individual excellent researchers. For the same reason a European Institute of Technology (EIT) matching MIT's excellence cannot be established top-down, but it could eventually evolve through an extended awards scheme.

The establishment of a European Research Council might be seen in this context. It could oversee such a scheme and guarantee that the executive agency in charge does not fall into the same trap as all agencies before which is to care for its own self-esteem and thereby forget its proper service function. The new European Young Investigator Awards (EURYI) awarded by the European Science Foundation (ESF) and the association of European Research Councils (EUROHORC) is a small step into the direction of an awards scheme. But with 25 awards per year at the level of 1M€ each these are far too selective and elitist to fulfil the function intended with our proposal.

This proposal is not meant at all as a criticism concerning the current funding policy pursued worldwide in similar ways, but it rather envisions an even more effective future policy for Europe. On the contrary, our judgment is that the EU is doing quite well in its funding policy in relation to its competitors, especially in the area of IT. Among the competitors in a sense are also the member states which often act somewhat parochial and less far-sighted than the Commission. In so far European IT would not have developed so powerfully since the early eighties except for the various programs run by the Commission.

The first such major programme was the specific programme ESPRIT starting in 1983 more or less in response to the Fifth Generation Project of Japan. I dare to say that the European identification process was strongly influenced by this first major and successful programme. It played a model role for many later programmes in IT as in many other areas. Shortly after the beginning of ESPRIT the general four-years Framework Programs (FP) were initiated with FP1 in 1984, although only with FP2 they “started to be seen as an important means of creating a European RTD policy” (Compañó et al. 2004, p.50). From there on they took a wider focus on various areas including IT. Although ICT always has played a particularly important role in any of them, its financial share decreased from 40% in FP2 down to about 20% in FP6. These figures do not include the (small) Human Resources and Mobility (HRM) shares in FPs which of course also contribute to ICT.

Despite this relative decline, IT continues to play a major role in the Commission as can be seen from the fact that besides the Directorate General (DG) Research there is the separate DG IST focussing to a large extent on ICT and its role in society. In fact ICT has been increasingly accepted as the driver of current growth, as witnessed by the past generation of unprecedented US productivity. Therefore it has become an essential policy priority in Europe as reflected by the Lisbon targets, since 2000.

On the demand side, the low level of ICT-penetration, the growth effect of institutional and regulatory measures supporting the ICT products as a result of a more robust income growth create ample scope for the diffusion of ICT sectors. On the supply side, real convergence and the narrowing of income/wealth levels between different regions (economic cohesion) will both be accelerated by ICT as well as closing the digital divide – if the policies are in place to enable this.

We are now in the middle of FP6 (2002–2006) while FP7 is already beginning to take shape in the form of several reports produced under a variety of perspectives such as (Nordmann 2004, Wahlster 2004) and others. FP7 is expected to be implemented in 2006. The total budget of FP6 amounts to 17 B€ (billion Euros) of which 3.6 B€ are allocated to IST (information society technology) which of course includes IT. In comparison the EU spends ten times more on agriculture, or 40% of the entire EU budget on 2% of the employment. For FP7 the Commission aims at 13 B€ for ICT. The activities carried out in this area are intended to stimulate the development in Europe of both hardware and software technologies and applications at the heart of the creation of the Information Society.

Since most funding is bounded by 50% of the total costs, the remaining costs being contributed by the partners, the total amount of investment is actually about twice as much. As the figures given in the previous section show still much more would be needed to meet the Lisbon targets and to extend the funding in accordance with the proposal at the beginning of the current section.

A novel feature in FP6 are the additional funding schemes of *integrated projects* with a strategic and application-oriented focus and of *networks of excellence* supporting the collaboration of leading researchers in subareas (EC 2002), both of which have already brought encouraging results.

Space restrictions do not allow of course to discuss the IT projects funded by the Commission in the past and investigate the effects of this funding in any detail. In fact systematic evaluations of this kind are rare and usually do not excel in precision and specificity, just like our discussions here. It seems nevertheless illustrative to have a look at a few selected projects in order to get a feel of what is done and what can be achieved (further examples are scattered within the remaining text).

Generally FP6 is funding projects in IT (or more generally IST) which are directed towards realizing the Ambient Intelligence (AmI) vision (Friedewald and Da Costa 2003). This human-centered approach aims to offer every European citizen, anywhere and anytime, any service, technology or application. Important technical elements of this approach are listed in the following table (for the technical details see Section 4). The subsequent basic research project is a good example in this direction.

Table of Technical Elements of AmI

<i>Ambients</i>	<i>Intelligence</i>
<i>Embedded Systems</i>	<i>Common sense reasoning</i>
<i>I/O Devices</i>	<i>Computational intelligence</i>
<i>MEMS</i>	<i>Context arousal</i>
<i>Sensors</i>	<i>Emotions and computing</i>
<i>Smart materials</i>	<i>Multimedia</i>
<i>Ubiquitous Comms</i>	<i>Multi-modal interactions</i>
<i>Communities and Environments</i>	
<i>Participatory</i>	
<i>Prototyping, hands-on</i>	
<i>Security</i>	
<i>Software Engineering</i>	
<i>Technology Platform</i>	
<i>Integration Issues</i>	

WonderWeb was an EU IST project funded by the initiative on Future and Emerging Technologies (FET) within FP6 (see <http://wonderweb.semanticweb.com>). Within the project an “Ontology Infrastructure for the Semantic Web” was built (Oberle et al. 2005). The project is a model for “strengthening the strengths” in European research and for aiming at European leadership in key technology. Namely, the web is obviously of outmost importance for science and technology as well as for society in general, now and in the forthcoming future. Its functions will be greatly enhanced by semantic features which “understand” the users’ intentions better than possible with statistically evaluated syntax as done with search engines like Google.

In order to realize this vision knowledge must be processed in the web which in turn requires an ontology as a basic tool represented in some standardized language. The standard ontology web language OWL was developed (among other achievements) in this project which has been adopted internationally for the forthcoming semantic web. This success is grounded in the solid research basis in description logics within the European research community.

The project could serve as an example for the idea behind the awards scheme proposal made further above in this section. This is because the participants could have been named by the international peers in this field off-hand because they know that the participants are the key players in the area. So the heavy paper work involved in any EU funded project could have been spared in this particular one as in many others by simply awarding those researchers funds without strings attached. In fact, senior scientists like the present author could easily contribute to add similarly promising names to the database envisaged above. (This also exemplifies that the HRM programme is not sufficient, as one might think at first sight, for what is proposed here.)

The Project CHIL (Computers in the Human Interaction Loop) is more generally aiming at realizing the AmI vision to provide computer services delivered to humans in implicit, indirect and unobtrusive way while they interact with humans. It comprises 15 competent partners from Europe and the US (<http://chil.server.de>).

The Project Adaptive Services Grid (ASG) coordinated by the University of Potsdam (Prof. Weske) develops a software platform which combines the technologies of the Semantic Web (see above) and Grid Computing (see Section 4.9), a good example for the urgent vertical integration of technologies. With 26 partners it is a rather large project which plans to have a prototype of the ASG-platform ready by 2006.

The big FP6 project Wear-IT-at-Work (<http://www.wearITatwork.com>) with 36 prominent big players (Airbus, SAP, Siemens etc.) under the coordination of Prof. Otthein Herzog not only aims at realizing the AmI vision in the sector of modeling work processes but additionally builds on the already mentioned European strength in mobile systems. The focus is on wearable systems which support the work processes in offices, factories or in the field (eg. for maintenance). This comprises the hardware, the input/output systems and the software. The project pursues 4 prototype scenarios: fire-brigade, hospital, aircraft industry, car industry.

The project Apnee-Tu (coordinated by the Fraunhofer Institute for Applied Research, Prof. Thomas Rose) is an example for a successful public/private partnership which has led to the commercialization of informations from regulatory bodies through businesses.

Another EU financed project is Macs (Multi-sensory Autonomous Cognitive Systems Interacting with Dynamics Environments for Perceiving and Using Affordances). The goal is to build robots which react flexibly to changing circumstances by exploration.

Mirror is an EU funded project inspired by the so-called mirror neurons in primates which are characterized by the fact that they not only fire when the animal grasps actively but also when they watch another one grasping (ie. they mirror the other animals behavior to their own). Similarly the project develops a system called Cyber Glove using this idea which collects visual and movement data enabling a humanoid robot with arm and finger to behave in a complex way. The project has demonstrated the importance of representation and understanding for learning behavior.²

The RobotCup Project (<http://www.robotcup.org>) technically coordinated by David Vernon more generally aims at the development of a humanoid robot with cognitive abilities acquired by exploration, manipulation and imitation of its environment. The project will also produce an opensource platform for robots developed out of Yarp (yet another robot platform).

ORCHESTRA (Open Architecture and Spatial Data Infrastructure for Risk Management) is building a generic software infrastructure for coping with risk and disasters (<http://www.eu-orchestra.org>).

Swarm-bots is a FET project coordinated by Marco Dorigo from the Free University in Brussels and inventor of the concept of swarm intelligence. It features robots which intelligently cooperate in a way as known from insects such as ants and has recently been

² Mirror neurons were first discovered by Vittorio Gallese and Giacomo Rizzolatti at the University of Parma. Only recently they together with Marco Iacoboni discovered a further function of mirror neurons (Iacoboni et al. 2004). What is telling for the European situation is the fact that after their great first success they are now working at the University of California at Los Angeles and no more in Europe.

selected by FET as one of its success stories (see <http://www.cordis.lu/ist/fet/press.htm#success>).

Projects like the last five, a category of which many more examples could be given, are desirable because they typically require the participation of experts from various disciplines rarely to be found at a single institution or even in a single member state. So only on the European level is it possible to gather the collective expertise on an international quality level. In some cases even non-European researchers participate such as in RobotCup with Rodney Brooks from MIT as partner. Encouraging scientists to cooperate on challenging subjects of this kind is therefore an important ingredient in the EU funding policy.

Occasionally this results even in the creation of a new area, as it happened with the newly emerging area of Cognitive Computer Vision triggered by FP5. It is converging in nature and extends the scope of traditional Computer Vision beyond object recognition and other familiar vision tasks to include a wide range of cognitive features. It was launched by funding a European Research network (<http://www.ecvision.org>) which included the design of a Research Roadmap (http://www.ecvision.org/research_planning/Research_Roadmap.htm) for this area as well as 9 projects within FP5 and so far 10 projects within FP6, RobotCup just mentioned being one of these.

We already mentioned in the previous section that Europe is ahead in grid technology. It is determined to build on this strength with a number of measures and with funds upwards of 350 M€ (Rifkin 2004, p.47f). The project Enabling Grids for E-science in Europe is envisioned to create the largest international grid infrastructure in the world, operating in seventy institutions across Europe with some twenty thousand PCs (see also Section 4.6). Another project, coordinated by France's National Center for Scientific Research, will connect seven supercomputers in Europe at optical network speeds. We come back to grid technology in Section 4.9.

The EC programme organises two main external activities to look into its ICT futures—FISTERA and ISTAG. FISTERA (Foresight on IST in Europe Research Action) is a series of projects while ISTAG is the IST Programme Advisory Group which has set up a series of working parties to look to the future of these issues. Much is made of ambient computing discussed in more detail in the subsequent section. The IST Future and Emerging Technologies (FET), already mentioned above, supports visionary research projects that help define and concentrate new research areas for future IST. We will outline here the ISTAG activity.

ISTAG is a formal advisory group with members nominated by the EC, complemented by a Social Impact group³, established in 2002 to offer advice to the Commission on the future of ICT in the FP. The activities of ISTAG will be organised around the main themes that will help achieve the above; they can cover:

- the *IST research content*, including notably a revisiting – but not rewriting – and updating of the Ambient Intelligence Vision (ISTAG WG1);
- the *research infrastructures*, human resources and facilities include reflection on how Europe could build or reinforce its centres of excellence that are worldwide references and attract top researchers from all over the world (ISTAG WG2);

³ "...The group will explore scenarios and visions for the socio-economic developments of the Information and Knowledge Society. It will operate as a reflection group providing suggestions on policy and research issues, and exploring the best use of ICTs in business and in private life. The role of the public authorities in these developments, including the regulatory framework, will be a major focus..."

- the *exploitation of the research results* and links between research and technology development and world standards, issues related to usability and acceptability in order to improve research impact (ISTAG WG3);
- *funding mechanisms* and partnerships; this would notably include cooperation between different types of organisations (universities, national labs, large enterprises, SMEs), the coordination of IST and national activities/initiatives with, in particular, models and strategies for the best participation of “new members states” (ISTAG WG4).

The visions of ISTAG in terms of the research perspectives are considered in the material of the subsequent section. For the future R&D and related policy agendas, ISTAG reviewed the work of 2002-3 and recently summarised its views (ISTAG 2003), which it sees in the following key areas.

- *Research for integration – using different technologies to reach the aims*
- *Open standards – allows innovation and flexibility while allowing co-operative working*
- *Interoperability – needed for seamless and diverse implementations and layering*
- *System level focus – mastering complexity by aiming for integration of sub- and systems*
- *Utilisation of available resources – ERA type objectives of focusing research cohesively*
- *Alignment of public procurement – using the 15% GDP as lead users to create markets*
- *Grand challenges – to demonstrate that technology based systems can solve major problems*
- *Experience and Application Centres in labs and real world cases – like schools, hospitals.*

The prerequisite for producing top researchers in IT or elsewhere is an efficient high-quality educational system. Again the national instruments often seem not effective enough to stimulate innovations in the system. Of course the EU by its legal construction is restricted in this direction to a limited number of measures such as awarding funds to excellent educators in the sense of the awarding scheme proposed above. Another such measure is the excellent Erasmus Mundus programme which is defined as follows.

“The Erasmus Mundus programme is a co-operation and mobility programme in the field of higher education (see http://europa.eu.int/comm/education/programmes/mundus/index_en.html). It aims to enhance quality in European higher education and to promote intercultural understanding through co-operation with third countries. The programme is intended to strengthen European co-operation and international links in higher education by supporting high-quality European Masters Courses, by enabling students and visiting scholars from around the world to engage in postgraduate study at European universities, as well as by encouraging the outgoing mobility of European students and scholars towards third countries.”

The programme features a planned financial envelope of 230 million Euro for the period 2004–2008 and complements the Erasmus programme which exists since 1987. For students it is a very popular programme. Some 1.2 million have already been funded for studying abroad within the EU for a limited time. But also professors are seizing these opportunities; in 2003/2004 18500 taught at a partner university. There is probably no better way to exchange knowledge among the member states, foster the integration of Europe and the cooperation with the rest of the world at the educational level.

Space and time restrictions do not allow to present here a detailed analysis of funding programmes in IT within the member states. In terms of money they surpass EU funding by far. For instance, Germany has funded R&D just in microsystems with 540 M€(million €) in the years 1990–2002. In (Rogers 2004) the ICT futures perspectives of the 11 member states (MS) Austria, Belgium, CZ Republic, France, Germany, Hungary, Ireland, Netherlands, Spain, Sweden, and UK are described. An analysis of the key topics in the programmes of

these MS resulted in the observation that there are by far not enough efforts towards a technology push as considered in the Lisbon strategy. The majority of efforts are focussed on “new generation-” and application-type topics and relatively little on new research areas.

4. Forward Look: Long-Term Challenges and Visions

The present section covers the core contributions of the present report. While the previous sections treated the past and present, we are now looking into the technological future by projecting the current state of the art and current trends into the next 10 to 15 years.

The presentation follows a top-down approach which is described in more details in the first subsection. Each subsection does not only outline promising perspectives in a particular subarea of IT but points to particular opportunities for the European Research Area.

4.1 Introduction

Information Technology (IT) is a wide field. A perspective of its future development has to structure the field in a meaningful way according to some abstraction. The abstract view taken here is described in detail in the subsequent subsection. This includes a compact circumscription of what IT stands for. The subsection also sets the pointers to the material contained in the remainder of the section.

The structure adopted in the present section is a top-down one. Top means the phenomenological level of IT systems in some environment, bottom the physical level of such a system. In between we find a number of levels of abstractions which are common in this field.

In IT we experience the trend towards modelling more and more of reality in computational systems. There is literally no part of reality which might not be subject to such modelling, including intelligent human beings as the most challenging goal. This explains why we start with Artificial Intelligence in Subsection 4.3 and Virtual Reality in 4.4 as the most general system behaviour.

Systems are embedded in reality, foremost they are used by humans in their various domains of activity. So already at the phenomenological level we have to take the interaction of systems with humans and with fields of applications into account which therefore are treated in the subsequent subsections 4.5 and 4.6. Besides their interaction with humans, systems are embedded in all of reality including the physical one which is the topic of Subsection 4.7. So altogether sections 4.3–4.7 all deal with the modelling of the real world and its interaction with these artifacts.

Virtually any IT system is made up of software and hardware. The view on such a system is generally structured in terms of layers of abstraction. At the highest level we have the software programmed in some high-level programming language. Programming is therefore the next topic in Subsection 4.8. The architectural layer is one of the important intermediate layers which is discussed separately in Subsection 4.9, while 4.10 takes a look at all those levels at the same time. The lowest level is then the physical one covered in Subsection 4.11.

Each of this nine topics offers a fascinating perspective for future development and the text points to a great variety of technological opportunities. Additional pointers for a large list of technologies can be found in a table in (Compañó et al. 2004, p.68f) along with an indication about the standing of Europe in comparison with its competitors for each of them. All these pointers are given with the idea in mind that the ERA may seize these opportunities towards a

beneficial economic development in Europe. Apart from these detailed hints the section ends in Subsection 4.12 with a list of challenge problems which are suggested for a special consideration in the next European Framework Programme FP7.

4.2 Structuring IT

An area like Information Technology (IT) is so wide that the recognition of trends requires a particularly high level of abstraction to avoid being drowned in a sea of zillions of details. In order the abstraction to be meaningful it needs to be based on the essence characterizing the field. What is the essence characterizing IT and the science behind it which is computer science?

As the name suggests IT deals with information and its processing. So then what is information? Basically, *information* requires two things: a physical pattern and an interpreting process. For instance, hieroglyphs carry information only for those who possess the interpreting process ie. the semantics of the underlying language, DNA can be read only with the biochemical processes realized by nature and by biotechnology, the program stored in the memory of a computer as a binary code can be executed by a computer only by means of a compiler or interpreter, and so forth. In any of these and many other examples there is a physical pattern (the hieroglyphs, the DNA double helix, the bit sequence) and an interpreting process.

As to the physical pattern it can be digital or continuous. The three examples all employ digital patterns. An example of a continuous pattern is any spoken sentence (addressed to some person understanding the same language).

Nature holds a great variety of interpreting processes in store. In addition to our example of the biochemical processes involved in interpreting DNA we may mention another example from physics. Think of a particle a hitting another one b . The impulse of b after the collision is the result of a certain combination of the ones of a and b before the collision. So the impulse of a particle may as well be regarded as a physical pattern which is interpreted by a physical process which in this case we call collision. There are countless of physical phenomena like our example of particle collisions. In other words, information processes are abundant in the physical world; the quantum mechanical phenomena of matter may in fact be viewed as an informational ones. As we enter the post-silicon area of computation we have to keep this fact in mind, and it is for this reason that we started this subsection with these very general comments.

Computers realize information processes but they are particular in the following sense. Namely, they realize *universal* computational (or interpreting) processes which means that *any* computational process can be simulated on a computer. This statement is subject to Church's thesis which for traditional computation has generally been taken for granted (while new forms like quantum computing – see Section 4.11 – might change this attitude). This is what makes computers so flexible and universally useful.

The period of the evolution of computer systems over the past half century has opened a wide gulf between the computational (or artificial or virtual) and the real world. The patterns given as input to a system for interpretation (in the sense of the information concept defined above) mostly is only poorly reflecting the original patterns of reality. In contrast, in nature computation (or information processing) is intimately woven into various other patterns (physical, chemical, biological, etc.). It has therefore been recognized that like in nature computation favorably should more closely be embedded into the real (physical, biological, cognitive and social) world. This is the deeper reason for the recent emergence of topics like

ambient intelligence, ubiquitous computing, and so on; these topics will be discussed in the subsequent five sections.

Coming back to the information processes carried out by computers, a fundamental feature of the underlying methodology is the distinction of various levels of abstraction. The lowest level is characterized exclusively by physical processes; in other words computers at the basic level are physical devices.⁴ The next level up abstracts from the physical details and is characterized by bits. With several further intermediate levels (such as computer architecture, abstract machine, assembler, operating system, efficient programming language) we eventually reach the application level at which the computer in some way substitutes an expert in the field of application. We have not yet reached the level at which experts might communicate with computers the way they communicate among their likes.

Running programs on computers partially consists in an interpreting process which transforms information represented on a given level in terms of the corresponding information on the next lower level. There is still a great potential for improvements at each of these levels. This holds especially for the case where computing devices are embedded in technical and real world systems as described above. This potential is discussed in Section 4.11 for the physical level and in Section 4.10 for the higher ones. The sections 4.8 and 4.9 are pertinent to this context and covering special issues of particular relevance. Their contents are briefly discussed as follows.

Any system may be characterized in two different ways, namely by its requirement specification (or *spec* for short) and by its code. The spec makes the function of the code accessible to users (and systems) in a declarative way. It is more abstract in the sense that different codes may fulfil the same spec (while truly differing specs may never belong to the same code). The spec is therefore the appropriate piece of information for characterizing the system and its embedding in the environment. This fact will be used in the subsequent topics.

In principle a complete spec is all one needs to automatically derive from it a working system. Program synthesis, as the method underlying such a derivation is called, however has proved to be extremely hard in general. Recent trends in object-oriented modelling have given a fresh push to the efforts towards automating programming to a higher degree, centering around UML. Given the billion Euros market for software this issue is worth a special focus which here can be found in Section 4.8.

With an appropriate focus on specs further profitable advances could be achieved. For instance, they would allow to identify common subproblems, hence the sharing of components, in a systematic way. They also would enable a better interoperability of different systems. If the spec would include a modelling of the environment, including the users, the embedding in the widest sense could be enhanced substantially. We address all these issues in Subsection 4.8 as well.

4.3 Artificial Intelligence

The longterm goal of making systems as smart as, or even smarter than, people is pursued in the area of Artificial Intelligence (AI). This goal could also be termed “virtualization of the human mind” although the bodily basis has to be taken into account as well. AI has matured at a remarkable speed after the hype of the eighties of the last century. The nineties have witnessed spectacular successes like the defeat of Chess World Champion Kasparov against the system Deep Blue or the automatic proof of a mathematical conjecture which was open

⁴ One has to note that from the human point of view this physical level is not accessible with our cognitive means other than again through an abstracting description in some technical language.

for sixty years. More important is the fact that AI technology is now integrated in a great many systems like in Windows, in web technology systems (eg. search engines), etc. It has become essential for many applications (like data mining).

AI is vigorously driven by a long-term vision. The field aims at both understanding human intelligence and realizing intelligence in human-made systems. These two goals are intimately connected and cannot fruitfully be pursued in separation. Unfortunately, for certain historical reasons the research communities at some point around the late seventies of the last century have been separated to some extent into those who pursue the study of human intelligence under the label of Cognitive Science (CogSci) and those who build intelligent systems (AI). In order to overcome this unfortunate scism, it has been proposed to reunite the two parts CogSci and AI under the common label of *Intellectics* (Bibel 1992).

Here, in the context of IT, we will focus mostly on the AI part of Intellectics and refer to (Bibel et al. 2004) for the general Intellectics perspective. From an IT point of view AI refers to implanting into IT systems so much intelligence that they are able to cooperate with humans at the same level as do humans among themselves. Since “intelligence” is not a simple method or technology or tool but rather a complex set of behavioral capabilities and strategies AI possibly requires all other technology as its basis. It is for this reason that in our top-down presentation we place it at the beginning.

It has now become a standard to structure this wide area of AI from the viewpoint of an intelligent agent in a complex environment (cf. the leading textbook on AI, Russell and Norvig 2003). In fact the environment may itself be regarded as such an agent or a collection of different agents, so that the agent view allows a uniform treatment of many aspects of the world. Under this view even grid computing discussed in Section 4.9 might be regarded as distributed AI with a great variety of agents, although AI has rarely taken into account the kind of low-level “agents” now considered in grid computing (such as electronic devices possibly at the nano-level). Nevertheless the relationship suggests that AI and grid computing should definitely cooperate.

The core of AI consists in problem solving techniques at various levels of sophistication whereby the term problem solving is used in its broadest sense and includes planning, decision making, designing, and so forth. The simplest level considers the world as a space of (labeled) state points and the problem solving activity consists in a search for a path from the current state to a desired one. Simple as this approach is, its applicability is virtually unlimited because many practical problems may be modelled within this paradigm. The last ten years of research have for instance led to extremely successful general methods for solving hard algorithmic problems by stochastic local search guided by metaheuristics (Glover 1989; Hoos and Stützle 2004). Some of the metaheuristics are copied from nature’s mechanisms such as evolution (evolutionary algorithms or computation, genetic algorithms and programming) (Holland 1975; Rechenberg 1973; Fogel et al. 1966), from natural behavior of biological beings such as ants (Bonabeau et al. 1999; Dorigo and Stützle 2004), or are derived from the neuronal model of the human brain (connectionism) (Rumelhart et al. 1986). These search techniques are not only extremely successful on standard architectures, but may have applications in future computational devices as well which perhaps integrate biological mechanisms.

At the next level of sophistication the labels attached to states become structures. With this structural enrichment problem solving may amount to the classification or the learning of features in certain applications. If we go a step further states are not just labeled points, but characterized by the knowledge available about them. At this level the agent has general knowledge about the world including knowledge concerning the utilities of certain states and

it sets goals which maximize the expected total utility. While problem solving still amounts to searching for a path through different states towards the goal, the transitions from state to state are characterized by knowledge-based rules rather than pairs of points. Since a substantial aspect of knowledge is the presence of deductive relationships among the pieces of available knowledge, deductive, abductive and inductive reasoning is an additional inherent part in a knowledge-based agent. In terms of the previous level one could say that the focus has shifted from the state points to the contents and the structure of the labels which here consist of knowledge structures. One of several further features of this level is a probabilistic measure on top of the knowledge level to cope with the incompleteness of our knowledge about the state of the world. In summary, the state of the art in knowledge-based agents reflects a convergence of previously separated disciplines, namely search, knowledge processing and transitions planning (from AI), deduction, abduction, induction (from logic/AI), probability theory (from mathematics), and decision theory (from economics).

Obviously this short characterization of knowledge-based agents leaves out many interesting aspects in view of applications such as the semantic web (characterized by knowledge features and already mentioned in Section 3 in the context of a particular project), a strategic research objective in FP6 (Compañó et al. 2004, p.54), e-commerce (auctioning, dynamic pricing, contracting etc.), tutoring, administration, etc. But it should have become clear that knowledge systems offer an enormous potential in any area where knowledge plays a leading role which indeed is virtually every area. The promise was already recognized decades ago when thousands of expert systems were built and integrated into standard systems as special components which serve the industry in numerous applications. With the advanced and extended theoretical basis the potential is now even much greater and may play a crucial role in the NBIC– or converging technologies.

For the importance of knowledge the MIT has launched a large project named “Open mind common sense database” aiming at the coordinated collection of hundreds of millions of units of human common sense knowledge (Singh 2002). A similar project, CYC, so far has reached one and a half million of such knowledge units. They are phrased on the basis of more than a hundred thousand concepts which form an ontology (ie. a structured set of concepts and terms) of great generality. Paul Allen, the cofounder of Microsoft, is funding a project called “Halo” aimed at creating the “digital Aristotle” by putting all of world’s scientific knowledge into a system. The half-year phase Halo I has already produced amazing results with a remarkable European contribution.

Once the technology for establishing such large knowledge bases has become standard, it will also be useful for formalizing the metalevel of the natural sciences and of engineering (ie. the expertise of scientists and engineers), for hardening the “soft sciences” like the humanities and social sciences, for improving the mutual understanding between nations with differing cultures, but also for individuals in overcoming the fugitivity of their thoughts by enhancing the human problem solving capability through access to and association of thoughts from quite different times in their lifetime stored in those knowledge bases. The trend towards these goals is already underway as can be seen from the great number of ontologies already operative and in use such as Wordnet, Enterprise Ontology, Gene Ontology, Process Ontology, IEEE Standard Ontology, Cancer Ontology, and so forth (Mizoguchi 2004). It is also recognizable in the growing importance of UML (see Section 4.8) which shares a lot with ontologies although the respective communities continue to ignore each other.

Problem solving as discussed so far is only part of AI. An intelligent agent must be capable of perception. Perceptions come in a variety of modes: acoustic, visual, odorous, tactile, etc. In each of these areas there is a vast potential for improving the current technology at the

nano- and bio-level. The transformation of the percepts in any of these modes into knowledge pieces describing world states is still a fundamental challenge for AI despite the impressive level of performance of state of the art natural language understanding (and translation), speech recognition and vision systems. Unsurprisingly knowledge systems technology plays a fundamental role also here. These man/machine interfacing systems will be indispensable in a future Ambient Intelligence (AmI – see Section 4.5) easing the use of technological tools for the casual user (in stark contrast indeed to the current situation). Europe is particularly strong in natural language technology which also plays a central role in search engines like Google. In order to maintain Europe's cultural lead a cross-lingual "European Google" based on databases and knowledge systems for European languages (including, but not exclusively, English) is highly desirable. Since copying Google technology will not be sufficient to become successful on the market, the project would have to be more challenging by including novel semantic web features.

The third fundamental capability of an intelligent agent apart from problem solving and perception is manipulation. This topic leads us to the area of robots. While it is impressive to watch two-legged, homonoid robots, like Asimo from Honda, Orio from Sony, Johnnie from TUM or Troddler from MIT, moving around and stepping up stairs, or of Spirit and Opportunity operating on the Mars in an amazing way, robotic research has quite a distance yet to go until the challenge of a team of robots beating the then world-master team in soccer will come true (set as a milestone for 2050). Yet the goal has been set and will be achieved in some future with many practically useful side-results such as household robots, intelligent support for aging people, more flexible prosthesis devices, a revolutionized farming technology, to mention just a few out of numerous attractive perspectives.

European research has recently achieved enormous advances in robotics research taking advantage of biological knowledge (cf. also the respective EU projects listed in Section 3). The idea is to substitute the rigid joints in robots like Asimo by elastic joints in analogy with animal joints and put intelligence into the mechanism. This bionic construction principle derived from biocybernetic insights leads to elastic, thus much more elegant and faster movements and to robots who are cheaper by two levels of magnitude. Further details can be found in <http://www.biorob.de/>.

The area of robotics is much wider than these examples might suggest. Combined with the trend towards miniaturization (see Section 4.7) the field of microrobotics is growing rapidly which generally is seen more as a subfield of micromechatronics than of AI. But with the convergence of technologies and the need to make microrobots autonomic AI is bound to play a role in this field as well. Autonomous systems play also a role in the virtual world in the form of so-called softbots which are like robots except for the manipulation capabilities.

A subspecies of AI-robots, so-called reflex agents and first promoted by Rodney Brooks from MIT, wires input percepts directly to manipulation forces, thereby taking advantage as much of the underlying physical laws as possible. For instance think of insect-like creatures stepping down a slope without any energy consumption whatsoever except for exploiting the gravitational forces. New materials and bio-structures might help to realize new solutions in this promising area which is likely to become a paradigm area for the convergence of technologies. There is no doubt that the resulting technology will also be integrated into more intelligent robots.

At the other extreme of reflex agents there is the perspective of realizing consciousness in machines which might even be a prerequisite for true intelligence. It is probably true that a conscious machine will need external sensing, since we believe that sensory input, together with memory and processing, is an essential component of a system that is capable of

consciousness, one of the long term goals of AI. Our brains handle sensory information from the outside world, pre-process it, remember it (or at least remember faded echoes of the processed signals), analyse it, and make decisions based on this analysis. We can even replay memories of sensations, though usually badly faded and blurred. Pre-processing is done in our subconscious, much even by the sensory cells themselves. We aren't aware of the movements of the hairs in our inner ear that actually 'hear' a sound, only the processed sensation from this collective activity; similarly, we aren't aware of the individual molecular detections on our tongue or in our nose, just of the resultant taste or smell. In computers we might be able to realize all these external sensing modes and even further ones not available to people (Bibel et al. 2004, Sect. 3.9). While our experience is based on real time sensation, our inner thoughts and feelings are based on internal sensation. We can sense and feel the occurrences of thoughts. Thoughts often have an actual feeling, sometimes energetic, sometimes sluggish, or pleasant or unpleasant. Of course, they can cause emotional states to change as well as feelings. All these are the kinds of topics which arise in the context of consciousness, a wide area for fundamental research indeed.

There has been much debate in AI concerning the formal approach to be taken. Today the predominant attitude seems to be a spirit of opportunism: whatever method brings some advance is welcome, be it logic-based formalisms, neural nets, game and decision theory, evolutionary methods, swarm intelligence, or what have you. The current feeling is that only a complex mix will achieve high intelligence on a broader basis.

Artificially intelligent agents will also need to feature distributed problem solving and social intelligence, hence also exhibit emotional behavior with which they are able to react appropriately to humans the way these are used to. There are few efforts in the direction of modelling emotions on a deeper level (beyond the Avatars discussed in the next section) despite the great importance for human interaction. More generally, organisational behavior and roles including ethics will similarly be modelled in a rational way, a challenge which requires the collaboration with the social disciplines. First results have been published in AI publication organs (such as AIJ).

Generally, the importance of AI for IT in general lies in the fact that the acceptability of complex technology by ordinary citizens without IT training is directly correlated with the intelligence of the systems; humans simply prefer to collaborate with systems "at equal eye-level" and get angry at stupid machines. But AI is an extremely complex problem which needs much further basic and applicational research for further progress. This research must continue to be interdisciplinary and in cooperation with disciplines like CogSci (hence Intellectics), NeuroScience, Psychology, Physiology, Philosophy, etc.

4.4 Virtual and Augmented Reality

To some extent the universal computer may model any phenomenon in the real world, static or dynamic. The represented information can be presented to the user in various modes, eg. textually, picturally, acoustically, etc. Since the visual channel is of particular importance for humans, graphical data processing (GDP) has become a particularly important subdiscipline. It develops techniques to render information in a visual mode to the user. Visualisation of huge data sets with a size of hundreds of millions of volume elements like those arising in computer tomography or in simulations of the processes in a combustion engine are achieved with volume rendering procedures. The goal is to let the information appear on some medium (eg. a computer screen) as if it were real.

The state of the art in this area is demonstrated in various films such as in "The Day after Tomorrow" by Emmerich which shows movie pictures of a New York as if they were taken in

an ice period. Computer animated figures behave in a way which appears perfectly natural because the animation perfectly respects the physical laws underlying movement of body parts, light reflections, structural material appearance, face expressions reflecting moods and emotions, etc. The more human features were integrated the closer the graphics community had to cooperate with AI researchers, and in fact it was an AI group which started this part of the film industry in the late eighties.

The technology involved has become a sizable industry for movies, TV, and games featuring high growth rates. There are a number of challenges ahead of us. One of them is Interactive 3D-TV, another Free-Viewpoint Video. The perspective is the integration of the real surrounding with the virtual pictures as already realized in prototype systems (eg. at the MIT Media-Lab). It could have applications far beyond entertainment, eg. in education and practicing of playing a musical instrument, say, or in design and retailing (selecting/designing a dress).

This technology is of importance also for “serious” applications where visualization is helpful. For instance, Avatars, ie. software characters impersonating real or imaginary characters, are now used as tourist guides, traffic guides, tutors, etc. Seismic 3D data have been visualized as though one could look through the earth, eg. to support the oil industry. This way human senses can be enhanced and reality be augmented. An example of augmented reality is a headset which allows the driver of a car to see the traffic scene augmented with indications for the driving directions. It is under development by Siemens (Computer Zeitung 6, 7.2.05). Headsets for guiding repairing work may soon appear on the market. Also with headsets molecular structures can be made visible to the human researcher as realized at the University of North-Carolina. Of course there are the already standard possibilities to visualize planned buildings or landscapes, organs in the body eg. for supporting an operation, cultural treasures, etc. The variety of applications is seemingly unlimited.

While visualization is a particularly important part of virtual reality, many other kinds are possible. We talk here of simulation and modelling. Combustion engines have been modelled to learn what’s going on in the combustion cell. Cars have been modelled to learn about their dynamic features. Modelling and simulation have in fact replaced the costly development of physical prototypes. System modelling in IT is used to predict performance risks, capacity planning, code efficiency etc. Simulation is indispensable in weather forecasting, climate research, economics, social behaviour, and so forth. A challenging example is the simulation of a living cell which is pursued in an FP6 project. A whole area has been initiated under the label of Artificial Life in which the mechanisms behind living entities are studied.

While modelling is a truly active and promising area there is still a challenge which has not been attacked so far. Namely, modelling and simulation is still mostly realized in a number crunching fashion without a direct link to knowledge. In fact there are two promising directions how knowledge could favorably play a role in modelling. For one, if there is a model of some scenario, say a building, then, along with commonsense knowledge, the model implicitly carries a lot useful knowledge which could be communicated to the user. For a simple example, if we talk about two adjacent rooms commonsense knowledge tells us that the two rooms share a wall (with the potential of common electrical or other installation, say). But no graphics system at present is able to make such knowledge explicit and useful in the context of planning and problem solving while a knowledge-based model would be in a position to provide this information to the user.

The other direction concerns the direct integration of formalized knowledge into the modelling process. This challenge is related to program synthesis discussed in Section 4.8. Imagine a weather simulation system. If it had the macro view used by human

metereologists about low and high pressure systems, the direction of their moves, and thousands of other knowledge details of this kind, much better simulation results could be achieved with far less computational power. In other examples one could even think of visual modelling exclusively on the basis of knowledge. So marrying current simulation techniques with knowledge systems techniques is one promising area for a future research focus.

4.5 Human-Computer Interaction (HCI)

In a Delphi study by FISTERA (Popper 2004) the option “establishing more user-friendly systems” was chosen as the most important issue for concentration of R&D efforts, followed by “enhancing security of transactions and personal information”. Indeed there is a particularly urgent need to make the IT systems more suitable for the common citizen. As we said at the end of Section 4.3 this ultimately requires the systems to feature a certain level of artificial intelligence.

While computational speed and storage capacity have increased at an incredible rate for decades, the interfaces between humans and machines are still rather archaic. Input typically is given by typing, output via typed text or figures on displays or on paper. The four most important types of displays surrounding us today are the Cathode Ray Tube (CTR), the Liquid Crystal Display (LCD), the Plasma Display Panel (PDP) and the upcoming Polymer Light Emitting Display (PLED). Breakthroughs could come through new interfaces (eg. multi-sensoriality, multi-modality, multi-lingualism, virtual and augmented reality, telepresence, input/output by way of direct brain/machine or brain/brain interfaces) and displays technologies (eg. wearable devices, head-mounted displays, micro-displays, and 3D displays). Further we may expect in a few years haptic interfaces, 3D information visualization, touch pads embedded in a variety of objects and gesture capturing.

These technological perspectives have lead to the vision of Ambient Intelligence (AmI) characterizing the focus of FP6. This vision traces back to 1988 when Mark Weiser, the chief architect of the renowned Xerox Palo Alto Research Center, coined the term “ubiquitous computing” for his vision of a pervasive ICT infrastructure including all everyday objects (see Section 4.7). In Europe this vision is combined with a perspective for improving the social fabric of our societies (Ducatel et al. 2001; Friedewald and Da Costa 2003; ISTAG 2003). It puts the emphasis on user-friendliness, efficient and distributed services support, user-empowerment and support for human interactions. ICT-based artefacts and computers would fade into the background. People would be surrounded by multimodal, intelligent and intuitive interfaces embedded in all kinds of objects. Interaction would be possible with all human senses in an intuitive way. The environment would recognise individuals and their needs and wants, as well as changes in the individuals, needs, wants, or environment. It would respond in a seamless, unobtrusive and often invisible way, nevertheless remaining under the control of humans. Intelligent agents would eventually make decisions that automatically serve a person or notify a person of a need to make a decision or to carry out an action.

Of course there is another way to look at this vision. If an environment anticipates the person’s needs and wants, it at the same time restricts the person’s freedom in a certain way. This shows that there is a fine line between having environments at the service of the humans, and having the humans at the service of environments. AmI has considerable potential to develop into environments that de facto reduce freedom, rather than empower the ‘inhabitants’. Nevertheless, it is the goal of AmI to achieve the latter and avoid the former by appropriately modelling the users. In short, computers should conform to and serve the needs of humans rather than require people to conform to computers by learning specific skills and performing lengthy tasks. Interactions between humans and computers would become relaxing and enjoyable without steep learning curves.

The vision of AmI as being developed within the ISTAG reports is far-reaching and assumes a paradigm shift in computing from machine-centred towards human-centred computing. It argues for placing human beings at the centre of future developments. Technologies will be designed for people rather than making people adapt to technologies.

Arguably, the AmI vision encompasses the convergence between ICT and cognition. Making the technological artefacts easier to use requires a deep understanding of how humans interact with them. This in turn requires the goal of a rather deep understanding of human cognition. This goal lies at the root of the discipline of *Intellectics* (Bibel 1992) with its two branches, the more technology oriented *Artificial Intelligence* (AI) and the more human oriented *Cognitive Science* (CogSci), as already pointed out in Section 4.3. In other words, AI and CogSci may well be seen as the central prerequisite of AmI. Basic research in these areas on topics like knowledge systems, deduction, uncertainty reasoning, argumentation and many others is therefore of greatest importance. For instance, the HCI will remain rudimentary unless computers are empowered by a certain degree of reasoning capabilities and natural language communication.

In addition the information retrieval techniques need to improve in order to be able to cope with the mass of generated data. In fact retrieving data does no more suffice as there are many more data than useful information in them. Further, as there is too much useful information around us already today, its reduction to appropriate knowledge pieces is a prerequisite for being useful for humans. So also here we are coming back to the semantic net paradigm mentioned already in Section 4.3.

Even a partial realization of the AmI vision will aggravate the security and privacy problems already today plaguing the industry. Therefore along with these perspectives goes the need to provide for a global dependability and security framework, for guaranteeing privacy and data protection as well as freedom from intrusion (viruses, spam, advertising, etc.). As the methods of software production improve (see Section 4.8) it will be easier to react promptly and reliably to security problems. So this part is actually a technical problem which is complex but not unsolvable. The privacy issue amounts to a tradeoff deal: it depends how much we gain from giving away some of our privacy. Once and if the details of this deal are known to the public and choices among different options are available everyone can make his or her own choice. Finally, it is obvious that the development of all the HCI tools necessarily involves in-depth socio-economic research to precise the needs, the concepts, and the feasibilities as well as their problems/risks (in social, economic, legal, and technological terms).

4.6 Fields of Applications for IT

Information Technology is a cross-sectoral discipline par excellence. Its applications virtually cover any sector and any discipline. Evidence for this can for instance be seen if one studies the wide range of successful EU-funded projects listed in (European Commission 2004). They are taken from agriculture, energy, environment, medicine and health, life sciences, industrial research, transport, science and society. Many of them crucially depend on IT whether they deal with plant health diagnostics (involving a microchip), efficient combustion (using a simulated model), water quality of the Danube (using modelling), stroke patients recovering (involving robotics), designer desktop for train drivers (with substantial IT components), to mention just a few examples.

IT tools have become so common in science and technology that it often is no more even noticed how substantial the IT part is in these developments. This share will even further increase in the future. The late Woody Bledsoe, one of the founding fathers of AI, envisioned

that eventually there will only be one science left, a convergence which is driven by the computational paradigm behind IT (Bibel et al. 2004, Section 4.1).

Because of this omnipresence of IT it is impossible within the present report to cover all applications in any reasonable way. Every discipline or sector is afflicted in a substantial way including sciences, engineering, development, manufacturing, work organisation, business, management, government, retailing and commerce, services, transportation, logistics, finances, law, health, household, education and learning, entertainment (infotainment), elderly, regional development and planning, environment, and so forth. Note that this affliction is not restricted to the use of computational tools but often involves a redefinition of the area. Major developments following this trend have been the revolution in the communication technology in the eighties and the transformation of the biological sciences (eg. bioinformatics) in the nineties of the last century. The present subsection is meant to touch upon a few such areas and to demonstrate the future potential of this kind of redefinition.

In *science and technology* this trend has been identified in terms of what is called converging sciences and technologies (Nordmann 2004). It is expected that this convergence is affecting the cognitive sciences and technologies on the one side and the physical sciences and technologies on the other, as it did affect – and is still affecting – the biological and life sciences (“Bioinformatics”, “Neuroinformatics”, etc.) including Cytomics (ie. the area covering the biologically oriented aspects of the life sciences). The term e-science, referring to the vision of a universal use of grid computing (see Section 4.9), points into the same direction (see eg. <http://www.eu-egee.org/>). Even Mathematics is in a revolutionary transition phase after famous – let alone many less spectacular – mathematical problems have been solved with the computer for the first time like the four-colour problem (posed by the Guthrie brothers 1852, solved by Kenneth Appel and Wolfgang Haken 1976 and by Georges Gonthier 2005), Kepler’s conjecture (solved by Thomas Hales 1998), Robbins’ problem (solved by William McCune 1996), and so forth.

Also *engineering* will continue its trend towards “computational engineering”. Thereby knowledge systems capturing engineering knowledge as well as computational problem-solving techniques will play an increasing role. Engineering thereby does not only comprise the technical domain but also the service sector which is underdeveloped in this respect in Europe.

Design and development of products could nomore be imagined without computational tools. Recall from Section 2 that 90% of all innovations in the automobil industry are driven by ICT. CAD systems support the individual designers and developers. But these have to collaborate. For instance, in the automotive industry it is common that a hundred different developers create ten thousand files which need to be combined in a consistent way. Today this challenge is met with additional configuration management tools.

Materials science is in a revolutionary transition. While materials have been selected for production on the basis of the properties exhibited in passive structures, now the trend goes towards active structures which change these properties in reaction to sensor data. Such structures are developed in the area of mechatronics. The crucial ingredience is some kind of computational tool within them, however it is realized. Such materials will become standard in many sectors, eg. in the car industry.

Manufacturing and production relies increasingly on computer-controlled tools, and as they become more sophisticated, so will we see more personalisation and greater customer involvement. Since the Internet allows this interaction from anywhere, customer location is not an issue. Designers may be in a very different location from the fabrication unit that builds

their prototypes. These perspectives are captured by what is called the *MANUFUTURE* paradigm and they hold the promise of attaining sustainable production in the near future (IPTS 2003). This future in production will be determined by intelligent agent systems which organise themselves in an adaptive way according to the varying conditions and take decisions in a decentralized way. This way stability, scalability and flexibility for the production system as a whole will be achieved.

A wide field of application is the modelling in a system of the *business* processes which occur in an enterprise. It provides the infrastructure for storing the data needed for the various functions, supporting all kinds of activities and controlling all processes in companies. The challenge is to build a platform which achieves all this in a coherent, uniform and tailored way integrating the applications needed. A particularly important and unsettled task thereby is the integration of knowledge systems (see Section 4.3) rather than just the complex knowledge management systems which by themselves are rarely useful in practice. The architecture of such a platform traditionally involves top-down the data warehouse, middleware, client/server subsystems, connectivity, operating system, and hardware. A recent trend favors the introduction of service-oriented system architectures for the business process management which features a richer top-down structure: the real-time enterprise at the top level, cooperate performance management, business processes, a software-based service-oriented architecture, applications (like the enterprise resource planning, the management of supply chains, of relationships with customers and suppliers, of the product life-cycle), an infrastructure for all these applications, the integration of all enterprise applications, and so-called application programmer interfaces, or APIs (like XML, webservices, J2EE) at the bottom level. In order to support the collaboration of enterprises interoperability is another important requirement for such systems which is becoming ever more important as the market structure is shifting towards a network commerce in a globalized economy based on IT.

E-government is the term describing the IT support for regulatory agencies. To some extent the requirements are similar to those for modelling business processes. The Commission is pushing this area (EC 2003). We understand this term in a broader sense covering all ICT support for the entire public sector including its executive, legislative and legal domains. An example is the *law* sector which is only beginning to integrate IT in its processes in some parts of Europe (<http://www.e-justice.de>) while many judges, for instance in Spain, have not even yet any access to a PC. But like in engineering we are now also experiencing already knowledge systems in law which support both the law expert as well as the citizen in analyzing the rights in a certain situation which involves legal knowledge and reasoning about it (Bibel 2005). The potential behind this technology which goes far beyond what is meant by e-government may lead to a true revolution in the legal domain and may result in better and more consistent laws and generally in more justice. It may also become the main driver in the harmonization of law in a Europe with 25 plus 1 different law systems. So IT will transform the infrastructure (ie. e-government) and reform the subject itself. These two different aspects hold true for all sectors in the public domain. Another example is the *strategic funding* of research and development which should take the role of a pioneer in this trend eg. by involving knowledge bases in foresighting as well as in capturing the expertise available in Europe (cf. Bibel et al. 2004, GenRec3, Sect.5.1). These kinds of transformations in the public domain will deeply affect our future societies with many positive perspectives, not least including politics (Bibel 2003).

The *military* sector is increasingly relying on ICT. The US demonstrated the power which can be enforced through ICT in any of their worldwide operations, not least in the Iraqi war.

While Europe's *service* sector is expanding for decades, it lags behind in terms of innovation, with a few notable exceptions. For instance, Europe is strong in *retailing* (eg. Carrefour and Metro) in international comparison. IT will continue to dramatically change the way we are shopping. Futurestore of Metro is a first step. "Smart shopping assistants" will provide the customer with all kinds of useful shopping information in a personalized manner such as price comparisons, quality evaluations, health suggestions, and so forth (Wahlster 2004, Grand Challenge #11). Shopping through the web (cf. the commercial success of Ebay), automated auctions, improved methods of customer research, eg. by agent-based modelling techniques (Terano 2005), and further computational methods will influence the market in a substantial way. Similar techniques will lead to a more transparent and optimized *financial* system. We also see a great future in a flexible public *transportation* system (see Sect. 4.12). In general *logistics* has still great potential for optimization through IT (see Sect. 4.7). The *life sciences* or *health* sector is already so penetrated by ICT that e-health has already become a standard term. Related to e-health are the opportunities which technology, especially ICT, is offering for active ageing which is of particular importance for Europe's ageing societies in the appliances, health and other sectors.

Finally, IT is providing more and more the roles of intelligent, personalized and supportive *assistants* for individuals and households. One of the big themes for innovations is the "smart home" which for instance would feature an intelligent networking of all devices, appliances and systems. E-learning is becoming a major economic sector. Especially for the growing number of elder people supporting technology is becoming an important economic and social factor. Robotics, knowledge-based advice systems, monitoring systems for health and security, IT-enhanced prosthetics, communication systems, and other technology will allow elderly people to lead a satisfying life even at a high age. Also leisure and *entertainment* as well as the *media* are a growing subsector of IT.

IT is without any value unless it is applied to the various sectors in society. For this reason any report on IT without pointing out the relevance of applications is not worth being written. With this subsection we wanted to point out the unlimited potential of IT for enhancing Europe's economic standing. Any region is doing well which improves its infrastructure in the widest sense, ie. infrastructure in all sectors such as those mentioned in this subsection but also many others. The key technology for infrastructural optimization is IT. So it remains technology No. 1 also for the years to come.

4.7 Coupling the Real and the Virtual

The topics treated so far in the present section all focused on the virtual world being built by IT, surrounded by the real world. People mostly remained the only link between the two. There is a vigorous trend towards a physical space with cyberspace convergence, ie. to link the real and the virtual more directly due to novel sensor, monitoring and control technology.

Radio frequency identification (RFID) *tags* play the most important role in the new buzz about tag based customisation. An RFID system consists of three components: a number of mobile transponders attached to the goods to be identified, one or more stationary readers to identify the transponders, and the back-end IT system that processes the transaction data of the transponder. Transponders range from 1 bit to 256 kbytes. They are active (with an accompanying power supply) or passive (inductive). Flexible substrates like organic polymers allow more compact and thus smaller packagings than today's circuits in silicon. In principle, polymer circuits are slower and larger than silicon circuits. However, they can be manufactured in simple print processes at small cost. There is still a number of open questions concerning the life span and switching speeds of polymer transistors.

RFID technology is expected to excel in logistics applications, but is still waiting for its breakthrough. They are already used to trace pallets on their way from the factory to the customer. But their use has a far greater potential. For instance, in retailing the technology allows the early detection of sold-off shelves, the automatic price tagging by digital price displays and faster cashing procedures by automatic scans of the goods in the trolley. In manufacturing RFID would allow a workpiece-centered, decentralized control of material flow, the automatic management of complex stores with mixed pallets and without fixed storage locations and the authentication of spare parts, eg. in the aircraft industry. More generally, “smart labels” should close the gap between the physical flow of goods and the information flow in the IT systems. In a foresight study the take-off for the mass market of RFID tags at the level of individual objects is expected to take place around 2015.

By that time they will cost only a few cents each and store the identity of any object. This allows the object to be linked to any electronic functionality on the network. Customers could look at an object and, instead of asking a poorly trained assistant for information, could find out all about it on the network. Their personal profile – the customers could be identified by a tag in their loyalty card – could be consulted to make sure the information is tailored to their needs. Advances such as these will obviously have an impact on marketing precision when it comes to adapting to different customers. But by adding cyberspace functionality to any object, they can also open whole new markets. It is suddenly as if the object has two existences, one in the real world and one in the computer.

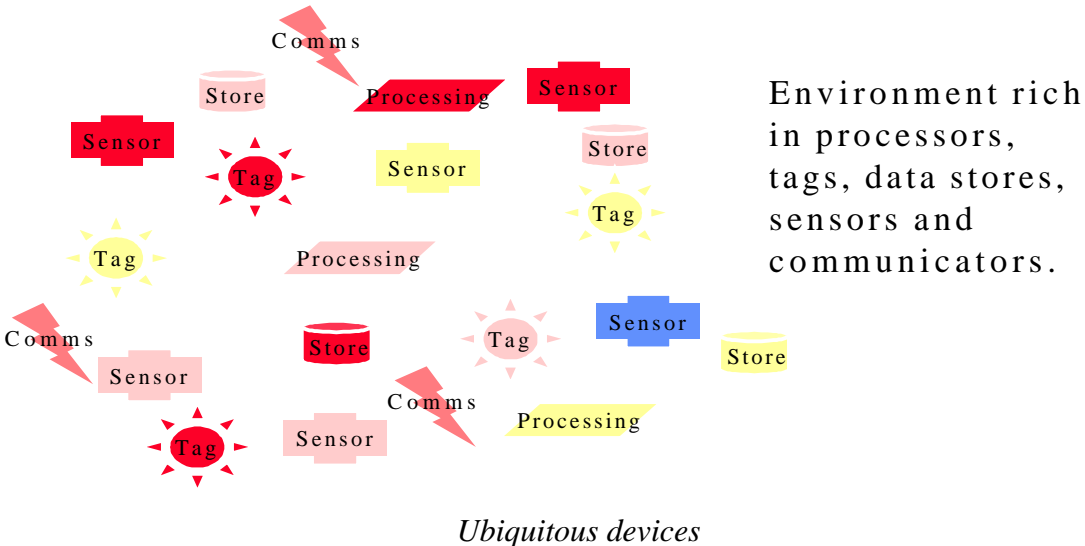
Imagine eating a Bassetts’ Jelly Baby. Now imagine eating a future jelly baby, if Bassetts have decided to enhance them with silicone edible-electronic tags. Because of its sophisticated cyberspace part, the jelly baby can now scream (through your PC speakers or Bluetooth headphones), and can fight back. It could link to its friends on a peer to peer network, and organise a denial of service attack on your home PC, or launch a virus and trash your hard drive. Jelly baby eating would be elevated to an extreme sport, with the perceived danger and thrill of big game hunting. Now imagine what price Bassetts could sell them for. Marketeers will be able to enhance many everyday commodity products by adding some imaginative cyberspace linkages to them.

Marketeers will be able to take this a stage further. They have linked the product into cyberspace and enhanced its value. Now they can grow the cyberspace part, make more of it, spread into adjacent areas, and increase the product breadth. The cyberspace part may often become more valuable than the initial product, and can then be spun off as a standalone product or service. This could even be a launch strategy for a cyberspace product, such as a web site. Make an attractive physical product that links to the cyberspace product, with the physical item acting simply as a lure. Then we have gone full circle, since this is like using a ball-point pen with a web-site URL on the side. This begs the question, whether it is better to make pens and sell the marketing potential, or to start with the other product and then find a suitable ‘pen’. Either way could be successful.

However, it is by imaginatively using the combination of physical and cyberspace that the best products can be made, not just by using one of them as a link to the other. A child’s doll has more play value if it links to the computer and the net. It allows the child to access more intelligence than can be included economically in the doll itself, and allows activities such as networking with other doll owners. Manufacturers may be able to sell virtual doll’s houses on-line, and allow the child to customise them, rather like on ‘The Sims’. We would expect to see physical doll accessories for ‘The Sims’ next Christmas to complete the circle again. Dolls may have social lives with other dolls on the same street, with little girls partly watching these living soaps, and partly orchestrating them.

This all sounds like child’s play, but we are seeing a huge increase in the amount of play time for adults too. Millions of adults play on-line games such as Everquest, some of them in their forties or older. Some of these games are spilling over into real life, with conventions and accessories, even down to marketing game status and skills on e-Bay. Some people already use these games to meet their friends. Attractive virtual locations can be developed and hired for meetings, training, communication, shopping, and so on. Virtual environments are where the domains of mental space and cyberspace converge. Physical and mental convergence has been with us for millennia, from toys to filing cabinets. The convergence of physical space with cyberspace will be mainly demonstrated through on-line toys and tag-based services. All three of these domains will interact strongly, and the result will be more products and services, bigger marketplaces, and most importantly a place where the border between the product and clever marketing disappear.

The basis for all this will be an environment rich in devices of the kind already discussed in Section 4.5. It was foreseen by Mark Weiser who predicted: “In the 21st century the technology revolution will move into the everyday, the small and the invisible ... The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.” Such an environment is illustrated in the following picture (with the pictorial symbols explained therein – “Comms” being short for communicators).



As with RFIDs, all kinds of chips and other IT components are getting smaller, more integrated and embedded in technological devices as well as in natural reality. The areas of microelectronics and photonics are driving the field. Of particular actuality are micro-electromechanical (MEMS) or even micro-optoelectromechanical systems (MOEMS). Microfluidics is another new technology which involves the design and production of (MEMS or other) devices that deal with extremely small volumes of fluids. “Lab-on-a-chip” is a vision connected with such devices. In general we are talking here about (integrated) *microsystems* (Botthof et al. 2003). If these kinds of systems additionally integrate some software they are termed *embedded systems*. The further development of microsystems is tabbed by DARPA as “the next revolution” (Lemnios 2004). The market figures support this view. The world-market in complete microsystems grew from 14 B\$ (billion US\$) in 1996 to 50 B\$ in 2002. It is expected to reach 68 B\$ in 2005 and estimates for 2010 amount to more than 200 B\$ (BMBF 2004).

By the end of this decade, it will be possible to build simple identifier, memory and processing chips, sensors, and short range communication devices, all smaller than human skin cells, which are about 10 microns. We could print or blast these chips in significant numbers into the upper layers of the skin and, by using self-organisation technology, arrange them into useful circuits and consumer electronic gadgets. Semiconductor circuits can already be printed today using inkjet printers, so we could imagine some of the circuits being painlessly printed onto our hands in a corner shop. The idea is to use a layered architecture, with a few components deep in the skin that would stay there permanently, in contact with blood capillaries and nerve endings. They could communicate by infrared with others higher in the skin, that would wash or wear away after a few days. Other chips could be factory assembled in thin polymer membranes that adhere to the skin like children's temporary tattoos, and large scale circuitry could be embedded in stick-on patches rather like Elastoplasts. The combination of layers allows entire gadgets to be built, and establishes links between our bodies and the electronic domain, including the whole of the Internet. Let's have a look at what we could build.

Medical sensors could be implanted that could monitor our blood chemistry 24 hours a day and 7 days a week and keep in touch with hospital computers via our phones. These computers could remotely control drug dispensers and thus keep our condition under constant check. We could even print special membranes with pores that can be electronically opened and closed to enable accurate dosage and thus improve drug efficiency.

Cellphones, MP3 players, electronic diaries and other consumer electronics could be printed into our wrists, with full keyboards. These could remain almost invisible until we touch them, when they could light up. The circuitry itself would be made of dispersed groups of invisibly small devices, so we may show no more than a very slight colour change in that area of skin before the device is switched on.

The displays for these devices could be based on small organic LEDs. We could have a simple single indicator light, an active tattoo or an entire computer display. Having a TV printed onto the back of our hands might be quite appealing. It will certainly make some very interesting body adornment possibilities. We could even see some real teletubbies!

It would be possible to link active skin technology to cosmetics and perfumery to good effect too, as well as to the pervasive ICT environment that we expect to live in by the next ten to fifteen years. Some of the earliest examples of successful nanotechnology are in cosmetics. Colours can be made by using diffraction as well as dyes, so simply changing the surface texture of a material can be enough to change its colour dramatically (that's how butterfly wings are coloured). So if we could tell the makeup what colour to make with its nano-sized particles, the components could be rearranged to achieve it. The idea of a digital bathroom mirror was invented to enable this. Imagine a lady putting on her makeup in the morning, which can be very time consuming. The digital mirror would show her a set of alternative designs recommended for her makeup. She puts the smart makeup all over her face without much care and then selects the image she wants on the mirror. The makeup can then configure itself to achieve that image, using the (invisible) active skin underlay. All through the day, the active makeup could change its appearance according to the regime she has selected, business-like in the office, seductive at her lunchtime liaison with her fiancée. The same would work for her video nail varnish and her perfume. Active skin includes the capability to print a thin warming element that can vaporise different components of the active perfume on request.

Another electronic idea for the female market is to make use of the new field of silicone-based electronics. The volume inside a typical breast implant is huge by electronic standards,

so we could do almost anything in an enhanced implant, from mammary memory to a full blown computer.

It will also become possible to link to nerves in due course, maybe as early as 2015, to record and replay sensations. We may meet someone in a virtual environment, and be able to feel a handshake, since we have already recorded what a real handshake feels like. We could simply replay the same nerve signals as those generated by the real thing, into the same nerves. We would need to print active skin over our hands and fingers to get convincing immersive environments, but not necessarily over our whole bodies. Some people might opt for additional patches, so that they could have sex via networks, or patches for sports, giving computer aided feedback to assist training. We could certainly have greatly enhanced computer interfaces for computer games. We would expect that the quality and range of inputs would improve until we have the early 21st century equivalent of the Star Trek holodeck, which wasn't supposed to arrive until the 25th century. The links would probably make use of carbon nanotubes (see Subsection 4.11), which are thin enough to be painlessly implantable. Eventually, we may be able to tap into the spinal cord or brain instead of individual nerve endings, but this would be much more difficult, hence will happen much later.

As we see the linkage between the virtual and the real carries a great potential. But of course there are many risks and dangers involved as well. Preventing the loss of data, guaranteeing the safety of data, recycling chips, avoiding health hazards are just a few of the challenges involved in framing such a future.

4.8 Automation of Programming

Configuring systems, locating and overcoming defaults, use of help-facilities, and all that still remains the domain of well-trained specialists and is normally driving the casual user to despair. The reason is that any of those tasks requires the interaction with complex software (SW) at a level of understanding not available to common users. The user instead would like to simply state the requests in natural language and expect the system to solve the problem on its own. Such a system would have to be capable to transform the informal request into a formal specification and on its basis automatically program itself, a process also known as *program synthesis*, which treats programming quite appropriately in the form of knowledge operations.

Although IT was very successful in producing large and complex software products, the discipline of software engineering is still in a state of crisis. Between one and seven bugs per 1000 lines of code may be found in an average system according to a US study. The Standish Group reports that the percentage of successful software projects has decreased from 34% in 2002 to 28% in 2004. The rest of the surveyed projects failed to provide the expected functions, to fulfill the requirements, or were just given up for various reasons. A spectacular example of such a failure was demonstrated to the public through the scandal in 2004 with the failed introduction of a toll system for trucks on German autobahns which was delayed by one and a half years causing losses of several billions of Euros. Similar delivery delays are the norm in all sectors and in small as well as large enterprises using complex software systems. So we may ask the following critical questions.

- Why is it that even the best teams produce fewer than **10** lines of code/day?
- Why are **6** errors found per every thousand lines of code?
- Why is **one of every three** large projects scrapped before ever being completed?

- Why is only **1 in 8** finished software projects considered “successful”?
- Why are we still experiencing gigantic losses due to erroneous SW code like the destruction of the Ariane-5 prototype and the Climate Orbiter which missed the Mars?

Another aspect of this bottleneck can be observed in the monsters of current operating systems (OS). The inflexibility of OS production is blocking the functioning of the market forces in IT, this way causing the unfortunate and continuing dominance of a single company. Only the open-source movement around Linux has now become the largest threat the software giant Microsoft has ever faced.

The bottleneck is particularly visible in programming multiprocessor systems. The programming languages developed for coping with the inherent parallelism are so complex that rarely are these systems performing the way they could in theory. More automation in the programming task, ie. more program synthesis, would again be the remedy for the problem.

In order to improve the deplorable situation in the SW production the industry has now started to take the problem more serious and transform itself into a SW industry in the sense of the word. Recently the concept of software delivery optimization has been proposed which regards the SW development as a regular business process to be carried out like other industrial production processes resulting in software as a commodity. Part of this process is the descriptive specification of the functions to be realized in some formal language and the translation of this specification into programming code, partially by some development system and partially by hand. UML (universal modelling language) or DSL (domain specific modelling languages) are the formalisms from which the software can then be derived in a way which achieves an automation rate of upto 80% by today's standard. Currently there is an ongoing debate whether UML might perhaps be too general so that DSLs would appear to be more appropriate. It is a useless discussion because it has found an answer in the area of computational logic long before: the general logical structures hidden in UML cannot be avoided altogether in any approach to synthesis, but semantical information as present in DSLs can be of great help too.

At any rate program synthesis is back in the headlines even though under new names like model-based programming or model-driven application or software development. Today any integrated development environment (IDE) for SW production already supports UML in the sense just described. Unfortunately there are rarely interactions between the big SW industries producing IDEs and the logic-based program synthesis community. Extremely successful systems have been developed by the latter the best of which is KIDS from the Kestrel Institute in Palo Alto, California. DARPA rated KIDS as one of the best successes under its funding policy. Nothing of the kind of KIDS' technology is used in today's IDEs although no successful synthesis technique can circumvent the logical level. So there is still a great potential for future improvements. Thereby the goal must be an interactive synthesis from informal task descriptions.

This research direction has a particular relevance for Europe's economy. This is because labor force is extremely costly in Europe for which reason much of Europe's software production is outsourced to India, Mexico, Russia etc. This works well for software as a commodity. But the margins of this type of products are shrinking dramatically (Carr 2004). It is the customized product which economically matters more than ever. Program synthesis has the potential of dramatically decreasing the manpower needed for SW production of any kind. So funding research in program synthesis might eventually lead to a major push for the European SW industry in particular and IT in general. Governmental actions like the US software initiative launched during the Clinton administration aimed at a similar direction.

The software industry is still growing and penetrating many sectors because the functionality of many products or services is determined by SW in a rising degree. For instance, the share of software in a car today lies at around 5% while in 2020 it will reach a level of 13%. In a cell-phone the share was 40% in 1999 while today it is already 70%. Producers today try to reduce the costs for software development and the failure rates with two different strategies. One consists in the standardization of development processes so that SW moduls can be used multiply. The other aims at exploiting synergies in different production areas so that software can be shared in similar products. A successful example of the second strategy is “syngo”, a uniform human interface for numerous, in fact 52 products from Siemens in the medical sector which is installed 22,000 times worldwide. With syngo development costs could be reduced by more than a hundred million Euros. The resulting uniformity of the interface adds to the commercial success of this strategy.

Both strategies could again be supported by program synthesis techniques since standardization and similarity could systematically and automatically be detected in formal specifications. The example demonstrates the economic potential behind such an approach. It is therefore worthwhile to invest more in formalizing the spec of systems also from this point of view. If the spec comprises the modelling of the users including the knowledge about cognitive constraints and user preferences then solutions may be developed which simplify the use of the resulting devices considerably, for instance, by modelling the interface of different devices in a rather analogous way. In industry this is called a common interface platform for its products and involves a standardization of the underlying architecture. Apart from modelling the user within the spec the embedding of computational systems into reality requires the spec also to cover the surrounding technology of the kind discussed in the previous section.

It is a fact of life that systems are developed independently of, and sometimes in competition with, each other. Nevertheless in reality they need to cooperate with each other. A further issue is therefore to realize the interoperability of differing systems by so-called web-services and other means which again would be alleviated substantially by investing more on the spec-part of systems.

Apart from these methods for the development of large systems novel computing paradigms are promising for particular niches of applications. One such paradigm is biomimetic or organic computing aiming at the construction of self-organizing systems following principles known from biology in order to overcome the growing system complexity. Experiments have demonstrated that for instance the control of traffic lights can be optimized this way to avoid traffic jams. Similarly, *autonomic computing* aims at the capability of systems to solve incurring problems locally and without human interaction. A whole set of methods lies behind the term metaheuristics (Hoos and Stützle 2004) already mentioned in Section 4.3. It allows to solve complex problems with rather simple and easily programmable algorithms using stochastic local search. Possibly with methods of the kinds just listed *self-adaptive software systems* for numerous applications are now in the focus of interest.

In summary, the task of software production is so complex and the software economy so prominent that every effort is worthwhile to improve Europe’s standing in this domain.

4.9 System Architectures

In our descent from the highest level of intelligent systems or agents we have now reached the architectural system level. Although architectures play a role at all, even the highest, levels and have been mentioned in previous sections (eg. 4.7), they are usually regarded as the

hardware/software interface (Hennessy and Patterson 1998) and in that sense are grounded in the physical level which explains the placement of the current section.

Any modern computer has five classical components: the processor with its two parts control and datapath, the memory, the input and output. Although ultimately a computer is a physical device, its inner logic cannot be understood without the architectural level of abstraction. At this level we are focusing on computer functions in terms of small steps, called instructions (eg. addition of the contents of two memory locations). The selection of a set of instructions determines the structure of the computer, hence the term *instruction set architecture*, or simply *architecture*.

The area of computer architecture is a fascinating success story which unfortunately took place primarily in the US. Moore's well-known law (see Section 4.11) to a substantial extent is due to this success. At this level the synthesis of hardware from specifications has already become real, an achievement still not reached to a comparable degree at the software level as discussed in the previous section. Although the hardware market is dominated by non-European companies there are chances for Europe at the architectural level in niches for specialized architectures.

In the seventies and eighties the idea of customized hardware (eg. for applications like inferencing) was intensively pursued. In the eighties, the progress of hardware performance turned out to be so fast that the advantages of application architectures were soon devaluated by the increase of the speed of the universal processors. The same is still true today. However, it remains a fact that the intrinsic computational efficiency obtained by an architecture that fully matches the application is by three orders of magnitude faster than by a general-purpose and programmable architecture (Aarts and Marzano 2003). In this enormous gap lies a great potential for improving system performance. With automatic synthesis available, applicable to hardware exactly as to software production, customized chips could be designed much more economically. The automation of synthesis will become even more crucial if the "hardware" will consist of structures at the nano-scale and the distinction between hardware and software might become even more blurred. However, the escalating costs of starting the production of a new integrated circuit with current technology will restrict this flexibility among a range of configurable chips.

Architecture extends beyond the configuration of single processor computers. First of all high-performance computing is taking advantage of multi-processor systems. Despite particular efforts on the European level in the eighties of the last century, Europe was not able to catch up with the US in this specialized domain either, probably because its technology is too closely relying on the expertise in the single processor technology. As we are now entering the AmI scenarios with many processors of different kinds distributed in the environment (recall the figure with ubiquitous devices in Subsection 4.7), new challenges are arising which may well be seen as chances for Europe to enter the new market opportunities. This shows that communication connectivity is actually part of an architecture for this new world of computational reality. Therefore, although communication is explicitly not a topic of this report, we have to touch upon this wide field which anyway is grounded on IT's technology.

Although networks were already established as far back as the sixties of the last century, the explosion of the amount of distributed computing occurred only in the nineties after the commercialization of the world-wide web (www) based on the Internet. The Internet triggered the convergence of IT with communication and media technology to ICT. It also opened the views of computation as an ubiquitous phenomenon pervading all aspects of our lives and all parts of tools, material and organic bodies, artificial and natural ones, hence termed pervasive

computing. The current extension of these views to physical matter and biological processes – the world as a computer – may be seen as a logical continuation of this vein of technological thinking. In other words the architectures will become even more complex and encompassing.

The Internet architecture is based on a level model with the levels (from bottom up) network interface, Internet protocol (eg. IP, ARP, ICMP, IGMP), host-to-host-transport (eg. TCP), and application (eg. HTTP, FTP, SMTP). As we see each level higher than the interface level is characterized by certain protocols (ie. specialized software). As we all may experience daily, this architecture again is a fantastic success-story which will continue well into the future with a great variety of opportunities.

One novel trend is the cooperation of differing and incompatible functional modules (possibly realized in different languages such as Java, ie. J2EE, or Dotnet) through so-called web-services on top of the Internet protocol. As one can imagine these web-services may become extremely complex which again is building up pressure to improve program synthesis capabilities as noted in the previous section.

This trend has culminated in the idea to extend the Internet architecture toward an architecture which allows *grid computing* (Berman et al. 2003; Foster et al. 2004). The basic idea of grid computing is to build an Internet-like grid which allows to establish virtual organizations which share resources of all kinds (data, computation power, applicational functions). Imagine a smaller company which needs certain functional moduls for its business processes but cannot afford to buy and maintain an expensive platform of the kind discussed in Subsection 4.6. With grid computing it could temporarily establish a virtual organization with some supplier of these services this way satisfying its needs as if it had the platform at its own disposal, except that of course it has to pay for the service. Obviously this sharing of resources has attractions not only for businesses, but for any other organization like research institutions, governments etc. (see eg. <http://www.eu-datagrid.org/>).

Along with the trend towards pervasive computing information and communication technologies are steadily shifting from text-centric to broad, sensory-based systems (including vision and sound but also tactile and feedback forces) that engage participants in multiple ways.

Despite the prominence of distributed computing and networking this area again suffers from enormous and far from solved problems which will be further aggravated as the number of computing elements, their variety and the amount of exchanged information increases. Apart from the extensively studied problems of security, quality of service, and reliability the users are suffering from information pollution by being swamped with junk- or spam-mail which is floating around in a quantity of billions so that the amount of automatically generated email has already surpassed that of the remaining one. Despite the impressive performance of search engines, upon search for specific knowledge users are bothered with floods of irrelevant information. The Bundesverband der Deutschen Industrie e.V. (BDI) and the Fraunhofer Gesellschaft (FhG) have therefore concluded in eight theses that Europe has good chances in this particular area to establish a leading position with technology that solves the present problems not least by exploiting AI technology (intelligent software assistants, semantic web, intuitive use) (Wahlster and Weyrich 2003). Recall that in Subsection 4.3 we have pointed out the relevance of (agent-based) AI also to grid computing.

4.10 The Potential in the Levels of Abstraction

Before we descend to the lowest level of abstraction in the next section, we want to have a look at all levels together.

Recall from Subsection 4.2 that the distinction of these levels of abstraction has been, and will continue to be, extremely helpful in the development of IT. However there is also a price to be paid here. What really counts are only two levels, one for the input from the outside world (data, programs, requests, etc.) and one for the physical level. All intermediate levels are meant to make the complexity feasible for the human expert in IT. Their price is an overhead in resources. We need compilers to translate the programs into assembler code and assemblers to transform this code into machine language which in turn has to be processed by the architecture in the physical hardware.

There is still a great potential in optimization at each of these levels as well as in the entire process. These kinds of optimizations are less spectacular than applications, the advantages of which everybody can grasp immediately. Therefore there is the tendency in funding policies to promote the more spectacular achievements. But the optimizations in the levels of abstraction for instance by more appropriate description languages and their synthesis to programs, by improving compilers, by more clever ways of executions of instructions, and so forth are at least as important for progress in IT as are spectacular applications because the latter are not possible without the former.

As the field is maturing part of this optimization process may consist in eliminating intermediate levels altogether. This may for instance be done by hardwiring applications directly into chips. In the context of AmI where a great variety of inputs are to be coped with this will be a necessary condition for making progress and narrowing the gulf between the physical and the virtual world which we spoke of in Subsection 4.2.

4.11 The Physical Level

Among the levels of abstraction introduced in Subsection 4.2 the grounding level, to which this section is devoted, naturally is of particular importance. While this level in current technology is correctly characterized as a “physical” level we will see that disciplines other than physics, like for instance chemistry and biology, begin to play a role in this regard.

The computer technology for some decades has been based on the transistor invented in 1947 and on integrated circuits (IC) invented in 1958. Both are realized mainly in silicon by use of CMOS (complementary metal oxide semiconductor) technology. It has been named a micro-system technology because its structures for decades could be measured in micrometres. But recently transistors as small as 4nm (nanometers) have already been realized in the laboratory so that the CMOS technology may be predicted to stay with us well into the nano-age.

This trend of miniaturization, with a doubling of the data density in integrated circuits every eighteen months in accordance with Moore’s (first) empirical law, has reached a density of more than a billion transistors on Intel’s most recent Itanium-4 chip leaving room of the size of 65nm for each transistor. This trend towards ever higher densities at the same time sped up the central processing units (CPU) of computers. Now it is even possible to integrate on a chip not only the processor but also silicon memory which speeds up also the reading/storing bottleneck of the von Neumann architecture.

The general trends in this vein are the following ones. In the period from 1990 through 2001 CPU speed has increased 393 times. The recently announced “Cell processor” developed by IBM, Sony and Toshiba could move close to the Teraflops (ie. trillion operations per second). In the same period disc capacity has increased 1200 times, available random access memory (RAM) 128 times, wireless transfer speed 18 times and battery energy density 2.7 times (Aarts and Marzano 2003). Transfer and energy technology are not the topic of this report. So here we focus on CPU and memory beginning with *CPU*.

Despite this ongoing progress in CMOS technology, competitors to the standard physical CMOS basis of computation are pursued in the laboratories worldwide. This is because in a decade or so the progress in this technology is expected to level off for two reasons. The first is Moore's second empirical law saying that the costs for building a chip factory rise exponentially and with a higher speed than the sizes of the transistors are getting smaller. Eg. currently the costs for such a factory are at 3-4 billion Dollars, while by 2010 they are expected to cost 10 billion or more. The shift to larger fabs, handling 300 mm wafers in leading edge plants, has been justified by a lower cost per transistor. The transition to 450 mm wafers and to larger fabs, as originally planned in the ITRS roadmap, is being challenged. The second reason comes from physical phenomena such as increased heat dissipation, or lies in the physical boundaries for further miniaturization given by the atomic distances at which undesired quantum mechanical phenomena begin to play essential roles. Characteristically, the competitors to CMOS technology all are convergent technological in nature in the sense of (Nordmann 2004).

One idea is to use molecules for computation or units of memory, noting that they can be switched between different configurations – depending, for instance, on the presence or absence of a single electron – or they can react with other molecules. On a different line first experiments have demonstrated that molecular solutions could be used as computers for solving hard problems (Adleman 1994). This kind of bio- (or bionic or molecular) computing could in fact overcome the complexity barrier hindering the von Neumann computer architecture in present use. On the other hand little progress has been made in this particular area and it is hard to perceive that computers could be made with molecular soups in the near future.

But there is a variety of other ideas. Some rely on the field effects used in CMOS transistors or on the transport of electron charges and its modification through a physical effect such as current channel pinch, spin effect, molecular orbital modification, Coulomb blockade, and Josephson effect. Others exploit effects like nuclear spin (nuclear magnetic resonance, or NMR, computing), electron states in atoms (quantum optics devices, spin electronics or spintronics), DNA hybridisation (DNA computing), ion transport and biomolecules (like neurons).

In particular, a molecular-scale computer architecture could also be made with nanotubes and/or semiconductor nanowires in sort of a hybrid technique combining CMOS with novel features. In Israel transistors were built out of carbon nanotubes (CNT) using DNA as a template (Chang 2003). Similarly, the company Infineon succeeded in demonstrating CNT electric switches (Focus 2004). HP researcher Phil Kuekes carries a patent on a molecular-electronic technique to produce ICs whereby the components consist of molecules and wires at the nano-scale, ie. of a thickness of currently 40nm and theoretically 2nm (Computer Zeitung 7, 2005). Complex logic functions as well as a 64 bit memory have already been realized in this molecular electronic technique. These technical achievements at the nano-scale open the perspectives for possibilities like even more densely packed transistors on chips – or rather in some different form like integrated in the fibre of your shirt – than possible with CMOS technology. They offer a number of advantages over current chip technology, not least because of a much simpler and hence cheaper chemical production technique, of less rigorous requirements on precision, and of less energy consumption.

The energy aspect behind the CNT technology is particularly important and could transform not only the transistor technology but also the electric power grid. This is because nanotube-based “quantum wires” could feature so little electrical resistance that they do not

dissipate electricity as heat (Jonietz 2005) which would revolutionize much of electrical engineering.

There is a wide spectrum of further options such as optical, opto-electronic, or photonic functional components. For instance photonic chips have prototypically been developed to allow for all-optical processing of signals transferred through optical fibres so that conversion to and from electronic signals would not be needed at switches and routers.

The most radical idea for computer alternatives is to use physical phenomena at the atomic (possibly even subatomic) particle level for computing devices. At this level phenomena described in quantum mechanical (and quantum electro-dynamical) terms (spins of atoms, ions, and electrons, or polarisation of photons) provide again a potential for computing devices which could overcome the already mentioned complexity barrier, mainly because a quantum state can be a superposition of possible values of a physical quantity. There are however great technical difficulties with this idea so that a potential application may lurk only in some distant future.

Nevertheless, Quantum Information Processing and Communication (QIPC) has become a new scientific field with origins in the late 80's and early 90's. There is a major world-wide effort to advance research in QIPC, which has led to a deeper and broader understanding of the fundamental laws of the quantum world, of information theory and computer science. The number and quality of the research papers published worldwide is a testimony of the intense research in the field. Many of them can be found at the Los Alamos National Laboratory (LANL) repository (<http://xxx.lanl.gov/archive/quant-ph>).

Quantum computation has the main goal to develop a quantum information processor (QIP) that would exploit the quantum superposition principle to perform an extraordinarily large number of commutations simultaneously. This “quantum parallelism” would permit the efficient solution of a certain class of problems, such as the factorization of large integer numbers. Among ten or more approaches are being pursued; some are scalable and have already achieved a lab model manipulating 7-8 qubits, eg. trapped ions, atoms and cavity QED (quantum electrodynamics), linear optics, etc. Others are at an earlier stage of development like superconducting Josephson junctions. More details can be found in an US QIPC Roadmap at <http://qist.lanl.gov/> and in a European strategic report at <http://www.cordis.lu/ist/fet/qipc.htm>.

To mention a few experiments from abroad, Ray Simmonds and his team of the Institute of Standards and Technology at Boulder recently realized the entanglement of electrons in two supraconducting microchips using the Josephson-junction as a quantum bit (qubit) which looks a great step towards a quantum computer (Simmonds et al. 2005). Also, Hasegawa and co-researchers at the National Institute for Material Science and at Riken in Japan have developed a switch in form of 1nm long bridge between a platinum and a silver sulphide wire which can be switched on and off at 1 MHz with a potential to speed it up to 1 GHz (<http://www.nims.go.jp/eng/> and <http://www.riken.go.jp/>).

Quantum communication explores the exploitation of quantum entanglement and has been very successful in practical realisations. Experiments in quantum communications along optical fibres have led to demonstrations at distances of 10-12 km; larger distances should be reached within the next 5 years. Quantum communication in free space is currently under intense investigation by the group of Prof. Zeilinger in Austria, the group of Prof. Gisin in Geneva and the research groups in the LANL in the US. Within a decade, it will be possible to place sources of entangled photons on satellites, which will allow global quantum communication, teleportation and perfectly secure cryptography. In the next ten years, quantum communication is expected to become an established technology and a commercial

product. Prototypically it has already found an application in guaranteeing the safety of money. For instance, Toshiba has developed a promising quantum-cryptography system (<http://www.toshiba-europe.com/research/crl/>).

European research has played a leading role and has reached a critical mass since the early stages of QIPC, both at EC and at national level. For a brief overview see <ftp://ftp.cordis.lu/pub/ist/docs/fet/qip2-eu-03.pdf>. Two documents illustrate the current status of research in Europe: “*QIPC: strategic report on current status, visions and goals for research in Europe*”, and “*QIPC in Europe*”, a collection of 30 articles in popular science style by 58 scientists from all over Europe. The entire text of both documents is available on <http://www.cordis.lu/ist/fet/qipc.htm>. All these examples demonstrate that the area has a potential for disruptive developments, possibly earlier than currently expected.

So far the perspectives for future CPU technologies. Let us now focus on *memory* devices. The current state of the art is reflected by magnetic tapes and disks as well as optical discs. In magnetic disks, information is stored on tracks separated by a few microns (10^{-6} m). Along the track a single bit of information might be stored on a length of track of less than 100 nm, giving a storage density of 15 Gbit per cm^2 (1 Gbit = 10^9 bit). With self-assembled structures of magnetic particles in the 10 nm range the data density could possibly be increased by two orders of magnitude (Wood et al. 2003). (For comparison we mention that hard disks today reach about 150 bits/mm².)

The technological principle of optical discs or DVDs (digital versatile disks) continues the tradition of lithography and consists in “writing” marks on a surface (of a polymer) which can be read by a laser beam (nanoimprint lithography or NIL). This kind of polymer memory is still a widely open field which is expected to allow optical memory discs in the range of Terabits (1 Tbit = 10^{12} bit). For instance, in Japan a Holographic Versatile Disc (HVD) is in development with a capacity of a Terabyte. The transfer rate of this technology is 1Gbyte per second, 40 times as fast as a DVD with a capacity of 5 Gbytes.

Atomic force microscope (AFM) technology, invented by two European Nobel prize winners, allows to write and read far smaller marks than possible with the currently used lasers whose limit is set by the wave length of the laser light. In the long-term there is therefore a potential in exploiting this technology for radically new memory devices.

For realizing the AmI vision, besides processor and memory, *sensors* are of fundamental importance. Again there is wide spectrum in sensor technology which we cannot cover here at any length. We just mention that today it is possible to tag even proteins and viruses in the body.

While in general Europe does not have market presence apart with the US and Japan in processor and memory technology, the expected revolution opens many new opportunities. Some have already been seized; for instance the Norwegian company Opticom is a pioneer in polymer memory technology. Generally, Europe is strong in the natural sciences underlying these developments and in nanotechnology. What so far is missing is the pioneering courage to jump to commercial applications of nano-electronics, medical nano-biotechnology, etc. for bringing new products on the market.

4.12 Challenge Problems

The previous subsections have outlined many opportunities for research and development in the area of IT. To a great deal the funding of these opportunities should be following a bottom-up strategy like the one in Section 3. Complementary to it the funding of major challenge problems of particular relevance for Europe’s development should be pursued.

In (Nordmann 2004) “Converging technologies for natural language processing” was proposed as a flagship research project which would have a substantial IT component. In (Wahlster 2004) eleven such challenge problems for the domain of ICT have been listed and described. They include “The Multilingual Companion”, “The Service Robot Companion”, “The Self-Monitoring and Self-Repairing Computer”, “The Internet Police Agent”, and “The Intelligent Retail Store”, to mention several of them. All of them are well founded and are backed by the present report. However we would like to extend this list by those proposed in (Bibel et al. 2004, Section 5.3) and add here further ones. First of all we would like to complement “The 100% Safe Car” proposed in (Wahlster 2004) with the following challenge problem.

Integrated Hybrid Transportation System. One of the treasures of the European inheritance are its cities and its cultural landscapes. Many of them still attract millions of visitors from abroad every year which is an important source for a thriving economy. At the same time this inheritance is already endangered by a brutal traffic which has a damaging potential to ruin our health (exhaust, noise, accidents, etc.), the cities’ architecture, certainly their flair (just compare the Paris of today with that half a century ago), and the ecology of the landscapes (such as the Alps). The reason for this unfortunate trend is causally linked to an obviously flawed transportation system which rests on individual vehicles of considerable size and weight (cars) for transporting the mass of little more than 50kg (ie. persons; for goods the same considerations apply). We do have much more effective public transportation means (limousines, busses, trains, planes) than the car which together might well compete with private cars except that they rarely or never provide a door-to-door connection as economical, comfortable and fast as with a car. The inherent problems lie in the fringes of the individual systems (eg. door to bus station, and vice versa, especially in the country-side where 60% of the population live), in the high costs of inefficiently used taxis, in the lack of coping with the luggage problem in a door to door fashion, and in the poor and unreliable connections. In order to overcome these problems in a future public transportation system one would need a more flexible, much more economic limousine system than taxis provide today as well as a powerful information system which binds all the different transportation systems together in service for each individual customer and optimizes the overall performance of the entire system per customer.

The technology for many features of such a system is in principle available but needs to be woven into a single complex system. These features include individual, though anonymous, locating and thus tracing (eg. RFIDs from Section 4.7) of, and caring for, each individual passenger (including his/her luggage as well as front-door-pickup and delivery), route and connection optimization in real-time, and automatic pricing and payment schemes. The public support of developing prototype systems of this kind would at least be a first step towards coming back to the relatively peaceful cities and landscapes of the past.

Relying on market forces does not help in this particular case. Waste of energy is still not punished by the market in a way which would hurt the customer in a locally notable way. There is still no real competition in each separate sector. Coordination across sector boundaries is not encouraged. On the contrary overcome regulations protect the state of the system (eg. the taxi business). The infrastructure for smart integrated system would require a major investment in which no individual sector is interested.

Semantic Law Support System. While ICT has penetrated many sectors of our societies essential ones like politics and law are still more or less unaffected by technology. In essence they are pursued much like two thousand years ago. A change in this respect is overdue. Law would suite as a first candidate for its formal character which lends itself to a certain grade of

automation. (Bibel 2005) outlines the many possibilities how IT could enhance the current situation of law systems. They include the establishment of a legal ontology, a legal knowledge system, and various kinds of support systems. A focus for a EU-funded challenge project might be the harmonization of the EU law with the law systems of its 25 members.

Programming Automation. In Subsection 4.8 the state of the art in programming has been described and the potential for a raise in the degree of automation pointed out. A project could be funded which focuses on a relatively complex programming task and instead of just programming it, first builds a program synthesis system which is able to solve the task on the basis of a descriptive specification (eg. in UML). Obviously, for the particular task selected this approach would amount to an enormous detour. But the idea of course is that the synthesis system through this exercise would reach a level of performance useful for many more applications including autonomous computing.

Humanoid Robot. In Subsection 4.3 we discussed the promising perspective of humanoid robots based on bionic and cognitive construction principles. Since Europe is ahead of its competitors in this area and enjoys a particularly strong science base in the respective areas, a focus on this research topic would be particularly advantageous. Such a robot is expected to feature part of its intelligence in its construction design. In addition the challenge is to link this built-in intelligence with cognitive intelligence of the human kind (ie. abstraction, reasoning, planning, etc.).

5. Conclusions

This report has summarized the contents of a large number of documents concerning the status of Information Technology (IT) from a European perspective. In this final section we will present the findings in a compact form and draw several conclusions from the insights obtained.

Our informal evaluation of the strengths, weaknesses, opportunities and threats are summarized in the table on the following page. From this table as well as from the remaining text we generate the condensed SWOT (strengths, weaknesses, opportunities, threats) table on the page thereafter which summarizes the report's most important technological findings and recommendations.

Generally, we have seen that ICT and IST rank as the most important among the key technologies deserving a continued special attention due to its economic and societal relevance.

On the other hand, we had to note that Europe lags behind in comparison with the US, Japan, etc. in most factors including the number of patents, the spending levels in R&D and in education, the number of researchers, the percentage of corporate research, the low ICT employment intensity, the slow penetration of ICT and its computational paradigm in other areas (especially in Social Sciences and Humanities), the net business profits, and many others so that it has to increase its efforts substantially.

We noted nine major trends in the technological evolution: convergence of sciences and technologies, miniaturization and integration of devices, distribution of computation and problem solving, growing system autonomy and transparency, migration from analogue to digital, from fixed to mobile, and from voice/text to multimedia equipment, exploitation of a variety of natural phenomena for computation, closer coupling of real and virtual, and the approximation of virtual to real.

<i>strengths</i>	<i>weaknesses</i>	<i>opportunities</i>	<i>threats</i>
talented, well-educated people rich in ideas, excellent intellectual capacity and scientific basis	fragmentation of activities, systems and structures; lack of synergy, inter-sectoral/ interdisciplinary collaboration	fresh motivation and commitment of new members, use of IT methods for overcoming systemic failures	falling behind in global competition, “brain drain”
excelling member states (Finland, UK, Netherlands, Sweden, Ireland, Denmark, etc.), excellent regional initiatives (Grenoble, Dresden, etc.)	lagging far behind US and Japan in number of patents, R&D expenditure, and numbers of researchers, especially in enterprises	hope for increase of EU budget for research	paralysing cost increases for financing social systems
EU strong in a few sectors of ICT (mobile, services, embedded systems, microsystems, application SW)	EU behind in several sectors of ICT (processors, systems SW, peripheral systems)	ICT in all respects the most important area, furthering innovation	[ICT causing relatively few environmental problems, so no threat in this respect]
scientific excellence in natural sciences for novel devices	weak position in fabless IC and OS markets	disruptive changes in technological development	rising competitive gap in ICT
powerful chemical industry for polymer technology	lack of ambition for novel applications of nanotechnology	intellectual capacity of SMEs	potential risks by nano-particles
huge service sector, including public sector	little research in service area	huge potential for ICT in service area, integration of KBs	ignoring the manufacturing basis must be avoided
FPs like FP6, national funding schemes	lack of integration of genius people	awards scheme introduction	overhead in top-down funding

The integration of the virtual into the real has been one of our two structuring characteristics of the wide field of IT. The other is the standard structuring by levels of abstraction. So the most promising and far-reaching vision for the future is the integration of intelligent systems within human communities (at the highest as well as lower levels). This is why AI, virtual reality, (multimodal) HCI and generally the coupling of the real with the virtual are top issues for R&D in the coming years. This is true in general but also in view of the long list of applicational fields with their particular features. We therefore regard the topics discussed in the respective subsections 4.3–4.7 as of utmost importance. For this reason

three of our proposed challenge problems, an Integrated Hybrid Transportation System, a Semantic Law Support System and the Humanoid Robot, are taken from this domain.

	Strengths	Weaknesses
Opportunities	<p>Exploit EU peoples' ingenuity and strengths in natural and formal sciences and engineering in innovative areas like bionic and cognitive robotics, knowledge systems, program synthesis combined with novel programming paradigms, computational devices at the nano-level.</p> <p>Continue focussing on grid technology.</p> <p>Take continued advantage of Europe's industrial strengths (mobile communications, business platforms with integrated knowledge systems, microsystems, chemical knowhow for novel computational devices like polymeres).</p>	<p>Take advantage of the disruptions expected in chip technology, of the potential in novel computational paradigms for application SW, and of the opportunities for SW with enhanced HCI.</p> <p>Integrate intelligent systems within the natural, human, but also technical sphere.</p> <p>Apply ICT to improve the optimization of structures and the removal of systemic failures currently hindering innovation.</p>
Threats	<p>To avoid a threatening traffic collapse establish an ICT-based public transportation system which guides and carries people and their luggage from door to door competitive with private cars in terms of costs and speed.</p> <p>Enhance competition among EU members by strengthening those who do better in ICT than others.</p> <p>Further the integration of ICT, especially of knowledge processing and with the help of CogSci, into the social sciences and humanities, starting with the law sector to harmonize the 25 plus 1 law systems in the EU.</p>	<p>Enhance research level in the service sector to match the one in the manufacturing sector and this way get Europe to become fully competitive in a balanced way.</p> <p>Complement current top-down funding schemes with bottom-up award scheme, also to reverse the brain drain, to strengthen SMEs and to reduce the overhead in the current funding schemes.</p> <p>Bring European competitiveness in harmony with social coherence.</p>

Of equal importance is the transformation of software production into a scientific discipline or, in other words, the Programming Automation, our fourth proposed challenge problem. In Subsection 4.8 we have emphasized the importance of focussing on modelling (ie. descriptively specifying) planned systems within their context or environment. The realization of an implemented system on the basis of such a model can, and must, become a formal production process which guarantees formal correctness in relation to the model. The software industry must take into account and integrate the existing formal methods. But this direction also requires a continued support of basic research in disciplines like logic, mathematics, theoretical computer science, etc.

Apart from these two main directions there is a wide variety of potential improvements of IT on all its levels of abstractions not least on the physical level which, due to physical laws, will not allow the undisrupted continuation of the current evolution of CMOS chips so that here radical innovations are to be expected in the near future.

More generally, we support the three main political goals of the Commissioner for IST, Viviane Reding, which are an open and stable market for the ICT economy, innovations triggered by research funding and initiations of industrial applications and the integration of the EU citizens into the information society.

I would like to complete this report with a general observation which seems to be of greatest importance for the longterm perspective. It is a commonplace that our present world has become more complex than ever and complexity has therefore become a new buzzword. Though the world has remained as complex as it ever has been. What has changed is our ability to influence ever more complex parts of the world and with them the future of the entire world. This ability has been enabled by technology.

The consequence of this development is a growing responsibility of mankind to do this shaping in a way beneficial for the present and future generations and for the world as a whole. The “technology” for this shaping, decision making, designing of social structures and mechanisms has remained pretty much the same as in the times of early Greek democracy: arguing, misunderstanding, talking, forgetting, reminding, missing important points, group dynamics, dominance, power, and all that. It is constrained by the individual’s limited mental capabilities. In order to overcome these limitations the capabilities must be empowered by assisting technology. This is why AI and CogSci (or intellectics) along with ICT technologies will have to play a dominant role in the coming phase since only these (especially AI) hold ready technological answers to the problems at issue.

In this view it is important but not enough to call for a contribution of the social sciences and humanities (SS&H). True, intellectics does not provide any contents for solving human and social problems; it is the area of SS&H which provides these contents. But it is intellectics which holds in store the methodological framework to cope with the sheer quantitative amount of relevant knowledge involved and to channel these contents towards consistent results and with them towards a beneficial future. It does enable synergy and a design comprising all aspects including social and environmental ones whereas the traditional democratic “technology” along with SS&H has always tended to bear oversimplification, inconsistencies, confusion and blockades. Note that taking advantage of the potential of intellectics technology does not at all imply to take a mechanistic viewpoint of nature and society. It merely provides the best available tool to support our coping with a world which otherwise is too complex to grasp let alone to manage.

In summary, at the highest level of normative foresight and of planning for a beneficial future we must take note of the importance of psychological, social and environmental issues along with the purely technological and economic ones. But immediately next to this highest level lies the diffusion and penetration of intellectics methodology and technology as the second most important subgoal because its achievement is a prerequisite to reach those goals at the highest level and our traditional ways of planning, design, decision making and problem solving have proved insufficient for the complex tasks ahead of us.

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