Converging Technologies
and the Natural, Social and Cultural World

Special Interest Group Report for the European Commission via an Expert Group on ***Foresighting the New Technology Wave***

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0. Executive Summary

The pace of technological progress is ever more breath-taking. The continuing increase in the speed of development seems to result in an unprecedented qualitative effect, namely the convergence of technologies. A product like a computer combines the results of a number of disciplines in science and this number may increase as well. As it expands rapidly science and technology seems to be on its way towards an integration at the same time, so that we may talk of *converging technologies*.

Because of this trend one might expect a synergy of developments in rather different areas such as in nano, bio, info, and cogno, or shortly NBIC, technology. In the wake of such expectations several countries, starting with the USA, have taken measures for providing extra funding to further this trend of convergent NBIC technologies.

In response to these observations the European Commission has set up a High Level Expert Group (HLEG) on "Foresighting the New Technology Wave" (FoNTWave). A subgroup thereof produced the present report on the forseeable impacts of this wave, which includes a number of recommendations to the Commission to be listed shortly. The proprietary characteristic of this subgroup has been a particular emphasis within NBIC on the I (information) and the C (cognition). It viewed the self, persons, groups, society, and culture in a context which includes ever more powerful hybrid and purely artefactual objects and networks.

In preparation of the resulting recommendations the group followed the principle that *research and technology should serve humanity and the world rather than being carried out for its own sake*. For this reason the report after the introduction starts with a section offering an exemplary analysis of some of the world's pressing problems. We think that priorities in research and development must also derive from these kinds of considerations and not only from technological opportunities. However fascinating a scientific or technological area may be, societal problems may still deserve higher priorities; for instance, as it becomes ever more clear that the world's climate may threaten the survival of thousands of species, perhaps including even the human one, to take just one out of many such actual problems, then such a general problem must in our opinion be taken as a guide for designing a preference policy. In this vein we hope that this section of the report not only explains the gist of some of our recommendations but also contributes to a rising awareness of our principle just mentioned.

Recommendations concerning NBIC technology must of course be based on a careful analysis of the scientific areas and the corresponding technologies involved. As we are talking here of a huge body of knowledge spanning from physics all the way through to the humanities, it is obvious that due to space limitations only the most important topics can be touched upon. Nevertheless we believe that Section 3 provides an extensive overview of current trends and expected developments in the main areas of NBIC, especially with respect to converging technologies. While there are many reviews of this kind in the literature, the one in this report is unusual because of its unprecedented breadth without compromising in the reliability of the technical details. For instance, we survey the different possibilities which are in store for computers for the "post silicon" era where converging techologies necessarily will play a prominent role. Besides the well-known technologies in the four major areas in NBIC, Ambient Intelligence, a major theme heralded by the IST Advisory Group of the European Commission, Artificial Intelligence (AI), Cognitive Science (CogSci), organic technologies, Artificial Life (AL) including even machine consciousness, Grid Computing and Simulation are among the presented topics.

While the perspectives and options for technological development are discussed in Section 3 in a more or less value-free manner, it is clear that the technology looming at the horizon raises a lot of questions and concerns. Thereby the public expectations range from enthusiasm, hailing the advent of a new Renaissance, to doom predictions. Indeed there are really promising perspectives opened by new technological possibilities. On the other hand technology in general is already now becoming so complex or is meddling so deeply in nature's structures that the dangers of loosing control over man's creations is of realistic concern. Especially Europeans are also concerned with their valuable environmental and cultural heritage which they are not willing to trade in merely for the sake of technological advancement. For all these reasons the group took pains to envision a balanced view between the need for Europe to seize the leadership into a beneficial future backed by technological advancement without compromising on its traditional values.

The basis for such a balanced evaluation is laid in Section 4 which discusses the main issues involved. These include questions concerning the underlying normative value system, the problems involved in facing decisions about technological development under extreme uncertainties, the technological risks and their management, procedural options which seem appropriate for handling the development of the forthcoming technology in a way which avoids major problems for the health and well-being of the people in particular and the world in general. Interestingly, converging technology also provokes issues concerning the role of the traditional boundaries between the disciplines, not only those within science and technology but also in the social sciences. The latter is caused by a growing body of hard scientific results in Intellectics (ie. AI and Cognitive Science) and Neuroscience with a potential for tremendous impacts on the social sciences which are still based mostly on commonsense psychology rather than hard scientifically established facts. In consequence, this potential may also reach the fundamentals of the structures of and the mechanisms in our societies.

0.1. General recommendations

All these issues find expression in a number of recommendations to the European Commission presented in detail in Section 5. Here we just list these recommendations without further comments. They are structured in three subsets, viz. general recommendations (GenRec), specific recommendations (SpecRec), and challenge problems. All recommendations are also designed to exert a possible influence to future framework programs. The details for this possible role are explained in Section 5.

GenRec1. *The technological development must not continue to destroy the delicate balance in the natural and cultural world in the crude way as in the past, but rather contribute to the preservation of the wonderful variety in all aspects (including material, technological, ecological, cultural ones, etc.) fortunately still in existence in this world and particularly in Europe.*

GenRec2. *In larger NBIC projects an ongoing assessment of the potential impact of the developed technology is considered essential. The methods of assessment should be empirical by way of installing and testing prototype systems, but also be done in a simulative and modelling manner. In order to improve the modelling techniques an expansion of basic research in Intellectics (ie. AI and Cognitive Science) towards positively influencing a "hardening" of the social sciences is deemed necessary.*

GenRec3. *The development of quantitative methods and assessment tools for the entire life cycle of the new converging technologies as well as for its full system impact including regulations and laws should receive a high priority. This includes support for the decision making from the funding phase through the implementation and maintenance of the technology within some environment, thereby respecting assessed technical and ethical limits.*

GenRec4. *Encourage the development of a whole society model from which the impact of special recommendations can be analysed which might produce recommendations for European market potentials thereby exploiting the potential of the advanced simulation and modelling techniques including those from AI.*

GenRec5. *Converging technologies as well as scientific knowledge accumulated in Intellectics and Neuroscience shed a harsh light on the dubious boundaries between the traditional disciplines. It is strongly recommended to the Commission to contribute by its various actions, not least by its funding policy, to a truly scientific evaluation of the merits of this traditional structure as well as of the role of some of the disciplines, and also to take steps towards a structure which is more in line with the modern scientific "Weltbild".*

GenRec6. *Any decision for funding some technological development must be based on a rational perspective for a potentially beneficial contribution to some of the problems facing the world* (of the kind discussed in Section 2).

GenRec7. *Europe must focus its balanced efforts to keep its leading position or, where needed, catch up in the individual basic research and development areas involved in NBIC as well as in its converging technologies.*

GenRec8. *Explore the development of an advanced ethic which is consistent with the modern scientific "Weltbild" and rests on the European values which evolved over the centuries.*

0.2. Specific recommendations

SpecRecs. *We propose to lay a particular emphasis in the funding of*

1. **Software synthesis;**
2. **Intelligent user interfaces;**
3. **Uncertainty reasoning, argumentation;**
4. **Ontologies and knowledge bases (KB);**
    - **4.1 KBs in education;**
    - **4.2 Legal KBs;**
    - **4.3 KB on science & technology foresight;**
5. **Deduction;**
6. **Semantic web;**
7. **Knowledge extraction;**
8. **Evolution and self-organization.**

0.3. Challenge problems:

(1) *Natural Language Processing*;

(2) *Integrated Hybrid Transportation System*,

(3) *Assistants with Global "Conscience"*.

1. Introduction

A High Level Expert Group on "Foresighting the New Technology Wave" (*FoNTWave* 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 consisted in foresighting the evolution of the following four technological areas.

- Nanotechnologies
- Biotechnologies
- Information Technologies
- Cognitive Sciences and Technologies

There are notable indications that these different areas to some extent are on their way of converging into a single one, briefly called NBIC (for nano-, bio-, info-, cogno-) technologies. This convergence aspect formed one of the focus points of Fontwave. The group was expected to elaborate recommendations to the Commission concerning the advancement and support for NBIC as well as the social and competitive impact on Europe at a 10-20 year horizon within the perspectives of the European Research Area (ERA) and as part of the "Lisbon Strategy" for the EU.

Within the Fontwave group special interest groups (SIGs) were formed with particular subtasks. One of these SIGs focused on "Society, Cognition, and Group Performance" as its working theme. The aim was to identify the potential benefits as well as the risks and uncertainties of the foreseeable technological developments due to the NBIC wave. The group thereby focused on issues of performance of individuals, groups, societies (ie. a web of groups of groups), and culture. The present report is the outcome of this work.

The group structured its work along three dimensions. First it identified a selected variety of problems in our present world worthy of efforts for improvement not least also by technological means. These are discussed at the outset in Section 2, which reflects the group's emphasis on a human-driven approach, ie. from people to technology and not vice versa. Second the group analyzed technological trends in the NBIC area which to some extent might have the potential to be helpful in overcoming these kinds of problems (Section 3). Third it discussed the likely future lines of development and evaluated them in terms of the desiderata worked out in the first place (Section 4). The results of this work are stated in Section 5 in the form of a number of recommendations including proposals for two exemplary challenge projects.

The group consisted of the following experts: Daniel Andler (University of Paris-Sorbonne and École Normale Supérieur), Wolfgang Bibel (Darmstadt University of Technology and University of British Columbia, Vancouver; rapporteur), Olivier da Costa (European Commission / Joint Research Centre / Institute for Prospective Technological Studies), Günter Küppers (University of Bielefeld), Ian D. Pearson (BT, Ipswich), Walter van de Velte (Camporosso, Brussels).

The group acknowledges useful comments on the text from the core group of Fontwave, especially from Jürgen Altmann, and the guidance provided by Paraskevas Caracostas, Elie Faroult and Mike Rogers from the Commission.

1.1. Background

Fontwave's work was initiated by the European Commission partially in response to the National Science Foundation Report "Converging Technologies for Improving Human Performances" (Roco & Bainbridge 2002). It might be useful to recall some elements from this report.

The starting point of the document is that sciences, despite of their still increasing trend towards specialisation, become so interrelated that they depend on each other and need to converge.

> "*. . . if the Cognitive Scientists can think it,*
> *the Nano people can build it,*
> *the Bio people can implement it, and*
> *the IT people can monitor and control it*"

In this vein the report presents extremely ambitious statements and visions of what technological convergence would achieve in the next ten to twenty years: "*Examples of payoffs will include improving work efficiency and learning, enhancing individual sensory and cognitive capabilities, revolutionary changes in healthcare, improving both individual and group creativity, highly effective communication techniques including brain to brain interaction, perfecting human-machine interfaces including neuro-morphic engineering, enhancing human capabilities for defence purposes, reaching sustainable development using NBIC tools, and ameliorating the physical and cognitive decline that is common to the ageing mind.*"

The ways in which the converging NBIC technologies could benefit humankind in the coming 20 years are exposed within five major application areas which are named by the report's section headlines as follows.

B. Expanding Human Cognition and Communication
C. Improving Human Health and Physical Capabilities
D. Enhancing Group and Societal Outcomes
E. National Security
F. Unifying Science and Education

If the visions presented in this report are striking, the values underlying much of this work are strongly positivistic and individualistic. Science and Technology are out to be harnessed for our good, and given the right incitements, a "new Eden can be created on Earth". However, the emphasis is not so much, as one might have expected in view of the new Eden, on increasing the quality of life, social cohesion or on solving humankind's main challenges of access to safe water, sustainable development, peace etc. It was commented that "*it says nothing about the rest of the world, the issues of poverty and deprivation, of sharing, of any benefits to the global challenges facing the 95% of the world's population who are not US.*" (Svanfeldt & Rogers 2003) The emphasis is among others on "*accelerating advancement of mental, physical and overall human performance*", that is to say to increase human efficiency and productivity. In the same line, it is noteworthy that some of the most elaborate visions concern new warfare technologies.

To summarize, several of the authors of the US report are convinced that this convergence of technologies is going to revolutionize the world, and some indicate that one of the aims of the national R&D priority on converging technologies should be the security and lasting superiority of the US. Eg. one author writes that in "*deterrence, intelligence gathering, and lethal combat ... it is essential to be technologically as far ahead of potential opponents as possible.*"

1.2. European Values

In the European context, the balance of emphasis is a different one. While Europe does not abhor addressing "mental, physical and overal human performance" of the individual, it lays an equal emphasis on the social and economic dimensions of sustainable development. Examples for the latter are issues of access to information and knowledge and the resulting impacts on societies' and economies' ability to innovate, of equality and justice with respect to access opportunities, and of individual capabilities to learn or engage socially and politically.

Recent ICT developments on the one hand make it feasible to access information at an unprecedented level of quantities. On the other hand, ICT applications enable the employment of fine-grained access policies to data bases and knowledge repositories that have the potential to significantly change traditional conditions of access and use of knowledge and information. New ways of exploitation and commercialisation of data, information and knowledge emerge, which may allow new types of income generation, but which may also conflict with principles of openness to information and knowledge, if these are understood as public goods.

With regard to these issues the NSF report (Roco & Bainbridge 2002) mainly addresses the opportunities by these changed ways of data and knowledge access for improving human performances. It fails to envision the opportunities for all mankind but rather seems to have in mind the already richer and better-adapted segments of our society, including the young, urban, socially-privileged and mobile techno-freaks who both welcome innovation and have the money to afford it. To some extent this reflects the philosophy of developing technologies in a world in which the pressure on humans to improve their performance in accordance with a set standard is increasing by the day in the economic field (as homo economicus), in the social environment (eg. by pretending eternal youth and beauty), or on the battle field.

Therefore, within the frame of a cohesive society set up by the Lisbon strategy, it is essential to extend this perspective to groups and societies, including those which are currently excluded from the liberal globalisation. Thereby the European values need to be respected. This means that the European qualities of the diversity in language, culture and heritage as well as of the relative homogeneity in the social fabric should be enhanced by the technological developments. Similarly, we have to envisage the ethical dimensions of the converging technologies (see Section 4.8).

2. Desiderata for Changes in Societies

The technological development is driven by the engineers on the one hand and by the consumers, ie. by the society at large, on the other. The future of NBIC technology, ie. the engineers' perspective, will be discussed in Section 3 while the present section takes the consumers' point of view. With this choice of sequence we want to emphasize our top-down approach by pointing out various aspects of the individual and societal reality which call for improvement of the present situation. Obviously the section will not make an attempt to be comprehensive in any way. Rather the selected aspects have to be seen as exemplary for demands and desires of the kind to be addressed in a more extensive review. Also the selection must not be interpreted as implying that the mentioned aspects could (or should) be solved by technology alone. The extent of its contribution to such a solution is addressed in Section 4.

Technology is preferably not developed for the technology's own sake but to enable people to live a more fulfilling and happy life, without compromising the rights of the future generations to do the same (in view of sustainable development). In order to make recommendations for the promotion of particular strains of technological development it is therefore mandatory to have an idea what the technology might be useful for in terms of peoples' needs and desires. Unfortunately it is already not easy for a single person to express what he or she really wants let alone for the society at large. It is even much harder if not impossible to find out what people might want in two decades from now, especially if then possibilities and options might be realized that today we do not even dream of. It is historically well-established that preferences, norms and values underly changes over the years, a fact which complicates predictions of this kind even further.

Faced with this inherent difficulty, what we can do is to analyze the present problems of people and societies assuming that people basically remain the same in the near future in their attitudes towards these problems and that overcoming them would hence be in their interest. In the present section this analysis is performed focussing on the performances of individuals, then of groups, and finally of societies (ie. webs of groups of groups and individuals). Obviously we cannot provide a comprehensive overview of all aspects of individuals and societies; rather the idea is to select a number of exemplary areas in which a substantial improvement of the described problems could result from technological progress.

2.1. Individuals

Certain converging technologies have the potential to improve human cognition. For instance direct human/machine interfaces will allow instantaneous access to the global stock of information and knowledge without today's cumbersome manipulations of computers. This way huge knowledge bases may directly be accessed as well as instructed to store current thoughts and deliberations at the cognitive level of the individual human being. This allows to overcome the volativity of our thoughts and to enhance our problem solving capabilities.

Would it not be desirable that forgetting an upcoming date, the name of an encountered person would never occur to us again? Or, faced with the task for solving a problem all relevant knowledge (possibly including guidance how to approach the search for a solution) would readily be available in a cognitively appropriate way. Or, when making a logical or other mistake this would kindly be pointed out to us. Or, in some creative activity earlier thoughts and ideas could be reactivated at any given time. Enhancement of our senses in dependence of actual needs is similarly desirable.

Apart from these general capabilities let us consider two particular contexts, namely individual education and health.

2.1.1. Learning

There is general agreement that learning and education is the key for societies in the age of globalisation. Education covers the entire life of any individual. From fundamental research in psychology and neurology we know that already the first, say, five years in human life are of great importance for an individual's later chances (which is not at all to say that the remaining years are of little relevance in terms of education). Unfortunately, parents get children with little or no instruction on how to treat and educate their babies. Even worse, Grandma is rarely around any more to help with her advice from a long life's experience.

What is needed is education of parents in the first place and additional practical advice to them in individual situations. Of course it is hardly possible to require that all parents attend special "parent schools" nor could one imagine to provide an educator for each family. Technology might be of great help with advice systems based on ICT acting as educational assistants in many problematic circumstances.

One of the fundamental problems in primary and secondary schools is the prevailing ignorance of individual needs of the pupils. Teachers typically have too little time for finding out what the particular problems of an individual pupil are in grasping the understanding of the subject. This again would be an appropriate area for system assistants which could point out the weak points to the teacher for individual support.

Through intelligent and web-based systems anyone can be instructed in a customized way on an internationally top quality level. This would lead to a juster educational system serving the slums in Africa to some extent equally as the graduate students at Stanford. In Section 2.2 we will come back to details of a future education and learning system.

2.1.2. Health and Welfare

Of fundamental importance for any individual human being is the physical and mental health. It is known that more than two thirds of all health related problems could be eliminated by more reasonable living and eating habits and by optimizing body functions like posture, movement, breathing, nutrition, digestion, etc.

It is also known that education is a great asset in this respect, ie. statistically more educated people (in the "developed" countries) are far healthier than less educated ones. Knowledge systems in terms of intelligent assistents could therefore monitor people's behavior and educate them non-intrusively in living a healthy life (see the challenge problems in Section 5). In the remaining and dramatically reduced number of cases of health problems the technological ability to detect and monitor key illnesses could create a greater reliance on "out-patient" approaches to health care delivery combined with individualized indications of drug and other therapies which avoid the inconsistencies experienced in today's medical practice.

Millions of people are suffering from the psychological tortures which are brought along with today's practices in personal and professional lifes. Often the psychological conditions result in serious physical health problems. Only if we learn more about the mechanisms of the psyche and of the communication with others, will we be able to attack these problems in a fundamental way. Modelling techniques from ICT are the only known methods which bear a great promise towards this end, especially if combined with the results established in Cognitive Science. If the accumulated knowledge of this kind will be available to the envisaged intelligent assistant systems, many problems of this kind could be overcome.

2.1.3. Improved Physical Performance

Physical activity is what links us to our environment and it is obviously essential for our 'being' in the world. It is of course also essential in many professional activities. It also plays an important role in physical well-being.What has been said about physical health under the preceding heading applies similarly to the improvement of the body's physical conditions in every respect.

2.1.4. Inclusion through Empowerment

The European society model is an inclusive one. It aims at the full participation of everybody with respect to individual differences, for instance due to handicaps or differences in capabilities. Though convergent technology may be used to 'repair' some of these differences this is not necessarily the best solution, for one because it stigmatizes differences as faults and may lead to a spiral of striving for an 'ideal' body, even by those that are objectively speaking in perfect health and have all capabilities and faculties one may normally expect from a human being.

Inclusion follows from giving everybody the possibilities for interaction with the world and with one another, in mutual respect. Convergent technologies can help to restore the capabilities of interaction. Whether this happens by in-body technologies or in-environment technologies depends on numerous factors. It should be clear, however, that in-body technologies are not the only direction possible.

2.1.5. Entertainment

The emerging technology enables people to escape from reality, a trend already in full swing. Society has to decide whether this necessarily is the way to go.

2.1.6. Security

A sense of security is probably the precondition for a satisfactory living. Security has become an issue of rising actuality, for a variety of factors. While NBIC technology will offer means to protect individuals, it also introduces dangers of a different kind of insecurity discussed in more detail in Section 4.

2.2. Groups

Within this subsection we consider groups of people in which the individuals at least in principle have direct contact with the other group members. In contrast to this group concept in societies (or webs of groups of groups), discussed in the subsequent subsection, the members have only indirect contact with other members through some kind of media.

2.2.1. Communication

Researchers have tape-recorded conversations among people. A thorough analysis of this material has demonstrated how little we understand each other in such conversations, mostly talking at cross purposes. The issue is thus to improve communication and understanding between people with new information-sharing, knowledge-transmission and content-exchange practices.

Similarly the processes of collective thinking have not changed much over the last 2000 years, from let's say an assembly of nobles in the antic Athens to the board of a 21st century company. It is still based on the talking of single individuals (nowadays with the help of PowerPoint presentations), each at his/her turn, and the others listening. It is well-known that in this style of debate the information transfer is extremely poor. For one, there is a tremendous loss of information and knowledge by the successive presentations of one by the other, because the main point of a speaker, if properly understood at all, may well be forgotten when some time later raised again by a counterspeaker. Also, no speaker is able to present all the context in which his/her statement is embedded. Therefore more often than not are statements misunderstood by the interlocutors.

Even in the case of written documents misinterpretations are rather the norm except in cases where the author is a perfect writer and is well aware of the knowledge state of his/her readers. Additional problems occur within the context of an information-overload and an environment dominated by obtrusive multimedia signals and information pollution (eg. dynamic images and sounds). People in general and executives in particular have less time and attention to concentrate on written documents. In Section 3 we discuss technologies which offer the potential to support the communication and working within groups in a radically new way. In the present section we continue to discuss desirable aspects in group behaviour within various settings.

2.2.2. Teaching[1]

Technological innovation has already contributed to the development of better teaching support tools, thus allowing for a flexible and customised learning plan which provides people with improved chances for access to and success in educational institutions, work activities and in general lifelong learning.

Teaching is still based on the process of oral transmission of knowledge from one to few. New educational/learning paradigms put the emphasis on the *learning-centered* pattern rather than on the *teaching-centered* model. They are based on the active learning approach (to learn by doing, communication and sharing) rather than the passive learning approach (to learn by watching and listening, Montessori etc.).

While the didactics' heart of the teaching-centered model is based on teachers and their knowledge, in the learning-centered model learners play an active role by building, according to a *customised learning action plan*, the knowledge and training path best fitting their own pace and style. The active methodology proposes:

- to learn with all senses (eyes, ears, hand, nose and tongue);
- to learn with all methods (at school, on network);

[1] This section is adapted from "*AmI@Life –Ambient Intelligence in Everyday Life Roadmap*" (Friedewald & Da Costa 2003)

- to access knowledge without space and time constrains (anywhere and anytime).

Moreover, learning should not be restricted to learning knowledge, or even just to learning information, but should be based upon four pillars:

- learning in order to know, and learning how to learn;
- learning to do;
- learning to live together;
- learning to be.

All of the above is part of visions where education and learning are not confined only to school years. On the contrary, the need for knowledge and training lasts a whole lifetime ("lifelong learning") both at the professional and at the personal level. The educational/learning process becomes more and more flexible, independent and permanent and actually all educational/learning phases are integrated and projected into an ubiquitous learning environment, based on a horizontal approach in terms of methodologies, technologies, tools and services.

The future technologies for education and learning in these visions will be especially targeted towards organising the knowledge. The knowledge organisation will have to be new methodology driven, advanced ICT supported and new common standards based. The more important phases in the knowledge organisation are:

- acquisition,
- validation,
- representation,
- dissemination.

In the future Knowledge Society the knowledge will be directly accessed by way of the Cyberspace. In the education/learning area the knowledge will be organised in Learning Objects (LO) that represent *a reusable media-independent chunk of information used as a modular building block for e-learning content*, where by information we consider not only a document, but an expert, an experience, a contact, etc. In a future view we can envisage a *knowledge space* full of LOs like web-seminars, lessons, digital libraries, digital museums etc. All LOs will be organised by a standard meta data classification system and made available in the network. In this knowledge space a user may just specify his/her desiderata (ie. the user profile) and build a personal learning path resulting in the connection and integration of LOs which are suitable for his/her needs (ie. profile). Common standards (such as SCORM) will be necessary to manage knowledge and the learning objects (through meta data) in an efficient and effective way in this advanced ICT scenario.

The main tools and applications in this education and learning future vision will be characterized by the following driving factors (cf. Section 3):

- virtual environment and virtual community,
- use of intelligent agents in the learning and knowledge evaluation processes,
- seamless, adaptive and interactive user interfaces,
- intelligent retrieval tools,

- active network at the local, civic and global level,
- mobile technology,
- growth in computer capacity/speed, shrinkage in computer size,
- display devices evolution,
- low-cost communication and computer technology,
- ubiquitous use of intelligent robots.

2.2.3. New Forms of Socialisation

Only half a century ago, people were meeting within closed and pre-determined circles: neighbours, colleagues, clubs, etc. Now, as people are traveling and moving more and more, and as family structures are becoming less rigid, new ways of socialising become more and more needed. Even with the recent proliferation of communication tools, the feeling of loneliness is ever more widespread in cities, suburbs, even in villages in the countryside and the number of single people and single-parent families is steadily increasing.

The paradox is that the crowds who surround us every day constitute a huge waste of social capital. City-dwellers pass everyday within a few meters of people who could give them a ride home, buy an item they are trying to sell, or consider them as potential friends or partners.

This situation has also dramatic consequences for the socialisation of the youth which is driven by the media in an uncontrolled way rather than by parents, teachers, relatives, neighbours, social groups and so forth (Schwarte 2002). The effects of this trend can among others be read off the criminal statistics which shows frighteningly increasing figures especially for children with less than 14 years as well as for teenagers (14 – 18 years).

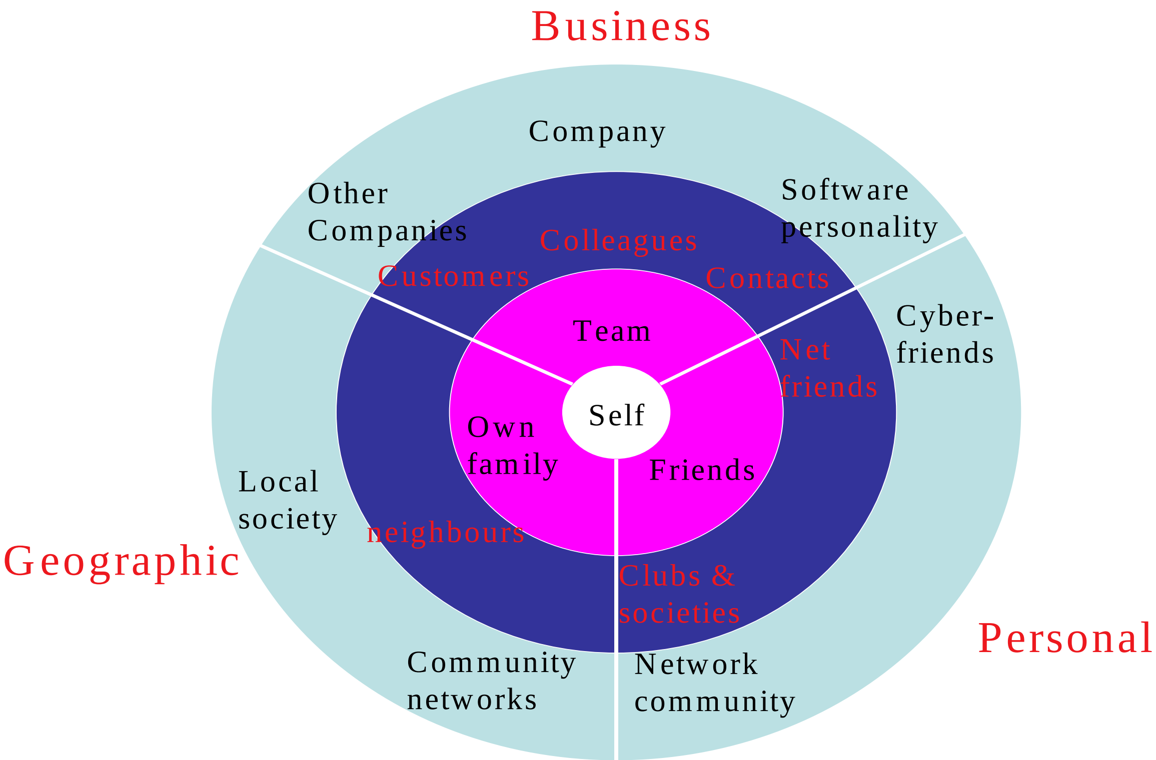
The general issue is therefore to enrich communication and community life through humanised technology, interactive environments in which people and autonomous systems can get in touch, establish a relation and co-operate in real time. The vision is that the Ambient Intelligence (AmI) technologies (see Section 3.5) could change the paradigm of socialisation by putting seamlessly and unobtrusively people into contact on the basis of comparable, permanent patterns of interest or specific request. Dynamic networking makes it possible to tap those resources through a momentary alliance among transient interest groups, like people commuting to a certain district, needing a taxi to go to the airport, or sharing similar health concerns (cf. Dimitrios D-Me, transfer of data via ICT handshake). Ad-hoc wireless social contacts or communities between like-minded or shared-interest strangers could therefore emerge spontaneously following negotiation of their respective avatars.

Important developments in communication and networking are required to realize such a vision (such as 3G+ mobile systems, fixed/mobile integration, WLAN and broadband networks). Breakthroughs could come through new interfaces (multi-sensoriality, multi-modality, multi-lingualism, virtual and augmented reality, telepresence, breakthroughs in input/output) and displays technologies (wearable devices, HMD and microdisplays, 3D displays) which will be discussed in Section 3. The challenges in terms of trust, confidence and security are enormous (privacy, anonymity protection, Identity Management Systems).

2.2.4. Synthetic Personalities and Human Relationships

Already in the previous subsection we mentioned the problems with the socialization of the youth and the resulting conflicts with the remaining society. One might also think of the hatred built into the heads of the Palestinean people, to mention just one out of many conflict regions in the world. These conflicts, even after reaching a fair and just settlement taking into account all interests at stake, could only be solved by a long resocialization process, requiring a therapeut for each of the inflicted persons. We will never find so many therapeuts as to solve such problems in this way.

Perhaps synthetic personalities could provide a partial remedy. As these come on line, people will start to include AI entities among their colleagues and friends. Eventually we will even see people form strong emotional bonds with such entities (as it happened already with Weizenbaum's early Eliza). The following figure illustrates the structure of the social environment of any individual as it may evolve in the future in terms of including net and cyber friends, community networks and so forth.



2.2.5. The Future of Inter-Personal Messaging Technology

Exchanging messages is part of any of the group interactions discussed within the present section. Inter-personal messaging and the underlying technologies are therefore important enough to deserve a special treatment in the present subsection.

Messaging technology has evolved a lot since cavemen learned to scrawl marks on rocks and it will evolve much further over the next several years as convergence and miniaturisation provide new technology platforms for future services. Instant messaging, email, text, voice and video messages now play a big part in most people's lives. Although it is unidirectional communication, messaging isn't just half of a conversation. An important factor in its success is that the recipient can deal with the message when it is convenient to do so, or not at all.

Other factors that are often important are anonymity, distance, lack of physical proximity of the sender and recipient, and the sender's freedom to construct the message at their own speed instead of having to relay it in real time.

Any of us that have ever watched Star Trek may wonder why we still don't have the instant voice messaging that the Enterprise crew uses to communicate. The message is instantly relayed by the computer to the correct individual or room based on just their name and context. The context of knowing who is speaking enables the message to be addressed based on a single name. Accepting that today's crude voice based dialling still falls far short of what is needed, we will soon have access to intuitive instant voice messaging, which will quickly become an important service for social groups. Imagine a small clique of teenage girls, who are unable to survive without constantly talking to each other. If they can just speak and their friends can hear them, all the time, they would presumably be happy. This might possibly be done by social conferencing calls, which could provide an 'always on' call among the group. The majority of children, who are less exclusively connected, would prefer messaging technology. Children generally have different sets of friends, even if there is considerable overlap. In practice, children might use instant voice messaging technology with some of their friends, while being in a permanent conference with a particular clique. Of course, such services will not only be for children, but it is likely that they will be by far the largest user group.

Some personal messaging can be automated, between personality badges. These store information about us, our work, our personality, sexual preferences and availability. They will exchange information with badges belonging to other people (under our control of course), and alert us when we meet someone who is mutually compatible. This could be a fun way of meeting new friends, dates or business partners. There are several potential variants of this kind of gadget, such as an 'I fancy you' gadget that you can point and click at someone you are interested in, but which only has any effect if they have also declared interest in you. This idea crystallises out one of the main reasons that messaging has taken off so well. It cuts through the embarrassment that people often feel when trying to talk face to face with someone. Approaching someone directly incurs the risk of rejection, whereas clicking a button on a gadget only alerts them if they are also interested in you, so the rejections are filtered out electronically without the pain. As a result, we may see many more speculative approaches. While this is likely to improve people's social lives, it also carries a potential danger of splitting up existing relationships as it becomes easier for people to 'shop around for a better model' even after they have committed to a person.

Some of these personality badges above use directional messaging. Another version of directional messaging that is likely to have a popular social function is inter-car messaging. It is now illegal to use a mobile phone while driving a car unless it is hand-free, but the maturing of hands-free technology coupled with the fact that many people are in passenger seats will allow it to take off. Imagine being able to tell the person in front to move over so you can get past, to stop picking their nose, or to warn an oncoming vehicle of a problem down the road. It could also be useful for groups on an outing, split between cars.

Outside of the car, directional messaging could be a superb source of mischief allowing people to message specific passers by. Even without directionality, some people already use Bluetooth to send people anonymous business cards with a message in place of the name. Many people don't get round to setting up the names of their mobile phones when they get them, so choosing which of the several phones in the available list is the correct one involves a fair degree of guesswork. Nevertheless, relying purely on luck appeals to some people when they have the cover of anonymity, even though almost anyone in a few metres radius could receive the message. A few people in railway carriages have already found this a productive means of picking up random dates. Adding directionality would allow precision targeting, but may also reduce the available anonymity. This kind of function combines a degree of excitement with the ability to bypass rejection embarrassment.

Bypassing the fear of rejection also partly explains the massive success of text messaging, why it is so often used for flirtation and why it can also be so dangerous for existing relationships. While it certainly can be a lot of fun in the short term, providing excitement and novelty or frequent new relationships, it may result in people holding too many shallow relationships without the rewards of a few deep ones. It also undermines the trust between people that is so critical to optimal bonding. So socially, it is a mixed bag of benefits and problems. What it does indicate is that when a new technology satisfies a latent desire, it can take off very quickly, whether the desire is good or bad.

A more refined messaging platform that combines some anonymity with higher precision targeting could use addressing by interest. People could send messages to those people with particular interests, within a defined geographic area. So you could quickly arrange a meeting of like minds in the vicinity, or co-ordinate a flash mob. It could even allow people at a conference, airport or rail station to quickly converge with others with similar business interests so that they can do deals, get some advice, or collaborate informally on a piece of work of mutual interest.

As the technology matures, our digital bubbles will make the world a much more interesting place. As we wander around, our bubbles will interact with the smart environment. Sensors, communication, storage and processing devices will be everywhere. This is called *pervasive* ICT, pervasive not only by physical ubiquity, but also because the technology will enter every area of our lives. This digital air notionally has the information (and algorithms) suspended in it, waiting for us to pass through that air-space before allowing us to access the information. Messaging technology can allow corporate and personal web sites to extend into this physical environment, broadcasting some material via wireless LANs or mobile networks to those people walking past, giving the web a local geographic overlay. We can think of this as street cyberspace.

Many of these services would lend themselves to abuse, either by nuisance individuals, spammers, or companies using intrusive or irritating marketing. Since there is no clear technology difference between a genuinely wanted message and spam, there needs to be a heavy layer of filtering technology between the user and the rest of the world. Some of the early hype for 3G mobile told us that we would expect to be bombarded with adverts from shops as we walk past them, offering us personalised promotions. While this is certainly feasible using the combination of positioning systems and personal profiling, most of us would set our filters to exclude such in your face advertising most of the time. But occasionally we actually want marketing information or special discounts, so the filters have to be smart. The user will effectively live in a semi-permeable digital bubble, shielded from unwanted marketing messages or unwelcome intrusions by individuals, while allowing appropriate messages and information through. Construction of this bubble will require a high degree of personal profiling technology. Either the system or our individual devices, or both, will gradually get to know us and our preferences. Stuff that we welcome will be allowed through, and stuff we don't want will be kept out. This will vary according to where we are, what we are doing, who we are with, and other contextual parameters, such as whether we are working or playing. These context engines have been in development for years and will take a few more to become really useful, but without these smart shields, it is unlikely that the markets will achieve their full potential.

Some believe that cultural information delivery will be a bigger service than advertising, mainly because it is more likely to be pulled down by the user, in contrast to advertising, which very quickly reaches a level where we reject it. When we are tourists in another city, we welcome information about the places around us. If we are interested in art, we may want to see the paintings produced by the chap living in the house we are walking past. Similarly, sitting opposite someone on the train who looks interesting, our digital bubbles could interact to exchange material. People are content. Combining such 'bubble cyberspace' with the personality badges, we can discretely check out the 'output' of someone nearby before enabling our personality badges to introduce us.

So overall, messaging technology has a great deal of future potential. Provided that we can protect our privacy and filter out abuse, there are many areas where our social and cultural lives could be improved, and other areas where clever marketers can get precisely targeted access to people at just the right moment.

2.2.6. Remote Socialisation, Family Life and Virtual Environments

More and more family members are living in different countries or even continents. Separations for professional reasons are becoming more frequent and longer. The issue is therefore to allow people to spend time together even if, because of the constraints of modern life or for other reasons, they are in geographically dispersed locations. Interface and displays will be the key enabling technologies. Telepresence, if and when it is feasible, would be a major breakthrough.

Much work is ongoing in the field of virtual environments. These environments aim to create pseudo realistic environments for human interaction. These environments may be based on real places or entirely imaginary. Virtual reality technology provides a basic starting platform, and then communications and sensor technologies build this into a useful communications platform. In the ultimate development, the environment would not offer only video and audio, but also tactile interaction and smell if required. Technology could achieve this by using developments such as active skin, which could potentially provide duplex links to the peripheral nervous system, allowing sensations of all kinds to be detected, recorded, stored, recovered across a network, and replayed. This could make good use of NBIC technologies in achieving the nervous system links.

Companies such as BT in the UK consider that any technologies that allow loneliness to be addressed will be very successful in the marketplace. Although active skin is a far future technology field, large screen conferencing technologies can be adapted in the near future to give the user the feel of being next to someone, giving full life-sized images with all the body language richness of natural face to face communication. This requires the use of broadband links if high latency is to be avoided, but broadband is already high on the political agenda across Europe.

2.3. Societies

Modern societies have become extremely complex in all respects. Everyone requests a fair treatment as a result of decisions affecting millions of people. No single politician is able to fulfill these requests. The purpose of the present section is to reflect the major challenges of the populations anywhere in the world. Again it does not intend to provide a comprehensive overview of all dimensions of societies. The idea is rather to select a number of exemplary areas in which a substantial improvement of the described problems could result from technological progress.

2.3.1. Social Participation

The shorter-term issue is to enable the remote and nevertheless effective participation of members to community life and beyond, even if they are not in the geographical location. This may allow people who are travelling frequently to play a more active role in social life. It may also allow any civilian to take a more active role in the political decision process at the regional or national level. In a longer term perspective, new forms of participation could emerge.

Participation takes different forms. Traditional participation in politics, union, religion can be enriched by e-consultations, voting or new forms of democratic consultations, referenda (e-government). New forms of participation such as involvement in human rights or environment NGOs, etc. would also benefit from e-participation. The local community life (sports, culture, education, events, etc.) would also be supported and enhanced by the new AmI technologies.

2.3.2. Improved Social Cohesion

Stability in any society will not be achieved unless there is a minimum of social cohesion. The issue is to improve the fate of the less well-off people in our societies such as the unemployed, the illegal immigrants, minorities, poor, homeless, drug-addicts, and so forth. One focus direction is to increase the accessibility of relevant information and services. The challenges are enormous considering that:

- In certain cases, there has been no kind of any previous contact with computers or ICT, in other cases the emotional relation with technologies is radically different (eg. immigrant communities use a lot the telephone on IP and the satellite TV);
- Neither can it be assumed that the most distressed people have any willingness to participate in any kind of technology-based activity or process;
- What these groups in the population need the most is human contacts, social care, (material) opportunities, and AmI cannot substitute for them.

Here the key factor for success is the human-based functions and instructions for use and user-friendliness. A low user cost would also be decisive. The fundamental question remains: do emerging technologies have the potential to “make the difference” by taking some of them aboard?

2.3.3. Public Problem Solving and Politics

As pointed out above our societies are becoming too complex to be understood by individuals. Individual problem solving is therefore doomed to failure facing the challenges at a social, political and economic level. While the idea behind democratic mechanisms is undisputable, the realization of these as problem solving mechanisms in their present form leads to even less satisfying solutions for society’s problems. The complexity can only be overcome by technological support.

It is the technology of knowledge systems in the most general sense which offers a great promise in this respect. Radical changes in the way the democratic idea is realized in terms of voting procedures, novel and more promising ways of democratic representation, opinion polling, balancing mechanisms to respect differences in opinions, and so forth are to be expected on such a technological basis (Bibel 2003).

Further expectations concern a lean administration in contrast to the monsters of bureaucracy experienced today, a taxation which is simple to use, but sophisticated in view of fairness, a social justice which is based on rationally agreed values and which deserves its name, a smarter environment (like homes, cars, clothing, workplaces, public spaces including highways, shopping malls, and so forth), a further improved logistics technology, a customized point-to-point and combined multi-mode transportation system (see the challenge problem in Section 5) substituting the chaos on our streets -- ever seen its extreme in India or other "developing" countries? --, an environmentally acceptable industrial sector with design and production processes which improve rather than destroy environmental quality, sustainable technological measures of energy preservation as well as energy provision, a balanced and just financial system on the national and global level, an entertainment sector which provides customized joy and active involvement for individuals, an ease of the consequences of disabilities and of the ageing society, and many more.

It is obvious that the realization of any of these possibilities would raise the competitiveness of Europe to a substantial degree, a view also supported by ISTAG Reports such as (ISTAG 2003) which argue for an Ambient Intelligence (AmI).

2.3.4. Law Systems

One of the areas which urgently demands for technical advancement is law. Especially in the European Union there is the need to harmonize legislation across its polyglot members. If not done in a systematic way the legal situation may turn further into a mess. While the basic concepts and mechanisms for technical support of the great variety of tasks in the legal domain have been developed to an impressive degree of maturity in the area of AI and law, only a very few member-states of the EU have grasped this potential, yet only to a very limited extent. The following lists the possibilities based on technology which is already available (Bibel 2003).

A principled development of legal knowledge systems could make accessible the abundance of cases, rules, theories, procedures, hierarchies of authority, norms and meta-rules based on systematically developed ontologies of concepts in a way which goes far beyond the mere keyword-based retrieval of the underlying texts practiced today. It is known that 80 % of all legal disputes are settled "on the court house steps"; given the maturity of the underlying field (Rissland et al 2003) it is a realistic perspective for the next two decades to settle those "easy" cases more or less in a purely technology-driven way.

But the technological support will not be restricted to case-settlements but may as well be applied to task orientations such as advocacy, adjudication, advising, planning, and drafting, and administration which all share the fundamental task of legal analysis of the facts and circumstances and how they relate to the relevant law.

There is an unprecedented opportunity in clarifying the facts underlying legal cases by accessing the information supplied by ambient intelligence which hitherto has had to be the subject of ample speculation by judges. We simply "ask" the actual environment what really happened. The same environmental function can of course also help to enforce the law. It would also allow various types of 'punishment' based on a wider spectrum of freedom-depriving and degrees of coercion. Of course, these visions also provoke the fears of a "1984" or "Big Brother" perspective which certainly has to be avoided by appropriate measures of private sphere protection, anonymity (except for the purposes just mentioned), and so forth.

The interaction of conceptually clean systems with the traditional body of law would clearly reveal many of its weaknesses and this way trigger an overhaul of the entire legal system including the above-mentioned harmonization among member states. In the same vein a technological revolution in the way of *generating* new law can be expected which eventually will as well be applied to the formation of consistent and convincing ethical norms for our societies.

In a principled development of a law system different levels of abstractions might be realized in a way so that people can again understand the law which can be summarized (at the highest level) in a few statements like those of the Ten Commandments. This way people would be confronted with soft law of this kind rather than with tons of specific regulations.

2.3.5. Defence

Military issues fall in fact under similar considerations as law and its enforcement. Here we are just dealing of law on a global scale. Imperialism, colonialism, fascism, racism, and so forth have no meaningful function in a world guided by a common world law (envisioned already by the philosopher Immanuel Kant). Once it is in place wars become obsolete since disputes can be solved in a legal way. This is certainly not to say that the enforcement of a world law would be possible without the capacity to apply military force as we experience nearly daily with the widespread terrorism.

2.3.6. Developing World

Even though the world GNP has been increasing continuously for decades, a large fraction of the world population is still suffering from unbelievable misery such as deprivation from safe water or from minimal food supply, oppression by dictatorships, bloody wars, personal insecurity, global degradation of the environment, deterioration of social and family safety nets, etc. Technological developments do not usually address these challenges in the first place. Hopefully, the developments of NBIC technology will ultimately benefit the entire mankind by bringing the knowledge necessary for a prosperous development in any part of the world and improve the economic and cultural balance between states similarly as that between the people in democratic countries by enhanced mechanisms described in Section 3. This is the major claim that needs to be scrutinized. Although we focus our attention in this report on Europe and thus the situation in a western-style state, all the considerations apply analogously to the tremendous problems at an international scale as well, although we are of course not claiming that technology alone will bring heaven on earth.

2.3.7. Sustainable Food Production

Food production will remain a biological process with optimal results if those processes may take place under optimal conditions. Knowledge is the crucial resource to care for establishing such conditions which tend to be rather complex ones in contrast to the monocultural conditions prevailing in today’s farming. NBIC sensor techniques will play the role of monitoring devices to maintain optimal conditions. In addition smart robots will substitute the destructive giant technological tools like tractors weighing tons in the agricultural sector. An optimized logistic system will allow to distribute the (raw or refined) products with minimal energy consumption and damage by poisonous exhaust. In this vein agriculture will become part of the evolving bio-systemics (Bouchard 2003). This evolution may be the only route towards successfully feeding more than 8 billion people on earth without continuing to destroy huge areas of rich and vulnerable eco-systems.

There are at least three non-technological factors that need to be taken into account. First there is the increasing impact of a drift in the global climate. A second factor is geo-economics. When optimal food production depends heavily on technology, it may outcompete, even more than it already does, local production. Developing countries will become more dependable rather than self-sustainable. A third factor is geo-politics. There needs to be a political will, especially among the world's leading governments, to see sustainable food production in the light of global interest and development. Experience so far shows that this will is not acquired. Food is, today, an instrument of modern colonialism and of political pressure.

2.3.8. Sustainable Energy Production

Much the same as can be said for food can be said about energy as far as political considerations are concerned. Technologically, the new wave is expected to trigger an enormous push towards a more sustainable energy production. Perspectives center around the use of hydrogen, of fuel cells, a solution of the problems surrounding atomic energy production (including the potential of the transmutation of atoms for coping with radioactive waste), a possible breakthrough in the fusion technology, and especially an increase of the efficiency of energy conversion processes at all stages, a reduction of the energy demand by more intelligent use (better insulation, switch off when unused, etc.), and a distributed collection and use of renewable energy sources; for instance, nano-technology could help in developing solar cells with a much higher efficiency degree than possible today.

2.3.9. Protection of the Environment

Humankind so far has governed its actions based exclusively on its self-interest and ignoring the interests of the rest of the creatures on earth except if these clearly coincided with our own ones. We begin now to experience the consequences of these attitudes in the effects on the world climate, on the balance of huge ecosystems such as the ocean, the rainforest, the antarctic, and so forth. We begin to realize that these dramatic changes will have an enormous economic effect as well and that the extinction of tens of thousands of species per year eventually might also threaten the basis for our own existence. And finally we begin to realize how dramatic those threatening effects would become if a world population of 8 billion would adopt a careless lifestyle like that in the industrial countries. It is therefore high time to move from the human-centered towards a global perspective in which humankind is just one among countless other species deserving the right for existence in exactly the same way as us.

Converging technologies do offer the potential to "sharply reducing our environmental footprints" (Phoenix 2003). For instance, one of the reasons behind this dangerous development just outlined lies in the locally oriented way of thinking of humans or groups of humans. System-based assistants could compensate this local human nature with globally oriented advice based on global aspects of the respective situations (see the challenge problems in Section 5).

3. Technological Perspectives

3.1. Introduction

In this section the perspectives of the anticipated technological development are described where the emphasis is on those with an impact on individuals, groups, and the society as a whole. Again the material is not to be misunderstood to pretend completeness in any way although it covers a truly wide range of technologies. The selection of material to some extent reflects the expertise of the SIG members and just illustrates the kind of technology expected to evolve up to the year 2020. As we present the technological perspectives we will not judge their values nor do we relate them explicitly in this section to the needs discussed in the previous one. The critical aspects of such technology and the relationship among the two issues will be the topic of the next section.

In detail we discuss the trends in computer and communication technologies and their interfaces with the human user, and outline the technological vision behind Ambient Intelligence which will include Artificial Intelligence and Cognitive Science systems. A particular challenge thereby is the question of machine consciousness for which a rough understanding begins to emerge. As the digital and virtual world continues to grow rapidly the bridge to the real world is becoming an ever more important issue especially for manufacturing and trade, with RFID tags being the latest buzz. Having discussed all these topics centering around ICT we will then turn to issues of convergence with biological technologies from Biocomputing over organic technologies such as Biomimetics to Artificial Life. The section ends with a review of the rapidly growing Grid Computing idea and of the wide area of Simulation and Modelling, both already raising issues relevant for the gist of the subsequent Section 4.

3.2. Information and Communication Technologies

Historically the first fifty years after the completion of the Zuse3 computer technologically were dominated by the use of computers as numerical calculating and storage machines. In the eighties the computational paradigm has then started to pervade also the communication and media technology. The result of this novel process may be regarded as the first stage of convergent technology. The computational paradigm has now continued to pervade further areas, foremost biotechnology and engineering, and is on the verge of entering nano- and cogno-technology and thus resulting in the convergent technology termed NBIC-technology at the outset of this paper. In reviewing the perspectives of information and communication technology (ICT) realizing the computational paradigm we now proceed bottom-up, starting with the physical basis of computers.

The computer technology for some decades has been based on the transistor realized in CMOS (complementary metal oxide semiconductor) technology. This has been considered a micro-system technology (with structures measuring micrometres). But transistors as small as 8nm (nanometers) have already been realized 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 law, has at the same time sped up the central processing units (CPU) of computers. In the period from

1990 through 2001 CPU speed has increased 393 times. 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). Let us first focus on the CPU.

Despite the ongoing progress, competitors to the standard physical CMOS basis of computation are pursued in the laboratories worldwide. The reason is that in a decade or so the progress in this technology is expected to level off. Characteristically, the competitors all are convergent technological in nature. 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) 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 ideas pursued in the same vein. They rely on electron transport and its modification through a physical effect such as current channel pinch, spin effect, molecular orbital modification, Coulomb blockade, Josephson effect. Other effects are envisaged like nuclear spin (nuclear magnetic resonance, or NMR, computing), electron states in atoms (quantum optics devices, spin electronics), DNA hybridisation (DNA computing), ion transport and biomolecules (like neurons).

In a different vein a molecular based computer architecture could also be made with nanotubes and semiconductor nanowires. In Israel transistors were built out of carbon nanotubes (CNT) using DNA as a template (Chang 2003). Infineon succeeded in inventing CNT electric switches (Focus 2004). These technical achievements at the nano-scale open the perspectives for many more possibilities like even more densely packed transistors on chips (or rather in some different form) than possible with CMOS technology.

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 mechanics (and quantum electro dynamics) 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.

Returning now to the already mentioned data storage capacity 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 one 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 a factor of 1000 (Wood et al. 2003).

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. Atomic force microscope (AFM) technology 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.

The wireless data transfer is currently determined by the GSM (global system for mobile communication) standard which is expected to be substituted by the ITM2000 (international mobile telecommunications for the year 2000) family of standards which includes UMTS (universal mobile telecommunications system). With this technology transfer rates of 384 Kbit per second will be achieved and a convergence with the solid nets will take place which will allow transfer rates of several Mbit/s or more depending on the kind of cables used. This technological development is pushed by the exploding use of the internet in which the amount of data transferred doubles every three months (Warnecke 1999). Note, however, that today already more than 50% of the mail traffic consists of automatically generated (junk) mail.

We mentioned above that in the eleven past years battery energy density has increased by a factor of meagre 2.7. Low-power issues will however play an important role in the evolution of ubiquitous computing. This is therefore a topic where nano-technology might become crucial for a breakthrough in distributed low-power supply.

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). The interface perspectives are discussed in Section 3.4.

3.3. Software

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 continuing increase of computer power will of course be of some help towards implementing more human-centered interface technology. The crucial issue in this sector – as in many others – will be an improvement of software production which can still be regarded as the most important bottleneck plaguing the industry already for decades. It will not be overcome in the short, perhaps not even in the middle range.

The consequences of this bottleneck can be observed in many areas of the computing industry. The monsters of current operating systems (OS) are striking witnesses. The inflexibility of OS production is also blocking the functioning of the market forces in IT, this way causing the unfortunate dominance of a single company.

The application software market suffers from similar problems which have been demonstrated to the public by the recent scandal concerning the failed introduction of a toll system for trucks in Germany which is expected to be delayed by perhaps two or more years. Similar delays are the norm in all sectors involving complex software systems. The deeper reason lies in the negligence by all drivers behind ICT of the area of automation of programming including program synthesis from descriptive, informal and incomplete specifications. Progress in this particular area would certainly advance the smartness of systems much faster than by nano-technology. Unfortunately market forces fail in cases like that where big investments precede measurable progress and profit. Governmental actions like the US software initiative launched during the Clinton administration seem to be the only hope for a change in the longer time frame. New approaches to programming like those discussed in Section 3.10 might help in certain applications.

In the eighties the idea of customized hardware for applications like inferencing was heavily pursued. At that time 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 processor. 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 produced 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 blurred.

3.4. Communication Networks

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 lifes 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. For the present evolution of ubiquitous computing the so-called middleware with corresponding protocols (on top of the communication protocols) will allow multiple networked applications to co-exist and co-operate.

Along with the trend towards pervasive computing and communication technologies are already 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. The next generation of ICT may contribute to facilitating new modes of experiencing the environment and may change the way people communicate information, knowledge, ideas, concepts, sensations, feelings and experience through new communication tools.

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 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 assistents, semantic web, intuitive use) (Wahlster and Weyrich 2003).

3.5. Interface Technologies and Miniaturisation

In Section 3.2 we ended with stating the still archaic state of interface technology. 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, HMD and microdisplays, 3D displays). It is obvious that the development of such 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).

Chips components are getting smaller. 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 allows 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 24/7 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.

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 2010. 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 even 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, 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.

In Section 2.2 we have already discussed some technological means for communication between people such as through messaging technology. Section 3.8 will present further perspectives in terms of so-called RFIDs. These and others will establish novel links between people and the environment as well as between people and machines.

Augmented reality and awareness interfaces are another aspect of the advancing interface technologies. They are already used eg. in support of repair activities (special glasses etc.), cultural guides via Atavars, etc. and will continue to expand their areas of applicability.

Interfacing is not restricted to linking humans with the computer but in a more general sense also concerned with linking the digital devices with the rest of the real world. Like with the computers the trend here is also towards miniaturisation. On the micro-level we are dealing here with microelectronics, photonics, and especially microelectromechanical systems (MEMS) and their integration into integrated microsystems, by DARPA tabbed as the next revolution (Lemnios 2004).

3.6. The Ambient Intelligence Vision

As we mentioned in the previous section the interface between human users and computers is still far from what would be desirable. On the other hand we have in principle the technological insight to enhance this interface in a radical way. This potential in the coming evolution of ICT has led experts to outline such a future technology. This outline has become known under the term “Ambient Intelligence” (AmI) which refers to a vision of the future information society stemming from the convergence of ubiquitous computing, ubiquitous communication and intelligent user-friendly interfaces. This vision has been described in the ISTAG-Scenarios of Ambient Intelligence in 2010 (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.

Within the AmI vision ICT-based artefacts and computers would fade into the background. People would be surrounded by intelligent and intuitive interfaces embedded in all kinds of objects. 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. Ambient intelligence 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. 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 "Ambient Intelligence" 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*. We will use all three terms interchangeably in accordance with common practice. In other words, AI may well be seen as the central prerequisite of AmI; the similarity of the abbreviations is indeed not accidental. For that reason we will now discuss AI at length in the next section.

3.7. Artificial Intelligence and Cognitive Science

Artificial Intelligence (AI) has matured in 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 for sixty years. More important is the fact that AI technology is now integrated in a great many systems such as in web technology systems (eg. search engines) and is vital for many applications (like data mining).

It has now become a standard to structure this wide area 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 grid computing discussed in Section 3.12 may 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). But it is certain that AI and grid computing should definitely cooperate.

The core of AI consists in problem solving techniques at various levels of sophistication. 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 practically 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 (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) (Bonabeau et al. 1999), from natural behavior of biological beings such as ants (Dorigo and Stützle 2004), or are derived from the neuronal model of the human brain (connectionism). 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. If structures are attached to states, in some applications problem solving may amount to the classification or the learning of features.

At the next level of sophistication the 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), 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 practically 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 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 – see Section 4.1) of great generality.

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).

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 indispensible in a future Ambient Intelligence (AmI) easing the use of technological tools for the casual user (in stark contrast indeed to the current situation).

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 observe a two-legged robot, like Asimo from Honda, stepping up stairs in a rather elegant way, or of Spirit and Opportunity currently operating on the Mars in an impressive 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). It is especially the need for converging technology from even further areas which in this particular area has to be fulfilled. 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, a revolutionized farming technology, to mention just three out of numerous attractive perspectives.

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.

Artificially intelligent agents will also need to feature social intelligence, hence exhibit emotional behavior with which they are able to react appropriately to humans the way these are used to. Avatars will play their expected roles modelling human ones. More generally, organisational behavior and roles including ethics will similarly be modelled in a rational way.

3.8. Cognitive Science

The view taken of AI so far emphasizes its technological aspects. The founders of AI have always seen also the scientific aspect of this discipline aiming at the understanding of human intelligence and cognition. Unfortunately, this aspect is now often associated more with Cognitive Science as a separate discipline. To emphasize the importance of keeping both aspects together within a single discipline, *Intellectics* (Bibel 1992) has been proposed as a name for AI along with Cognitive Science (or *CogSci*). In this subsection we will very briefly address the CogSci part of Intellectics.

CogSci has evolved in the last decades to a booming science discovering many scientifically established insights into many of the cognitive functions of humans. In the UK a foresight project is underway which already has produced a series of reviews of the state of the art in cognitive systems. These include topics like sensory processing including speech recognition, auditory processing, vision, representations, and learning (Hughes 2003); action specification and selection (Barnard et al. 2003); learning and memory aspects like working, long-term, episodic, semantic, value, emotional, spatial and event memory (Morris et al. 2003); representation and learning (Walsh and Laughlin 2003); self-organisation and pattern formation (Willshaw 2003); speech and language processing (Marslen-Wilson 2003); social cognition including distinguishing the self and other agents, imitation, deception, complex emotions, empathy, morality, cultural evolution, but also communication failures like autism, psychopathy and others (Frith and Blakemore 2003); and finally advanced Neuroscience technologies such as brain imaging, single-cell and multiple single-unit recording, optical imaging, and combinations thereof (Ahmed et al. 2003).

In face of this excellent material there is no point here to go into further details of the huge body of knowledge now available in CogSci, which unfortunately is often ignored. In Section 4.7 we will discuss the importance of taking this knowledge into account.

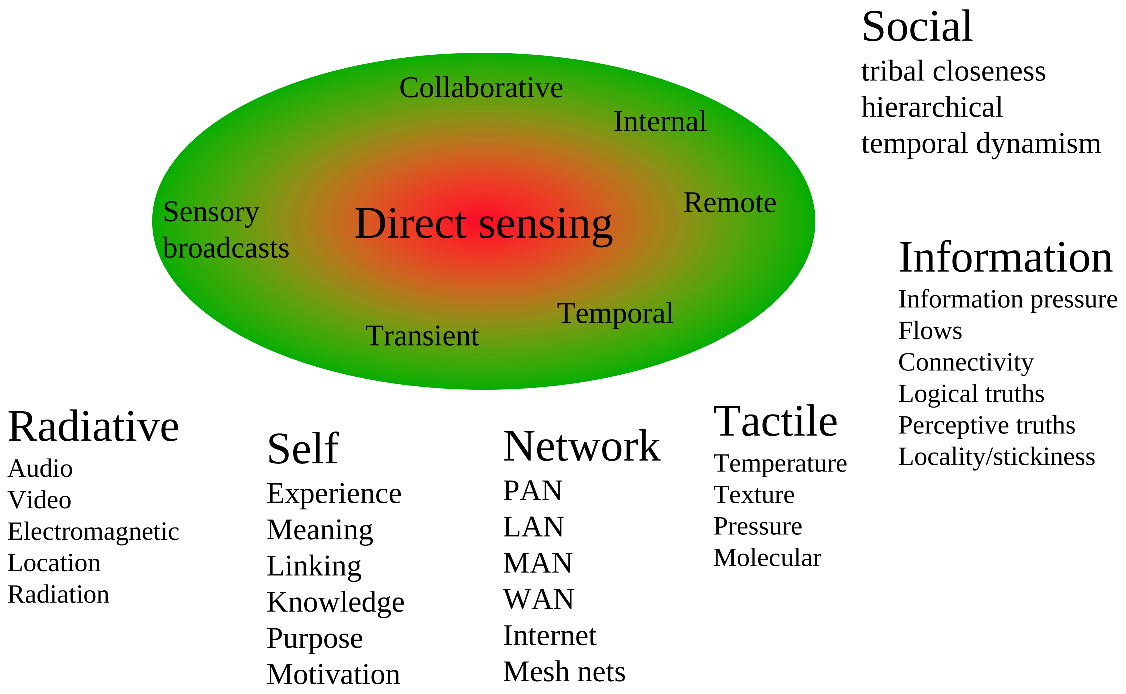
Some of the particularly challenging issues of Intellectics for their importance are discussed separately in the next section.

3.9. Machine Consciousness

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.

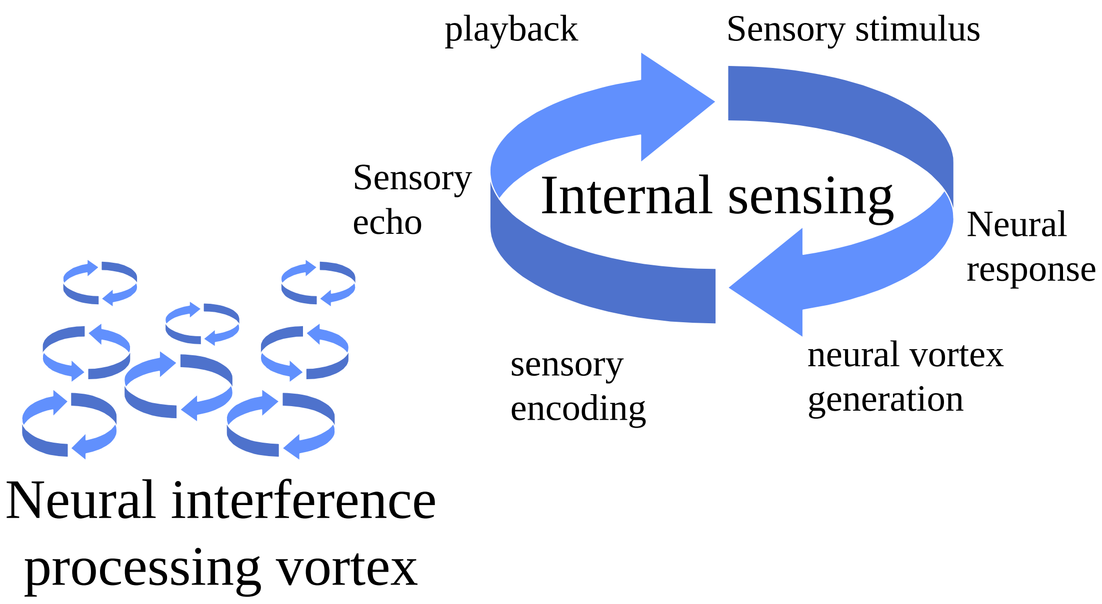
In computers we might be able to realize all these external sensing modes and even further ones not available to people. The following picture illustrates the variety of possibilities in such sensing modes and technical features within an envisioned future global sensor network.



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.

3.9.1. Internal Sensors and Feedback

Internal sensory feedback is assumed to be a critical component of consciousness. Internal sensing allows us to feel the processes and impacts of thoughts. A crude model for synthetic consciousness based on internal sensing is illustrated in the following picture.

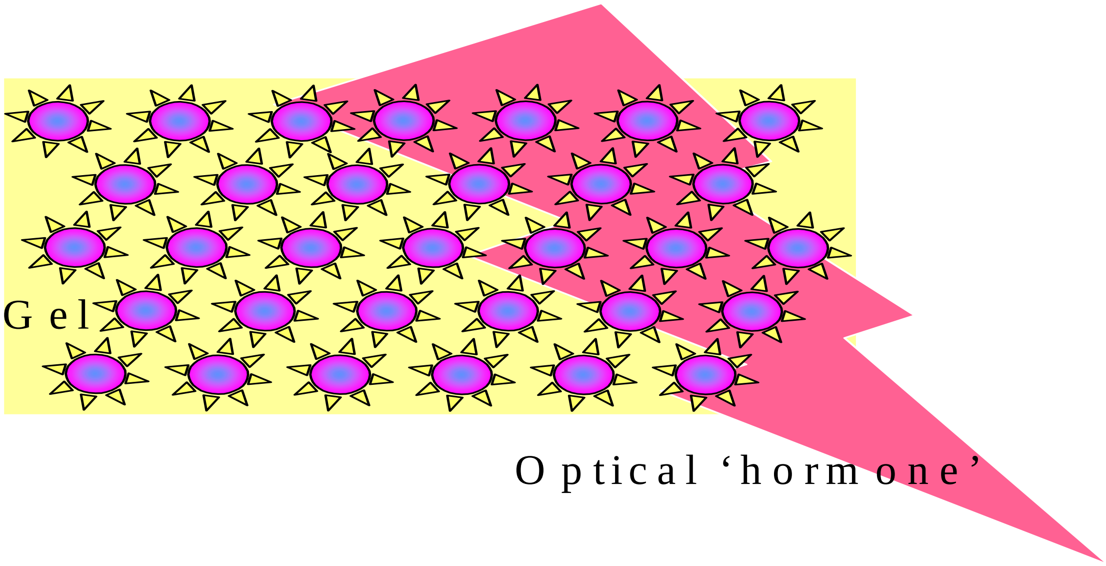


It shows the cyclic structure of internal sensing whereby the sensory stimulus is some internal state or process, which leads to some neural response this way generating a single neural vortex. The neural interference between many of such vortices is supposed to create new thoughts and the sensation of thinking

3.10. Emotions

Emotions are similar in essence to feelings that arise through our external sensory system. There is a feeling associated with being happy, sad, angry, elated, and so on. These may therefore be emulated by an internal sensory system of the kind just discussed.

Emotions can also be an important factor in the decisions we make or the thoughts we think. This effect may be emulated by applying a bias to the neural behaviours in the appropriate active region of the matrix of neural processing elements (possibly realised by already existing CNN-chips, ie. cellular neural networks, see Mainzer 2003, pp. 127ff). In an optical neural matrix, we may do this simply by applying a pool of light of the appropriate frequencies to the required region(s). This realisation of emotions by applying a light beam to a region of optical neurons is illustrated in the following picture.



It illustrates a 3-dimensional gel with a suspension of neurons, say a trillion in 100ml. These are connected optically sending off light beams to nearby neurons in the order of two million such connections. The red area illustrates a lightbeam which changes the responses equivalent to the function of a hormon. To be sure this is only an artificial model of what could happen in the brain. But beyond its explanatory nature it has more potential for technical applications because of the high numbers of neurons which could be realised and because of the integration of optical technology.

3.10.1. Supervisory Role

It feels like we have some sort of mental supervisory agent, that allows us to think about what we are thinking, or how we feel, but the actual 'experience' of this is sensory, not logical. Again, this may be emulated simply as an internal sensory feedback loop. Alternatively, it could be modelled logically through *logics of knowing* (see Bibel 2003). However, this appearance of a supervisor is now discarded as a real explanation for consciousness by current neurologists. They insist there is no supervisory function, no 'seat of consciousness', no-one 'driving'. Today this is thought to be a distributed effect, with consciousness arising by some distributed means.

On the other hand, the general principles of virtual biomimetics hold that it isn't necessary to copy nature precisely in order to gain insights from it. It may be entirely possible to achieve genuine consciousness in a machine using such a supervisor, even if this is not an accurate explanation of how it is achieved in humans. Either approach may be attempted. Ultimately, the goal is to achieve advanced consciousness, not necessarily to emulate humans.

3.10.2. Filters and Interference Processing

Filters are obviously an important factor in sorting information, sifting the useful or interesting from the rest. But filters may also be used as a processing mechanism, especially when based on pattern matching rather than sequential algorithms. Pattern matching may be done by neural networks. The outputs of those neurons directly interact with outputs from other batches of neurons that result from other pattern matches. This matching and interaction would happen continuously as signal waves propagate and reverberate around the neural matrix.

The ‘mental model’ within the machine uses the mechanisms of sensory recording and replay, essentially replaying the neural behaviours that resulted from the original stimulus, either randomly, or as a result of another stimulus, such as a pattern match occurring. This is called a phantom experience, and is akin to memory recall in humans, reliving an experience, or repeating it in a dream. A number of such experiences may play simultaneously throughout the neural matrix, resulting in a neural vortex, with some neurons being stimulated by multiple replays. The neural waves reproducing these experiences essentially interfere at these neurons, resulting in interference processing. This ‘cross fertilisation’ may result in new ‘thoughts’, by creating patterns that match onto other stored experiences or memories, thereby stimulating new activity from the affected neurons.

These internal sensory playbacks compete for attention with external inputs as a focus for consciousness. The matrix’s attention will wander between such processes as they rise and fall in relative magnitude, indeed consciousness may be focused simply by relative magnitude of competing processes, therefore removing any need for a supervisory role. The ability of these replays to interfere with other neurons and reawaken stored memories for replay ensures a continuous consciousness, intermittently focused on the outside world and sometimes focused on internal memory recall, and sometimes on the new patterns or thoughts stimulated by the interaction and interference of these processes. Consciousness itself may result simply from ongoing sensation of this interference and competition. There is always something going on to be sensed.

Short term memories would be expected to reverberate around the system for some time, in proportion to the magnitude of the original experience.

3.10.3. What Are Ideas Made of?

When we talk of ideas and concepts, we often talk of ‘visualising’ them. We often construct fuzzy internal ‘videos’ or relationship pictures, which may have parts of other sensory memories attached, to illustrate the ideas to ourselves, so that we can manipulate them. In that sense, many are composed of recycled elements of things of which we have experience, even if that experience is just seeing something in a film or reading about it. This simple model can work for a large proportion of our internalised concepts. This works well with the idea of phantom sensory replay addressed earlier.

3.10.4. Understanding

Understanding is a set of concepts in our mind with interrelationships between them. This collectively makes up a dynamic mental model. New experiences and thoughts may lead to concepts or relationships being created, deleted or modified. Thinking is the process or arriving at understanding, involving recognising instances of concepts and establishing connections between them (Perlovsky 2000). According to this reference perception is when a subset of data in the external world corresponds to a concept in our mind. Any structure that we perceive does not exist only in the outside world but is imposed by our mind. Perception is the process by which a stream of sensory data becomes a recognised pattern. Cognition is similar where a bunch of disparate concepts suddenly comes together to make sense (like the interference processing above). It is recognising that one concept is a particular case of another broader concept. Relationships between previously unrelated concepts may this way be established.

Perlovsky says that in both cases, a fuzzy a priori model dormant in our minds is suddenly activated by input signals and this model imposes its structure on these signals. In the process it becomes less fuzzy and more structured, the model resonating with the input. This view is in line with the filter and pattern recognition systems suggested above, and should therefore be capable of machine reproduction.

3.11. Coupling the Real and the Virtual

The AmI vision is based on a number observations and assumptions concerning the technological trends. One of these trends is the ongoing *miniaturization* of computing devices. Because of this trend along with the possibilities of wireless networking and the progress in power technology it becomes possible to embed such devices in all kinds of tools and objects, even in living organisms down to individual cells or bacteria, and so forth. The applications range from *smart materials*, programmed to exhibit varying structural properties, to the possibilities of an *active skin* which adapts eg. to the changes of the light in the environment. We will encounter applications of *embedding* in this and the following sections.

One consequence of miniaturization and embedding is that technologies (like computers and others) become invisible. They also become non-localisable and non-localised. Because of these properties a whole range of novel applications is looming at the horizon. In particular it becomes possible to couple the real world closer with the digital one. This perspective underlies one of our challenge problems (transportation) in Section 5.

One specific technology in this context is the association of objects with radio frequency identifications, or RFID tags which will be treated in this subsection along with the resulting perspectives for manufacturing.

3.11.1. RFID Tags and Physical Space/Cyberspace Convergence

There is now a new buzz about tag based customisation. *Radio frequency ID tags* 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 customer 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 two 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.

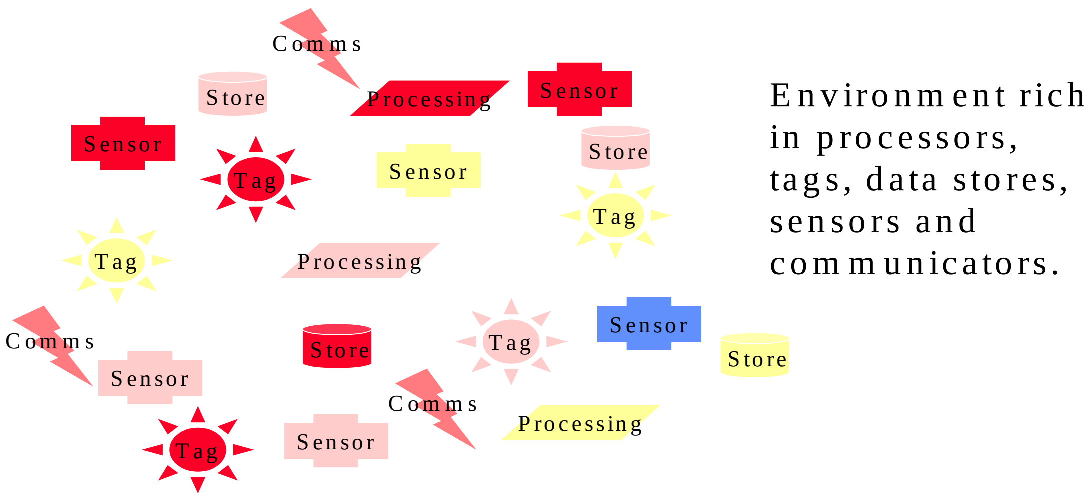
Imagine eating a Bassetts' Jelly Baby. Now imagine eating a future jelly baby, if Bassetts have decided to enhance them with silicone edible-electronic tags. Because of its sophisticated cyberspace part, the jelly baby can now scream (through your PC speakers or Bluetooth headphones), and can fight back. 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 one, 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' either this Christmas or next 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 discussed in the previous sections (and of the kind treated in Section 3.11). Such an environment is illustrated in the following picture (with the pictural symbols explained therein – "Comms" being short for communicators).



Ubiquitous devices

3.11.2. Manufacturing

Starting with the invention process, computers will become increasingly adept at analysing customer needs, based on the enormous volume of data collected at the point of sale. Trends can be spotted and linked to lifestyles, and gaps in the market identified. Computers are also already inventing useful objects, by taking ideas that have been developed in one field and applying them in another. This cross fertilisation is often used by humans when brainstorming but works just as well for machines. Humans and machines will mostly work together though, making the most of their relative strengths. Customers may be involved frequently during the later invention stages and throughout the design process. Even when a concept is just a few bits in a computer file, visualisation technology can help customers to appreciate the possibilities and feed their comments into the design process, often inventing features that perhaps an engineer might have overlooked and omitted. Virtual environment technology is able to use avatars (3-D computer likenesses of people) in realistic synthetic environments to show users how a product might fit into their lives, thus taking a much more active part in the design and customisation of products. A woman choosing a design for a new wedding outfit might be able to try it out at a virtual reception with her friends, who are simultaneously co-ordinating their outfits for the same wedding.

People often resist the notion that computers can be creative, but they can already write music and novels that are almost indistinguishable from human produce. Design lends itself to similar automation. Computers can sample various design styles and produce endless variations and combinations. Evolution techniques can interact with the user to steer designs in directions that the user wants, thus increasing the degree of fit and improving personalisation and individuality.

Manufacturing itself relies increasingly on computer-controlled tools, and as they become more sophisticated, so we will see more personalisation and greater customer involvement. Since the net 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.

There will certainly be a great deal more inclusion of information technology in products. Pervasive computing will include myriads of tags and activators that are built into products of all kinds. Radio frequency identity tags are the first generation of these, and are expected to replace barcodes in many products over the next few years. For instance, SAP is just marketing a system of this kind. However, ultra-simple computing, data storage and sensor devices will also be developed. Products can be located, identified, and communicated with, even involved in processing. Chips will be absolutely everywhere. We are already considering many applications for chips inside our skin, and jelly babies that scream when you bite off their heads! However, adding chips doesn’t imply adding huge expense. The same chip that powered the Apple 2 computer in the early 1980s would be 0.15mm across today, cost a cent and still run 2000 times faster! Identity chips are also expected to enter the market at around the cent mark. They can be interrogated and programmed from up to a meter away. Because these activators will generally be self-organised and use short range communications, they can be easily located in any product without the need for accurate positioning. We would expect them to be mixed in with the plastic in mouldings for example.

These chips will help a great deal with the trend towards treating some physical products as part of a service rather than being sold outright. The customer might buy a television ‘service’, and the actual TV set is remotely maintained by the leasing company. This allows service bundles to be tailored for long after the TV delivery. Adding activators gives the capability to include low cost processing, remote sensing, location and identification facilities. The service provider could ensure that the product only works at the agreed location, remotely diagnose faults, upgrade software and adjust the service levels. This kind of package might be suitable for many of the products we use in the future, and make economically feasible many services that rely on kit that becomes rapidly obsolescent. Many other products will still be bought outright, but in many cases will still contain such chippery because it allows the buyer to maintain them. Kids could police their belongings to prevent their ‘borrowing’, use or abuse by siblings.

Packaging will be affected by the changes in the way people shop. If they are dealing direct with the manufacturer, there is much less need for any packaging that is designed to catch the eye on a store shelf. It can be much more functional. This would reduce costs for at least part of the output. But it also will change the brand perception, which will become less visually anchored and more identified by advertising that links products to lifestyle aspirations. We will see a migration of brand influence also to third party quality assessors, who will help customer decide which product they want from the hundreds available worldwide from web-based ordering. These assessors will tell you which one you need for your personal lifestyle and your budget.

The distribution industry takes the product from the factory gate to the customer, and this too will change. When dealing via the phone or net, we rely on postal services or couriers to bring the product to us, and often we are away from home when it arrives. This is obviously unsatisfactory and won’t be accepted in a few years. Instead, we will have two tier distribution that takes the product from the manufacturer to a local warehouse, specified by the customer, and they act as our local receiver. They hold onto the goods until it is a convenient time for us. Over time, this local distributor may become much more powerful. Often we want goods of a particular specification, but don’t care much who makes it, since quality is ubiquitously acceptable. We may be happy to ask our friendly distributor to use one of their contacts to get us what we need at a good price at the right time. They will be in a good position to develop and exploit this kind of loyalty and trust.

After-sales activity can be facilitated greatly by means of chips in the product. They may be able to put an electronic manual on our TV screen via the web, or assist in fault diagnosis. Customers will be able to add new facilities or simplify interfaces by removing those they don’t want. Products will slip easily into electronically managed homes and offices, though we shouldn’t expect these to be quite so widespread as some hype would suggest. In particular, we must guard against adding any functionality that isn’t fail-safe or doesn’t have an easy physical operation mechanism when the software inevitably fails. An automated kitchen sounds nice, but if it doesn’t work when the kids need breakfast before going to school in ten minutes, we will see a new social phenomenon of kitchen rage.

Finally, all products eventually die or need replaced, and green culture dictates that they should be recyclable. Clever use of materials has already given us phones that dismantle themselves when they are dropped into hot water. Embedded identification chips will direct materials for appropriate recycling too.

Apart from all these changes in the manufacturing cycle, we will also see the ubiquitous changes in corporate structures. Personnel and finance departments are routinely being outsourced already, and often automated at the same time, so that they need far fewer staff even in the outsourcing company. Other departments will see similar downsizing until we get to very lean companies with a few elite people backed up by an army of smart machines and software. The rest of the people will simply have to retrain, and because new jobs eventually get automated too, this will be a regular cycle for many workers. It is inevitable in the endless pursuit of better quality and functionality at ever-lower cost.

3.12. Bioinformatics, Neuro-Informatics and Neuro-IT

One of the areas where convergent technology is successfully evolving is Bioinformatics. As usual with new disciplines its boundaries are not clearly drawn. Even its name varies considerably: apart from Bioinformatics also *theoretical biology, computational biology, biocomputing* and others are in use although these other names are usually associated with different subareas (eg. computational biology with the computational modelling of biological phenomena). The area is characterized by the methodological approach which merges biological terms and knowledge with concepts from Computer Science or Informatics and especially from Artificial Intelligence (AI). AI is of particular relevance since the search spaces for solutions to particular problems are huge and can especially be coped with by AI methods which have been developed for treating such huge spaces of data and structures.

A recent issue of the journal Machine Learning (vol. 52, no. 1–2, 2003) focuses especially on “Machine Learning in the Genomics Era”. Similarly the AI magazine (vol. 25, no. 1, 2004) more generally focuses on “AI and Bioinformatics” and presents several exemplary applications of AI techniques to problems in Bioinformatics. Here we just mention a few of them from this issue.

As is well-known the genes of biological organisms are carried by the DNA (deoxyribonucleic acid) molecule contained in the chromosomes. The collection of all genes of an organism is called a genome. A central thesis is that the genome carries all the information necessary to construct and operate a living agent. For that reason determining the DNA sequence of living organisms in sequencing projects has become a dominant activity in bioinformatics. For several dozens of organisms, including humans, the complete genome sequence and for tens of thousands others important parts of it are now known.

Microarray or gene chips are recently developed devices to detect tens of thousands of sequences simultaneously. The interpretation of the massiv data produced in such experiments requires advanced AI technology. Especially machine learning techniques have turned out to be crucial for the interpretation of the resulting data. For instance to determine which combination of genes is responsible for some desease requires the discovery of regularities in a huge amount of data taken from samples containing about 10,000 genes measured on a gene-expression microarray. This is a daunting task for a human but a relatively natural one for a machine learning algorithm.

This is just a specific example of the general problem of what is the function of each of the genes in the sense of its role in the processes of life, among many other problems concerning for instance the processes of transcribing the gene information into RNA (ribonucleic acid) and of translating the resulting nucleid acid messages into protein molecules, the main actors in the biological mechanism. This translation process is called gene-expression. Already the machine learning techniques are also useful in gene-expression analysis. Other approaches work with lexical analysis whereby ontologies (eg. the Gene Ontology) play a fundamental role. Particularly successful are Inductive Logic Programming approaches to the prediction of gene functions.

Since biological data are extremely complex, the discovery of novel relationships is a challenging task and often surpasses the capabilities of the human mind. There is a long history in AI in the subarea of automatic discovery. The techniques evolved from it seem to excel in the area of Biological Sciences as demonstrated by a system called HAMB which has led to numerous interesting novel discoveries.

Two further and related areas where ICT converges with (neuro-) biology is *Neuro-Informatics and Neuro-IT*. Neuro-Informatics can be characterized as the area where computer science (especially AI) concepts and technologies are applied to the modelling of aspects of the brain. Conversely, in Neuro-IT the neurosciences contribute to IT paradigms. Obviously, the neurosciences are closely related to the cognitive sciences. The distinction might be phrased such that the neurosciences study the brain at the biological level while the cognitive sciences (see Section 3.6) take a more abstract approach on what is called the cognitive level and are concerned with higher level concepts like memory, learning, social cognition, mind etc. But the boundaries are so fuzzy that it would be reasonable to merge all these subareas into a single one in the spirit of converging technologies. Intellectics coined in 1980 (Bibel 1992) was meant to combine just AI and CogSci. It could be extended to also include the neuro-sciences and thus cover the entire area studying all the phenomena concerned with the intellect and the underlying brain, be it natural or artificial.

Within the Framework Programme FP5 the Thematic Network *Neuro-IT.net* has been established which comprises far more than a hundred researchers from close to a hundred institutes and SMEs (see http://www.neuro-it.net). It is aimed at building a critical mass of new interdisciplinary research excellence at the interfaces between the neurosciences and Information Technology in Europe. In a Roadmap (Knoll and de Kamps 2003) it has outlined three major challenge projects, viz. the *Brainship, Factor-10* and *Constructed Brain* projects, which are deeling with interfacing the brain with computers, with artefacts that evolve their cognition and motor control, their skills, or even their bodies and “brains” autonomously, and with the computational modelling and simulation of the entire brain.

A lot of research is already being conducted in this entire area worldwide. A list of EU funded projects within FP5 of this nature may be found in (IST-FET 2003). Example topics in this list are a CYBERnetic HAND prothesis, artificial vision systems, or the creation of an electronic tissue for phylogeny, ontogeny and epigenesis based machines which should be capable of evolution, growth, self-repair, self-replication and learning. Obviously this research is intimately related with the Artificial Life research to be discussed in Section 3.11 and with that reported in the following section.

3.13. Organic Technologies

Converging technologies may change the way in which we think about the relationship between the natural and the artificial. So far we have been developing our technologies as sophisticated mechanisms that are used to fashion tools. These tools become the extension of our bodies and minds (for the dualists) and enable us in more powerful interactions with environments and people.

Organic technologies are different. They are like nature itself. Think, for instance, of ambient intelligence, not as something being designed, but as something that grows around and with us. Its design is closer to the craft of the garden designer and gardener, than it is to that of the engineer.

Converging technologies confound the living and non-living, the natural and the artificial in a single new substance of reality.

3.13.1. Biomimetic Self Organisation

You will have seen ant colonies, the ants wandering around busily, often seeming to walk around at random. Ants are small and don't have much brain – so aren't very smart. In spite of this, the colony manages to gather food efficiently, and organise itself in many apparently complex activities. Such observations have created a whole new field in engineering, called biomimetics, basically copying good ideas from nature in our own engineering; the meta-heuristics discussed in the section on Artificial Intelligence and Organic Computing are important subfields of biomimetics.

The ants are an excellent example of what we can learn. Let's consider just the task of gathering food. If we were to build an ant colony using traditional engineering practices today, we might have a central headquarter with lots of ants maintaining a huge database that records the location of all the best food supplies are, what they contain, and how much food is left. It would probably have a personnel department, managing which ants are dealing with which food supply, their personnel records, how much they have brought back to the nest this week, when they are next due for promotion. We would have a logistics department, working out the best route to the food and issuing maps to each ant so that they could find where they are going. We would have a procurement department, sending out scouts to find and map out the local food supplies and check regularly how much remains. We would have a medical department, dealing with ants that get injured on the job, and probably many other departments too for other support functions.

Now look at the same task from an ant's point of view. If an ant stumbles across some food, it carries what it can back to the nest, laying a pheromone trail with its abdomen. When it gets to the nest with the food, it drops it. If an ant stumbles across a pheromone trail, it follows it away from the nest. Otherwise, it just walks around at random. These four very simple rules are all that are needed. Ants don't need to know where the food is, the combination of random walking and pheromone trails ensure that food is eventually found. Efficiency is less than perfect, but that doesn't matter to the colony. This simplicity of solution is abundant in nature, but such solutions aren't just simpler, they are more robust too. If a few ants die or are injured, the food gathering still works, it just takes a little longer, but then there are fewer ants to feed, so the magnitude of the problem neatly scales with the available resources. If you randomly delete a few lines from a computer programme, it will probably not work at all.

When BT (the UK-based telecoms company, formerly British Telecom) looked at the complex task of network management from this new perspective, many new, simpler, more robust techniques were found, and the work is continuing. Their research now has a whole team looking at Biomimetics. The mechanisms that nature uses for self organisation of hair follicles on a fruit fly's abdomen have inspired a new mobile network design mechanism. The process of evolution has inspired genetic algorithms that allow new software to be written by computers. Random mutations of the code are tested against other mutations in a competitive environment in the computer's memory. The best suited programs survive to the next generation. Over thousands of generations, a crude piece of original code mutates into something that does the task very well indeed, often with fewer bugs and a more elegant design that would have been achieved by human programmers. The techniques have also been adapted to design hardware. Humans aren't redundant yet, because the techniques still only work in limited fields of development. There is still some way to go before computers become as good as people at writing code, but it is still expected that most programs will be written by computers one day, perhaps as early as 2010. Nature has had three billion years of research time to generate its various solutions. Now that human engineers have rejected their earlier arrogant view that they must know better than nature, they are discovering new ideas regularly. Of course, copying the idea is just the start, techniques that work fine in nature usually have to be adapted to our artificial world, but biomimetics already makes a significant contribution to engineering development and we can expect it to rise sharply over the next decade.

The main advantages that biomimetics confers are simplicity, compactness, elegance of design, cost, reliability and more graceful degradation of performance when a failure occurs, and perhaps most of all, the relative hands-off nature of systems that use such principles. For example, the emulation of the ant-like principle in network management makes for a system that should sort itself out most of the time, adapting to changing traffic patterns, even rebalancing loads and routing around problems when a cable is cut through by a mechanical digger (an occurrence that happens all too often). Even synthetic ants have very little need for intervention.

Biomimetics isn't constrained to solutions from the animal world. Humans pass on ideas by word of mouth and advertising, which are robust ways of spreading information that don't need elaborately designed networks. Physics and chemistry offer many solutions too. If we aren't prejudiced about the source of ideas, they may be found everywhere.

3.13.2. Artificial Life

The notion of artificial life will take on a whole different meaning. So far, artificial life has been mostly bread within the virtual worlds, not in reality. With converging technologies, however, there is no obstacle to 'programming' the same evolutionary mechanisms in physical substance. Artificial life will be as real as life itself, but it will not be limited to reproducing life-forms that are similar to ours.

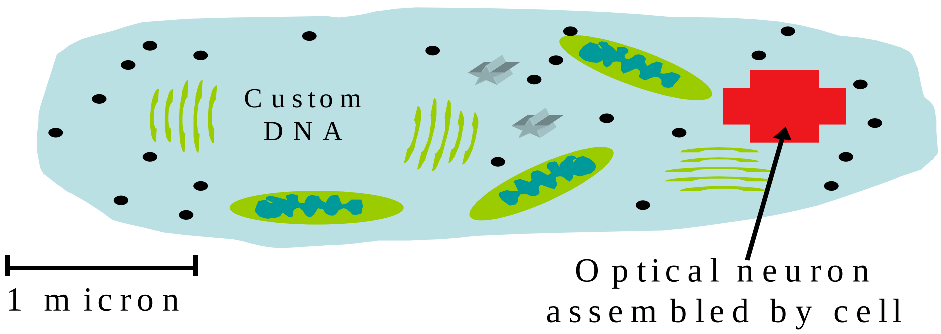
There may be some potential in artificial botany, aiming at ambient intelligence inspired by plant-life, rather than animal life. Such a study could grow intelligent ambiences for people to live in, similar to the way in which a forest or a garden develops.

3.13.3. Bacteria as life in real world and in cyberspace

The most publicised work in genetic modification to date has been in making crops that are resistant to pests or weedkillers, have a better shelf life or taste, or that can grow in conditions where unmodified organisms would be unable to thrive. Reaction to the technology has often been negative. Many people are even more concerned by future prospects of customised children. However, one of the most significant areas of future development will be in using proteins within living cells to assemble nano-structures such as small molecular clusters or tiny electronic circuits (ribosomes assemble amino acids into specific proteins trillions of times a day in each of our bodies). The next decade will see enormous effort concentrated in working out the precise mechanisms used by the many biological proteins, and will give us many tools for this kind of assembly.

Meanwhile, development of molecular switches is accelerating, along with molecular sensing technology, as is of course the use of carbon nanotubes to act as wires linking the switches and sensors. Such bottom up assembly is often hailed as the natural replacement for today's lithography, which is becoming increasingly difficult as feature sizes fall. So far however, the assembly has been assumed by most people to be done by tiny machines, not by biological cells. If bacteria can be genetically modified to do the assembly of circuitry, it will be a major breakthrough.

Another would be that the circuitry could actually stay inside a bacterium, and be powered by the bacterium's own biological powerhouses, the mitochondria. In a decade or two, there could well be bacteria that enclose fully functioning electronic circuits. Even though the circuitry within each cell might be limited, self organisation could link many bacteria together into useful computing, storage or sensing devices as illustrated in the picture below.



Bacteria linked together via infrared, to make sophisticated self organising circuits

The picture shows a single bacterium, ie. one cell, which is selfsupporting (while a neuron is not really a cell but more like a mechanism). The bacterium's mitochondria is shown in green which realizes the cell's energy mechanism. Each of such a bacterium may optically be connected to other cells.

Bacteria of this kind would self replicate quite naturally, with their computing power growing organically. It might become possible to grow very large and powerful computers in this way, without the traditional problems of power supply and heat dissipation directly taken care of by nature. Using an evolutionary design methodology, it might be possible to program large clusters for consciousness. It is a frightening thought, but in the far future, your yoghurt might be much smarter than you are!

Of course, once the circuits in the bacteria are linked into the global networks, the bacteria start to have an existence in cyberspace too. Artificial intelligence may be anchored physically in the bacterium, but extend and be amplified by extra intelligence in the network. Bacteria can collectively form very sophisticated entities that might physically span the globe. In fact, artificial life can take on a dual existence even if the physical object has no greater intelligence than an identity tag.

3.14. Grid Computing

Grid Computing refers to an emerging vision of combining many computational and informational resources down to the nano scale which we already mentioned briefly at the beginning of Section 3.6. It is seen also as a new tool for computer simulation and group performance through knowledge sharing and novel forms of co-operation (innovation networks).

Grid computing is developing at an almost incredible speed. It has significant potentials to reshape the ways in which resources such as data, information and knowledge, can be produced, distributed, utilised and exploited in networked contexts – not only in science and R&D but also throughout society. It is expected that grid computing will play a central role in approaching and forming the so-called 'knowledge society', possibly with a similar or deeper impact than the Internet.

The term *grid computing* has different meanings for different people. Early visions of 'the grid' derived from the metaphor of the electrical power grids, and in analogy to that the ubiquitous availability of virtual resources like computing power, data or knowledge 'in every house' was envisioned under this term.

Nowadays, we might distinguish two meanings, a narrow and a wide one. In the narrow sense the useage of a grid architecture is to run one computation on many distributed CPUs through a high-speed network (Nakamura et al. 2004). In the wider sense grid computing refers to a concept based on an infrastructure that enables the collaborative use of resources such as high-end computers, networks, databases, and scientific instruments owned and managed by multiple organisations. In the context of research, grid computing is mainly understood as an electronic infrastructure for the sharing of large-scale resources in research partnerships, leading to new forms of 'e-Science' (Foster 2000; Johnston 2002; Kunze and Marten 2002; Baxevanidis et al. 2002; Hey and Trefethen 2002).

The grid metaphor also indicates the dimension of efforts that have to be made to create an all-embracing grid infrastructure and the multitude and importance of the socio-economic implications necessitating a long-term research conception.

Recently, different types of grid computing can be found in the literature, eg. *computational grids* enabling the sharing of large-scale computing power, *data grids* enabling the utilisation of large dispersed data bases, and *knowledge grids* enabling queries on multiple dispersed data bases utilising data mining and extraction methods to optimise and combine responses from different sources. Additionally, different user communities can be identified. While grid computing emerged in specific academic and engineering communities, its usage is now envisaged to extend to further academic disciplines like the Life Sciences (Arzberger et al. 2004), to public and corporate research partnerships, to business, and (more visionary) to private persons. Improvements in the access and utilisation opportunities of processing power, data sets, information and knowledge are promised, providing enhanced opportunities for smaller research units, small and medium sized enterprises or even the citizen to obtain many high-level resources 'on demand'. To achieve the full momentum and to fully exploit the potentials of grid computing those extensions of usage fields are crucially important.

Another development line worth detailed consideration is the development of the '*knowledge grid*' (Zhuge 2002). Here, issues of resource and knowledge discovery, the prerequisites of knowledge sharing, and of the exploitation of knowledge seem to be those most important for intensive research, also assuming that the 'knowledge grid' is spreading to wide user areas of society.

Grid computing is about to spread to industrial and private applications. Extending this trend we are touching visions of the 'one grid' or 'the grid economy'. At the end may stand the vision of the 'World Wide Grid' (WWG), which may have the potential to supplement and partially displace the World Wide Web (WWW) under the condition of finding those grid applications which are attractive for industry and private persons.

However, several *socio-economic challenges* have to be targeted to realise those potentials, in particular managerial and economic issues of coordinated resource sharing and problem solving in dynamic, inter-institutional virtual organisations. The main challenges, which became apparent recently, are access control, resource allocation and resource discovery. Grid-enabled resource sharing requires particular prerequisites especially when resources stem from different types of organisations such as public or private entities.

From a perspective of the sociology of science, grid computing gains tremendous importance since its application changes the production of knowledge as well as the structure and types of knowledge. Grid computing empowers the production, processing and distribution of unprecedented quantities of data. However, the socio-political influence of grids on general changes of the science system are still hard to predict.

What is also becoming visible is the integration of several scientific methods in grid computing, specifically theory, experiment, and computation. Here, grid computing reinforces the trend in the usage of *computer models and simulations* in scientific processes which extend and partially substitute the 'traditional' approaches of theoretical analysis and experimentation. Computer models utilise analysis and visualisation capabilities to generate added insights into the dynamics of complex natural or social systems, which would be visible neither in the underlying equation systems nor in the numeric solutions. Computer models have a pragmatic potential in research by enabling scientific analyses of huge data sets and, therefore, the generation of knowledge not accessible through theory and experiment.

The need for specific *considerations of the legal, organisational and socio-political requirements* in academia and in public/private partnerships to pave the way for the success of grid computing is also recognised by the grid technology community. However, the socio-economic challenges of grid computing are newly recognized research issues, in other words, these research issues are characterised by *a great degree of novelty* and cannot be treated within the research tradition followed so far. This makes the assessment of the societal impacts even more uncertain.

3.15. Simulations

Computer simulations are becoming an important tool in many areas of scientific research, especially in cases where traditional mathematical methods fail in view of the analysis of highly complex systems. In many cases, there is no other method of investigation at hand, be it that analytical methods break down because of the non-linear behaviour of complex systems, or that experimental methods are too risky or simply too expensive or infeasible. To mention just some examples out of the broad spectrum where computer simulations are applied: How would two galaxies interact if they collide, how is a car body deformed during an accident, ie. in a virtual crash test, how do people react to a specific marketing strategy introducing a new product on the market, or how will the global climate change over the next fifty years?

Many institutes around the world are working on large scale simulators for answering these questions. Recent examples are the following ones. NASA uses a 512 processors computer to model atmospheric and oceanic circulation. Other computers use as many as 2200 processors, such as System X, used by Virginia Tech for a variety of simulations, and although it is the 3rd fastest computer in the world, it only cost $5M. The Whole Earth Simulator in Japan aims to simulate the entire environment. A number of other computer systems simulate the environment to a large degree for regional purposes such as earthquake or tidal wave modelling. Such computers will be useful in estimating the impacts on the environment of some future NBIC technologies. In areas where nanotech and biotech are considered as a potential means to reduce CO_2 and the effects of global warming, we will need access to such resources to ascertain the likely impacts. This is essential in any environmental intervention to ensure that we don't make matters worse.

Agent based modelling is commonly used in industry to try to predict market behavior. It relies on simulating individuals and guessing their likely behaviour in given circumstances. Today they are based on a very crude model of human behavior; but progress in cognitive science and psychology should help improve their success. Also, ambient intelligence puts people at the centre of computing systems, and provides a direct means of monitoring behaviour. If used well, the convergence of Intellectics (ie. Cognitive Science & AI) and ICT via ambient intelligence will provide huge volumes of useful data that can be used to optimize industrial marketing and product design. Further ahead, convergence of ICT and Intellectics with biotech, perhaps using nanotech components, will allow even greater direct integration of products with humans, enabling a direct feedback of human requirements into the design cycle.

Computer simulations constitute a particular class of models, distinct from theoretical models that are tractable by analytical methods. Admittedly, simulations often are based on theoretical models (eg. a system of non-linear partial differential equations), but even in these cases simulations are an autonomous instrument of knowledge production and not just numerical solutions of the underlying set of mathematical equations. A simulation can be viewed as the imitation of a dynamic process by a generative mechanism. There are different types of generative mechanisms including discrete difference equations to imitate the dynamics of continous processes in nature and society, complex agents with specific behaviour to imitate social interaction, local rules of changes to imitate the emergence of a global dynamics, and neural networks to imitate pattern formation and recognition. These generative mechanisms are informed by theoretical or empirical models but not defined by them.

Computer simulations must in a way be autonomous and independent from realistic models because simulations can become unstable as a result of increasing calculation errors. These errors result from the bounded representation of numbers in computers. In highly non-linear systems the resulting small calculation errors may build up due to the recursiveness of the calculations. To avoid such instabilities and to achieve stability at least in most cases non-realistic mechanisms have to be introduced into the simulation program. Simulation models in climate research, for instance, introduce the constancy of kinetic energy to overcome the instability problem which is in contradiction to the physical laws of dissipative systems (Küppers & Lenhard 2004). Therefore, the stable performance of a simulation counts more than its relation to reality. Especially cellular automata and agent-based simulation models are far away from a realistic approach to the underlying concrete phenomena.

Epistemologically speaking, computer simulations are by no means numerical calculations of a solution of a mathematical model of a certain realm of reality. Computer simulations are models of models imitating the dynamics of a real process. As simulations form an important part of scientific and technological practice, questions about its value and nature become more urging. What is the nature of the knowledge produced by simulations? Are we observing the emergence of a new science of handling complexity and of modelling? In particular, what can be said about the validity and certainty of simulation-based knowledge? Therefore, the validation of the results obtained by simulations cannot rely on the basic principles of a theory. Simulation results have to be compared to reality more directly.

This instantly creates a specific problem of validation especially when simulations are employed in situations where no direct access to reality is possible (because of high costs or high risks). Concerning the impacts on the scientific conduct, it has yet to be proved if simulations lead to a more problem-oriented thinking in models, to the production and handling of larger sets of data, and to a more intensive networking of diverse societal actors, this way opening the research process for more stakeholders and integrating the social context in simulation models. It is assumed that simulations are well suited for interdisciplinary cooperation and 're-use' in many disciplines.

With regard to grid-based simulation, integrated *simulation methods* are promising decisive breakthroughs for the analysis of highly complex systems, if they are implemented on adequate computational grid-architectures. Therefore questions concerning the quality of simulation knowledge is of growing importance also in this context: What are the epistemic characteristics of such simulation-based knowledge? What special techniques of validation must be developed to certify this kind of knowledge? Furthermore, successful applications of simulations on a computational grid achieve an integration of different knowledge and data resources. How can one characterise this kind of integration? Can computational grids solve the much debated problems of integrating heterogeneous models and resources? Which changes of simulation modelling are implied by the transformation on a grid?

Especially the possibilities of grid computing with respect to simulations offer new perspectives to use simulations as *virtual realities* in the realm of (interactive) computer games, product advertisement and private services (eg. entertainment). A new dimension of analysis is required because grid computing will allow the integration of decentralised services into the final product of virtuality.

4. Evaluation of the Perspectives

In the previous two sections we have presented a rather independent view of the problems in our societies on the one hand and the technical possibilities and opportunities on the other. The present section is meant to link these two aspects together whereby our focus will be on converging technology. In other words the task of this section would consist in evaluating for each of the societal aspects from Section 2 which of the technological expectations might be useful and thus should be furthered.

Obviously this would amount to a huge task which would break the limitations in space available and in time needed. Further predicting technological and social evolution is beyond our present capabilities. For these reasons this group is convinced that beyond the precautionary principle the only viable way of evaluation consists in foreseeing procedures with which the future development and the role of its drivers can be monitored and the resulting data be evaluated. The rationale behind this section is therefore to outline the ingrediences and the structure of these procedures rather than take any position in individual cases of concern wrt. technological development.

This outline is illustrated with selected examples which to some extent are chosen especially with the convergence aspect in mind. This requires a clarification of what we understand by this concept which is the topic of Section 4.1.

Any evaluation is based on a value system. To indicate the kind of value system underlying our considerations we include a section (4.2) on basic normative desiderata as well as on ethical and cultural issues. In addition the Fontwave group in a separate report (Ringland 2004) has elaborated four scenarios for Europe in 2020, tabbed *Alternative Lifestyles, Competitive Europe, Regional Calm,* and *Global Capitalism*. We refer to that report for any details of the description of these scenarios. Our group basically takes the viewpoint of Competitive Europe which more or less coincides with the Lisbon Strategy of the EU.

On the basis of these normative prerequisites we assume a rational approach to the decision making within the envisioned procedures. Section 4.3 describes the mechanisms behind this rational approach and the potential for support by technology. Section 4.4 deals with the uncertainty in general, the procedures have to cope with, as well as with the technological risks and their management and the questions concerning the reliability and scope of the mechanisms from Section 4.3. Section 4.5 provides a snapshot of market opportunities in technology as opposed to the lack of knowledge in the respective scientific areas and to other hindrances. The list is structured according to possible combinations in terms of convergence of the four main technologies in NBIC. With these concrete items in mind we discuss in Section 4.6 some of the aspects of the procedures for coping with the social and political impacts of the technological evolution.

Our stance on a rational approach has the consequence that the measurement of these impacts in our opinion should be performed in a truly scientific way and not on the basis of the commonsense psychology underlying the traditional social sciences and humanities. The discipline which represents this request is Cognitive Science (or, more generally, Intellectics). Section 4.7 is meant to clarify its role in this respect.

To avoid the impression of an overly optimistic picture of the role of technology in the societal evolution which Section 3 might have aroused we emphasize that we see technology as just one element in a bigger picture which includes mental attitudes, societal structures, social change, working conditions and many other aspects. Nevertheless technology has a substantial influence so that the choice of the "right" technology may indeed make a big difference. We hope that the envisaged procedures of this section beneficially support this choice.

4.1. Convergent Technology

According to Thomas Kuhn revolutionary inventions are tied up with a break with prevailing paradigms. Such a break often goes in hand with a merge of the perspectives of two different scientific areas. Such a merge requires a rethinking of the basic paradigms of each and this way opens the eye for a new look at old problems. This is why interdisciplinary work often has been so productive and because of that is strongly encouraged by funding agencies.

With the acceleration of the scientific and technological development also the frequency of interactions among different disciplines increases rapidly which ties the different disciplines together up to a degree at which their boundaries begin to fade. There are strong signs for this degree being rather close. To understand what this means it is necessary to understand the basis (or epistemology) of any discipline (cf. Bibel 2003, pp. 262ff).

A discipline is made up first of an ontological commitment, ie. of the entities it wants to talk about. Second it requires a vocabulary, the concepts (forming the terminology), for denoting these entities. Both together is termed an *ontology* which includes a semantic of the concepts, ie. a relationship of the concepts and the entities. On the basis of such an ontology the discipline is then built by accumulating knowledge about the entities expressed in terms of the terminology. The knowledge may reflect observations, causal relationships, induced general laws to mention important examples. Although rarely mentioned explicitly any discipline rests on basic assumptions, also called paradigms (formally playing the same role as the knowledge). Finally, the body of knowledge includes also practical expertise, methodologies and techniques concerning the way of investigations which again can be seen as a special kind of knowledge. So in essence a discipline consists of an ontology and a body of knowledge whereby the latter can be differentiated into a set of paradigms, the established knowledge and the investigational expertise.

Interdisciplinary collaboration may therefore have two effects. First of all it requires a broadening of the ontological basis on both sides and second it makes available a richer body of knowledge. At a time where a computer (the info part I) at the gate level functions according to the laws of physics at the micro and even nano level (N) but is able to simulate cognitive functions (C), model biological cell processes (B) and so forth, an understanding of all these NBIC phenomena requires the ontologies and knowledge underlying all these relevant disciplines. Since this is happening with many aspects of the technological evolution as described in Section 3, we may well speak of the accelerating phenomenon of *convergence* of the sciences and their resulting technologies.

Convergence is realized in pieces. Already today there are many interdisciplinary explorations in pairs of the fields under consideration, especially in IC (the strong links between CS and Intellectics, ie. AI and CogSci), NB (the blurred boundaries between physics, chemistry and biology), BI (especially in the form of Bioinformatics), and NI (the attempts to build computers on the basis of nanophenomena). The point is that this trend will continue, especially on the technological side, linking pairs of such pairs and so forth until NBIC will become a huge coherent discipline with a common ontology and with integrated technologies. This latter vision however is at least decades away and therefore beyond the time horizon viewed in this paper.

Having clarified our understanding of convergence we point out the following observations. The phenomenon as such is not at all a novel one. Merging of ontologies and knowledge has taken place at any time in the history of science. What is new is the predominance of this merging happening today which may indeed lead to a new quality of scientific insight and technological achievement. On the other hand convergence does not mean that all NBIC phenomena will be reduced to the terminology of the physical level, eg. in the sense that cognitive functions like the mind's memory will from now on be described in terms of quantum mechanics. We will continue to use different levels of functional abstractions. But these different levels will be related to one another in an interpretative way (like the interpretations that occur in a computer reading a high-level language program, interpreting it in assembler and further down up to the physical level).

4.2. Normative Desiderata

People wish to fulfill their basic needs and desires as physical, mental and emotional beings. Maslov (1943) supposes that they do so according to the following priority list.

1. ***Physiological (water, food, shelter);***
2. ***Safety (security, protection);***
3. ***Social needs (belonging, love);***
4. ***Esteem (self-esteem, recognition, status);***
5. ***Self-actualisation.***

The present state of the world is characterized by extreme differences in the fulfillment of these needs both at the individual as well as the societal level. The fact that single persons are as wealthy as all the people together from big states is justified by no rational argument. The technological development should thus serve to *reduce the differences in peoples' chances* substantially with the desirable consequence of a fairer distribution of wealth and opportunities resulting in more harmony within this world. In Section 2 we have seen several instances of problems arising from the violation of this general norm such as the lack of food for billions of people or the lack of even basic educational opportunities. The principle is not restricted to a given generation but also requests that future generations will have fair chances in comparison to ours'.

A second fundamental issue is the great variety in nature as well as in people, societies and cultures. In history these differences have been the cause for many bloody conflicts, for suppression and deprivation. An actual example is provided by the differences between the muslim and the western world which terrorists take as an excuse for their destructive actions. Today we should know better and, with the help of technology, *build bridges between the various attitudes, habits, languages, sets of beliefs and values,* and so forth.

A third fundamental issue concerning peoples' needs and desires is that they are in conflict with each other because people are thinking in local terms and thus unable to oversee the various consequences of their actions. Anyone, to illustrate this issue by an example, is attracted by beautiful landscapes as can be seen from the millions of vacationeers each year. Unfortunately the same people are involved in a variety of actions fulfilling other needs and desires that endanger the beauty of such landscapes by pollution, climate change, destruction, and so forth. Technology should help in teaching people to *bring their desires in consistency with each other*. Partly related to this principle Section 5 proposes the challenge problem *Assistants with global "conscience"*.

The three norms just stated might be regarded as the initial fragment of a future ethic at a rather high level of specification (similarly to the Ten Commandments). Worked out in greater detail – as recommendation GenRec8 in Section 5 suggests – such an ethic would include a specification of the balance among these three norms from which solutions to specific problem scenarios might be derived. In fact technology could even support this generation of norms and of the balance specification in an inductive way from specific cases. In such a way we could achieve an "equilibrium between People, Planet and Profit" (Aarts and Marzano 2003, p.8). Note that the stated norms together allow for competition, differentiation and reward in contrast to the ideological equalization badly experienced in communism.

Ethics is an important, but not the only general aspect to be considered in the evaluation of the new technology wave. Science and technology affects the entire social, legal, ethical and cultural world. While this report will address some of the social and political aspects in the subsequent sections it must refer to documents produced by other subgroups within Fontwave wrt. legal, ethical and cultural ones. Especially there is the "*SIG#2-report on the ethical, legal and societal aspects of the converging technologies (NBIC)*" as well as a contribution on "Converging Technologies and Culture" by the Fontwave member Eleonora Barbieri Masini.

4.3. Rational Decision Making under Uncertainties

The technological possibilities described in Section 3 are so rich that societies have to focus on a selection among these. Such a selection requires decisions to be made. Decision making is a well-known and well-studied process. In the best of circumstances we can calculate the consequences of our different options for decisions and choose the best among the resulting scenarios. Unfortunately such a calculation is complicated enormously by the following two facts.

First of all we do not exactly know the underlying causal relationships of phenomena happening in the world, especially those in the social world. This means that we have to cope with a lot of uncertainties in all knowledge involved in the attempted calculations. Secondly it is not at all trivial to determine the best among a variety of scenarios. Even if we restrict the valuation to a single aspect, different people might have far differing views on the values of some state wrt. this particular aspect. The problems of valuation become even more complex if different, in fact many aspects are taken into consideration at the same time. How should the weights of two different aspects be set in relation to each other? Only if we could solve these problems of reaching a consensus on both the values of states wrt. single aspects and a weighting function balancing among all the possible aspects, could we then assign a value to such a complex state and compare it with that of another state.

Notwithstanding these difficulties there is no other rational way of deciding on a variety of options in a given situation. In fact it is highly recommendable to use the techniques first developed in Economics and further refined and computationally optimized in Intellectics for reaching fundamental decisions about the future development of R&T in a systematic way. Of course this is not the place to describe these techniques in any detail; we rather refer to the literature in this regard, eg. to the chapters 16 and 17 in (Russell & Norvig 2003).

For the rest of this entire section we will have such a rational computational model of decision making in mind. Thereby the underlying knowledge is reasonably assumed to be provided by the various disciplines. The required valuations might be determined in a democratic way and in consistency with generally accepted ethic norms like those discussed in the previous subsection in an exemplary way.

We consider this rational decision making to be so fundamental though rarely pursued in the public decision making process that it might be one of the important tasks of the European Commission to fund projects realizing it in certain areas and wrt. certain problems to be decided. A recommendation of this kind (GenRec3) will be listed in Section 5.

While we have emphasized sofar in this section a need to introduce more rationality into decision making processes, this plea does not mean to devaluate the virtues of human intuitive thinking at all. But we see intuition as a function on top of a rational analysis of the grounds for a decision in which systems excel (including explaining their findings). As demonstrated by zillions of daily examples, human decisions based on intuition alone often overlook even simplest facts. On the other hand we cannot expect systems to achieve human-level overall excellence in the midterm perspective. So the emphasis must be laid on an ideal combination of the strengths of both systems on the one hand and human knowhow and intuition on the other.

4.4. Uncertainties, Technological Risks and Their Management

Technology itself is neither good nor bad; it is how we use it that makes the difference. For that reason it is advisable to anticipate potential problems beforehand and take the risks into consideration in the decision process outlined in the previous subsection. Risks are not born equally; some are harmless, others are inacceptable under any circumstances, given the ethical principles such as those in Section 4.2. Let us look into some of these issues in the present subsection.

A familiar example of technological risks is nuclear energy production. For decades the debate on pros and cons of this technology have been hotly debated. The Commissionar responsible for energy and transport, Loyola de Palacio, put the dilemma of this discussion into the words: “Either we shut down the nuclear sector and give up on Kyoto, or we do not shut down the nuclear sector and we respect Kyoto. It is as simple as that: sometimes you have to put it crudely so that people understand.” Whether or not he is right in this assessment (that there is no third alternative) is not the issue here. Rather, in view of converging technologies especially on the nano-sector, we must face the potential dangers involved in any technology that fiddles with the fundamental mechanisms of matter.

In the case of nuclear energy it is a fact that no solution has been found or is in sight for managing the high-level waste in the order of tens of thousands of tonnes which, according to the technological state of the art, remains active for thousands if not hundreds of thousands of years (Nuclear Energy 2004). A single terrorist act against such a deposit could cause a desaster in comparison with which Chernobyl would look like a harmless accident. This raises the ethical question whether on the basis of ethical principles such a risk is acceptable under any circumstances.

Unfortunately the risks related to nano-technology might even be more desastrous a point worth for discussion here. Recent findings of a study indicate that single-walled carbon nanotubes of the kind used for many applications have considerable toxic effects on animals (Schuler 2004). Similar findings are reported in (Nano's Troubled Waters 2004). If these still disputed findings would be confirmed in further studies then we must face the perspective that it seems impossible within our present state of knowledge to contain these nanotubes if used in ever more applications. In addition we already have the negative analogue experience that inhaled ultrafine particles catalyse reactions in the body and upon entry into cells initiate immune system reactions (TAB 2003). We must therefore include in our calculations a dangerously high probability that toxic nanotubes or other nanoparticles with unknown effects will pervade the entire food chain and this way possibly contaminate the environment at a large scale. In the extreme there is the particularly threatening vision that self-replicating nanobots could destroy all life on earth (known as the "grey goo problem"). So again this raises the question whether under these circumstances the uncontrolled tampering with nano-material is consistent with our ethic principles (see the recommendation GenRec3 in Section 5). Let us view this question in a more general perspective.

The biological nature excels in diversity. In fact the stability of nature seems to rest on an evolutionarily grown diversity which is balanced in a rather subtle way. A wonderful example for this stability is the Amazone rain forest which features an incredible diversity in organisms. But we had to learn that this balance and stability is rather volatile. If islands are created in the rain forest by human interventions in the surrounding area, the balance rapidly breaks down just because the island area is no more large enough to maintain the complex net of interactions among the hundreds of millions of creatures. That is why ecologists warn against the destruction of rain forests or against the danger of allowing genetically manipulated organisms (GMOs) to spread out into the natural world. Faced with the unconceivable complexity of nature we have no idea what the consequences of such changes might be for the future of this wonderful world.

No one has ever talked about the ecostructure at the physical level of nature. But it is obvious that among the potentially possible physical structures only a tiny subset was realized through evolution. Since nature is built on top of this physical structure it is completely unpredictable whether a major intrusion by mankind into the balance of this structure might not have drastic consequences which could never more be contained. At the very least this potential danger must be kept in mind as technology at the nano-level evolves. For the time being the nano-experiments carried out in laboratories around the world seem not dangerous in this respect. But the more futuristic perspectives envisioned by researchers like Drexler are qualitatively different in this respect.

As to the feasibility of these futuristic perspectives doubts have been raised for instance by Smalley. He asserts that atoms cannot simply be pushed together to make them react as desired, in the manner fancied by Drexler, but that their chemical environment must be controlled in great detail, through a many-dimensional hyperspace, and that this cannot be achieved with simple robotics (Nanotechnology 2003).

On the other hand we are already in the middle of an increasing interference with the molecular level of the human organism through pharmacology. Drugs like Contergan or Lipobay have demonstrated the high risk involved in meddling with the balance of the human body with chemicals. They may just be the tips of a huge iceberg since for most drugs their causal effects in the body are scarcely known and the statistics data is rather limited and certainly inconclusive because of the complexity of the net of parameters involved. Just think of the undisputable effects of homeopathic treatments (even of animals). Given the minimal concentration of homeopathic drugs, a possible conclusion is that somehow the structure of atoms or particles must carry the relevant information. If so, who dares to guarantee the safety of standard pharmacological drugs in view of the person's health stability over decades?

As far as ICT (beyond nanotechnology) is concerned many of its potential problems are already among us in some form or another (Mainzer 2003) (and several have already been mentioned in Section 3 under technological aspects). Some of them are the intrusion into the privacy sphere, criminal and terrorist attacks (cyberterrorism), economic espionage, the raising flood of junk mail drowning regular email, and the looming dangers of electro-smog caused by ICT equipment. These problems are again technological in nature and can be solved technologically, if we are ready to invest sufficient capacity into these areas of security, quality of service and reliability including privacy enhancing technology (like smart cards).

There are clearly many more problems to be anticipated than could be listed here. In comparison to the fears arising from nano- and biotechnology they seem to be more "containable" due to their occurrence at the knowledge level controlled by people rather than at the physical particles or biomolecular level controlled by nature.

4.4.1. Enduring uncertainties

The risks of new technologies is but one dimension in the space of uncertainty wrt. foresighting the technological future which our group has faced. Another consists in the variety of speculative working hypotheses underlying the scientific enterprise by which the course of mainstream research is guided. In this subsection we address the problems involved in this particular dimension.

An important conclusion of our group is therefore that there are enduring divergences on essential points, and that it is not within the capabilities of this group, nor, judging from the present state of the literature, of any group, to dispose of these divergences. What has been done is to identify some of the main sources of disagreement, which are the following ones.

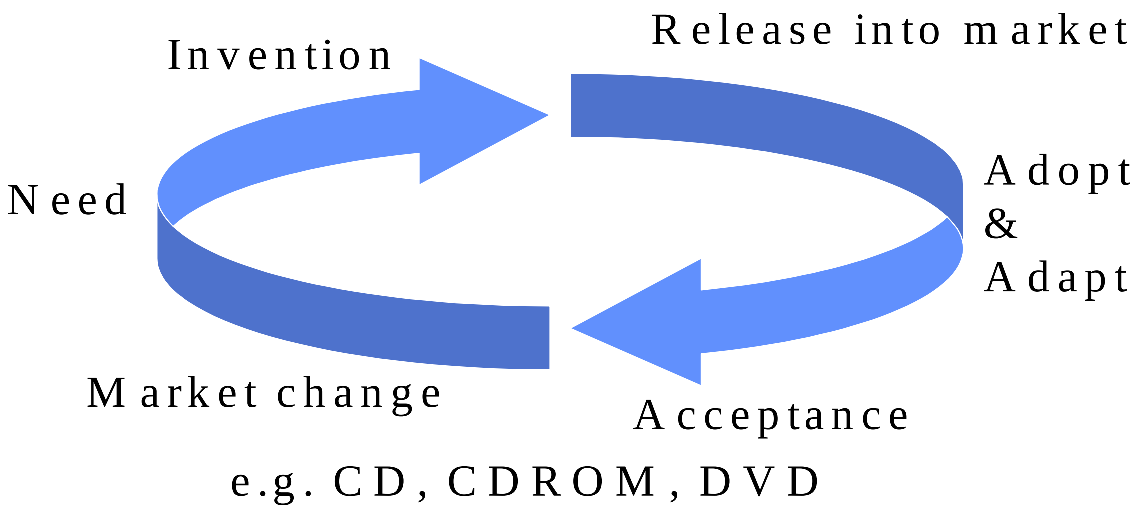
1. To what extent and within what time-scales are the various perspectives of AI (artificial intelligence), advanced computer-based complex information-processing, AmI (ambient intelligence), and AL (artifical life) actually feasible?
2. How much rests on the feasibility of so-called strong AI and strong AL? (Strong AI consists in artefacts endowed with at least some of the crucial features of human intelligence, such as consciousness, a sense of self, emotions, responsibility, autonomy, and so forth; strong AL is the same, with biological life instead of intelligence: devices with some of the deep characteristics of life, such as self-regulation and metabolism, self-reproduction and persistence through change, individuality, etc.) Weak AI and AL are already with us, and will undoubtedly take on larger and new dimensions. The question is, will they eventually lead to the strong versions, and if so, is that a good thing, and what are the other consequences which the mere growth of the weak versions would not carry?
3. To what extent is it possible and desirable to increase the power and breadth of applicability of decision-support software (of the kind discussed in Section 4.3)? How much automation can and should go into decision-making? Do the known techniques for individual decision-assistance generalize in a value-free fashion to collective decision-making?
4. How much independence can and should be maintained between Computer Science and AI-driven technological research and basic Cognitive Science (see Section 4.7)?

5. How much independence can and should be maintained between Computer Science and AI-driven technological research and basic Social Science (especially Sociology, Political Science, Social Psychology, Anthropology)?

This situation leads the group to include among its recommendations the inclusion, at the appropriate level, of a dimension of constructive technological assessment on an ongoing basis, whose periodical reports would serve as input to resource-allocating agencies as well as citizens' and institutional ethical and policy-making organs (see recommendation GenRec3 in Section 5). Further GenRec5 recommends an evaluation of the present disciplinary structure.

4.5. Relating Gaps and Needs to Market Opportunities

The structure of this report is intended to lead from social needs through technical opportunities to solutions. A comprehensive analysis accomplishing this chain of reasoning would amount to a major project far beyond the narrow limitations within which this report was produced. This section is not more than an insufficient and very restricted first step in this direction. Before we describe what it offers it is helpful to remind of what is called the *innovation cycle* illustrated in the following picture.

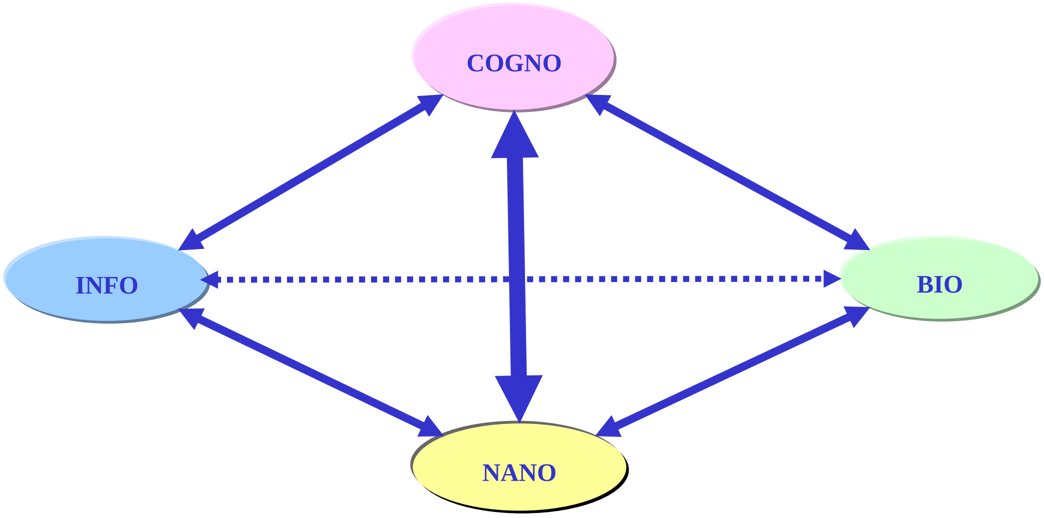


Innovation cycle

As the market changes through societal processes new needs evolve stimulating inventions. The resulting products enter the market, are adapted and adopted, and through acceptance influence the societal processes again. In the next subsection we will propose a modification of this basic structure as to move the adaption and adoption phase already into the invention phase for the case of complex technology with unpredictable effects.

So in contrast to what we would have to do in terms of our intentions underlying this report's structure we must restrict ourselves to mostly technology-related instead of social aspects associated with converging technologies. Specifically, we consider all convergence combinations, ie. 2-, 3- and 4-way convergence of NBIC technologies (NB, NI, etc.) as illustrated in the following picture.

For each combination we contrast a small list of scientific and technological gaps (written in black) with a small list of possible market opportunities (in red).



Note that this distinction is rather neutral with respect to the scenarios mentioned at the outset of this Section 4, although exhibiting a Lisbon strategy flair.

Nano-Bio
DNA manipulation is still embryonic
Proteomics many years from maturity
Unable yet to design new bases and protein systems
Lack of knowledge of impact of nanoparticles on organisms and environment
Hostile public
Concerns about weaponry use
Lack of design knowledge for synthetic nanotech based organism colonies

Organic customisation
Synthetic nanotech based organism colonies
Extremely small organisms
DNA compression (reduction of redundancy)
Synthetic viruses for DNA enhancement

Nano-Info
Most engineers locked into digital and silicon mindset, few could address use of DNA computing for example
Lack of quantum engineering capability
Lack of bottom up manufacturing capability

Markets for high speed computing well established
Cost and size reductions enabling pervasive ICT and AmI visions to be realised

Nano-Cogno
Difficult to link N & C conventionally except via I
due to lack of knowledge of non-electronic processing systems

Sensory augmentation via nanotech particles or structures
Mechanical intelligence via MEMS and NEMS?
Intelligence via basic physics and chemistry using emergence from small-scale interactions (Stephen Wolfram)

Bio-Info
Lack of electronic materials that are safe in the body

Room temperature printable electronics needed to reduce cost

DNA based in-body processing for synthetic immune systems and cancer control
Telecare & Bioinformatics already are large fields
Flexible displays will be ideal for body monitoring purposes
Active skin
Emotional jewellery
Emotion monitoring

Bio-Cogno
Little understanding of biological computation methods
Only biological intelligence mechanism is neural based

Positive feedback loop is strong between B&C
Use of stem cells in brain regeneration after stroke or accident
Biological sensors often superior to man-made,
so could be used to enhance engineering systems

Info-Cogno
Concepts of cyberspace are still very immature,
so we don't know how artificially intelligent entities could progress
Persistent lack of understanding of consciousness
Little understanding of what makes life
Strong AI researchers seen by many as cranks
Lack of legal framework for independent inorganic artificial life or conscious machines
No understanding how we might manage hybrid life forms
that exist both in cyberspace and physical world

Use of cyberspace linked to augment objects in physical world
Smart responsive environments, AmI & PICT
Obvious commercial advantages from high levels of AI
Conscious computers can handle extra kinds of tasks
Affective computing
Human-free companies
Autonomous systems

Nano-Bio-Info[2]
We can't even do Bio-Info links well at large scales

Advanced bio-monitoring
Advanced telecare systems
Precision drug targeting
Cancer cell detection and destruction

NBC
(ie. NB+NC+BC+…)

Biological intelligence augmentation
Artificial brain cells
MEMS-based and NEMS-based intelligence, sensing, actuation that can be linked to biological systems

Nano-Info-Cogno[3]

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[2] ie. NB+BI+NI+…
[3] ie. NI+NC+IC+…

Bottom up assembly of highly advanced IC systems

Bio-Info-Cogno[4]
Early stages of chip-nerve links, hard to mix silicon with biology
Disagreements between neuroscientists on nature and mechanisms of consciousness
No understanding how we might manage hybrid life forms
that exist both in cyberspace and physical world
Little understanding of effects on neurons
of trying to make direct brain linkages via nanotech contacts

Enhancement of intelligence and sensory capabilities
Remote sensory monitoring, recording and stimulation

Nano-Bio-Info-Cogno
Powerful technology combination attractive to weapon use – policing difficult

Sensors & Sensor nets
Hybrid systems
Biological customisation
Smart bacteria
Full direct brain link
Mental immortality

An example for how close we already are to the opportunity part of this last full NBIC section we mention experiments with monkeys with brain implanted chips which move cursors purely by thoughts (The Sunday Times 2004) which eventually could help eg. spinal injury victims.

While, as we said, the distinction made in this section falls short of our intentions we will now discuss what has to be done in this respect in a general way in the following section.

4.6. Social and Political Impacts

The assessment of technological developments with respect to social implications is a non-trivial problem. Many attempts to produce relevant knowledge about possible pathways of technological developments and about alternatives with fewer social risks have failed. The expectations and demands to shape complex processes have therefore been reduced considerably. It will already be rated a success if during the development of new technologies technological alternatives with fewer negative social consequences are identified in time.

This means that a transition from a classical technology assessment towards a new form of "*Begleitforschung*" (accompanying social research) has taken place which is able to shape the technological development as it evolves. Begleitforschung has already been carried out in modern biotechnology. There are to our knowledge no experiences yet with converging technologies like in NBIC. The uncertainty which is characteristic for the complex dynamics involved in a way multiplies here because of the co-evolutive effects of the mutual interaction of individual technologies in the case of a convergence.

A characteristic feature of the new approach is the implementation of social research (viz. Begleitforschung) into the development of new technologies. By the participation of social scientists a critical reflection is installed which identifies in a timely fashion possible alternatives with fewer negative social consequences. This integration of social scientists (of a

[4] ie. BI+BC+IC+ ….

certain calibre – see the next section) into the process of knowledge production within science and technology introduces extra scientific criteria of relevance as socially obligatory. In the same way as in innovation networks to be introduced now different rationalities can be integrated into a single one.

Innovation networks emerged as a new form of organisation beyond the classical forms of market and hierarchy because innovations – new products or technologies – are becoming ever more uncertain. The reasons for the increasing uncertainty of innovation processes are the following ones.

- Innovations are growing in complexity because more and more functions must be integrated into them.
- The market is becoming increasingly less transparent and more turbulent, and launching a new product is becoming more of a risk. For a new product, quality alone is no longer decisive for its commercial success.
- The third reason for the increasing risk of innovation can be seen in a growing dependence on the available knowledge for the success of an innovation. Labels such as the "knowledge society" and "knowledge-based industry" point to a fundamental change in the role of knowledge. It has now become the raw material for technological and social innovation processes.

Modern innovations are viewed neither as the outcome of invention and marketing strategies in individual companies in response to complete knowledge about relevant demand states, nor as fitting the picture of a passive transformation of scientific knowledge into applied knowledge and then – mediated by company R&D departments – into products that are ready for the market. In contrast to the traditional perspective, modern innovation research has created a far more differentiated picture of technology development in which the concepts of uncertainty, lack of transparency and acceptance play a central role.

Altogether technological development is no longer seen as a linearly sequential process that can be traced back to rational decisions. Within the framework of research on technology production, the innovation concept circumscribes also the construction of an application context and anticipated visions of use, of institutional decisions and cultural models, practical experiences with the development of a technology, the commercial, market-oriented considerations, and, not least, the transformation of interests and utopias in order to mold the future into new marketable products, and procedures that, in turn, (may) trigger numerous learning processes and feedback permeating as far back as to basic science.

As future-related projects, innovation processes are always fraught with uncertainty and contingency. They contain assumptions about future applications and uses. They model a social-technological application context in which the technological ideas are developed and, later, the artefacts are implemented experimentally. Modern innovation processes couple the technology developers' visions of use with the applied practice of users. The observation of these network structures between the generation, application and regulation of innovations has led to a new way of modelling innovation dynamics, namely to the model of innovation networks.

Innovations are produced regularly in networked structures ranging from producer-user relations to complex networks of science, business, politics, law and administration. The common concern of network theories in innovation research is to bring about a shift in perspective from the analysis of industrial innovation processes to the organisation of innovation processes among and between companies, and thereby replace mono-causal explanatory schemes (economic, technological, power-theoretical, etc.) with more complex assumptions.

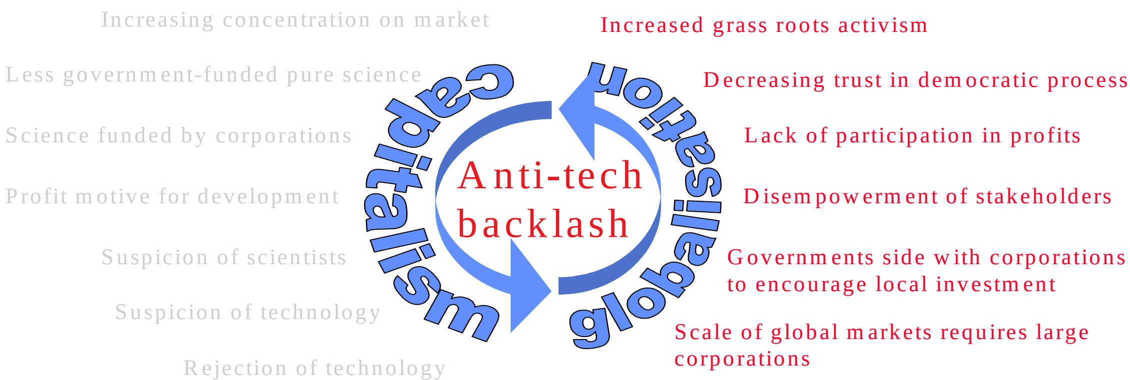
This paradigm shift in innovation research can be used as a model for regulating social impacts of new technologies. As in the case of classical innovation networks the integration of the social dimension into converging technologies allows to identify alternatives with different impacts during the innovation process. A particularly promising way in view of such an innovation network type along with the integration of social scientists (of a certain calibre) consists in the early implementation of prototype systems within social structures. This allows the collection of empirical data about the impacts of systems on individuals and groups of people. This obviously is only feasible if no potential risks for the health of people is involved in the implementation of the systems within social structures. Because of the expected promise this proposal is included into the list of recommendations as GenRec2 in Section 5.

The rising grade of dependence on technological tools and of their sophistication involves the danger to widen the gulf between those who have access to it and the have-nots which must be avoided without compromising the advantages of market forces. History teaches that technological changes always yielded winners as well as losers. With technological means (such as knowledge systems) we are now in a position to cushion these effects.

4.6.1. Interaction with the public

Begleitforschung and innovation networks as discussed before are still carried out by an elite without integration of the general public. For many reasons steps towards a kind of *democratisation of science* are needed. Here we just mention a few important issues in this context.

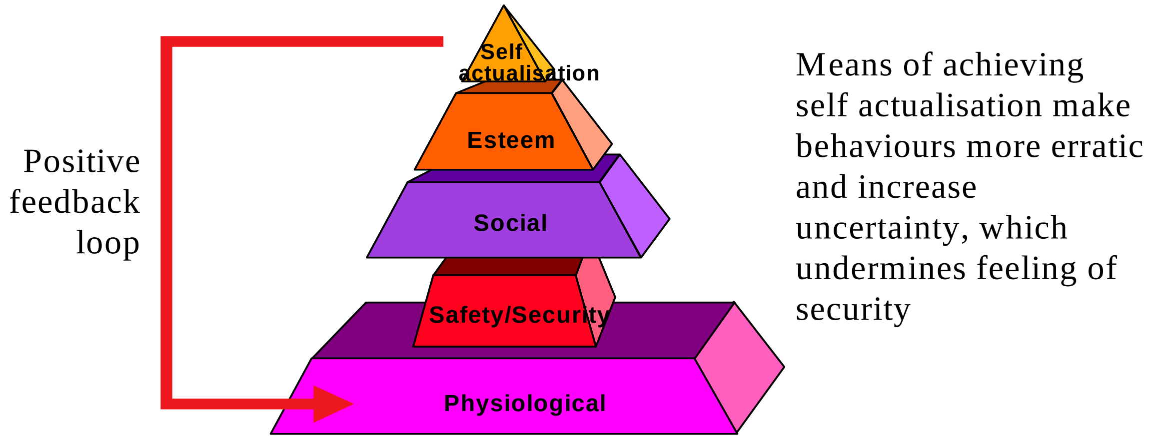
The technological evolution is tightly connected to the continuing trend towards globalisation which is opposed by a sizeable fragment of the populations worldwide. The mechanisms behind these protest movements are illustrated by the following figure.



Mechanisms leading to anti-technology/anti-globalisation

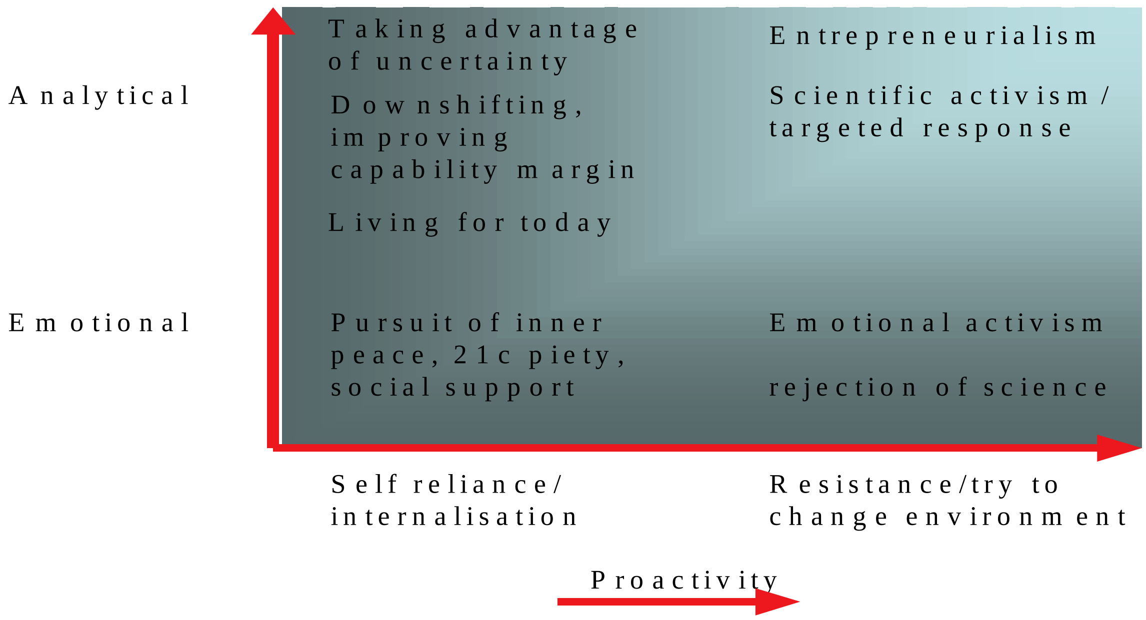
The picture shows the linkage between globalisation and capitalism are linked and how the interaction can cause antitechnological backlash. In reading it from the bottom right it explains how one item causes the next one.

These mechanisms are based on fundamental attitudes of people like the ones described by Maslov (see Section 4.2). Recall the priority list of basic needs and desires from there which is present in the following picture still in the right priority sequence. However, the picture illustrates how an increasing uncertainty in our world due to technological evolution undermines the security level (illustrated by a smaller than normally required layer) in a cyclic process indicated by the feedback arrow (for more details see Pearson 2003).



Modified Maslow hierarchy of needs showing undermining of security layer

There are different possible responses to the uncertainty resulting from the technological complexity. The following picture (taken from Pearson 2003) illustrates the space of these possibilities in two dimensions. The one dimension reflects the varying degree of proactivity vs. inactivity while the other measures the possible mix of emotional and rational reactions. Some of the possible responses are located at the respective points in this space.



Social responses to increasing uncertainty

In order to cope with these individual and social mechanisms it is mandatory that more efforts must be made to involve the public in the processes of scientific and technological evolution. Means of this involvement reach from science musems/centers/parks/worlds to popular science events for the public (including award ceremonies) to presentations in the media and, finally, to a broader integration of science and technology into the educational system.

As throughout this report the issues covered are important but cannot provide a comprehensive analysis. Another special interest group within Fontwave produced a report on the transformational effect of NBIC technologies on the economy to which we refer the interested reader for many further aspects.

4.7. The Role of Cognitive Science

The "C" in NBIC in the sense of human and artificial cognition has not received the appropriate attention in the text of this report so far. The present section is meant to make good for this omission upto this point. It starts with pointing to the prevalence of commonsense psychology (eg. in the social sciences), then discusses the relevance of Cognitive Science (CogSci) and the accessibility of its body of knowledge for information and computer technology (ICT) as well as for the social sciences, focuses on social cognition within CogSci, and ends with a CogSci view of how to establish theories of society and culture. The text touches on deep questions concerning the out-dated structure of the disciplines in science and the humanities, the role of the latter, and their mutual relationships.

Scientific versus commonsense psychology as a source and basis for computational technologies, *or*,

4.7.1. The texture of the human mind and bridging the cognitive knowledge gap[5]

We are guided, in our everyday dealings, by a well-adapted mental toolkit which allows us to identify entities and some of their crucial properties, and plan our own actions accordingly. Tigers, stones, dormant waters, human beings, lava, light, shadows, mushrooms, flies, dead branches, rainstorms behave in very different ways, respond to circumstances in very different ways, bring about very different results, and it is crucial to our survival and prosperity to be able to predict, and sometimes to explain, these properties. This toolkit of skills or tacit knowledge constitutes, as it were, the basic cognitive apparatus of humans. Some of the resources in that toolkit are, or through informal education become, self-conscious, and thus deployable in general and counterfactual reasoning, for example in the context of a planning task: this constitutes a first layer of (primary) knowledge. Next, thousands of years of cumulative hard thinking, especially in learned circles (philosophical, political, literary, etc.), has lead to the constitution of yet a second layer of knowledge, which may be called for short philosophical or nonscientific psychology. Commonsense psychology is a mix of those two layers, unsystematic, lay psychology on the one side and cumulative, consciously pursued and transmitted, learned psychology on the other.

There are excellent evolutionary reasons why commonsense psychology works in a large array of circumstances. Insofar as predicting, planning and explaining skills are important for survival, one may surmise that to a large extent lay psychology is itself part of our natural cognitive endowment, and had been selected due to its functional virtues in certain important situations common in the pleistocene, when natural selection was putting the last touches on the human lineage. The learned layer has, to a large extent, been selected through cultural evolution: literary, political, philosophical psychology has gradually been refined so as to yield explanations and predictions which were judged, on balance, to be true and/or useful in situations common in the cultures where they evolved.

[5] This section owes a lot to a suggestion made by Roberto Casati during the session 'Intelligence and cognition research' of the FET meeting held in Brussels on 21-21 April 2004. Quotes refer to the written note which he kindly made available to me.

Over the last couple of centuries, Psychology has become a scientific domain, much the way Physics, Chemistry, Geology, Meteorology, Metallurgy, Taxonomy, Physiology, etc. became scientific domains, following in the steps of the 'folk' knowledge which had accumulated in the course of human history, alternately building upon it, refining it, and partly undermining or overthrowing it. It has become accepted wisdom that the physical and life sciences are to a very large extent at variance with the corresponding bodies of folk knowledge. Not so, by a very long shot, for psychology and what is now known as cognitive science. It is still widely believed that the pronouncements of folk or 'intuitive' psychology are on balance scientifically sound.

The cognitive foundations of NBIC remain to a large extent predicated on that belief, albeit set in the sophisticated scientific framework provided by computer science and AI. The merits as well as the limits of this (not usually deliberate) theoretical choice have become pretty clear in the last 15 years. There are indeed areas of competence, and contexts, in which commonsense psychology, possibly marginally improved by empirical findings, delivers the necessary characterizations of those skills which are being simulated or enhanced. But there are large areas where this is not the case, and that is, presumably, one important reason for a partial strategic retreat of AI in favor of neural net models, neurocomputing and cognitive neuroscience.

'Areas' is a convenient label for at least two large families of circumstances: those where commonsense psychology has very little of value to propose (eg. lexical access, grammar, 3d-vision, motor planning, etc.) ; and those where the natural boundaries are crossed, due to technological advances (eg. decision-making in complex man-computer networks) or cultural changes (emotional disturbances in today's workplace, warfare etc.), or both (advanced technologies in non-Western and/or non-affluent populations). In fact, these examples are so well-publicized that one may be tempted to regard the issue as trivial. It is not: NBIC is going to create situations which are to an order of magnitude further removed from the pleistocene, and commonsense fixes will no longer be remotedly adequate to deal with those.

A couple of objections should be considered at this point. The first is that, as has been widely held during most of last century, wo/man has no nature, and thus can be taught or shaped into very nearly any possibly cognitive/mental structure. Knowledge of the natural basis of her/his cognitive abilities is thus not essential, bearing at most on matters of quantitative limits (memory, computational speed, proneness to error, resistance to fatigue, etc.). The idea is that native cognitive resources are no more relevant to the understanding and shaping of actual mental abilities and processes than thermodynamics to the cross-country itinerary of a beat generation poet or serial killer, despite the fact that thermodynamics describe and predict the workings of the car he is driving. But this idea is wrong: the evidence is overwhelmingly in favor of very strong constraints on possible adult cognitive architectures stemming from the innate, species-specific endowment. *Tabula rasa* is thus as profound an error as the symmetric raw reductionism, which implausibly claims that thermodynamics is all you need to account for the hero's coast-to-coast wandering. The mistake is compounded by the naive positivistic assumption that we somehow possess the basic concepts needed to account for human cognition, such as seeing, hearing, understanding, reasoning, believing, deciding, emotions, and so forth. Surely scientific psychology must preserve these as *explananda*, just as Newtonian dynamics had to account for the rising of the sun and the sinking of the ship. But is doesn't follow that seeings, hearings, decidings, emotions need be among the basic categories of Cognitive Science any more than risings and sinkings belong to the vocabulary of Physics. Obvious perhaps to the historian of science, but yet we would be ill-advised not to give it a thought in the present context: Is that mistake not prevalent in a lot of today's sciences of man, as it is in AI and other technological entreprises ?

The second objection is that knowledge need not be explicit and theoretical in order to drive technological and practical progress, which often results from building into material and immaterial innovations devices or processes which *in fact* reflect or implement yet to be discovered laws of nature. This is quite right, but is no objection to the enterprise of uncovering those laws, nor to the very idea that there are laws to be discovered, and whose existence, whether or not they are known or surmised as yet, determine the *texture* of the human mind. Somewhat in the way that wood has a grain which the carpenter knows better than to go against, human mentality has a texture which determines the extent to which enhancements and prostheses will succeed: that simple idea, no great insight in itself, must be given sufficient salience. The difficulty is that intuitive or commonsense acquaintance with this texture is real, and this blinds us to the fact that it may be mistaken or incomplete. Ineffective or disastrous technologies are probably the only cure against this blindspot, provided they are recognised as such and properly diagnosed.

Finally, the claim that theoretical understanding of the human mind is a legitimate entreprise does not amount to the scientistic, hubristic assertion that it, and it alone, can bring about the complete solution to the conceptual and practical problems posed by the human mind and the converging technologies. In fact, one can be both mildly pessimistic on that count and still argue that one cannot afford to bypass theoretical science: those countries which left aerodynamics in the hands of poorly funded absent-minded physicists unwittingly gave up on planes.

Making the knowledge already secured by CogSci accessible to technologists and social scientists, *or,* Bridging the cognitive knowledge gap[6]

Contrary to what may be concluded from the last remark, Cognitive Science is already way beyond the stage which Psychology had reached in its precognitive phases (although admittedly it has yet to take in all of the wisdom and empirical discoveries of these previous phases). This is due, to a large extent, to a combination of three factors: mere endurance, conceptual advances, and an enormous expansion of the realm of empirically investigatable phenomena, at both the cerebral and functional (*ie.* psychological and linguistic) levels. But whatever the causes, the fact concerning the current stage of CogSci remains and has yet to be taken note of and exploited. Cognitive science brings in not only precise, quantitative information which alone can enable certain technological advances; but it has also, perhaps more importantly, uncovered qualitative, conceptually profound phenomena which go against commonsense understanding of central cognitive, emotive or motivational, sensory, and motor functions. There is thus a need to 'fill the gap between science-inspired and commonsense-oriented specifications for design', by rethinking the 'architectures' of our artefacts and bringing them in closer alignment, not only at the fine-grain level, with natural-biological architectures as we are beginning to understand them (roughly, making them more *brain-like),* but also at the coarse-grain level, making them more *mind-like.* Actually, this amounts to going back on a choice deliberately made mid-way in the history of AI, when Marvin Minsky at MIT urged a liberation from the constraint of likeness to the natural mind, which the previous phase of 'cognitive simulation' championed by Herbert Simon and Alan Newell at Carnegie-Mellon had made much of, thus linking nascent AI with nascent CogSci. The difference of course is that today's CogSci is a far cry, in substance though not aim, from Simon and Newell's original conception (though not from their later work). In fact AI has

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6 This section owes a lot to a suggestion made by Roberto Casati during the session 'Intelligence and cognition research' of the FET meeting held in Brussels on 21-21 April 2004. Quotes refer to the written note which he kindly made available to me.

continued upto this day to pursue both strands of exploration along with the – in this sense – neutral logic-based third strand represented by John McCarthy.

Now the practical-political question is, how can we facilitate the production of cognitive machines which mirror the relevant architectural features of cognitive organisms as revealed by scientific psychology? One obvious answer is, by making available to, and assimilable by, ICT (and thus CT in a broader sense) designers the knowledge produced by Cognitive Science. The suggestion there (owing to Casati) is to develop 'Cognomics' (a neologism fashioned after 'Genomics' of course), a set of information processing and retrieving tools, requiring standardization of technical language, benchmarking, indexing and so forth, which allows the non-specialist, whether a technologist or a cognitive scientist working in a distant area, to rapidly identify and incorporate knowledge about a given process or function. A similar suggestion in this vein is taking Intellectics as a "remarriage" of AI and CogSci more serious than in the past 25 years. AI people and cognitive scientists are very close in their scientific methods and, together, could build a bridge between ICT, well familiar also to AI, and the social sciences, closer to the cognitive scientists. Another idea is to integrate traditional subdisciplines (which closely follow an age-honored slicing up of the mind into clear-cut faculties and senses, whose unreality is increasingly apparent) into unified research labs. A third suggestion is to integrate technology, especially related to robotics, with cognitive science, which tends to focus on 'thinking'.

4.7.2. Social cognition in a world increasingly shaped by CTs

Social cognition covers two related, yet distinct, endeavors in Cognitive Science. One is the study of the psychological and cerebral foundations of the individual's ability to deal with others and the social world. The other is the understanding of the cognitive resources which the individual, as well as the group, can tap for their cognitive needs and that are distributed in the socially-shaped environment. Both areas are of crucial importance at the present juncture, and are, finally, being actively pursued with the required rigour, after a period where arbitrary armchair constructions, anecdotal evidence, and unguided empirical observations, played the main role. Both areas are of immediate relevance to the converging technologies, but will become even more essential as these technologies start reshaping our world.

Indeed, the most direct and profound effect of NBIC is to change the boundaries between the self and the environment, where the environment includes at the same time people, groups of people, informal and formal institutions, arenas and places, both physical and informational, where goods and beliefs are traded and transformed. Just as we have witnessed in the last 10-15 years unwanted effects on some fragile individuals' sense of reality and responsibility of the use of computer games and internet surfing and chatting, we will be confronted with far more frequent and deep transformations of people's and groups' self-understanding. Identifying, describing, understanding, and, if necessary, preventing or correcting such changes is a priority, whose neglect might lead to one or both of these consequences: (i) a technology is developed, spreads, and causes deep damage to some individuals and to the very tissue of society; (ii) a technology is prevented from developing and spreading due to unexpected societal fears or misunderstandings of its basis and potential.

Although it is not yet clear exactly how much mileage is to be gotten, in the short term, from progress in the basic sciences of cognition, and although we must, in the interim, to a large extent rely on the empirical know-how amassed by traditional social science and social and political practices, the fact remains that cognitive science holds the promise of a considerably deeper, and thus eventually more efficient, understanding of these phenomena. The importance of these phenomena in the XXIst century cannot be overstressed, as an increasing proportion of an increasing total number of human beings will directly benefit, or suffer, from the converging technologies, whether or not these keep all their promises: even if much of tomorrow's CTs were to remain conceptually close to what we already know today[7], rather than signal a sea-change in our most basic categories, mind-sets, life-styles and so on, the mere exponential spread of the technologies, and the fact that they will increasingly provide the easiest, and often the only, passageway to essential goods (*eg.* encyclopaedic and expert knowledge, human contact, administrative and financial authorization, political empowerment, practical projects, etc.), endow them with an enormous potential for change.

Scientific versus commonsense theories of society and culture as a framework for

4.7.3. Developing social uses of CTs and for assessing their potential impact

Regardless of the extent to which the Social Sciences have, and will in the future, integrate findings and concepts from the cognitive sciences (as well as from AI and Neuroscience), the arguments presented in the previous two subsections concerning the need to favor scientific over commonsense psychology in developing NBIC devices and systems carry over to Social Science. The concern here is the kind of knowledge of social phenomena in the broadest sense, including everything that falls in between of the purview of Anthropology and micro-Economics, along with Sociology, Social Psychology, Demography, Human Geography, Social Medicine, Epidemiology, etc. Here also, there is a commonsense and a scientific sort of knowledge, although one draws on both of them and the boundary is porous and fuzzy. Here also, despite lip service rendered to the need to exploit scientific, rather than commonsense, sources of social knowledge, the actual designing, and impact-assessing practices instinctively rely on the latter, not the former (cf. Bibel 2003, Ch. 4 and 5). Here also, the mistake stems from the notion that the basic architecture of sociality is transparently available to commonsense (enriched, as before, by the wealth of accumulated experience, the historical and literary wisdom, etc.). Here also, this is hardly seen as a mistake because commonsense seems to show that *anything* is possible, while Social Science (though admittedly not unanimous on this) rather believes in social laws which together define the *texture* of sociality. Here also, the knowledge already secured by the serious branches of Social Science is hard to access, and a recommendation would be to set up 'Socionomics' on the model of Casati's 'Cognomics'. Another suggestion would be to integrate social scientists in cognitive and design labs, and to mix applied, hands-on social scientists with theoreticians. The research paradigm underlying Intellectics would certainly be a good and relatively natural and easy start.

[7] Here we must make the point that, at least as concerns societal implications of the CTs, it is simply incoherent and counterproductive to insist on isolating the effects of convergence *per se* from the mere *additive* effects of the different component technologies. It may be the case that Fontwave's main task is to focus on the synergy, and leave the (possibly easier and shorter-term) study of the effects of each separate technology to other, more specialized and feebler-minded groups. But as far as consequences (on society etc.) go, there is no in-principle difference from the effects of the synergy and the combined effects, in loco, of the separate strands. The metaphor that comes to mind is this: the cook may think, with good reason, that there is a world of difference between the carefully prepared dish and its ingredients, but as far as the digestive tract goes, the two are pretty much indistinguishable. More seriously, there is indeed a difference which lies in the intentional and systematic character of the combination, but this difference is minor when it comes to measuring the end effects. Moreover, the powers that rule over our fates have limited attention span and will probably not spend separate moments heeding the advice of the other groups and heeding ours.

5. Recommendations and Conclusion

This report by a subgroup of the High Level Expert Group (HLEG) on "Foresighting the New Technology Wave" (*FoNTWave* or simply Fontwave) was written to elaborate recommendations to the European Commission in view of the NBIC (nano, bio, info, cogno) technology wave and its forseeable impacts. In preparation to achieving this major goal the group pursued three subgoals. First it focused on a variety of apparent problems in our present world for which technological developments could contribute to an amelioration (Section 2). Second it reviewed the recent and future technological developments and their potential in an unprejudiced way whereby a timespan of 10 to 20 years was envisaged (Section 3). On the basis of this two-fold analysis the group started an evaluation of the technology in view of the problems to be solved as well as of those which might be caused by introducing those new technologies (Section 4).

It is obvious that the group could not carry out its three subgoals in a comprehensive way despite the fact that the report has grown beyond the originally expected size. The world is full of problems which would fill books rather than several pages. Similarly there is an explosion in the technological development which can no more be comprehensively summarized in a single report by a few experts. We nevertheless hope that the selection taken is in some sense representative and addresses the most important aspects.

The report falls especially short from a comprehensive solution in terms of its evaluational part in Section 4. This section cannot do more than demonstrate in exemplary ways what kind of directions would have to be researched in order to arrive at founded evaluations. The task itself is a grand one which could hardly be completed by several major projects, let alone by a small group of experts within a very short time. One of the major intrinsic problems for solving this task is the uncertainty involved in predicting the future needs of people as well as the evolution of technology along with its impacts. Given this uncertainty it is natural that even within a small group of experts – to some extent even in each of them – we find a wide range of differing opinions about which technological evolution would be beneficial for the European Union and for the world at large. For this reason our subsequent recommendations, resulting from the analysis in the previous sections, are phrased in a rather careful way avoiding preferences in absolute terms without compromising clearity.

Our recommendations are divided into the three categories of general and specific recommendations and challenge problems. The general recommendations are of the nature of more general research policy guidelines. Some of them might be useful for the Commission's framework program if specified in more detail. The specific recommendations are such that they could be included directly into the framework program. The challenge problems are complex problems requiring the contribution from many technological areas for their solution and promising a particularly beneficial effect on Europe. They would have to be treated in a special way in future research funding.

5.1. General recommendations

GenRec1. *The technological development must not continue to destroy the delicate balance in the natural and cultural world in the crude way as in the past, but rather contribute to the preservation of the wonderful variety in all aspects (including material, technological, ecological, cultural ones, etc.) fortunately still in existence in this world and particularly in Europe.* This general and undisputed principle is not meant to block future technological development but rather guide it in a beneficial way. It generally underlies the subsequent more specific recommendations.

GenRec2. *In larger NBIC projects an ongoing assessment of the potential impact of the developed technology is considered essential. The methods of assessment should be empirical by way of installing and testing prototype systems, but also be done in a simulative and modelling manner. In order to improve the modelling techniques an expansion of basic research in Intellectics (ie. AI and Cognitive Science) towards positively influencing a "hardening" of the social sciences is deemed necessary.* Sections 4.6 and 4.7 have established the grounds for this recommendation which is considered particularly important in view of the serious risks that are involved in several of the NBIC technologies. Some of these risks have been discussed in Section 4.4. The methods of assessment addressed here go beyond those typically applied by social scientists in terms of their scientific precision and reliability. It is for that reason that Intellectics come into play here. As argued in Section 4.7 a substantial part of today's social sciences is built on the grounds of commonsense psychology rather than on truly scientifically established facts about the cognitive nature of humans from Intellectics and Neuroscience. Especially CogSci's role is important for diminuishing the cognitive knowledge gap in this respect while AI offers the methods for modelling (eg. knowledge-based modelling). CogSci is certainly also one of the areas where Europe has to catch up in the sense of GenRec7.

GenRec3. *The development of quantitative methods and assessment tools for the entire life cycle of the new converging technologies as well as for its full system impact including regulations and laws should receive a high priority. This includes support for the decision making from the funding phase through the implementation and maintenance of the technology within some environment, thereby respecting assessed technical and ethical limits.* The decision structures addressed here have been discussed in Section 4.3 and the need for their activation in Section 4.4. Altogether the recommendation calls for a more rational approach to technology assessment supported also by technology and for an ongoing constructive technology assessment. It also encourages the European Commission to establish and implement regulations on a European level which, for instance, safeguard the prevention of releasing nano-material with untested properties into the environment in an uncontrolled way.

GenRec4. *Encourage the development of a whole society model from which the impact of special recommendations can be analysed which might produce recommendations for European market potentials thereby exploiting the potential of the advanced simulation and modelling techniques including those from AI.* The time seems ripe and the methods and techniques seem available (see Section 3) to put foresighting on more formal grounds which in turn requires more formal models of society and its evolution. While the group appreciates the known difficulties experienced in previous attempts towards society models, it is convinced that the full potential of knowledge-based modelling at a sufficiently high level of abstraction has never been fully exhausted (if tried ever). With this recommendation pointing out market potentials the group would also like to emphasize the importance of the European research and technology policy for a healthy European economy.

GenRec5. *Converging technologies as well as scientific knowledge accumulated in Intellectics and Neuroscience shed a harsh light on the dubious boundaries between the traditional disciplines. It is strongly recommended to the Commission to contribute by its various actions, not least by its funding policy, to a truly scientific evaluation of the merits of this traditional structure as well as of the role of some of the disciplines, and also to take steps towards a structure which is more in line with the modern scientific "Weltbild".* The rationale behind this recommendation has been provided in Section 4.7, at the end of Section 4.4, and is distributed in other parts of the report. A particular issue in this context is the research direction and the proper role of the traditional humanities and social sciences. While a considerable part of their research does not withstand a scrutiny wrt. hard scientific criteria, they may even with this part still fulfill an important role in our societies which however should be clarified. The assessment might be carried out on an ongoing basis, whereby periodical reports would serve as input to resource-allocating agencies as well as citizens' and institutional ethical and policy-making organs.

GenRec6. *Any decision for funding some technological development must be based on a rational perspective for a potentially beneficial contribution to some of the problems facing the world* (of the kind discussed in Section 2). Project proposals are required to provide convincing arguments in this regard as one of the relevant criteria for the funding decision. We expect that this linkage will raise the consciousness for the responsibility we all have for the future of Europe and the world. Obviously, basic research will need to be less convincing in this regard than the development of technology to be launched in the near future.

GenRec7. *Europe must focus its balanced efforts to keep its leading position or, where needed, catch up in the individual basic research and development areas involved in NBIC as well as in its converging technologies.* Section 3 of this report has discussed many of the topics which deserve continued funding. By "balanced" we mean that the funding of new developments is not realized at the cost of ongoing ones. For instance, while research on software development is of already longstanding concern, it must be maintained at the same or even higher level, and under no circumstances be reduced, say in favor of currently more fashionable topics. Also, basic research must sufficiently be funded also in disputed domains (such as artificial consciousness to mention just one, though prominent example), unless extraordinary amounts of money are at stake (which is mostly not the case in the entire NBIC area).

GenRec8. *Explore the development of an advanced ethic which is consistent with the modern scientific "Weltbild" and rests on the European values which evolved over the centuries.* There is a considerable scepticism whether the churches as well as Philosophy approach this problem in a way which is appropriate for Europe of the 21st century. On the other hand, there is already a considerable body of hard scientific knowledge (in Intellectics and Intellectics-related Philosophy) available supporting such a far-reaching goal in the spirit of Section 4.2.

5.2. Specific recommendations

SpecRecs. *We propose to lay a particular emphasis in the funding of* 1. Software synthesis; 2. Intelligent user interfaces; 3. Uncertainty reasoning, argumentation; 4. Ontologies and knowledge bases (KB); 4.1 KBs in education; 4.2 Legal KBs; 4.3 KB on science & technology foresight; 5. Deduction; 6. Semantic web; 7. Knowledge extraction; 8. Evolution and self-organization.

This recommendation complements the GenRec7 by pointing out specific subjects which are deemed especially in need of more concerted efforts in view of their potential for contributing to an improvement of the problems discussed in Section 2.

5.3. Challenge problems

Natural Language Processing. The Europe of 25 nations with mostly different natural languages (NL) faces exorbitant problems of communication among individuals and institutions. Any substantial progress in a technological support for overcoming these problems would amount to a tremendous improvement for all Europeans. At the same time Europe is actually leading worldwide in the technology of processing natural language. This means that any such progress would at the same time offer a great market potential for the technology which could of course be similarly useful in other parts of the world. Although NL systems have already reached an astonishing level of performance we still need overcome a considerable distance to process NL in systems at the same ease as do humans. This challenge includes the different modes of written as well as acoustic NL understanding systems, written and spoken NL generation systems, and translation systems.

Integrated Hybrid Transportation System. One of the treasures of the European inheritage 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 inheritage 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 Alpes). 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 transportation means (planes, trains, busses) which might well compete with cars except that they rarely or never provide a door-to-door connection as comfortable and fast as with a private car. The inherent problems lie in the fringes of the individual systems (eg. door to bus station, or vize versa) as well as in their poor connections. In order to overcome these problems 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 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 like individual, though anonymous, locating and thus tracing (eg. RFIDs from Section 3.8), and caring for, each individual passenger (including his/her luggage as well as front-door-pickup and delivery) and connection optimization is in principle available and truly NBIC of nature (see Section 3, eg. 3.6, 3.8, etc.) but needs to be woven into a single complex system. The public support of developing prototype systems of this kind would at least be a first step back to the relatively peaceful cities and landscapes of the past.

Assistants with global "conscience". Humans by nature are agents which think, act and judge in a locally oriented way. From a global perspective this local orientation turns out to accumulate in disadvantageous, sometimes even desastrous effects. The collective damage to the environment, the collective behavior in certain traffic situations causing unnecessary congestion and accidents, collective political misbehavior of the masses like in German national socialism of the Hitler time, and the mutual misunderstanding among people are some of an unlimited number of examples familiar to everyone. System-based assistants could compensate this local human nature with globally oriented advice based on global aspects of the respective situation. For instance, the selection of a transportation means by some individual is decided on the basis of supposed convenience and individual costs, considerations which could be complemented by the assistant with arguments concerning the overall costs, the damage to the environment, less immediate effects on the health of the individual as well as of all others and so forth. An assistant of this kind which is restricted in its competence to a specific area of application (such as transportation, nutrition, politics or others) would not only be a great challenge but also tap on many aspects of NBIC.

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