Converging Technologies and their impact on the Social Sciences and Humanities (CONTECS)

An analysis of critical issues and a suggestion for a future research agenda

Final Report

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Table of Contents

Executive Summary I

Selected Proposals for Science Policy Action VI

1 Introduction: The concept of convergence and its relevance for the Social Sciences and Humanities 1

2 Presentation of the CONTECS project and method 5

3 The agenda: SSH research and technological convergence 7

3.1 Tracing the origins of the convergence debate and sketching impacts on R&D 7

3.2 The Role of Cognitive Science 13

3.3 Interdisciplinarity: The common denominator of CT? 17

3.4 Ethical questions and the technology assessment view 22

3.5 Natural science taking over SSH domains: New deterministic models of man 27

3.6 The role of enhancement and other narratives of convergence 35

3.7 A non-exhaustive list of relevant SSH fields 40

4 Summary and outlook 43

Literature 47

Appendices

A R&D Trends in Converging Technologies

(Authors: Bernd Beckert, Clemens Blümel, Michael Friedewald, Axel Thielmann)

B Cognitive science within Convergence: Key issues in the European context

(Authors: Daniel Andler, Simon Barthelmé)

C The Ontological Politics of Convergence

(Authors: Steve Woolgar, Christopher Coenen, Elena Simakova)

D Current trends in RTD policy on Converging Technologies

(Authors: Michael Rader, Christopher Coenen, Torsten Fleischer, Beate-Josefine Luber, Christiane Quendt)

Executive Summary

The project CONTECS (Converging Technologies – and their impact on the Social Sciences and Humanities) was a Specific Support Action (SSA) funded by the European Commission to assist the Commission in setting up a research agenda in connection with converging technologies. Items on this agenda can either be related to research on the process of convergence itself or to research supporting technological convergence.

In the current decade, a new concept of "Converging Technologies" (CT) has become a buzzword in research and technology policy expert circles. This concept differs from older notions of CT which are used, for example, in the computer and media industries. At the core of the new concept are relations, synergies or fusions between broad fields of research and development, such as nanoscience and -technology, biotechnology and the life sciences, information and communication technologies, cognitive science and neurotechnologies. Robotics, Artificial Intelligence and other fields of research and development (R&D) are also taken into account in the discussions. The debate on converging technologies has therefore been characterised as a "forum for exploring the future impact of all science and engineering" (George Khushf at a CONTECS workshop).

The starting point of the discussions about the CT was a 2001 research and technology policy initiative in the US which has often (and, in a way, incorrectly) been regarded as a major official US initiative. This so-called NBIC initiative (nano, bio, info, cogno) put emphasis on the aspect of "improving human performance" and, in particular, on the issue of "human enhancement", i.e. the technological augmentation of human capabilities and modification of human corporeality and intellect. Despite reservations about the strong military focus of the NBIC initiative, other aspects of the concept resonated strongly in other parts of the world, including Europe where the European Commission set up a High-Level Expert Group: "Foresighting the New Technology Wave".

The major findings of this expert group reflected the intention to develop a different approach to technological convergence to that pursued by the US initiative. While the latter focuses strongly on enhancement of the individual human being, the European concept of "Converging Technologies for the European Knowledge Society" (CTEKS) adopts a demand-driven approach in which CT respond to societal needs and demands. A major theme in both the US and European approaches is cooperation between the disciplines: the European approach makes a special issue of interdisciplinary cooperation and its specific conditions and problems, whereas the US approach argues

for a new unity of science underpinned by reductionism enabled by the possibility of tracking virtually everything down to the nano-level.

While the research policy activities on convergence, which until recently have largely been confined to foresight projects, reflect the international diversity of agendas, the debate on CT, even in the European Union, still exhibits a clear focus, namely technologies that can be used for "human enhancement", for a massive modification of human bodies in terms of a possible "reconstruction of man", or even for the creation of "posthuman" beings. These wide-ranging visions which have not only accompanied, but, in a way, determined the discourse on CT have already sparked debates in research fields such as the ethics of technology, technology assessment, utopian studies, theology, and in diverse subfields of science and technology studies (STS). There is therefore a growing body of scholarly literature on the CT topic, although the CT concept is not yet very apparent in the pertinent natural sciences and engineering fields.

In the policy context, several actors have embraced the new concept of convergence, most forcefully the European Union which, for example, has installed "converging sciences and technologies" as a central concept in its funding activities on nanotechnologies and nanosciences. In general, one can observe that most of the new political initiatives on CT are distancing themselves from the original NBIC initiative, at least when it comes to the more visionary aspects, in particular in the field of "human enhancement". In the scholarly literature on CT, which is together with a rather small number of foresight and innovation reports, the main manifestation of the new discourse on convergence, three tendencies can be observed: First, the discussions and research activities on the CT topic have broadened and intensified, leading, for example, to the publication of several CT special issues in academic journals and a stronger presence of the convergence issue at academic conferences. Second, the accompanying research on CT has shifted its focus to less visionary topics such as potential new modes of inter- and transdisciplinarity, of science and society interrelations as well as empirical aspects of processes of technoscientific convergence. Last but not least, the previously largely ethical analysis of the topic of "human enhancement" has been supplemented with studies on the historical, cultural and policy contexts of the visionary discourse on convergence and of related discussions.

However, the social sciences and humanities (SSH) still lack a comprehensive and integrated agenda with regard to CT. The development of ideas for such an agenda was the main task of the CONTECS project on behalf of the European Commission. All pertinent policy initiatives agree about the profoundly transformative character of the ongoing and emerging processes of technoscientific convergence. They also agree

that not only the ethics of technology, but a wide range of SSH should contribute to both understanding and shaping these processes and their societal context.

Against this background, the present paper starts by introducing the new concept of CT and with some general remarks on its relevance for the SSH (Ch.1), followed by a short description of the CONTECS project (Ch.2). In its main part (Ch.3), the paper outlines six major aspects of the overlap between Converging Technologies and Social Sciences and Humanities. Within each of this six areas, several research questions and challenges for the SSH are formulated. These research questions constitute items proposed for a future research agenda for the SSH in Europe and should contribute to a European approach to Converging Technologies. In order to keep this executive summary concise, the single research questions are not listed here. Instead, a short characterisation of the central fields in which the respective research questions evolve will be given in the following.

The six fields are:

- **The origins of the convergence debate and an analysis of real-world impacts of CT visions** (Ch.3.1) – this section examines to what extent the concept of convergence has found its way into agendas for research and development policies worldwide, and also attempts a realistic assessment of the US NBIC initiative and its impact. It emerges that the NBIC initiative, far from being a major official research policy initiative of the US, had its main function to argue for further financial support for nanotechnologies and that it contains "visions" rather than genuine roadmaps for a development of converging technologies or a "new renaissance of science". Assessments of the state of development of technological areas where convergence is likely to take place, showed that experts regarded progress in brain enhancement and physical enhancement as furthest removed in terms of realisation from the visions for the areas. In some cases, researchers are paying lip-service to the visions to secure funding, but there are also indications that researchers in certain areas of the cognitive sciences regard personal enhancement as a realistic and worthwhile goal to guide their research.
- **The special role of Cognitive Science** (Ch.3.2) – the Cognitive Sciences were viewed by CONTECS as the key element towards the realisation of CT in sense of the NBIC initiative. Expectations in this direction have been fuelled by enormous progress in the neurosciences, due not least to new instruments available to observe, control and possibly manipulate processes within the human brain at the level of neurons. Today, very little of Cognitive Science concerns itself with phenomena happening at the nanoscale. Molecular neuroscience, which is active in this field, lies on the outer fringes of Cognitive Science. Although it is recognised that information transmission happens at a molecular level in the brain, few cognitive scientists will find the fact relevant to their work. Effort should be devoted to investigating what our lives are expected to look like when what is in gestation in CT now reaches maturity.

- **The question whether interdisciplinarity is the common denominator of the CT development** (Ch.3.3) – both the NBIC and the CTEKS concepts devote much attention to issues of cooperation between scientific disciplines to realise applications of CT. While the NBIC initiative argues for underpinning cooperation through a base of common knowledge at the nano-level, the CTEKS concept argues for strong interdisciplinary cooperation including both hard sciences and social sciences. The problems and issues here are mainly not unique to CT and have been investigated before. A specific problem within CT is the low degree of interdisciplinary integration. Although this is true for interdisciplinarity in general, there is more research needed focussing on knowledge overlap at the local level. With the absence of a common basis for interdisciplinary research, it is necessary to study the "epistemic cultures" of the disciplines involved, in order to identify possible obstacles for cooperation caused by different styles of scientific reasoning. As elsewhere, institutional barriers should be analysed and applied to the needs of concrete CT research.
- **Ethical questions and critical issues from a technology assessment view** (Ch.3.4) - much of the current ethical discourse is focused on impacts of technologies and applications that are still very remote in time if they can indeed ever be realised. CT are frequently used to discuss more general questions arising in connection with applications of technology, particularly those for human enhancement. Given the visions existing for the development of CT and likely applications in controversial areas, there is a need for a timely societal debate which could be facilitated by citizen involvement. Further needs related to CT exist in the areas of education, legal regulation and risk governance. There is finally a need to examine in which areas of regulation international agreements are required and in which areas national regulation is appropriate.
- **The assumption that natural science will take over traditional SSH domains which may further the spreading of deterministic models of man** (Ch.3.5) – attempts to "naturalise" the social sciences have a long and controversial tradition. While the social sciences and humanities frequently apply methods from mathematics and hard sciences, this does not bring with it a transformation of the SSH into hard science. While previous attempts to formalise the SSH have met with limited (though real) success, the rise of research into complex systems is bound to extend the reach of formal approaches. However, the crucial development is brought about by the development of *empirical* approaches from cognitive science, neuroscience and evolutionary biology, which carry a promise or a threat of reductionism. In conjunction with enhanced formal tools, these disciplines offer new opportunities for proponents of a radical form of naturalisation, which is regarded as threatening by both the SSH and the affected citizen. The question thus raised is how far naturalisation should go or be allowed to go. It might reach, according to the present tacit consensus, lower (animal) faculties as well as the most general and formal conditions of higher faculties, leaving out some "core content" which is the province of SSH. It is worthwhile researching what new possibilities for formalisation and empirical naturalisation of the SSH exist and what this implies for the central traditions and disciplines of the SSH.

- **The role of enhancement and of other narratives of convergence in the genesis and shaping of the CT debate** (Ch.3.6) – ontological politics are the processes, practices, discussions, struggles and contentions whereby the existence and character of entities are defined, constructed and brought into being. Ontological politics help define the focus and targets for CT. The contributions to the genesis and shaping of the discourse on CT of various actors are therefore analysed with regard to specific positions within the relevant discursive and institutional fields. From this perspective, the discussions on CT and what counts in them as expert or "authoritative" knowledge are examined. CONTECS distinguished two approaches to the analysis of ontological politics. First was a description of the parallel constitution of the debate on CT and on nanotechnology-related far-ranging visions and of intensified discussions of "human enhancement" enriched with an analysis of the historical roots of transhumanism. Second was an analysis of the ways in which ontologies are enacted, kept alive and performed in contemporary discussions about CT. By exposing, analysing and demystifying ontological politics, especially those associated with the posthumanist and, more general, the technofuturist background of the most heatedly discussed visions, the SSH may be able to draw more attention to issues that are largely neglected in the debates on CT.

In chapter 3, the relevant research questions for the SSH are emphasised in **bold**. The research questions are the result of a comprehensive analysis of different CT aspects which are documented in detail in the annexes A to D of this report. In addition, earlier deliverables can be downloaded from the project website www.contecs.fraunhofer.de. The research included document analysis, literature reviews and expert interviews with researchers and engineers in the different technology areas as well as in the SSH community. The results of the first deliverables and suggestions for a future SSH research agenda were discussed and extended in two expert workshops in October 2006 (Brussels) and October 2007 (Paris). The draft agenda was presented and discussed at the CONTECS final conference in Brussels in April 2008. Based on the discussions and the final conference, concrete policy recommendations were extracted from our work. The recommendations follow on the next two pages.

Chapter 3.7 presents a (non-exhaustive) list of SSH disciplines and research fields which are relevant for the analysis or shaping of technoscientific processes of convergence. The paper concludes with a general summary and an outlook (Ch.4). In this conclusion, we argue that a strong engagement of a broad variety of SSH in the debate, analysis and shaping of actual processes of technoscientific convergence can decisively contribute to overcoming a one-dimensional, sociologically and philosophically naïve conception of these processes and to embedding the dynamic developments in the NBIC fields into the European Knowledge Society.

Selected Proposals for Science Policy Action

The function of the proposals described in this section is to highlight important areas for *science policy action*. They are a selection of ideas for an SSH research agenda on CT, and to an extent exclude important areas for future research which are also detailed in the complete report. At the same time, the recommendations are one outcome of the fruitful discussions at the CONTECS final conference in Brussels, April 16th 2008. The authors gratefully acknowledge all participants' contributions to the discussion and to an inspiring exchange of ideas, both at this final conference and the two workshops during the course of the project.

A) *Strategic role for the SSH in the Development of Key Technologies:*

Create the financial and institutional conditions for the SSH to contribute to the development of complex key technologies, such as converging technologies, in the frame of strong European innovation systems in the interest of the citizens. (*Expected benefits*: Early identification of promising CT application fields; "early-warning system" with regard to ethical and societal concerns related to the CT; promoting the co-evolution of European knowledge societies and cultural diversity.)

B) *Broadening the knowledge base of policy-makers:*

Fund empirical research on processes of technoscientific convergence and support efforts to their precise conceptualisation to enable balanced strategic decisions in R&D policy, the identification of new fields and their trajectories, and pinpoint funding of CT projects. (*Expected benefits*: Contributing to a sound basis for R&D policy decision-making; avoidance of "hype"-driven misallocations of resources; early identification of disciplinary, inter- and transdisciplinary reconfigurations.)

C) *SSH enabling CT development:*

Support active contribution of the SSH to the development of CT through analysis of existing experience with participation of the SSH in technology development projects, the identification of critical factors for success under various conditions, and the provision of funding for strongly interdisciplinary and transdisciplinary pilot CT projects in which the SSH are involved in different ways (e.g. active contributions to Cognitive Science or the "embedding" of SSH researchers into CT projects). Important aspects are the framing of the SSH by "hard" scientists and the framing of the "hard sciences" by the SSH. (*Expected benefits*: Exploration of new avenues for strongly interdisciplinary cooperation; strengthening societal and application aspects in the natural and engineering sciences; establishing SSH as "converging sciences".)

D) ***Awareness raising:***

The weak current involvement of the SSH in converging technologies is due in part to lack of awareness of the opportunities existing in this field. Science policy could encourage participation of the SSH in CT development by activities to raise awareness including the broad dissemination of the results of projects such as CONTECS and of other relevant projects on CT within SSH communities. (*Expected benefits*: Tapping underused or unused knowledge resources in the SSH which are relevant in the CT context; sensitisation of the SSH with regard to the CT and their societal implications.)

E) ***SSH as "mediators" and "translators":***

The SSH could take the lead in fostering a broad public dialogue on CT aimed at avoiding counterproductive "hypes" and identifying societal demands and innovative applications which correspond to policy goals. Such a discourse would also address the "social limits" to CT and questions such as "What is the distinction between human and posthuman and what does it mean to be posthuman?". (*Expected benefits*: Furthering new modes of communication between policy-makers, natural scientists and engineers and the public; identification and inclusion of a broad range of relevant stakeholders; "translating" S&T options into policy options.)

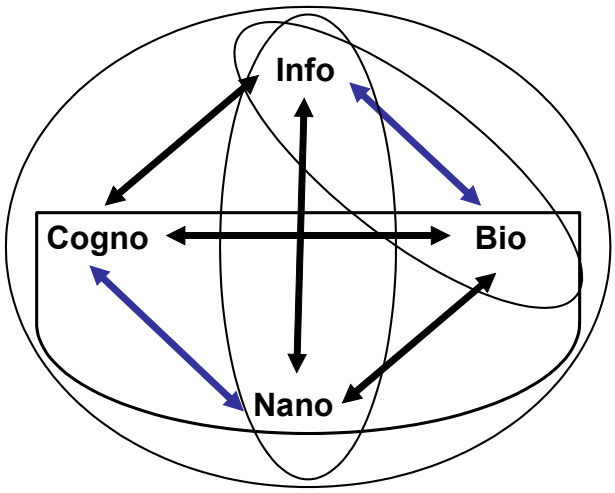
1 Introduction: The concept of convergence and its relevance for the Social Sciences and Humanities

Convergence in connection with science and technology is a frequent topic in scientific and scholarly discourses, and also in the popular press. A familiar example is the convergence of computing equipment and domestic consumer electronics, but the term is also used to describe the coming together of scientific disciplines to solve problems common to these disciplines, initially through interdisciplinary cooperation. If the area of overlap is of a more permanent nature, this cooperation can develop into a convergence drawing on elements from each of the scientific disciplines to form a new discipline, or sub-discipline, with its own institutions, infrastructure, and trajectories (Bunge 2003, Doorn 2006).

While the latter kind of convergence is obviously of significance to a project concerned with the setting of agendas for the social sciences and humanities, the entry point to the CONTECS project were the "converging" technologies. Here, convergence is used to denote the development of technologies drawing on a combination of research findings from different disciplines. The extent to which converging technologies require, or at least benefit from, a convergence of scientific research fields is a matter deserving further analysis. One precondition for such an analysis is a more refined concept of convergence which takes into account different modes of convergence as well as the specific interrelations of highly transdisciplinary (sub)fields of R&D which are situated at the intersections of the key areas of science and technology.

Given the history and character of the debate on CT, the "natural" starting point for CONTECS was, however, the more general concept of convergence of the so-called NBIC quartet: nanotechnology, biotechnology, information technology and the cognitive sciences (including the pertinent sciences or technology fields). This concept of technological convergence was first advanced by Roco and Bainbridge in the documentation of the first NBIC conference 2001 in Washington, D.C. (Roco and Bainbridge 2003). The concept is frequently illustrated by the so-called NBIC tetrahedron (figure 1). In their introductory article the authors claim that convergence is taking place as a synergistic combination of four major provinces of science and technology, each of which is currently progressing at a rapid rate: (a) nanoscience and nanotechnology; (b) biotechnology and biomedicine, including genetic engineering; (c): information technology, including advanced computing and communications; and (d) cognitive science, including cognitive neuroscience (Roco and Bainbridge 2003).

Figure 1: Convergence of Nano, Bio, Info and Cogno (NBIC) (Roco and Bainbridge 2003, p. 2)



The assertion is that these sciences have now "reached a watershed at which they must combine in order to advance most rapidly" (Roco and Bainbridge 2003, p. 2). As structuring principles for future technologies the research objects of the NBIC fields like atoms, genes, neurons and bits are accounted for (Roco and Bainbridge 2003, p. 71f). Referring to the NBIC concept, it has been suggested that "(a)t the nanoscale atoms, circuits, DNA code, neurons and bits become conceptually interchangeable" (Bouchard 2003, p.12).

Whereas the NBIC concept addresses above all science and technology, NBIC advocates have from the beginning been raising questions concerning its implications for society, education, and governance. One indication for this is the first Roco & Bainbridge report which is not structured around the respective technologies or research fields but around socially relevant goals and application fields. The report organises its odd 70 articles into the following sections:

- Expanding human cognition and communication
- Improving human health and physical capabilities
- Enhancing group and societal outcomes
- National security
- Unifying science and education.

The social consequences of the technology development are discussed in each of these sections. And the section "Unifying science and education" (Roco and Bainbridge 2003), but also three subsequent reports (Roco and Montemagno 2004, Bainbridge and Roco 2006a, Bainbridge and Roco 2006b) contain extensive discussion of the role of the Social Sciences and Humanities as a research area.

The report contains several very strong visions, such as human enhancement as the *leitmotiv* of technological development for converging technologies and also a "renaissance of science" based on the reduction of virtually everything to processes on the nanoscale.

Due to the high strategic importance attached to this kind of convergence, the concept attracted a great deal of attention in other regions of the world. Examples of more or less direct reactions to the NBIC report are the setting up of a high-level expert group "Foresighting the New Technology Wave" by DG Research of the European Commission which developed the CTEKS Agenda ("Converging Technologies for the European Knowledge Society") and at least two activities by the Canadian government: Defence R&D Canada and the Canadian Pilot Foresight exercise on "Biosystemics" (for other examples cf. Rader et al. 2007; TAB 2008).

In contrast to the U.S. approach which exhibits a strong technodeterminist approach (see for example the analysis of Schmidt 2007), the European approach to converging technologies starts with social and environmental goals. In its report "Converging Technologies - Shaping the Future of European Societies", the European High Level Expert Group encourages research on topics that are highly valued, thus hoping to initiate technology developments in the desired areas. A number of areas are identified where progress through convergence is considered to be desirable (HLEG 2004), for example:

- Health, including "lab-on-a-chip" technologies for fast screening and early diagnosis of diseases, intelligent prostheses interacting with brain signals from patients and transmitting sensory information.
- Education with applications like invisible knowledge space, learning objects and smart surroundings.
- ICT Infrastructure with environmental monitoring through ambient sensing devices to alert agencies of pollutants and inform individuals about the distribution of allergens, integration of information about food products.
- Energy with new energy carriers and forms of storage, new energy sources emulating nature, exploring renewable energy sources, photovoltaic, hydrogen, geothermal and solar energy.

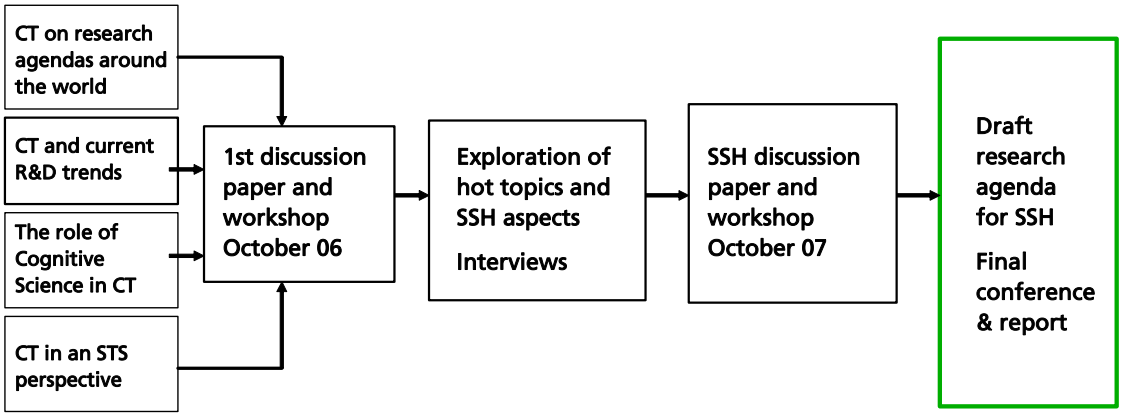
A wide range of SSH aspects is being addressed in the debate on converging technologies. In principle SSH involvement in the debate has two sides, namely contributions of SSH research on convergence, and contributions and contributions of SSH research for or in processes of convergence. On the one hand it can be asked what the Social Sciences and Humanities can contribute toward understanding the processes of scientific and technological convergence, to analysing the new modes of knowledge

production, to assessing the diffusion of the concept into research programmes and to grasping the role of visions in concrete technology development processes. On the other hand it can be asked what the process of convergence means for the development of a future SSH research program. Following the assumption that scientific and technological convergence will have far-reaching consequences for society and the economy, it can be assumed that the current SSH research will have to react in one way or the other to the challenge of convergence. Both aspects of SSH involvement were discussed in the CONTECS project and the main findings will be presented in the following sections.

2 Presentation of the CONTECS project and method

CONTECS (Converging Technologies - and their impact on the Social Sciences and Humanities) was a research project funded by the European Commission with the aim of contributing to a future research agenda for the SSH in the light of ongoing processes of technological (NBIC) convergence. The project started in February 2006 and its final results were presented at a conference in April 2008 in Brussels. The project is a collaborative activity in which four partners from universities and research organisations were involved. The project was co-ordinated by Fraunhofer ISI (Karlsruhe) and included the Research Centre Karlsruhe, the Saïd Business School (Oxford) and the Ecole Normale Superieure (Paris).

Figure 2: Work packages and activities of the CONTECS project



The aim of the project was to suggest a research agenda for the SSH on the basis of a comprehensive understanding of the convergence process. Figure 2 shows the tasks undertaken for this purpose with a subdivision into research policy (top box in left-hand column), technological aspects (second box from top), the role of cognitive sciences for the converging technologies and, in the bottom-most box, converging technologies from the STS perspective. The first phase included an analysis of the central documents of the CT debate and of additional information on the topic available in the academic literature and on the Internet. A one-day workshop was organised in October 2006 in Brussels to discuss the results of this first phase with about 20 researchers and experts from Europe and the United States. Recurring themes of this discussion, so called "hot topics", were identified and used to structure the second phase of the project. The second phase of CONTECS included personal and telephone interviews with researchers and central figures of the NBIC and CTEKS debate. The interviews produced new insights into the different strands of research in the project and resulted in a set of consolidated papers and a SSH discussion paper listing and describing nine central SSH areas. This SSH discussion paper was the basis of a second expert work-

shop in October 2007 in Paris involving SSH researchers both from Europe and from North America. Based on workshop input and further research, the relevant areas for the reearch agenda were condensed to six. These six central areas and the research questions evolving from them will be presented in the following.

The basis for the following chapters are four deliverables which make up annexes A to D of this report. The annexes are authored by the different partners in the project and they comprise additional information and a comprehensive description of the respective methods.

3 The agenda: SSH research and technological convergence

3.1 Tracing the origins of the convergence debate and sketching impacts on R&D

How did the concept of convergence diffuse into research programmes?

As far as it is possible to discern today, the term "converging technologies" referring to the combination of nanotechnology, biotechnology, information technology and the cognitive sciences (NBIC) emerged from the US National Nanotechnology Initiative (NNI). NBIC appears to have been conceived largely as a successor to the nanotechnology program with the aim of securing continued funding. The "grand visions" developed for NBIC must be evaluated against this background. Interviews in the US indicate that these visions, such as the unity of science or radical human enhancement have not been taken at face value in the US. Most notably, there has never been any genuine national US policy or national debate on converging technologies and human enhancement as has frequently been assumed in Europe.

The role of radical visions in science policy is a possible topic for further investigation. Another topic in this connection is the "genesis" of visions, more specifically the fate of the NBIC vision between its emergence at the NSF/DOC workshop and the current situation. A further interesting research question is: what is actually at the core of the NBIC vision? Is it nanotechnology or biology and what is the role of the cognitive sciences in converging technologies? To what extent does the vision of NBIC convergence still build on the notion of bio-info convergence in the "information paradigm" (Castells 1996)?

As a result of the existence of the US NBIC initiative and its perceived key role in securing industrial competitiveness, initiatives addressing a similar range of converging technologies were developed for other regions, most notably Canada and Europe. These initiatives are usually described as having a different approach and as pursuing different goals to the US NBIC initiative. **One might thus assume that the critical issues for the social sciences and humanities would also be different to those relevant for the NBIC approach for enhancing human performance, or at least to give different emphasis to the issues involved. But is this really the case?**

Due to the lack of a widely accepted definition of what constitutes convergence and also to a lack of currency of the term itself, "convergence" is used by a broad variety of stakeholders and other actors to convey their own visions of the aims and nature of convergence. "Convergence" itself is finding more frequent use in recent years in con-

nection with technology. A familiar example is the convergence of computing equipment and consumer media electronics and another important case is the convergence of the formerly separate infrastructures for the transmission and exchange of data, broadcasting and telecommunications. Convergence can also take place between previously separate scientific disciplines, for example where these convergence on a common subject, each bringing its methods to bear. The dividing line between various kinds of research involving cooperation between different scientific disciplines and convergence has already been the subject of the EU FP6 project EMCOTEC.

The impression gained from work for CONTECS and other NBIC-related projects is that scientists working in fields belonging to the converging technologies do not use the term and are sometimes even unaware that it exists. The term seems to have originated in the sphere of research policy, which raises questions about its use by policy makers and its discovery and adoption for strategic reasons by researchers.

There is currently little evidence of spectacular advances involving the complete NBIC quartet, so it might be more relevant to look at specific directions of convergence of pairs or trios of the technologies, like synthetic biology and neuroscience where there is most likely progress which could not have been achieved without convergence.

One aspect of this type of convergence is a possible shift in emphasis from engineering to the life sciences, from attempting to model processes found in nature towards replicating and amplifying these same processes in living organisms. This implies examination of connections and links between previously separate areas of science.

In a more speculative vein, a question linked with the replication of processes concerns the implications of hybridised human beings for the social sciences, e.g.: **If technology is believed to replicate natural processes linked with specifically "human" properties, does this imply that artificial or hybrid intelligence should have the same rights and obligations as humans?**

A question related to shifts in the definition of concepts or to differences in concepts in general is whether these shifts bring with them changes to the relevant agenda of the social sciences and humanities.

While the converging technologies do raise many questions in the social realm, it is a question to what extent these are generic issues related to technologies and to what extent they are specific to converging technology. Thus it should be asked whether it

makes sense to deal with all topics under the common umbrella of "convergence" or to tackle them separately, although a distinction should obviously be made.

Technologies like CT have been very successful in enhancing their legitimisation by claiming a close alignment of their research agenda with the industrial research agenda. This has also been seen in other fields, for instance molecular biology where it was possible to hugely increase funding because of the promises that were made by scientists to emphasise the economic significance of research in the field. There is a sharp distinction between legitimacy in the scientific field, where the criteria for scientific value are still publications in scientific journals and other forms of peer acknowledgement, and recognition as a funding area of key strategic or economic importance. **The different frames of reference for scientific research in such fields and the conflicts and strategies arising as a result of the need to address them are a topic for SSH research.**

What are scientific drivers of CT? Do researchers use the concept in their everyday work? What is the role of visions in the process of research and technology development? How is industry involved in the convergence process?

After analysing the diffusion of the convergence concept in the different national research planning contexts where programmes determine actual research and scientific development, another important question concerns the scientific drivers of CT. This leads to the question whether or not the concept is actually being used as a guiding vision by researchers in their every-day work. In fact it is not clear whether the convergence idea is something which has been invented by a few research planners and gratefully adopted by the so-called "transhumanist" movement (that argues for radical "human enhancement" which might lead to a transformation of the human species), or something which has come out of the scientific community itself as a result of the observation of technological development and its organisational requirements. As a result, convergence might be either a normative concept imposed on researchers by science politics or a science-driven concept embodying future requirements for collaborative research and technology development.

In order to approach this question we made an attempt to determine the distance between the visions of the NBIC debate and actual developments in the relevant areas (see appendix A and Beckert, Blümel, Friedewald 2007). We propose employing assessments by experts of the distance between visions and realities as an indicator for the relevance of the concept: A greater distance, i.e. technological realisability at some remote point in the future, would make the use of convergence as a normative concept more plausible than its use in the frame of a science-driven concept.

In a first step it was necessary to determine the relevant areas, applications and research fields that are possibly being affected by or driving the development of convergence. An analysis of the central documents of the debate in the U.S. and in Europe resulted in the identification of more than 100 individual technology development and application fields, scientific areas and research fields in which convergence is claimed to be under way or where convergence is expected to take place in the future. With the help of experts from different technology backgrounds, the R&D fields were clustered according to thematic similarities, common methods, mutual closeness and frequency of occurrence in the main policy documents. The clustering exercise resulted in eight areas in which it was possible to locate almost all research and development fields related to CT. The eight areas are

- neuroscience and brain enhancement,
- physical enhancement and biomedicine,
- synthetic biology,
- human-machine interfaces,
- sensors,
- pattern recognition,
- computer-based modelling of the world, and
- robots and intelligent software and devices.

To be able to confront the virulent visions with the state of the art in research and technology development, the visions were extracted from the central policy documents and an assessment was made of the state of the art in the respective research and technology development areas. This was accomplished by the analysis of scientific overview articles as well as reports on specific areas of the NBIC subject matter. The overview articles include Silberglitt et al. 2006; Shmulewitz et al. 2006 and Grillner et al. 2005. Articles mainly from a journal of the Institute of Electrical and Electronics Engineers (IEEE, engineering) and "Nature" (natural sciences) were used to assess advances in individual application areas. Analysis drew on the know-how of experts from the Fraunhofer network in Germany and of several external experts who were interviewed for this exercise. **The intention of the interviews with researchers and engineers was to gather information on the extent to which scientific practice is affected by the notion of convergence and in which ways technological convergence is actually taking place.**

Analysis of the visions and of cutting-edge research in the overlapping fields of nano, bio, info and cogno shows that scientific convergence is indeed under way in various fields. Central impulses for convergence are coming from the field of neuroscience.

Multi- and interdisciplinary research and development seem to be the core of technological convergence. Investigation on the application areas of NBIC has shown that the central fields of CT, such as neuro and brain enhancement, physical enhancement and biomedicine and - with some restrictions - also the relatively new field of synthetic biology, are characterised by the incorporation and combination of previously separate existing research fields by a process of technological convergence. Indicators are new potential applications, interdisciplinary co-operation and research projects. There is thus evidence of both scientific and technological convergence.

However, analysis has also shown that visions and cutting-edge research are considerably remote from each other in all eight fields. The gap is especially wide in the two human enhancement fields (brain enhancement and physical enhancement) and also in Synthetic Biology. In almost all of the remaining fields, the distance is not as significant and visions can be expected to turn into concrete applications in the not too distant future. In neuroscience and biomedicine there is a strong focus on medical applications and improvements of existing treatments and therapies. The enhancement of brain and body functions is not mentioned as an explicit goal in the projects concerned. Even so, the recent German National Foresight project has revealed that "personal enhancement" is regarded by participants in the foresight process from the cognitive sciences as an interesting and worthwhile area of research, in contrast to participants from the health area (Cuhls & Ganz 2008, p.35).

Across all eight fields, it can be stated that convergence is essential for progress almost everywhere and that it encompasses a broad variety of sub-fields and sub-disciplines. From a technological perspective, there is no "lead convergence" to be found. However, it has become obvious that scientific "pacemakers" of convergence are neuroscience, biomedicine and Synthetic Biology. In all eight fields, the need for interdisciplinary co-operation is considered to be central.

In some areas such as Artificial Intelligence, convergence does not describe a new approach but includes an existing research field, which could profit from a more rigorous trans- and interdisciplinary approach as suggested by CT. The cognitive sciences have always been interdisciplinary in nature and are characterised by the conventional benefits and problems of interdisciplinary work. **The very label "cognitive sciences" insinuates that there is no true unity between the various disciplines in the domain. An interesting research question is whether there is any basis for the convergence of these disciplines into cognitive science (singular).**

Another point is the awareness of scientists of the concept of convergence, especially in the form of NBIC convergence. In view of the inconsistent development of the real science and technology landscape, it may be concluded that the convergence concept

works primarily as a political concept or a concept for research managers. In the interviews, it emerged that the term was so new that researchers are mostly not aware of NBIC-convergence, even if they work in the middle of a discipline belonging to those described as convergent, busy with technology developments in the conceptual overlap between nano, bio, info and cognitive science. Thus, the NBIC concept of technological convergence currently seems not to be at a stage where it actually guides the actions of scientists or shapes concrete technology developments. However, there is not yet sufficient evidence to provide convincing grounds for this claim. **The question "Are researchers in the labs actually and consciously working towards convergence?" needs further attention and research.** Some scientists reported in the interviews that they pay some lip service to the hype in order to receive funding money and that apart from that the concept does not matter in their daily work. However, we should not conclude that this actually is the case it might well be that the concept concretely guides them in one way or the other. **The research question therefore is to find out how the concept of convergence actually may motivate or guide researchers in the labs and what difference it makes in their daily work and in the results of their research.**

We also found that the concept has not yet reached the level of being relevant for enterprises and industry. Although there are some approaches in the research labs of large firms in the biopharmaceutical or biomedical area that could be termed "technological convergence" and some interest in new processes of convergence on the part of bio and infotech firms, the NBIC concept itself has not yet triggered specific investments and has not yet fuelled expectations in the corporate world.

3.2 The Role of Cognitive Science

The Cognitive Sciences (CS) were given special prominence in CONTECS due to the key role they apparently play in the original concept in relation to enhancing human performance. In the concept, it is assumed that new tools and instruments for the nano-level will become readily available to analyse, manipulate and replicate cognitive processes at this level.

We will not rehearse here the definition and historical background to the CS provided in the project deliverable (see appendix B) but will focus instead on a description of the Cognitive Sciences in their relationship to the Converging Technologies.

We found that while the Cognitive Sciences were given a prominent role in the original NBIC formulation, the precise delineation of the relationship of the last component to the first three is problematical. A telling fact is that Cogno is essentially ignored or misrepresented by many scientists working in Nano, Bio or Info, together with the symmetric phenomenon of a near-complete ignorance, on the part of most cognitive scientists, of the NBIC/CT problematic, indeed, of the very notion or even the label.

Two areas of obvious interaction (which does not imply convergence) can be readily identified:

- A large part of the projected contributions of IT (Info) have to do with building devices which can assist individuals and groups in their handling of information and their decision processes. In other words, IT comes in, to a great extent, to supplement certain cognitive processes, and thus could benefit much more from a scientific understanding of human cognition than it presently does. In addition, parts of IT take their inspiration from natural cognition to solve information processing problems (e.g., artificial intelligence, software agents, etc.)
- The Bio component contains a particularly promising aspect, viz. intervention on the nervous system by pharmacological or hybrid bio-physical means. Cognitive science is the theoretical framework within which the science of brain function is developed; thus it seems reasonable to take on cognitive science if one wants to develop good brain-connected devices.

It is far less obvious how the CS at this stage could be in any way directly involved in a synergy with Nano research.

So where do the CS belong in the grand scheme of things? Deeply enmeshed in the NBIC concept, is the idea that the entire enterprise aims at "improving human performance": thus an understanding of pre-NBIC human performance is required, so as to channel the quest for adequate augmentations or enhancements in a fruitful and benevolent direction. The CS therefore provides a framework for enhancement; conver-

gence of the CS with the NBI components is grafted in through the claim that the CS are really about the nano-level as well. We found both ideas to be questionable.

Despite lip service being occasionally rendered, in the enormous NBIC literature, to cognitive science, the initiators of the concept actually have in mind a very special understanding of the field. This becomes clear when one asks what actual role is assigned to cognitive science. It splits into two disjoint parts, brain science on one hand, "intellectics" on the other intellectics being a word coined by Wolfgang Bibel (cf. Hölldobler 2000), by which he understands, essentially, artificial intelligence informed by cognitive science. This seems not unreasonable until one notices one glaring lacuna, that of psychology. The very idea of cognitive science is to develop the agenda of psychology with the help of new methods, or rather new perspectives, provided by the study of formal processing of information on one hand, workings of the brain tissue and structure, on the other, and with the guidance of evolutionary biology, anthropology and linguistics. Technological interventions on the nervous system, plus computer-based 'intelligent' devices do not together make up a cohesive approach within cognitive science.

This primacy claim of nano is bound to be met with an even higher degree of scepticism by most cognitive scientists, for both practical and theoretical reasons. Today, very little of cognitive science concerns itself with phenomena happening at the nanoscale. This is the exclusive province of molecular neuroscience, which lies on the outer fringes of cognitive science. Although it is recognised that information transmission happens at a molecular level in the brain, few cognitive scientists will find the fact relevant to their work. Within the core disciplines of cognitive science (systems neuroscience, psychology, linguistics) it is often argued that cognitive systems exhibit several different levels for analysis, and that the lower levels are by and large irrelevant to the higher ones. The strong physical reductionism present in the CT literature is therefore unlikely to resonate well with the dominant strands of cognitive science. It may be perceived as a form of what the philosopher Daniel Dennett (1995) calls "greedy reductionism", i.e. an attempt to explain away phenomena by claiming they "boil down to" some lower level. To say that, for example, cognition "simply boils down to" molecules has no explanatory power; rather, it robs cognitive science of its subject matter.

Reconceptualising the problem situation

As we have already suggested, thinking about cognitive science and CT by giving the nano-level a central role may not be the most appropriate theoretical outlook. The key finding of previous work on CT, and of work done during the course of the CONTECS project, is that much of what is interesting and new in science and technology today is happening across disciplinary boundaries rather than within. That does not imply that

cross-fertilisation is a new phenomenon, nor does it indicate necessarily that scientific disciplines will soon disappear as institutions. Despite the well-documented failures of previous reductionist programs, it just might be the case that nanoscience will in the end play a central role as the foundation for a unified science. But what is clear is that local convergence processes are real, and that they generate technological advances at an unprecedented pace.

What is needed is then to look at concrete advances being made to try to get a sense of where CT might be going. CONTECS has made progress in that direction by cataloguing recent developments, and by building a picture of convergence as a social process – who is involved and why. More is needed, but already we can begin to sort out the relevant questions from those that are not so relevant.

The Cognitive Sciences as a laboratory of convergence

The rise of the Cognitive Sciences is probably the greatest experiment in interdisciplinary in modern science. We believe it provides a strong test bed for models of convergence, and a potentially invaluable source of empirical observations.

The topic of interdisciplinary has been raised by many participants in CONTECS interviews and workshops. Concerns expressed include issues of culture and language ("bridge-building"), issues of power (inequality between disciplines), of incentive structures, of education. **What is the right institutional environment to foster interdisciplinary research? What about curricula? What is the impact of interdisciplinary work on individual careers?**

These are all issues that the CS has had to tackle. Some notable institutional and organisational outcomes include:

- a reshaping of the field around objects (memory, perception, social cognition, etc.), as witnessed by the appearance of object-based journals and conferences.
- the creation of "brain science" and "cognitive science" research centres and curricula.
- the further blurring of boundaries brought about by the success of brain imaging, which involves many psychologists as well as neuroscientists.

The concrete processes, the hurdles encountered, the resilience of older forms of organisation in the CS open avenues for SSH research in convergence.

Known unknowns, unknown unknowns

It is of course quite natural that the most spectacular claims made around CT have attracted the most attention. Unlimited prospects for human enhancement, including push-button learning, a high-throughput "sixth sense", dematerialisation and immortality, are all tantalising visions. The nearer prospects should not be neglected in favour of far-fetched possible worlds. This is important to keep in mind again if our goal is to engage SSH scholars in an inquiry about CT: most of them will be put off by the far-fetched visions, regarding them, not without reason, as insufficiently supported, and we do not wish them to simply ignore issues which they can, and should, address, and which only they can pursue in a robust way.

We can bracket out the possibility of extreme forms of human enhancement: CT brings enough for our preoccupation. **We need to invest the greater part of our effort in investigating "TechLife": what can our lives are expected to look like when what is in gestation in CT now reaches maturity?** This is a "known unknown": we know, at least roughly, what those technologies are going to be; what we do not know is their impact on our personal lives and on society. "Translife", the future lives of trans-humans, however, is an "unknown unknown". What enhancements are possible is open to question, and so is the issue of whether society will let those developments happen at all. We suggest that, regardless of how fascinating the question may be, not too many resources should be devoted to the issue of transhumanism; we have more pressing matters to deal with. In the deliverable we highlight clusters of topics that seem to us of particular importance (appendix B):

- Self-understanding of self, kin, society
- Knowledge and competences
- Politics and economics in TechLife
- The "New AI"
- Prospects for enhancement: constraints vs. tradeoffs

3.3 Interdisciplinarity: The common denominator of CT?

The CONTECS project has been dealing with two related but separate types of convergence: scientific convergence consisting of the cooperation and cross-fertilisation of different scientific disciplines working on a common topic, and technological convergence, meaning the use of the findings from different disciplines in specific applications and products of technology. In the former area, the US NBIC report and the EU CTEKS concept make very different propositions for scientific convergence. While the NBIC report argues for a common basis of all science at the nanoscale, the CTEKS concept makes a strong case for interdisciplinary cooperation between existing disciplines. While this does not exclude the possibility of true convergence to form new scientific disciplines or sub-disciplines, this is not an essential element of the CTEKS concept as understood by CONTECS. **The extent to which converging technologies require, or at least benefit from, a convergence of scientific research is a matter deserving further research.**

The word convergence implies a degree of fusion of the different sciences and it is more than just sporadic intersections or temporary cooperation between different fields or people coming together to work on a special topic. It implies that the tools, the languages, and the mindsets are going to feed together at some point in the future. This will lead to a blurring of the borders and the identities of the disciplines in this area of common interest. **In most cases, the "parent" disciplines will continue to exist, although a topic of research could be to examine whether the area where convergence is taking place is now excluded from the agendas of the parent disciplines.**

It appears that convergence takes place at the level of doing things and constructing things, not necessarily at the theoretical level. Convergence thus seems to aim at the building of entirely new structures, or objects, or artefacts, or devices. **Technological convergence might affect the way scientific knowledge is produced and contribute to recent trends towards new forms of "technoscience", an issue which deserves closer attention.**

One question that arises in this context is whether some sort of new field with a permanent status which might evolve into one or more new scientific disciplines or sub-disciplines is being created or whether it will be something that will disappear once the different projects have been finished. There is also the issue of encouraging people to work in interdisciplinary fields, since it currently seems that working in interdisciplinary teams for any real length of time is an item in academic biographies that is seldom rewarded or acknowledged as a scientific achievement.

Scientific convergence is taking place as a result of the growing need for interdisciplinary research (Shmulewitz et al. 2006), which is itself the result of the growing role of societal problems as drivers for technological development. The NBIC concept encompasses at least four fields of science and technology development and thus needs to incorporate very different competencies (Mehta 2002; Pilarski et al. 2004). Today, interdisciplinary research is one of the hot topics in research and technology policy (see NEST 2004).

Many programmes in the leading industrial countries are concerned with fostering cooperation between the disciplines. But producing real collaboration remains a difficult task. Often the notion of interdisciplinary research is the expression of lip service and does not go beyond a mere participation of different disciplines (Weingart 1997; Turner 2000). Meanwhile there is a whole branch of research emerging especially in the field of science and technology studies dealing with this topic (Weingart & Stehr 2000; Klein 1990; Klein 2000). Disciplines differ in their degree of problem orientation and according to their reference to application contexts (Jansen 1998; Hasse 1996). Due to these findings, interdisciplinary research is particularly addressed both in the cognitive and in the organisational dimension (Whitley 2000; Heinze 2006). While there is much research on the cognitive dimension of interdisciplinary (Jantsch 1972; Kocka et al. 1987), studies on the institutional dimension, focusing on the practices of interdisciplinary research in emerging technological fields like CT, are still rare.

There are two dimensions for further examination in the context of interdisciplinary research and technological convergence: The first dimension is **seeking a common basis for research projects that enables the intended integration.** In what ways are the different disciplines involved in the context of the whole project? The philosophy of science has made strong efforts to differentiate between several kinds of interdisciplinary research. Schmidt (2008), for example, found at least four types of interdisciplinary research enabling integration: Theoretical, methodological, problem orientated and object orientated interdisciplinary. Examining these four types of interdisciplinary in relation to the concept of technological convergence Schmidt concludes that CT is based on a weak understanding of interdisciplinary, which he terms "object-oriented interdisciplinary. According to his analysis there is no theoretical or methodological framework or paradigm that is able to transcend the different fields of research in CT (Schmidt 2008, see also Gordijn 2006).

The **second dimension for the analysis of interdisciplinary is the institutional or organisational level.** Here one can ask to what extent the integration of disciplines has succeeded in any particular field. With the growing importance of nano- and biotechnologies, the interdisciplinary structure of these fields of research has been analysed by Schummer 2004; Heinze 2004, Meyer 1998, Meyer 2001 and Rafols/Meyer

2007. The result was that with respect to publication data there is no evidence for interdisciplinary integration in the nanosciences (in contrast, for example, to the material sciences, see Bensaude-Vincent 2001). Nanosciences play an important role in the CT debate. The fact that interdisciplinary integration has not yet taken place can be shown by looking at the interdisciplinary rate (IR) in publications (see Schummer 2004). The IR shows how many authors from different disciplines contribute to a specific publication. There is growing evidence that this rate in CT is not higher than in other fields of research, meaning that research and development is still very fragmented in CT (Rafols/Meyer 2007).

Schummer explains this still dominant orientation along established scientific disciplines and organisational entities hinting at cognitive orientations. He focuses on cognitive dimensions and organisational orientations arguing that a common basis for disciplinary integration can only be achieved in a technology or knowledge overlap (e.g. methods or theories). When the size of the objects under study (nano) is taken as a common basis for interdisciplinary integration in the nano-biosciences, chemistry, physics and biology are perceived as converging at the nanoscale. Another important issue that could serve as a common basis for a field of research might be a leading aim, for which certain knowledge can be used, for example saving energy in the environmental sciences. According to Schummer both factors are not sufficient: Using size as common basis, there are so many different objects of research that can be analysed that interdisciplinary integration becomes almost impossible (Schummer 2004: 16). On the other hand, the technological aim, e.g. the end that can be reached with the technology is not concrete enough for a stimulation of interdisciplinary research.

Arguments referring to cognitive dimensions as obstacles for interdisciplinary (Schummer 2007) are not the only explanations for the fact that interdisciplinary research is difficult in the CT context. During the project some interviewees also reported that institutional conditions are a special barrier for interdisciplinary research (see Beckert et al. 2007). Since the institutionalisation of science is still oriented towards the established disciplines, the practices of interdisciplinary research often seem to clash with the reproduction of existing structures. Doing interdisciplinary research therefore often obstructs individual scientific careers more than it furthers them. Several researchers reported hybrid knowledge might be helpful for scientific breakthroughs but is not the best qualification for access to academic institutions.

Institutional conditions for interdisciplinary research in emerging technologies differ strongly between countries and fields of research (De May 2000). The university and science systems of different countries have different incentives for interdisciplinary (Llerena/Meyer-Krahmer 2003). According to Jong (2006), the Anglo Saxon countries have changed institutional structures to enable interdisciplinary research. One example

for this is the situation in graduate schools in the UK as compared to the situation for example in Germany[1]. In Germany, disciplinary structures still dominate PhD education while in the UK research in these schools is much more oriented towards problems transcending disciplinary confines (Jong forthcoming). Interdisciplinary training and research will become more and more important in the development of CT as a field of research in its own right.

Some authors also explain differences in interdisciplinary integration with the governance structures of science: One thesis is the extent to which the absence of hierarchical structures facilitates interdisciplinary research (Jong 2006b). It can also be shown that hierarchical structures differ a lot among European countries: Again Simcha Jong reports huge differences between the UK and Germany. In the latter country, hierarchical structures seem to be very persistent and often hinder interdisciplinary cooperation.

Focusing on the practices of interdisciplinary as a field of research which is currently not sufficiently analysed, one can find different types of interdisciplinary research practices. During the 19th century the model of one leading science (in many cases physics) with many assisting sciences dominated the projects in natural sciences and engineering. Many have argued that this model is no longer valid for the description of interdisciplinary scientific projects (e.g. Bärmark/Wallén 1986). Modern scientific projects are said to be much more horizontally designed, with different leading disciplines, resulting in a hybrid governance structure of research projects (Rafohls/Meyer 2007).

Research questions in the field of interdisciplinary are thus not hard to find: Uncovering practices and problems of interdisciplinary research remains an important task for scholars of science and technology studies. For further research we suggest to distinguish between general questions of interdisciplinary research that can be applied to CT and specific problems with interdisciplinary that are raised within a CT context. One of these specific problems within CT is the low degree of interdisciplinary integration. Although this is true for the general level, there is more research needed focussing on knowledge overlap at the local level and the concrete level of individual projects.

With the absence of a common basis for interdisciplinary research it is necessary to study the epistemic cultures (Knorr-Cetina 1999) of those cooperating

1 This might be changing as a result of the two-round national "competition" for acknowledgement as "elite universities", where one element is the setting up of graduate schools. One of the first "winners," the University of Karlsruhe, will reorganise its research in problem-oriented programmes, while retaining the faculty structure for bachelor and master level education.

disciplines in order to get an idea what might be the obstacles for cooperation that are caused by different styles of scientific reasoning. But there are also some general issues of interdisciplinary that need attention in the CT context. Institutional barriers should be analysed and applied to the needs of concrete CT research.

3.4 Ethical questions and the technology assessment view

It is apparent from analyses of the state of development of converging technologies, that there is still a huge gap between the visions on CT and actual applications. As a result, ethical and social questions related to CT have a tendency towards speculation, including some that will be raised in this chapter. The applications of converging technologies that will necessitate the discussion of important social and ethical issues have not yet been developed and are not likely to be developed in the foreseeable future. Furthermore, future applications of convergence are very hard to predict. There may be a whole range of applications or scientific fields that benefit from convergence but have not yet been sufficiently explored or even discovered. The report by the European HLEG "Forecasting the New Technology Wave" mentions a number of urgent problems related to human health or the environment which might be addressed by converging technologies or at least by interdisciplinary endeavours, which are simply not "sexy" enough to have caught widespread attention and thus have taken a back seat in ethical discussions of converging technologies to futuristic issues, such as the rights of hybrid human-machine actors or the implications of memory amplification through external memories interfacing directly with the human brain. Relevant contributions to the analysis and discussion of real and possible future CT have been made by the European Group on Ethics which has, for example, worked on ICT implants in the human body and on nanomedicine, from a broad ethical perspective.

Technology assessment looks at the technologies themselves and does not simply reflect ethical questions without an examination of their relation to reality. Long-term trends in these technologies have to be identified, but those now visible should not necessarily be taken at face-value. Although most technological fields and applications are not yet sufficiently mature for detailed assessment, it is timely and important to take the possible ethical and social issues, resulting from currently visible stakeholder interests, into account.

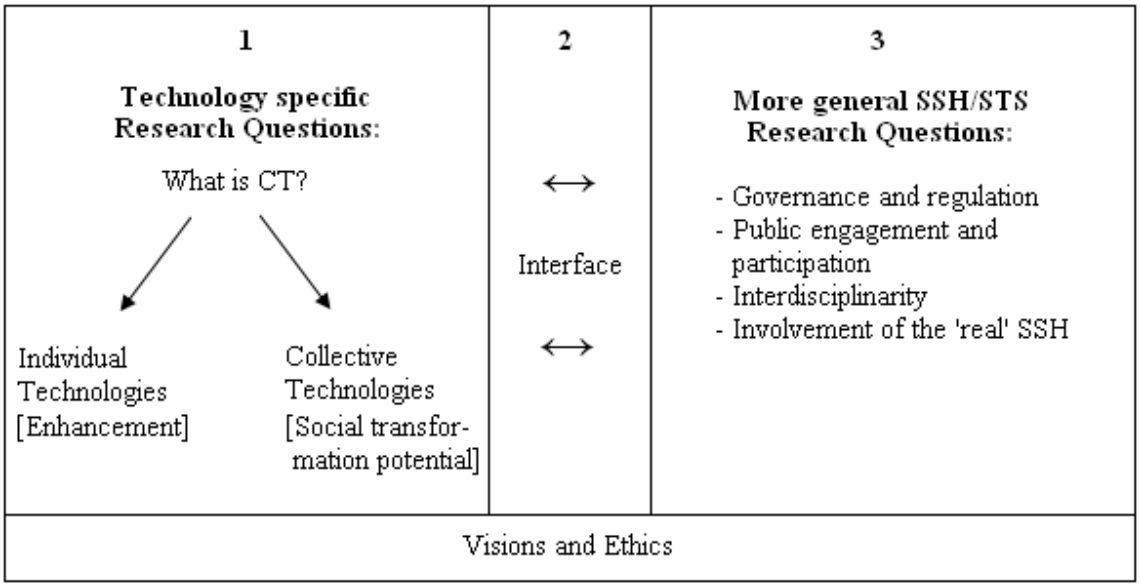
A second point that is important to note before defining ethical questions, is that it is very hard to separate ethics as a research field from social and legal issues. During the workshop in Paris in October 2007, it was suggested that ethics should be discussed in connection with the various social and legal issues, instead of setting up a separate ethical discourse.

In the overall research for the CONTECS project, different social issues that are of interest within the CT debate have been discerned. Some of them apply to specific applications or combinations of the converging technologies involved, and not the whole quartet of NBIC. Other social issues apply to technology in general rather than specific

technologies and thus not only NBIC convergence. Therefore, social issues can be distinguished by different dimensions (see figure 3): Type 1 issues are CT-specific research questions, SSH issues that could not be addressed when using an 'application example' other than CT. Converging technologies themselves can be divided into individual and collective technologies. The type 2 dimension is the interface between more general SSH/STS research questions and CT-specific research questions. The working hypothesis that this framework implies is that the more general SSH/STS research questions (type 3) are questions that can be expected to rise as a result of random technologies other than CT, e.g. nanotechnology, biotechnology, etc. In the type 3 research questions, CT can be seen as an 'application example' for more general SSH issues. Visions and ethics permeate all dimensions. These are general SSH topics as all technologies bring with them issues concerning visions and ethics, but obviously there are specific issues concerning CT. In this all-embracing position, visions and ethics can serve as a communication function between type 1 and type 3 issues.

The question that arises from the working hypothesis underlying here is: **Is there something specific about the interface of SSH issues with CT? And if there is something special, what are the specifics of CT? These would also be questions of interest for a future SSH agenda.**

Figure 3: Dimensions of SSH issues



At present, the SSH seem to be focusing almost exclusively on the enhancement issue, while there are other social issues that also require attention and have a similarly large social transformation potential, e.g. the matter of data protection,

the right to privacy and liability for (ultimately programmed) autonomous systems. All of these issues can also arise as a result of CT applications.

The debate about enhancement raises several important matters. There are some issues that seem intrinsic to the debate about cognitive enhancement, independent of the method – NBIC-based or not – under examination or which individuals are involved. **The issues fundamental to the debate include: issues around what it means to be human, human dignity, human nature, deference for nature and human diversity. Additionally they include challenges to established concepts of personhood and personal identity. Related to these issues are of course the questions of (self-) determination and free will. Then there are issues that concern the feeling of "cheating" that people have about cognitive enhancement such as work ethics, aspiration, effort, and authenticity.**

Ethical and social implications of cognitive enhancement will recur in every debate on the subject. The debate on converging technologies has fuelled such debates, but the discussions apparently again drift away from convergence to a more general debate of the issue, usually in connection with existing possibilities, such as the conventional use of drugs in the treatment of mental disorders, or currently outlawed applications, such as doping in sports. While direct machine-brain interfaces are already functional, their current use is restricted for purely technical reasons to severe disorders – applications offering promise of enhancement require considerable technical refinement which is currently a very remote possibility.[2]

Various enhancement methods may also be relevant with regard to the following: a balance of benefits and harms (although in most cases, the risks are very unclear); issues around equity, coercion and pressure (social and economic aspects, such as disadvantages through lack of enhancement, implications of enhancement for economics); the basis for distinguishing a genuinely novel method from conventional methods; the distinction between "natural" and "unnatural" enhancement; tendencies of an intensified medicalisation; the distinction between permanent and temporary modifications of the human body. All these issues are relevant when talking about cognitive or physical enhancement.

Then there are the more general social and ethical issues. Some questions in this area are still only 'on the horizon'; they are unlikely to be an issue in the foreseeable future. Even so, there is one issue requiring attention from the very start: **the analysis and**

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2 Cf. on this matter the recent assessment by the British Medical Association: Boosting your brainpower: ethical aspects of cognitive enhancements. BMA, November 2007.

clarification of the borders between therapy, enhancement and recreation. There is also the question of how to deal with norms, beliefs and value conflicts in the course of CT development, e.g. whether there is any need to expose and discuss the approaches and motivations of scientists active in the development of converging technologies. Important aspects are the relevance of an engineering approach in the context of convergence as well as the idea that machines and human brains process information in an identical way – as insinuated by Minsky's "meat machine" metaphor for the human brain. **With regard to these and other fundamental issues, we should notice and widen the focus of the CT debate on the context of Western civilisation. There is a need to take views from other cultural backgrounds into account.**

Furthermore, there are the participatory questions, e.g. the issue of citizen involvement in science and technology-related deliberation and decision processes. CT will affect everyone; their consequences cannot be isolated and confined only to active users: the choices of some will have an effect on others and on society as a whole. Therefore the need for a broader public debate increases. It is important however to strike a balance: On the one hand, it might be too early to discuss some aspects of the CT debate as most applications are not even technically feasible yet, on the other hand it might be too late if we wait too long.

Participation is faced with the well-known problem of timing: if it takes place too early, information on the technologies, their applications and implications will not be well-defined, but once there are actual applications it is difficult to find any adequate means of regulation and for the consideration of citizens' perspectives. Early debate on what is desirable and what less so provides those involved in actual development with information useful to design technology. All currently visible stakeholders should be involved in this debate; including policy makers, researchers from a broad variety of scientific and non-hard-science disciplines, doctors, insurance companies, companies with an interest in producing applications of CT, patient organisations, NGOs.

CT development is likely to have an impact on societal and legal systems. How will we deal with this impact? Research should be conducted on mechanisms for the regulation and shaping of scientific development. Governance and regulation is for a large part dependent on a strong public debate. Therefore it is also the responsibility of politicians to organise a timely public engagement. Education will have to be arranged to further public understanding of CT and science in general. Furthermore, the role and responsibility of scientists in connection with specific novel applications requires discussion.

For most of the converging technologies, when they become commercially available, there is sufficient justification for their regulation, especially enhancement technologies, as they potentially have many far-reaching effects. **If these technologies become available, policy makers will have to think about quality criteria for devices and implants, and devise approval procedures for the use in therapy, rehabilitation or for lifestyle/recreational use. Also, as a result of access to converging technologies, new divides within and between societies may emerge. This can be anticipated in advance and accordingly, international agreements can be made.**

A first step in the governance of CT will be concerned with risks: risk characterisation, risk assessment, risk management and risk communication. These governance developments will, at least in Europe, mostly be guided by the precautionary principle. Foresight (including 'vision assessment') can be used as a means for achieving a broad societal consensus on desirable or likely future developments. **In order to produce a set of regulations that works, it is important to identify social, individual, scientific, economical and political drivers and demands, and ways and means to balance them. In order to recognise these, research platforms, support structures and networks between the different disciplines could be established.**

There are some legal consequences of CT intervention as well: implications for personal privacy and freedom, patient rights, responsibility, accountability and security. Also, if it becomes possible one day to enhance humans; another issue will be the legal status of these 'enhanced humans'. Furthermore, there is a danger of criminal use by individuals, institutions or systems. Therefore, if this is to be regulated successfully, then it has to be done through international rather than national regulations.

However, there remain questions about the ability of national governments to impose and enforce regulations on controversial areas of research and development.

3.5 Natural science taking over SSH domains: New deterministic models of man

To 'naturalise' a domain is to make it clear that it belongs to nature, and thus that it can be accounted for with the sole help of the natural sciences. CT carries strong naturalistic trends, yet at the same time it includes artificial projects; that these are not necessarily contradictory was already an object for debate in the first phases of artificial intelligence, and is a topic which is worth exploring in the new context of CT. However, in this section we focus on naturalisation, and the apprehension with which naturalising themes and programmes are met in both academic and lay circles.

Are the SSH reconcilable with CT?

There is little doubt that a major obstacle standing in the way of interdisciplinary approaches involving CT and SSH is a profound distrust, and sometimes distaste, on the SSH side, for 'naturalisation'. Uncontroversially, CT deploys tools from the natural sciences in attempts to understand and/or change the human realm or condition, on either the individual or the social level. This endeavour is sometimes, though not always, coupled with a rather derogatory view of the accomplishments and prospects of SSH as traditionally conceived. Equally clearly, mainstream SSH, especially in the 20th century, insist on a more or less total autonomy from the natural sciences, often coupled with a militant conception of humanity requiring protection from the encroachments of natural science and its accompanying reifying technologies.

It is therefore quite important to clarify the roots and presuppositions of this seemingly irreconcilable difference, so as to facilitate a pluralistic, tolerant attitude within SSH, as well as within CT: the aim is not to bring every current within each domain to get actively involved in or even favourable in principle to cooperation with the other side. Rather, what one could hope for is a climate in which cooperation is regarded as mutually beneficial and not illegitimate or ill-conceived with regard to its scientific and practical goals. SSH teams could work on CT-related themes, or with CT people, without thereby relinquishing their intrinsic connection with their disciplines.

'Hardening' the 'soft' sciences: previous attempts

Whether the sciences of man are *real* sciences, and whether, if so, they are or should strive to be indistinguishable from the natural sciences, is a venerable issue, as old as the social sciences and humanities (SSH) themselves. On the whole, those who defend *bifurcationism,* according to which SSH are both genuine sciences and genuinely different from the natural sciences (NS), have been the dominant voice. *Monists* are usually regarded as reductionistic, deterministic and essentially false, naive or mis-

guided, although this position also has strong scientific proponents. We focus here on features of the present situation which may point to a novel understanding of the problematic, possibly reinforcing monist arguments.

Formal and quantitative methods are accepted, albeit not necessarily highly valued, components of traditional programmes *within* SSH. 'Scientific' SSH, in the narrow, 'hard' meaning of the word 'scientific', are familiar faces, especially in fields such as economics, linguistics, geography, palaeontology, demography, sociology as well as some provinces of history, political science, etc. A sometimes uneasy 'peaceful co-existence' has long been established between formal and quantitative approaches and mainstream, descriptive, narrative, phenomenological or hermeneutic approaches. The need to 'harden' the soft SSH is always a matter of heated debate in the disciplines concerned.

Two paths to naturalisation

So *what* is new? The answer, we believe (this is no straightforward matter of fact), is twofold.

First, it is often claimed that formal approaches have reached a new level, having matured and joined a new paradigm, complexity, which achieves a perspective in which natural and human/social phenomena are not merely, as in previous eras, seen as notionally united by virtue of a common structure, but also actually modelled in detail, yielding rich descriptions and reliable predictions. *The first and foremost mode of naturalisation is by way of methods, carrying the shared commitment of working with "complex systems", be they natural or social.*

Second, another, very different, route towards naturalisation has re-emerged, after a long eclipse extending into the 1960s. This is naturalisation in the original, strict or narrow sense, *via* what used to be called natural history and has now broadened and matured into the biological sciences, with a special role devolved to evolutionary biology and ethology, on the one hand, cognitive and systems neuroscience on the other. *The second mode of naturalisation is by way of reduction or integration, an appeal to human biology to account for the social.*

Potential obstacles

This second branch of the naturalistic enterprise appears to many scholars in SSH as the more threatening and dubious by far. For it is one thing to discover formal-mathematical structure in human affairs; quite another is to treat the SSH as a mere province of biology (a dramatic, and actually misleading way of putting it). Formalism may be limited in scope, or outright sterile (as the critics insist), at least it doesn't altogether pull

the rug from under SSHs' feet. For the task of uncovering the basic elements (the 'ontology') of the human order remains a daunting task which only SSH are competent to achieve. Quantitative social science, even buttressed by complexity theory, may perhaps predict how things will turn out, in favourable cases; they have nothing to say about *what it is* whose outcome is of interest. Compare: mathematicians may help meteorologists set up forecasting models; but only meteorologists can tell us what scientific ontology the study of weather and climate calls upon. The basic categories of SSH will never come out of complexity's hat: they have to be put there in the first place.

The distinction is especially clear when the denizens of the task domain misbehave–in other words, when they fail to conform to their assigned role in the model. So if winds, currents, tides, clouds, etc. don't quite conform to their specifications in the model, only a meteorologist can fix the problem. This is of little import in the case of meteorology: mathematics is so deeply embedded in the natural sciences that nothing much hangs on the precise distribution of labour. When it comes to SHS however, it's a different matter. Humans tend to resist in all sorts of ways to externally imposed categories, and only the finest skills and the long experience of the social scientist can be of any help in preventing the modelling enterprise from going hopelessly off track. So while meteorology and say sociology or demography play the lead role in such junctures, with mathematics (or complex systems theory) retrograded to their traditional function of obedient toolbox, the kind of adjustment which the leading discipline needs to make is, in the case of meteorology, naturalistic by definition, in the case of sociology or demography, it is deemed to be of a deeply different nature: bifurcation all over again.

Thus it appears that formal-quantitative, complexity-theory based approaches in SSH preserve, after all, the latter's specificities. By contrast, bio (neuro-cogno-evolutionary) naturalism may seem to want to impose the one true scientific ontology to SHS. In other words, while formalism doesn't necessarily imply reductionism, let alone eliminativism[3], bio-naturalism may carry reductive and even eliminative implications. For should bio-naturalistic research programmes eventually show (or be allowed to falsely convince us) that we humans are mere biological creatures, subject to both distal

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3 Reducing a realm or level of reality X to another Y means, roughly, to show that objects and processes of X can be fully accounted for in terms of Y. The arch example of scientific reduction is the molecular theory of heat: heat is *nothing over and above* molecular agitation, and temperature, the measure of heat, can be computed from kinetic parameters measuring the degree of agitation of the molecules (this is of course a *gross* oversimplification). However, this discovery does not make the use of heat and temperature illegitimate. Elimination (of X in favour of or relative to Y), on the other hand, implies in addition that X should be purged out of our scientific ontology: thus Galenic humors are accounted for in contemporary physiology by complex metabolic phenomena, and thereby ruled out of bounds of scientific medicine.

(evolutionary) and proximal (physiological and mechanical) causation leaving no room for any other type of fundamental determination, then indeed, or so the critics argue, the age-old images of man on which SSH are based would be discredited, and mainstream SSH would soon be displaced by biology, suitably extended.

Whether *in fact* the bio-naturalistic programmes are in a position to achieve extensive reductions or elimination can be disputed on several grounds, ranging from a historically-guided reconsideration of what has been achieved on that count in the natural sciences, to an empirical examination of what is actually afoot in these programmes.

A detailed examination of this issue, however useful in the academic context, hardly suffices.

For (1) bio-naturalism is intrinsically more disquieting than traditional formal social sciences because it lays claims on the individual, which for the most part was left alone by formal approaches, generally solely interested in social, collective phenomena, and content with a rudimentary, and much criticised model of *homo œconomicus*[4].

And (2) CT combine both kinds of naturalism, the formal-quantitative and the biological. The (subversive) idea which to a large extent drives CT is that by uncovering the formal or structural properties of certain phenomena, one reveals an essential feature of their ontology. In other words, in the case of thought, for example, there may be no *essence* hiding behind informational structure, although it is granted that there is a physical substratum realising the structure. This opens up an entirely new way of conceiving the 'moral sciences', making them accessible to a whole slew of methodologies belonging or akin to the natural sciences, without (necessarily) jeopardising their mental and social dimensions. This is really quite confusing (to most people) and calls for considerable efforts at explanation and clarification. It also paves the way for the technologies of artificial mind, body and life, which call for fresh ideas from SSH (including here specifically the humanities hiding behind the H).

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4 It might be objected here that from Durkheim's work on suicide to contemporary economic approaches of marriage (and other topics in 'freakonomics'), social scientists have very much laid claim on the individual. Our point is that they have done so from the outside, purporting to show that individual decisions, contrary to what appears to the agents themselves, are to a large extent determined by social (usually economic) factors. In other words, they make psychology irrelevant. Bio-naturalism, by contrast, holds psychology to be of paramount importance: digging into the very heart of our mental processes is an essential part of its programme, both for the sake of establishing a true, reasonably complete, scientific psychology, and as an indispensable starting point for understanding social and cultural phenomena.

Naturalism seen as a threat to free will

But just as CT is more technology than it is (pure) science, the concern is even more that of the citizen than is it that of the scholar. No doubt academics on both sides of the NS/SSH divide need to gain a better understanding of the scope and outlook of naturalistic programmes, and it may be of comfort to the SSH to discover that come what may, they will not soon be out of a job. On the other hand, *outside* academic circles the worry is that man himself may be robbed of an essential attribute. And the most likely victim, it often seems, is none other than freedom or autonomy: doctrines which seem to imply that freedom from natural determinism is an illusion are considered with suspicion, and technological ventures whose success is either dependent on material or natural determinisms operating on the human being, or consists of effectively imposing a new determinism, are viewed with abhorrence. CT may appear to add insult to injury, siding with deterministic doctrines and attempting to impose new, partial or total, modes of determinism.

The notion that man is what Spinoza calls an *imperium in imperio*, a self-governing entity within the natural order, is deeply rooted in both commonsense and a long moral tradition (which Spinoza himself opposed: see *Ethics*, Part III, Preface). Dilthey gave it a new twist, saving it from supernaturalism and thus making it compatible with an atheistic worldview, by claiming that what makes an action the specific action what it is, is not exhausted by its causal connections with the natural order: it is equally determined by the meaning which the agent gives it. This is the starting point for a philosophical reflection on free will, and the extent to which it is compatible with natural determinism. And it is also the point where many people outside academic circles want to dig in their heels.

But can they? Again, the question for us is: *Quid novo*? After all, deterministic paradigms in SSH have been around for a long time. Instances of natural determinism in the mental realm by chemical means are as old as wine, a physical substance sought after for its effects on the mental. They have taken on a much, much more significant (and, to some, sinister) dimension with the advent of modern psychotropic drugs–fifty years ago, long before CT! Mechanical naturalism was perhaps first illustrated by the first man to get frontal damage from falling off a tree; trepanation was practiced in Neolithic times and in Ancient Egypt.

The questions which beg to be taken up are thus not hard to find: **Are there *degrees* of natural determinism? Are *artificial* mood-altering or consciousness-altering interventions more threatening or ethically worrisome than *natural* ones? Why is Prozac more acceptable than electroconvulsive therapy? Is bionic intervention**

more of a threat to integrity than neuro-chemical or hormonal treatment because (1) it is or seems more irreversible, or because (2) it is more mechanical?

This latter candidate explanation raises a deep issue, which is the role of and reason for the resilience of what might be called 'folk dualism', the notion that we are composed of two distinct parts, the physical and the mental. Bionics alters the physical substrate, while chemistry 'only' alters the mental processes: somewhat surprisingly, while cutting someone's leg off is deemed to preserve her integrity as a human being, as a person, *because it is merely physical,* altering her mental processes by implanting a neural chip seems dangerous *because it is physical and not merely mental or psychic.* **We need to study these untutored intuitions, in order to uncover their underlying logic and to bring them in contact with scientific, technological and philosophical developments, and thus to get a better grasp on the cultural dynamics which the increasingly powerful and varied means of intervention on the human neuro-cognitive apparatus will beyond any doubt create.**

These heady issues, having to do with the "nano-bio-cogno" part of convergence, should not make us lose sight of more traditional concerns centred on the "info" component. **Where does legitimate decision-making aid stop, and where does manipulation begin? When does an indexing or tagging procedure on the internet start restricting freedom of information and impartiality? How much transparency is compatible with the tranquillity required for making a considered individual choice? Is access to exhaustive, detailed archives regarding one's public and private life, health, status, etc. a new human right? Need every one of the 6000+ languages still extant be provided with an automatic translation into every other?**

Some technological innovations are practically around the bend, and they carry predictably heavy consequences: today all our email communications are archived online, and available for full-text search. Already the necessity of memorising information has diminished. One can readily imagine the consequences of the same technology applied to voice communication!

The reason why these, and hundreds of similar issues which have been on the agenda for a while, have to do with CT is that they are part of the new AI agenda, which agenda is in part already turning into reality via high power informatics and internet, and is supposed to be fully achieved thanks to the convergence with the nano-info-bio components.

When is naturalisation acceptable?

To conclude, it would be worth exploring the following conjecture. Naturalisation remains acceptable, both to a majority of scholars in SSH and to public opinion, as long as what is being naturalised[5] is *either* a 'lower' cognitive faculty *or* that part of a 'higher' faculty which consists of an empty form, vessel, space of formal possibilities.

The former have a counterpart in non-human animals: for example, perception, navigation, motor control, elementary forms of memory. Examples of the latter include the language faculty, reasoning or "decision-making". Thus, the biological underpinnings of the ability to use language possessed by normal human subjects past the first few years is an acceptable candidate for naturalisation. Similarly, it is OK to naturalise a primitive form of logic, or of numeracy, and also OK to naturalise a general capacity to imitate or otherwise relate to other human beings, etc. But naturalisation (on the view we are conjecturing to be widely shared) cannot go beyond form and affect content. Thus, what someone is bound to say, believe, aim for specifically on a given occasion cannot be accounted for in naturalistic terms. As long as this boundary is not crossed, free will, responsibility, individuality, etc., are held out of reach of the natural sciences, and out of reach of technological intervention.

If this conjecture is false, it would be interesting to find out in what way and to what extent, and look further for the roots of resistance to naturalisation. If it is true, it would be interesting to study in great detail how the intuition is actually spelled out, in particular how people (whether lay or expert) draw the line between form and content; and how the intuition holds up against counter-evidence. It is important in this connection to emphasise that gaining a better understanding of intuition as a phenomenon, both untutored and deployed in philosophy or scientific discovery, has recently become a goal for cognitive science (especially developmental psychology, social cognition, cognitive and evolutionary anthropology) and philosophy. And that considerable interdisciplinary work is being deployed on the topic of social epistemology, briefly, the study of collective beliefs in relation to individual procedures of belief acquisition and change; this topic is approached both by naturalistically inclined investigators,

5 In both the strict sense of bio-naturalism and the loose sense of formal-quantitative methods.

close to cognitive science and philosophical naturalism, and social constructivists who are generally at odds with a naturalistic approach to cognition, and is thus a fertile ground for confrontation or collaboration.

3.6 The role of enhancement and other narratives of convergence

Assumptions, ideologies and visions on CT, their implications and their social transformational potential not only structure, but have, in a specific sense, generated the discourse on convergence. Visions of and references to the emergence of so-called "human enhancement technologies" constituted the framework in which the political and ethical debates on CT developed.

A key to obtaining insight into the wide range of characteristics of the phenomenon CT is to focus upon the ways in which different kinds of entity - human and non-human - are performed, i.e. introduced and used, in the discourse. The discussions of CT embody key assumptions about the ontological landscape which accompanies, is encouraged by and is enacted in relation to CT. **Our research (see appendix C) suggests that attention to the ontological politics of CT can give insight into the kinds of subject position, in a broadly Foucauldian sense, which are crucial to the take up and acceptance of these new technologies**. The contributions to the genesis and shaping of the discourse on CT of various actors are therefore analysed with regard to their specific positions within the relevant discursive and institutional fields. From this perspective, we have started to examine the discussions on CT and what counts in them as expert or "authoritative" knowledge.

The ontological politics of "human enhancement" encompass a broad variety of issues, sometimes even including the consumption of coffee or the use of spectacles, which by some actors in the discourse are described as a form of accepted human enhancement. However, in the debate on CT the focus is on new, emerging and visionary technologies which are claimed, by ardent commentators (such as some promoters of the US NBIC initiative and the "transhumanist" movement) and alarmed critics alike, to transform basic features of the human condition. Visions of "human enhancement technologies" range from rather concrete, project-related ideas, such as altering the metabolism of soldiers or developing sophisticated brain-machine interfaces, to far-ranging images of a posthuman future in which a man-machine-symbiotic terrestrial civilisation expands into outer space. Some posthumanist visionaries have even discussed the possibility that humanity will be replaced by intelligent machines, while others claim that a symbiotic man-machine hybridisation is mankind's only option to avoid this scenario, which would marginalise humans rather than enhancing them.

One interesting characteristic of the debate on CT is the fact that it entailed a broadening of discussions about posthumanity, "transhuman" forms of man-machine-symbiosis and "cyborgs" to include parts of the spheres of research and technology policy,

of the ethics of technology and of the natural and engineering sciences. Starting in the 1990s, these issues have already been discussed at length in fields such as media theory and art, cultural studies, and "cyborg studies". These discussions took place against the background of new conceptualisations in science and technology studies (STS). Nowadays a wide-ranging consensus in STS asserts that straightforward distinctions between the "technical" and the "social" can no longer be taken for granted. And even more traditional, philosophical approaches, such as the Habermasian critique of the "instrumentalisation" ("Technisierung") of human nature, discuss radical transhumanist or posthumanist visions of "human enhancement" as examples for a fusion of the organically grown with the technologically made.

Our investigations suggest that the distinction between the "technical" on the on hand and the "social"/"human" on the other hand is not adequately treated by giving equal weight to both "sides" of the dualities, nor by saying they co-exist, nor that they co-construct each other. Ontological politics comprise the processes, practices, discussions, struggles and contentions whereby the existence and character of entities are defined, constructed and brought into being. Crucially, the distinction between technical and social/human is one upshot of these politics. The distinction is not given but, as with the nature and existence of the other entities involved, is *contingent* upon these politics. The processes of ontological politics help define the focus and targets for CT. That is, these processes articulate and specify the kinds of entity, the nature, for example, of transhuman beings or cyborgs, which are claimed to be a result of CT. The success and take up of CT will depend on the outcome of these ontological politics. In other words, the outcome (effects, impacts, consequences) of the various moves, claims and performances of CT will depend on the extent to which its ontological politics make available subject positions which are adopted and enacted.

In our view, the ontological politics of CT will have a direct bearing on the kinds of issues and approaches which need to be considered by future SSH investigations into this phenomenon. For example, a CT-related redefinition of what counts as human (and transhuman) would have **significant implications for what SSH can take as their basic units of analysis**. In this sense, CT are not just potentially transformative of social and organisational life, they are also potentially transformative of the way social sciences and the humanities are done.

In the project, we have made some proposals on how to analyse the ontological politics of convergence and already started with such an analysis.

First, we have described the parallel constitution of the debate on CT and on nanotechnology-related far-ranging visions and of intensified discussions about "human enhancement". We have also drawn attention to the historical "roots" of transhumanism and of extreme images of a posthuman future which relate to highly collectivist visions of the first half of the 20th century. The recent and often extremely individualistic adaptations of these visions serve as powerful instruments in the ontological politics of convergence. It is important to note that these visions — "utopian" as well as "dystopian" ones — often function as central elements of worldviews with deep roots in the Western history of ideas and a political significance which exceeds research and technology policy in a narrow sense (Coenen 2007). We have drawn attention to the fact that members of the NBIC initiative in the US have not only advanced their transhumanist agenda in a humanist and individualistic rhetoric, but that they have also developed some totalising visions of individual and societal perfectibility, including ideas for a large-scale, high-tech based social and "cultural engineering". These visions are based on or derived from a wide range of intellectual traditions some of which are still underexposed in the discourse on CT. One important consequence of our analysis is that decisions about which social sciences and humanities approaches are appropriate to understanding CT, are themselves shaped by the ontological politics in play. **In any case, a wide range of SSH may contribute to illuminate the historical antecedents and formation of the discourse on CT, including the institutional and sociocultural landscape in which it is situated.**

Second, the project took a closer look at the ways in which ontology is enacted, kept alive and performed in contemporary discussions about CT. The textual analysis of the transcripts of four interviews with CT participants and of the protocol of a pertinent cyber chat was based on the assumption that a text (the interview transcripts; the cyber chat protocol) is constitutive of the phenomenon it describes (CT) as it introduces certain entities and performs relations - communities of actants/the moral order - between them. We examined in detail the ways in which CT are constituted by (re)defining boundaries between different constituencies/actants. The individual and collective actants to which various kinds of agency are ascribed include, for instance, individual scientists, policy making bodies, corporations, and members of expert/public domains. Specifically, we analysed the texts with regard to the questions of how expert membership in CT was performed, how the dynamics of NBIC components was assessed, and how they participants positioned themselves against the background of various redefinitions of the human "essence". **In the future, such analyses could be broadened and deepened, also by taking into account other subject positions as well as contributions to the debate on CT which are made by civil-society and policy actors.**

We found that the discussions about redefining the boundary between technology and the human body involve deliberations about the dynamics of moral order. These, in turn, involve the specification of which entities have the power to promote redefinitions and which become subjected/get access to the transformation. **It follows that we need to look more closely at the proposals and assessments of processes purportedly capable of redefining humanness, and of the moral ordering of such change. The efforts by different constituencies actively to shape CT-related discourses can be seen as a form of mutual "configuration" and might be analysed with a focus on the circumstances of storytelling (for example, in public consultations) and on which entities perform tellable stories about "human enhancement technologies" and other CT.**

The analysis of the constitution of the CT discourse from an institutional and historical perspective points to other possible elements of a CT-related SSH research agenda. The hitherto existing discourse on CT displays some very special, sometimes even bizarre ideological characteristics. **However, based on our analysis we may presume that the discourse is in some ways a possible blueprint for future discourses on new and emerging technologies. With convergence possibly becoming a paradigm for the political, societal and academic construction of technology discourses, also at EU level, there might be lessons to be learned from the debate on CT.** The political construction of "nanoconvergence" in the US, for example, provides evidence of the decisive role that major funding institutions play in setting the agenda and even in determining the goals and major contents of activities which are related to the ethical and social implications of S&T. EU activities on CT have not been marked by the same marginalisation of academic and other non-governmental contributors as was largely the case in the US. Moreover, the European debate on CT is arguably characterised by a greater degree of diversity of actors and views than is the political debate in the US. **SSH fields such as the ethics of technology, the philosophy of science, sociological STS and cultural studies, disability studies, the history of ideas, utopian studies, theology, technology assessment, future studies and policy analysis all might contribute to clarify and to self-reflectively shape future discourses and their underlying assumptions**.

In exchanging and communicating views, scientists, humanists, policy makers and others contribute to emerging narratives about what, for example, are the promises and pitfalls of "human enhancement". By engaging in these discussions they come to enact and perform the essential ingredients of what CT actually comprises. One result of all this is the emergence of what Foucauldians might call the CT subject position. **CT discourse thus makes available appropriate ways of thinking and being a CT sub-**

ject and bears directly on the nature and extent to which CT will enjoy successful take up.

In sketching these two ways of apprehending the ontological politics of CT, we have hardly scratched the surface. By exposing, analysing and demystifying ontological politics, especially those associated with the posthumanist and, more general, the techno futurist background of the most heatedly discussed visions, the **SSH may be able to draw more attention to issues that are largely neglected in the debates on CT**. **These include: (a) more realistic or ethically urgent uses of "human enhancement technologies" (e.g. drugs, deep brain stimulation, or future "mandatory enhancements" for soldiers and other groups); (b) artistic, lifestyle and identity-political forms or visions of "enhancement" and modification (e.g. in architecture, media art, science fiction, and queer politics); and (c) to distil socially needed/accepted and individually required enhancements of man-machine interactions out of the totalising visions of individual and societal perfectibility (as is characteristic of the more radical visions). However, this would also require a widening of the societal and ethical discourse on convergence.** The ontological politics of convergence might then become more difficult to handle, but also reflect more accurately the diversity of European cultures and societies.

A close examination of the ontological politics of CT will also enhance our understanding of the **interplay of society and S&T more generally**. To develop a programme of analysis along these lines, **the SSH may also: (a) analyse what is derived from "speculative ethics" (Nordmann 2007) and what refers to real innovations and convergences in debates about actual technoscientific developments, looking for their antecedents, but also for new qualities; (b) assess NBIC and other visions of the perfectibility of life and "human enhancement" against the background of traditions such as humanism, enlightenment thought and utopianism, taking into account the insight of the contingency of the human condition and religious views of human corporeality and mortality; and (c) analyse in what ways and to what extent the designers, developers, advocates and users of CT reinforce specific assumptions about the nature and operation of key concepts such as individuality, humanness and cognition.**

3.7 A non-exhaustive list of relevant SSH fields

In this section, we summarise from the previous sections, which SSH disciplines and research fields may contribute to a better understanding of the issues raised in the CT debate and the shaping of processes of convergence. This will not be done in the form of a systematic list making analytical distinctions, but in the shape of a catalogue.

-*Research Policy Analysis*: e.g. the analysis of funding of CT; the role of international competition and cooperation; role of institutions and agencies; the strategic context of CT initiatives

-*Discourse Analysis*: e.g. analysis of relations between policy actors, business, technology experts, NGOs and sociocultural movements in the CT debate; new forms of governance; ontological politics of convergence

-*Scientometrics*: e.g. relevance of concepts of convergence; inter- and transdisciplinary R&D

-*Sociology of Expectations in S&T*: e.g. relevance and role of visions; changing role of science in society

-*Philosophy and History of Science and Technology*: e.g. epistemological challenges; new modes of knowledge production; ontological status of CT developments; changing paradigms of science and technology

-*Ethics (Bio-, Nano-, Neuro-, Info-)*: e.g. distributive justice; human dignity; human enhancement and the topic of informed consent; free will

-*History of Ideas*: e.g. changing conceptions of man-machine interactions; interrelations of utopianism, eschatology and technoscientific visions

-*Theology*: eschatological qualities of technoscientific visions; conceptions of human nature and of the conditio humana

-*Anthropology*: e.g. man-artefact relations; trans- and posthumanism

-*Cultural Studies*: e.g. identity politics; R&D and science fiction; "posthumanist studies"; "cyborg studies"

-*Disability Studies*: e.g. prosthetic technologies; human enhancement; ideology of ableism; cultural impacts of CT and the related visions

-*Technology assessment (including vision assessment)*: e.g. R&D Foresight; societal, legal and ethical aspects of CT; relevance and role of visions; actor analysis; constructive and real-time technology assessment

-*Innovation analysis and aconomics*: e.g. innovation systems and CT; marketability of CT developments; benchmarking

-*Science and technology studies*: several of the above-mentioned topics and, for example, empirical analysis of processes of technoscientific convergence; participant observation and other "ethnological" approaches by "embedded" social scientists and humanists; systemic approaches

-*SSH as enablers and mediators of the public dialogue on CT*: e.g. citizen conferences, "upstream engagement", participatory technology assessment

-*Cognitive Science*: cf. Chapter 3.2; Cognitive Science as a "laboratory of convergence"

4 Summary and outlook

As our analysis has demonstrated the actual and potential relevance of technoscientific processes of convergence is still obfuscated by conceptual problems and by the impacts of a highly visionary and, in large parts, ideologically motivated discourse. There is obviously a great need for a more refined concept of convergence and a more nuanced and precise assessment of ongoing and emerging developments in science and technology. While the NBIC quartet might still be a useful starting point for the analysis of convergence, more differentiated conceptualisations are needed which also take into account various modes of convergence and interdisciplinary. In Chapter 3 of this report, we have presented some ideas of how to develop such a more nuanced approach.

The relevance of new concepts of convergence in recent EU and national funding schemes indicates that the CT concept, in spite of the only minor political relevance and present inactivity of the NBIC initiative in the US, is here to stay. There are clear tendencies towards overcoming the sociologically and philosophically naïve conceptualisation of convergence which was advanced by the NBIC initiative and its transhumanist and other enthusiastic allies. In particular, the rather crude mix of individualism with social engineering fantasies, the old-fashioned humanist framing of a transhumanist agenda, and the misrepresentation of cognitive sciences have impeded the adaptation of the NBIC agenda in Europe and elsewhere. At the same time, the European ethical debates on CT and human enhancement, in which experts from North America and other world regions often participate, display a high degree of diversity and integrated religious, transhumanist and diverse secular positions into the discourse in a less confrontational manner than in the US. Nevertheless, the discussions about CT are also still an element of a wider discourse in which technoscientific visions function as media of an "encrypted" political debate on the history and future prospects of modern societies. This debate deserves further attention by the pertinent SSH.

Beyond the hype and the problems of substantiating the concept of convergence for practical purposes, there seems to be something in the concept that addresses "real" developments in the scientific community and technoscientific practice. While the concept of convergence is apparently still little more than an "artefact" of science policy, accompanying research and transhumanist speculations, the relevance of inter- and transdisciplinarity in some cutting-edge research activities as well as the substantial funding of and investment in such activities demonstrate that convergence is, in a way, already a fact. The mode of presentation of the NBIC concept by Roco and Bainbridge may be flawed in many ways, but their goals are really worth attention and further analysis. Even if one disagrees with their special framing of the issue of convergence,

with their normative assumptions and their political agenda, it seems worth focussing on the nature of their core points.

In this context, the question is of utmost importance whether too much attention has been drawn to the topic of human enhancement even though there are other promising areas where there the approach could be used, e.g. monitoring the environment, saving energy, contributing to a sustainable development or dealing with the chances and challenges raised by the so-called "ageing societies". In fact, the strong focus on human enhancement in the CT debate might even be considered as a distraction from the real problems our societies are facing today. It might be argued that to focus on the human as a deficient entity that is ill or well is isolating human beings from their social contexts and natural environments. At the same time, the focus on "human enhancement" as well as the preoccupation with highly visionary scenarios might distract from more pressing ethical issues. Frequently mentioned examples for this are neurotechnological developments such as deep brain stimulation. In this context, it is also argued that CT are focused too strongly on enhancement of the individual – even those already advantaged in comparison with societal average – instead of attempting to enhance collective capabilities of societies or social groups.

Still rather underexposed are also possible short- and mid-term contributions of the SSH to the shaping of innovative processes in the fields of technoscientific convergence. Topics which are at the core of recent CT policy initiatives of the European Union or nation states such as Germany have only very rarely been examined from such a perspective. Cutting-edge research activities in fields such as prosthetic technology, sensory enhancement, smart system integration, robotics, nanomedicine, computer vision, and new man-computer interactions, which are already funded by the EU and member states, could profit from a more systematic integration of SSH perspectives and research which includes not only ethical research, but also such diverse fields as, for example, disability studies, social network analysis and media studies. As outlined above, the example of the cognitive sciences, in particular, demonstrates the existence of underused potentials of SSH research for the understanding and shaping of technoscientific convergence and its societal embedding.

SSH could also contribute to assessing the commercialisation prospects of emerging and future CT, even with regard to the so-called human enhancement technologies which, however, might raise a number of serious ethical issues. At the same time, fields such as technology assessment, science and technology studies, economics, or innovation research could significantly contribute to bridging the gap between visions and applications of convergence and analyse in greater depth the chances and challenges which arise in actual R&D on CT and their funding and promotion. Given the

known weaknesses of European innovation systems, it might also be worthwhile to consider the funding of pilot projects which include ("embed") social scientists or humanists into cutting-edge natural science or engineering research activities. And ethical research could extend its role far beyond the traditional, largely reactive "watchdog" function and instead help to shape innovation processes from the start, reflecting and bringing in the cultural diversity of European societies, their values and creativity.

In our view, a strong engagement of a broad variety of SSH in the debate, analysis and shaping of actual processes of technoscientific convergence could therefore decisively contribute to the overcoming of one-dimensional and naïve conceptions of these processes and to the embedding of the dynamic developments in the NBIC fields into the European Knowledge Society.

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Appendix A

R&D Trends in Converging Technologies

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Converging technologies and their impact on the social sciences and humanities (CONTECS)

Deliverable D3.1 – Part A

R&D Trends in Converging Technologies

April 2008
(based on an earlier version from September 2007)

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Table of contents

Objective and scope 1

Part I: The technology base for convergence 3

I.1 Introduction 3

I.2 Converging Technologies: Concepts and delineations 5

I.3 Visions and state of the art in converging science and technology fields 11

I.3.1 Neuro/Brain Enhancement 11

I.3.2 Physical enhancement and Biomedicine 17

I.3.4 Human-Machine Interfaces 33

I.3.5 Sensors 38

I.3.6 Computer-based modelling of the world 45

I.3.7 Pattern recognition 52

I.3.8 Robots and intelligent systems 54

I.3.9 Summary 58

Part II: Social Sciences and Humanities Aspects 61

II.1 SSH aspects from the main CT documents 61

II.1.1 Transferring methods and concepts 61

II.1.2 Organising interdisciplinarity for convergence 68

II.1.3 Education 72

II.1.4 Governance 75

II.1.5 "Salvation Promises" 77

II.1.6 Summary 79

II.2 SSH aspects evolving from the interviews 81

II.2.1 Introduction 81

II.2.2 Selection of interviewees and personal involvement 81

II.2.3 Awareness of the concept of technological convergence 83

II.2.4 Which developments in science and technology are associated with the concept of convergence? 84

II.2.5 To what extent is research interdisciplinary? 85

II.2.6 What are the ethical problems? 87

II.3 Two different narratives of technological convergence 89

Version 2: Convergence as a normative concept 93

References 99

Table of figures

Figure 1: Convergence of Nano, Bio, Info and Cogno (NBIC) on a general level 9

Figure 2: Allocating research areas to the overlapping areas of NBIC....11

Figure 3: Application areas in the CT debate as a result of the clustering exercise....12

Figure 4: Top-down and bottom-up approaches in the debate on converging technologies....13

Figure 5: Convergence in the biomedical sector 22

Figure 6: From genomics to social behaviour: Integrated studies of human behaviour and "Socio-Tech" 66

Figure 7: Socio-Tech: Understanding and predicting society on the basis of technical advances....67

Objective and scope

This paper is a reworked and extended version of deliverable 1.1 Part A titled "R&D Trends in Converging Technologies" from August 2006. In the centre of the original version was the analysis of the central documents of the NBIC (Nano, Bio, Info, Cogno) respectively the CTEKS (Converging Technologies for the European Knowledge Society) convergence and a confrontation of visions with the state of the art in the respective scientific and R&D fields.

In the meantime we reassessed our preliminary structuring of the field, deepened the analysis of the current research and technology development and gathered new information on Social Science and Humanities (SSH) aspects of Converging Technologies (CT).

Again a large part of the results presented in this paper stems from an extensive analysis of the relevant and available literature as well as many Internet sources. Other important sources for this deliverable were the expert workshop we organised in October 2006 in Brussels, the personal and telephone interviews we carried out between April and September 2007, and the discussions in the context of the workshop "Converging Science and Technologies. Research Trajectories and Institutional Settings" in May 2007 in Vienna, where the authors presented first results.

The central task of this deliverable is to contribute to an understanding of the technological basis of Converging Technologies and to put the visions in the context of current R&D activities. As such, it is a first step in the attempt to look more closely at what is actually happening on a concrete level within and between the involved disciplines and technology fields. In order to hear from the scientists themselves, what they know and think of technological convergence, we carried out a series of interviews, mainly with researchers and engineers in German research institutes and universities. The results of the expert interviews were incorporated into the text.

Based on the technological insights and including notions of the main contributions to the CT debate, specific SSH-aspects of CT can be identified. The SSH aspects of interest here mainly deal with aspects of interdisciplinary co-ooperation, including educational matters, governance questions and the function of the overboarding technological enthusiasm, an aspect in the CT debate we called "salvation promises". To sort out important aspects in this context, again a combination of document analysis and expert interviews was applied. Assessments of SSH aspects as they were given in the interviews are presented in a separate part of this paper.

According to the twofold task of this deliverable, the paper is organised in two parts: Part one deals with the structuring of the field and confronts CT visions with the state of the art research. Part two discusses selected SSH aspects of the CT debate, relying on prevalent CT visions and confronting them with SSH research traditions and current trends as well as professional assessments of selected scientists.

Condensing technological as well as SSH aspects we provide two different narratives of CT in the annex.

Part I: The technology base for convergence

I.1 Introduction

To define the term "Converging Technologies" (CT) and to determine the areas where convergence actually takes place or is considered to be necessary in the future is not an easy task. On the one hand the term is so new that researchers are not aware of convergence, even if they work in the middle of a converging discipline, busy with technology developments in the classical overlapping of NBIC. On the other hand the concept has developed a life of its own, brought up by a small number of science and technology visionaries, picked up and promoted by major research funding organisations and finally fuelling high expectations concerning the consequences of convergence for science and society among policy makers and the public.

The concept of convergence as well as the visions and expectations have been developed in an expert discourse within an expert community, which is still relatively small. The central documents, which are available for the analysis of the convergence concept, are four conference documentations from the United States (U.S.) and the reports from the High Level Expert Group (HLEG) in Europe.

The conferences in the United States took place 2001 in Washington D.C. (Roco and Bainbridge 2003), 2003 in Los Angeles (Roco and Montemagno 2004), 2004 in New York (Bainbridge and Roco 2006a) and 2005 in Hawaii (Bainbridge and Roco 2006b). Central actors at these conferences and editors of the respective documentations are Mihail C. Roco, who is the program manager of the National Nano Initiative (NII) and William Sims Bainbridge from the National Science Foundation (NSF).

Unlike the situation in the U.S., where the NBIC-debate is associated mainly with these two persons, in Europe there is a whole group of researchers responsible for analysing the CT development. The European Commission has set up High Level Expert Groups (HLEG) that have produced the major European documents in this field (HLEG 2004a, 2004b; Key Technologies Expert Group 2005; Staman et al. 2004; Ringland et al. 2004; Bibel et al. 2004).

It must be stated that visions, scenarios and images of the future are important for the emergence of new developments and the spreading of new concepts. However, due to the overboarding enthusiasm of the main proponents in the CT debate, especially in the U.S., it is sometimes difficult to separate hype from facts. What is more, the amount and diversity of scientific fields and technology areas which are expected to come together in the future are so vast that it seems that in the end almost everything is about

to converge. Therefore it is necessary to clarify what is understood by convergence on a conceptual level and then to determine the concrete areas where convergence is taking place or is expected to take place in the future.

Although conceptual questions of the CT debate are not at the centre of this paper, some suggestions will be made. Part 1 of this paper focuses on the analysis of concrete applications and technology fields as introduced by the proponents of the CT debate. In that respect, our contribution can also be read as a discourse analysis since its starting point is not the development of science and technology by its own but the array of technologies and visions brought in by the supporters of NBIC convergence.

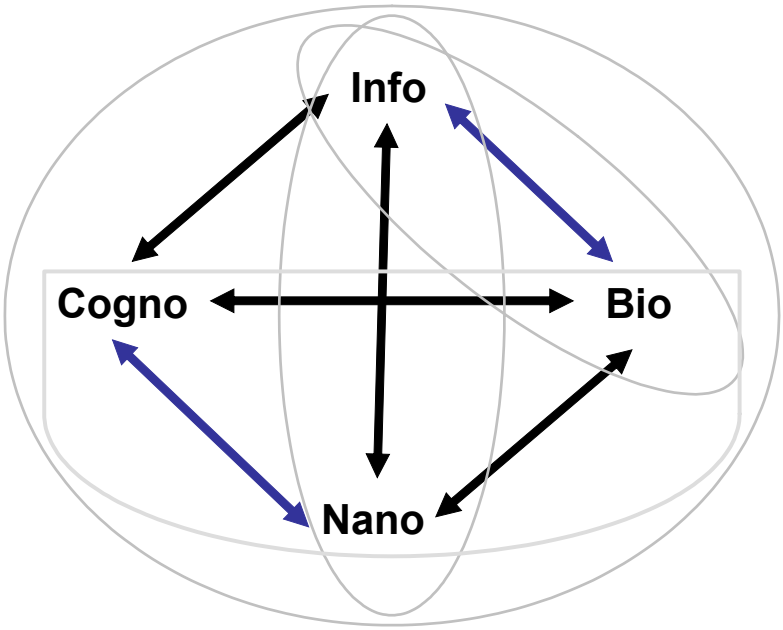
Apart from identifying and describing visions and projected application areas of the CT debate, part 1 of this paper also attempts to provide reality-check wherever possible, trying to separate science from science fiction by confronting the visions and anticipated scientific breakthroughs with the state of the art of current research in the respective areas. This reality-check may in turn contribute to the conceptual understanding of the convergence process.

The aim of this paper is to capture the breadth of areas in science and technology that may be affected by convergence. It thought to further the understanding of the technological basis of the CT development and put the visions in the context of the state of the art. As such, this paper can be seen as a collection of material and could function as a starting point for further investigations.

I.2 Converging Technologies: Concepts and delineations

Starting point for the analysis of convergence is the so-called NBIC tetrahedron (fig. 1), originally proposed by Roco and Bainbridge in the documentation of the first NBIC-conference, which took place in the year 2001 (Roco and Bainbridge 2003, p. 2). In their overview article at the beginning of the book they claim that convergence is taking place as a synergistic combination of four major NBIC provinces of science and technology, each of which is currently progressing at a rapid rate: (a) nanoscience and nanotechnology; (b) biotechnology and biomedicine, including genetic engineering; (c): information technology, including advanced computing and communications; and (d) cognitive science, including cognitive neuroscience (Roco and Bainbridge 2003).

Figure 1: Convergence of Nano, Bio, Info and Cogno (NBIC) on a general level



Source: Roco and Bainbridge 2003, p. 2

The assertion is that these sciences have now "reached a watershed at which they must combine in order to advance most rapidly" (Roco and Bainbridge 2003, p. 2). As structuring principles or building blocks for future technologies respective research objects of the NBIC fields like atoms, genes, neurons and bits are accounted for (Roco and Bainbridge 2003, p. 71f). What remains undecided in the article of Roco and Bainbridge is whether convergence is something already under way, which comes together under the new label of convergence, or something, which is called for in order to enable scientific breakthroughs in the future. The book presents a mixture of these

two aspects, blurring vision and current research thus making it difficult to identify areas where convergence is really taking place.

The structure of the documentation at least suggests some concrete areas where convergence might take place or is required:

- expanding human cognition and communication,
- improving human health and physical capabilities,
- enhancing group and societal outcomes,
- national security and
- unifying science and education.

In about 70 separate articles and statements, the different authors try to find evidence of convergence taking place or collecting arguments why convergence should take place in these selected fields.

In the European discourse, the question about which concrete research areas are affected by convergence and the guiding principles has also been discussed. Bibel et al. list a series of concrete research fields like artificial intelligence, sensors for smart environments, DNA compression, etc. and allocate these within the different overlapping areas of NanoBio, NanoInfo, NanoCogno, etc. (Bibel et al. 2004). Based on this list, one could draw a picture which is similar to the one by Roco and Bainbridge but which adds an additional level of detail (fig. 2).

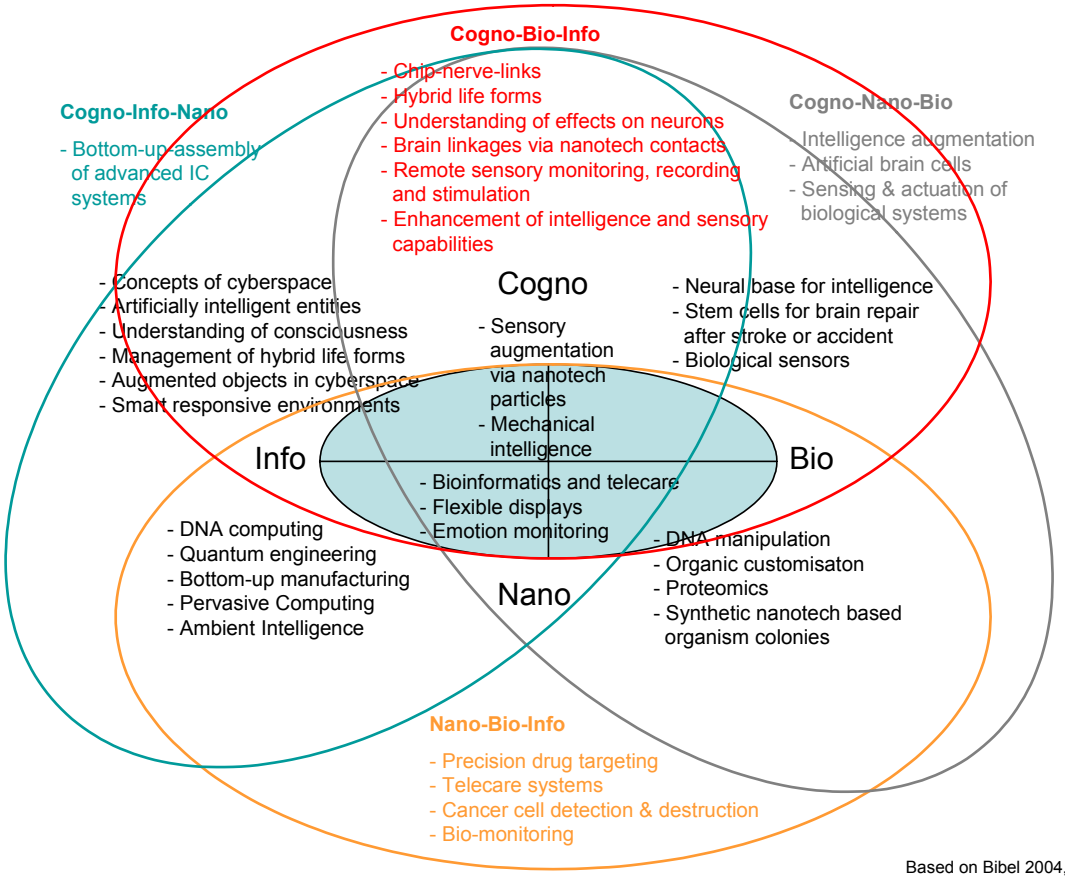
In their report "Converging Technologies - Shaping the Future of European Societies", the High Level Expert Group takes a different approach: Not the application areas where convergence might occur are of interest but the fields in which convergence should function as a pacemaker for scientific breakthroughs and innovations. The authors suggest that the European version of NBIC, called Converging Technologies for the European Knowledge Society (CTEKS) should be focused on research topics that are valued highly, thus initiating technology developments in the desired areas. Five areas were identified where progress through convergence is considered desirable (HLEG 2004a):

- **Health** ("lab-on-a-chip" technologies for fast screening and early diagnosis of diseases; intelligent prostheses interacting with brain signals from patients and transmitting sensory information back to them).
- **Education** (invisible knowledge space; learning objects and smart surroundings)
- **ICT Infrastructure** (environmental monitoring through ambient sensing devices to alert agencies of pollutants and inform individuals about the distribution of allergens; integration of information about food products, purchasing and consumption

patterns, individual states of health, diet plans, and medical expertise to combat obesity by advising individuals; integrated hybrid transportation systems and decoupling of GDP growth with increasing traffic; natural language processing).

- **Environment**
- **Energy** (new energy carriers and forms of storage, new energy sources emulating nature, exploring renewable energy sources; photovoltaic, hydrogen, geothermal and solar energy researchers should work together with geologists, geographers, anthropologists, and economists; intelligent dwelling, bio-mimetic technologies, integrating photovoltaics in smart materials; incorporating environmental sensors in information and regulation systems).

Figure 2: Allocating research areas to the overlapping areas of NBIC[1]



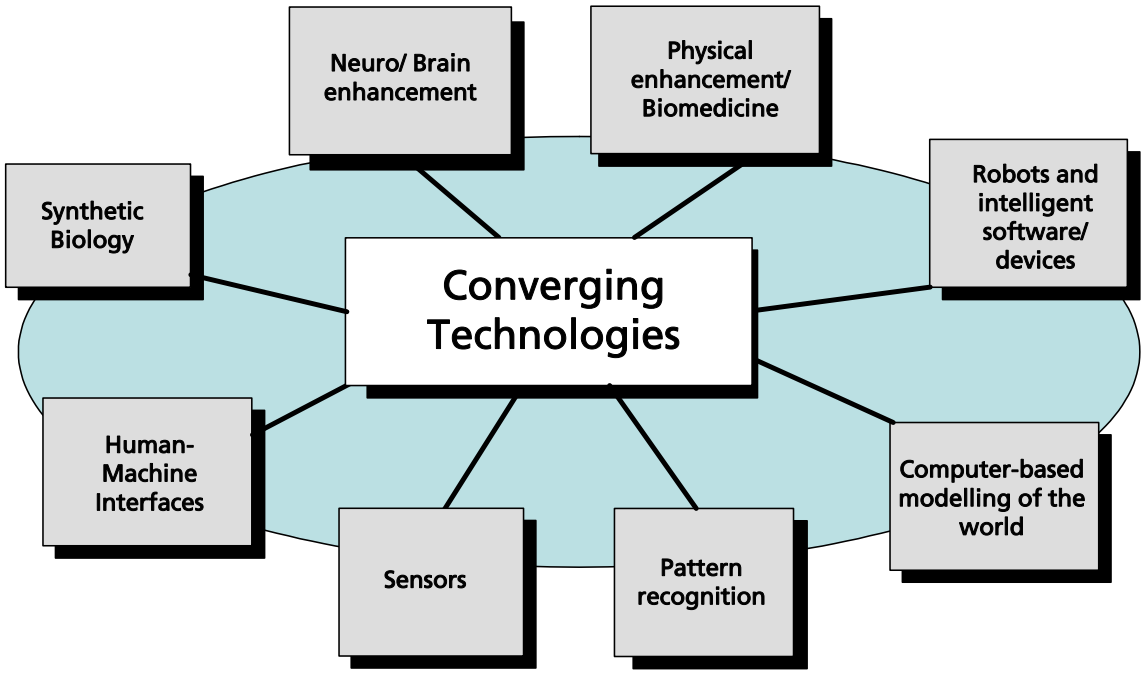
Source: Bibel et al. 2004, p.58

1 Due to lack of space the applications in the all-inclusive Nano-Bio-Info-Cogno overlap are not included in the drawing. These are: Sensors and sensor nets, hybrid systems (half cyberspace, half physical world), biological customisation, smart bacteria, full direct brain link, mental immortality (Bibel et al. 2004, p. 59).

Analysing the central documents of the NBIC debate in the U.S., like Roco and Bainbridge 2003, Roco and Montemagno 2004, Bainbridge and Roco 2006a, Bainbridge and Roco 2006b, and the CTEKS debate in Europe, like HLEG 2004a, 2004b, Key Technologies Expert Group 2005, Staman et al. 2004, Ringland et al. 2004 and Bibel et al. 2004 we used the following research question: *What are concrete areas in which the principles of convergence become obvious and relevant?*

As a result of the analysis more than 100 application fields were identified from the literature. The applications were then clustered into eight areas by subsuming single applications and Research & Development areas under top headings. The resulting eight areas are shown in figure 3.

Figure 3: Application areas in the CT debate as a result of the clustering exercise



Taking conceptual approaches and our application clustering approach into account it can be stated that the analysis of the debate on convergence can basically be carried out from two different starting points: Convergence can be seen as an abstract concept providing guiding principles for the general scientific development (top-down) or it can be considered as something that is already occurring in concrete application areas every day without a comprehensive planning and sometimes even without knowledge of the concept (bottom-up, see fig. 4).

The problem with these two perspectives is that the top-down approach is too general and the bottom-up approach has not been consequently followed yet. There is a gap between the general conceptual level and the concrete, practical level, which hints to the fact that in the CT debate a framework is still missing, that could concisely connect the application areas with the convergence concept and its visions.

Figure 4: Top-down and bottom-up approaches in the debate on converging technologies

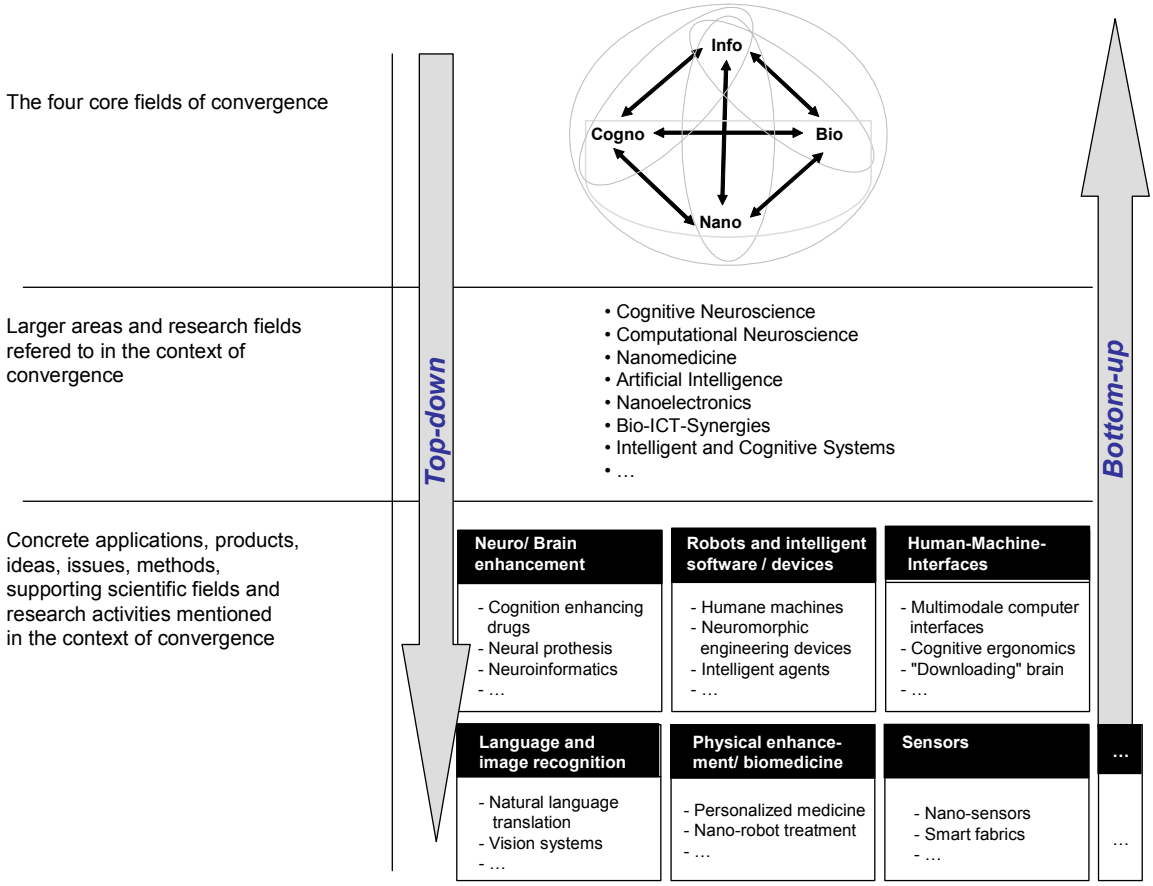


Figure 4 is an attempt to translate these observations into an overview. It shows three levels of concreteness, starting at the top from the least concrete level showing merely the four core fields of convergence. From the sheer notion of convergence a series of ideas and visions may originate which in turn might stimulate specific research on a more concrete level or in concrete application fields. The transfer of methods, insights, procedures, approaches, etc. from one discipline to another and new impulses from visions of convergence may be responsible for new developments in the levels below (top-down perspective).

On the other hand there is the bottom-up approach, where new research results give rise to new visions, as singular successes in the application fields may generate more general expectations about what might be achievable in that area in the future (bottom-up perspective).

Our approach is to take the bottom-up approach seriously and to examine research and technology development at the level of single researchers, research groups, disciplines or technology development areas rather than from the visionary point of view. Based on the knowledge of the research going on in the different fields, it is hoped that statements about the impacts of the concept of convergence can be made.

As stated above, the importance of visions is undisputed. An example of their effect is the current development in nanotechnology (cf. for example Lösch 2006). For Converging Technologies one important source of the visions is Bainbridge 2006. His collection of visions will be used in the following as an entry point, adding more visions from other CT-related documents as we proceed.

After presenting the visions, the state of the art in the respective field is determined. In a project like CONTECS, which has the Social Science and Humanities (SSH) aspects at its centre, such a state of the art review covering a wide range of technological areas can only be done to a certain extent. Besides the overview articles concerning covergent technologies in general also articles covering parts of the NBIC subject matter were considered for the analysis (for example van Lieshout et al. 2006; Silberglitt et al. 2006; Shmulewitz et al. 2006; Grillner et al. 2005).

I.3 Visions and state of the art in converging science and technology fields

I.3.1 Neuro/Brain Enhancement

Visions

The main goal of neuroscience research with its study of the nervous system is to understand how the human brain works. In order to achieve this goal it is necessary to analyse single neurons and the communication processes between them as well as the functioning of more complex cell structures and whole brain regions like the amygdala or the basal ganglia. It is hoped that one day scientists will be able to wholly understand and describe the biochemical and neuroelectrical processes associated with human intentions, impulses, feelings, beliefs etc. and to transfer that knowledge in terms of formally well-defined processes (Bainbridge 2006).

With regard to medical applications the treatment of neurodegenerative diseases like Alzheimer's or Parkinson's disease and mood disorders as well as the restoration of lost senses like vision or hearing are relevant research areas in the neuroscience area. In a vision of Bainbridge disabilities such as blindness, deafness and immobility states will be overcome by the year 2035 through assistive technologies (Bainbridge 2006, p. 343).

Besides this, the stimulation and enhancement of the human brain with the help of pharmaceutical products, genetic modifications or technical devices, such as implants or neural prostheses, is envisioned. To be more concrete, pharmaceutical products could prevent sleep deprivation, stimulate creativity or enhance memory and/or cognition (Goldblatt 2003, pp. 339-340). Another long-term goal is the development of technical devices that once may act as surrogate brain structures or even as "external memory extensions". For example Robinett states, that a "detailed understanding of how human memory works, where the bits are stored, and how it is wired will enable capacity to be increased, just as you now plug additional memory cards into your PC." For installation, a means of doing microsurgery is required (Robinett 2003, p. 168).

Bainbridge even expects that by the year 2050 brain functions and the brain as a whole could be modelled and simulated within a computer. He assumes that by this time a whole range of new research tools will be available to chart the structure and functions of the human mind allowing for a complete mapping of the connections in the human brain.

One of the projected tools might be wearable brain imaging technologies. As Chance and Kang expect, wearable brain imaging technologies will be available soon which will enable applications such as identifying children with learning disabilities, assessing the effectiveness in teaching techniques as well as identifying the emotional state of a human being (Bainbridge 2006, Chance and Kang 2003, p. 226).

A further and even more far-reaching vision formulated by Robinett is the substitution of eyeballs with new high-resolution electronic eyeballs, which could directly be "hooked up to the optic nerve" (Robinett 2003, p. 167).

State of the art

Understanding Thought Processes and Neuroimaging

Regarding the current state of neuroscientific research one could say that the processes on the level of single neurons ("bottom layer") as well as the functioning of greater parts of the brain ("top layer") are quite well understood. Responsible for progress in the latter area are new and improved neuroimaging methods like fMRI (functional magnetic resonance imaging), EEG (electroencephalography), and PET (positron emission tomography). However, little is known about the behaviour of cell structures consisting of up to several thousand neurons ("middle layer"). Furthermore, neuroscientists state that it is necessary to develop a multi-level approach which links together the different fields of investigation in order to reach a higher level of understanding (Elger et al. 2004, p. 31; Grillner et al., 2005, p. 614).

At the moment such a multi-level approach is far from being realised and the functioning of the brain is only partly understood. Nevertheless, a wide range of therapeutic approaches for the different brain-related diseases or impairments as well as possibilities of brain enhancement already exist today.

The enhancement of particular brain functions or rather the improvement of one's ability to learn with the help of different concentration-, meditation- and learning-techniques could be considered as natural means of brain-enhancement. This also counts for deliberate changes of maternal diet, which can influence the development of the foetus' brain in a positive way (Sandberg and Bostrom 2006).

Apart from "natural approaches" and the stimulating effects of caffeine or common herbs and spices, today there are several pharmaceuticals commercially available which influence the functioning of the human brain in different ways. The most famous examples are pharmaceuticals like the anti-depressant Prozac (active pharmaceutical ingredient: Fluoxetin) or the sleep-regulating drug Provigil (active pharmaceutical

ingredient: Modafinil). In fact, some of these drugs are already called "cosmetic psychopharmaceuticals" because they are used by people who are not ill. Instead, they are used in order to overcome shyness or to be able to work up to 40 hours without sleep.

Furthermore, memory drugs are being developed for the treatment of age-related cognitive decline. Currently, more than 60 pharmaceutical and biotechnology companies are working on these substances, with about 40 drugs already at the stage of clinical trials. The drug Memantine, which was developed for the treatment of moderate to severe Alzheimer's disease, has already been approved by the U. S. Food and Drug Administration (FDA) in 2003 (Sententia 2006, pp. 154-156). Additional examples are the modulation of working memory by cholinergic drugs or drugs that regulate the dopamine system and the improvement of learning abilities with the help of amphetamine (Sandberg and Bostrom 2006).

Thus, certain possibilities of drug-based brain-enhancement already exist and the research in this area has made some progress. Moreover, pharmaceutical companies which focus on the development and the commercialisation of memory enhancing drugs, like Cortex Pharmaceuticals, Memory Pharmaceuticals have been founded (Farah et al. 2004). Nevertheless, it has to be stated that intelligence-enhancing drugs or even "neurochemical brain modulators with high efficacy and negligible side effects which will cure mental illness and expand artistic expression" as described in the Bainbridge-report from 2006 will only be available in the long run. Silberglitt et al. (Silberglitt et al. 2006) state that it is "unlikely" that such drugs will be produced in the year 2020. Additionally, Bainbridge estimates that the just mentioned "brain modulators" will be commercially available in 2030 (Bainbridge 2006, p. 342).

Genetic enhancement

Given the current advances related to the targeted genetic modification of different kinds of organisms, the idea to enhance certain brain functions via genetic manipulation seems to be a logic consequence. The ever increasing amount of detailed biological and genetic information already enabled the identification of genes associated with behavioural and emotional traits and with the creation and maintenance of memory. For example, genes could be identified which are associated with interpersonal relationships or social cohesion and parent-child connections (Silberglitt et al. 2006, p. 149). Additionally, some targeted manipulations have already been tested with animals. For example, one group of researchers including the Nobel Prize winner Eric Kandel created fearless mice. Within the brains of these so called knock-out mice, the production of the protein stathmin was blocked. As a result, the

mice boldly explored experiments instead of being hesitant like normal mice. They also failed to develop a fear of cues that have been associated with electric shock (Shumyatsky et al. 2005, pp. 679). Another example is mentioned by Sandberg and Bostrom: In a comparable study rats could be made smarter by a manipulation of the NMDA receptor. However, these rats appeared to be more sensitive to certain forms of pain. In other experiments, improvements of memory could be achieved by increased amounts of brain growth factors and the signal transduction protein adenylyl cyclase (Sandberg and Bostrom 2006, p.20).

With regard to humans, genetic studies identified genes whose variations account for up to 5% of memory performance variation. These include the above mentioned genes for the NMDA receptor and adenylyl cyclase making them possible targets for genetic enhancement approaches (Sandberg and Bostrom 2006, p. 21). Furthermore, studies which focussed on the genetics of intelligence revealed that a large number of genetic variations influence the intelligence of individuals while each one taken alone has just limited influence. Hence, the genetic enhancement of intelligence through "the direct insertion of beneficial allele is unlikely to be efficient" (Sandberg and Bostrom 2006, p. 30).

So despite the results that were achieved in the above mentioned animal experiments the targeted enhancement of human intelligence by genetic manipulation is not yet a method, which researchers expect to be successful in the short-term.

Implants and prostheses

Regarding technical devices, the most established *non-invasive* technique to influence neuronal processes in the brain is the Transcranial Magnetic Stimulation (TMS) method, where rapidly changing magnetic fields induce currents in the brain and thereby activate brain nerves. The potentials of this method as a treatment for severe depression, drug-resistant epilepsy, auditory hallucinations and tinnitus are currently investigated. Apart from that, Sandberg and Bostrom state that TMS could positively influence motor learning-tasks, visuo-motor coordination, finger sequence tapping and even declarative memory consolidation during sleep (Sandberg and Bostrom 2006). Furthermore, researchers at the Defence Advanced Research Projects Agency (DARPA) are trying to develop a sleep-regulating device for Air-Force-pilots, which is based on TMS (Buse 2003)[2]. However, there seems to be great interindividual variety in responses making careful testing of suitable stimulation intensities, frequencies and locations necessary (Sandberg and Bostrom 2006, p. 27).

2 http://www.spiegel.de/spiegel/0,1518,238157,00.html

Another non-invasive approach which was patented by Sony[3] can also be mentioned in this context. An external device that fires ultrasound into certain areas of the brain can influence firing patterns in the targeted regions – creating 'sensory experiences' such as taste, sound or moving images. Although no experimental evidence exists that this method actually works, experts like Niels Birbaumer, neuroscientist at the University of Tübingen in Germany, state that the approach seems to be plausible (Hogan and Fox 2005)[4].

In addition to these non-invasive methods several *invasive* therapeutic approaches exist which aim at the restoration of senses or certain physiologic functions. For instance, Shmulewitz et al. list a series of companies which already have succeeded or are still trying to produce such devices. "The combination of miniaturised microelectronics, novel biomaterials and adaptive signal processing techniques has created the possibility of building artificial neural implants - spurring new ventures such as IMI (Intelligent Medical Implants in Zug, Switzerland), Optobionics (Naperville, IL, USA) and Cyberkinetics (Foxborough, MA, USA)." With regard to the restoration of senses two important areas of research are hearing and vision implants (Shmulewitz et al. 2006).

Concerning *hearing implants* for deaf or hearing-impaired people two kinds of neuro-implants exist: Cochlear implants and auditory brainstem implants.

Cochlear implants are on the market since three decades and several thousand of them have been introduced since. The basic parts of a cochlear implant are an external device consisting of a microphone, a speech processor and a transmitter and an internal device, which is placed under the skin behind the ear. The internal device includes a receiver, a stimulator and an array of up to 22 electrodes that stimulate the auditory nerves. Concerning the efficacy of cochlear implants, it has to be stated that the ability to understand speech or to listen to music remains limited (van Lieshout et al. 2006, pp. 50-51).

Auditory brainstem implants also consist of an external and an internal part. The major difference in comparison to cochlear implants is that the internal part is implanted into the brain and stimulates the area that normally receives the electrical signal from the ear directly. They have been commercially available since 1990 but only a few hundred devices have been implanted until today (Bolz et al. 2005, p. 43).

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3 Patents: US 6,536,440 B1 (granted in march 2003) and US 6,729,337 B2 (granted in may 2004)

4 http://www.newscientist.com/article.ns? id=mg18624944.600

Vision implants are more complicated compared to hearing implants. Currently, three different approaches are under development: epiretinal, subretinal and cortical implants.

Epiretinal implants consist of a camera and an implant, which is placed onto the retina and coupled to the ganglion cells and their axons. The image-information from the camera is processed and then transmitted to the implant, whose electrodes stimulate the neurons. Clinical tests with retinitis pigmentosa-patients showed that the patients were able to detect patterns in a pre-defined test-environment after a short training period (Bolz et al. 2005, p. 11). Furthermore, there are already enterprises that develop and produce epiretinal implants like Second Sight (USA) or Intelligent Medical Implants (Switzerland).

Subretinal implants contain thousands of light-sensitive microphotodiodes. They are implanted between the pigmented epithelium and the outer layer of the retina. The photodiodes convert light into currents, which then activate microelectrodes stimulating the retinal neurons. At the moment, there is only little information about the efficacy of these implants available, as the first clinical tests have just begun.[5] Consequently, commercial sales of subretinal implants are not expected to start before 2009 (van Lieshout et al. 2006, p. 54; Merabet et al. 2005, p. 72).

Cortical implants are based on the direct stimulation of the optic nerve or the visual cortex. Either a four-contact cuff-electrode placed around the optic nerve or the stimulating electrodes are directly introduced into the brain. The image-information is generated by a camera and an external processor and then sent to the implant via a wireless signal transmission (Merabet et al. 2005, p. 72). Although these implants are at an early development stage cortical vision prostheses have successfully been tested on retinitis pigmentosa-patients (Bolz et al. 2005, p. 49). According to Merabet et al., a test person was able to recognise orientation of lines and could also distinguish some shapes or even letters after four months of training.

Despite the overall progress that is made with regard to vision prostheses it has to be noted that the majority of the 'artificial eyes' was developed for people who suffer from diseases like retinitis pigmentosa and macular degeneration (Cohen 2007). These represent a minority of the blind – yet, there are no comparable solutions available for people who were born blind (Wickelgren 2006, p. 1124).

5 See for example: www.retina-implant.de/en/patients

Regarding research activities, which focus on the restoration of physiologic functions one important example, are the so called Deep Brain Stimulators (DBS). They were originally developed in order to ease the symptoms of Parkinson's disease and are functioning like pacemakers. A thin wire is placed in a particular part of the brain that controls movement. This wire is connected to an impulse-generating device, which is implanted under the collarbone making it possible to directly stimulate the patient's brain with electrical impulses. Today, DBS is also approved for dystonia, a degenerative brain disease such that over 20,000 of these systems have been implanted until now. Additionally, researchers are exploring the potential of DBS for other disorders like chronic pain, spinal cord injuries, epilepsy, depression, muscle spasticity and urge incontinence (Bolz et al. 2005, pp. 7, 50-52; Stieglitz 2006, p. 102).

With regard to non-medical purposes Sandberg and Bostrom state in their report, that an improvement of procedural learning by direct electrical stimulation of the basal ganglia was demonstrated in monkeys (Sandberg and Bostrom 2006, p. 25).

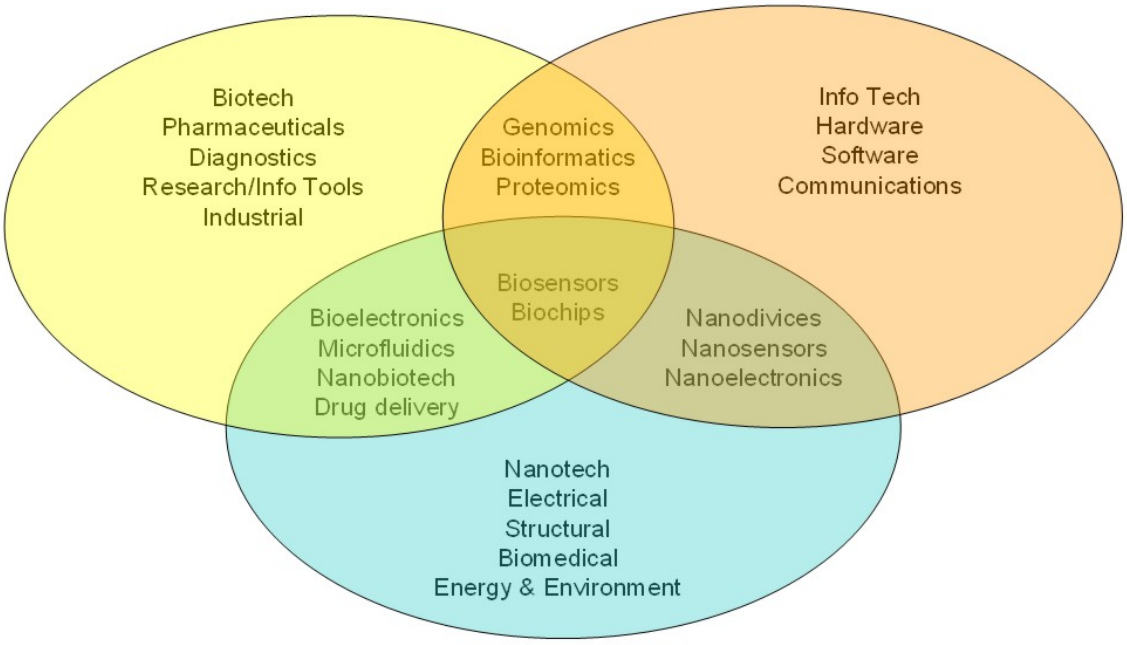
Neuroscience nowadays involves a variety of scientific disciplines like biology, psychology, computer science, physics, and medicine and utilises methods and tools from different research areas. Neuroscience researchers are convinced that progress can only be made through an intelligent combination of disciplines like nano- and biotechnology, information technology, genetic engineering and cognitive science. Thus, "Neuro/Brain enhancement" as a research field stands at the centre of the CT-debate. It attracts the largest share of attention due to its plans to simulate and manipulate brain processes, which - if realised successfully - could directly affect our concepts of the human self and identity.

I.3.2 Physical enhancement and Biomedicine

Visions

The enhancement of the human body as a natural counterpart to brain enhancement is a field where the convergence of different scientific disciplines and technologies is expected to lead to radical innovations. As Shmulewitz et al. point out, convergence in biomedicine will be the basis for new products, processes or devices: "When applied in the life sciences, the result is a new approach to prevention, screening, diagnosis, therapy, monitoring or disease management". In fig.5 possible emerging fields, devices, etc. are indicated in the overlap between the bio-, nano-, and info-technology sectors (Shmulewitz et al. 2006, p. 277).

Figure 5: Convergence in the biomedical sector



Source: Shmulewitz et al. 2006, p. 277

Further advances in bio- and nanotechnology are expected to lead to novel therapy methods and the possibilities of enhancing the physical capabilities of humans. Thus, the following categories might be strongly influenced by the converging technologies: *Therapies, Genomics and "Spare Parts"*.

The first category *Therapies* involves the use of nano-sized sensors and lab-on-a-chip systems for patient monitoring and diagnostic purposes. They should enable an earlier and more exact detection of diseases. Furthermore these systems should be the basis for decentral point-of-care applications - making central laboratories more and more obsolete. Also, a substantial part of research interest concentrates on solutions for targeted drug delivery. It is hoped to be able to create nanotechnology-based drug delivery systems, which are characterised by a very high specificity and enable the delivery of drugs in new ways. Another visionary approach which is often mentioned in the mass media also belongs to this category: nanorobots that move through the blood vessels and perform surgeries inside the body (Freitas 2005). Bainbridge states that in 2050 "nanorobots will perform surgery and administer treatments deep inside the human body" (Bainbridge 2006, p. 344).

The second category *Genomics* encompasses the two closely related areas of pharmacogenomics and pharmacogenetics. Pharmacogenetic studies suggest that the re-

sponse of individuals to different drugs can be predicted on the basis of genetic tests. As this would allow the development of pharmaceuticals that are tailored to the individual genetic makeup, pharmacogenomics and pharmacogenetics represent important elements of the trend towards the so called personalised medicine. A further component of genomics is research interest focusing on gene therapies.

As the label *"Spare Parts"* already indicates the third subset consists of research projects, which aim at the replacement of different parts of the human body or even the enhancement of their respective functions. Hence, one element is the development of exoskeletons that enable persons to carry high loads over long distances. Further important research areas are tissue engineering and regenerative medicine in general as well as the development of nanocoatings for implants and surgical instruments that prevent inflammatory responses.

State of the art

Therapies

Although nano-sized sensors and lab-on-a-chip systems to monitor physical processes fall in the category of biomedicine and therapies, they are not described in detail here but in section 3.5. This is because they form a central application field in the CT debate, which is well worth separate attention.

Also, the area of synthetic biology as discussed in section 3.3 is strongly related to fields, such as biomedicine, nanorobotics, nano-sized sensors, etc. and extends the medical aspects discussed in the present section to the more general aspects of biological engineering.

Thus, this section directly starts with the concept of drug delivery. Fundamental to the concept of nano drug delivery is the fact that nano-engineered materials can be used in order to release drugs at particular locations in the body. Thereby it is possible to reduce side effects and to reduce the required volume of drugs. For example, nano drug delivery systems that target only cancerous cells represent a very effective means to treat cancer (Silberglitt et al., 2006, p. 174).

At the moment, nanoparticle-based drug delivery is the area within nanomedicine research with the highest level of activity (Wagner and Zweck 2005, p. 30; de Groot and Loeffler 2006[6], p. 17). While the first related products were commercialised in the early 1990s, today there are about 100 products in the pipeline. Most of the currently avail-

6 http://www.nanoroad.net/download/roadmap_mh.pdf

able systems are first generation products, which were formulated as nanosuspensions in order to increase the solubility of drugs. Advanced second generation delivery systems aim to improve the pharmacokinetics of therapies and will also enable drugs to cross biological barriers (e. g. the blood brain barrier). Given the fact that none of the current delivery systems makes use of active targeting based on antibodies or aptamers this represents another field for future research (Wagner and Zweck 2005, pp. 30, 41 and 54). Overall, present R&D-activities on nanoparticle-based drug delivery focus on the following needs and problems (Wagner and Zweck 2005, p. 53; de Groot and Loeffler 2006, p. 17):

- *Reduction of side effects of drugs*: As many drugs are not specific and also accumulate in healthy tissue, nano delivery systems are under development in order to solve this problem ('targeted drug delivery'). Examples are liposomes, polymeric nanoparticles, and polymer-drug conjugates.
- *Delivery of labile biopharmaceuticals*: Therapies based on biopharmaceutical drugs often struggle with problems caused by poor stability of the active component. One strategy to deal with these problems is to create polymer-protein conjugates with the help of synthetic polymers.
- *Enhancement of the solubility of drugs*: Nearly half of the drugs currently under development are poorly soluble. Hence, the surfaces of some drug powders are increased by formulating the respective drugs as nanosuspensions, which leads to a higher solubility. Some nano-enabled reformulations are currently in clinical trials (Silberglitt et al. 2006, p. 194-195).
- *Transport of drugs over biological barriers*: Biological barriers like the blood brain barrier, the dermal barrier or the gastrointestinal tract often affect the transport-mechanism of drugs such that many nano-based drug delivery systems are developed in order to overcome these barriers. Research in this area is of particular importance for therapies against brain cancers and neurodegenerative diseases.
- *Gene therapy*: An essential part of gene therapies are the so called vectors. These vectors deliver the therapeutic gene to the target cells where it is inserted in order to substitute the disease-causing gene. Current therapies are based on viral vectors, which bear a high risk of pathogenic effects. Consequently, present research focuses on alternative non-viral solutions like liposomes or polymers.

Regarding the current state of nanoparticle-based drug delivery it can be stated that those therapies that are already in use or rather in clinical trials mainly focus on cancer and fungal infections (ESF 2005, p. 45)[7]. Nanomedicines, which will enter clinical routine within the next five years, include antiviral agents and drugs for the treatment of

7 http://www.esf.org/publication/214/Nanomedicine.pdf

arteriosclerosis, chronic lung diseases, and diabetes. Additionally, gene therapy and tissue engineering are further potential areas of application but it is estimated that it may take about 10 years until the first nano-based solutions become available (ESF 2005, p. 20).

Genomics

As already mentioned above, in the field of genomics pharmacogenomics and pharmacogenetics represent important components. Both deal with the influence of genetic variations on drug response and are therefore important approaches towards the so called personalised medicine. As it is estimated that 20 to 95 % of the variations in drug disposition and effects are caused by genetic differences these two areas of research offer the potential to improve the efficacy of drugs and to minimise their adverse effects (Evans and McLeod 2003, p. 538).

The science of pharmacogenomics focuses on the entire genome and is based on the identification of sites of variation in its sequence – the so called Single Nucleotide Polymorphisms (SNPs). It examines those variations that determine drug response and tries to figure out how they can be used to predict the response of different patients to a certain drug (Weatherall et al. 2005, p. 10)[8]. In contrast to that, pharmacogenetics concentrates on one or at most a few genes and analyses the single gene interactions with drugs.

Regarding the potential benefits of the research activities in these two areas it is hoped, that SNP screenings will improve the process of drug development and testing as they will make it possible to exclude those patients from clinical trials who would not benefit from the respective drug or who would even suffer from adverse effects. As a result, clinical trials could be smaller, faster and thus less expensive. Additionally, it is hoped to increase the physician's as well as the patient's confidence in prescribed drugs by pre-assessing an individual's reaction to a certain drug[9].

In order to illustrate the current state of pharmacogenomic and pharmagogenetic research the following paragraphs contain exemplary results of present-day studies.

- For example, recent studies on the drug metabolism showed, polymorphisms in the so called cytochrome P450 genes are one of the most important genetic causes of variations in drug-responses (Weatherall et al. 2005, p. 7). The reason for this is that the products of the cytochrome P450 genes are active in the liver and also

8 http://www.royalsoc.ac.uk/displaypagedoc.asp?id=17570

9 www.ncbi.nlm.nih.gov/About/primer/pharm.html

break down many drugs. Consequently, the use of a drug as well as the dose may be biased by polymorphisms in these genes. The CYP2D6 enzyme for instance, whose corresponding gene belongs to the cytochrome P450 group, is involved in the metabolism of about 25 % of all prescribed medicines, including some beta-blockers, antidepressants, and anti-psychotic drugs. Hence, Roche Diagnostics developed a gene-based test, which is able to detect poor, intermediate, extensive or ultra-rapid metabolisers according to variants in the CYP2D6 gene. One of the first applications of this test might be in hospital-based psychiatry (Weatherall et al. 2005, p. 11).

- Another well-known example is the breast cancer drug Herceptin that was approved in 1998 and apparently helped only one fifth of the patients. As it turned out, these patients had a mutation in their tumour cells, which the others had not. Later on, the company Genentech started selling Herceptin in combination with a diagnostic test ('HER2-test') that could identify those patients who would benefit from the drug (Hennen and Sauter 2006, p. 9-11)[10].

However, only few comparable drugs became available since then. Altogether, there are about 20 approved drugs - predominantly in the field of cancer - "where reference to genetic testing is made in the drug labelling or package insert as a guide to how the drug should be used" (Weatherall et al. 2005, p. 15)[11].

Regarding currently available pharmacogenetic DNA-tests, Hennen and Sauter list seven different tests in their report (Hennen and Sauter 2006, p. 13; cf. Weatherall et al. 2005, p. 17). The majority of them focus on the already mentioned polymorphisms in cytochrome P450 genes.

Overall, none of these tests had significant impact on clinical practice until now (Hennen and Sauter 2006, p.14; Weatherall et al. 2005, p. 13). Therefore, it could be stated that it is unlikely that pharmacogenetics will "revolutionise or personalise medical practice in the immediate future" (Weatherall et al. 2005, p. 1). Nevertheless, industrial researchers expect that - within the next five years - up to 10 % of those therapies that progress through phase III trials will include an associated diagnostic test. In the next ten years this portion may even increase to 20 % (Weatherall et al. 2005, p. 21).

Correspondingly, Silberglitt et al. predict that it will be possible to determine by genetic screening, whether an individual is more or less susceptible to certain diseases in 2020 (Silberglitt et al. 2006). According to this report, it is nonetheless unlikely that the

10 http://www.tab.fzk.de/de/projekt/zusammenfassung/hp13.pdf

11 http://www.sciam.com/article.cfm?chanID=sa004&articleID=0006C064-7701-12ED-B70183414B7F0000

design of drugs, which are specifically tailored, to one's genetic makeup will already be feasible within the same period.

In addition to pharmacogenomics and pharmacogenetics, gene therapy is a further important element of the category genomics. Within this area of research some 'spectacular' experiments were conducted during which mice and other animals were successfully 'enhanced'. For example, researchers at the Salk Institute in La Jolla produced mice whose muscles did not fatigue. As a result, the genetically modified mice were able to run twice the distance of normal mice (Wang et al. 2004, pp. 1532 et sqq.)[12]. During experiments at the University of Pennsylvania in 1998, mice retained muscle strength and speed due to a specific gene therapy although they were already at an old age. After the injection of the same gene into young mice these animals grew stronger and more muscular than normal ones[13],[14]. Despite these achievements gene therapy has not been that successful in the case of humans until now.

In September 1999, an 18-year-old participant who suffered from "ornithine transcarbamylase" (a rare inherited nitrogen metabolism disorder) died during a phase I clinical trial at the University of Pennsylvania due to an acute respiratory syndrome and multiorgan failure - apparently brought on by a massive immune system response. The therapy was based on an adenovirus vector, which was also administered to about 20 other individuals. It turned out that the adenoviruses were not that reliable in delivering the genes to where they were targeted. The viruses were applied onto the liver but also spread through other organs and into immune system cells (Fox 2000a, 2000b).

In another case clinical trials in the USA and France were suspended in 2002/2003 due to the fact that two cases of leukaemia appeared among the participants two years after treatment. The patients had received a gene therapy because they suffered from Severe Combined Immunodeficiency Syndrome (SCID), also known as 'bubble-boy syndrome', and had in fact benefited from the gene therapy. Nevertheless, it was assumed that the gene insertion has caused the leukaemia-cases (Fox 2003, p. 121).

In 2004, a team of German and Swiss researchers treated two young males who suffered from the so called chronic granulomatous disease (CGD), a rare genetic disease which affects the immune system, using retroviruses as a vector for the delivery of the intact gene into blood generating stem cells (Ott et al. 2006, p. 401 et sqq.). However, one of the patients died from septicaemia in early 2006. Although it seems to

12 http://www.newscientist.com/article.ns?id=dn6310

13 http://www.upenn.edu/researchatpenn/article.php?768&sci

14 http://www.sciencenews.com/articles/20041030/bob9.asp

be unlikely that there is a causal relationship between the gene therapy and the septicaemia the possibility could not be ruled out.

Despite the just mentioned uncertainties concerning the efficacy of gene therapy approaches, one therapy already gained governmental approval: In 2004, the Chinese State Food and Drug Administration approved a gene therapy – Gendicine, distributed by SiBiono GeneTech - which aims at the treatment of head and neck squamos cell carcinoma (Pearson et al. 2004, p. 3). According to Zhaohui Peng, CEO of Sibiono GeneTech, the therapy had been used to treat more than 2600 patients during the period between the date of approval and July 2005. For the year 2006 a total number of 50,000 patients is projected (Wilson 2005, p. 1014; Peng 2005, pp. 1016).

A further area of research, which also belongs to the 'Genomics' -category, is preimplantation genetic diagnostics (PGD). PGD is already being used for the detection of various monogenic disorders and sex selection, partly for non-medical reasons. Apart from that, one of the potential applications, which are often discussed during the controversial debates, which were caused by this method, was the targeted genetic selection of offspring, be it for strength, beauty, intelligence or similar characteristics. Regarding the current state of PGD, it has to be stated that applications of this kind are not possible at the moment. Furthermore, Silberglitt et al. state that it is "highly unlikely" that PGD could be used for such purposes by 2020 - independent of the ongoing ethical discussions (Silberglitt et al. 2006, p. 31).

"Spare Parts"

Artificially enhanced exoskeleton: Regarding the artificially enhanced exoskeleton, envisioned by former DARPA-manager Michael Goldblatt (Goldblatt 2003, p. 338) it can be stated that research in this particular area has already made considerable progress. In early 2004 researchers at the University of California at Berkeley presented a self-powered exoskeleton, which enabled its "pilot" to carry about 30 kg (70 pounds) as if it were merely 2 kg (5 pounds). The system consists of mechanical legs that are connected to the user at his feet and a vest that is attached to the frame of a rucksack. A network of more than 40 sensors is used in order to control the hydraulic actuators within the exoskeleton, such that the system takes its own weight and ensures that the centre of gravity stays within the pilot's footprint[15],[16]. Although this special prototype is not a suitable application in the battlefield it could be seen as a proof-of-concept.

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15 http://www.newscientist.com/article.ns?id=dn4750

16 http://www.berkeley.edu/news/media/releases/2004/03/03_exo.shtml

Biocompatible surfaces using nanotechnology: Many implants like hip-joints, knee-joints, spinal implants or stents have a short lifespan due to poor growth of bone on their surface or rather unsatisfactory interaction with surrounding cells and tissue (de Groot and Loeffler 2006, pp. 60-61). Therefore, the attempt to develop nano-structured materials that support bone-growth or more generally improve the cellular recognition of implant surfaces seems to be promising (Wagner and Zweck 2005, p. 97; Baumgartner et al. 2003, pp. 29 and 31). The current state of this particular area of research can be illustrated by the three following examples:

- Hydroxyapatite is a ceramic coating material which is used for dental and orthopedic implants. At the moment, research focuses on the development of coating methods that improve cell-adhesion and mineralisation of the surrounding tissue. The company Nano Interface Technology Inc. which is developing hydroxyapatite coatings for both dental and orthopaedic implants is already about to start clinical trials. One goal of Nano Interface Technology is to increase the lifespan of hip implants from about 12 years to 20 years.
- Titanium and titanium alloys are already well-established materials for implants because of their advantageous properties. However, nanoporous titanium oxide surfaces are now under development in order to improve the biocompatibility even further. When loaded with certain drugs or metals, these nano-structured surfaces could also serve as drug release systems (Wagner and Zweck 2005, p. 98; de Groot and Loeffler 2006, p. 65).
- Another goal is the improvement of wear resistance. For example, titanium is not suitable for knee joints due to its low wear resistance. However, cobalt chrome alloys which are often used for knee implants have a limited biocompatibility. Hence, nanocrystalline diamond coatings for titanium implants are currently under development because they are characterised by extreme hardness, wear resistance, low friction and high biocompatibility.

As these examples show, nano-structured materials have a certain potential to support the development of implants with an increased biocompatibility – but nevertheless it has to be kept in mind that research on the interaction of nanomaterials and living organisms has just begun. At the moment, only limited information is available concerning long-term effects and the potential toxicity of nanoparticles inside the human body (Wagner and Zweck 2005, p. 99).

Tissue Engineering and Regenerative Medicine: Concerning tissue engineering (TE), the first proof-of-concept was demonstrated in 1979 by Eugene Bell, a professor emeritus of Biology at MIT, who successfully grew skin in his laboratory. About 20 years later, in 1998, tissue engineered skin was approved by the FDA. Today, tissue engineered skin is still one of the main products. Given the fact, that no method is

available in order to induce angiogenesis, or the formation of blood vessels, the creation of whole organs remains problematic (IAC 2002, p. 1-2)[17]. As a consequence, only tissue engineered skin, cartilage and - to a limited extent - bone products have been commercialised until now. Furthermore, it has to be stated that the advantages in comparison to traditional approaches are actually still modest (Bock et al. 2005, p. 21)[18].

Certainly, one of the main goals of tissue engineering-research is the substitution of the tissue damaged during a heart attack. Although this seems to be an active research area and tests on humans are about to start in the near future Silberglitt et al. state that it might still take 15 years to develop successful solutions (Silberglitt et al. 2006, p. 28, 173).

With regard to the commercial sector, Lysaght and Hazlehurst state that more than 80 firms worldwide were engaged in tissue engineering-research and development in 2004. However, the majority of their products is still in clinical trials (Lysaght and Hazlehurst 2004, p. 309). Regarding the future development of tissue engineering research Silberglitt et al. estimate that "the design and engineering of living tissue for implementation and replacement" will be feasible in 2020 (Silberglitt et al. 2006).

Another area of medical research that also aims at the 'substitution' of cells, tissues or even organs is xenotransplantation, the transfer of cells and organs from one species to another (for example from pigs to humans). The main problems of this kind of therapy are immunologic rejection processes and the risk of cross-species transmission of animal infectious agents (SACX 2004)[19]. Until now, the field is still in its infancy – especially with regard to the transplantation of whole organs. Nevertheless, less 'complex' transplants like pig and cow heart valves to humans are very successful. In the United States about 500 people suffering from liver failure, Parkinson's disease, Huntington's disease, diabetes, intractable pain from cancer, melanoma or burns received xenotransplants during clinical trials. Additionally, about 1,000 burn patients received skin cells which were grown on mouse feeder cells beforehand (SACX 2004). However, Silberglitt et al. presume in their report that the transplantation of animal organs into humans will only be feasible by 2020 (Silberglitt et al. 2006).

17 http://www.gwu.edu/~cistp/research/biotech3.pdf

18 ftp://ftp.jrc.es/pub/EURdoc/eur21838en.pdf

19 http://www.nelsonerlick.com/PDF/NIH %20Report %20on %20State %20of %20Xenotransplantation %202005.pdf

Like in the research field "Neuro/Brain enhancement", also in the field "Physical enhancement and Biomedicine", convergence of different scientific fields and methods is clearly visible and widely applied. The area of biomedicine already has a certain history of convergence since its recent breakthroughs and products, like inhaled insulin or therapies combining devices and medication, have only become possible by combining different scientific and engineering methods.

I.3.3 Synthetic Biology

Visions

Synthetic biology is a highly interdisciplinary field of research and involves the synthesis of complex, biologically based or inspired systems which display functions that do not exist in nature. The underlying idea is the systematic design, construction or engineering of biological systems or devices being able to process information, manipulate chemicals, fabricate materials and structures, produce energy, provide food, and maintain and enhance human health and our environment. This engineering perspective could be used at all levels of the hierarchy of biological structures, i.e. from individual molecules to whole cells, tissues and organisms. One aspect of synthetic biology which distinguishes it from conventional genetic engineering is a heavy emphasis on developing foundational technologies that make the engineering of biology easier and more reliable. Another aspect addressed by synthetic biology is the re-design of existing biological systems for useful purposes. The re-design of such systems may also help to reveal gaps in our current understanding of biology (European Commission 2005, 2005b, 2006).

Synthetic biology combines nano-, bio-, and information technology and is nowadays seen as an example of converging technologies. A recent report even states, that "synthetic biology may be the converging technology, *par excellence*. Delve into the biographies of synbio´s luminaries and you´ll find Ph.D.s in chemical, electrical and biochemical engineering, physics and pharmacology (and surprisingly few biologists)" (ETC Group 2007).

Indeed, experts from numerous different research areas, such as engineering and production, molecular biology, systems biology, organic chemistry, informatics, nanobiotechnology, etc. are working together, taking existing biological pieces, transforming them into micro-machines and creating artificial systems that mimic the properties of living systems (biomimetics). By this, scientists can discover the basic principles that rule living systems, manipulate these systems, and eventually find

treatments for many diseases. Today's synthetic biologists are looking to channel genetic engineering from a hit-or-miss field of discovery to the type of discipline used by engineers to build bridges, computers and buildings. This approach can translate into more specific anticancer therapies and anti-viral drugs, as well as more efficient drug delivery systems that will have a significant impact on the healthcare industry (European Commission 2005, 2005b; ETC Group 2007; Ball 2005; Chopra and Kamma 2006).

Expectations on synthetic biology and future applications are high and range widely across scientific and engineering disciplines, from medicine to energy generation. Rationally engineered organisms might be designed to make useful materials (such as biodegradable plastics) from cheap and renewable raw materials, or to convert feedstock to fuels such as hydrogen and methanol. This could make the chemicals industry more environmentally friendly and sustainable. The ability of biological systems to control the structure of materials at the molecular level could also provide access to materials with new and improved properties, or devices such as machines and electronic circuitry structured at ultra-small scales. Synthetic biology might even have an impact comparable to the IT-revolution.

State of the art

The term Synthetic Biology was initially coined in 1980 by Barbara Hobom for the genetic engineering of bacteria using recombinant DNA technology and is in principle synonymous with bioengineering. In 2000 the term was again introduced by Eric Kool and other speakers at the annual meeting of the American Chemical Society in San Francisco and used to describe the synthesis of unnatural organic molecules that function in living systems or more broadly the efforts to re-design life. More recently, an engineering community has given further meaning to the term synthetic biology as the assembly of natural biological parts in unnatural ways (Benner and Sismour 2005; Sismour and Benner 2005; Pengcheng Fu 2006).

An actual definition of synthetic biology has been given in a recent report: the design and construction of new biological parts, devices and systems that do not exist in the natural world and also the redesign of existing biological systems to perform specific tasks. Advances in nanoscale technologies – manipulation of matter at the level of atoms and molecules – are contributing to advances in synthetic biology (ETC Group 2007).

In the last years, activities in the field of synthetic biology according to the above definition have further increased. There is a small but growing number of researchers, institutes but also start-ups that are trying to make use of the complex chemical

reactions in biological systems like DNA, bacteria, viruses, etc. Still, work under the label of synthetic biology is mainly done in the US. However, a corresponding community is being setup in Europe as well.

Three international scientific conferences on synthetic biology in the years 2004 and 2006 in the US and 2007 in Europe (Zurich, Switzerland) as well as various conferences in related fields help in promoting the young and fast expanding field[20]. Moreover, competitions like the International Genetically Engineered Machine Competition (iGEM) initiated by the Massachusetts Institute of Technology (MIT), which is taking place annually since 2004, foster interest of young scientists in this field and also help in devising experiments in synthetic biology, such as biological oscillators, counters, bacterial switches, photosensitive bacterial biofilms etc. (Chopra and Kamma 2006)[21].

An example of efforts to develop ongoing collaboration is the human practices component of the Synthetic Biology Engineering Research Center (SynBERC)[22], a collaboration among a number of leading research universities funded by the National Science Foundation (NSF) in the US. In Europe, the initiation of a synthetic biology community has been supported particularly by the European Commission with the funding program New and Emerging Sciences and Technologies (NEST). Besides fundamental research, also accompanying research is founded as in the case of the multi-partner project SYNBIOSAFE, which has been setup in January 2007 and investigates the biosafety, biosecurity and ethical aspects of synthetic biology. SYNBIOSAFE aims to proactively stimulate a debate on these issues in Europe as well. A number of further scientific programs are cited on the SYNBIOSAFE website[23].

The outcomes of the scientific competitions, collaboration projects and in particular the research results of the scientists working in that field attest the large potential of biological systems to be used as building blocks in future biological devices. As compared to electronic building blocks, like resistors and capacitors in an electrical circuit, in synthetic biology independent biological components, so called "bioparts", are assembled together into devices to function in a predetermined manner. The goal is to build parts, devices, and systems that work inside living cells. In an engineering sense,

20 http://syntheticbiology.org

21 http://www.igem2007.com

22 http://www.synberc.org

23 http://www.synbiosafe.eu

the cells must act as "power supplies" and "chassis", providing materials, energy, and other basic resources that are needed for proper system function.

However, if compared to the serial production of chips in semiconductor industry a fabrication of such biological systems in series is still out of reach. One reason for this is, that the tools available for building with biological components still have to reach a level of standardisation and utility equal to that in other engineering fields. Another has to do with methods and mindsets in biology. Until now, mostly scientists in the field work together in closed teams on isolated applications for special problems.

As an attempt to better coordinate the activities in the field and to provide a library of biological components similar to the libraries available to chip designers, the MIT has setup the Registry of Standard Biological Parts. So far the registry contains more than 1.000 individual components, so called BioBricks, developed at the MIT, SynBERC, or within the iGEM, etc. The registry includes many parts analogous to electronics, such as inverters, switches, counters, amplifiers, and components that can receive input or output a display (Endy 2005; Bio FAB Group 2006, Bio-Fab-Gruppe 2007)[24].

Although, most of the components developed so far have been important as proof-of-concept on the basis of fundamental research, R&D in synthetic biology in today´s sense is still in its infancy. Currently, there is a number of concepts and ideas which yet have to be realised but some niche products are already commercially available, since there is a handful of companies and organisations applying engineering principles and tools to commercial biological manufacturing. Examples are the non-profit BioBricks Foundation (Cambridge, Massachusetts), which is promoting open tools, standards and parts for biological engineering; the Firm Blue Heron Biotechnology (Bothell, Washington), focusing on DNA synthesis; Amyris Biotechnologies (Emeryville, California), which is engineering metabolic pathways for drug production in microbes; Codon Devices (Cambridge, Massachusetts), which is building artificial biological devices; the Foundation for Applied Molecular Evolution (Gainesville, Florida), which is generating novel proteins and materials; and the Firm Synthetic Genomics (Rockville, Maryland), which is engineering microbes to produce fuels (Bio FAB Group 2006, Bio-Fab-Gruppe 2007).

The application areas and possible future products originating from work in synthetic biology are widespread and a comprehensive overview would be beyond the scope of this report. Here, we highlight some recent activities and promising application ideas in the field: *Biologically based Nanoelectronic Devices* for use in display and sensor

24 http://parts.mit.edu

technology, *Biological Computers* in computer technology, and *Nanorobots or Molecular Machines* (due to their size and autonomous functionality) in biomedicine.

Biologically based Nanoelectronic Devices

Professor Angela M. Belcher from the Massachusetts Institute of Technology (MIT) engineered a version of the M13 bacteriophage, a six nanometre wide and one micrometer long tubular virus, binding to inorganic nanocrystals by repeatedly selecting the virus particles best able to cling to the nanocrystals. After some months she evolved a virus that held a chunk of material steadfastly on one end, like a ball and chain. By dissolving the virus particles she could make them align themselves thickly like hairs all capped with nanocrystals. The viruses are packed so densely that they essentially form thin films, which can be stacked closer together than other means can quickly achieve. The self-assembled thin films are interesting for the use as thin, flexible displays for example (Ross 2006).

Further studies with M13 binding to metal particles such as cobalt oxide and gold yielded metal nanowires that could be used in high energy-density electrodes. By growing the virus on a film it was possible to make a thin, flexible metal oxide coating suitable for storing energy chemically. This allows for example for the incorporation into lightweight and dense thin-film batteries based on the lithium-ion technology, since the cobalt oxide stores lithium-ions. The US military funding this project is interested in the development of electronic devices for military use. Other applications could by ultra-thin MP3-Players. Also, the M13 could be bound to chemically sensitive receptors in order to detect biological dangerous or toxic substances (Ross 2006, Ki Tea Nam et al. 2006, Pil Yoo et al. 2006).

Some of Belchers demonstrations have been turned into commercial devices such as solar cells and light-emitting diodes. Cambrios Technologies (California)[25], co-founded by Belcher, is developing a touch sensitive display on a flexible plastic layer which can be coiled up if not needed. A usable product is expected to be commercially available within 2007.

Furthermore, Cambrios Technologies is looking at genetically engineered viruses to find proteins that will interact with metals and inorganic substances. The company is concentrating on a protein that could enable semiconductor makers to inexpensively insert an insulating layer of cobalt, a procedure that some manufacturers are testing and may use to make 32-nanometer chips by 2010. The company is also working on a

25 http://www.cambrios.com

protein that could help LCD manufacturers build transparent transistors into their screens.

Biological Computers

The idea of biological computing was initially developed by Leonard Adleman of the University of Southern California, who demonstrated a proof-of-concept use of DNA for massively parallel computation problems (Adleman 1998). A DNA computer or molecular computer is basically a collection of specially selected DNA strands whose combinations will result in the solution to some problem. Technology is currently available both to select the initial strands and to filter the final solution. The promise of DNA computing is massive parallelism by taking advantage of the many different molecules of DNA to try many different possibilities at once. This can be much faster than a conventional computer, for which massive parallelism would require large amounts of hardware, not simply more DNA (Adleman 1998; Kari 2001). At this stage, the establishment of a methodology for DNA computing dominates research efforts, but the technology holds great promise for application to various computational problems in the future. The potential of DNA computing will further expand through the application of the vast number of DNA associations derived from genome information. Apart from DNA molecules, other biological molecules capable of storing molecular information may also be used to derive molecular computer principles. Further understanding of the formation of protein molecule structures in the future could lead to a peptide computer or protein computer that would support more complex algorithms (NISTEP 2001; van Lieshout et al. 2006).

In 2004, Ehud Shapiro, Yaakov Benenson and others at the Weizmann Institute announced in the journal Nature that they had constructed a DNA computer. This was coupled with an input and output module and is capable of diagnosing cancerous activity within a cell, and then releasing an anti-cancer drug upon diagnosis (Shapiro and Gil 2007; Shapiro and Benenson 2007).

Nanorobots or Molecular Machines

Justin Gallivan and Shana Topp, scientists at the Emory University, have opened the door to powerful new opportunities in drug delivery, environmental cleanup and synthetic biology by making use of an innovative method to control the movement of Escherichia coli (E. coli) in a chemical environment. Gallivan and Topp successfully reprogrammed E. coli's chemo-navigational system to detect, follow and precisely localise to specific chemical signals. In doing so, the scientists exploited E. coli's natural chemotaxis, a microbe's ability to move toward specific chemicals in its environment. They equipped E. coli with a "riboswitch," a segment of RNA that

changes shape when bound to certain small target molecules, which can then turn genes on or off. Chemotactic bacteria navigate in chemical environments by coupling their information processing capabilities to powerful, tiny molecular motors that propel the cells forward. Researchers have long envisioned reprogramming bacteria so that microbes capable of synthesising an anti-cancer drug, for instance, can be used to target diseased cells while sparing healthy cells of side effects (Topp and Gallivan 2007)[26].

Risks, Challenges, and Future Developments

The vast potential of synthetic biology to play an essential role in human life also raises new questions for bioethics, -security, -safety as well as the health and energy sector, etc. There is also an ongoing discussion of so-called societal issues[27]. Philip Ball, consultant editor for Nature states: …"if ever there were a science guaranteed to cause public alarm and outrage, this is it. Compared with conventional biotechnology and genetic engineering, the risks involved in synthetic biology are far scarier" (ETC Group 2007).

Even experts in the field of synthetic biology itself are convinced, that: "The field is evolving at such a rate that even today`s synthetic biologists may not be able to recognise the tools, products and concepts in a decade." … "more precise and effective methods to identify risks, monitor activities, and communicate concerns among the synthetic biology community are required. It is thus suggested that a professional society should be formed and a code of ethics should be developed to ensure a positive future impact for synthetic biology" (Pencheng Fu 2006).

I.3.4 Human-Machine Interfaces

Visions

The main goal of the research field "Human-Machine Interfaces" is to develop interfaces which enable direct connections between the human brain and artificial limbs or other prostheses as well as between humans and computers or other machines. These interfaces should make it possible to control external devices by mere brain-activity or sensory-feedback.

26 http://biosingularity.wordpress.com/tag/bioengineering

27 http://openwetware.org

The envisioned interfaces will possibly enable a large set of applications – ranging from the restoration to the augmentation of human performance. Once it is feasible to manipulate the movement of an artificial limb and receive sensory-feedback like pressure and temperature from the prosthesis, the direct neural control of complex machines and the enhancement of sensory functions get within range. Hence, brain-machine interfaces which enable remote interaction with robots in the deep sea or outer space are envisioned as well as the connection of the human brain to sensors for UV-light and ultrasound or to external memory extensions (Robinett 2003, pp. 167-168; van Lieshout 2006).

In addition, Bibel states that "it will become possible, maybe as early as 2015 to link to nerves, to record and replay sensations". Thus, one will be able to feel 'real' handshakes in virtual environments. As a result, sex over networks, new interfaces for computer games and augmented reality visions will become reality on the basis of miniaturised chips, sensors and digital memories (Bibel 2004, p. 27).

Bainbridge estimates that broadband connections between the brain and machines which will "transform work in factories, control automobiles, ensure military superiority, and enable new sports, art forms and modes of interaction between people" will be technically feasible in 2030 (Bainbridge 2006, p. 339). Consequently, the feasibility of the enhancement of human sensory, motor and cognitive performance - based on Brain-Machine-Interfaces - is also forecasted to be feasible by then (Bainbridge 2006, p. 342). Additionally, Bainbridge expects that the enlargement of one's memory space by external storage devices will be possible by the year 2050 (Bainbridge 2006, p. 344).

State of the art

Non-Invasive interfaces

Current research focussing on non-invasive interfaces is based on the possibility to monitor cerebral activity via the electroencephalogram (EEG): About 100 electrodes are placed externally on the scalp in order to record electric signals. Under the condition that the electric activity of the brain reflects motor intentions like the preparation of hand movements, it is possible to convert these signals into simple 'commands' like the movement of a cursor on a computer-screen (Bolz et al. 2005, pp. 62-63). The feasibility of this approach was demonstrated by researchers at the German Fraunhofer-Institute for Computer Architecture and Software Technology who developed a "mental typewriter" based on the EEG-technique (van Lieshout et al. 2006, p. 46; Blankertz et

al. 2006)[28]. However, this approach has one main drawback: because the skull acts as an attenuator of the neuronal signals the resulting signal to noise ratio is quite low. As a result, training of patients and adjustment of the software takes considerable time (Stieglitz 2006, p. 100). Nevertheless, test-persons were able to type up to 30 signs per minute using this technique (Bolz et al. 2005, p. 63).

Another non-invasive method has recently been demonstrated by researchers from the Honda Research Institute and the ATR Computational Neurosciences Laboratories in Japan.[29] Based on real-time functional magnetic resonance imaging (fMRI) of brain activity it was possible to 'decode' the finger-movement of volunteers who were asked to play 'rock, paper, scissors' – such that a robot hand could mimic these movements. Although the resulting time-lag between the subject's and the robot's movement was about 7 seconds an accuracy of 85 % was achieved[30].

Invasive interfaces

In order to overcome the above mentioned drawback of the EEG-approach one could place an electrode or arrays of several electrodes directly onto the brain's surface (Electrocorticography) or even directly into the brain (Bolz et al. 2005, p. 64). According to Sandberg and Bostrom, multielectrode recordings from more than 300 electrodes permanently implanted in the brain are currently state of the art (Sandberg and Bostrom 2006, p. 37). Additionally, the so called Utah Electrode Array (UEA -consisting of 100 mm x 1.5 mm long electrodes assembled on a four-millimetre square large chip) was approved by the US Food and Drug Administration in 2004. As a result, the company that produces these arrays – Cyberkinetics in Foxborough, USA[31] - started clinical trials with paralysed patients in the same year (Stieglitz 2006; Bolz et al. 2005, p. 65; van Lieshout et al. 2006, p. 45).

Regarding the state of the art of research in this area the most popular example are the experiments conducted by the team of Miguel A. L. Nicolelis at Duke University (Durham, North Carolina, USA).[32] At their laboratory a monkey was able to control a robotic arm with "the power of thought" via electrodes which were implanted directly in its brain (Nicolelis and Srinivasan 2003)

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28 http://www.newscientisttech.com/article.ns?id=dn8826

29 http://www.cns.atr.jp/News/20060526honda_atrE.html

30 http://www.newscientist.com/article.ns?id=dn9237

31 http://www.bioen.utah.edu/cni/projects.html

32 http://www.nicolelislab.net

Recently, a team led by John Donoghue of Brown University – who is also founder, director and CSO of Cyberkinetics – conducted experiments with a quadriplegic patient who had an UEA-implant. They state that their solution is four-times faster than previous ones and that the patient adapted to the system within several minutes during the first experimental session. The patient could control a computer cursor and thereby was able to open e-mails or to control a television – even while conversing. He could also move objects with a robotic arm (Hochberg et al. 2006, pp. 164-169; Abbott 2006, pp. 125-126).

Additionally, researchers of Stanford University recently presented a new approach to optimise the 'information throughput' of brain-machine interfaces: In their experiments two monkeys had 100 electrode arrays implanted in their dorsal premotor cortex. In comparison to existing methods which are based on the calculation of continuous trajectories, the neural activity was translated into a prediction of the intended target and the cursor was immediately placed on that spot. This way a performance rate of up to 6.5 bits per second - corresponding to about 15 words per minute – could be realised (Santhanam et al. 2006, p. 195).

Given the fact that the monitoring of eight selected channels seems to be sufficient to generate 3D-trajectories of arm movement (Stieglitz 2006, p. 103), research on brain implants like the UEA might eventually enable paralysed patients to control their own muscles.

In addition to the implantation of electrode-arrays into the brain another technology which also enables the constant monitoring as well as the direct manipulation of brain activity is currently under development: The so called neurovascular approach originally aims at the diagnosis and the treatment of abnormal brain function and is based on the injection of a catheter-like device into the vascular system of the brain. This device consists of several nanowires as electrodes as well as converters and amplifiers. As the nanowires would fit into capillaries it would therefore be possible to monitor the activity of the neurons that are penetrated by the capillaries (Llinás and Makarov 2003, pp. 245-246). Concerning the technical status of the neurovascular approach it can be stated that the necessary "nanowires" have already been manufactured. The bio-compatibility of these polymer-electrodes is tested in rats at the moment (Szentpétery 2006).

Regarding current research on Brain-Machine Interfaces one could say that the majority of the experiments are one-directional. In most cases the sensory feedback is visual which could be considered insufficient for tasks like grasping objects or even more complex movements required in daily life. Hence, bi-directional interfacing would be

beneficial for envisioned applications like the control of paralysed limbs or complex prosthetic devices (Stieglitz 2006, p. 103). However, some approaches aiming in this direction could already be identified. For example, the possibility to remotely control the direction of movement of rats by electrically stimulating different brain regions could be considered as a 'proof-of-concept' for the delivery of 'feedback' via brain implants (Xu et al. 2004, pp. 57 et sqq.).

Other approaches - some of which have already been tested with humans - primarily focus on the connection of electrodes to nerve fibres in the extremities rather than on brain implants. One example for this is the hand-prosthesis with sensory feedback.[33] Electrodes are connected to intact nerve stumps in the patient's arm such that the patient can control the fingers of the prosthesis in order to grab a cup of coffee for example. In addition, sensors within the prosthesis generate feedback-stimuli which enable the patient to sense pressure and temperature.[34] Based on the fact that clinical trials have recently begun, the developers of this prosthesis estimated a time-to-market of about five years.

Further examples which have also to be mentioned in this context, are the (self-) experiments carried out by Kevin Warwick from the University of Reading.[35] In 2002, Warwick underwent a surgery during which one 100-electrode array was implanted into the median nerve fibres of his left arm. This implant enabled him to control an electric wheelchair and an artificial hand – even on large distances by transmitting the signals over the Internet. Furthermore, he successfully tested an 'extra-sensory' input device for ultrasound. Finally, Warwick and his wife - who then had a similar implant in her arm - demonstrated the first 'direct electronic communication between the nervous systems' of two humans (van Lieshout et al. 2006, p. 55).

Despite the advances in the research on Brain-Machine-Interfaces, it has to be stated that the human brain is so complex that it is still very difficult to understand even its basic functions (van Lieshout et al. 2006, p. 47). Hence, there remain a lot of problems to be solved like those listed in the "Roadmap of Neuro-IT Development" (Knoll and de Kamps 2004, pp. 19-20)[36]:

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33 http://www.spiegel.de/wissenschaft/mensch/0,1518,426451,00.html

34 http://www.ibmt.fhg.de/gruppe_I/neuroprosthetics_projects.html

35 http://www.kevinwarwick.com

36 http://www.neuro-it.net/NeuroIT/Roadmap/RoadmapVersions/Roadmapv1.3

- Identification of optimal brain regions for electrode implantation,
- Identification of the coding strategy used in these brain areas,
- Understanding the limitations to cortical plasticity,
- Longevity and durability of electrodes,
- Contact between electrodes and nerves,
- Miniaturisation of the hardware,
- Research on alternatives to implanted electrodes as well as
- Better and faster algorithms.

Regarding the future development of Brain-Machine-Interfaces Silberglitt et al. state that it is unlikely that implantable computer chips which could be linked directly to brain activity will already be available in 2020 (Silberglitt et al. 2006).

Certainly the above described ambitious visions can be achieved only by combining disciplines like computer science and information technology with cognitive science, psychology but also material science, biomechanics, engineering and the like.

I.3.5 Sensors

Visions

Fundamental to the area of sensor-related R&D activities is the general objective to develop sensors with improved characteristics (response times, sensitivity, specificity etc.) while reducing their size at the same time. Additionally, the costs per unit should permit the establishment of widespread sensor-networks or the integration of sensors into products like clothes and food packaging (Golledge 2003, p. 135).

Due to the fact that sensors can be used for a great variety of purposes, a set of very diverse visions is connected to the field of sensor development. A substantial part of the visions articulated in NBIC-related documents like the report by Roco and Bainbridge focuses on the detection of chemical and biological warfare agents or poisonous substances in general and also on information about the environment like temperature, UV levels and concentrations of pollutants (Roco and Bainbridge 2003; Pierce 2003, p. 118). Somewhat related to this is the idea to build systems which could identify hijackers and/or terrorists via "remote detection of heart rate, adrenaline on the skin, and perhaps other chemicals connected with the 'fight or flight' reaction" (Fainberg 2003, p. 345).

In addition, it is planned to construct adaptive technical devices that are able to react to changing conditions, e. g. aircrafts with adaptive shape control, on the basis of nanosensors and -actuators (Venneri et al. 2003, p. 315).

Another considerable part of the sensor-related goals and visions concentrates on medical purposes including issues like the constant monitoring of the own health condition or improved in vivo monitoring methods. More generally, it is envisioned to develop fast, ultra-sensitive sensors which make possible improved diagnostics and thus earlier and better treatment of diseases. Ideas reach from wireless sensor networks and wearable sensors for medical self-monitoring to biochips or lab on a chip systems and nano-sized imaging/ diagnostics agents (Connolly 2003, p. 185; van Lieshout et al. 2006, pp. 67 and 80; Bainbridge 2006).

State of the art

As already mentioned above, sensors can be used for a great variety of purposes, e. g. detection of pollutants, monitoring of the needs of plants and animals in agriculture, food safety purposes or even the detection and identification of terrorists. Accordingly, sensor research and development is a very heterogeneous field - ranging from research on 'electronic noses' which can detect pollutants, toxic substances and explosive vapours to the development of physical and mechanical sensors for the measurement of quantities like temperature, acceleration, viscosity and the like. Further examples are (bio-) chemical and medical sensors for the determination of pH-levels, blood pressure etc. and for the detection of DNA (IEEE 2004; VDI-VDE-IT 2005).

With respect to the CT debate, here the research field "sensors" is understood in terms of systems for sensing and monitoring human beings and their environment. Regardless of the diversity and heterogeneity of sensor applications, some general trends can be identified underlying current research efforts. Apart from the already mentioned goals like improvement of sensor sensitivity and constant miniaturisation towards micro- and nano-sized sensors the main trends are the establishment of sensor-networks, the creation of adaptive systems ('adaptronics') based on miniaturised sensors and actuators and the development of integrated sensors (e. g. into clothes) as well as implantable devices. Hence current R&D trends can be subdivided into three strands: "Wireless sensor networks", "Adaptive systems" and "Sensors for (bio-) medical purposes".

Wireless sensor networks

Given the variety of sensors along with the advances regarding the miniaturisation of sensor-components and wireless networks the potential applications of wireless sensor

networks are very diverse. Some examples frequently mentioned in the literature include environmental monitoring, acoustic detection, seismic detection, military surveillance and industrial sensing, e.g. monitoring the abrasion of machine tools and so on (Huang 2003; Chong and Kumar 2003, p. 1251; Hills 2001). Furthermore, wireless sensor networks were one of the technologies included in the "10 Emerging Technologies that will change the world"-list published by "Technology Review"-magazine in 2003 (Roush et al. 2003).

The basic elements of wireless sensor networks are the "network-nodes", sometimes referred to as "motes", each of which consist of one or more sensors, microprocessors, power supply, data storage devices and "microradios". Regarding the size of these nodes, wireless sensor nodes used for environmental monitoring which have the size of an ordinary film canister may serve as an example. Sensors like these were already used in order to study the microclimate (light, humidity, pressure, temperature) throughout the volume of Giant Redwood trees (Culler et al. 2004, p. 42).

Apart from the above mentioned fields of application there are also several military applications of wireless sensor networks like the identification and tracking of enemy troops and vehicles or the detection of bioweapons and electromagnetic noise. For example, an unmanned aerial vehicle (UAV) was used in order to distributed/spread about 40 credit card-sized sensors along a road at a test-site. These sensors automatically established a network such that passing vehicles were detected on the basis of magnetic signals. Based on the vehicles' magnetic signatures the kind of the vehicle, their speed and their direction could be estimated. The respective results were sent to the headquarters via the UAV[37]. A further example is the development of the so called "smart mine field" which is financed by DARPA. The "smart mine field" consists of mines which build up a wireless network. As a result, the mines are able to detect "disturbances in the network" caused e. g. by breaching attempts of enemies and react to these disturbances by physically redistributing themselves (Huang 2003)[38].

With regard to the present state of the technological development, it could be stated that current research on wireless sensor networks basically aims at balancing conflicting goals such as processing speed, data storage capacity, communication bandwidth and energy supply (Culler et al. 2004, p. 41). Hence, important goals are the improvement of energy efficiency, the development of more efficient communication procedures, the reduction of stored and transferred data as well as the development of re-

37 http://www.forbesimg.com/forbes/2002/1028/306_print.html

38 http://www.darpa.mil/ato/programs/SHM/proginfo.html

configuration strategies which allow dynamic changes of the sensor networks (Elson and Estrin 2004, pp. 7-8; Chong and Kumar 2003, pp. 1252-1253). Additionally, there are already a few companies like the U. S.-based firms Ember, Dust, Crossbow and Sensoria that try to commercialise the concept of wireless sensor networks. For example, Dust Inc. is building MEMS sensors (MEMS - Microelectromechanical Systems) that fit into a cubic millimetre (Chong and Kumar 2003, p. 1250).

Correspondingly, Silberglitt et al. state in their report that "real-time surveillance" on the basis of pervasive sensors will be "highly feasible" in 2020 (Silberglitt et al. 2006).

Adaptive systems

Besides the just described variety of sensor applications one additional area is the construction of adaptive systems based on the simultaneous integration of (nano-) sensors and actuators into different devices. For instance, one popular vision is an adaptive shape control for aircrafts based on nanosensors and -actuators (Venneri et al. 2003, p. 315).

More generally, adaptronics ("adaptation through electronics") aims at the development of structures whose properties can be actively controlled and changed such that they can be adapted in an optimal way to changing operational conditions (Teuffel 2004, p. 12)[39]. Accordingly, it is envisioned that active or rather adaptive structures incorporating function-integrated materials like shape-memory alloys, piezoelectric and electrostrictive ceramics, magnetostrictive alloys and electroactive polymers "suppress vibrations, reduce noise, control deformation and recognise component damage" (Thum et al. 2005, p. 10)[40]. For example, material composites with integrated piezoelectric fibres can measure mechanical vibrations in car body parts, engines and wheel suspensions. Given these measurements, counter-movements can be generated which reduce the propagation of vibration (Thum et al. 2005, p. 10; Teuffel 2004, pp. 16-19).

Research on adaptive systems and "smart materials" began in the mid-80s and one of the first applications was the shape retention of a parabolic antenna orbiting on a satellite. Nowadays several functional materials are available, the first applications exist, and it is clear how to handle building blocks for adaptive structures. Nevertheless, experts state that adaptronics has not yet reached a level of technological maturity that meets market requirements (Weiner and Niesing 2006, pp. 39-40).

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39 http://www.patrick-teuffel.com/download/Teuffel_Entwerfen_Adaptiver_Strukturen.pdf

40 http://www.fraunhofer.de/fhg/Images/Perspektiven_eng_signposts_tcm6-52640.pdf

Sensors for (bio-) medical purposes

This category comprises all sensors which are developed for medical purposes or for research activities in the bio/life sciences. Main elements of this category are wearable sensors, nanosensors for imaging- and diagnostics as well as biochips.

Wearable Sensors: Some heart rate sensors that are integrated in wristbands or chest-belts are already commercially available. Popular examples are the products for cardiovascular fitness-training.[41] Another example are wrist-worn activity sensors that could be used to measure the effects of shift work or even to predict performance by monitoring sleep (Nesthus et al. 2002, p. 29)[42]. Apart from that, current research focuses on textiles with integrated fibres which serve as physiological sensors and as miniaturised global positioning systems (Silberglitt et al. 2006, p. 176). For instance, researchers at Georgia Tech developed the Smart Shirt: Optical and conductive fibres are integrated into the garment such that heart rate, EKG, respiration as well as temperature can be monitored. In case of a medical problem such shirt could be used to alert the wearer or a physician automatically (Meoli and May-Plumlee 2002). However, some of the envisioned components are not technologically mature yet. Hence, it may take 5 to 10 years until textiles with the whole set of functions enter the market (MacKenzie et al. 2003, p. 32; Silberglitt et al. 2006, p. XIX).

Nanosensors for imaging and diagnostics: With regard to the area of medical sensor technology one could identify very diverse reasons which led to an increase of nano-related research activities. However, the main motives are basically the following (Wagner and Zweck 2005, pp. 81 and 94; de Groot and Loeffler 2006, pp. 31-33):

- In comparison to existing methods nano-based diagnostic techniques have improved characteristics with regard to specificity, signal-to-noise ratios, photostability and so on.
- Nano-sized detection systems enable the development of miniaturised biosensors as well as the mass production of these sensors. Therefore, tests which are nowadays performed in central facilities (e. g. clinical laboratories) can be conducted at point- of-care sites or even by the patients themselves.
- Nanotechnology bears the potential of novel analytical methods. For example, atomic force microscope (AFM)-based technologies have been developed to manufacture nano-sized biochips and to read them out. This AFM-based technology could be utilised for the detection of whole viruses in clinical samples.

41 http://www.polar.fi

42 http://hfetag.dtic.mil/docs-meet/meet47_min.pdf

Agents for In Vivo Imaging: Currently available in vivo imaging methods are mainly based on 'conventional techniques' like ultrasound imaging or magnetic resonance imaging (MRI). Nonetheless, the utilisation of novel contrast agents – which are often based on nanomaterials – improved the in vivo imaging of processes on the cellular and the molecular level ('molecular diagnostics')(Wagner and Zweck 2005, p. 68).

However, the technological maturity of the agents for the respective/particular imaging methods is quite heterogeneous:

Within the field of MRI molecular imaging contrast agents like the so called super paramagnetic iron oxide particles are currently in clinical trials or already commercially available (e. g. Resovist developed by Schering). Agents like these could be used for the analysis of liver tumours or for the detection of lymph node metastases (Wagner and Zweck 2005, p. 69).

Concerning optical methods the so-called Quantum Dots (QDs) seem to be quite promising: QDs have already been used to image cell signal transduction, cancer markers, and tumours in living animals. But nevertheless the high toxicity of the semi-conductor materials which are necessary for the production of QDs represent a significant barrier with regard to the application in medical settings (Wagner and Zweck 2005, p. 72; Baumgartner et al. 2003, p. 25).

Regarding ultrasound imaging and nuclear methods it can be stated that no system has gained approval yet - although some imaging agents are presently under development (Wagner and Zweck 2005, pp. 70-71)

Overall, it is envisioned that nano-based contrast agents will make it possible to monitor the therapeutic effects of drugs ('theranostics') in the near future. As a result, the efficacy of drugs could be proved much faster than today. Furthermore, advanced imaging agents will probably enable an earlier diagnosis of cancer or cardiovascular diseases such that the efficiency of therapies could be improved (Wagner and Zweck 2005, p. 80).

In Vitro Diagnostics: Like 'in vivo imaging' the field of in vitro diagnostics has also benefited from nano-related research. According to a report by the European Science Foundation (ESF), the "first methods to monitor in vitro the assembly of multicomponent biological complexes, protein trafficking and the interactions between single molecules" have already been developed with the help of nanoparticles (ESF 2005, p. 15). Examples of nanoparticles used for in vitro diagnostics are the already mentioned quantum dots and gold nanoparticles.

Quantum dots have successfully been tested and used in academic cell biology-research for a few years. Given this state of development, several US-based companies recently started research activities on QDs which could be used for life science applications. Nevertheless, all diagnostic systems based on QDs are still in an early stage (Wagner and Zweck 2005, p. 82).

Gold nanoparticles are mainly used in rapid tests, e. g. home pregnancy tests, which indicate the presence of substances in liquids through the change of a colour or comparable visual evidence. In addition to these established applications, current research focuses on improved methods for the detection of biomolecules. For example, recently developed gold nanoparticles with attached DNA probes could be used for the detection of target DNA-sequences. Furthermore, ultra sensitive diagnostic tests which are based on magnetic nanoparticles are presently under development. These tests aim at diseases like cancer, Alzheimer, coronary artery disease and mad cow disease (Wagner and Zweck 2005, p. 83-84).

More generally, one could state, that current in vitro diagnostics-research tries to develop methods which enable the detection of diseases before the first symptoms appear. This would make it possible to make medicine preventive rather than reactive.

Biochips: Another important area of research within the field of in-vitro diagnostics are nanotechnology-based biosensors like nanoarrays and biochips ('lab-on-a-chip' systems). It is hoped that these sensors will make diagnostic tests feasible that are significantly more precise and faster than established methods. For example, biochips that include electrical detection systems generate a signal when the target substance is detected – making optical analyses obsolete (Wagner and Zweck 2005, p. 85). Furthermore, lab-on-a-chip systems can be used for syntheses of nanoscale materials as well as for analyses.

According to Wagner and Zweck, many nanotechnology-based biosensors have been subject of scientific research during the last decade such that they could enter the market in the near future. Accordingly, companies like Siemens Medical Solutions or InvitroGen have already started significant development research activities.

It can be summarised that biosensors based on micro- and nanotechnology have already reached a high level of maturity such that some of these sensors might be commercialised soon (Wagner and Zweck 2005, p. 94). Accordingly, Silberglitt et al. estimate in their report that rapid bioassays which indicate the presence of specific biological substances will almost certainly be available in the year 2020 (Silberglitt et al. 2006). Furthermore, MacKenzie et al. expect that handheld bioassay devices for

detecting poisonous substances within air, water or food will enter the market within the next 5 to 10 years (MacKenzie et al. 2003, p. 21).

I.3.6 Computer-based modelling of the world

This research field has to be understood as the modelling, simulation or mapping of "the real world" with the help of computers. Visions and ideas in this field reach from the prediction of computer generated virtual environments perfectly reproducing reality based on developments in virtual and augmented reality (VR and AR) to deep insights into living nature by making use of Bioinformatics and Computational Biology, Neuroinformatics and Computational Neuroscience (Batterson and Pope 2002; Bainbridge 2006; Bibel et al. 2004). Extreme visions even see the possibility to download the human brain into new hardware (Robinett 2003).

Visions

Virtual and Augmented Reality

Virtual Reality (VR) research aims at the development of technologies, which enable the interaction of a user with a computer-simulated environment. Until now, these virtual environments are in most cases visual experiences shown on different kinds of displays. In comparison to that, Augmented Reality (AR) approaches focus on the combination of "the real world" and computer generated graphics. The majority of the ideas and visions connected to VR technologies concentrate on training or rather experimental learning applications like flight simulators and "online laboratories" due to the fact that it is expected that VR will allow immersive high-fidelity simulations (Batterson and Pope 2002, pp. 419-420). With regard to AR, it can be stated that the visions in this area of research are more diverse as they also include military applications (e. g. projection of sniper locations and hidden infrastructure on a visor) and non-military applications like the visualisation of assembly steps or even "X-ray vision" (e. g. display of the position of hidden pipes and wires) during maintenance and construction activities as well as entertainment products (Etter 2003, p. 330).

Bioinformatics and Computational Biology

Bioinformatics derives knowledge from computer analysis of biological data. It refers to the development and advancement of algorithms, computational and statistical techniques, or theories to solve formal and practical problems posed by or inspired from the management and analysis of biological data. The data to be handled may be information stored in the genetic code, but also experimental results from various

sources, patient statistics, and scientific literature. Research in bioinformatics includes method development for storage, retrieval, and analysis of the data. Bioinformatics is a rapidly developing branch of biology and is highly interdisciplinary, using techniques and concepts from informatics, statistics, mathematics, chemistry, biochemistry, physics, and linguistics. It has many practical applications in different areas of biology and medicine.

The National Center for Biotechnology Information (NCBI 2001) gives the following definition of bioinformatics: "Bioinformatics is the field of science in which biology, computer science, and information technology merge into a single discipline. There are three important sub-disciplines within bioinformatics: the development of new algorithms and statistics with which to assess relationships among members of large data sets; the analysis and interpretation of various types of data including nucleotide and amino acid sequences, protein domains, and protein structures; and the development and implementation of tools that enable efficient access and management of different types of information."

Computational biology refers to hypothesis-driven investigation of a specific biological problem using computers, carried out with experimental and simulated data, with the primary goal of discovery and the advancement of biological knowledge. Computational biology goes beyond data analysis to look at the broader interface between computing and biology. A possible definition is: the development and application of data-analytical and theoretical methods, mathematical modelling and computational simulation techniques to the study of biological, behavioural, and social systems (http://www.geocities.com/bioinformaticsweb/index.html).

Bibel claims, that Bioinformatics is one of the areas "where convergent technology is successfully evolving" (Bibel 2004, p. 40) and include

- identifying candidate disease genes with high performance computing;
- RNA expression profiles and data mining of sugar cane response to low temperature;
- web-based tools for mining the NCI database for anticancer drug discovery;
- data mining the protein databank.

According to Johnson (Johnson 2003, p. 208) three activities are crucial for the success of bioinformatics and computational biology:

- the use of analytic methods to enable the presentation of biological information in digital fashion,

- the leveraging of massive digital storage systems and database technologies to manage the information obtained, and
- the application of digital analytic tools to identify patterns in the data that clarify causes and effects in biological systems, augmented by visualisation tools that enable the human mind to rapidly grasp these patterns.

Neuroinformatics and Computational Neuroscience

Besides the steady improvement of computing power the idea of building local or distributed computer clusters to create supercomputers has made it possible to address more and more complex or computing intensive problems in physics, chemistry, biology and neuroscience. Areas within computational science, such as bioinformatics or computational biology deal with the management and analysis of biological data and the application of computational approaches to biological phenomena. They are connected with the vision that one day it might be possible to develop a multiscalar simulation of biology ranging from the molecular to the societal level. At the moment, one can observe a movement of this field of research from structural analyses of genes and proteins towards analyses of interactions between genes and proteins, which will lead in the long run towards research activities on cellular and ontogenetic functions (Shoji and Mogi 2002). Yet, it is still not possible for example, to simulate the kinetics of protein folding (ebd.).

Neuroinformatics and computational neuroscience deal with the management and analysis of neuroscience data and the application of computational methods to study the function and mechanisms of the nervous system.

The Blue Brain project

New computational methods that combine experimental research with modern simulation techniques could enable researchers to improve understanding of information processes. Although neuroscientific research made considerable progress it remains unclear, how information processes work biologically. Can human information processing be understood by the patterns of neural signalling (Manifest)?

For this reasons research in this field on the interface between neuroscience and informatics is not only concerned with an understanding of the human brain but also with the simulation of processes in the brain in such ways that a machine can imitate "thinking". If it becomes possible to model the firing process of cortical structures, then,

it is assumed, human conscience itself and its basic rules ought to be understood (Pain 2006: 1)[43].

In this area Henry Markram, biologist and co leader of the "institute for mind and brain" (BMI) at the Swiss Federal University (ETH) plays a key role. Together with IBM he started to work at the "Blue Brain Project" using the computing power of Blue Gene (Markram 2006: 153). The aim of his project is to enable scientists to simulate processes in the human brain applying modern methods of computational models of the human brain (Stieler/Herden 2006: 34). Until 2015 Markram wants to calculate these processes with the help of the increasing calculative performance of computers. His main hypothesis: Human intelligence cannot be understood by "linear intelligence models" (Markram 2006:158). Rather, quantum leaps in the biological structure of intelligence have to be considered in detail, which means that different combinations of the same biological building blocks produce qualitatively different genes, proteins, acids and so on. Different combinations of ion channels for example are responsible for electrical diversity in the nervous system (Hodgkin/Huxley 1952). Rall showed that nonlinear conductancies in dendrites predominate. The integration of this line of research began by "incorporating Hodkin-Huxley-type active properties in Rall-type neuronal models to simulate realistic microcircuits carrying out realistic neural operations such as feedback and lateral inhibition" (Markram 2006:154).

According to Markram, this means that we cannot reduce complexity of human intelligence to some basic rules like –if/then conditions that still dominate the artificial intelligence, since they still follow the linear scheme; rather we have to look at the combination and interaction processes of the processes itself and to build machines that are able to process information in a nonlinear manner. Increasing computational capacity makes the simulation of multi neuron models possible that derive their empirical data from experimental research of the electrical processes inside and between neurons. Markram derives his data from brain slices of a rat. Electrical impulses inside the preserved brain slice are measured and calculated by continuously improving computer programs.

This allows Markram to simulate the processes of a neocortical column that consists of at least 3600 neurons which is the minimum size of a so called microcircuit (Stieler/Herden 2006:5). Theoretical basis for this selection of a rather small part of the human brain is the finding that the human brain consists of a finite number of universal neural networks that developed through a process of continuous reproduction. This

43 http://sciencecareers.sciencemag.org/career_development/previous_issues/articles/2006 (Zugriff: 4.04.2007)

approach allows to model brain interaction on the basis of continuous production of action potentials. The simulation model investigates how all these neural firings work together. Markram stimulates neurons with the help of a laser and looks in which ways other neurons react to this stimulation. Then he tries to synchronise the outputs of the measurements with the simulations (Stieler/Herden 2006: 36). For Calculating Neuronal interaction Markram uses NEURON, a program developed to model expansions of action potentials. The project shall result in a program made to graphically show which consequences stimulations of special brain region will have.

Markram choose to take columns from the sensory regions because connections with thalamus allow external validation. Data from the in vivo experiments are placed in a database where biological properties of these neurons (ion channel behaviour) can be used to find out the specific electrical properties of each neuron. Signals between two neurons are calculated on the basis of these programs. With the existing computer power it seems to be possible to simulate up to 100 000 complex neurons. However, it is the aim of the Blue Brain project one day to simulate the whole brain, that for humans consist of more than 1 million cortical column more than 10 trillion complex neurons) The project can only reach this aim under the presupposition that computing power is continuously improving. Markram expects a qualitatively new step in the processing speed due to energy problems of existing computers. Using this computing capacity the aim to find something about human seems to be supposable.

But there is also strong criticism to this kind of work. Especially neuro physicist Klaus Pawelzik doubts that data collection and extensive description is enough to understand the human brain. A consistent theory of neural firing is still missing (Technology Review 2005: 2). According to a list of well known other researchers the main problem of modern neuroscience that we know a lot about localisations of functions in the human brain by improved methods of neuro imaging and also the micro level of the small cells are well described in terms of models. Nevertheless, until today there is no theoretical model to predict interaction of a group of cells. According to Pawelzik, Markram cannot solve this problem by simulations (Technology Review 2005:2).

On the other hand it remains still unclear whether the cortical column that serves Markram as basic unit for investigations and simulations of the brain plays such a central role. Hypotheses concerning its function are not proofed until today. The cortical column, Pawelzik criticizes, is not understood at all – 85% of the processes can not be explained by existing theories (Technology Review 2005:3). Furthermore it is not enough to understand just one column in order to extra polarise the results to the whole brain. This method won't work since in non linear systems, whole systems have different properties than their parts. But the main problem is that the so called liquid

state machine may be able to reproduce neural responds to external stimulations but will not provide explanations for the invariance and extreme stability of human/mammalian information processing. Taken together all we know about human reasoning it seems to be unlikely that information processing doesn't collapse. But this is not the case. There are some evolutional mechanisms that make this system stable (Technology Review 2005:6). According to Pawelzik, these mechanisms are the object of research in the future (Technology Review 2005:6).

Virtual and Augmented Reality

Central to the concept of Virtual Reality (VR) is that the user interacts with a computer-simulated environment. Yet, most VR-applications are limited to audiovisual experiences. Systems that incorporate tactile information, 'force feedback', are still rare. Well-known examples of VR-applications are flight simulators used for the education of pilots which consist of 1:1 models of cockpits that can be moved hydraulically and have computer monitors instead of windows. Further examples are wide-screen displays and the so-called CAVEs (Cave Automatic Virtual Environments) that are nowadays used for purposes like digital prototyping in the automotive industry, design reviews in architecture or studies of ergonomics.

Apart form more general goals like the improvement of the display resolution, one important issue is the creation of the virtual environments. For example, concepts like computer integrated manufacturing (CIM) or the so-called digital factory approach necessitate detailed 3D-CAD-data of production facilities and the product-components. With regard to this, two courses of action can be named: First, the different modelling software solutions are continuously optimised in order to facilitate/improve the creation of 3D-models.[44] Second, (laser-) scanning devices for the 'digitalisation' of existing buildings and facilities are developed which allow a relatively quick generation of 3D-CAD-data of e. g. production plants.[45]

A concept that is closely related to VR is Augmented Reality (AR). Compared to VR, AR refers to the combination of the 'normal view of the real world' and additional computer generated graphics. An everyday life example for this technology can be found in sports television: the combination of 'normal' soccer broadcasts combined with overlaid computer generated graphics showing the distance between a free kick position and the goal or the indication of offside-positions is one of the already available applications

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44 http://www.autodesk.com; http://www.delmia.com; http://www.tecnomatix.com; http://www.dassault.com

45 http://www.iqvolution-services.com; http://www.zf-laser.com

of Augmented Reality. According to Milgram and Kishino (Milgram and Kishino 1994)[46], there is a 'mixed reality-continuum' reaching from the real environment to completely virtual environments. Within this continuum several AR-approaches exist: monitor-based video displays showing overlaid images, head-mounted displays (HMDs) with see-through capability and completely graphic display environments like CAVEs plus different variations of these examples.

Current AR-related research mainly focuses two aspects: the improvement of display technology with regard to characteristics like resolution, brightness, field of view, contrast (plus: size, weight and costs) and the exact tracking of the position and orientation of the user's head in order to enable correct matching of the overlaid graphics with the view of the surrounding world (Feiner 2002; Azuma et al. 2001, p. 35).

Regarding the future development of VR technology Bainbridge estimates that computer-generated virtual environments that are "so well tailored to the human senses that people will be as comfortable in virtual reality as in reality itself" will be technologically feasible in the year 2030 (Bainbridge 2006, p. 342).

With regard to computer simulations a general trend towards the connection or rather integration of former "stand-alone simulations" can be observed. Given the fact, that the majority of the available simulation software solutions is focused on specific problems/tasks their "explanatory power" is consequently more or less limited. Hence, it is hoped that approaches like "multi-scale modelling" or "parallel and distributed simulation" which are based on the integration of different models or rather simulations enable analyses of problems which could not be examined on the basis of single stand-alone software solutions (Fujimoto 2000).

Biological Information Processing

Biological systems appear to be much more energy efficient and robust than even the most advanced engineered systems. Even with today's chip technology it remains a challenge to build computer systems containing anything like the number of neurons and connections that make up the brain. Also simple elements such as providing power, and removing heat, are major issues in artificial systems. And yet through evolution the brain has developed efficient solutions to these challenges. Studying the brain can provide IT researchers also with new ways of thinking about the architecture of computers, both at the level of the individual components and as networks of connected processing units. Evolution has arrived at complex systems that can adapt to

46 http://vered.rose.utoronto.ca/people/paul_dir/IEICE94/ieice.html

their environment and, within limits, to damage. Biologically Inspired Complex Adaptive Systems (BICAS) look to nature for lessons (van Lieshout et al. 2006, p. 70).

Computer researchers can borrow from nature also in other ways. For example, concepts drawn from embryology and Darwinian evolution may lead to the development of devices that 'grow' and 'evolve' from simple basic components. The immune system of animals could also provide ideas for enhancing the security of computer networks. Biology could also provide ideas for the development of animal-like autonomous 'agents' that can learn their functions. These could be devices - hardware (robots) or software - that can be entrusted with specific tasks. Such systems could find applications in diverse areas as space exploration, telecommunications and computer games. While agents already exist, they lack the ability of living systems to work together and to respond to their environment. The falling costs of bandwidth and computing have enabled the growth of large-scale computing networks. For example, we are now moving towards decentralised systems in large computing networks (e. g. Grid Computing), in telecommunications, and defence. A challenge for network engineers is to develop networks that can configure themselves and adapt to changing demands and environments. Such systems should also have the ability to discover, diagnose impending failures, or outside threats, and to act to prevent any disruptions. Nature has tackled just this challenge in the development and evolution of the neural systems of humans and animals. (Morris et al. 2005; van Lieshout et al. 2006, p. 70).

I.3.7 Pattern recognition

Although pattern recognition is a broad area which generally aims at the identification and interpretation of signals and patterns by computers, the majority of the visions in the field are related to automatic speech recognition and the detection of visual patterns, called image recognition. Many pattern recognition techniques are based on databases, which include a certain amount of knowledge (rules, pattern samples) and a software component, which compares incoming data streams with the system's knowledge base. The main goal is to develop software solutions, which are able to recognise speech and images despite certain discrepancies between the received/incoming information and the stored datasets.

Visions

The visionary application ideas are quite diverse and encompass applications like natural language driven vehicles, automatic translation systems, surveillance systems to identify people and detect their activities, and many others.

For instance, *speech recognition* in combination with a text display is thought to serve as a "sensory substitution" for deaf people (Loomis 2003, p. 214). Other examples include voice-controlled guidance systems on the basis of GPS- and GIS-systems or natural language-driven mobiles (Wolbring and Golledge 2003, p. 272; Golledge 2003, p. 135). Furthermore, speech recognition systems play an important role within the Ambient Intelligence concept as they are supposed to ease "the use of technological tools for the casual user" (Bibel 2004, p. 30). An additional field of research that is closely related to speech recognition is the development of voice stress analysis systems, which might help to identify potential hijackers and/or terrorists in the future (Fainberg 2003, p. 345).

Regarding *image recognition* or rather computer vision systems, one central area of research is the recognition of faces and the classification of facial expressions like joy, anger and fear (van Lieshout et al. 2006, pp. 39-40; Fainberg 2003, p. 345).

Another approach to pattern recognition is the simulation of human perception mechanisms. The most prominent example of this strand of research is the so-called "connectionism" which hopes to simulate human perceptive (and also intellectual) abilities using artificial neural networks (Bishop 2001).

State of the art

Some examples for successful *speech recognition* based products already exist, like medical reporting systems or "reading tutors" for illiterate people. However, current software programs still miss 2 to 5% of all words.

Regarding *image recognition*, certain applications like industrial quality control systems on the basis of computer vision for the inspection of manufactured goods or systems for forest surveys and crop/land-use identification are well established. Yet, more complex tasks like the computer-based assessment of the aesthetic appearance of products or the recognition of faces remain difficult (van Lieshout et al. 2006). With respect to surveillance systems based on pattern recognition a variety of biometric methods like fingerprint, iris, face and voice recognition have already been established on the market.

An up to date example is the biometric passport (ePass) which has been introduced within the last two years in many states world wide. The ePass is a combined paper and electronic identity document using biometric data stored on a Radio Frequency IDentification tag (RFID-tag) to authenticate the citizenship of travellers. For authentication, the stored reference data like the digital photo is compared with actually acquired data. A key factor for the quality of biometric systems is the probability of errors. Thus, error rates like the false acceptance rate (FAR), the false rejection rate (FRR), etc. have to be optimized. Given the fact, that the existing mathematical modelling approaches and algorithms for pattern recognition still seem to be open for improvement some researchers conclude that multi-modal recognition methods might be a solution (Zhao et al. 2003).

For the development of successful pattern recognition systems, scientists and engineers from disciplines like linguistics, computer science, software programming and hardware development have to work together.

I.3.8 Robots and intelligent systems

This topic embraces visions and approaches that are predominantly influenced by concepts like Artificial Intelligence (AI), Sociable Technologies (ST) or Ubiquitous Computing (UbiComp).

The ability to rend machines closer to man, by creating artificial systems that interact in an ever-increasing human-like manner and blend into man's surroundings is a fundamental aspect of the goal behind the NBIC initiative. In addition, the invention of novel computing paradigms and systems for improved processing of human and biological data is a key to understand the converging technologies agenda. In this sense, natural machines and information processing in the NBIC cover a wide range of development areas. From biomimetic and bio-inspired processing systems to improve software and hardware robots that interact with man, such as swarming internet agents or cooperative factory robots, to new computing paradigms based on molecular, neurophysiologic and nanotechnology advances, the goal in natural systems is to absorb the advances of enabling NBIC technologies to generate more permeable and natural machines and information processing systems. The field thus draws heavily from advances in the cognitive sciences and molecular biology, as well as from hardware support and innovative solutions brought about by the nanotechnology revolution (Duch et al. 2005).

Visions

Central to the concept of AI is the idea that one day it might be possible to develop intelligent devices that "mimic cognitive processes of the brain and the mind", are functionally equivalent to the human brain and which could be used for a wide range of purposes and functions like sensing, perceiving, memorising, controlling, acting and learning (Moravec 1999, Kurzweil 2005, van Lieshout 2005) (http://www.efmn.info). Concerning research activities on AI and intelligent systems it has to be stated that very different disciplines are engaged in this field. Examples include software engineering, robotics, industrial automation and operations research (Albus et al. 2003, p. 282-284). Moreover, Albus et al. expect that intelligent systems will increase the economic productivity and will therefore create wealth (Albus et al. 2003, p. 287). In addition, he states that "intelligent machines have begun to exhibit a capacity for self-reproduction" such that an "exponential increase in the intelligent machine population" will occur because "machines can evolve from one generation to the next much faster and more efficiently than biological organisms" (Albus et al. 2003, p. 289).

The concept of ST aims at the development of intelligent devices and robots which offer people new forms of social relationships, e. g. medical care robots which could provide personal contacts or household robots that are able to support aging people. With respect to SSH, the ideas and visions within this category can be divided into three different subsets in principle:

(1) The first subset includes technical solutions which ease the establishment of social relationships or rather "augment our ability to be aware of with whom we may wish to connect" like the 'social sensing' devices described by Burger (Burger 2003). The central component of these 'social sensing' systems are *Personal Information Managers (PIMs)* that store their owner's personal profile and which can be connected via wireless ad-hoc-networks - operating just in the immediate vicinity (Burger 2003, p. 164-165).

(2) The second subset entails so-called *sociable robot technologies*, which offer people "new forms of social relationships" (Turkle 2003, p. 150). First examples of this kind of technology are toys like Furbies and Tamagotchies or Sony's AIBO. More visionary approaches, which also belong into this group focus on the development of medical care robots, which could provide 'personal contact', or household robots that are able to support aging people (HLEG 2004a; Bibel 2004, p. 30).

(3) The third group are the so-called *socially intelligent agents*: software programs which could "serve as intelligent tutors, nannies, personal shoppers, etc." and which could also be used to simulate the behaviour of groups of humans in order to analyse

"the efficacy, feasibility, and impact of new technologies, legislation, change in policies, or organisational strategy" (Carley 2003, p. 309).

The idea of UbiComp is that everyone will be surrounded by computing and networking technologies embedded in his or her respective environments. Hence, Ubiquitous Computing will make it possible to access needed information everywhere and will also provide different forms of distributed services and support (Bainbridge 2006). One important component of the concept is smart objects for everyday use (IST Advisory Group 2003) (http://www.cordis.lu/ist/istag-reports.html). Bainbridge (Bainbridge 2006, p. 341) assumes that the communication and information systems, which will build the basis for UbiComp environments, will have the capability to learn and adapt automatically - "based upon an understanding of human behaviour". Moreover, he predicts that "self-configuring, self-protecting, and self-monitoring" communication networks, which are necessary for ubiquitous computing, will soon be available (Bainbridge 2006, p. 341). According to Sandberg and Bostrom ambient intelligence and smart objects also have the potential to improve the effective cognitive power and memory of humans (http://www.enhanceproject.org). Consequently, the resulting "effectiveness of administrators in business, education, and government" will lead to the emergence of new organisational structures and management principles (Bainbridge 2006, p. 338).

A very imaginative vision mentioned by Albus et al. (Albus et al. 2003) in the first of the NBIC report is a system called *"The Personal Communicator"*. According to them this system would remove barriers to communication caused by physical disabilities, language differences, geographic distance, and variations in knowledge. Furthermore, it is stated that "The Communicator" will improve group decision-making processes, and will therefore enhance the effectiveness of cooperation in schools, corporations, and government agencies. Other areas of focus are in enhancing group creativity, cognitive engineering and learning as well as developments related to the networked society. A similar system has been described in the "Scenarios for Ambient Intelligence in 2010" where Dimitrios' "Digital Me" is embedded in his clothes, handles his communication intelligently by selecting the appropriate action for each call (IST Advisory Group 2001).

State of the art

Concerning the current state of AI, one could conclude that AI research has, even though it still lags behind its self-imposed expectations, already achieved certain advances in different sub-domains like expert systems, autonomous robots (e. g. "Stanley" the robot which won the DARPA Grand Challenge in 2005) and in AI theory

and algorithms, such as search and planning algorithms, machine learning or pattern recognition algorithms. Furthermore, AI has developed from a separate part of computer science to an area of research which influences other disciplines like the cognitive sciences, psychology, robotics etc. and vice versa (Waltz 2006; van Lieshout et al. 2006).

Regarding sociable technologies, first examples of this kind of technology were toys like Tamagotchies or Sony's AIBO. Moreover, certain positive effects caused by the use of such robots in hospitals and in homes for the elderly have already been demonstrated in different experiments, such as mood improvement by interaction with a seal robot (Wada et al. 2004). Nonetheless, it is emphasised that a deeper theoretical understanding of emotions is necessary for the advancement of emotional robotics.

Until now, the ubiquitous computing concept is still in its infancy but nevertheless some functioning proof-of-concept systems exist. They include for example different kinds of wearable computers, e. g. fabrics that incorporate electrical circuits and which could be used for health monitoring or the "smart environment" of the so called Gator Tech Smart House which is based on connected sensors, actuators and computers (Helal et al. 2005).

Nanorobots: The idea to develop nanorobots autonomously carring out activities, e.g. healing operations in the human body, has been controversly discussed in the last years (Drexler 1992; Smalley 2001, Whitesides 2001). The field of nanorobotics can be generally devided into two main areas (Weir et al. 2005, Freitas 2005, 2006):

1. The first area deals with the design, simulation, control, and coordination of robots with nanoscale dimensions. Much of the research conducted in this area remains highly theoretical at the present, primarily because of the difficulties in fabricating such devices. Although artificial nanorobots do not yet exist, nature´s biological nanorobotic systems do exist and provide evidence that they are at least possible. As a result, nanorobots have for the most part been explored in the biological context of nanomedicine (Requicha et al. 2003; Weir et al. 2005).

Examples have been discussed in section 4.2 in connection with drug delivery systems and in section 4.3 in connection with synthetically engineered biological robots. In terms of a top-down approach todays tiniest mechanically engineered robots have sizes in the range of a millimetre, with micrometer scale components. This kind of technology is called microrobotics.

2. The second area deals with the manipulation and/or assembly of nanoscale components with macroscale instruments or robots. Due to the advances in

nanotechnology and its rapidly growing number of potential applications, it is evident that practical technologies for the manipulation and assembly of nanoscale structures into functional nanodevices need to be developed. Nanomanipulation and nanoassembly may also play a crucial role in the development of artificial nanorobots themselves. Manipulation at the nanoscale is still in its infancy and the physical and chemical phenomena at this scale are not completely understood (Weir et al. 2005).

In the field "Robots and intelligent software/ devices", scientific disciplines like computer science, cognitive science, psychology and hardware development have to come together and combine methods in order to achieve substantial progress.

I.3.9 Summary

The analysis of the visions and the state of the art research in the overlapping fields of Nano, Bio, Info and Cogno has shown that convergence is indeed under way in various fields. Central impulses for convergence are coming from the field of neuroscience. Multi- and interdisciplinary research seems to be the key to future scientific break-throughs.

However, the analysis has shown that visions and the state of the art research are considerably distant from each other in all eight fields. The gap is especially wide in the two human enhancement fields, namely the Brain/Neuro enhancement and the Physical enhancement and Biomedicin areas. In the remaining six fields, the distance is not as wide and visions can turn into concrete applications in the not too distant future.

On reason for this finding might be that in the enhancement fields, there are more disciplines, methods and approaches to be combined than in the other fields. Here, the need for interdisciplinary research and technology development co-operation is very high combined with extremely high costs of failures.

In neuroscience and biomedicine there is a strong focus on medical applications and improvements of treatments and therapies. Clinical research and the focus on healing the human mind and body are not so present in the other six areas, maybe with the exception of synthetic biology. Current research priorities in these three fields do not mention enhancement as an explicit goal.

Looking at all eight fields, no pattern or "lead convergence" could be found. Convergence is needed almost everywhere encompassing very different sub-fields and sub-discipilnes. However, it became obvious that most impulses currently come from the three areas of neuro enhancement, physical enhancement and synthetic biology.

It has to be emphasised that a consequent application of the convergence concept may lead to very different results – even to results not thought of today. For example new understandings of the brain may have effects on the development of new IT-applications. Duch et al. (2005) list the following potential applications that might evolve from advances in brain research, supposed the convergence approach is followed consequently: "From biomimetic and bioinspired processing systems to improve software and hardware, robots that interact with man, such as swarming internet agents or cooperative factory bots, to new computing paradigms based on molecular, neurophysiologic and nanotechnology advances, such as quantum or DNA-computing systems, the new understanding could be used". But it also works the other way round, namely new computer hardware and data processing techniques could lead to a better understanding of the brain. Another example is the bioinformatics´ quest to model the evolution by simulating cell behaviour. From their simulations, an explanation model for cancer could result - or a method to build better computers (Böttcher 2006). These examples show that the outcome of the convergence development is open and does not necessarily have to lead to mental or physical enhancements as some proponents may suggest.

Also, in some areas such as artificial intelligence, which we subsumed in the field of "Robots and intelligent systems", convergence does not describe a new approach but includes an existing research field, which could profit from a more rigid trans- and interdisciplinary approach as suggested by CT.

All the technology areas mentioned above, including "Neuro/Brain Enhancement" have SSH-consequences of their own. In a next step, these will be worked out in detail. As a result, it will be possible to ask SSH-relevant questions on the basis of a better understanding of the developments in the different technology fields.

Part II: Social Sciences and Humanities Aspects

II.1 SSH aspects from the main CT documents

II.1.1 Transferring methods and concepts

A pre-eminent topic in the CT-discussion is the claim to transfer methods, approaches, concepts and insights from one science area to another in order to enable future scientific breakthroughs. The notion of multi- or interdisciplinary is at the bottom of the CT debate and has many facets. Whereas the concept of an overall convergence of Nano, Bio, Info and Cogno remains relatively vague, there are at least two areas where the transfer of methods and concepts is of special importance according to the central documents of the debate: The *transfer from the natural sciences to the social sciences* and the *transfer from biology or nature to information technology and engineering.* The second of the above areas relates to concepts like biomimetics, bioinspired nanoelectronics, biological language modelling, intelligent systems, software describing human functions, etc.

Visions

Transfer from natural sciences to social sciences

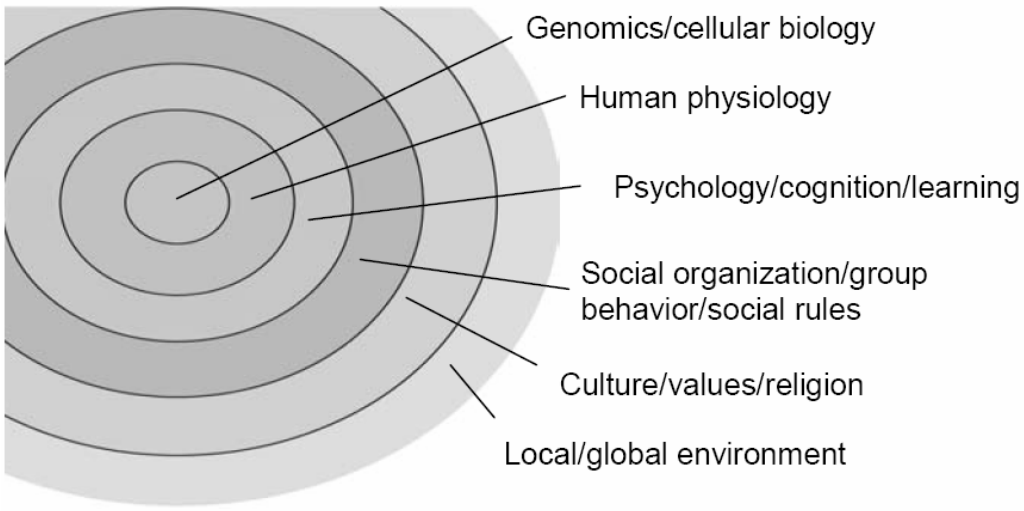
Concerning the transfer of concepts from the natural sciences to the social sciences the CT debate mainly follows the argument put forward by E. O. Wilson in his book "Consilience: The Unity of Knowledge" (Wilson 1998). Wilson, who is an evolutionary biologist, is convinced that the "world is orderly and can be explained by a small number of natural laws" (Wilson 1998, p. 4). This conviction also comprises human and social behaviour and implies that all social and cultural developments will be transparent and predictable as soon as the natural laws are understood. Wilson writes: "All tangible phenomena, from the birth of stars to the workings of social institutions, are based on material processes that are ultimately reducible, however long and tortuous the sequences, to the laws of physics. In support of this idea is the conclusion of biologists that humanity is kin to all other life forms by common descent" (Wilson 1998, p. 266). Bainbridge and Rocco explicitly refer to Wilson's book in the third NBIC-conference documentation (Bainbridge and Roco 2006, p. 1).

The CT debate is characterised by this movement from the smallest parts of matter to highly complex social and cultural phenomena. For example, Banfield draws the line from the molecular to the global scale (Banfield 2003, p. 294). In the documentation of the first US-conference on CT, Gerold Yonas and Jessica Glicken Turnley suggest to

connect natural science and behavioural science using an approach they call "Socio-Tech: The predictive Science of societal behaviour". An illustration of this idea is given in fig. 6.

The natural sciences and the social sciences should be brought together in order to describe and predict individual behaviour and the behaviour of whole societies. Beginning with advances in genomics and human physiology Yonas and Glicken Turnley are convinced that this understanding can be transferred and used for a full description and possible prediction of human behaviour and the development of societies (see fig. 7). "Socio-Tech" is defined as "the accumulation, manipulation, and integration of data from the life, social, and behavioural sciences, using tools and approaches provided by science and technology" (Yonas and Glicken Turnley 2003, p. 159). It draws on the convergence of information from the life sciences, the behavioural sciences including psychology and the study of cognition, and the social sciences. According to the authors, its data gathering and analysis approaches come from these fields and are significantly augmented by new tools from fields such as nanotechnology, engineering, and the information sciences. Also, agent-based simulations, models incorporating genetic algorithms, evolutionary computing techniques, and brain-machine interfaces provide new ways to gather data and to analyse the results.

Figure 6: From genomics to social behaviour: Integrated studies of human behaviour and "Socio-Tech"



Source: Yonas and Glicken Turnley 2003

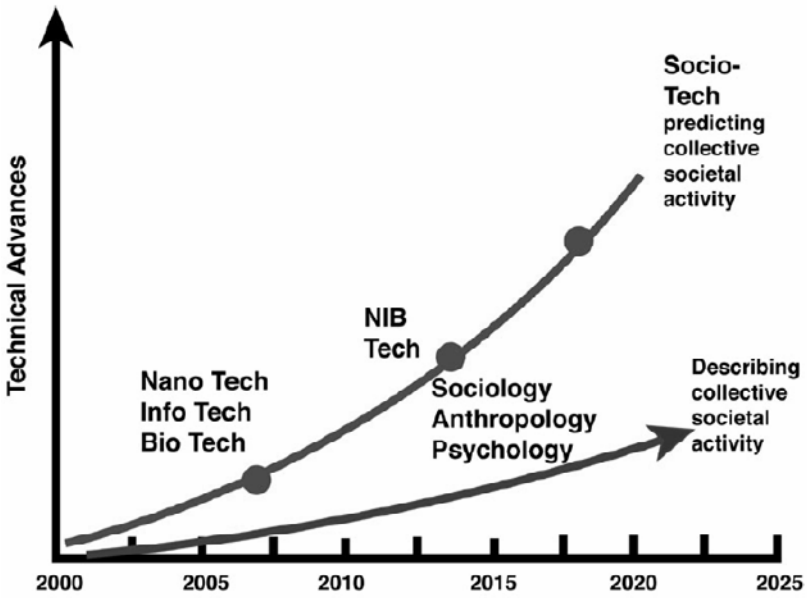
Taken together this knowledge will raise the ability to predict behaviours. It will also "allow us to interdict undesirable behaviours before they cause significant harm to

others and to support and encourage behaviours leading to greater social goods" (Yonas and Glicken Turnley 2003, p. 160).

Also, the daily decision making process is expected to be of better quality with a deeper understanding of the biochemical basis of life: "Average persons as well as policy makers will have a vastly improved awareness of cognitive, social, and biological forces operating their lives, enabling far better adjustment, creativity, and daily decision making" (Bainbridge 2006, p. 338).

Wilson as well as the proponents of CT criticise that the social sciences have not been able to develop methods that explain and predict human behaviour. The reason for this is that the "sciences of human culture have lacked a formal paradigm and a rigorous methodology." (Strong and Bainbridge 2003, p. 318; Wilson 1998, p. 181ff). Thus, a fresh approach to culture, based on biological metaphors and information science methodologies should be developed. One important reason - apart from providing valid explanations and predictions on social developments - is that this should provide cognitive science with a host of new research tools (Strong and Bainbridge 2003, p. 318). This remark illustrates that the transferring of concepts should work in both directions, whereas a prevalence of natural sciences concepts is always assumed.

Figure 7: Socio-Tech: Understanding and predicting society on the basis of technical advances



Source: Yonas and Glicken Turnley 2003

A fundamental concept when transferring natural science approaches to cultural phenomena is the "meme". Analogous to the gene in biological genetics, the "meme" is an element of culture that can be the basis of cultural variation, selection, and evolution. Strong and Bainbridge explain: "Because memes are passed from one individual to another through learning, characteristics an individual acquires during life can be transmitted to descendents. This is one of the reasons why memes may evolve more rapidly than genes" (Strong and Bainbridge 2003, p. 318). For decades, various anthropologists have considered whether or not there is a cultural equivalent of the human genome underlying differences of belief and behaviour across groups or whether cultural context differentially expresses elements from a common repertoire available to all humans. One way to approach the issue, Strong and Bainbridge suggest, is to study culture with methodologies similar to those of bioinformatics.

The preoccupation with memes as cultural equivalents to genes results in a vision which is expressed by Bainbridge in the third NBIC-documentation: "A fresh scientific approach to culture, based on concepts from evolutionary biology and classification techniques from information science, will greatly facilitate humanities scholarship, marketing of music or literature, and artistic innovation" (Bainbridge 2006, p. 342).

In his summary of CT-visions, Bainbridge lists the following future achievements in the context of systems transfer:

- Science will achieve great progress in understanding and predicting the behaviour of complex systems, at multiple scales and between the system and the environment (Bainbridge 2006, p. 343).
- A predictive science of the behaviour of societies will allow us to understand a wide range of socially disruptive events and allow us to put mitigating or preventive strategies in place before the harm occurs (Bainbridge 2006, p. 344).
- Extremely efficient research tools will extract previously unknown biological information from DNA, protein, cells, tissues, organisms, and society as a whole (Bainbridge 2006, p. 341).
- Average persons as well as policy makers will have a vastly improved awareness of cognitive, social, and biological forces operating their lives, enabling far better adjustment, creativity, and daily decision making (Bainbridge 2006, p. 338.

Transfer from biology or nature to information technology and engineering

Another example for transferring concepts from one science area to another is *Biomimetics*. According to Bibel et al., biomimetics is a new field in engineering basically copying good ideas from nature to engineering. Subfields of biomimetics are organic

computing and Artificial Intelligence. Also, genetic algorithms are mentioned in this area. The transfer of methods and principles from nature into artificial surroundings like software programming is the typical method followed here (Bibel et al. 2004, p. 42).

Bionics is another area in which the transfer idea is implemented. Here, the following fields are affected: robotics, locomotion (walking and the coordination of movements as a systemic problem), sensors and neural coordination (optical and sonic sensors), motions, neural networks, coupling of biomolecules with technical systems, e. g. electronic measuring, anthropological and biomedical technology (implants), use of microwaves, evolution and optimisation, simulations to improve systems (Nachtigall 2002).

Especially the translations of concepts from biology to information science and vice versa are expected to have important impacts in the future: From biomimetic and bioinspired processing systems to improve software and hardware robots that interact with man, such as swarming internet agents or cooperative factory bots, to new computing paradigms based on molecular, neurophysiologic and nanotechnology advances, such as quantum or DNA-computing systems, the new understanding could be used (Duch et al. 2005; Kolo et al. 1999).

Furthermore, nanotechnology is expected to profit from biology concepts: Porod et al. report of creating machine architectures with inspirations from biology, calling it "biologically inspired nanoelectronics" and Venneri et al. create a vision for a nanobiologically inspired aircraft (Porod et al. 2004; Venneri et al. 2003).

A paradigmatic example for concept transfer and the movement from the micro to macro level is an area called "Biological language modelling" which is preoccupied with the convergence of computational linguistics and biological chemistry. In their article in the first NBIC-conference documentation, Klein-Seetharaman and Reddy explain the vision in their field:

> *"The deeper analogy between biology and language suggests that successful sequence function mapping is fundamentally similar to the ability to retrieve, summarize, and translate in computational linguistics. (...) The strength of the analogy between biology and language lies in its ability to bridge across scales - atomic, nanostructural, microstructural, and macroscopic - enabling profit from the convergence of other disciplines. (...) It will be possible to examine what combinations of amino acid sequences give a meaningful sentence, and we will be able to predict where spelling mistakes are inconsequential for function and where they will cause dysfunction. At the most fundamental level, we aim at de-*

ciphering the rules for a general biological language, i. e., discovering what aspects are common to all sequences. This will enhance our fundamental understanding of biological molecules, in particular how proteins fold and function. At the second level, we ask how differences in concentrations, interactions, and activities of proteins result in formation and function of different cell-types and ultimately of organs within the same individual. This will allow us to understand the principles underlying cell differentiation. The third level will be to analyse the variations among individuals of the same species, the single nucleotide polymorphisms. We can then understand how differences in characteristics, such as intelligence or predisposition for diseases, are encoded in the genome sequence. Finally, the most general level will be to analyse differences in the biological languages of different organisms, with varying degree of relatedness. Ideally, all life on earth will be catalogued" (Klein-Seetharam and Reddy 2003, p. 428ff).

State of the art

Concerning the transfer of concepts, methods, approaches and insights from one discipline to another, it can be said that this is not exclusive to the CT debate. To the contrary, in almost all scientific areas the transfer of concepts and the integration of insights from different disciplines is happening every day. Science-Technology researchers are generally expecting important future breakthroughs from these approaches rather than from advancements within certain disciplines (Schwartz 2003, p. 161ff). Although there might be still too few incentives for researchers to engage in interdisciplinary projects (see chapter 4.9), claims for interdisciplinarity are anything but new.

What makes it difficult to define the state of the art in transferring concepts is the fact that within NBIC, there are so many and very heterogeneously structured areas involved. Some of them were mentioned above.

Transfer from natural sciences to social sciences

With the focus on the Social Sciences and Humanities (SSH), one approach surely needs further attention: The transfer of natural science concepts to the realm of social science as it was described in the paragraph on "Socio-Tech". Whereas E. O. Wilson carefully tries to avoid the notion of biological determinism of human behaviour, the CT debate, at least in the US-context, does not. As such, this discussion resembles socio-technical and social engineering approaches of the 1960s and 1970s, which were developed in a climate of planning euphoria and the conviction, that national economies and the society as a whole can be universally controlled by applying scientific planning tools (Brinckmann 2006). Today, these approaches are clearly in a minority position.

Mainstream Science & Technology Studies as well as Political Science would strongly argue against the notion of planning and prediction of society as a whole on the basis of biological or evolutionary principles, respectively. They would also point to the discussion in the context of transferring biological and information technology concepts to society under the headline of "cybernetics" which was brought up by the American mathematician Norbert Wiener in the 1940s and 1950s (Bluma 2004).

However, the verve and omnipresence of the biological determinism and reductionism of the CT debate might prompt the social sciences to systematically deal with the concept anew. A common line of argument is that - even if it is right that the arts and the humanities will ultimately yield to reduction - it is not imaginable how humans with their limitations can actually do it. It is held that in the social sciences like sociology, economics, and psychology, for example, and even more so in the world of the humanities and the arts, reduction is so complex that an attempt to reduce them to simple natural laws and reassemble them to the complex phenomena they are is "comparable (in reverse order) of putting Humpty Dumpty back together again" (Littrell 2004). Dennis Littrell in his book review of Wilson's Consilience gives the following analogy:

> *"I cannot even imagine how reductionism could help us to understand a poem. There is a dictum among poets that "nothing defines the poem but the poem itself." No amount of reduction will allow us to understand what makes the poem tick. This is because the poem is an experience, a human emotional, intellectual, sensual experience dependent upon not only the literal meaning of the words, but on their connotations, their sounds, their rhythm, their relationships to one another, their syntax, their allusions, their history, their use by other poets, etc., and also what the individual reader of the poem brings to the experience. Reduce the poem and you do not have an understanding of the poem. At best you have an essay on the poem, at worst something alien to the aesthetic experience. In essence, I should say that the problem with consilience is that our experience is not reducible"* (Littrell 2004).

Interviews have shown that consilience of science is not a serious topic in the social sciences and humanities. The consilience of science for social and humanities are supposed to become a grand narrative of scientific progress that is usually rejected by Science-Technology-Studies scholars.

Also, the concept of the "meme", as an analogy to the gene determining biological development, has been criticised by social scientists. Although some researchers hold that the "meme" is a concept that could revolutionise the social sciences as the discov-

ery of DNA and the genetic code did for biology, most social scientists are convinced that the concept cannot produce a general theory of social evolution mainly because requirements for Darwinian evolution do not map into the social domain (Aunger 2000).

Opponents of the meme-concept hold that there is a lot we do not understand about human behaviour in groups, its relation to learning, cognition, or culture. There is no general theory that situates cognition or culture in an evolutionary framework, Darwinian or otherwise. It is also hard to conduct science in the social domain, not just because it is difficult to conduct experiments, but also because it is difficult to be objective. Even Strong and Bainbridge admit that "prior efforts to 'darwinise' culture have a long and ignoble history" (Strong and Bainbridge 2003, p. 318). The question naturally arises as to what is new that might allow progress this time around?

Transfer from biology or nature to information technology and engineering

Concerning the "fresh approach" to culture on the basis of biological metaphors and information science methodologies which is called for in the CT debate in the U.S., it has to be noted that this approach goes beyond a mere operationalisation of social science concepts for natural sciences in order to get new impulses in the brain research as is the case in the field of social neuroscience (Halligan et al. 2005)[47]. It has a much more general pretence, claiming that the social science might only overcome its alleged non-scientificness, when opening to concepts of the natural sciences.

II.1.2 Organising interdisciplinarity for convergence

Visions

Because convergence can only occur when different disciplines and technology areas come together and combine methods, approaches, concepts and insights, interdisciplinarity and the ways to realise it stand at the centre of the idea. Put as a vision, consequent interdisciplinary research will revolutionise the work of scientists: "This revolution will occur when scientists begin to import approaches pioneered in other sciences, for example genetic research employing principles from natural language processing and cultural research employing principles from genetics" (Bainbridge 2006, p. 339).

In addition to transferring approaches from other sciences, a new services science discipline will emerge, based on knowledge and skills at the intersection of existing disci-

47 http://www.esrcsocietytoday.ac.uk

plines, "with the ability to increase the probability of success of complex service industries and to improve organisational management in general (Bainbridge 2006, p. 341).

This goes together with the hope that in the future, individuals and teams will be able to communicate and cooperate profitably across traditional barriers of culture, language, distance, and professional specialisation. According to Bainbridge, this will result in a significant increase in effectiveness of groups, organisations, and multinational partnerships (Bainbridge 2006, p. 338).

The question is, how can this be done and what instruments can be used to enable interdisciplinary thought and research. The main authors of the CT debate have two answers to this question: The first refers to artificial brain enhancements, which is expected to be feasible in the future and the second states that interdisciplinary research requires interdisciplinary education including the respective incentive structures.

Typical for the first possibility is Bainbridge's statement that in the future, using brain enhancement technology, "people from all backgrounds and of all ranges of ability will learn valuable new knowledge and skills more reliably and quickly, whether in school, on the job, or at home" (Bainbridge 2006, p. 338). Networks with new connecting equipment will also contribute to this leap in education and learning (Strong and Bainbridge 2003; Bainbridge 2004; Horn 1998).

The second answer to the interdisciplinarity challenge is associated with the idea of consilience of all sciences, whether natural science or social science, mentioned in the section above. Bainbridge summarizes this vision as a statement, claiming that in the future, formal education "will be transformed by a unified but diverse curriculum based on a comprehensive, hierarchical intellectual paradigm for understanding the architecture of the physical world from the nanoscale through the cosmic scale" (Bainbridge 2006, p. 339).

Concerning concrete measures or changes in established incentive structures which could foster interdisciplinarity in research and technology development, nothing specific or new is being proposed by the CT-supporters. Their suggestions are rather general as a typical statement by Duch et al. shows (Duch et al. 2005):

> *"How to train new engineers and scientists to use these new concepts as basis for a new way of thinking, hence creating their own new culture? On one side, to be a convergent engineer means to have a wide multidisciplinary background covering the most important fields and technologies associated to the NBIC disciplines. However, because of the wide range of domains involved, it is impossi-*

ble to be expert in all of them. That is, very skilled specialists will still be needed for each specialised domain and/or focused applications. However, those specialists should be very open-minded and ready to integrate and/or to work in close relations with many other technologies that can be very different from their own working topics. Anyway, what is clear is that to fully develop NBIC technologies and their applications, a lot of training courses are needed in order to change the technology culture, e. g. the way of thinking of the new engineers. Moreover, to have a real impact on the NBIC world of tomorrow, we should start as soon as possible with training programs focused on the appropriate subjects."

To illustrate the scope of interdisciplinary research needed to develop NBIC-applications, a statement by Duch et al. shall be given here:

"As with the other components of the NBIC initiative, the revolution spurred by genetics can only bridge the gap from lab to man when mutually enabled by converging technologies. Based firmly on the revolution of bioinformatics, genetics can target issues like gene therapy and the genetic engineering of crops, but it can also advance converging technologies by deciphering crucial aspects of the development of brains or unveiling the complex molecular interactions in biological nanoactuators, transducers and enzymatic reactions. Its future interplay with nanotechnologies for the creation of pervasive systems, drug delivery modules or cellular interfaces, and with information technologies for the creation of models of cells and minimal genomes, may hold the key to dramatic advances. In addition, genetic engineering may also bring about the possibility to engineer man in a novel and profound way, allowing the directed growing of natural prostheses and more natural brain-machine interfaces. In this effort, genetic and somatic engineering will be assisted heavily by bioinformatics, but also by advances the micro-mechanisation and automation of molecular biology techniques, and by new advances in nanotechnology that allow the development of enhanced cell interfaces and drug-delivery systems" (Duch et al. 2005).

Although they strongly focus on genetics it becomes clear how comprehensive the idea of convergence is seen and what the scope of expectations is.

Another area, where the need for interdisciplinary research becomes obvious is the field of prosthetic limbs and organs (see also section 4.2). In order to produce fully adapted muscular stimulators and prosthetic limbs and organs it is necessary to bring together various technological fields. Duch et al. 2005 list the following technologies: "from newly developed nanotechniques for improving biocompatibility in implants, point-delivering neurotransmitters or habilitating nano-sized sensors, to huge

technological development in information processing techniques and micromechanics to create neural prosthesis or a powerful boost in the understanding of brain machinery and function" (Duch et al. 2005).

Convergence ideally works both ways, mutually enabling the advance of basic research and the improvement of health at the same time. It is expected that converging technologies will allow to monitor and manipulate many parallel events in real time and will provide powerful tools not only for basic neuroscience research but also for the diagnosis and treatment of many neurological diseases: "This integration will provide the basis for the design and development of large arrays of devices, multiplexed functional systems and platforms able to safely interact with a complex biological structure such as the nervous system" (Duch et al. 2005).

State of the Art

Interdisciplinary research is surely a field which draws a lot of attention and study by its own and which is an important subject outside the NBIC debate as well (Thompson-Klein 2003; Stehr and Weingart 2000). But it has a special meaning within the NBIC debate which actually describes a research area not yet existing and claiming to bring unity to science and revolutionary scientific results at the same time.

As a blueprint for dealing with interdisciplinary aspects, nanoscience and -technology could be used, where similar problems and issues arise (Gorman 2003a, 2003b). However, it has been stated that in the nano field, what is happening is not interdisciplinary research but multidisciplinarity, meaning the loose involvement of different knowledge areas and the absence of established systematic connections, overlaps or integrations (Schummer 2004a, p. 11). In fact it has been criticised that "there is currently a naive rush from the badly understood interdisciplinarity towards new visions of super-interdisciplinarity to be centred on nanotechnology" (Schummer 2004a, p. 9). "Super-interdisciplinarity" refers to the unity of all sciences or at least to a series of scientific disciplines. According to Schummer, neither in nanotechnology nor in the field of converging technologies interdisciplinary programs have been established yet.

It is also an open question in how far the claim for interdisciplinarity is in many cases just lip-service considering that fact that scientific merits are still to be achieved within established disciplines within canonised subjects. Schummer has noted that most researchers continue to stay within their theoretical frameworks thus making interdisciplinarity a hollow promise (Schummer 2004c).

Interviews with researchers in the US and Germany brought some insights in how interdisciplinarity is perceived in research practice. Among scientists there was consensus towards the fact that interdisciplinary research in the way it is governmentally funded is not always improving scientific output. In many scientific fields interdisciplinarity is only the product of external settings: In these fields there are no internal scientific processes that foster interdisciplinary research. Some of the scientists argued, it would not improve individual career opportunities.

On a more general level, it is considered an open question whether breakthroughs will arise from interdisciplinary projects or from advances within certain disciplines (Schwartz 2003). Here, CT-supporters tend towards the first option, practically ruling out the possibility that critical progress can also be achieved within established disciplines. However, no concrete instruments or specific approaches to realise inter-disciplinarity are suggested by the proponents of NBIC convergence. It is stated on a general level that researchers should work together across institutionalised scientific borders, but no systematic attempts have been made so far to suggest how this can been done specifically with respect to convergence.

Interestingly it seems that the question, how interdisciplinarity actually can be supported and managed in the field of convergence is getting more attention as the concept of convergence is getting more concrete: Whereas the contributions to the 2002-NBIC-conference documentation seem to deal with multi-, trans- and interdisciplinarity on a rather general level, in the following conference documentations the discussion is more detailed and concrete examples of successful combinations of knowledge bases from different disciplines are reported from. The same is true for the European documents on converging technologies. Especially the report of the Special Interest Group 2 "Cultural Configuration of Convergence" discusses the difference between a "nothing new"-approach and a "break through boundaries"-approach (Staman et al. 2004, p.2ff).

It is suggested to analyse this observation more deeply in the course of the CONTECS-project since a special form of interdisciplinarity seems to remain even as other claims of the NBIC-debate may vanish.

II.1.3 Education

Visions

The category "Education" within the CT debate consists of two thematic fields. The first deals with methods to increase the learning capacity by stimulating and enhancing

brain activities and memory. This field forms a continuum ranging from mental training as a "natural" cognitive strategy to the artificial acquisition of knowledge and skills by uploading information into the brain using human-machine interfaces. The second field deals with concepts of understanding, and holds that an improved understanding of the biophysical principles of the human brain and the exploration of the sources of human creativity can lead to expanded learning methods and better creative abilities. Although there are overlappings with the fields "Neuro/Brain Enhancement" and "Transferring methods and concepts" as well as "Organising interdisciplinarity for convergence" which are described separately above, education is a separate area which deserves special attention because convergence might have far-reaching consequences for future methods and systems of education.

The first strand within convergence and education starts with training-based performance enhancement of the brain as opposed to biological modifications and considers "natural" cognitive strategies like mental training and memory arts as techniques to improve cognitive performance. The area of technologically enhanced memory and learning starts with the vision to develop sophisticated monitoring of brain activity and biofeedback techniques which will be applied in order to facilitate education "by assessing students´ learning strengths and improving their attention" (Bainbridge 2006, p. 341). It continues with the vision of "Individualised Education" which will be based on the identification of genotypic or phenotypic mitigations and thus enabling appropriate education (Batterson and Pope 2003, p. 418).

Also, virtual environments and virtual reality systems which will be available with new qualities as the convergence of neurosciences and information technology proceeds, can be used for education and training (Roco and Montemagno 2004, p. 8f). This will also improve long distance education and trainings thus having the potential to change the whole educational system.

On a biophysical level, so-called neuroceuticals will increasingly be available to enhance an individual's learning capacity as well as concentration spans and reduce the need for sleep (see section 4.1). Complementary, non-pharmaceutical methods for altering, e. g. enhancing brain functions will increasingly being developed. Methods like Transcranal Magnetic Stimulation (TMS) or vagus nerve stimulation and deep-brain stimulation will also be used to enhance learning capacities in the view of some CT-supporters.

The enhancement-idea culminates in the vision of "Instant learning", as Robinett puts it: If the structure of knowledge were fully understood, and if we controlled the "hardware and software environment" of the mind, (…) just get the knowledge file and

run the integrate procedure. Get a Ph.D. in Mathematics with "one click" (Robinett 2003, p. 169).

The second thematic field within "Education" concerns the understanding of brain processes that are responsible for an individual's successful and effective learning. Understanding the connection between brain functions and education is the prerequisite for adequate new teaching methods and as such the research in the understanding forms a separate field in the CT debate (Bransford et al. 1999).

One of the aspects of this venue is to understand visual language, the communication by pictures, icons, and diagrams: "With support from developments in information technology, visual language has the potential for increasing human "bandwidth," the capacity to take in, comprehend, and more efficiently synthesise large amounts of new information. It has this capacity on the individual, group, and organisational levels. As this convergence occurs, visual language will enhance our ability to communicate, teach and work in fields such as nanotechnology and biotechnology (Horn 2003, p. 141). In other words, a deep understanding of visual language will permit more effective interdisciplinary communication, more complex thinking, and breakthroughs in education (Bainbridge 2006, p. 341).

Also, with an advanced understanding of the wellsprings of human creativity and with the help of new tools to enhance brain activities, engineers, architects, and designers will, according to Bainbridge experience, tremendously expanded creative abilities (Bainbridge 2006, p. 338).

The projected unification of the sciences will also have profound effects on the educational system: It is foreseen that the new knowledge base and new cross-disciplinary concepts will radically transform the system of science and engineering education. However, it is left open what this transformation actually looks like (Bainbridge 2006, p. 342).

State of the Art

Concerning the state of the art of research and technology development in the first area - where natural, pharmaceutical, and artificial brain enhancements are considered - detailed information was given in the sections 4.1, 4.3, and 4.4.

Concerning the second area which deals with the understanding of learning processes, some hints can be found in section 4.8. However, it can be said that in the field of education - as important as it may be within the CT debate - only very few concrete

results can be found. One of the few exceptions is "neuroeducation", a research field which deals with the neural basis of learning and which tries to derive concrete teaching techniques from this understanding. It has to be stated that some of the new approaches to education claiming to be based on neuroscience are not new. They get a new legitimation by neuroscience results and can claim concepts like emotionally stimulated learning or individually experiencing instead of learning by mere lectures (learning by doing) to be scientifically supported and validated.

Another exception is the detailed outline of a new, CT-based curriculum for K-12, developed by James Batterson and Alan T. Pope in the documentation of the first US-NBIC conference. They line out their vision in a seven-page article claiming that converging technologies hold the promise to revolutionise the teaching in grades K-12 and beyond. They describe how the interplay of the different technologies could affect the current curricula in terms of content, processes and tools for K-12 education (Batterson and Pope 2003).

II.1.4 Governance

In a wider, non-technical sense, convergence has consequences for the economy, politics and law, and society as a whole. These aspects of the CT-discussion are summarised in this section although some aspects are directly related to technical advances which are discussed in more detail in the technical sections of this paper.

Under the headline "Governance" all aspects in the CT debate can be brought together which deal with the economic, legal and political frameworks affecting the development of NBIC - and being affected by the NBIC-development at the same time. Here, it is not possible to speak of "visions" but rather of "approaches" of the different sub-systems of society towards the technical development.

In the business sector, it is expected that new organisational forms need to emerge in order to develop and manage NBIC-products (Carley 2003). Adaptive enterprises as a function of NBIC products are being discussed as well as business management as agent of change for the integration of converging technologies (Spohrer and Engelbart 2003). Balancing Opportunities and Investments for NBIC are also a subject (Williams and Kuekes 2003) and it is being discussed how multisector and multidisciplinary regional clustering of organisations can be achieved (Roco and Montemagno 2004, p. 9).

On a more general level, the impact of converging technologies on the future of business and economy has been discussed from the beginning of the debate, for example by Canton in the documentation of the first US-conference (Canton 2003). Canton

claims that the convergence of NBIC technologies has the potential to realign the nation's economy (Canton 2003, p. 74). But also in the European debate on convergence, economic effects and measures to put Europe at the top of the research and development have been discussed (Ringland et al. 2004).

Concerning necessary adaptations of the legal system, only very general suggestions have been made so far. Sonia Miller, an attorney-at-law in New York, reports that she was the only attorney present at the second NBIC-conference in Washington, D.C. In her contribution to the conference documentation she dwells on rather general aspects like the traditional role of law in society, methods of instruction in the education of lawyers and the need of the legal system to follow scientific research closely. In her contribution to the next NBIC conference (Miller 2004), she discusses how science confronts the law with new methods of scientific evidence. As an example she uses a novel forensic application of psychophysiological research called "Brain fingerprinting". Brain fingerprinting is a real-time assessment of an individual's response to a stimuli in the form of words or pictures presented on a computer monitor, with electrical brain responses measured non-invasively through a patented headband equipped with sensors. The aim is to find out whether or not the brain of a suspect contains information about the crime-scene, only someone could have who was actually there. In 2001 brain fingerprinting was admitted in a court trial and was responsible for exonerating a prisoner who spent 22 years in prison for a murder he allegedly did not commit. Miller says that the court was confronted with the question: "Is brain fingerprinting science or pseudoscience?" and "How to distinguish fact from hype?" (Miller 2006, p. 281).

Put as a vision, Bainbridge sees a transformation of the legal system due to the convergence development: "Convergence of technologies will be so central to social change that it will transform the law and legal institutions, as various legal specialities merge, new ones emerge, and new issues challenge courts and legislatures (Bainbridge 2006, p. 341).

Concerning public discourse and ethical questions of the CT-development, a fundamental difference between the U.S. and the European discussion is that in Europe, ethics are considered to be an intrinsic component to progress. The CTECS-approach of the European Commission claims that technological advancement "must harmonise with the values of diversity, social justice, international security, and environmental responsibility" (HLEG 2004a). However, ethical questions of the NBIC-development were also discussed at the latest U.S. conference 2005 in Hawaii and made available as a documentation in early 2006 (Bainbridge and Roco 2006). In this documentation ethical questions are discussed concerning "Neuroethics of Memory Drugs" (Sentenia 2006),

new ethical dilemmas posed by "Neuropolicy" (Lynch 2006), and concerning the Enhancement of Human Performance (Khushf 2006).

In Europe the topics for public discourse in the context of CT were collected in the Special Interest Group 2 of the High Level Expert Group which dealt with the cultural configurations of Convergence (Staman et al. 2004). In their report, the authors list the following issues to be considered:

- Human and constitutional rights; human autonomy, dignity, privacy, integrity, etc.
- Public moral, comprehensive views and social identity
- Economic and institutional Science and Technology (S&T) pressure on society for instance on public goods (the commons)
- Fostering the European identity in S&T policy
- Identifying and handling risks and their perceptions.

Whereas these points seem to be of a very general nature, it is possible with the information collected in this paper to determine the specific ethical issues in the respective technology areas and assess their implications. This will be done in a next step.

II.1.5 "Salvation Promises"

As a kind of residual category, the label "Salvation Promises" was created to collect comprehensive concepts which put the NBIC convergence at the centre and claim that almost all problems will be solved due to the future technological development.

So far, all of these visions are coming from the U.S. context. European experts have noted that salvation promises of this kind are "moral value-loaded" (Staman et al. 2004, p. 2). Convergence as a salvation promise refers to a machine thinking metaphor and the ideal of enhancement. Accordingly, the enhancement of man and nature is the main challenge of modern society. This thinking is partly result of a close connection between (some of) the CT advocates and transhumanism, an international intellectual and cultural movement supporting the use of sciences and technologies to enhance human abilities and ameliorate the supposedly undesirable and unnecessary aspects of the human condition, like illness, aging and even death (a more detailed analysis of the interplay between transhumanism and CT can be found in Schummer 2004b or Coenen 2006).

The salvation promises listed below as statements only, can be examined in more detail in a next step. A deeper examination should then be able to answer the question

where these salvation promises come from and what role they play in the debate on converging technologies.

- Free availability of information to disadvantaged people around the world will improve their agricultural production, health, nutrition, and economic status (Bainbridge 2006, p. 340).
- Renewable energy technologies, such as photovoltaics and new technologies, such as hydrogen fuel cells and combined heat and power systems, will allow homes and businesses to drop out of the power transmission (Tonn 2006, p. 310f.).
- Transportation will be safe, cheap, and fast due to ubiquitous real-time information systems, extremely high-efficiency vehicle designs, and the use of synthetic materials and machines fabricated from the nanoscale for optimum performance (Bainbridge 2006, p. 339)
- We will have the technological means to ensure an adequate food supply, clean air, and clean water (Bainbridge 2006, p. 342).
- Rather than stereotyping some people as disabled, or praising others as talented, society will grant everybody the right to decide for themselves what abilities they want to have (Bainbridge 2006, p. 344).
- The vast promise of outer space will finally be realised by means of efficient launch vehicles, robotic construction of extraterrestrial bases, and profitable exploitation of the resources of the Moon, Mars, or near-Earth approaching asteroids (Bainbridge 2006, p. 338).
- Speed-of-light Travel: If a mind is data that runs on a processor (and its sensors and actuators), then that data — that mind — can travel at the speed of light as bits in a communication path. Thus, Mars is less than an hour away at light speed (Robinett 2003, p. 169).
- Self-Directed Evolution: If mind is program and data, and we control the hardware and the software, then we can make changes as we see fit (Robinett 2003, p. 169).
- Download yourself into new hardware: Imagine that the brain is fully understood, and therefore the mechanisms and data structures for knowledge, personality, character traits, habits, and so on are known. Imagine further that, for an individual, the data describing that person's knowledge, personality, and so forth, could be extracted from his brain. In that case, his mind could be "run" on different hardware, many staggering options open up: No death (You back yourself up. You get new hardware as needed.); Turn up the clock speed (Goodbye, millisecond-speed neurons; hello, nanosecond-speed electronics.) (Robinett 2003, p. 169).
- Hive mind: With knowledge no longer encapsulated in individuals, the distinction between individuals and the entirety of humanity would blur. Think Vulcan mind-

> meld. We would perhaps become more of a hive mind — an enormous, single, intelligent entity (Robinett 2003, p. 169).

II.1.6 Summary

In order to grasp all aspects of the CT-discussion, a division was made between technological applications in a narrow sense (part A) and areas which are considered SSH fields (part B). With the exception of "Salvation Promises", all of the presented SSH aspects play an important role in the convergence debate. Especially the thematic field of "Organising interdisciplinarity for convergence" seems to be of importance. Here, the educational system and the traditional separation between disciplines is an issue. In this context, the transfer of methods, concepts and tools from one scientific discipline to another is essential for scientific advances.

However, when it comes to transferring natural science methods to the Social Sciences and Humanities as suggested by Yonas and Glicken Turnley (2003) and Strong and Bainbridge (2003) with reference to Wilson (1998), the way to materialism and determinism seems to be paved. This is a way of thinking, SSH-researchers were convinced would belong to a long gone past. But it seems that with the diffusion of the convergence concept and especially in the context of neuroscience research, the idea of biochemical determination of all human life including the social and cultural life is experiencing a revival. SSH-researchers need to find new answers in the light of new scientific results. They have to deal with the strong insistence of neuroscientists and the proponents of convergence that the human and social behaviour will soon be fully understood and could be simulated and manipulated if only the basic physical and bio-chemical laws will be discovered.

II.2 SSH aspects evolving from the interviews

II.2.1 Introduction

This section documents the interview results and mainly concerns the SSH aspects of Converging Technologies. The interviews were carried out between April and September 2007. Interview partners were mostly German researchers in the fields of engineering, brain research, design of intelligent devices, the social sciences and also politicians involved in research policy.

In our selection of experts, we attached value to an overweight of natural scientists and engineers because our aim was to find out more about real science and technology developments. Since cognitive and neurosciences are supposed to make huge contributions to the convergence of technologies, most of our interviewees were from these fields. However, also social scientists were interviewed.

For the interviews we used a guideline, which also structures the way the results are presented here: Firstly, we will summarise to what extent researchers reported to be aware of the concept of technological convergence. Then we will report on the concrete developments in science and technology that were associated with convergence. In section three we will report on new findings concerning governance of interdisciplinary research. Since interdisciplinary research is an important aspect in the process of technological convergence, we asked in what concrete sense it is considered important. It turned out that interviewees regarded organising interdisciplinary research as a serious challenge. In the last section we will summarise what ethical aspects were mentioned by the interviewees besides the enhancement issue.

II.2.2 Selection of interviewees and personal involvement

Before we start with the presentation of the interview results we shortly introduce the disciplinary and biographical background of our interviewees for a better understanding of their positions. Because of anonymity reasons we use numbers to identify the different interviewees.

> Interviewee 1 is physicists located in Alabama, USA. Problems of interdisciplinary research are his main fields of study. He is dealing with different issues of interdisciplinary research. Having finished his PhD in philosophy, his main fields of research are philosophy of science and possible applications. He critically evaluates developments in the field of

converging technologies from both perspectives as a professional physicist and as a philosopher of science.

Interviewee 2 is employed as engineer in a German research institute for applied science leading the department of neuroprosthetics. Regarding his biographical background one can say that he has full experience of both the scientific as well the industrial institutional field: He has worked for a company as well in clinical research and he is also involved in teaching activities. His research is dedicated to the development of sensors for BCI (brain – computer interfaces). Applications in this field of research are paradigmatic "convergent technologies" in character, he says.

Interviewee 3 is professor in the department of neuroinformatics at a German university. He studied information science and finished his PhD in physiology. Thus he always felt like a disciplinary hybrid which also affected his teaching activites. Staff members in his department are teaching and doing research in robotics, artificial networks and new forms of modelling intelligence.

Interviewee 4 is researcher in the department of neurophysics at a large German University. His work is dedicated to problems with modelling information processes in the human brain.

Interviewee 5 is researcher at another big German university, working on technical problems of the brain computer interface.

Interviewee 6 is known as one of the leading social scientists in the social study of technology. He published to heterogeneous fields like artificial intelligence, ubiquitous computing, informatics and robotics from a social science point of view.

The last Interviewee used to be a member of the High Level Expert group for converging technologies in Europe. He studied physics and social sciences in Bielefeld and worked in a research institute for plasma physics in Garching near Munich. Today he is a professor at a renowned technical university in Germany.

II.2.3 Awareness of the concept of technological convergence

One of our observations was that the concept of converging technologies was first triggered by research managers and actors in the political arena rather than from scientists. In the interviews we wanted to find out if this observation was correct and asked whether the concept was known or not. During the interviews our impression was consolidated: The term is mainly used in political contexts or in direct interaction with funding agencies where research and technology policy is important.

Researchers whose work can be assigned to those fields we identified as major application areas often said that they have not heard of the concept at all. But thei reported that their work has taken on a stronger interdisciplinary character. But the majority of experts intervewed could not say, in which direction technologies converge and how the technological development can be described accordingly.

Those who stated to be familiar with the concept differed strongly in the meaning of this term. For our second interviewee, Converging Technologies are aimed at focussing research and technology of scientific disciplines to only one aim. In contrast to interdisciplinary research, convergence does not mean simply the participation of different disciplines but instead a stronger orientation on the project of a single product development. Other interviewees regarded converging technologies as more than the simple combination of technologies but rather as research strategy for new methods and products. All of those who were familiar with the concept did not agree with the restriction of just four technologies (Nano, Bio, Info; Cogno). Additionally synthetic biology is seen as a key area of convergence that was not explicitly mentioned in the Roco/Bainbridge report simply because the technology is so new.

Summarising the results of answers to this topic gives a rather ambivalent picture for the awareness level of the convergence concept: To some of the experts converging technologies or a unifying paradigm does not exist at the level of research practice. Others reported awareness of the concept but used it strategically by means of finding financial support by research funding organisations.

The interviews also showed that there is no unifying meaning of the term convergence even to those who were aware of the concept. Apart from these differences almost all interviewees were able to underwrite the usefulness of the concept in general. Thus "Convergent technologies" is merely a reflexive term that describes not a specific technology but rather a technological and scientific development. In order to get to know about scientific developments more specifically we asked researchers about their view.

II.2.4 Which developments in science and technology are associated with the concept of convergence?

For most of the researchers the major development that can be associated with CT is the convergence of scientific research at the nanoscale. At this scale it becomes rather hard to decide whether scientific work can be declared as chemistry, physics or material science. The trend is known as molecularisation in biology and medicine (Kay 1996) but certainly affected also others in the natural sciences and in engineering. This is the reason why for some of the interviewees, converging technology works just as another term for nanotechnologies. Two Interviewees saw the increasing dependence on interdisciplinary research as important development that can be associated with the convergence concept.

Many of those who were interviewed were active in the field of brain research or neuroscience since cognitive science was seen as important feature of technological convergence. In this application field intelligent implants for sensory perception or implants for the restoration of functions were good examples for research. Building electrodes in this area especially means to be very sensitive to the problem of biocompatibility. To these researchers building interfaces between biological and technical systems is the main challenge for science and industry demanding convergent technologies. Advances in basic research in the neurosciences enable new applications in this especially with the integration of theoretical physics.

These new technologies that arise between empirical research on the brain and medical applications for the brain are seen as a good example for convergent technologies. Because of the permanent dealing with biological and technical systems one Interviewee perceives new developments in medical technology in general as convergent technology. One important field of application are neuroprosthetics where continuous technological progress leads to miniaturisation that can be combined with new findings of medical research (see also Bolz et al. 2005: 9).

A different perspective on scientific development was taken by one interviewee: From his point of view, converging technologies can be regarded as grand scientific project. He interprets Roco and Bainbridges approach as an attempt to construct a new unifying paradigm for modern engineering, explaining and constructing biological objects. In analogy to classical physics, convergent technology aims at building another grand theory that can solve problems of our time. Clearly he mentioned conceptual deficits in nanoscience and technology since there is no methodological and theoretical exchange beyond top down and bottom up. Insofar "Convergent Technologies" is more

a claim than an already existing methodological paradigm. The convergence of science at the nanoscale has not led to sufficient technological solutions so far.

Although one of the interviewees did not want to use the concept of convergence he reported about considerable developments in the field of machine learning which is in fact triggered by co-operations between theoretical informatics, mathematics and statistics.

II.2.5 To what extent is research interdisciplinary?

Since technological convergence involves at least four technologies and many more scientific disciplines, organising interdisciplinary research is an important question for the facilitation of convergence. What new pressures and structural features exist for this research at the borders of disciplines? Are there any new forms of interdisciplinary research that can serve as orientations for researchers or are disciplinary research orientations prevailing? These questions were asked in the third part of the interviews.

The claim for interdisciplinary research is one of the most prominent topics of contemporary science and technology policy. Often, many scientists complain, this claim is just lip service without practical results (Weingart 1999). The convergence of emerging technologies now is a new challenge for interdisciplinary research. What makes it different? Does the term convergence mean anything more than interdisciplinarity? Bainbridge (2006, p. 338) has claimed that the development of new technologies might lead to the consilience of all sciences as a new form of interdisciplinary organisation. However, our interviews suggest that this might be quite unlikely considering cultural differences between disciplines.

One interviewee said that converging technologies necessitate new forms of organisations. New organisational structures strongly influence rapid technological development. In contrast to the interdisciplinary paradigm, converging technologies mean not only participation or contribution but also to go beyond borders of disciplines. The interviewee reported experiences from a preliminary study for retina implants in 1994 when nobody could even imagine technological opportunities of such applications. In the beginning most of the participants simply denied the possibility of developing such a machine but when the process continued people tried to overcome scientific doubts.

This example can be used to show to what extent technological convergence produces intensified interdisciplinary research in the light of new applications. But what drives scientific development? Are there also inherent mechanisms fostering interdisciplinary research?

One interviewee shed light on the situation in the field of neuroscience. Neuroscience is a huge field to which many disciplines contribute. But during the last 5 years one could observe growing significance of interdisciplinary co- publication. One explanation for this phenomenon is simply the pure mass of articles during the past 20 years without theoretical framework. A structuring of the findings became more and more difficult. New articles, he claims, can now only be accepted with an existing theoretical framework. Therefore many experimental brain researchers cooperate with neuro physicists, information scientists and mathematicians in order to generate theoretically grounded research designs.

Some of the interviewees stressed the existence of obstacles for interdisciplinary research. Especially interviewee 2 working in the field of brain computer interfaces stated that there is a huge gap between the valuation and the facilitation of interdisciplinary research. There are strong reasons why these forms should be encouraged since progression can be merely expected at the borders of disciplines. But working in this environment is not at all favourable for individual careers. Getting a tenure ship is harder for those working in interdisciplinary environments. In his opinion, this is particularly true for parts of the research associated with convergence due to the fact that especially medicine is very disciplinary oriented. Those obstacles to interdisciplinary research are stronger in Germany than in the United States. Since a lot more interdisciplinary research centres exist there, it is much easier to organise interdisciplinary research. Nevertheless during the past few years the situation improved by the founding of new research institutes and master programs that integrate theoretical subjects like informatics and mathematics for the study of the brain and biological systems.

By contrast, another interviewee states, concrete practices of interdisciplinary research are not dependent on structural features. Rather, success is highly dependent on persons involved in the projects. That is why he prefers to work and cooperate with really open-minded researchers without hierarchical orientations. The possibilities to work in such open environments might differ between institutional settings and disciplinary cultures. Regarding his own experiences he reports strong differences between medicine and mathematics for example.

According to his research orientation as a researcher in the field of the social studies of technology our fifth interviewee mainly described general features of interdisciplinary research. Referring to converging technologies he argued that interdisciplinary research is changing in character. In comparison to earlier forms of interdisciplinarity he found that new of interdisciplinary organisation forms miss the dominance of a key discipline. Rather research is organised in heterogeneous but merely equal

relationships between disciplines. Whereas in the 19th century with the evolution of physics, interdisciplinary research was characterised by the dominance of a guiding discipline, novel settings show greater equality considering the importance of theoretical and methodological approaches. Where concrete problems are to be solved many more approaches have to be taken account of.

II.2.6 What are the ethical problems?

In the last part of the expert interviews, interviewees were asked about ethical issues that they see arising in the course of new technological development in the areas associated with convergence. Currently, technological convergence is in a state where applications are only foreseeable. The discussion for what ends this kind of research should be pursued has therefore just begun. Some of the interviewees reflected in our interviews for the first time about possible risks and changes that might necessitate ethical considerations. In the U.S., enhancement of human performance was one vision to guide research but discussion arose whether this should be more important than for example improving therapeutic methods. Altering the human condition in a fundamental way may bring about many ethical issues.

Seen from the perspective of natural scientists as well as social scientists the questions arises, in what kind of socio technical world we want to live in, since the possibilities of social control might improve. There are a variety of issues and problems that can be discussed of which these are most important ones mentioned in the interviews:

- Enhancement issue: The possibility to physically enhance people raises philosophical questions about the very human nature. Physiological enhancement blurs the boundaries between what can be considered human and what can be perceived technical or artificial.
- Technological convergence will also contribute to the development of intelligent robots. In which ways can humans be substituted by robots? What are the consequences for social interaction?
- Sharpening of social inequality: When technological implants enable humans to process information faster than possible competitors, the question is raised how social justice can be guaranteed. Some interviewees assumed that it can sharpen the contrast between different social strata insofar wealthier parts of the population will be able to afford technological instruments that will further improve their relative competitive position.
- Neuroscience research - especially neuroimaging methods - are expected to contribute to a better understanding of the human brain and its correlates. But

what can be done with the growing knowledge about human information processes and what consequences does such knowledge have?

- With new processing technologies that combine different methods of brain research, neuroscientists get new information about mental states and personality structures. For what purposes can this knowledge be used? How can mental privacy still be guaranteed?
- Seen from a jurisdictional perspective, the application of converging technologies raises questions about the very nature of guilt. When all processes of the brain can be observed and analyzed, will this change the guiding principles about whom and when someone should be punished?
- The existence of sensory implants and other tools improves possibilities of social control. For example new results in brain research will make it much easier to find out whether someone lies or not with much higher precision than traditional lie detectors.
- When our mental states and personal features are discovered, will this information be used for commercial purposes? The emerging field of neuromarketing poses the question whether information about our mental states can be manipulated in a way that product presentation can always be adapted according to our needs and wishes. Although there are some indicators showing that this kind of research is very advanced yet it should be regarded important for ethical consideration as well.
- One interviewee also reports ethical problems with animal experiments. Empirical brain research necessitates operations on animals. Some ethicists criticise that those experiments are undertaken without narcosis. Seen from the perspective of the researchers this is the only possibility to gather information about brain functions since neuronal processes can be only looked at when neuronal response is not altered by inhibitors.

This list is of course not completely filing all possible ethical aspects of CT. It shows that neuroscience research is raising many ethical questions. Most researchers agree that one should deal with these questions in a public dialogue. Ethical considerations should be dealt scientifically by professionals. One Interviewee states that new interdisciplinary programs of study that combine knowledge about the human brain with knowledge about ethical issues could improve the situation. As an example he mentioned the "Berlin School of Mind and Brain" (www.mind-and-brain.de) where neuroscientists as well as philosophers and ethicists work together.

II.3 Two different narratives of technological convergence

Version 1: Science-driven convergence

What is CT?

"Converging technologies" is the next big thing. Far-sighted scientists and research planners sensed a development and saw the chances if only the concept was followed and reinforced in a systematic way. Now on the political agenda, convergence will trigger new scientific ventures and lead to important breakthroughs in many different areas such as biomedicine or neurotechnology. Today, the development may be at an early stage but soon convergence will have the same importance for society that digitalisation and informatisation had in the past.

Role of visions

Leading visions are important in the sense that they reduce spaces of uncertainty. To introduce a narrative into the different and sometimes contradictory developments of science that construes convergence as a collaborative effort for example to "understand the human brain" may motivate new co-operations and interdisciplinary projects. However, radical visions of any sorts will not mirror in the daily research work of scientists.

Enhance-ment

Joint efforts to heal and improve human physical and mental capacities are part of the convergence development. However, the enhancement idea does not dominate it. Alternative framings are also possible and find their way into national and trans-national research programmes. Alternative framings could be: CT to allow for new self-sufficient societies, CT to save the natural environment, CT to realise renewable energies.

Governance & regulation

Science and research communities still have their own governance structures, even in a possible age of convergence. However, new technical developments are always seen as advantages in the international scientific and economic competition. Thus the state has the role to support these developments. Another field of governmental activity is to increase the acceptance of technical developments in the society.

Public participation

In the different application fields where convergence plays a role, different approaches to ensure societal acceptance are necessary. In most medical application fields, acceptance can be assumed. However, different biophysical developments as well as neurotechnical applications will be discussed controversly in the society. A discussion process needs to be initiated.

Ethics of science & technology

Like with genetic modifications or stem cell research, in many new areas of convergence, ethical questions will play an important role, especially when it comes to technologies potentially able to redefine what it means to be human. Upstream ethics engagement will be an important principle. Ethics of science and technology will have to be adjusted in the light of new technologies. But they will potentially govern over pure technological feasibility. However, this is quite difficult in the light of an international scientific and economic competition and it requires trans-national co-operations.

Dis-"Unity" of science

The relation between the natural and the social sciences will be characterised by a new dialogue. The materialistic basis for human thinking and behaving will move to the centre of attention and it will be responsible for the return of the debate about nature vs. nurture. On the other hand, social science methods like psychological classifications of human traits, intentions and actions will be used by neuroscientists and biologists in order to understand the materialistic base. The new dialogue will take into account that there is a space beyond natural laws to be discovered by the study of interrelations, as quantum physics has shown in the past.

Inter-disciplinarity

Interdisciplinarity is the heart of the matter of convergence in this narrative. It has many aspects and involves the convergence areas to different degrees. Interdisciplinarity is the new paradigm, and scientific breakthroughs will be expected from combining methods and approaches from different disciplines and engineering fields. A model for this new importance may be the field of cognitive science. New ways of co-operation and new approaches in education may profit from experiences made in this area.

Involve-ment of "real" SSH

Established, "real" SSH is reluctant to enter the discussion on convergence. The idea of interdisciplinary work seems nothing new to established SSH researchers. Far-reaching visions of convergence which imply fundamental changes in society are met with scepticism. But if SSH researchers join the debate, they are mostly occupied with defending existing positions for example in the "free-will" debate with neurotechnology or by maintaining integrity and the so-called oversight function of SSH.

Social transfor-mation potential

The potential for social transformation is high in this narrative, depending on the development in the different technology fields. This means that new ways of human enhancement are only one aspect of the transformational potential of CT. Others refer to a whole range of new applications and products the convergence development will have made possible.

Version 2: Convergence as a normative concept

What is CT?

"Converging technologies" is a buzz word and has only few connections to real developments in science and technology development. The concept was brought up by a few rather dubious research planners and transhumanists. The scientific community will follow the far-fetched visions of its inventors only because research money was allocated to the subject. For that matter, researchers will more and more label their work as "convergent" and some progress will be made in understanding and enhancing the human brain.

Role of visions

Visions of a fundamental change in the way, individuals and society are perceived dominate the discussion. In a normative and almost missionary way, the main actors of the convergence debate develop their visions and hope for a respective reflection in the daily work of scientists. Like the "man on the moon" project, the main actors of the convergence debate hope to be able to trigger something like a "brain on a chip" project.

Enhance-ment

Enhancing human physical and mental performance is the dominant framing of the CT debate. Every effort is seen as a contribution to the ultimate goal to technically prolong life, to artificially extend human memory and mental capacities and to overcome human limitations.

Governance & regulation

Since convergence has a strong normative dimension, every regulatory or research funding activity that supports the idea of human enhancement is welcomed. However, the state should not dictate the exact terms of research because scientists know better. A fundamental re-definition of the human condition will require fundamental adjustments of governmental functions and regulations. In addition, the military will play an important role as a major funding source and user of convergent applications.

Public participation

The advantages of new convergent applications speak for themselves. Consequently, public engagement and participation do not play a major role. Convergence is another – and for some even the final – step of technical progress. Society will have to adapt to the circumstances prearranged by technology.

Ethics of science & technology

Ethics of science and technology are restricted to the ultimate goal of human enhancement. Society as a whole, its values and ethics will automatically adapt to it in the face of the advantages and blessings of convergence. The precautionary principle in science and technology will be replaced by a so

called proactionary principle which weights overall advantages over particular possible harms. Liability regulations concerning new technologies will be loosened.

Dis-"Unity" of science

The world of NBIC convergence will be characterised by the "unity of science" in the sense that natural science principles and methods dominate all science fields and will be transferred to all areas of the social sciences and humanities. A new renaissance will be the result in which all aspects of human thinking and behaviour will be deciphered as phenomena of a set of natural laws. This new understanding will open up possibilities to influence and manipulate human behaviour in the desired direction.

Inter-disciplinarity

Interdisciplinarity is a vehicle to achieve the visions of NBIC convergence. It is also considered crucial in this narrative, although it mostly excludes the social sciences and humanities as we know them today. University organisations and study subjects will be changed reflecting the need for interdisciplinarity in natural sciences and engineering. The curriculum will be changed based on a comprehensive, hierarchical intellectual paradigm for understanding the architecture of the physical world from the nanoscale through the cosmic scale.

Involve-ment of "real" SSH

"Real" SSH researchers feel the need to adapt their research and education programmes to convergence because of the overwhelming success of new applications stemming from the overlappings of NBIC. Established SSH researchers will need to change their positions on nature vs. norture as well a many other positions in the light of new insights into the human brain. A fundamental revision of SSH as a scientific venture will be the result.

Social transfor-mation potential

Convergence will lead to profound social changes. This is mainly due to the possibility to enhance and manipulate humans in many new ways. The question will not only be who sets the rules but also, who can afford the technology or treatments for enhancement. Also, there will be enlarged possibilities to control and better organise people by CT.

The two narratives side-by-side

Version 1: Science-driven convergence	Version 2: Convergence as a normative concept
1. What is CT? What is actually happening? What are the drivers?	
"Converging technologies" is the next big thing. Far-sighted scientists and research planners sensed a development and saw the chances if only the concept was followed and reinforced in a systematic way. Now on the political agenda, convergence will trigger new scientific ventures and lead to important breakthroughs in many different areas such as biomedicine or neurotechnology. Today, the development may be at an early stage but soon convergence will have the same importance for society that digitalisation and informatisation had in the past.	"Converging technologies" is a buzz word and has only few connections to real developments in science and technology development. The concept was brought up by a few rather dubious research planners and transhumanists. The scientific community will follow the far-fetched visions of its inventors only because research money was allocated to the subject. For that matter, researchers will more and more label their work as "convergent" and some progress will be made in understanding and enhancing the human brain.
2. Role of assumptions, ideologies and (radical visions)	
Leading visions are important in the sense that they reduce spaces of uncertainty. To introduce a narrative into the different and sometimes contradictory developments of science that construes convergence as a collaborative effort for example to "understand the human brain" may motivate new cooperations and interdisciplinary projects. However, radical visions of any sorts will not mirror in the daily research work of scientists.	Visions of a fundamental change in the way, individuals and society are perceived dominate the discussion. In a normative and almost missionary way, the main actors of the convergence debate develop their visions and hope for a respective reflection in the daily work of scientists. Like the "man on the moon" project, the main actors of the convergence debate hope to be able to trigger something like a "brain on a chip" project.

3. Role of enhancement in CT	
Joint efforts to heal and improve human physical and mental capacities are part of the convergence development. However, the enhancement idea does not dominate it. Alternative framings are also possible and find their way into national and trans-national research programmes. Alternative framings could be: CT to allow for new self-sufficient societies, CT to save the natural environment, CT to realise renewable energies.	Enhancing human physical and mental performance is the dominant framing of the CT debate. Every effort is seen as a contribution to the ultimate goal to technically prolong life, to artificially extend human memory and mental capacities and to overcome human limitations.
4. Governance and regulation	
Science and research communities still have their own governance structures, even in a possible age of convergence. However, new technical developments are always seen as advantages in the international scientific and economic competition. Thus the state has the role to support these developments. Another field of governmental activity is to increase the acceptance of technical developments in the society.	Since convergence has a strong normative dimension, every regulatory or research funding activity that supports the idea of human enhancement is welcomed. However, the state should not dictate the exact terms of research because scientists know better. A fundamental re-definition of the human condition will require fundamental adjustments of governmental functions and regulations. In addition, the military will play an important role as a major funding source and user of convergent applications.

5. Public engagement and participation	
In the different application fields where convergence plays a role, different approaches to ensure societal acceptance are necessary. In most medical application fields, acceptance can be assumed. However, different biophysical developments as well as neurotechnical applications will be discussed controversly in the society. A discussion process needs to be initiated.	The advantages of new convergent applications speak for themselves. Consequently, public engagement and participation do not play a major role. Convergence is another – and for some even the final – step of technical progress. Society will have to adapt to the circumstances prearranged by technology.
6. Ethics of science and technology	
Like with genetic modifications or stem cell research, in many new areas of convergence, ethical questions will play an important role, especially when it comes to technologies potentially able to redefine what it means to be human. Upstream ethics engagement will be an important principle. Ethics of science and technology will have to be adjusted in the light of new technologies. But they will potentially govern over pure technological feasibility. However, this is quite difficult in the light of an international scientific and economic competition and it requires trans-national cooperations.	Ethics of science and technology are restricted to the ultimate goal of human enhancement. Society as a whole, its values and ethics will automatically adapt to it in the face of the advantages and blessings of convergence. The precautionary principle in science and technology will be replaced by a so called proactionary principle which weights overall advantages over particular possible harms. Liability regulations concerning new technologies will be loosened.

7. Dis-"Unity" of science and methodological questions	
The relation between the natural and the social sciences will be characterised by a new dialogue. The materialistic basis for human thinking and behaving will move to the centre of attention and it will be responsible for the return of the debate about nature vs. nurture. On the other hand, social science methods like psychological classifications of human traits, intentions and actions will be used by neuroscientists and biologists in order to understand the materialistic base. The new dialogue will take into account that there is a space beyond natural laws to be discovered by the study of interrelations, as quantum physics has shown in the past.	The world of NBIC convergence will be characterised by the "unity of science" in the sense that natural science principles and methods dominate all science fields and will be transferred to all areas of the social sciences and humanities. A new renaissance will be the result in which all aspects of human thinking and behaviour will be deciphered as phenomena of a set of natural laws. This new understanding will open up possibilities to influence and manipulate human behaviour in the desired direction.
8. Interdisciplinarity including educational matters	
Interdisciplinarity is the heart of the matter of convergence in this narrative. It has many aspects and involves the convergence areas to different degrees. Interdisciplinarity is the new paradigm, and scientific breakthroughs will be expected from combining methods and approaches from different disciplines and engineering fields. A model for this new importance may be the field of cognitive science. New ways of cooperation and new approaches in education may profit from experiences made in this area.	Interdisciplinarity is a vehicle to achieve the visions of NBIC convergence. It is also considered crucial in this narrative, although it mostly excludes the social sciences and humanities as we know them today. University organisations and study subjects will be changed reflecting the need for interdisciplinarity in natural sciences and engineering. The curriculum will be changed based on a comprehensive, hierarchical intellectual paradigm for understanding the architecture of the physical world from the nanoscale through the cosmic scale.

9. Involvement of the "real" SSH in the CT debates	
Established, "real" SSH is reluctant to enter the discussion on convergence. The idea of interdisciplinary work seems nothing new to established SSH researchers. Far-reaching visions of convergence which imply fundamental changes in society are met with scepticism. But if SSH researchers join the debate, they are mostly occupied with defending existing positions for example in the "free-will" debate with neurotechnology or by maintaining integrity and the so-called oversight function of SSH.	"Real" SSH researchers feel the need to adapt their research and education programmes to convergence because of the overwhelming success of new applications stemming from the overlappings of NBIC. Established SSH researchers will need to change their positions on nature vs. norture as well a many other positions in the light of new insights into the human brain. A fundamental revision of SSH as a scientific venture will be the result.
10. Implications, social transformation potential of CT	
The potential for social transformation is high in this narrative, depending on the development in the different technology fields. This means that new ways of human enhancement are only one aspect of the transformational potential of CT. Others refer to a whole range of new applications and products the convergence development will have made possible.	Convergence will lead to profound social changes. This is mainly due to the possibility to enhance and manipulate humans in many new ways. The question will not only be who sets the rules but also, who can afford the technology or treatments for enhancement. Also, there will be enlarged possibilities to control and better organise people by CT.

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Appendix B

Cognitive science within Convergence: Key issues in the European context

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Converging technologies and their impact on the social sciences and humanities (CONTECS)

Deliverable D3.1 – Part B

Cognitive science within Convergence: Key issues in the European context

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(based on an earlier version from October 2007)

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We can expect that in the future, cognitive science will supply man with new tools, electronic or not, that will be better suited to our cognitive needs and that may increase the quality of our lives. In many areas, it is not technology that sets the limits, but rather our lack of understanding of how human cognition works.

Peter Gärdenfors

Application must be preceded by knowledge.

Max Planck

Table of contents

I.1 Introduction: Purpose and scope of the present document 1

I.2 Cognitive science: what it is and how it relates to CT.....5

I.2.1 Cognitive science: scope and structure 5
I.2.1.a Object.....5
I.2.1.b Information processing and the structures that implement it 6
I.2.2 Who does what in cognitive science? Division of labour, internal and external interactions 7
I.2.2.a Division of labour (A): Pure and applied cognitive science 7
I.2.2.b Division of labour (B): Natural and artificial cognition 8
I.2.2.c Cognitive science and its environment: direct and indirect contributions to the field 9
I.2.3 The uneasy relations between cognitive science and the Three Technologies 10
I.2.3.a How did cognitive science get involved in the first place? 10
I.2.3.b The cognitive science which NBIC has in mind 11
I.2.3.c Why NBCI and all related CT programs require the collaboration of the entire field of cognitive science, and not just some 'technological' outposts.....12
I.2.3.d Cognitive science can and must contribute to CT on four distinct levels.....13
I.2.3.e Persisting problems in the family: Cognitive science and the Three as uncomfortable bedfellows. No Nano says Cogno.....15

I.3 An overview of cognitive science in Europe – its strengths and weaknesses 19

I.3.1 A glimpse of history: three phases in the development of cognitive science.....19
I.3.2 Assets and handicaps of European cognitive science.....22
I.3.2.a Liabilities (I) Why cognitive science goes against the grain of European scholarly culture 23

I.3.2.b A general pessimistic outlook in Europe? 26
I.3.2.c Liabilities (II): Institutional and sociological features in Europe inimical to cognitive science 27
I.3.2.d High and low-brow science 28
But this is not always how the policy-maker sees it, when she meets with a succession of leaders in the field. When lobbying for funds and attention, they speak with what inevitably appears, to her, as several, often dissonant voices. Faced with the problem of helping what sounds to her as a divided community, the policy-maker may then well decide to put things in perspective and do little or nothing until the dust settles. Nor is this an idle concern: there are enough examples to show that cognitive science, compared with other fields, is very poor at making its voice heard. 30
I.3.2.e Assets of European cognitive science 31

I.4 Live issues raised by cognitive science in relation to CTs and beyond 33

I.4.1 A critical eye: Reconceptualising the problem situation 33
I.4.1.a The very idea of CT 33
I.4.1.b Europe versus the US? 34
I.4.1.c Speculations, unknown knowns, and unknown unknowns 35
I.4.2 How to get the ball rolling between SSH and CT by taking one's bearing on cognitive science 35
I.4.2.a Incremental knowledge in the sciences of man 35
I.4.2.b Novelty, cycles and permanence 37
I.4.2.c Three kinds of issues 37
I.4.2.d Where to start? Taking inspiration from fruitful ongoing programs 38
I.4.3 Issues related to the "known unknown" 39
I.4.3.a Cluster of issues #1: Self-understanding of self, kin, society 39
I.4.3.b Cluster of issues #2: Knowledge and competences 42
I.4.3.c Cluster of issues #3: Politics and economics in TechLife 45
I.4.4 Issues related to the "unknown unknown" 47

I.4.4.a The new AI in the light of the old and the current 47
I.4.4.b Prospects for enhancement: constraints vs. tradeoffs 52

II.1 Methodology and summary of results....57

II.2 Cognitive science at work in CT: some examples 61

II.2.1 School for cognitive engineers....61
II.2.2 R&D park in micro- and nanotechnologies 63
II.2.3 Federation of European Ergonomics Societies....65
II.2.4 European Biopharmaceutical Enterprises (EBE) 67
II.2.5 Laboratorium voor Neuro- en Psychofysiologie 69
II.2.6 SONY Computer Science Laboratory (CSL)....71
II.2.7 Neuromarketing.be, i-mémoires, Neurosense 73
II.2.8 Convergence in telecommunications 75
II.2.9 Semantic web 77
II.2.10 Cognitive/Behavioural economics....79
II.2.11 ICN & FIL, University College London 81
II.2.12 Edinburgh School of Informatics 83
II.2.13 Lund University: Cognitive science 85
II.2.14 Max Planck Institutes, Berlin, Frankfurt, Leipzig 87

I.1 Introduction: Purpose and scope of the present document

A working hypothesis of the CONTECS consortium is that cognitive science plays a key role in the converging technologies. It is therefore important to start out with as clear a picture as possible of what cognitive science is and how it figures on the European scientific scene. In particular, there is a need to prepare the grounds for a precise identification of areas, within the NBIC perspective, in which cognitive science has a definite contribution to make. But it is also necessary to gain a better understanding of the cultural significance which cognitive science takes on, especially in the European context, which is not identical with the American. Indeed, it can be surmised that part of the mutual relevance of the converging technologies and the humanities and social science springs from the cognitive dimension, which is present on both sides.

As a contribution towards these goals, the present report offers a concise overview of the position of cognitive science in the European Union, together with a representative sample of activities, in the widest sense of the notion, which cognitive science gives rise to, within Europe. It has two parts. Part A is based on a previous report, and associated documents, authored by D. Andler, and consists in a conceptual and historical characterisation of the field of cognitive science, including the particular obstacles it faces in Europe, and the opportunities which nonetheless arise there. Part B attempts to present a picture of the actual situation in the realm of technology, including both ongoing developments and more or less distant ventures.

Part I

Cognitive science and its surroundings:

The intellectual landscape in a European perspective

I.2 Cognitive science: what it is and how it relates to CT

I.2.1 Cognitive science: scope and structure

I.2.1.a Object

Cognitive science is one of the most ambitious scientific enterprise of the 21st century. Its object is the mind, or rather, the functions and processes of the mind, which are also, to a large extent, those of the brain. It is inherently multidisciplinary, consisting in a sheaf of interconnected research programs involving to various degrees psychology, neuroscience, evolutionary theory, linguistics, computer science, philosophy, logic, decision theory, anthropology and various branches of social science, physics, mathematics, complex systems, and more.

Far from positing at the outset a 'definition' of the mind and its constituent parts, cognitive science takes it as one of its main goals to develop a wide-ranging and open-ended taxonomy of functions, states and processes which appear to belong to or partake of the mental realm, without imposing any restriction on what counts as mental. Thus, next to phenomena which most people associate with cognitive science (under that or another label, for cognitive science goes under many names[1]), such as memory, reasoning, knowledge acquisition, problem-solving, categorisation, and more generally 'thought' (*i.e.* conceptual, deliberative conscious mental transactions), cognitive scientists are concerned to an equal if not higher degree with linguistic competence, perception, motor control, action, emotions, social cognition and culture, morality, selfhood, and consciousness itself.

But a mere list of topics is hardly enough to give a flavour of the domain. The structure of cognitive science is essential. It is complex, reflecting the structure of its domain as it conceives it at the outset.

---

1 Informatics, intellectics, neuroinformatics, biological cybernetics, cognitive neuroscience, artificial intelligence logic-language-computation, language & information, information & computation are just some of the locutions which have been, at various times, used to refer to fields roughly co-extensive with, or purported to occupy a central position in, cognitive science. Of course, with each label comes a certain theoretical stance with respect to the object of inquiry and to the general form of the results it should aim for.

I.2.1.b Information processing and the structures that implement it

At the most basic level, cognitive science is constructed in conformity with a version of the distinction, familiar from biology, of *form* versus *function*[2]. Here, 'form' is the brain, or rather, the brain structures at various levels of aggregation; and 'function' is the mind, or rather, the mental (including perceptual, motor and emotional/motivational) processes at various temporal scales. This distinction is transformed, in the contemporary context of cognitive science, by the notion of *information:* the key idea is that mental processes are at bottom informational (although some clarification remains to be provided on what this means precisely). So that functions are to be analysed as operating on information. On the structure side, then, there are physical (biological or man-made) mechanisms which *realise* or *implement* these informational processes. This is usually rendered by the term 'computational' (which *must*, on pain of a rather tragic misunderstanding, be interpreted in this very general sense: far from all cognitive scientists subscribe to the computer model of the mind, and some even claim to be wary of the form/structure distinction; still, the characterisation provided up to this point, with a suitably supple construal of 'information' and 'computation', would draw the assent of almost everyone working in the field).

Cognitive science subscribes, in general terms, to a program which consists in determining *what* it is that the brain does, and *how* it does it. To a first approximation, psychology, linguistics, social science, sometimes with the help of philosophy and logic, are in charge of the *what* part of the program; and neuroscience, with the *how* part. However, this way of putting the division of labour does not do justice to four important aspects of the inquiry:

1. *Non-biological cognition.* The project of building artefacts endowed with informational capabilities comparable, in some interesting respects, to those of the adult human brain, implicates a notion of realisation which is broader than the one offered by the brain sciences: artificial intelligence, as part of computer science, and other modelling approaches drawing on a variety of paradigms from physics and mathematics, are important contributors to cognitive science.
2. *Abnormal cognition.* Normal adult human brains and minds are just one (important) case in a large family which includes human infants and children, abnormal, diseased, lesioned and senescent subjects, pre-*Sapiens* humans, and non-human animals: developmental psychology and neuroscience, neuropsychology, psychiatry and pharmacology, ethology, paleontology, anthropology

2 The description of the structure of cognitive science which follows is taken nearly *verbatim,* with minor clarifications, from the report Andler 2005: §4.A.

and evolutionary biology all have an essential role to play.

3. *Understanding biological constraints.* As is already abundantly clear from study of abnormal cognition, the *what* and the *how* cannot be completely dissociated: the deep structures of the mind, or in other words the basic categories on which to found a theory of mental functions (which is what psychology, linguistics etc. aim for) are presumably not determinable on the sole basis of psychological, linguistic, ... experimentation, seconded by conceptual and logical analysis. Neuroscience will almost certainly (and in fact has begun to) force a reconsideration of these basic categories. Symmetrically, neuroscience cannot establish a research program on its own: it wouldn't know what to look for without the help of the other disciplines.
4. *Cognition in context.* Over the last ten or twelve years, it has dawned upon many cognitive scientists that the initially plausible distinction between the individual mind/brain and its environment, has severe limitations. In between, so to speak, lie the collective effects or properties of communities of minds/brains, themselves immersed in a material/informational environment. Seen from this perspective, minds are not just brains understood at the functional level. *Externalism* is in this context the name of the general research program, now pursued on many fronts, which stems from the intuition that minds are, to a degree much greater than initially imagined, *socially and environmentally constituted entities*. The social sciences, evolutionary biology, ecology are called in for help at this juncture.

I.2.2 Who does what in cognitive science? Division of labour, internal and external interactions

Cognitive science is a highly diverse field, whose contours are somewhat blurry. To get a hold on its organisation, it is useful to define its take a look at its internal division of labour, and at the interactions of cognitive science with its neighbouring disciplines.

I.2.2.a Division of labour (A): Pure and applied cognitive science

As elsewhere in science, there is no denying that cognitive science research supports a *fundamental / applied* dichotomy. It is already present in the training of advanced students. One kind of program is geared towards classical academic careers devoted to the elucidation of normal and pathological cognition, and focussed on empirical and conceptual problems which arise in this pursuit. The other kind of program prepares students to jobs in industry, health, military or administrative institutions.

Fields of application are quite numerous and diverse. They can be categorised according to the area of application: Education (initial, continuing, remedial), health (including mental health, motor and perceptual enhancement or remediation), information,

language processing and communication, decision making and expertise, cognitive ergonomics (design of objects and interfaces), commerce (e.g. neuromarketing, which purports to apply brain imaging to the study of consumer behaviour), traffic control, etc. They can be distinguished according to the grade of involvement of cognitive-scientific theory, ranging from high to low; or according to whether they aim at the elaboration of methodologies (e.g., in the educational field, pedagogical methods based on evidence-based theories) or tools (software and computational environments which actually mesh with the cognitive abilities of the participants and the context in which they operate). Part II of the present document provides examples of a wide variety of undertakings in applied cognitive science.

I.2.2.b Division of labour (B): Natural and artificial cognition

Brains undoubtedly exist, and so do, in a different sort of way, the mental lives of ordinary human beings. But what about *cognition?* What sort of existence does it have? Why do we need the concept at all? One answer is that cognition usefully subsumes varieties of mental processes undergone by humans, and thus, by abstraction and idealisation, leads to a general perspective on a fundamental ability of our species. A further answer is that this ability is but a variety of a wider genus, unevenly distributed among other biological species. Bluntly put, other animals undergo mental-like processes which form coherent sets of abilities, animal forms of cognition which are interrelated and of which human cognition is one.

Yet a third, and considerably more controversial answer is that cognition has an even more general standing, encompassing as it does non-biological forms. But do these forms actually exist? Of course not, at least they didn't *before* the quest for them began. And even today, there is nothing strictly *factual* about whether they really do exist. 'Intelligent' artefacts are 'intelligent', many will claim, only in a derivative way, and as to their possessing some form of 'cognition', something which they share with natural beings, that is even less clear. So we are left with two ways of granting some consistency to the notion of artificial cognition: either we insist that only a narrow, bio-centric fatalism can blind us to the possibility of non-natural cognitive systems; or we argue in favour of an abstract or formal view of cognition, say as information-processing of a certain sort, such that (i) natural cognitive systems are cognitive by way of instantiating the formal definition, and (ii) artificial systems, either already existing, or conceivable, also instantiate the definition.

However this essential debate, initiated by Turing's famous 1950 *Mind* paper, is finally settled, the impartial observer can clearly discern two related research goals: one is to elucidate the properties common to natural intelligent organisms (theoretical cognitive

science in the strict sense); another is to plan, construct, analyse and improve systems which are behaviourally equivalent, or nearly so, along one or another dimension, to natural cognitive systems: they function *like* real (natural) cognitive systems, they thus exhibit *ersatz* cognition, and leave it to the philosophers of mind and historians of science to work out whether it is fruitful to maintain a hard and fast difference between *ersatz* cognition and the 'real', original, genuine article. Meanwhile, there is plenty of mutual inspiration between the two populations of workers, and this suffices, when examining converging technologies, for example, to justify adopting the wide construal of the field. For our purposes, AI is part of (applied) cognitive science, and formal theories of reasoning, or artificial life, or complex systems, are also branches of, or feed into, the domain.

I.2.2.c Cognitive science and its environment: direct and indirect contributions to the field

The mention of a discipline 'feeding into' rather than plain 'belonging to' the field of cognitive science is motivated by the recognition of one last important feature of the intellectual landscape. According to yet another organising principle, some disciplines lie closer to the heart of the topic than others: these 'core' disciplines take as their immediate object the natural systems which embody cognitive functions, while others provide tools to the core disciplines. Thus psychology and neuroscience, on the one hand, parts of linguistics or anthropology, on the other, belong to the core. While logic, formal models from computer science, statistics, mathematics, complexity theory, as well as some programs in linguistics, economics, social science, plus of course the whole of 'artificial cognition', belong to the outer ring, remaining in more or less direct contact with the core.

The study of minds and brains raises a tremendous array of questions which only the best specialists in these highly theoretical fields can illuminate. Their contribution is not only a boon to the 'core' cognitive sciences; they also boost the tool-providing fields themselves. Computer scientists, physicists and mathematicians are confronted with entirely new problems. For example, how can a column of a definite number of elements (of neurons) transform an input signal of intensity $\boldsymbol{x}$ into an output signal of intensity $\boldsymbol{y}$? Or: How can a three-dimensional shape be retrieved from a two-dimensional pattern of retinal activation? Or again: How can one retrieve the electric activity inside the skull from the measurements of the electric field on the skull? Or: How can one integrate data from several imaging techniques applied to a single brain process? These are genuine mathematical problems which were raised in the course of neuroscientific investigations and tool-making. Neural coding, computational geometry,

evolution of complex systems, learning algorithms for neural nets are some examples, among many, of new topics brought about in this way.

The very notion of modelling, or model construction, already so well developed in the empirical sciences (from meteorology to geology, aeronautics, particle physics, materials, etc.), has undergone a considerable transformation to respond to the need to accommodate models of cognitive activities and systems. Another important case, one deserving examination for its own sake, is that of evolutionary theory, which has been tremendously stimulated by problems posed by cognitive psychology and anthropology. Indirect benefits are thus the effect of developments in cognitive science on traditional disciplines. They are a tremendous source of new problems, as the more enlightened among the representatives of these disciplines have come to realize.

What is true for the hard sciences is if anything even more relevant for the sciences of man. Cognitive science, of course, directly contributes fresh insights into the individual's mental capacities, which in turn play a role in other inquiries in social science. No less obviously, philosophy and linguistics, being active participants in the cognitive enterprise, have undergone a profound renewal. The recent emergence of cognitive economics or cognitive sociology, as well as the gradual transformation of social psychology, are other, less immediate consequences of the rise of cognitive science. But it seems likely that many more areas within the social sciences and humanities should be, in the long run, affected by cognitive science. Both because they will have to deal with, accept, reject or transform, approaches, conjectures and concepts produced by cognitive science, but at a more global level because they will benefit from the energy and methods of this newcomer. Cognitive science, it is essential to understand, is not out to *replace* the main branches of social science, let alone humanities. But it does have the potential to challenge some of their set ways and entrenched convictions, and to encourage novel approaches and institutional arrangements.

I.2.3 The uneasy relations between cognitive science and the Three Technologies

I.2.3.a How did cognitive science get involved in the first place?

Numerous attempts have been made, also in other reports by the CONTECS consortium, to carefully map the multiple intersections and relations within the NBIC Foursome (see in particular Deliverable 3.1 Part A). The least one can say is that the presence of the Cogno component is not at all a straightforward matter. No better evidence for this is the fact that Cogno is essentially ignored or misrepresented by many scientists working in Nano, Bio or Info, together with the symmetric phenomenon of a

near-complete ignorance, on the part of most cognitive scientists, of the NBIC/CT problematic, indeed, of the very notion or even the label.

Thus it might be of some interest to ask anew why the creators of the NBIC concept felt the need to tack on Cogno to the already potent mix of the Three Technologies. There are, we surmise, three reasons why they did.

The first is that a large part of the projected contributions of IT (Info) has to do with building devices which can assist individuals and groups in their handling of information and their decision processes. In other words, IT comes in, to a great extent, to supplement certain cognitive processes, and the need is felt to characterise such processes.

The second reason is that the Bio component contains a particularly promising component, *viz.* intervention on the nervous system by pharmacological or hybrid bio-physical means. Cognitive science is the theoretical framework within which the science of brain function is developed; thus it seems reasonable to take on cognitive science if one wants to develop good brain-connected devices.

The final reason, which may seem to coincide with the first but is considerably broader and is deeply enmeshed in the very idea of NBIC, is that the entire enterprise aims at "improving human performance": thus an understanding of pre-NBIC human performance is required, so as to channel the quest for adequate augmentations or enhancements in a fruitful and benevolent direction.

I.2.3.b The cognitive science which NBIC has in mind

Despite lip service being occasionally rendered, in the enormous NBIC literature, to cognitive science, the initiators of the concept actually have in mind a very special understanding of the field. This becomes clear when one asks what actual role is assigned to cognitive science. It splits into two disjoint parts, brain science on one hand, "intellectics" on the other -intellectics being a word coined by Wolfgang Bibel[3], by which he understands, essentially, artificial intelligence informed by cognitive science. This seems not unreasonable until one notices one glaring lacuna, that of psychology. The very idea of cognitive science is to develop the agenda of psychology with the help of new methods, or rather new perspectives, provided by the study of formal processing of information on one hand, workings of the brain tissue and structure, on the other, and with the guidance of evolutionary biology, anthropology and linguistics. Technological interventions on the nervous system, plus computer-based 'intelligent' devices

3 Steffen Hölldobler (Editor), *Intellectics and Computational Logic - Papers in Honor of Wolfgang Bibel,* Springer, 2000.

do not together make up a cohesive approach within cognitive science. Nor do they amount to a new organic outgrowth of cognitive science, which would be some "cognitive technology", as Bainbridge suggests[4].

I.2.3.c Why NBCI and all related CT programs require the collaboration of the entire field of cognitive science, and not just some 'technological' outposts

The absence of psychology may appear from the outside as a complaint typical of the frustrated specialist, one seeking to restore the pristine purity and pre-eminence of his field. But it actually touches on a deep issue. There is a distinct possibility that the promoters of NBIC are unaware of the central issue in cognitive science, which is precisely to erect an (approximately) true ***psychology.*** They often sound as if they have not taken in the lessons of the early phases of AI, which had been similarly hasty about psychology and paid the price by all but vanishing from the cognitive science scene.

The mistake then, and again the temptation now within NBIC, is to take for granted, or at least to consider as basically correct, the pronouncements of our commonsense psychology. It turns out that despite its being indeed correct in some kinds of situations, and despite the crucial role it plays in our self-understanding as both singular individuals and as members of the human species, commonsense or "folk" psychology is either outright mistaken, or more often simply mute on a considerable set of phenomena crucial for scientific psychology and thus more broadly cognitive science, and eventually for large parts of the CT ambitions. To be sure, there is an awareness, in the general public and within CT circles, of some notorious results showing that we are prone to making certain mistakes, typically in evaluating our own motives for our choices, or in estimating the likelihood of some event, or again in predicting what our behaviour, or that of others, would be in certain situations, etc. These are lessons which were drawn, for better and for worse, from Freudianism and from social psychology, decades ago, and the more recent work in cognitive science has brought a fresh batch of similar phenomena, more finely described and explained. The problem is that these more flagrant, and easily characterised misconceptions barely scratch the surface of our misconceptions, or plain ignorance, of the underpinnings of our mental lives. In particular, commonsense delivers precious few reliable intuitions on the basic ontology of the mental: remembering, learning, understanding, reasoning, inferring, computing, deciding, seeing, etc., do not seem to be the sort of basic things from which we can deve-

4 Bainbridge, William Sims, Roco, Mihail C., eds., *Managing Nano-Bio-Info-Cogno Innovations,* Springer, 2006: page 204.

lop a scientific understanding of the mind without at least some serious preliminary reform.

Rushing into computer models or computer-based devices which purport to extend our cognitive abilities without a serious theory of the appropriate part of our cognitive apparatus is bound to fail. As Bainbridge concedes, "Cognitive technologies augment the capabilities of the human mind, and thus they require a proper understanding of how the mind works[5] (Pinker, 1997)"[6]. But the reference to S. Pinker's best-selling book betrays a misconception of where we stand with respect to the question: we don't know very much yet about how the mind works; we feel a bit more confident about how to go about finding out. So while it may be possible, in areas where a technology is an outgrowth of a highly mature science, to take one without the other, and blend it with technologies from different scientific origins, this is not an option with cognitive science, pure and applied.

I.2.3.d Cognitive science can and must contribute to CT on four distinct levels

Once the dynamics of cognitive science is firmly established, it is possible analytically to discern direct points of contact between applied cognitive science and the Three Technologies, as has been meticulously done in other documents. This first level of interaction is uncontroversial, being constitutive of the NBIC and CT perspectives, and explicitly laid out in their manifestos, actually, the direct contacts are really with Bio and Info, Nano being in the role of an indirect enabler. They break down into three areas. The first involves mainly information science and includes topics falling under the label of artificial intelligence, construed quite broadly so as to cover human-computer interface (HCI), human-centred computing, cognitive engineering, besides such well-identified headings as natural language processing (NLP), computer-aided decision-making, design, teaching etc., artificial vision and classical robotics. The second concerns neuroscience: directly, where the CTs intervene as applications at the integrative level (cognitive repair or enhancement, motor and sensorial prostheses); indirectly at the cellular, molecular levels, or again in pharmacology and medicine. The third combines the information-scientific and neuroscientific poles, with neuroinformatics understood as covering neuroscientifically plausible neural models, neural information processing, informational tools and foundations of functional brain imagery, neurorobotics, neural

5 Steven Pinker, *How the mind works*, New York: W. W. Norton & Company, 1997.

6 Bainbridge & Roco *2006: 204.*

implants, etc. Also included would be such applications as e-health, as well as various forms of ambient intelligence.

The second level where cognitive science comes is the one where the proposed technological solutions are adjusted, either pre or post facto, to their human ends and capabilities, This is what Bainbridge points out in the above quote, and is put indirectly yet clearly by Peter Gardenfors in the incipit, which is worth copying here: "We can expect that in the future, cognitive science will supply man with new tools, electronic or not, that will be better suited to our cognitive needs and that may increase the quality of our lives, In many areas, it is not the technology that sets the limits, but rather our lack of understanding of how human cognition works." In the present discussion, the tools are to be supplied not just by cognitive science, but by the CTs combined; and cognitive science's distinct additional contribution lies in the adjustment of the technological devices to the natural cognitive processes which they are supposed to facilitate or even sometimes replace.

The third level where cognitive science can be active is the conceptual and critical examination of the ongoing research programs in CTs. Cognitive science, in contradistinction with the Three Technologies, has an active philosophical component whose expertise lies precisely in this sort of examination. These "in house" philosophers are in a position quite distinct from the "embedded" philosophers which Info, Bio and now Nano have taken along in their campaigns. Cognitive philosophers (and some of their colleagues from psychology, linguistics or anthropology) are both actors and surveyors of their field. They have developed a keen sense of what conceptual and disciplinary ingredients can or cannot contribute to a given goal. Thanks to their strong background in philosophy of science, they have acquired a special sensitivity to the problems of interdisciplinarity, reduction, consilience, unity, strong programs with modest results, historical amnesia, etc. In particular, they have been engaged in a prolonged investigation of the issue of naturalism, and the discussions of this topic which adorn the CT debates seem very rudimentary by comparison. It is a pity that the philosophers engaged in cognitive science have not yet paid much attention to CT, and they should very much be encouraged to do so.

Finally, as has been mentioned already, cognitive science can function as a paradigm of 'deep' interdisciplinarity –where 'deep' is a 'thick' concept with both descriptive and evaluative elements descriptively, a program is interdisciplinary in the deep sense if its starting point is a fairly well-delineated problem whose solution eludes any singly established discipline; evaluatively, deep interdisciplinarity is about getting things done rather than spending too much time in characterising the precise modus operandi, intentional states, etc., which have made it possible.

I.2.3.e Persisting problems in the family: Cognitive science and the Three as uncomfortable bedfellows. No Nano says Cogno

Despite, and probably to some extent because, of this large potential of cognitive science for CT, the relation between the partners have not been particularly warm or intense. The most obvious reason is that cognitive science is the sole member adorned with the 'science' label. This creates both conceptual and socio-psychological problems, which Bainbridge[7], in a moment of repentance, aims at redressing by claiming that, from the start, there were science AND technology in all four of the cardinal directions: nanoscience next to nanotechnology, etc, and conversely cognitive technology next to cognitive science. This is a dubious claim, and anyway does not make the problem disappear. The implication of nano-technologists, bio-technologists, info-technologists is unproblematic, that of cognitive scientists is. The Three view cognitive science with suspicion: intellectuals lost in their speculations, with little to show of industrial value. Conversely, cognitive science still reels from the negative association with its former, now failed leader, artificial intelligence. It firmly believes that AI (in its first avatar) was NOT, contrary to its fondest hope, the royal way to what it called 'natural intelligence' (roughly, human cognition); and that simulating before having gained an understanding of what it is that one is simulating was a serious mistake, with the added consequence that AI failed also in its main objective, *i.e.* to endow machines with intelligence.

There is another, conceptually deeper reason why cognitive science tends to keep its distance. One basic tenet of CT as conceptualised in the original Roco & Bainbridge report is the role played by the nano-scale as the nexus of convergence. This assumes that the nano level is the relevant one for the understanding of not only physics and biology, but also cognition. This idea of a supremacy of nano by virtue of its purported ultimate material grounding is beginning to be questioned in the CT community, as witness the following passage from one of our interviews (Angel Wilkinson, 11 June 2007):

> From the US perspective yes the nano is the strongest - the ability to control things on an ever smallest scale possible has definitely come through. But there are other literatures: you can get to the small through biotech and not through material science. And the US perspective is nano through material science route, not nanotech through nanosciences route. It's very difficult to separate them out once you get to that le-

7 *Loc. cit.*, 204.

> vel. You can't get to nano through the biotech. It's a manipulation on the molecular level. And this involves computer science because you need that way of looking at the small scale to understand what molecules you are manipulating. And it's got a form of engineering in it if you want to get to the molecular production. The US tried to major on nano, but increasingly the recognition is that nano is not a thing. It's something on a small scale. It's on a combination with something else that it creates the potential.

This primacy claim of nano is bound to be met with an even higher degree of scepticism by most cognitive scientists, for both practical and theoretical reasons.

Today, very little of cognitive science concerns itself with phenomena happening at the nano-scale. This is the exclusive province of molecular neuroscience, which lies in the outer fringes of cognitive science. Although it is recognised that information transmission happens at a molecular level in the brain, few cognitive scientists will find the fact relevant to their work. Within the core disciplines of cognitive science (systems neuroscience, psychology, linguistics) it is often argued that cognitive systems exhibit several different levels for analysis, and that the lower levels are by and large irrelevant to the higher ones.

To put this in more concrete terms, a knowledge of the intricate mechanisms of synaptic transmissions is of no use when one is interested in the acquisition of grammar, and vice-versa. Even though language operations might ultimately be implemented at a level that involves synaptic transmission of information, this does not imply that a theory of linguistic processing must include molecular mechanisms – these are actually quite separate things.

The strong physical reductionism present in the CT literature is therefore unlikely to resonate well with the dominant strands of cognitive science. It may be perceived as a form of what the philosopher Daniel Dennett[8] calls "greedy reductionism", is an attempt to explain away phenomena by claiming they "boil down to" some lower level. To say that, for example, cognition "simply boils down to" molecules has no explanatory power; rather, it robs cognitive science of its subject matter.

One must also take into account a wariness on the part of scientists towards the claims of CT. Researchers have become sceptical of trends in science policy, and like to believe they can play the system by exploiting those trends to their advantage. One interviewee noted that CT reminded him of 5th-generation computers, whereby American

8 Dennett, Daniel C., *Darwin's Dangerous Idea,* New York: Simon & Schuster, 1995.

computer science labs took advantage of a general mood of competitiveness with Japan to obtain increased funding, even though none of them actually believed in the feasibility of intelligent 5th-generation machines. That interviewee added that in the same way very few people among those who benefited from nanoscience funding actually worked at the nano level. Another confirmed that this was a very common attitude, at least among French scientists: jumping on the nanotechnology bandwagon is seen as just a way of giving the system what it wants in order to carry on the type of research scientists are actually interested in, which might have very little to do with nanotech.

Promoting a CT agenda centred around nanotechnology, which, as we note above, is of no relevance to most cognitive scientists, may encourage exactly that type of attitude. Proposals and applications will be written with CT "pasted on" otherwise typical cognitive science projects.

It would therefore be important to encourage a policy and cultural shift towards areas where convergence between cognitive science and NBI is actually happening, rather than on sometimes fuzzy appeals to the unity of nature.

I.3 An overview of cognitive science in Europe – its strengths and weaknesses

The state of European cognitive science is best understood with reference to its historical development. We begin with a brief history of the field.

I.3.1 A glimpse of history: three phases in the development of cognitive science[9]

Cognitive science emerged long before its current label was minted, *viz.* roughly sixty years ago (the label was slowly adopted beginning in the late 1960s). Its development has gone through three stages, the third of which has just begun:

Phase I. From, roughly, 1943 to 1970, there appeared all the major themes and research agendas which can in retrospect be seen as forming the matrix from which cognitive science as we know it emerged. This was the era of the pioneers. The cardinal notion of the computer was central, Artificial Intelligence was the integrating 'interdiscipline' in charge of providing the conceptual 'glue', and the 'computational paradigm' was the 'only game in town', while generative linguistics was the prime example of a thorough reconceptualisation of a traditional disciplines in a cognitive-scientific perspective.

Phase II. From the early 1970s to the end of the 1990s, cognitive science underwent a process of quantitative development, accompanied by the formation of academic institutions such as graduate programs, institutes, departments, journals etc. Psychology and philosophy took pride of place, while on the modelling-engineering side 'connectionism' or 'neural nets' or 'neurocomputing', as it came to be variously known, challenged the 'symbolic' or 'classical' approach typical of Phase I.

Phase III. In the last few years, cognitive science has, on the one hand, shifted its centre of gravity towards neuroscience and, on the other hand, reached an explosive stage in qualitative and quantitative growth. A wealth of new topics and frameworks have emerged, while much mainstream science pursues directions opened during phases I and II.

Let us take a brief look at this historical development from the European standpoint.

Phase I. Europe took off to a very good start. Although the field is often presented as an American invention, and while many of its sources were indeed American, in fact the very idea, if not the name, of cognitive science can be traced to European minds, such as the British mathematician Alan Turing and his student Donald Michie, a pioneer of AI and machine learning, the Swiss developmental psychologist Jean Piaget,

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9 This subsection is drawn, with minor modifications, from Andler 2005: §2.c.

the Russian social and developmental psychologist Lev Vygotsky, the French biologist and Nobel laureate Jacques Monod. Moreover, some of these prominent thinkers were also organizers and set up pioneering centres for example in Edinburgh, Geneva, or Royaumont near Paris. Europe was then at the forefront of research in (what is now known as) cognitive neuroscience and especially neuropsychology, developmental psychology, general cognitive psychology, generative linguistics, robotics, neurophysiology, mathematics for complex systems, a form of pre-cognitive, naturalistic anthropology, experimental economics, etc. It was essentially free of the American obsession with behaviourism and the generally anti-theoretical stance of many American research programs in psychology and the social sciences. It also had developed strong views on the necessary integration of disciplines, and included antidotes to the 'tunnel vision' which was to dominate the field in the subsequent phase, by emphasising the importance of social and cultural factors in development.

Phase II. In the US, during the 1977-1987 decade, the Sloan and the Systems Development Foundations gave out large grants (over 17 million dollars for Sloan, 26 for SDF) to a number of academic centres (Stanford, UC Berkeley, UCSD, MIT, Penn, Northwestern, Carnegie-Mellon, Yale, U. Texas at Austin, etc.) for setting up interdisciplinary institutes in cognitive science. The NSF and the DOD also made large funds available for pure and applied cognitive science, which allowed departments of psychology, brain science, linguistics, computer science, physics, electrical engineering, applied mathematics to expand in the direction of cognitive studies, in particular to bias their hiring policies in favour of scientists with an interest in cognition. Philosophy got interested to the point where soon philosophy of mind, with its close associate philosophy of language, became the most active branch in many departments, displacing philosophy of science. Interdepartmental graduate programs, and in some cases full-fledged departments in cognitive science were set up. Similarly, Japan, prompted in part by an ambitious vision of AI (the so-called 'Fifth Generation'), in part by a strong tradition in robotics, in part by an interest and know-how in the brain sciences, set up powerful centres such as the Riken Brain Science Institute (Riken BSI) in 1997. More recently, the McDonnell-Pew Foundation has devoted considerable resources to the development of cognitive science in English-speaking countries.

Meanwhile, in Europe, similar developments were taking place, but on a considerably smaller scale, and at a slower pace. The two main factors which prevented cognitive science in Europe from gaining the sort of dynamics which it was acquiring elsewhere are, first, the reluctance of funding sources to divert serious amounts of money away from the established disciplines, and more generally the lack of mobility of the national scientific communities; and second, the specific resistance put up by the establishments within each discipline against the cognitive turn which some in the discipline

wanted to take. Cognitive science had for a long time a rather poor reputation in many scientific subcommunities, and those, near the top, who were inclined to favour it, were outnumbered. We'll take a closer look at this resistance in the next section, as it is far from having entirely subsided.

What did save European cognitive science, to such an extent that, despite its relative weakness, it remains a major player on many fronts, was a combination of factors, mainly:

- The traditions developed during Phase I, in limited circles, were kept alive and renewed locally by small interdisciplinary groups, often led or encouraged by philosophers. New journals and learned societies helped scholars and students think of their work as fitting most naturally in the framework provided by cognitive science.
- A decisive orientation towards cutting-edge cognitive science was taken by some first-class centres in one or the other of the contributing disciplines (e.g. psychology, especially in Britain; neuroscience, especially in Germany, France and Italy; linguistics, especially in France, Italy and the Netherlands, soon followed by Germany; logic and computation, especially in Britain, the Netherlands and France; etc.)
- On a much broader scale, the role played by Britain, which alone in Europe was able to develop strong programs in nearly every area of cognitive science, but especially in cognitive psychology and cognitive neuroscience, as well as computational models and philosophy.

Phase III. Several phenomena coalesced towards the end of the 1990s and led to an explosive development of cognitive science worldwide:

- During Phase II, cognitive science met mostly with success. Threats or accusations of failure which had hindered it in during Phase I became rare. This left room for an exponential growth which reached a critical point around that time.
- Neuroscience took possession of new imaging tools which opened up a new frontier towards which literally tens of thousands of scientists converged.
- Cognitive science was finally perceived as an unequalled source of inspiration for several basic disciplines, on the one hand, new technologies on the other (thus the NBIC movement). Correlatively, cognitive science opened up internal frontiers and released a number of scientists, mostly of the younger generations, from the strictures imposed by a misplaced sense of loyalty to their discipline.
- The Asian giants (Japan, China, India) decided to give priority to cognitive science (not necessarily under that name) and threw in, or announced their intention to invest, some immense resources in the field.

Europe is now at a distinct disadvantage. Despite the efforts deployed during Phase II, it seldom succeeded in creating world-class centres large enough to reach critical mass, to attract a high enough proportion of the very best students, and to federate all the relevant disciplines and paradigms. The number of technological platforms and sophisticated equipment is way below target. The best young scientists, often Europeans with an extensive international experience, have all too many professional reasons to choose North America, Australia, Japan over Europe to take root and found labs and schools. Some of the most innovative traditions are dying out without replacement. The barriers between pure and applied research are still in place in several, though not all, the old scientific leading nations.

The European Community, held back by the subsidiarity principle, was unable to make up for the lack of determination of national policies. It also overemphasised finalised programs in areas which were insufficiently theory-intensive to lead to durable progress, at the expense of vastly more promising and less costly basic research.

These negative factors have common roots, which will be explored in the next section. This disadvantage is nevertheless far from being definitive. Europe numbers many excellent groups, a strong academic organisation and a modernised industrial structure. It attracts good scientists from all over the world, despite losing too many of its own children to the brain drain, and nothing essential, save quite generally better work and institutional conditions, would seem to prevent Europe from participating fully in the constitution of a science of the mind/brain well articulated with technology, on the one hand, and social science on the other, and able to contribute to solving pressing problems in education, health, security, governance, etc.

I.3.2 Assets and handicaps of European cognitive science

The question which we now turn to is this: What are the possible trajectories for cognitive science in Europe? A reasoned answer is beyond the capabilities of our team, but we hope that the Consortium will provide the necessary resources, while examining the broader issue of opportunities for European development in the converging technologies. What we can contribute at this early stage is a preliminary analysis of the negative and positive factors, whether institutional, sociological or cultural which we see as specifically European and which are likely to hinder, or to enhance, progress in cognitive science. We shall start with the most pervasive and general factors (which for the sake of this document we label 'cultural') and move on to the less pervasive (and thus possibly easier to counterbalance).

I.3.2.a Liabilities (I) Why cognitive science goes against the grain of European scholarly culture[10]

One of the impediments to the development of cognitive science in Europe is the hostility it faces from parts of academia. That attitude has cultural roots, to which we now turn.

Philosophy: the analytic/continental divide

It is widely agreed that by and large, there are two basic styles current in contemporary philosophy, one, roughly, inherited from German idealism, the other from British empiricism, Central European logical positivism or empiricism, and American pragmatism. The first, sometimes called 'Continental', tends to be historically inclined, is mostly attentive to phenomenology and existentialism, gives priority to the construction of broad worldviews over arguments and concrete examples, has closer links with art, particularly literature, history and politics than with science, towards which it generally feels in opposition. The second, labelled 'analytic'[11], has no enduring interest in the history of philosophy, regards most of the post-Kantian tradition as mistaken, considers itself as continuing the modern rationalist tradition by following in the footsteps of Russell, Moore, Frege, the Vienna Circle around Carnap, Neurath and Reichenbach, the Polish logic school, favours problem-setting and problem-solving over world-making and cultural agenda-setting, believes in stepwise progress and cumulativity in philosophy as in the sciences, to which it feels in close proximity both stylistically or methodologically and in topic choice, and is generally inclined towards interaction with inquiries and skills concerned with concrete issues in contemporary life.

This 'divide' is anything but clear-cut and definitive; in fact, many observers believe that it is destined to remain a feature of XXth century philosophy and that we are already witnessing a wide redistribution and crossing-over. Perhaps so: we may well be seeing the end of a 'hundred year war'. The hard fact of the divide remains, and has been decisive in shaping the intellectual landscape in which cognitive science emerged.

For contingent reasons (the most important of which is World War II), although analytic philosophy owes most of its initial inspiration to thinkers from Continental Europe, it has taken root, over the last 50 years, in English-speaking countries. Continental philosophy, on the other hand, is labelled after its geographical distribution: it is the reigning philosophical style in countries such as France, Germany, Italy, Spain. As might be

10 This subsection is taken from Andler 2005: §3.A.a, with minor changes.

11 'Analytical' in British English.

expected, Northern Europe (the Netherlands, the Nordic countries, Poland) lean on the analytic side, while retaining some ties with the Continental tradition.

The relevance of this excursion in the typology of philosophy is this: analytic philosophy has had, on the whole, a beneficial influence on the development of cognitive science, and this is directly correlated with the fact that Britain and Northern Europe have been and remain more hospitable to cognitive science than the rest of Europe.

Although this may well change, the analytic/continental divide is a crucial factor, mostly a negative one in our perspective, and one which should be borne in mind in policy-making: (i) the Continental tradition had impeded the development of cognitive science by hindering cross-fertilisation with the sciences of man, and creating a climate of ideological hostility; (ii) because of this, the divide has projected onto the European map of cognitive science: analytically-oriented countries have tended to foster cooperation with the sciences of man, continental-leaning countries have pushed cognitive science into the arms of the natural sciences and mathematics. The European cognitive-scientific landscape is, for this reason among others, highly diverse.

Of course, the most immediate effect of the divide stems from the direct involvement of philosophy in cognitive science. As a matter of historical fact, and for pretty straightforward reasons (having to do with the problem-solving attitude, regard for science and empirical data, expertise in matters logical, linguistic and broadly scientific, relative freedom with respect to tradition), a crushing majority of contributions and contributors from philosophy belong to the analytic side of the divide. The flip side is that a rather huge proportion of the philosophical population, in Continental countries, has kept out of the cognitive revolution, with consequent impoverishment of both: analytic philosophy has drawn considerable benefits from cognitive science, in terms of vitality, jobs, opening up to new ideas (including continental ones!), second only to what cognitive science has gained. If more philosophers, and more of philosophy, were to participate, no doubt the benefits would grow in proportion. To what extent this can be encouraged remains however to be determined.

Psychology: opposition from psychoanalysis

Cognitive psychology, which started out as a school within a subfield of experimental psychology, and has by now all but engulfed it entirely (leaving out various orientations in applied psychology). However, it has met with constant and resolute opposition from psychoanalysis and psychiatry, and in many European countries, especially with Continental loyalties in philosophy, the best students interested in the workings of the mind have been drawn away from scientific psychology. Combined with the pull exerted by strong traditions in physiology and neurology, the psychoanalytic current has all but

dried up experimental psychology in many countries such as France or Italy, and to a far lesser extent in German-speaking countries, again sparing the British Isles (which also harboured a vigorous psychoanalytic school). Budding cognitive psychology has felt the need to insulate itself from psychoanalysis and psychoanalytic psychiatry, with their militant anti-science stand. This, again, has resulted in missed opportunities and mutual impoverishment. Again, the divide is perhaps less strongly felt, and less deleterious, in the Nordic countries.

Social science: social constructivism and the Continental influence

Indifference at best, cold and not so cold war on some occasions, have been the preferred form of intercourse between the cognitive and the social sciences in Europe. Relations have not been exactly friendly elsewhere, but European social science has tended to regard cognitive science with particular mistrust. The reasons are two-fold. The first, which is not specific to Europe, is that cognitive science has seemed for a long time, with some exceptions as always, to ignore the social dimension of human existence and thought, and has tended to focus on the individual, as generic member of a species, rather than the social, historically situated individual. This was, and is, in no case easy to integrate in a social-scientific world-view. What made it particularly unpalatable to many social scientists working in Europe was the deep-seated conviction that man is through and through a socially constructed being, with no non-trivial determinations stemming from his belonging in the natural order. This went along with a broadly progressive-liberal view in politics and an enduring fascination with themes from existentialist and constructivist thinkers. This was, and is, chiefly a matter of doctrine and scientific judgement. The second reason has to do with intellectual styles: the Continental influence, in the philosophical sense, has pervaded much of continental social science, making it reluctant to engage in a step-by-step, empirically based, argumentative critical dialogue with the analytically-minded cognitive scientists.

The perverse effects of the primacy of theory: the impoverished and insulated applied sciences and arts. Gresham's law

Up to this point, we have been considering trends and tensions within basic science. In most of Europe, again, the part where philosophy tends to be the Continental variety, theoretical knowledge is often regarded as superior to, and clearly separate from, practical knowledge and skills. The best minds are strongly invited to join the ranks of theoretical fields, leaving the more modest pursuits of applied knowledge to more modestly endowed intellects. Needless to say, this hierarchy is not based on reason or efficiency, and is nothing but a cultural bias, not a universal law, although it certainly comes in the wake of a long tradition in the West, with traces in the US and elsewhere.

Theoreticism hits Europe particularly hard. The result is an impoverishment of the applied fields, such as education, health, engineering, the liberal arts, etc. This is true in all areas, but our concern here is with cognition. As the theoreticians are loath to stoop to 'educate' the 'professionals' (and possibly also up to their necks trying to remain cutting-edge under unfavourable circumstances), the task is left to some more or less well-meaning popularisers, or worse, fuzzy-minded or mediocre theorists, who give cognitive science a bad name. According to Gresham's law, bad money drives out good: any decent presentation of cognitive science, of its goals, assumptions, and possible contributions, is simply inaudible today for a large fraction of the general public and for many professional sectors. Neuroscientists, some of them famous, great producers of trade books, transmit a competent and appealing but often biased image of cognitive science, as nothing over and above neuroscience conducted by cultivated, imaginative and humanistic biologists. With some exceptions, the better, or least noxious, popular books on cognitive science tend to be the work of philosophers, psychologists and linguists.

I.3.2.b A general pessimistic outlook in Europe?

In practical terms, its goal is to secure a much more faithful and complete picture of human nature, whose cognitive-neural determinants far outweigh any other (such as, say, mechanical-metabolic), in order to identify or better circumscribe some of the sources of human ills and pains, collective and individual, mental and physical, and some of the resources which could be tapped within the human body/mind. This knowledge, both negative (the dismissal of ignorance, error and prejudice) and positive (the understanding of the capacities of the mind/brain) is presumed to bring with it recommendations, if not fail-safe recipes, for improving the lot of mankind.

This runs counter to European 'wisdom'. First, Europeans have learnt the hard way that scientific enterprises do not necessarily lead to obvious improvements in the human condition: evil and powerlessness do not recede as a mechanical effect of the advance of knowledge. In that sense, in so far as there is a contemporary European Zeitgeist, it is profoundly alien to the optimism of Enlightenment. Second, scientists and intellectuals incline towards skepticism (which is nothing but epistemic pessimism) regarding any claim of radical novelty in the distribution of scientific roles: they are firm disbelievers in 'new sciences' of any stripe. Scientific revolutions, and breakthroughs do occur, but seldom do they dislodge established disciplines, according to this view. Previous proclamations in the same ballpark as (what is commonly perceived as) cognitive science, such as cybernetics, general systems theory, or artificial intelligence, have not led to the promised landslide, thus fortifying the skeptic's refusal to take seriously what he sees as the latest fad. Third, cognitive science straddles the natural and the human

sciences, thus crossing what many European thinkers see as an inviolable border: the naturalistic stance of cognitive science is repulsive to them. Worse, any breakthrough in the naturalistic account of human phenomena (e.g. the unreasonable efficacy of chemicals in alleviating mental illness) they see as mostly bad news: freedom, and the privilege of social and historical conditions as sole genuine constraints limiting that freedom, are both put in question. Crucially, all of this applies to CT as well as to cognitive science. We will return to that issue in a later section.

I.3.2.c Liabilities (II): Institutional and sociological features in Europe inimical to cognitive science

There is no point here in rehearsing the general negative factors in the academic and R&D institutions in Europe which affect cognitive science in roughly the way they hinder other fields. We shall focus instead on factors which constitute handicaps affecting more specifically, although not necessarily only, cognitive science. Yet it must be stressed that emerging disciplines are more vulnerable than well-established ones to defective management practices and other overall dysfunction of science policy, including of course inadequate and/or poorly distributed funding.

Resistance to cognitive science as a kind of scientific venture

The most salient features of cognitive science as a scientific enterprise are, uncontroversially, its youth and bottom-up, unplanned emergence, on the one hand, the involvement of several disciplines on the other.

Both of these traits make it less than appealing to most European scientific structures. First, these institutions are traditionally-minded and hostile to innovations, despite claims to the contrary. Established disciplines are top-down affairs, with senior members and tradition dictating what counts as 'real' or 'good' science. The centralisation of most decisions, in national as well as transnational structures, only compounds this authoritarian spirit. Decisions make at the top tend to reinforce intermediate and local establishments, entailing winner-take-all effects to the benefit of 'star' disciplines and specialities.

Cognitive science, by contrast, has no recognised intellectual 'pedigree'. It comes along with fascinating problems which hadn't been thought of, and ideas for solving them which usually belong to no known tradition of 'real' or 'good' science. Its achievements are discounted on the same grounds: how can they compare with the deep theorems of mathematics, the stunning empirical discoveries of molecular biology, or the conceptual feats of particle physics?

Second, and more severely, the hostility of the scientific establishment to inter- or even multi-disciplinarity (despite a recurrent pretence to encourage them) makes it hard for cognitive scientists, especially in the early stages of their career, and even more for students, to obtain decent conditions and minimal guarantees of finding a job or getting promoted, as the case may be. The choice of cognitive science remains, to this day, decidedly more hazardous than that of most other fields, with the result that, statistically, it loses to them a fair proportion of the better students who, attracted as they are, prefer a career less adventurous albeit possibly less exciting intellectually. A rational system would, on the contrary, put a premium on students and scientists willing to put in the considerable extra effort of mastering several trades and maintaining a sometimes difficult dialogue with a variety of partners which do not partake of the same tradition, don't speak the same language, have different ideas of what counts as good evidence, convincing argument, worthwhile result, and do not depend on the same authorities and are not subject to the same criteria for their promotion and professional well-being.

I.3.2.d High and low-brow science

Science is aristocratic the world over, but more so in the Old World than elsewhere. The various branches of science enjoy widely different prestige, and the hierarchies, although differing somewhat from one national tradition to the next, tend to remain quite rigid.

This poses a serious problem for cognitive science in Europe, as compared to countries where such a rigid scale would seem bizarre. Indeed, not only do its key subfields not belong to mother disciplines among the most highly-prized (note however that the pecking order is beginning to change under the pressure of the student masses, who are deserting the star fields), but a creative practice of cognitive science rests on a deflationist view of disciplines. Someone imbued with thoughts about whether some concept, explanation or novel idea is part of *real* 'mathematics', 'physics', 'linguistics', 'anthropology', ' philosophy' or 'biology', is presumably not going to immerse himself productively in cognitive science. Thus there is a need to shake away the aristocratic, fixist conception of disciplines still too prevalent among European students and scholars.

The cultural divide

Cognitive science straddles not only disciplines, but scientific cultures. The natural sciences and the sciences of man contribute about equally to cognitive science. This collaboration, although not unique (economics, demography, geography provide other examples), sits uneasily with a tradition, strong in Europe and well-entrenched in Con-

tinental philosophy, which follows the German philosopher Dilthey (1833-1911) in finding a difference in nature, not just degree of development or topic, between the *Geisteswissenschaften* and the *Naturwissenschaften,* the sciences of Man and Nature. Cognitive science cannot accommodate such a sharp bifurcation, although there is some room for negotiation. In practice, the sciences of man must at least be willing to consider the possibility that the natural sciences may have a contribution to make to some of their investigations, and vice-versa.

The situation is further complicated by the intervention of yet two other cultures. One is engineering, admittedly close to natural science, but with a very different perspective. Engineers design complex mechanisms which perform preassigned functions, and are rather indifferent to laws: to take up a distinction owing to the famous and recently deceased evolutionary biologist, Ernst Mayr (1904-2004), engineers are interested in 'proximal' causes. Physicists are mostly after 'distal' causes: they seek a theoretical understanding of why the mechanisms which are at work are doing what they are doing, rather than something else, and why these mechanisms and not others have been recruited to do what they are doing; they are interested in *general constraints*, in explanations which are as overarching as possible. Biology sits somewhere in between, and in fact the brain is forcing a redistribution of roles and priorities between these fields. There remains, nonetheless, a rather profound cultural difference between the engineer's and the natural scientist's approaches, and again, divisions in Europe are more rigid than in other parts of the scientific world, impeding progress.

Similar remarks can be made concerning the fourth culture implicated in cognitive science, namely, the health sciences. Physicians, psychiatrists, physical therapists, speech therapists, prostheticians, optometricists, etc. are a very different lot again. Their theoretical interests are very limited; they obviously have a lot in common with the engineers, yet they share with the human sciences a concern with human beings, but with a specific emphasis on the ailing individual, and the demand that something be done *now*, whatever the state of the *theoretical* art.

The problems this mix of cultures raises are essentially the same as those which arise from interdisciplinarity, only made more intractable by the increased distances in both intellectual and institutional terms. At university, taking computer science and psychology may be hard, but not as hard as psychiatry and linguistics, or engineering and anthropology... And similarly for the more advanced stages of the cognitive scientist's career.

"Ugly duckling" status of participating branches within the parent discipline

Cognitive science involves various specialties belonging to a number of traditional disciplines. Now the inequalitarian attitude which prevails, in most European countries, regarding the core disciplines, extends, within each of those, to their subfields. And as luck would have it, those subfields which take a part in the cognitive science enterprise tend to enjoy low status within their parent discipline or at least, a low level of popularity among students, the professional elite and policy makers. This seems to be true across the board, *i.e.* for all major disciplines, and in most of Europe, with the occasional exception of Britain or other parts of Northern Europe. Thus the sorts of philosophy, psychology, biology, mathematics, physics, anthropology, social science, and computer science which intervene in cognitive science have generally low standing within their respective parent discipline. The problem here is two-fold. On the one hand, as for previous obstacles, these hierarchical divisions severely limit the flow of gifted students, fecund ideas, and above all, funds, towards the subdisciplines most relevant to cognitive science. On the other hand, the need for each of these subdisciplines to fight for respectability and material and human resources leads them to claim for themselves, within cognitive science, a lion's share of the credit, and to resist criticism from other subsectors. This is not conducive, to say the least, to the kind of harmonious collaborations on which cognitive science depends to make serious progress.

Speaking with too many voices

As we have seen, cognitive science has many faces. This is both an asset and a liability, and has nothing to do with Europe in particular. In the US and Japan also, cognitive science is sometimes presented as an outgrowth of neuroscience, sometimes as a modern form of psychology, sometimes as the long-awaited wedding of neuroscience and psychology, sometimes as a joint venture of linguistics, informatics and logic, sometimes as artificial intelligence and advanced computer science, sometimes, as in this report, broadly and somewhat abstractly as the convergence of many disciplines on a given object of inquiry. These various presentations are compatible, and moreover a multiplicity of overlapping subterritories is a major factor of robustness and creativity.

But this is not always how the policy-maker sees it, when she meets with a succession of leaders in the field. When lobbying for funds and attention, they speak with what inevitably appears, to her, as several, often dissonant voices. Faced with the problem of helping what sounds to her as a divided community, the policy-maker may then well decide to put things in perspective and do little or nothing until the dust settles. Nor is this an idle concern: there are enough

examples to show that cognitive science, compared with other fields, is very poor at making its voice heard.

I.3.2.e Assets of European cognitive science

The last point extends to what comes now, viz. a brief assessment of specific assets and opportunities of European cognitive science. However, details are less important and we can be much briefer, for two reasons: first, when things are going well, the best one can do is to leave them in peace; second, insofar as cognitive science can offer some successful enterprises as examples or models for the CTs, in the normative sense this time, these are best presented in concrete terms, and this is what Part B of this report attempts to do. It is important, nonetheless, to convey a sense of reasoned optimism and to identify some very general factors which can play in Europe's favour.

What is already working well: European centres of excellence

Europe boasts a rather large number of centres and teams which contribute to the cognitive sciences at the very highest level, and whose contribution is second to none. The scientists involved, whether junior, confirmed or senior, are by vocation as well as necessity highly connected internationally, and thus intellectually mobile and forward-looking. The pool of well-trained, open-minded, highly motivated, autonomous students is considerable.

In many areas, in particular within robotics, neuroscience, psychophysics, statistical and dynamical models, logic, developmental psychology, pharmacology, linguistics ... (the list is not supposed to be complete), Europeans are in the lead or among the world leaders. This is due, in general, to a combination of a strong paradigm initiated locally with the existence of a centre good enough to have reached international visibility and thus benefit from a flux of top-notch visitors. Examples abound[12].

What may turn out to be an advantage: European diversity

Europe is, overall, in the position of the challenger: thus it tries harder than the leader, with some striking results. Trying harder means, in this case, thinking longer to produce better work, making the best of perennially scarce resources, and finding ways of exploiting synergies. Thus we find scientists looking for deeper principles, elaborating better experiments (more likely to succeed, more robust, more general), finding novel theoretical conjectures, seeking to exploit new (and forgotten) sources of inspiration.

12 A partial list, with some details, can be found in Andler 2005.

We discover that Europe organizes more innovative conferences; that it produces about half of the best journals in the field; that some of its centres and graduate programs combine interdisciplinarity and excellence at a level unknown in the US.

Next, some of the features of European intellectual traditions, institutional set-ups and research policies which were listed above as having a negative effect on the development of the field could play, in a slightly different context, to its advantage. Old-world sophistication, which gets in the way in the early stages of a new discipline, can be an advantage in mid-game. Strong traditional disciplines may have powerful tools to contribute when the theories become mature and complex enough, as well as high-powered minds to apply them, seldom a trivial job. Having kept a number of traditions alive, European scholars can make them available to the international community while taking advantage of their expertise when it turns out that one such tradition has a contribution to make; a case in point is phenomenology: it turns out that Husserl and Merleau-Ponty offer considerable resources to the cognitive science of consciousness, agency and self. The European reluctance to close institutions down allows the survival of intellectual 'species' which would go extinct in a more ruthlessly competitive environment. As we know from ecology and epidemiology, maintaining variety in a population can bring many advantages. Many strains of scientific thought are alive, though not necessarily successful, in the recesses of European campuses and institutes. Thus Europe keeps a stock of ideas, most of which will remain sterile, but some of which may get a chance as some of the initial ideas lose their momentum. Conformism, which tends elsewhere to kill diversity, is limited in Europe, paradoxically enough, by provincialism. National or local pride and respect for tradition keep some scholars and schools from rallying the most recent bandwagon, and induce them instead to push their ideas further.

Last, but not least, next to this variety of ideas, Europe exhibits a variety of social realities unequalled among the advanced regions in the world. Its cultures, languages, mores, social skills, administrative traditions, political and financial systems, etc., present a tremendous number of significant differences; yet remain comparable along most dimensions. This concrete experience of variety is a priceless source of insights for cognitive science, and also provides it with opportunities for applying Mill's method of differences, by way of experiments (thought experiments, laboratory experiments, experiments set up for non-scientific purposes by the societies themselves as they adopt or try out some particular change) and comparative observations. Of course, in order to exploit to the full such possibilities, cognitive science must establish a close collaboration with the social sciences.

I.4 Live issues raised by cognitive science in relation to CTs and beyond

I.4.1 A critical eye: Reconceptualising the problem situation

The goal of a document such as this is to contribute, to some degree, to the elaboration of policies which will turn out to be beneficial to the peoples of the European Union. It is not in the first instance to adjudicate the extent to which Roco and Bainbridge, or other prominent thinkers in the field, were right or wrong. We take our topic of inquiry to be NOT the set of texts and thoughts of these authors, but rather what they are pointing at, viz., the coming technological advances and their impact on our societies and their members. As Nick Bostrom put it in his interview with CONTECS members, disregarding for a moment his emphasis on visions which may not be productive and focussing instead on conceptual structure:

"If the wider goal for EU is to use it as a concept, or not, it is better to have a discussion on a different ground, not as a yes or no to converging technologies, but if there are any alternatives of other exciting higher concepts that could be used. To focus on creative vision of what a European research can develop. There have to be alternative visions from creative people on alternative ways of organising things. Then one can choose between rather than saying yes or no."

On the other hand, Roco, Bainbridge *et al.* have effectively oriented the discussion to such an extent that we cannot hope to escape entirely their way of conceptualising it if we mean to enter in a fruitful collaborative search for the best policy recommendations. We must therefore steer a path between slavish commentaries (no matter how critical they may be, in a sense they remain enslaved to their object) of NBIC, CTEKS, etc., and offering an entirely new way of considering the matter and a new vocabulary with which to discuss it, as if nothing had been said up to now. This is what we mean by 'reconceptualising': we feel we should try and shake off the hold of certain misconceptions which go along with the established rules of the game, without altogether appearing to change the topic. We are seeking, in other words, to secure some degree of elbow room for our thinking about these complex issues, and to free ourselves to some extent at least from the conceptual grid imposed by the over-abundant literature from and about the NBIC think-tank.

I.4.1.a The very idea of CT

As we have already suggested, thinking about cognitive science and CT by giving the nano level a central role may not be the most appropriate theoretical outlook. The key

finding of previous work on CT, and of work done during the course of the CONTECS project, is that much of what is interesting and new in science and technology today is happening across disciplinary boundaries rather than within. That does not imply that cross-fertilisation is a new phenomenon, nor does it indicate necessarily that scientific disciplines will soon disappear as institutions. It just might be the case, despite the well-documented failures of previous reductionist programs, that nanoscience will in the end play a central role as the foundation for a unified science. But what is clear is that local convergence processes are real, and that they generate technological advances at an unprecedented pace.

What is needed is then to look at concrete advances being made to try to get a sense of where CT might be going. CONTECS has made progress in that direction by cataloguing recent developments, and by building a picture of convergence as a social process – who is involved and why. More is needed, but already we can begin to sort out the relevant questions from the not so relevant ones.

I.4.1.b Europe versus the US?

As a member of the high-level expert group (HLEG) which produced the Nordmann 2004 report on the European vision of CT, the first author of the present document fully endorses the notion that the question at hand can, and should be envisaged in the context of the European Union, a context which for a great number of reasons is rather different from the US context. In fact, in part I.2 as well as in several preparatory documents and related talks, we attempted to show that cognitive science, as the last link in the CT chain leading to social applications, is especially sensitive to, and holds the greatest potential for European values and needs. Here we only wish to issue a warning against going overboard, and pitting a European vision (wise and benevolent) against a US vision (loathsome). In particular, the temptation to link Europe with a high moral stand and the US with the mere pursuit of technological, economic and military superiority is to be resisted. As the example of neuroethics shows, US scholars are full participants and often prime movers in the ethical and societal debate, and having generally been on the front-line of technological progress, they have an acute awareness of its downside. And they are no less concerned than their European counterparts, witness their active interest and achievements in the quest for alternative, technology-based methods in education, with the potential of technology for progressive social change. Conversely, Europe has seen, in just one generation, the emergence of a less than compassionate and progressive political and philosophical current, which tends to promote values and goals traditionally associated with a US world view.

There are in fact, we submit, more commonalities than differences between the US and European situations regarding CTs, and this is important to bear in mind when we seek ways of engaging fruitful interactions between SSH and CTs.

I.4.1.c Speculations, unknown knowns, and unknown unknowns

It is of course quite natural that the most spectacular claims made around CT have attracted the most attention. A universal communication machine, able to bridge not only the language divide, but also inequalities in knowledge. Unlimited prospects for human enhancement, including push-button learning, a high-throughput "sixth sense", dematerialisation and immortality, etc., etc. We will have something to say later as to certain misconstruals regarding our cognitive functions which those ideas rely on, but, even more importantly, the nearer prospects should not be neglected in favour of far-fetched possible worlds. This is important to keep in mind again if our goal is to engage SSH scholars in an inquiry about CT: most of them will be put off by the far-fetched visions, regarding them, not without reason, as insufficiently supported, and we don't want them to simply ignore issues which they can, and should, address, and which only they can pursue in a robust way.

We can bracket out the possibility of extreme forms of human enhancement: CT brings enough to preoccupy ourselves with. We need to invest the greater part of our effort in investigating "TechLife": what can our lives are expected to look like when what is in gestation in CT now reaches maturity? This is a "known unknown" : we know, at least roughly, what those technologies are going to be; what we do not know is their impact on our personal lives and on society.

"Translife", the future lives of trans-humans, however, is an "unknown unknown". What enhancements are possible is open to question, and so is the issue of whether society will let those developments happen at all. We suggest that, regardless of how fascinating the question may be, not too many resources should be devoted to the issue of transhumanism; we have more pressing matters to deal with.

I.4.2 How to get the ball rolling between SSH and CT by taking one's bearing on cognitive science

I.4.2.a Incremental knowledge in the sciences of man

The sciences of man, Wittgenstein famously said, "are forever in their infancy". This is not the place to develop the well-worn analysis of the problems which have beset these disciplines from their beginning: apparently unable to stabilise and become truly cu-

mulative, like the natural sciences. As we know, these traits are actually in part the reflection of yet another problem, which has to do with the inability to communicate with the lay public: there is in fact more stable knowledge and more accumulation than is known outside the narrow circle of specialists, and this may have to do to some extent with the structure of the subject matter, yet does not seem to be beyond remedy altogether.

Although we have no specific suggestions to offer at this stage, we believe it is worth pausing for the briefest moment to reflect, at this juncture, on the hoped-for effects of CONTECS and beyond. We would like to see a set of coherent, proactive, usable lines of investigation develop within the sciences of man, regarding the technological advances which are going to shape, for better and for worse, the world our children and grand-children will inhabit. This will require precisely the kind of relative stability and cumulativity which seem to forever elude the disciplines which we would like to engage massively, and not only by their (vanguard? lunatic? desperate?) fringe.

Now in order to meet this challenge, there are a couple of levers at our disposal, which are, not fortuitously, intimately linked with the very topic which we would like to see the SSH take on.

The first is that cognitive science offers the hope of a partial naturalisation of the sciences of man. We cannot hope to develop this important point in detail, but we do want to stress some essential qualifications:

- the naturalisation which we have in mind is about as distant from the one envisaged by the importers of the Wilsonian concept of 'consilience' as it is from post-modern constructivism;
- it is minimally reductive;
- being partial, it is compatible with a number of common assumptions carried by the SSHs self-understanding;
- it leaves open the deep ontological and ethical issues regarding what is to be thought of as 'nature';
- it does not merely rest on the prospects of neuroscience: naturalising cognition does not boil down to developing a natural science of the brain;
- finally, such a program is not just a dream: one can clearly discern, in the more advanced forms of cognitive psychology and anthropology, as well as in modelling approaches the beginning of an execution, which provides a flavour of what a semi-naturalised cognitive science, and its extensions to the sciences of man, would look like.

The second is that information, communication and cognitive technologies will contribute, as they probably already have (the extent to and manner in which they have should be thoroughly investigated), to our means of structuring, consolidating, communicating and customising the inherently fragmented products of the sciences of man, so that their core findings as well as their myriad detailed conclusions can be accessed and deployed outside the academic professions, bringing them in return a new form of 'experimental' resource.

I.4.2.b Novelty, cycles and permanence

Leaving aside the tired cliché that history repeats itself, it is fairly safe to say that things are rarely as novel as they are made out to be. This maxim applies of course to CT, and calls for caution in two ways. First, among the technological developments promised by CT, which can be considered genuinely novel, and which are simply old ideas re-branded? Second, if one considers CT as a social phenomenon, what new developments does it bring to the sociological organisation of science? Disciplinary boundaries have been crossed before, so is it just a matter of scale and intensity?

On another level, the world of science and science policy is highly subject to trends and fashions, from cybernetics to general systems theory, catastrophe theory, chaos theory and more. Many have gone by, without delivering on much of what was once promised. Does CT stand to fall into the same trap or is it really different this time? Research into the field needs to examine itself and tread carefully when it makes predictions.

Finally, there is an almost unavoidable bias, in the foresight business, in favour of novelty over permanence. The bias is quantitative: it tends to overestimate the 'proportion' of evolving over permanent features. But it is also perspectively: evolution always takes place, both as an objective phenomenon and in our understanding, against a backdrop of invariance. This explains at once why flying elephants are not something we need to worry about (no more than prime ministers replaced by computers, as AI once proposed) and why we so often misjudge the effects of a new technology: we get our invariants wrong.

I.4.2.c Three kinds of issues

There are three distinct kinds of issues to be debated when it comes to the "known unknowns" of CT.

First, what will we actually achieve? Of all current developments within CT and cognitive science, which are promising, which are likely dead ends and which are uncertain

in the strong sense where no probability assignment can be made? We need to provide plausible answers to this question that if we are to answer anything else.

Second, what problems (practical as well as ethical) will these achievements raise in terms of new possibilities for action? The technologies that impact the most on our lives are those that "enable" rather than those that are incremental improvements on pre-existing technologies; e.g. vectorised drug delivery vs. nanoparticles for sunscreen. A focus on the former will help answer that question.

Third, what problems will arise from our new knowledge of ourselves? Cognitive science, by building a scientific model of the human mind, will upset the commonsense notions we hold about our thoughts, our actions, our identity. It may provide new means to control and shape behaviour. This is bound to create problems, at the individual and societal level, that will have to be looked into.

Let us propose labels for these three categories of questions : the CAN problem, the DO problem and the KNOW problem. Examples are salient in the neuroethics literature (see e.g. the University of Pennsylvania Neuroethics program site: http://neuroethics.upenn.edu/). Can we improve human memory by a factor of 100 by neural grafts or controlled neural growth during development? Is a CAN question. Given that an apparently effective anti-sleep molecule now exists, what would the impact be of making it widely available? How will we assess students who can go without sleep? Must we then force all students to take the drug? Must we prohibit it? These are DO questions. Finally, given that neuroscience has begun to provide precise data regarding consciousness and decision processes in the brain, how will our self-understanding accommodate them so as to preserve, or discard, our present concepts of personhood, responsibility and freedom? That is a KNOW question.

I.4.2.d Where to start? Taking inspiration from fruitful ongoing programs

What CONTECS is after may sometimes appear as Mission impossible. Consider GMOs: the complexity of the conceptual, scientific and technological issue was by several orders of magnitude less than that of CT, yet it is generally acknowledged that we failed to address it adequately. Nanoscience is worried that its promises will only be met by either fear or scepticism. CT as a whole is immensely more difficult to tackle, and besides involves ideas and attitudes which are generally repugnant to the mainstream of SSH in Europe. So how can we hope to meet with some success in our enterprise?

We believe a good starting point might be to look at research programs on related or similar questions which seem to be fruitful and to attract high-quality investigators. We can think of a few examples, but it would be worth identifying them more systematically, and emulate and examine them to find out what are the likely factors which account for their relative success. Our examples are from applied ethics and certain programs in cognitive science itself. We do not share one of our interviewees' dismissive appraisals of neuroethics:

> If you look at cogno, there are two main SSH directions: neuroethics, which are every bit as shallow as bioethics, and the strange desire to locate everything problematic about human behaviour and cognition in images of the brain. (Jazanoff interview)

and from an examination of the current work we believe to the contrary that neuroethics, a branch of bioethics, is setting an example to follow. The work is interdisciplinary, focused, communicated in a rigorous fashion, and to some extent cumulative. There is now a good circulation of ideas coming from philosophy, from pure and applied ethics, from clinical medicine, from biological research and from assessment, innovation and foresight studies. A similar case could probably be made about a field which we have not looked at from close, that of environmental studies and in particular environmental ethics. As for cognitive science, it can be argued that the interactions between philosophers and empirical scientists have at their best illustrated the sort of synergy which we would like to encourage in the work we want to promote.

I.4.3 Issues related to the "known unknown"

I.4.3.a Cluster of issues #1: Self-understanding of self, kin, society

Being oneself

The notion of the self is basic to both intuitive and scientific psychology. We have an immediate sense of being "one" (unity of the self), and of there being a clear boundary between ourselves and our environment. The cognitive sciences, and especially cognitive neuroscience, have begun to tackle that concept.

Neuropsychology and psychiatry have uncovered a number of "disorders of the self" that sometimes arise following brain injuries. As an example, some patients are afflicted with so-called alien hand syndrome: they express the belief that a paralysed mem-

ber is not theirs, but actually belongs to someone else, showing a disturbance in their sense of being in control of their own body. Schizophrenic patients sometimes express similar delusions, claiming that someone else is in control of one of their body parts. The study of neurological and psychiatric cases helps to better define the sense of self in normal function, and in the case of the former, may highlight certain brain areas necessary to proper function.

Cognitive neuroscience experiments have tried to identify brain centres associated with processing of concepts associated with the self, in order to determine whether the sense of self was supported by dedicated brain areas[13]. Cognitive ethologists have been interested in self-related processing in non-human species: an example of that is the famous "mirror test", where the animal has to identify its own image in a mirror. Elephants have been shown to pass that test[14], along with chimps and orang-utans. The extent to which non-human species show some form of self-consciousness is still controversial, but advances in the field might shake some beliefs we had about our own specificity.

As a 2002 *Nature* editorial on the scientific study of the self noted : "That our own identity can be dissected into its component parts, that these components can be studied separately, and that many of our intuitions about our own mental lives will prove wrong, these are revolutionary ideas that will require patient explanation, and we should not expect them to be accepted easily or quickly".

Being part of (multiple circles)

Social cognition is the part of cognitive science that deals with the cognitive tasks that arise in a social context. It encompasses social neuroscience, much of social psychology, developmental psychology, parts of ethology, and is closely related to the social sciences, especially those that focus on the individual agent. Examples of questions raised by social cognition asked are: How do we ascribe beliefs and intentions to other agents? When and why do we act in an altruistic way? How do we understand and retain facts about our relationship to people, and relationships between others?

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13 For a review, see Gillihan, S. J., & Farah, M. J., "Is self special? A critical review of evidence from experimental psychology and cognitive neuroscience", *Psychological Bulletin* **131** (2005), 76-97.

14 Joshua M. Plotnik, Frans B. M. de Waal, and Diana Reiss, "Self-recognition in an Asian elephant", *(Proceedings of the National Academy of Science* **103 (**2006): 45.

This area of cognitive science is one of the least developed, but it is also among the fastest-growing. It is not unlikely that the kind of social changes brought about by CT will drive the demand for a better understanding of social cognition. We are witnessing massive alterations in the ways humans communicate and form groups: in the space of two decades, the Internet has given us email, the blog, social networking and virtual worlds. Taken together, they have abolished the constraints of geography and distance in the formation of human groups while increasing those of connectedness and shared networks.

The massive increase in possibilities for communication that CT is foreseen to bring about can only exacerbate those tendencies. Our social environments will be profoundly modified: this is prime material for the study of social cognition. How will we understand ourselves, our connections, our allegiances, our relationships, the manifold bonds that form the social fabric, when the majority of communications are electronic rather than face-to-face?

Wanting, striving, aiming, hoping

It is cliché, and thus slightly embarrassing, to stress that human beings are primordially desiring creatures: we want, strive, aim, hope, and of course fear and dread; we also experience regret, shame, resentment, humiliation, pride, elation, sadness and suffering. The relevance of this 'hot' dimension of our experience cannot be understated when it comes to assessing the impact of technologies on our lives, from the most mundane details regarding the daily comforts of the Western consumer, to the most lurid deployments in enterprises of subjection and violence, and to geo-strategy, mass indoctrination, and all forms of conflict.

Whether or not this is adequately captured, globally, on some level, by the principle of utility maximisation (which has of late come under possibly lethal criticism from philosophy, behavioural economics, anthropology and cognitive science), there is an increasing awareness of the need to apply a much more fine-grained approach to the dynamics of individual and group preferences than has been traditionally assumed.

Technologists are aware, of course, of the need to take account of what they think of as the emotional or affective side. For example, robotics is putting some efforts in endowing robots with properties akin to certain basic emotions in humans, in particular the ability to invoke empathy in human users (school children for example). However, here as in so many other cases, the problem is that technologists tend to rely on fairly rudimentary notions of emotions, empathy and so forth, drawn from anecdotal evidence, second-hand reports and of course their own experience and intuitions.

The good news is that cognitive science has made impressive progress on the emotional-affective front, throwing light on the complex structure of human motivation. Of particular interest is the attention devoted to *variations* in contents; it is *not* assumed that motivations are roughly similar across spatio-temporal contexts. Tools are available to combine findings concerning invariance in cognitive structure and variability in content and even forms of normativity, making it possible for mainstream social scientists, historians and anthropologists especially, as well as philosophers, to engage in a fruitful discussion with cognitive scientists. The battle lines of the age-old war of relativism versus nativism or objectivism (sometimes misnamed 'positivism') have moved to such an extent that one wonders whether there still remains a fight worth fighting. Again, the level of sophistication and the sheer energy of current research in the field are quite striking. SSH related to CT should give a high priority to the establishment of conditions under which CT could profit from it.

Rights and wrongs

It is often stressed that already under the present conditions, human rights are at severe risk. For example, newspapers regularly publish editorials in the form of obituaries of the modern notion of privacy. Of course neuroethics is to a large extent occupied with the issue. It need therefore not be argued at length that issues of human rights, and of wrongs inflicted to human individuals and communities, are of the utmost importance, and that CT are by themselves quite incompetent to deal with them at the required depth. The level of awareness regarding these matters is certainly high in CT circles, but the resources are lacking. However again it is not enough to call in legal philosophers, ethicists, political scientists etc. and ask them to deliver their verdicts or offer their visions in abstracto. Cognitive science has something to say about the very idea of human rights (cp. the work on self or personhood, on the onto- and epigenesis of morality, on altruism etc., issues closely connected to that of human right). What is required in this instance is a long-term collaboration between SSH, cognitive science and the Three Technologies.

I.4.3.b Cluster of issues #2: Knowledge and competences

IT in education, the school of the future, life-long learning

There is considerable interest right now in using the Info component of CT, with some input from Cogno, to remedy, enhance and in various ways change the traditional methods used in schools, and more generally in educational systems, including informal and off-campus settings, and involving remedial education for the physically or mentally impaired, as well as the socially disadvantaged or otherwise ill-adapted students and

adults. Microsoft has been running for several years an international program, Partners in Learning, which sponsors activities and study groups devoted to the issue of new technologies (essentially of course computer-based) in learning. A yearly 'School of the Future World Summit' gathers hundreds of 'innovative teachers' around decision makers, school leaders, educational psychologists, technologists, architects etc. to think about what the schools of the future could and should look like, and to inspect and compare experimental programs and practices already in place all over the world. On the other hand, it is clear that these experiments have up until now made only modest inroads in the fortress of traditional education. It should not, and is usually not taken for granted that technology is the magic bullet, and that the old system is all bad. Still, there is a very real need, felt just about everywhere except perhaps in the most elite institutions, for new ideas about teaching, and even more pressing, for an educational system able to adapt to, and capitalise on, the technologies which students, teachers and adults in general use extensively outside of the academic system. Surprisingly perhaps, it is apparently no simple task, despite the mostly very positive effects of technologically simple devices which are being increasingly introduced in schools.

There are, we submit, two broad set of reasons for this state of affairs. First, the required social, political, institutional knowledge is still not in place, despite the century-old efforts of philosophers, educators, economists, social scientists; and particularly, the knowledge hasn't been articulated with the corpus produced by academic schools of education. Besides, quite obviously, education is not merely a matter of getting the right theories in the right minds at the right time. Education is a matter of politics in the highest sense of the word; it involves action in a politically structured community. Here, it might be thought, CT has little to contribute. However, SSH has a lot to contribute and it should be goaded into devoting more resources, and high-caliber manpower, to such questions.

The second reason for the slow progress is the insufficient involvement of cognitive science. One leading thinker in the field, John Bruer, head of the James S. McDonnell Foundation, argues that cognitive science is to education what biology is to medicine[15]. He also authored in (1997) an influential paper entitled "Education and the Brain: A Bridge Too Far,", in which he argued, persuasively we believe, that neuroscience cannot directly inform educational policies and methods, but that it needs the mediation of psychology. Bruer's ideas are controversial, but they are respected and they do set the scene for what is to come: a considerably higher level of interaction between cognitive

15 *Schools for Thought: A Science of Learning in the Classroom*, Cambridge, MA: Mit Press, 1994.

science and education science. CT is, of course, an indispensable participant, both as part of the problem (what to do about it when we think of educating people tomorrow, in TechLife, where education is both formal and informal, 'front-loading' and life-long) and as part of the solution. Finally, it should be stressed once again that cognitive science alone cannot get the job done: a tremendous role goes to SSH.

Knowledge management

The impact of the Internet on the modes of acquiring, producing and transmitting knowledge is hard to overstate. Not so long ago, the major problem for scholars and students was to get access to sources of knowledge – finding a rare book, tracking down references in the depths of libraries. The Internet has turned that problem upside down: now the hardest part is by far to filter and fuse over-abundant sources of information. In academia in particular, the exponential trend in publication growth makes it near-impossible for researchers to keep up with anything beyond their own narrow field, and to find the rare innovative publications in a sea of derivative, low quality works.

Technical and social solutions are arising: search engine technology has improved tremendously, social evaluation tools help filter content, and the incredibly successful Wikipedia online encyclopaedia has managed to harness the distributed knowledge of volunteers to produce useful, up-to-date syntheses. Although this goes some way towards solving the problem of finding information, it does not do help solving the problem of determining what sources of information can be trusted, nor how to resolve possible disagreements between sources. The challenges that lie ahead for the information technologies are a at the confluence of the social and the technical: how to integrate social mechanisms of trust, reviewing, and rating with automated techniques for relevance determination and information retrieval?

This brings us close to cognitive science. Considering the cognitive challenges of the new information environment brings us even closer: we have come a long way since the Renaissance, and the basic cognitive skills of our age may be changing. In the antiquity, at a point in history were written documents were expensive to produce and hard to procure, learning often meant learning by heart. Greek intellectuals elaborated sophisticated cognitive techniques designed to help them remember entire speeches or documents[16], that survived until the Renaissance and the invention of the printing press. The Jewish and Islamic traditions also emphasised rote learning of extremely large pieces of religious and legal writings. Centuries of Renaissance-inspired educa-

16 Frances A. Yates, *The Art of Memory,* Pimlico, 1966.

tion in Europe, with its accompanying cornucopia of Latin grammar rules, also required good capacities for rote learning in students. Today, it seems that Google dealt the final blow to that tradition: for what is the point of knowing something by heart, when that piece of information is a few keypresses away?

The cognitive demands have changed: it matters less to know something, than to know how to find out about it. We have come to rely more and more on external memories, rather than on our own. Whether this a good thing is, of course, debatable. For example, the consequences on the learning of foreign languages might not be entirely positive : adult learning of a foreign language requires rote learning of countless abstract lists and rules, and no amount of search engine prowess is going to change that.

Educational systems are already trying to adapt to the new conditions, although this has largely consisted so far in finding clever solutions to keep up with the convenience of modern Internet plagiarism. Shaping new programs and renovating curricula to cope with the changes will doubtlessly benefit from the input of the cognitive sciences. They will have to work hand-in-hand with the sciences of education, and with the information sciences, in order to rethink learning environments.

I.4.3.c Cluster of issues #3: Politics and economics in TechLife

CT and the technologist illusion

What we call the technologist illusion is the belief that problems that are political and social in nature can be solved through technology. That illusion is very present in some of the writings on CT but is of course far more general. The root of the illusion lies in the seemingly simple solutions that technology provides to genuinely difficult political or moral problems. We will illustrate here a few examples linked to CT.

One particularly telling example can be found in the use of technology in the judicial system, and, more generally, in deviancy control. It is evident that some technological advances have been of real help to the judicial system: this includes all the modern tools of scientific forensics, from fingerprints to DNA tests. Along with that progress, there has been a tendency to offload moral responsibility to a supposedly neutral or objective technology. In a criminal trial, the stakes are very high, objectivity is unattainable, and it is tempting to relieve oneself of responsibility (as a juror, or as a lawyer, or as a judge) by relying on "scientific evidence". This is forgetting that scientific evidence is context-dependent, and is useless outside of human interpretation – DNA tests may have high reliability, but a judicial decision still involves a human being deciding the fate of another.

A similar tendency is at work in the technological control of "deviancy". Scientific history is ripe with examples of claims of the possibility objective measures of deviant tendencies, along with bogus etiologies made according to current scientific fashions. From phrenology to craniometry to the beginnings of criminology[17] in the 19th and early 20th century, to the current trend for biometrics or automated detection of "suspicious behaviour", there is an uninterrupted historical line. On the side of society, there is the temptation to offload some of its hardest problems to science, on the side of science, there are overblown claims of efficacy by some researchers. This explains why the polygraph "lie detector" is still in use despite the fact that its complete lack of objectivity has been public knowledge for half a century[18], and why claims of the existence of a "criminal gene" are so popular with the media[19].

One must therefore be wary of similarly naïve approaches to governance and democracy. It is for example unclear whether online voting will improve turnout and decrease the perceived distance between citizens and their representatives. On a similar level, making the workings of legislative institutions more transparent by putting very thorough proceedings online risks being completely inoperant if most citizens lack the background knowledge (or the time and inclination) to make sense of said information. For democracy as for justice, the hardest problems have no obvious technological solution.

Politics, economics and CT : the short and mid-term

With that word of warning in mind, it remains that technological change most definitely has political and economical consequences. The reflection on CT and society must go beyond the level of ethics and deal directly with those consequences. As we argue above, the most urgent thing for foresight efforts to focus on are those technologies that are either in development now or virtually around the corner.

The state of technology in 10 or 20 years' time is relatively predictable. Given that, what countries/parts of the world are more likely to benefit? Within countries, what groups will be affected and how? What is the potential impact on international relations and on trade? What will be the role of CT in the global challenges ahead, and, first and

17 See for example, S.J. Gould, *The Mismeasure of Man,* Penguin,1981.

18 John L. Andreassi. Psychophysiology: Human Behavior And Physiological Response (Lawrence Elbaum, 2006)

19 *Cp.* also France's Nicolas Sarkozy's declaration that paedophilia is genetic in nature (published in an interview with philosopher Michel Onfray in *Philosophie Magazine*).

foremost, climate change? On a normative level, what changes may be required in the European political and economic systems ?

Questions as these can only be fruitfully answered by broadening the focus from technology studies to global trends in politics and economics. The SSH must be enrolled in the effort, in order to set the CT debate in its proper context, to inform it by reference to history, to economic theories of technological change, to views from political science, sociology and anthropology, etc. We need to enrich the debate by taking in more varied viewpoints.

I.4.4 Issues related to the "unknown unknown"

I.4.4.a The new AI in the light of the old and the current

Artificial Intelligence is a textbook example of a research program that oversold itself into academic marginality. Its early proponents famously claimed in the 1950s that machine implementations of human intelligence were well within the reach of the scientific community. While AI had some early successes (the General Problem Solver, a program that proved theorems in propositional logic, or the first programs that could beat humans at chess), by the mid-1970s it was clear that AI had failed to hold up to its promise. The discipline went through a little 'Ice Age' of its own, suffering diminished funding and a decrease in academic prestige. This backlash was accompanied by hard criticism aiming at the core of AI, the idea that human intelligence was reproducible in machines. Philosophers such as Hubert Dreyfus and John Searle cast doubts on the very premisses of the endeavour[20].

This pressured a number of AI practitioners into redefining their field in a more modest way. For some AI is the study of "everything computers can't do yet" (which certainly lowers expectations as far as concrete results are concerned). Others chose to recast their subfield as "machine learning", "computational statistics", "artificial neural networks", or "machine vision", letting go of their AI label.

What AI brought to the scientific world

Given this rather bleak assessment, what is the outlook for AI among the converging sciences ? It must first be noted that AI, while having fared well below the expectations

20 Dreyfus, Hubert L. *What Computers Can't Do,* New York: Harper & Row, 1972; augm. edition: *What Computers* Still *Can't Do,* Cambridge, MA: MIT Press, 1993. John Searle, "Minds, Brains, and Programs", *Behavioral and Brain Sciences* **3** (1980), 417-424.

it had set for itself, has not been entirely barren, far from it. Machine learning is now a well-established field that has had tremendous impact on the older discipline of statistics. Most modern successful methods for non-linear regression and classification have come from advances in machine learning and artificial neural networks. Computational linguistics has begun to produce some useful results, including concrete applications like automatic translation or natural language query systems. Machine vision is now able to solve some real-world problems reasonably well (e.g., face or character recognition).

It must also be chalked down to AI's credit that it provided a lot of the early work on graph theory, on heuristics, on discrete optimisation, and on automata theory; all of which have either moved into their own subfields or found applications where they were not expected (languages and automata theory are crucial to the design of compilers and interpreters for computer languages)

AI started out with two sub-programs : one aimed at a formalisation of human knowledge, and the other at teaching a machine to learn "by itself" simple, well-delimited tasks. It is only the former that has failed; the latter has given us most of the successes cited above. What we suggest here is that perhaps the time has come when will see the first useful applications of formalised human knowledge.

The future of AI

Regarding the future of AI, a few factors likely to have a large impact can be readily identified. We'll discuss two of them briefly, but we will devote more space to the specific role of a possible convergence between applied AI and the other cognitive sciences.

The first factor may seem obvious, but its role must not be understated. Increases in processing speed and storage capacity allow machines to be more "intelligent" everyday. AI methods that used to be costly in terms of processing power and/or memory capacity are now everyday technologies in computer science (graph traversal techniques, for example). We will see this process accelerate as (A) personal computers go on growing in power and (B) consumer appliances turn more and more into small-scale digital workstations. Tomorrow's digital everyman will be surrounded with little pieces of computational intelligence. Those mechanisms might not be cutting-edge AI, but constant interaction with many of those mechanisms will keep the user within a permanent, almost transparent "technological cloud".

Large-scale AI will become prevalent in research and industry applications. Cheap, extensive storage solutions, combined with the rapid expansion of digital content have made extremely large datasets more than a possibility. Already, companies have very

large amounts of consumer data available, and that only keeps increasing. Large-scale computing solutions have gotten considerably cheaper with the advent of clusters supercomputing. Accordingly, Customer Resources Management and Data Mining are now two of the hottest topics in business, and both draw heavily on AI research. Moreover, the generalisation of ERPs (Enterprise Resource Planners), and the high organisational and environmental complexity that modern multinational firms face, will provide both the demand and the required data for AI "decisional aides".

The second factor has already been hinted at in the section on knowledge management: perhaps the most important force driving research in applied AI today is the demand from search engines and other sectors that need to organise knowledge automatically, to make it available for query, and to rank difference pieces of information according to their respective relevance to the user. Research centres funded by Google, Microsoft, and Yahoo produce some of the most advanced research today in Machine Learning and Natural Language Processing.

Influence from the cognitive sciences

The third factor is closer to our preoccupations. We mentioned that AI had succeeded in building machines that learn, but failed in its efforts to incorporate human knowledge into computational intelligence. We wish to suggest here that AI might achieve the latter by working more closely with the other cognitive sciences, mainly cognitive psychology, linguistics, and to a lesser extent neuroscience.

While some successful AI ideas originally took their inspiration from biology (ant colony optimisation, reinforcement learning, to name but two), cross-fertilisation within the cognitive sciences has not been as thorough as anticipated. The time may now be ripe for the cognitive sciences to provide the ingredients for next-generation AI.

Although AI researchers did try from the early beginnings to incorporate human knowledge into applications such as expert systems, this has largely failed to yield useful results. One of the reasons behind this may be the dominance of predicate logic over much of AI until the mid-90s. Under predicate logic, reasoning can only be performed over propositions that are either true or false. By and large, this has been shown to be inadequate for modelling real-world tasks. The dominant paradigm now uses the language of probability to encode uncertain knowledge, and employs sophisticated tools from statistics and decision theory to reason and act while taking into account the uncertain nature of real-world knowledge.

This parallels recent developments in cognitive psychology and neuroscience, where models of the mind based on probability theory are now dominant. Natural intelligence

is now viewed as acquiring knowledge through inference from incomplete information, rather than using the classical syllogisms once thought to embody the nature of human reasoning.

The recent development of so-called "Bayesian networks"[21] provided the means to build AI systems that incorporate uncertain expert knowledge, carry out automated inference tasks from data, and present the results in a meaningful way, possibly cast as an aide to decision. A very large class of previously separate problems have been recast as examples of Bayesian network learning: this includes hidden variable models (a traditional topic in signal processing), causal inference from correlational data (AI and statistics), and human and animal causal inference and perceptual learning (cognitive science). Bayesian networks are possibly one of the most important theoretical areas for Info/Cogno convergence.

Another recent trend has to do with artificial systems that take inspiration from studies of cognitive development in humans and animals. The new field of "developmental robotics" builds robots that learn seemingly trivial tasks, like going about in an environment without bouncing off walls, or properly grabbing objects. These are tasks that all human infants need to master, and it is hoped that developmental robotics will provide insights for the psychology and biology of development, not only learn from it. The main realisation is that robots like children need to learn to interact with a complex environment, starting out with simple heuristics only.

As mentioned above, another area of study that shows promise is that of software agents. With links to artificial life (AL), and artificial social systems, the field of software agents builds autonomous goal-directed entities and lets them interact with humans or among themselves. This has two potential applications: one is to build systems that are able to adapt to human users, rather than have it the other way around, and the other is to tackle a class of hard problems that may yield more easily to "swarm" or "collective" intelligence. Both have links to the cognitive sciences. The former is tied to cognitive ergonomics, which studies how humans interact with artificial systems. The latter is tied to formal models of social interaction, which are concerned with the emergence of social phenomena from the interaction of simple, local mechanisms.

More generally, in the last fifty or sixty years, the understanding of "rationality" among cognitive and social scientists has radically changed. No longer is chess playing considered to epitomise human rationality in action. Clever heuristics are thought to underlie

21 Judea Pearl, *Probabilistic Reasoning in Intelligent Systems,* Morgan Kaufmann, 1988.

successful decision making[22]. Thanks largely to the work of Antonio Damasio[23], emotions have entered the picture and are no longer considered opposed to rationality. Lastly, "commonsense" or "folk" knowledge has become an object of interest to cognitive anthropologists interested in how people build theories of the world that "work".

The influence of these ideas on AI research is now apparent. "Naive physics" tries to replicate the way people build simplified models of object movements. Incorporating some measure of common sense into software agents is a major challenge to the field. Emotions are also gradually being taken into account : some design robots to display human emotions. Tellingly, AI visionary Marvin Minsky, who argued two decades ago for incorporating common sense into AI systems, recently issued a book[24] where he claims that emotions represent different modes of thinking and should be replicated in machines.

The return of "strong AI"?

Owing to a large extent to the impulse of American inventor and visionary Raymond Kurzweil, "strong AI" is making a comeback. "Strong AI" is the belief that human or superhuman intelligence is achievable in machines. In Kurzweil's vision, the achievement of superhuman AI leads to a "Singularity", an new age for humanity where machines take over science and technological progress. According to Kurzweil, this is achievable within the next 25 years[25].

That is rather surprising, given that AI has so far failed to crack a number of problems that even non-human cognition deals with effortlessly: for instance effective, flexible visual and auditory perception. Language is very much an unsolved problem, but a requirement for anything that is worthy of the name of intelligence. How is superhuman intelligence achievable then?

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22 Gerd Gigerenzer, Peter M. Todd, ABC Research Group. Simple heuristics that make us smart. (Oxford University Press, New York 1999)

23 Antonio Damasio, *Descartes' Error: Emotion, Reason, and the Human Brain,* Penguin Books,1994.

24 Marvin Minsky. *The Emotion Machine,* New York: Simon and Schuster, 2006.

25 *Cp*. Kurzweil, Raymond, "Why We Can Be Confident of Turing Test Capability Within a Quarter Century", http://www.kurzweilai.net/meme/frame.html?main=/articles/art0683.html (2006). See his *The Singularity is Near,* Viking, 2005; and N. Bostrom, When machines outstmart humans, *Futures* **35** (2003), 759-764.

The strategy on the part of Kurzweil and his followers[26] has been to retreat from the particular (where AI struggles) to the general. Several articles on Kurzweil's website put forward designs for a "general intelligence", one with the flexibility to deal with a wide variety of problem areas. The belief that general AI systems could deal with any problem thrown at them has been a mainstay of the field: the very same claim was often made for logical systems, then neural networks, then support vector machines, until it was discovered that they require heavy human input before they become useful for anything more complicated than toy problems.

Kurzweil's ideas are very much on the fringe. It remains to be seen whether AI will achieve human-level performance in a reasonable subset of cognitive tasks in the next 50 years. The days when superhuman machines become our new overlords still belong in the science-fiction literature "strong AI" believers affectionate.

I.4.4.b Prospects for enhancement: constraints vs. tradeoffs

The type of mind enhancements that are put forward in the CT literature are often striking in the lack of knowledge of cognitive science they demonstrate. One common misunderstanding is the confusion between constraints and tradeoffs, and the other is an unwarranted confidence in the power of genetic modification.

Cognitive science has established that the mind has sharp limits in its processing abilities. Our working memory is limited to a few items at a time. Our perceptual systems can only monitor a few aspects of the world at anyone time. We do not memorise things we do not pay attention to, etc. Some of those limits may stem from what is achievable given that our brains are made of "biological hardware", and that their overall architecture is fixed. Others are not proper limits but useful compromises that allow us to function properly in our environment.

Attentional processing in perception is a perfect example. We only pay attention to a few aspects of the environment because there has to be a compromise between monitoring a large number of parameters poorly and monitoring only a few very well. In a normal environment, paying attention to a few is all we need, because we do so in a flexible way. While reading we can focus our resources on precise perception of a very narrow part of the visual field. While driving we look for movement over a very large area and disregard details.

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26 See for example B. Goertzel & C. Pennachin, *General Artificial Intelligence,* Springer, 2007.

Memory limitations can be understood in much the same way: forgetting is a necessary process for memory to be useful at all. In the famous short story from *Ficciones* (1944) entitled "Funes The Memorious," Jorge Luis Borges tells the story of Funes, a fictional young man with hypermnesia, a capacity to recall everything that ever happened to him in full detail. That amasing capacity is a curse rather than a blessing: Funes has very little control over his own thoughts, since nearly everything triggers a memory.

Proposals for brain enhancement often stem from a false analogy between brain and computer : while computers can be given upgrades in memory or processing power with only advantageous effects on their operation, it is doubtful whether the same is possible with the brain at all. Increasing memory might very well slow processing down, diminishing the usefulness of a memory implant (which in any case has yet to be proven realistic from a neurological point of view).

The same belief in free lunches pervades the literature in genetic enhancement: it is not uncommon to read that genetic modifications will "increase intelligence"[27], with an assumed proof-of-concept in the genetically engineered "smart mice" of Tsien et al[28]. Leaving aside the questions of the complicated interactions with the environment, there remains the fact that intelligence is a multi-dimensional trait, and that some genetic variation which may impact one trait in a positive way may also detract from another, and may also have some side effects beyond the purely cognitive. The net effect would be not one of enhancement, but of trading more of an ability for less of an other, a less appealing prospect.

Before we even begin to comment on the potential improvements to human cognition, we need a better understanding of the trade-offs involved. Evolution built a sophisticated machine that often walks a very fine line, and tampering with it is likely to break more things than it fixes.

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27 To take an example from the field of policy research, cf. National Human Genome Research Institute, "Exploring the Ethical Boundaries on Genomic and Genetic Research" (Workshop Summary, 2002). In the ethics literature, cf. for example Wolfram Henn, "Consumerism in prenatal diagnosis: a challenge for ethical guidelines", *The Journal of Medical Ethics*, **26** (2000): 444-446.

28 Tang YP, Shimizu E, Dube GR, Rampon C, Kerchner GA, Zhuo M, Liu G, Tsien JZ. "Genetic enhancement of learning and memory in mice", *Nature*, **401** (1999), 6748: 63-9.

PART II

A sample of European

CT-related R&D and academic activities

in cognitive science

II.1 Methodology and summary of results[29]

In this part we present a very preliminary attempt at getting a grasp on concrete issues raised by the emergence of the converging technologies which call for attention on the part of the social sciences and humanities.

The rather confounding diversity of activities linked, in one or another way, to CT, and the number of aspects which are of relevance to SSH are daunting. We have tried to gather a representative sample, as it were, of CT activities each of which illustrates how a given combination of societal dimensions is affected and/or addressed by a given activity.

The result of this exercise is open-ended in at least three ways:

1. It can be read as a partial list of the key SSH issues raised by real-world CT, a list which is not only to be completed, but pruned along the way. The difference with the list resulting from Part I is quite simply that the present one starts from the reality of grass-root institutions and initiatives, as opposed to the more theory-driven approach adopted in Part I; concomitantly, it focuses on enterprises which are wholly or in part involved in applied cognitive science, in accordance with the emphasis on cognitive science in the CT framework.

2. It can be read as the beginning of a list of important centres, activities and initiatives which together form the material basis of European CT. Again, the list, if it is of sufficient interest, it would have to be pruned and completed, but also amended insofar as its items will require redescriptions, clusterings and other refinements.

3. It tries to identify, whenever possible, an expert of the activity listed, who could be called in by CONTECS (or a follow-up group) at some later stage to provide a deeper understanding of the stakes and issues from the point of view of his/her base or constituency.

Over and above the incompleteness of the work, we must admit to not being sure that this is the right way to proceed. We hope to at least contribute in this way to the Consortium's undertaking, by having identified institutions, stakeholders, themes and experts, but are eager to see the Consortium incorporate what it will find useful and spec-

29 Part II owes a lot to the work of Vincent Pargade, who worked as a research assistant on this project during its initial phase.

ify what more, if anything needs to be done in the direction we have begun to explore[30].

We provide thumbnail descriptions of 14 concrete sources, loci or fields of application for cognitive science and converging technologies. Their selection is the combined result of design (our attempt to locate some of the most important types of activities) and chance (the relative ease of access, in the limited time available and under seasonal and geographic constraints, of documentation on instances of these activities). They form a highly heterogeneous lot, ranging from a single cutting-edge lab in neuroscience to an engineering school, to a campus grouping schools and start-ups, to a federation of learned societies, to an entire field... There is a disproportionate amount of French entities, but this, if necessary, can easily be corrected in a later investigation.

We aim at being synthetic and concise, and therefore provide no more than a thin introduction to each example, together with a quick run-down of the major players involved. Additional documents, articles, web sites screenshots and references are available on the CD-ROM delivered as a complement of the present document.

The fourteen items in our sample can be clustered under four themes: (a) Cognitive engineering, (b) Biotechnologies & neuroscience, (c) Telecommunications & commercial strategies, (d) Basic research.

The first three sectors of activity in the list, *viz.* IDC, MINATEC and Ergonomics, concern, in different ways, what is known as *cognitive engineering* or *cognitive technologies*. IDC is an engineering school which is interested in immediate and concrete applications of knowledge about cognition, such as human factor engineering and knowledge management. MINATEC is a new centre in nanotechnologies which is poised to draw maximum benefits from the nano-cogno-bio-IT convergence. Ergonomics, a field of applied research, is presented also because it offers a different perspective on the relations between human and artificial cognition and their professional implications: Human-Computer Interfaces (HCI) are part of the picture, but so are health and work, as well as the determination of European norms.

Under the second label, biotechnologies and neuroscience, one finds various activities and actors in the domain of industrial and R&D interests on life as a material. Themes encountered here range from industrial organisation and research activities in neuroscience to bio- & neuroethics. Once again we present mainstream actors such as biopharmaceutical groups and neuroscience laboratories, and move on to emerging

30 Part II was actually completed during the first stage of our work, and thus constituted a stepping stone to further work of the IENS partner and the group as a whole.

commercial activities such as neuromarketing, as well as projects for toys and everyday technologies, as exemplified by Sony's researches in robotics, based on cognitive science.

Third we take a look at what is taking place right now in the area of telecommunications area, from projects and economic strategies to converging firms and applications. Convergence is realized, in this instance, at the commercial level. The essential points here are (i) Convergence is actually being realised in the services society; (ii) This convergence is achieved by building on knowledge about human communication and comprehension originating in cognitive science; (iii) How the industry develops marketing strategies which take into account some of the latest results on the human condition. Item 10, Behavioural and cognitive economics, sits on the borderline between marketing and economics

Finally we present four main European actors in basic research in cognitive science, with the goal of suggesting some of the specific ways in which the field can enable technological outcomes.

The following table sums up the list of institutions which are described in the next section.

#	Name of entity	Nature	Field	Cluster
1	Institut de cognitique (IDC)	Engineering school	Cognitive engineering	(a) Cognitive engineering
2	Minatec/Minalogic	Research park & industrial consortium	Micro and nanotechnogies, smart processors	(a) Cognitive engineering
3	Federation of European Ergonomics Societies	Professional organisation (academic)	Ergonomics	(a) Cognitive engineering
4	European Biopharmaceutical Enterprises	Professional organisation (industrial)	Biotechnologies	(b) Biotechn. & neurosc.
5	Laboratorium voor Neuro- en Psychofysiologie	Research lab in a medical school	Neuroscience	(b) Biotechn. & neurosc.
6	Sony CSL	Industry R&D laboratory	Robotics, neurobotics, artificial life	(b) Biotechn. & neurosc.
7	Neuromarketing.be, i-mémoires, Neurosense	Start-ups	Neuromarketing	(b) Biotechn. & neurosc.
8	France Telecom, British Telecom, Ericsson, Napster, Skype, etc.	Telecom giants and internet providers	Convergence in telecom	(c) Telecommunication
9	W3C, ERCIM and VTT	Consortia, applied R&D center	Semantic web	(c) Telecommunication
10	New Economics Foundation	Independent 'think & do tank'	Cognitive/behavioral economics	Basic research and policy advising
11	ICN & FIL, Univ. Coll. London	Connected research institutes in a public university	Cognitive neuroscience, functional imagery	(d) Basic research in cogsci

#	Name of entity	Nature	Field	Cluster
12	Edinburgh School of Informatics	Large institute in public university	General computer science, formal models of cognition, A-life etc.	(d) Basic research in cogsci
13	Lund University: Cog. Science Dpt	Small university department in a rich environment	Pure and applied cognitive science	(d) Basic research in cogsci
14	Max Planck Institutes	Human development. Integrated neuroscience. Primate and human development	Cognitive science, in particular neuroscience, anthropology, cultural and educational applications	(d) Basic research in cogsci

II.2 Cognitive science at work in CT: some examples

II.2.1 School for cognitive engineers

What	Institut de cognitique (IDC)
Domain	Cognition, knowledge management, cognitive ergonomics
Where	Université de Bordeaux II, Victor Segalen
When	Opened September 2004
Sponsors	Bordeaux Université II & *Aerospace Valley*
Information	http://www.scico.u-bordeaux2.fr/scico/ tel : (0033) 557571700

Description

IDC is the first school in Europe specifically geared to training cognitive engineers. It is an outgrowth of the Cognitive Science Department of Bordeaux University, prompted by a call for offer from the aerospace sector, especially from Airbus. This sector, of prime European importance, is more and more in need of engineers controlling "*Human factors".* Both civilian and military purposes call for the development of intelligent and strategic materials, devices, and software.

Role of cognitive science, of CT

Cognitive science is the core discipline in both basic and applied work on knowledge and human factor management. Scientific understanding of natural and artificial cognition is the key to developing industrials technologies of high interest.

From the beginning of the curriculum, students are made to work in pluridisciplinary teams. They are to take part in large industrial R&D projects including device-building (link with nano…), software development and Knowledge Management [KN] (…with IT…) and natural cognition control (…with bio).

Projects & partnerships

In the present initial phase, mostly with Thalès and Airbus, to which IDC provides engineers specialised in Human Factors.

Industrial partners: some examples

Name of firm	*Sector of activity*	*Type of firm*	*Scientific interests in:*
Airbus	Aeronautics	European Giant	Human factor
Thalès	Aeronautics	National Giant	Human factor, intelligent devices
Eurisco	Systems engineering	Private firm	Cognitive engineering, KM

Potential in converging technologies (examples)

Cogno+Info: knowledge management software

Cogno+Nano: intelligent components for aeronautics, Intelligent fighting drones

ƒ Socio-cultural dimension, stakes, links with SSH

The whole "human factor" problematic, notion of engineering cognition, military applications perspectives.

Expert to be consulted

Benoît Le Blanc, lecturer at Bordeaux II, expert in KM & cognitive technologies (cog-techs)

II.2.2 R&D park in micro- and nanotechnologies

What	Minatec – Minalogic
Domain	Micro & nanotechnologies
Where	Grenoble, France
When	Formally opened in 2006 (concentration begun in 2001)
Sponsors	A long list of firms, state enterprises and regional authorities with national and European backing
Information	www.minatec.com, HYPERLINK "http://www.minalogic.com/" www.minalogic.com

Description

Minalogic and Minatec together constitute a research park based on the considerable resources of the Grenoble region in micro and software technologies. Grenoble boasts a considerable human potential: 17000 research positions, distributed over 220 laboratories in 5 international centres of research, 53000 students, 10 schools of engineering, 13350 professionals working in 30 national companies and 20 start-ups.

Minalogic more specifically aims to become the first European centre for miniaturised intelligent chips and the third in the world. Minatec is the brand new and first European centre in micro and nanotechnologies; it boasts 3500 engineers and scientists from several disciplines. The leading actors include CEA-Léti (CEA is the French Atomic Energy Commission; 'Léti' stands for Laboratoire d'Electronique de Technologie de l'Information) and the engineering school INPG (Institut National Polytechnique de Grenoble). The initial investment of €400 million should lead to the formation, over a 10-year period, of a major industrial consortium, for which €4 billion have already been ear-marked.

Role of cognitive science, of CT

This project is meant to embrace the entire CT vision: nano, bio, info and cogno each have a strong presence and are poised for interactions. Cognitive science comes in, more specifically, in the attempt to build intelligent artefacts to be intelligent. The European dimension is there, and the notion of convergence at work is strongly rooted in concrete perspectives.

Projects & partnerships

The list is very long, and includes representatives of nano-bio-info as well as of cogno.

Name of firm	*Sector of activity*	*Type of firm*	*Scientific interests in:*
Air Liquide	Electronic systems	Private firm	Software, information technology
Thales	Aeronautics	National Giant	Materials, cognitive techs
Alcatel	Telecom	Part state-owned	IT, materials, cog tech
CEA/Léti	Energy	Research lab owned by state agency	Physics & nano

Potential in converging technologies

Among many: miniaturised materials, intelligent ships, biochips, strategic decision-making.

Socio-cultural dimension, stakes, links with SSH

Knowledge management poses acute political, social and economic issues. More generally, just about all SSH issues raised by CT are relevant for this project.

Expert to be consulted

Bernard Ruffieux (INPG/INRIA) : nanotechnology patents, decision strategy, cognitive economics.

II.2.3 Federation of European Ergonomics Societies

What	Federation of national professional societies
Domain	Ergonomics
When	One meeting every year since 2003
Sponsors	Representative members of Europeans ergonomics societies
Information	http://www.fees-network.org/

Description

According to the official definition of the International Ergonomics Association, adopted in 2000, *ergonomics* (or *human factors*) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimise human well-being and overall system performance. European societies are very concerned by these issues and almost every member state has its own society of ergonomics. The discipline has three divisions: physical, cognitive and organisational ergonomics, which deal, respectively, with the physical aptitudes and weaknesses of human body at work, the mental processes deployed by the working agent, especially in her interactions with complex informational systems, and the structure and social dynamics of the global work environment in a given company or area. Ergonomists tend to employ their knowledge of humans and of working condition to secure, improve, and transform deficient or dangerous professional situations.

Role of cognitive science, of CT

Cognitive science provides the basic scientific knowledge of human cognition which is required to analyse and improve situations of work, to predict and if necessary prevent outcomes (such as wrong decisions in emergency situations), and finally to build human-computer interfaces (HCI). Ergonomists study, in concrete situations, the agent's performance involving perception, memory, reasoning, and motor response, as well as attentional and emotional factors.

Projects & partnerships

The E.U. extends considerable support to work in ergonomics all over the continent. The field was one of the priorities of FP6 and will surely remain important in the FP7 perspective.

Partners of the Federation and/or member societies, include national and European agencies, such as the European Agency for Safety and Health at Work, the European Foundation for the Improvement of Living and Working Conditions, the European Centre for the Development of Vocational Training.

Potential in converging technologies

Biotechnology for health, nanotechnologies and nanosciences, knowledge-based multifunctional materials and new production processes and devices, new production processes and devices, nanotechnologies, new materials and new production technologies for improved security and quality of life, aeronautics and space HCI, societal trends in the knowledge-based society and their implications for the quality of life, changes in work in the knowledge society.

Socio-cultural dimension, stakes, links with SSH

Ergonomics raises all the political, societal and ethical issues related to work and labour. In addition, the relations between the human operator and the increasingly sophisticated, partly autonomous, 'intelligent' machines she uses, pose a whole new set problems. The well-being, and perceived quality of work conditions, is yet another set of issues.

Expert to be consulted

Not identified.

II.2.4 European Biopharmaceutical Enterprises (EBE)

What	Association of industrial firms within the EU
Domain	Biotechnology, pharmaceutical industry
Where	Brussels
When	Founded in 2000
Sponsors	65 members company
Information	http://www.ebe-efpia.org/, tel:+32(0)2.626.25.62

Description

EBE represents the biotechnology lobby in European Union. The bio-pharmaceutical industry is bound to become a major partner of CT in the years to come, with special relevance to cognitive science. EBE's 65 member companies act together to defend and make pharmaceutical interests prosper in Europe. Linked to the biggest actors of drug industry, it is spread all over the continent, especially in Germany, France, Switzerland, Netherlands, the Nordic countries and the U.K. In 2003, the pharmaceutical sector spent €8,354 million on R&D; it numbered 1,879 companies and 87,000 employees. We also provide some documents on the Biovalley 'pole of competitiveness' as an example of industrial synergies between Germany, Switzerland and France. Projects and issues in the area are of vital importance. According to Jeremy Rifkin, the 21st century will be the Biotech century. Europe is obviously determined to play a lead role in the field.

Role of cognitive science, of CT

When biotechnologies turn to brain and cognition, they become part of cognitive science. Brain researches and the whole neuroscience part of cognitive science are the fundamental research areas at the basis of brain medicine. Alzheimer and Parkinson's diseases are of great focus for the biopharmaceutical industry, they are also main areas of researches in cognitive neurosciences, which can already be seen has a convergent research program.

Projects & partnerships

Biotechnologies are widely funded by the FP6 and will surely be one of the FP7 priority. Private and public stakeholders are many. Biotechnology is one of the greatest economic trend of our age. Corporations such as Bayer, Novartis and others are household concepts.

Potential in converging technologies

There are many reasons why the European biotechnological sector is bound to be a major player in CT, one of them being 'geographic' convergence. However, a limitation may be that for the moment, *Europe seems preoccupied by health and ageing priorities, paying scant attention to the human performance perspective.*

Socio-cultural dimension, stakes, links with SSH

Public health, measures of perceived well-being, cost of health, therapeutic vs. enhancement use of drugs, more generally bio and medical ethics, business ethics and the pharmaceutical lobbying, public debates on OGM, intellectual property.

Expert to be consulted

Not identified.

II.2.5 Laboratorium voor Neuro- en Psychofysiologie

What	Research laboratory in a medical school
Domain	Neuroscience: comparative primate and human neuroimagery
Where	Katholieke Universiteit Leuven, Belgium
Sponsors	Medical school, European and international funds
Information	http://neuroserv.med.kuleuven.be/index.php

Description

The neuro/psychophysiology laboratory of the Leuven University is one of the best European labs in brain science, easily holding its own against international competition (the US and Japan) in the field of functional imagery of the human and primate brains. It has established alliances with both academic and industrial centres. It provides industry with basic knowledge of high precision needed for the elaboration of innovative cognitive technologies.

Role of cognitive science, of CT

This is a cognitive science laboratory. Regarding CT, it is engaged in a number of collaborations on applied research projects, aiming for NBIC products such as intelligent devices, neuro-robots, nano-ships for regulating brain activities, etc.

Projects & partnerships

1/ Academic: Typically, top-notch scientists are regular or occasional visitors in several institutions abroad. One instance is the appointment of the head of the laboratory, Guy Orban, as adjunct faculty as Ecole normale supérieure, and as visiting professor at Collège de France in 2006-7.

2/ Industrial: The lab is involved with several innovative companies working on evolved robotics and artificial cognitive systems. These projects belong to the field of *neuromimetics,* which aims at exploiting knowledge of some aspects of brain functioning to build artificial brains for clever robots.

3/ Institutional: The Leuven team is supported by the European Union.

Industrial partners

Name of firm	*Type of firm*	*Information*	*Scientific interests in:*
Neurobotics	Private firm	http://www.neurobotics.org/	Advanced robotics
Neuroprobe	Private firm	http://www.neuroprobes.org/	Tools for research
DIRAC	Private firm	http://www.diracproject.org/	Artificial cognitive system
Neuro-it	Private firm	http://www.neuro-it.net/	Neurocomputing

Socio-cultural dimension, stakes, links with SSH

Bioethics, intellectual property and animal experimentation are the main issues.

Expert to be consulted

Guy Orban

II.2.6 SONY Computer Science Laboratory (CSL)

What	Industrial laboratory
Domain	Neural networks, robotics, neurobotics, artificial life (ALife)
Where	Paris
Sponsor	SONY
Information	http://www.csl.sony.fr/, www.fkaplan.com

Description

Sony CSL Paris is the outgrowth of the world-famous Japanese Sony R&D Laboratory. We present it here as an example of how private companies with R&D poles can be interested in European scientific knowledge in cognitive science and CT. Sony CSL Paris is a cutting-edge lab working on ideas with definite economic potential. It involves top scientists like Frédéric Kaplan, a well-regarded scientist in cognitive science and an engineer for Sony. CSL has European partnerships and is committed in several scientific projects, some of them funded by the EU IST program.

Neurobotics, the core of research at CSL, is engineering of robots by means of artificial neural networks (the expression is fairly new; see www.neurobotics.org for more information). When these networks are designed after biological neural networks, the method is called neuromimetism. CSL is currently working on robotic small dogs robots which exhibit amasingly realistic abilities such as learning how to walk, responding to their master, etc.

Role of cognitive science, of CT

The work at CSL already exploits the output of convergence, and constitutes a rather typical example of what can be achieved right now in CT. Electronics, material science, robotics, IT, AI and cognitive science are involved in making intelligent robots of this kind. While cognitive science provides knowledge on intelligence and neural processing, on vision, audition and basic neurosciences, other branches of CT such as IT and micro-electronics provide a means to implement these solutions. The potential further applications, in particular in the next generation of entertainment devices, is enormous. Also, this technology plays an enabling role in many fields of applied science.

Projects & partnerships

Sony has of course wide industrial partnerships. What is interesting for us is to remark that the lab is also in collaboration universities and with E.U instances such as the IST

program, in working on projects as spikeforce, enactive, and on developmental robotics.

Academic partners (a sample)

Institution	Location	Topic	Information
Vrije Universiteit	Brussels	Artificial intelligence	http://www.vub.ac.be/english/index.php
Hospital Pitié-Salpétrière	Paris	Neurosciences	http://www.ifrns.chups.jussieu.fr/
INFM (National Institute for the Physics of Matter, a network of research units)	Genoa (Italy)	Physics	http://www.infm.it/

Socio-cultural dimension, stakes, links with SSH

Man/robot interaction at home, at school, on the workplace: psychological and ethical aspects. Games; virtual reality. General issues raised by artificial intelligence and ambient intelligence.

Experts to be consulted

Olivier Coenen, Frederic Kaplan (both at CSL)

II.2.7 Neuromarketing.be, i-mémoires, Neurosense

What	Start-up firms
Domain	Neuromarketing (cognitive neuroscience applied to marketing)
Where	Brussels, Lyon, Oxford respectively.
Sponsors	Private initiatives of (active or former) academic scientists
When	Recently created
Information	http://www.neuromarketing.be/index.htm, http://www.neurosense.com

Description

Neuromarketing consists in exploiting cognitive neuroscience for marketing analyses. It is a service few companies provide. *Neurosense*, for example, claims to "offer both strategic guidance about the way in which brain imaging techniques and psychological tools can be used to address key questions in marketing, as well as a full functional neuroimaging and behavioural testing service". Neuromarketing investigates what happens in someone's brain when they want a product, are thinking of acquiring it, etc. It is expected that the knowledge of brain processes will provide a way to influence people's mind more efficiently than can be achieved by the usual, nonscientific methods uses by marketing up till now.

Projects & partnerships

A sample of clients of Neuromarketing.be: Coach Europe, Bruxelles formation, Optimum Management, CEFORA, IBGE, Nestlé, UCL, Panel & Média...

Role of cognitive science, of CT

Cognitive neuroscience and psychology are domains within cognitive science. However, marketing is typically studied in social psychology departments, which until recently were not in the best of terms with cognitive psychology. To this day, relations remain usually fairly tense, a situation which neuromarketing is not likely to improve at first, the situation. With respect to mainstream cognitive science, what makes neuromarketing special is the way scientific investigation is used for strictly utilitarian purposes.

Socio-cultural dimension, stakes, links with SSH

Using science for the sole purpose of improving advertising raises ethical issues. It also requires careful examination from the axiologically neutral standpoints of sociology and economy.

Expert to be consulted

Olivier Koenig (i-mémoires, Université de Lyon 2)

II.2.8 Convergence in telecommunications

What	France Telecom/ BT/ Ericsson/ Napster/Skype etc.
Domain	Telecommunications
Where	World-wide
When	Happening right now
Information	Many articles available on the net

Description

Convergence is a term prevalent in today's telecom marketplace. It is also a major industrial trend, which is different from, yet potentially connected with the emergence of CT. Convergence, in the telecom context, refers to the fact, or hope, that a single provider offers the complete spectrum of services, which up until now are provided by different entities. In this highly competitive domain, convergence has been the R&D strategy of such giants as France Telecom, BritishTelecom, BrasilTelecom, ChinaTelecom and others. In concrete terms, it consists in furnishing mobile internet accesses, in fusioning landlines and mobile phones with other devices such as cam-recorders, camera, vid-phones etc. France Telecom's NExT project, for example, is a step towards the transformation of the telecom company into a general service provider company: internet, all media, services of all sorts. Another concrete example is the « Fix-Mobile Alliance » (FMA) which includes 24 operators all over the planet (AT&T, KPN, Telecom Italia, Deutsche Telecom, etc.) whose aim is to position themselves favourably in the competition which is about to start. According to Informa Telecoms & Media, a consulting group, the world market for FMC (fix mobile convergence) will be worth $28 billions in 2011, when it will provide 5% of all telecom devices, and 3% of the contracts in 5 years.

Role of cognitive science, of CT

HCI (or its more specialised branch 'Useability') will have a role to play in this sector. Consumer devices have to have friendly and efficient interfaces in the domain of vision, audition and touch. Information processing all over the converging networks will be handled by IT engineers, miniaturisation will be of prime importance. The Bio dimension is left out for the time being.

Projects & partnerships

This area is too immense to be summarized, all major telecom companies having their network and strategies. Let's pick as our one example the potential partnership France-telecom/Microsoft for the NExT project aiming at providing mobile internet accesses.

Socio-cultural dimension, stakes, links with SSH

The concentration in the hands of a single, possibly monopolistic and certainly oligopolistic provider, of such a crucial commodity, in today's society, as means of telecommunication, is bound to raise considerable political and economic problems, in particular in developing countries. The complexity of the devices sold to the consumer forces on him/her certain patterns and ways of communicating, which raises ethical issues. The study of these patterns is also a theme for interdisciplinary research involving pragmatics, sociology, anthropology, philosophy and other fields in SSH.

Expert to be consulted

Not identified

II.2.9 Semantic web

What	World Wide Web Consortium (W3C)
Domain	Internet, computer science, information systems, linguistics
Who	A variety of organisations and a permanent staff; W3C is hosted in Europe by ERCIM (European Research Consortium for Informatics and Mathematics)
Information	http://www.w3.org/, http://www.ercim.org/

What	VTT Technical Research Centre of Finland, a large private applied research organisation
Domain	Many areas, of which information systems and hardware
Who	A little under 3000 staff
Information	http://www.vtt.fi

Description

On definitions widely accepted in the world of IT, knowledge differs from 'mere' information. It is rumoured that we live today in an *information society* and that we are called to move on to a *knowledge society.* What this seems to boil down to is the notion that people will want, and obtain, access to wide areas of knowledge, not only to information (facts with no potential for further enrichment). The so-called *semantic web* project is an attempt to realise this mutation by organising the *content* of the internet in a knowledge-like manner. Work in logic, semantics, computer science have brought about tools and languages to organise information in a manner that is accessible for all in a smart way. There now are norms in this domain and the main world actor is the W3C organisation. It pools the efforts of computer scientists all over the world to determine norms for, and improve the internet. It has a European host, ERCIM. ERCIM a consortium if 17 member institutes which work on a wide variety of topics in applied mathematics and computer science, among which many concerning IT, internet and convergence. ERCIM receives funding from the U.E. As an example of a member of ERCIM, we zoom in on the Finnish R&D giant VTT. VTT provides work and organizes researches in every CT fields: IT and Communication technologies, machinery, material, industrial engineering, transport and logistics, biotechnologies and pharmaceuticals, food industry, chemistry, energy, buildings, environment. It has a media and inter-

net subdivision which works on semantic data and meta-data creations: the semantic web. It is also active in European R&D politics lobbying.

Role of cognitive science, of CT

Regarding the semantic web, cognitive science provides expertise in semantics, modal logic, artificial intelligence, and more generally in the formalisation of bodies of knowledge; it also brings in HCI. As for CT, VTT is an example of a research structure which is able to handle all the building blocks required for CT innovations. In addition, VTT is proactively envisaging the commercialisation side of CT. To that extent, it can be seen as a model for CT development.

Projects & partnerships

Here again the collaborations are innumerable. Refer to www.ercim/activity/expertise.html to see the different collaborations taking place for instance with INRIA, a member of ERCIM and an active stake-holder in the Minatec project is described above (B1). Here are a couple more examples:

Project	Partner	Domain
ACGT	PHILIPS electronic netherland	Biomedical knowledge sharing
ICT-related trends	ISTFET (U.E)	ICT

Potential in converging technologies

The IT and cogno fields are related to this sector of activity. The first and over influencing CT produced by these researches will be the semantic web. If you refer to the converging telecom interest for the internet, you can infer a world-wide impact of these related research programs on knowledge, telecommunications and their commercial applications.

Socio-cultural dimension, stakes, links with SSH

The very idea of the 'knowledge society' seems to call for a very serious examination. The social role of the web is another central topic.

Expert to be consulted

(on Metadata) Asta Bäck, VTT (+358 20 722 4536) (to be confirmed)

II.2.10 Cognitive/Behavioural economics

What	NEF (New Economics Foundation), an independent think tank
Domain	Experimental economics
Where	London
Who	Economists, lecturers, writers, entrepreneurs, etc.
Information resources	http://www.neweconomics.org

Description

Economic theory was for a long time exclusively, and remains centrally concerned with axiomatic models based on strong idealisations of economic agents. For the last fifty years, a new, empirical approach has emerged; it insists on basing its results on the behaviour of real agents and firms in actual economic situations. Irrational behaviours, unexpected strategic choices, for example, belong to its domain. Due in part to the rise of cognitive themes and the production of experimental paradigms by cognitive psychology, in part to an intrinsic dynamic, this behavioural economics has gained momentum and produces results which can be used by scholars, public policy makers and corporations.

The particular importance of economics as an active force in society means that changes in economics as a science are bound to have a profound impact on our societies. Thanks to a deeper understanding of strategic thinking and human behaviour, economics is reinforcing its regulatory power. Policy design, roadmaps for R&D, innovation and diffusion, etc., will be affected.

The British think-tank (or rather, as it self-describes, think & do tank) NEF advises policy makers with the aim of a fair future, and takes into account such scientific novelties in the understanding of the human mind as limited rationality and fairness considerations. The uses to which economics is put are of *determining* importance in the way future technologies will be managed.

Role of cognitive science, of CT

Behavioural economics is a convergence between cognitive psychology and experimental economics. They share protocols and assumptions about the way the mind can be investigated. There are a number of scientists which are trained both as psychologists and as economists (Colin F. Camerer, a professor at Caltech, is a well-known example).

Industrial partners and potential for CT

In the United States, corporations fund some work in experimental economics. In Europe and in France things are different but there exists links between this work and industry. INPG, the Grenoble institute we have already encountered (B1) has a centre on applied economics, which is linked with the industrial activities of the Grenoble area in the field of new technologies. Behavioural game theory applied to strategic decisions on patents and markets is both taught and used in this area of CT. This is an example of the special role which economics plays in CT (as in other areas of R&D): it shapes the policy, and thus the technological output.

Socio-cultural dimension, stakes, links with SSH

Economics is first and foremost a social science. Philosophical, both epistemic and ethical, are posed by the development of a new approach in economics, and by a new role which the discipline takes on in scientific and technological policy-making.

Expert to be consulted

Bernard Ruffieux (INPG/INRIA): Patents for nanotechnologies, decision strategy, cognitive economics

II.2.11 ICN & FIL, University College London

What	Institute of Cognitive Neuroscience & Functional Imaging Lab
Domain	Cognitive neuroscience, Brain imaging
Where	University College, Queen Square London, England.
Who	100 scientists, including PhD and postgraduate students
Information resources	http://www.icn.ucl.ac.uk , www.fil.ion.ucl.ac.uk

Description

The ICN is an interdisciplinary research institute at UCL. It studies how mental processes relate to the human brain, in health and disease, for adults and children. It fosters an interdisciplinary approach to these issues, by bringing together researchers from: the Psychology Department; the Institute of Neurology; the Anatomy Department; and the Human Communication Department; plus by using a wide range of methods. It enjoys close collaborative links with neighbours in Queen Square, including the Wellcome Department of Imaging Neuroscience (Functional Imaging Lab); the Gatsby Computational Neuroscience Unit; the Institute of Movement Neuroscience; and the National Hospital for Neurology and Neurosurgery. The prime scientific goal of the Wellcome Department of Imaging Neuroscience (WDIN) and the Leopold Muller Functional Imaging Laboratory (FIL) is to understand human brain function from a mechanistic perspective using a system levels analysis of data acquired using functional neuroimaging including fMRI, EEG and MEG. The framework for the conduct of these studies includes classical techniques of experimental psychology and the cognitive neurosciences, as well as more theoretical approaches, based on perspectives from computational neuroscience. In short, the group of institutes around Queen Square are a perfect example of interdisciplinary cognitive science. It is not surprising that UCL is regarded as a European leader in the field.

Role of cognitive science, of CT

Obvious. An interesting issue is the way technology, involving high-powered computer science, information technologies, and biology, are actually enrolled, on the spot, to produce instruments for neuroimaging, and thus for cognitive science. It is a case of nano-info-bio (actually, nano is not yet implemented, we are still at micro scale) directly enabling cogno.

Projects & partnerships

UCL has many British funding sources, both public and private, such as the Biotechnology and Biological Sciences Research Council (BBSRC), CEC, Medical Research Council, Leverhulme Trust, Wellcome trust, the Royal Society etc. It also receives funds from European and other international agencies. The BBSRC is UK's leading funding agency for academic research and training in the non-clinical life sciences. BBSRC is committed to facilitating the application of knowledge and new technologies arising from the research that it funds for the benefit of the UK economy and society in general.

Potential in converging technologies (examples)

The Bio + Cogno part in NBIC convergence partly rely on cognitive neuroscience knowledge in order to operate properly on cerebral systems.

Socio-cultural dimension, stakes, links with SSH

Neuroethics is fast becoming a central concern, and has taken off in the US. Europe should be encouraged to develop this subfield of bio-ethics. High-powered neuroscience raises economic problems, and issues in technology transfer.

Expert to be consulted

Richard Frackowiak (FIL & DEC, ENS Paris)

II.2.12 Edinburgh School of Informatics

What	Research centre in informatics at the University of Edinburgh
Where	Edinburgh, Scotland
Who	University staff & students
Information	http://www.inf.ed.ac.uk/research/

Description

The University of Edinburgh boasts the largest concentration, within the UK, of excellence in the area comprising Informatics, Artificial Intelligence, Cognitive Science, and Computer Science. It has seven Research Institutes that promote and coordinate research in various areas such as neural computation, intelligent systems and their applications, communicating and collaborating systems, perception, action and behaviour etc. Artificial life and bioinformatics are also present, which is of relevance in a CT perspective.

Role of cognitive science, of CT

Obvious. The main interactions are with Info, of course, but Nano will come in via hardware for 'ambient intelligence', and Bio as a consumer of innovations, in bioinformatics and as an inspiration for biological computing. An example comes next.

Projects & partnerships (examples, among many)

Bioinformatics: The Computational Systems Biology Group and the Systems Biology Institute have recently launched a 3-year collaboration in the development of drug discovery and disease treatment approaches. The mapping of the human genome and the availability of powerful computing technology have advanced epigenetics into a new research model, called systems biology.

And the partnership is attracting both commercial and academic interest, including support from GlaxoSmithKlein and IBM, through which the consortium will have access to some of the world's fastest computational modelling facilities.

Artificial Life is devoted to a new discipline that investigates the scientific, engineering, philosophical, and social issues involved in our rapidly increasing technological ability to synthesise life-like behaviours from scratch in computers, machines, molecules, and other alternative media.

There is a rich history of artificial life research at Edinburgh University, involving researchers from various different departments, schools and institutes. Within the School of Informatics, the most active research groups in this area are in the Institute of Perception, Action and Behaviour (IPAB) (especially in the areas of robotics and evolutionary algorithms), the Centre for Intelligent Systems and their Applications (CISA) (evolutionary algorithms, ant colony optimisation and artificial immune systems), and the Institute of Adaptive and Neural Computation (IANC) (artificial learning systems and neuroinformatics). Elsewhere in the University, the School of Philosophy, Psychology and Language Sciences is home to the Language Evolution and Computation Research Unit and the Department of Philosophy, and the School of Biological Sciences is home to the Institute of Evolutionary Biology. There is also close links with the Centre for Emergent Computation at Napier University.

Software engineering: Industrial links with: BT, HSE, IBM, Imperial Cancer Research Fund, LUCAS Aerospace, Philips, Rover, Scottish Widows, and others.

Industrial partners: examples

Name	Sector	Type of group	Scientific interests in:
GlaxoSmithKlein	Pharmaceutical	Corporation	Bio + IT
IBM	IT	Corporation	NBIC
BT	telecom	National giant	Software and telecom convergence

Potential in converging technologies

Edinburgh clearly offers another clear example of a main actor in NBIC convergence within Europe. The Edinburgh School of Informatics extends from the traditional fields of IT to all the others aspects of technological, intellectual and commercial convergence. Private partners are many and feasible, ground-breaking projects are already in place. It is a typical centre of excellence, visible from afar. It is a hot spot of European CT potential.

Socio-cultural dimension, stakes, links with SSH

Due to its full NBIC potential, Edinburgh University offers the widest possible repertory of issues for SSH in the area of CT.

Expert to be consulted

Not identified

II.2.13 Lund University: Cognitive science

What	Cognitive science department, Lund University
Where	Lund, Sweden
When	Founded in 1988
Who	Fifteen PhD students & three postdoc
Information resources	http://www.lucs.lu.se/ and http://www.xrce.xerox.com/

Description

Lund university is a research centre of excellence situated in Sweden. It is representative of Nordic countries interest in cognitive science. Main research topics are concept formation, learning, language and eye-movement, cognitive design, evolution, robotics, computer simulation, intentionality, everyday cognition. Originally grounded on mainstream symbolico-computational paradigm of cognitive science, researches at Lund today intend to move toward a more efficient and realistic scientific framework. Works on representation and robotics can be seen as fundamental developments towards intellectual and technological breakthrough. Lund activities cover a wide range of topics and then substantially sustain high level pure and applied cognitive science in Nordic Europe.

Role of cognitive science, of CT

Lund University is situated at the IT – Cogno interface. Current work bears on developing cognitive knowledge in order to implement new possibilities in new technologies. Work in robotics, computer science and HCI are of particular interest in this area.

Projects & partnerships

Many projects are underway. Some of the main ones are funded by the E.U: FP 5 or 6, others by the SSF: Swedish foundation for strategic research (such as the conceptual space project), others by the Swedish national board of industrial and technological development (the artificial hand project). Here are a few examples:

LAVA (Learning for Adaptable Visual Assistants, May 2002 - April 2005): The goal is to create fundamental enabling technologies for cognitive vision systems and to understand the systems- and user-level aspects of their applications. Technologically, the objectives are the robust and efficient categorisation and interpretation of large numbers of objects, scenes and events, in real settings, and automatic online acquisition of

knowledge of categories, for convenient construction of applications. *Partner*: Xerox & other research centres.

Artificial hand project: The overall objective is to develop a new strategy for motor control of functional hand prostheses based on electrical signals generated from multiple muscle electrodes or microchips implanted in the peripheral or central nervous system. The use of Artificial Neural Network (ANN) is essential to fulfil this purpose. The purpose is also to develop systems for artificial sensibility to be applied to such hand prostheses and to patients with loss of sensory nerve function. The overall goal is to create new possibilities for rehabilitation of amputees and paralysed patients.

Mind Races: A three-year EC funded project (Sixth Framework Programme - Information Society and Technologies - Cognitive Systems) launched in October 2004 and involving 8 partners, it is mainly focused on the concept of anticipation. The general goal of the Mind RACES project is to investigate different anticipatory cognitive mechanisms and architectures in order to build Cognitive Systems endowed with the ability to predict the outcome of their actions, to build a model of future events, to control their perception anticipating future stimuli and to emotionally react to possible future scenarios. Such Anticipatory Cognitive Systems are meant to contribute to the successful implementation of ambient intelligence.

Industrial partners: examples

name	sector	Type of group	Scientific interests in:
Xerox	IT services	Corporation. U.S.A	IT + Cogno
NOZE	IT services	Start-up Italy	Open source softwares

Potential in converging technologies

IT + Cogno: Artificial cognitive systems for robotics and ambient intelligence, adaptable visual assistants

IT + Cogno (+ Bio + Nano?): Artificial Hand (towards surgery or enhancement?)

Socio-cultural dimension, stakes, links with SSH

Cognitive science applied to typical NBIC projects: knowledge society, artificial limbs, enhancement, etc. : matters of feasibility and desirability, familiar issues

Expert to be consulted

Peter Gärdenfors (founder of the Department; also member of the Scientific Board of the Département d'études cognitives at Ecole normale supérieure Paris)

II.2.14 Max Planck Institutes, Berlin, Frankfurt, Leipzig

What	Research centres
Domain	Pure & applied cognitive science
Where	Germany: Berlin, Frankfurt, Leipzig
When	Opened respectively in 1963,1914, 1997
Who	Researchers among the 4200 scientists of the Max Planck Society
Information	http://www.mpg.de/ & centers' web-sites & http://www.garching-innovation.mpg.de/en/

Description

The Max Planck Society for the Advancement of Science (MPS), Berlin, is the largest organisation for basic research in Germany. The MPS operates eighty institutes and a few temporary research centres. This is of course not the place to present the MPS in detail. It should be stressed, however, that it combines diversity of disciplines with a simple, homogeneous organisation, and that this combination of features put it in a favourable position to create and sustain a move to converging technologies.

The Max Planck research units in cognitive science are among the best in the world. First we present three hot spots of European research in cognitive science, second we pay attention to the role of the Max Planck society, which is the administrative organ under which are regrouped all the MP Institutes.

The Max Planck Institute for Human Development situated in **Berlin** is a multidisciplinary research institute dedicated to the study of human development and education, and their evolutionary, social, historical, and institutional contexts. Education, psychology, and sociology, enriched by the work of colleagues from such fields as cognitive neuroscience, mathematics, economics, computer science, evolutionary biology, and the humanities are cooperating towards a sound understanding of human cognitive abilities.

Research at the Frankfurt Institute belongs to neuroscience. It addresses the principles of the organisation of the mammalian central nervous system (CNS) at many different levels of analysis, ranging from molecular to behavioural studies. Anatomical, biochemical and physiological methods are applied to identify general principles of organisation which are shared by the brains of animals and humans. It has three departments which can be see in a hierarchy of rising complexity: the neurochemical, neuroanatomical and neurophysiological department.

The aim of the institute in Leipzig is to investigate the history of humankind with the help of comparative analyses of different genes, cultures, cognitive abilities, languages and social systems of past and present human populations as well as those of primates closely related to human beings from an interdisciplinary perspective. The **Department of Developmental and Comparative Psychology** directed by Michael Tomasello investigates cognitive and social-cognitive processes in humans and their nearest primate relatives. Of special interest are the uniquely human cognitive, social-cognitive, and symbolic processes involved in cultural learning and creation. The department has three main areas of research: *Primate Cognition*, in which great ape species understand their physical and social worlds are investigated; *The Ontogeny of Human Social Cognition*, in which the social-cognitive skills of children from around 9 months to around 4 years of age is investigated. Recent interests include: understanding intentions, understanding attention, imitation, prelinguistic gestures such as pointing, understanding communicative intentions, collaboration, pretense, and understanding false belief; and *The acquisition of language*.

Projects & partnerships

Numerous partners are involved in the transfer of technology: On the one hand, there are the researchers at the Max Planck Institutes, on the other, the representatives from industry. There are also the patent office, private legal practices and, no less important, **Garching Innovation (GI)**, the technology transfer organisation of the Max Planck Society. GI was founded in 1970. It consists of an interdisciplinary team of scientists, business people, and lawyers. Garching Innovation has the task of organising the technology transfer procedure and of mediating between the various partners. It advises the individual institutes regarding the development and copyrighting of inventions; it organizes the collaboration between inventors and lawyers of patent law; it informs industry about new patents; and it negotiates the licensing conditions. The returns from the contracts go to the Max Planck Society. An advisory board consisting of politicians, scientific experts, and business representatives monitors the work of GI. Since 1979, Garching Innovation has looked after about 2,600 inventions and concluded 1,556 usufructuary agreements. To date, the total returns amount to about EUR 200 million, half of which originate abroad.

Role of cognitive science, of CT

MP Institutes in cognitive science number among the most influent in Europe and largely contribute to Germany's second place after the UK in the field of cognitive science. There is reason to believe that their network structure allows them to connect many aspects of scientific innovation. Combined with the efficient, one-actor (GI)

method for technology transfer, this structure makes the MPS a plausible candidate for the development of important CT activity.

Industrial partners: examples

name	Sector	Type of group	Scientific interests in:
Siemens / CTI	IT	Corporation	Brain imaging techs
Wellcome Trust (Sanger institute)	Biomedical science, technology transfer	Charity	health
Creatogene bioscience	Bioscience, pharmaceu-ticals	Spin-off (among the 65 from MPS)	Biotechnologies

Appendix C

The Ontological Politics of Convergence

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Converging technologies and their impact on the social sciences and humanities (CONTECS)

Deliverable D3.2

The Ontological Politics of Convergence

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Based on an earlier version from September 2007

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Table of contents

Objective and scope 1

1 Introduction 3

2 Theoretical resources 3

3 Historical and institutional origins of CT visions 5

3.1 Drivers of the debate on convergence and their use of visions 6

3.2 The genesis and historical antecedents of the visions 14

4 Performing the ontological landscape of converging technologies 19

4.1 Performing expert membership in CT 20

4.2 The dynamics of NBIC components 25

4.2.1 The trouble with definitions 25

4.2.2 Performing communities 27

4.3 Redefining human "essence"? 30

5 Conclusions 35

6 References 39

Objective and scope

The argument of this paper derives mainly from work carried out by the EC funded Converging Technologies (CONTECS) project http://www.contecs.fraunhofer.de/. Our thanks to colleagues in the CONTECS team. This paper builds on an earlier deliverable, a background report on visions and discourse in converging technologies (Woolgar, 2006), and is in partial fulfilment of the objectives of the second phase of CONTECS, viz "consolidating existing deliverables" and "deepening the list of recurrent themes".

1 Introduction

What are the implications for the Social Sciences and Humanities (SSH) which arise from the convergence of Nano, Bio-, and Information-Technologies and Cognitive Sciences (NBIC)? The question is crucial because of the nature and extent of claims about the massive transformational potential of "Converging Technologies" (CT).

The considerable enthusiasm, not to say hype, around this phenomenon is accompanied by a profusion of uses of the term "Converging Technology", in a variety of different national, international and policy contexts. It is tempting to try to start from, if not arrive at, a definition of CT, a consensual or majority view of what exactly are converging technologies. However, this would be to miss one of the most striking and important features of current discussions about CT – the fact that there is wide variation in what counts as CT and in what are its prospects and likely significance. So this paper takes another starting point. We instead take the differences in conceptions, visions, stories and assessments of CT as the impetus for our analysis. The lack of consensus is itself a useful basis for understanding the social and organisational dimensions of the emergence and currency of CT. In the sense we explain below, definitions of CT need to be treated as a form of constitutive discourse.

Our particular interest in CT concerns: 1) the role of assumptions, ideologies and visions 2) the governance and regulation of CT and 3) the implications and social transformational potential of CT. Our particular focus for accessing these features of CT is the broad assembly of discussions about human enhancement. As we argue below, the key to obtaining insight into this wide range of characteristics of the phenomenon is to focus upon the ways in which different kinds of entity - human and non human - are performed in the discourse of CT. Our approach is to suppose that discussions of CT embody key assumptions about the ontological landscape which accompanies, is encouraged by and is enacted in relation to CT. As we discuss, this approach also provides a powerful handle on governance and regulation. Specifically, we suggest that attention to the ontological politics of CT gives insight into the kinds of subject position which might arise and, in this broadly Foucauldian sense, gives us a novel way into understanding governance and regulation.

In the next section we describe the theoretical resources which inform our conception of ontological politics, drawing on a combination of science and technology studies (STS) and neo-Foucauldian theory. We then turn our attention to the historical and institutional contexts of CT. To what extent do the assumptions, ideologies and visions of these contexts constrain and enable our understanding of the issues for SSH research into CT? In particular, how have the prevalent assumptions of a variety of

past institutional contexts come to define the current ontological landscape for discussions about CT? Our fourth section examines in detail some features of the organisation of contemporary CT discourse. Drawing on interviews and discussions involving prominent CT spokespersons, we consider how the structuring of the ontological landscape for CT raises key questions for SSH interests in CT. Finally, we conclude by identifying the major implications of this study for future research in SSH.

2 Theoretical resources

STS is a large multidiscipline which has driven successive dramatic shifts in ways of rethinking the social, organisational and political dimensions of new technologies. Its complex history is baldly summarised by saying that STS a) initially challenged the dominant assumption of technological determinism, insisting on the relevance of social and historical factors in the genesis and impacts of new technologies. Subsequently, b) it was realised that the ensuring binary division of labour – the attention of different sets of scholars to broadly technical and to broadly social factors – merely reinstantiated the core phenomenon, namely the achieved distinction between the technical and the social. As a result, various efforts were made to overcome the binary divide including, for example, advocacy of ideas such as co-construction and actor network theory. Arguably, these efforts tended to repeat and re-enact the base distinctions between the technical and the social, the human and the non human and so on. Most recently, c) attention has been more focused on technology construed as a form of discourse which performs the existence and relationship between various entities. In particular, it is recognised, this discourse provides for the constitution and relevance of certain entities in relation to the technology. For example, the existence, nature, capacity and defining features of humans, and/or their cognitive attributes are enacted in and through the technical description of the means by which they might be enhanced.

This last approach includes the especially important feature that apparently straightforward distinctions between the "technical" and the "social" can no longer be taken for granted; nor is that the case that this distinction is adequately treated by giving equal weight to both "sides" of the duality, nor by saying they co-exist, nor that they co-construct each other. As we note below, attempts to articulate the divide in this way merely restate and re-enact the core phenomenon of the binary divide, as if this was not itself a thoroughly contingent outcome of particular social- historical circumstances (for example, Shapin and Schaffer, 1985). This leads to the oft noted and common phenomenon that consideration of, for example, the "ethical dimensions" of technology, is always assigned a disengaged, antecedent position. In conferences on new technological developments, for example, a session on ethics is where the "soft stuff" is considered, often during a sparsely attended session on the final day, after the "hard" technical stuff has been given due attention. The "liberal" view is that topics like ethics (say) "need to be taken into account". The technology as discourse position insists instead that this, the achieved antecedence of the social and ethical, is part of the phenomenon to be explained and confronted. It allows us to ask how and with what effect does the discourse of new technology establish which kinds of things, people, activities are antecedent to "core" technical attributes?

The idea of ontological politics is taken from this broad strand of recent work in STS (especially e.g. Mol, 2002; Haraway 1992a, 1992b; Law 1996; 2004; Thompson 1998; Woolgar and Neyland, forthcoming). The term derives from the contention that ontologies are contingent rather than given. The phrase "relational ontology" is used in this context. Ontological politics comprise the processes, practices, discussions, struggles and contentions whereby the existence and character of entities are defined, constructed and brought into being. The important point is that the nature and existence of entities is contingent upon these politics. In particular, discussions about, and activities in relation to, the likely effects of new technologies, are part and parcel of the processes whereby the capacities, effects, likely beneficiaries, advocates and resistors of these technologies become identified and defined.

For our purposes, the notion of ontological politics is crucial in three main respects. First, the processes of ontological politics help define the focus and targets for convergent technologies. That is, these processes articulate and specify the kinds of entity, the nature, for example, of transhuman beings or cyborgs, which CT are claimed to bring about. Second, and as a corollary to this, the development, success and take up of CT will depend on the outcome of these ontological politics. In other words, the outcome (effects, impacts, consequences) of the various moves, claims and performances of CT will depend on the extent to which its ontological politics make available subject positions which are adopted and enacted. As we shall see, this line of argument opens up a new set of approaches to governance. In this view, governance is no longer just about mechanisms of regulation and control of technologies (and technologists) which stand apart from the "technical content" of those technologies. Instead, governance is construed as a more pervasive and insidious politics whereby the supposed "technical content" itself performs subject positions.[1] Third, the ontological politics of CT will have a direct bearing on the kinds of issues and approaches which need to be considered by future SSH investigations into this phenomenon. For example, to the extent that CT successfully redefine what counts as human (and transhuman) has significant implications for what (and how) social sciences can continue to take as their basic unit of analysis. In this sense, CT are not just potentially transformative of social and organisational life, they are also potentially transformative of the way social sciences and the humanities is done.

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1 By analogy with the well known STS distinction between weak and strong programmes in the sociology of scientific knowledge (eg Bloor, 1976), Woolgar and Neyland (forthcoming) develop the distinction between weak and strong governance.

3 Historical and institutional origins of CT visions

In the following, we discuss the institutional contexts and ideological traditions which have shaped the current ontological landscape of convergence. The most relevant institutional context is to be found in the US where the discussions on CT originated. A very prominent, albeit partly camouflaged ideological feature of the discourse on CT is the influence of posthumanism on the ethico-political discussions about convergence and related visions (such as "human enhancement"). Posthumanism can be defined as both a worldview, with roots mainly in the early-mid 20th century, and a movement ("transhumanists", "extropians" etc.) promoting this worldview, which is directed towards overcoming physical and cognitive limits on the human condition (cf. Coenen 2006, 2007).

With the advent of nanotechnology, the "Joy debate" (Joy 2000) and the emergence of CT as a topic, we have witnessed how elements of this worldview have been reactivated, rearranged, and integrated into the overall discourse on S&T and their societal implications. The ontological politics of convergence were shaped, if not preconfigured, within an institutional context that was marked by an intense interplay of research policy, on the one hand, and technofuturist professionals or activists (including organised transhumanists), on the other. From this, a series of questions follow with regard to the implications of convergence for the SSH and a related European strategy:

- Which values and beliefs originally shaped the debate on convergence? With what kind of visions do we have to deal here and where do they come from? What role did and do these visions and their underlying values and belief systems play in the ontological politics of convergence?

- In what kind of institutional contexts has the debate on CT been started and shaped? Who were its drivers and which other actor groups have played a role? What about SSH and their contributions to the ontological politics of convergence in this context?

- What challenges for European research policy and academia arise from the posthumanist framing of the debate on CT? What can we learn from the genesis and antecedents of the debate on convergence with regard to a European strategy for CT and related SSH research?

3.1 Drivers of the debate on convergence and their use of visions

By means of bold mid-term or extremely far-reaching technoscientific and societal visions, some of them rather eerie to observers, the US initiative on CT, the so-called "NBIC initiative" (nano, bio, info, cogno), applied the US government's nanotechnology strategy of "hype and hope" (Bond 2002; cf. Paschen et al. 2004) to a wide range of other sciences and technologies. The initiative derived from the funding of technology assessment activities and was seen by the US National Science Foundation (NSF), the funding agency, as an important element of its activities on the ethical, legal and societal implications (ELSI) of nanotechnology. CT became a political issue due to conferences (cf. Roco/Bainbridge 2002; Roco/Montemagno 2004; Bainbridge/Roco 2006a, 2006b) and (to a lesser extent) social science and humanities studies into ELSI of new developments in science and technology (S&T). As a topic, CT is, first and foremost, a product of such "accompanying" activities. The notion of a "merging of two worlds: the kingdom of fact, and the kingdom of values", which is seen as characteristic of the ontological politics of S&T in general (Law, 2004: 2), is therefore an appropriate, if not necessary starting point for an analysis of the debate on CT.

Two key figures of the NBIC initiative are Mihail C. Roco – a National Science Foundation (NSF) officer and "architect" of the US National Nanotechnology Initiative (NNI) – and another NSF officer, William S. Bainbridge, a professional sociologist of religion and space enthusiast, who has been responsible since the 1990s for projects at the interfaces of social, behavioural and economic sciences and information technology research. Bainbridge has acted as the link between the initiative and organised transhumanism, at least since 2003, and himself published very far-flung visions of an extraterrestrial, posthuman civilisation and an overcoming of death by technical means (e.g. Bainbridge 2004b).

The NBIC initiative's programme (Roco/Bainbridge 2002; pp. 1, 5f. and 18-20) includes the vision that "the human body will be more durable, healthy, energetic, easier to repair, and resistant to many kinds of stress, biological threats, and aging processes" and a view of a transformed civilisation looming on the horizon, in which advances in nanoconvergence will enhance sensory and cognitive capabilities (also "for defense purposes") and enable "brain to brain interaction". This might then lead to "wholly new ethical principles" that will govern "areas of radical technological advance, such as the acceptance of brain implants, the role of robots in human society, and the ambiguity of death in an era of increasing experimentation with cloning". Moreover, the editors hope that technological convergence hand in hand with "human convergence" will lead to a "golden age", characterised by "world peace, universal prosperity, and evolution to a

higher level of compassion and accomplishment". Humanity might then become something "like a single, distributed and interconnected 'brain'" or a "networked society of billions of human beings"– possibly regulated with the help of "a predictive science of society" (Yonas/Glicken Turnley 2002), by applying "advanced corrective actions, based on the convergence ideas of NBIC" and an "engineering" (Bainbridge 2004a) of culture. Some participants were impressed by the long-term potential for "uploading" aspects of individual personality to computers and robots, thereby expanding the scope of human experience and longevity (Roco/Bainbridge 2002, p.86).

The visionary programme of the NBIC initiative has thereby become an important point of reference in a political discourse which does not exclude visions of a massive modification of human bodies in terms of a possible "reconstruction of man" (Bonazzi 2006) or of the creation of "posthuman" beings (e.g. in the US 21st Century Nanotechnology Research and Development Act; cf. NRC 2006). Moreover, the initiative itself and some of its key promoters have aired speculations about an extraterrestrial far future of our civilisation which might be transformed into a symbiotic man-machine superstructure. We are also invited to consider potential uses of converging sciences and technologies – including applied brain research a – for the creation of new social technologies which might guarantee a safe passage into this future world (e.g. Yonas/Glicken Turnley 2002). Citing some official claims about the potentials of nanomedicine, a conservative US critic wrote that even other "grand ambitions", such as the elimination of "suffering and death from cancer" by 2015, "pale in comparison to the claims made by National Science Foundation officials about the looming 'NBIC convergence'" and "new possibilities for the radical control and enhancement of the human form" (Keiper 2007, p. 65). In his view, the claims made by the NBIC initiative "are just a stone's throw away from the transhumanist dreams of using nanotechnology and other new techniques to merge man and machine, and for man to fundamentally alter and eventually leave behind his given biological nature". He concludes: "The fact that some of those enamoured of this absurd fantasy work for the National Science Foundation is worrisome, but it doesn't make the fantasy any less absurd".

3.1.1 Dealing with ethical and societal implications

Much of the stir and irritation that have been caused by the NBIC initiative can be explained by diverging views on the nature and role of ELSI (ethical, legal, and societal implications) in the discourse on convergence. The initiative's key players, reacting to harsh critique of their ideas, have stressed that they were extremely eager to include

societal aspects of the CT as early as possible into the debate. It should not be overlooked that Roco and Bainbridge organised an NNI workshop on "Societal Implications of Nanoscience and Nanotechnology", in September 2000 (Roco/ Bainbridge 2001), and that the NSF also cooperated with the European Commission on these issues (Roco/Tomellini 2002). However, after the start of the debate on CT, following the publication of the first NBIC report (Roco/Bainbridge 2002), these efforts were only rarely (e.g. Paschen et al. 2004) analysed, and, if so, often only as element of the context of the highly visionary and ethically problematic NBIC agenda. The reports on these efforts not only included valuable contributions by social scientists and humanists, but also refrained from infusing posthumanist propaganda into the discourse. Instead, science-fictional and posthumanist ideas were discussed rather critical, often in form of boundary-work vis-à-vis the nanofuturism of K. Eric Drexler and its gloomy adaptation by Bill Joy (2000). And the first report of the NBIC initiative (Roco/Bainbridge 2002) clearly built on the earlier reports. It tried to systematically integrate the topic of ethical and social implications by referring to it throughout the strategic parts of the text and by including contributions of social scientists and humanists.

However, a closer look reveals that the efforts of the NBIC initiative's key players must inevitably have alienated the majority of those in the SSH who work on the relationships between science, technology, society, and ethics as well as a variety of socio-political actor groups. One reason for this is the first NBIC report's peculiar blend of (a) state-of-the-art reflections on the relationships between science, technology, and society, (b) crude techno-determinisms, and (c) the instrumentalisation of highly speculative ethical and societal implications of the CT in a strategy of "hype and hope". All NBIC initiative's publications predominantly display a strong technoscientific and political agenda, with the contributions provided by the (mere handful of) social scientists and humanists giving their colleagues the impression of being only minor attachments. In the two recent publications (Bainbridge/Roco 2006a, 2006b), more sceptical social scientists and humanists are largely missing, and highly optimistic ones, some of them organised transhumanists, have been invited to contribute articles. More importantly, most of the ideas brought forward by the key players of the initiative (including several non-academic technology experts and promoters) are characterised by a strongly affirmative, "uncritical" and "unreflective" stance, incompatible with the state of the art in STS, technology assessment and related fields of research. The fact that Roco and Bainbridge not only framed the discussions, but also wrote the most important parts of the publications themselves furthered the impression that the initiative was not interested in a sober and serious reflection on the ethical and societal implications of the CT.

Their involvement embodied the assumption, identified above as just one phase within the development of STS perspectives, that matters of ELSI are antecedent to the technical content of CT. Here, it may be useful to have a short look back to the institutional context from which the NBIC initiative originated: In the 1990s, the acronym "ELSI" had become a regular part of bioethical and research policy parlance due to the US Human Genome Project, which had run a so-called "ELSI" programme, the world's largest bioethics research programme. "ELSI" was used here as an acronym for "ethical, legal, and social issues". However, the early US nano research policy community preferred to speak of nanotechnology's "societal" and economic "impact(s)". One of its reports (NSTC-IWGN 1999) displays an approach which is fairly technodeterministic, promising "enormous" economic and societal "returns" and "benefits" from nanotechnology and outlining a wide range of applications. The report was very optimistic indeed, claiming that the potential of "nanotechnology to transform so many aspect of human existence is almost without precedent" (NSTC-IWGN 1999, Technical Summary, p. xv). However, its outline of application fields was rather "down-to-earth" – with one notable exception: While there was not one single social scientist or humanist among the numerous "academic contributors", one short sub-chapter of the report was written by a private sector representative, namely James Canton, a sociologist by training, who describes himself on his website as "renowned global futurist, social scientist, keynote presenter, author, and visionary business advisor". The sub-chapter is the only one dedicated exclusively to societal aspects and titled "The Social Impact of Nanotechnology: A Vision to the Future" (Canton 1999). Here are the seeds of the NBIC initiative. Possibly inspired by academic concepts of a nano-bio-info-convergence, emanating from the social-scientific discourse on ICT and media convergence (e.g. Castells 1996), Canton, who subsequently became one of the "fathers" of the NBIC initiative and contributed to several of its publications, wrote: "Nanotechnology's impact on society will be comprehensive, touching all aspects of lifestyle, quality of life, and community. (…) The convergence of nanotechnology with the other three power tools of the twenty-first century – computers, networks, and biotechnology – will provide powerful new choices never experienced in any society at any time in the history of humankind" (Canton 1999, p. 179). In his long list of examples for a "higher quality of existence" in the future, he foresees the emergence of "(s)ynthetic tissue and organs, genetic and biomolecular engineering, and 'directed evolution'", and "new choices" for the "augmentation of cognitive processes, and increase of physical and sensory performance".

The NBIC initiative continued this infusion of posthumanist topics into the discourse on nanoconvergence and aired even bolder visions. But at the same time it stressed the relevance of ethical implications. In one of the most controversial parts of the first NBIC

report – with the title "Transformation of Civilization" (Roco/Bainbridge, pp. 18-20) – this culminates in an enthusiastic vision of the future. In this future, "human identity and dignity must be preserved (…) and (t)he ultimate control will remain with humans and human society", thanks to "proper attention to safeguards, ethical issues, and societal needs". But the promised "new levels of subtlety and sophistication" in "(a)rt, music, and literature" and the enhancement of "the mental qualities of life and the innate human appreciation for beauty" will take place in a world society that is organised as a "collective social system", similar to a "larger form of a biological organism" which will be governed with the help of a "predictive science of society" and "advanced corrective actions, based on the convergence ideas of NBIC". In another strategic part of the report, we learn that "(t)he ability to control the genetics of humans, animals, and agricultural plants will greatly benefit human welfare; widespread consensus about ethical, legal, and moral issues will be built in the process" (p. 5)

In light of these and many other, similar statements, Roco's and Bainbridge's reflections on the "complex interplay of social and technical factors" (p. 10), their ideas on "Ethical Issues and Public Involvement in Decision Making" (p. 12) and their recommendation to include "social scientists and humanistic scholars, such as philosophers of ethics" in the "social process of setting visions for nanotechnology" rather alienated than fascinated social scientists and humanists. Obviously frustrated by their reactions, Roco recently propagated an "ELSI+" ("extended ethical, legal, and societal issues") approach, which should not only include the ELSI, but also policy, security, and "education gap" issues (Bainbridge/Roco 2006, p. 13-15). He criticised "one working group in the European Community" (probably: EU HLEG 2004) and the Netherlands Department of Justice for playing down "the message of the scientific contents" of the first NBIC report. His own ELSI+ approach should not be used "primarily as a 'defense approach' against concerns but as an approach to help innovation and positive outcomes by responsibly applying converging technologies" (p. 14). In his view, the first NBIC report, while coloured with "cultural, ideological and political influences" is "based on scientific evidence and underlines the need to respect the human condition, democracy, and serving human needs."

3.1.2 A trap for the social sciences and humanities

One of the most striking features of the debate on CT is the intellectual and personal interconnections of the NBIC initiative and posthumanism, represented by the NSF officer Bainbridge and his ideas on convergence. Their interplay has already been analysed in several articles and reports (cf. e.g. Coenen 2006, 2007; Paschen et al.

2004; Schummer 2004; STOA 2006) and can be summed up and updated as follows: On the one hand, the NBIC initiative often stressed the fact that it was supported or joined by renowned scientists and representatives of government agencies and important firms and distanced itself from Drexlerian nanofuturism (Drexler 1986), Bill Joy's posthumanist gloomy Drexlerian visions (Joy 2000), and transhumanism. On the other hand, Bainbridge has acted as a link between transhumanism and the initiative, at least since 2003. Critics of the initiative – among them US conservatives, American and European academics and technology experts, EU research policy officials, ecologists, leftists, Christian laymen and theologians, and European natural scientists and engineers – reacted by pointing out the proximity of the NBIC visionary programme and initiative to transhumanism, science fiction and rather dubious research fields (such as "memetics"; cf. Strong/Bainbridge 2002; Bainbridge 2004a) and the disguise of extreme visions in a presumable serious hard science, engineering and policy agenda. The coupling of such visions with ideas of US military and cultural supremacy furthered the irritations, in particular in Europe. In Europe, under the influence of an EU high-level expert group's report on CT (HLEG 2004), and elsewhere a multi-faceted critique of the initiative, its political ambitions and the metaphysical underpinnings of its visions emerged. In America, those involved in the initiative from the SSH, also criticised some of the initiative's central features, but the critique came, with notable exceptions, rather late, was brought forward mainly outside the initiative's activities (e.g. Khushf 2005), and tended to ignore or belittle the transhumanist background. Meanwhile, however, the linkages between the initiative and transhumanism have become obvious, with NSF's Bainbridge having become a kind of "grand old man" and "father figure" of the (predominantly young or middle-aged) organised transhumanists and transhumanist activists contributing to the new publications of the initiative (e.g. Hughes 2006).

Bainbridge and other transhumanists active in the debates on CT and human enhancement still often point out their qualifications or expertise in technoscientific areas which they acquired before becoming scholars or in the course of their professional lives. However, they have positioned themselves mainly as ethicists and experts on the ELSI of new technologies, in accordance with their professional backgrounds (mainly social sciences and philosophy). Basically they are experts on and promoters of visionary ideas about the technosciences and their relevance for the future of our civilisation and the human species. They tend to dramatise the prospects of new technologies and societal processes, focusing on best- and worst-case scenarios (cf. Schummer 2004, 2006). On several occasions, Bainbridge (2003, 2005a, 2006) has conjured up massive future conflict between large parts of Western societies over cognitive science and other converging fields, for example, "the coming conflict"

between "convergenists" (his term) and "religion (…) and other reactionary forces" (Bainbridge 2005b, p. xiv). He warns his transhumanist audiences of their future persecution by a technophobe mainstream or establishment (Bainbridge 2003, 2006). In a non-polemical, but similar way, the NBIC initiative as a whole has used bold mid-term and far-reaching visions to foster a sense of urgency with regard to the prospect of convergence. In an "economy of attention" such a strategy is commonplace, but it is detrimental to SSH research into the actual and realistic future implications of converging technologies.

Certainly, this development cannot be wholly explained by the influence of individual key players alone, but must be looked at in the wider institutional context (cf. TAB 2008). The initiative's focus on the augmentation of human cognition and other capabilities ("human enhancement") was facilitated by the fact that several institutions were interested in a deliberation on this theme with regard to nanoconvergence: The Defense Advanced Research Project Agency (DARPA) of the Department of Defense used the opportunity to promote some of its pertinent, cutting-edge research projects; the foresight think tank of Sandia National Laboratories introduced its ideas on the future role of the NBIC fields in a global security context; and the Technology Administration of the Department of Commerce included posthumanist and "human enhancement" aspects in its nanoconvergence strategy of "hype and hope". The NSF's interest in the convergence issue was predominantly motivated by the hope to consolidate and continue its mainly NNI-related increase in relevance, compared to other funding agencies. The strategy underlying the NBIC initiative and other NSF activities was to bring in biotechnology and cognitive science: "Converging Technologies was originally conceptualized as a successor to NNI (…). It is also a potential joint successor of NNI and ITR (Information Technology Research initiative), as the latest projects funded under ITR would indicate. ITR and NNI provide the technological 'push' with broad science and engineering platforms. Realizing the human potential, 'the pull', would include the biotechnology and cognitive technologies" (Bainbridge/Roco 2006b, p. 13).

There was a window of opportunity and it was used by the posthumanists inside and outside the NBIC initiative. With a mixed strategy of camouflage and frankness, they managed to infuse an indeed highly optimistic and determinist, but still rather "down-to-earth" discourse on S&T with elements of their quasi-religious worldview.

At first glance paradoxically, the intense boundary-work within the nano community vis-à-vis Drexlerian nanofuturism that took place in the aftermath of the "Joy debate" facilitated this infusion. Although Bainbridge and his fellow travellers promoted elements of the very same worldview that also informed the writings of Drexler and Joy

(e.g. Ray Kurzweil's visions; cf. Kurzweil 2005), they were able to do this within the framework of an initiative that has been called a "Federal inter-agency activity" by NSF officials. Protests and critique came largely from outside (US conservatives such as the US President's Council on Bioethics, left-wing social scientists and activists such as Langdon Winner and the ETC Group, various European critics), but not from US research and technology policy actors although they were at the same time so eager to delineate the field of nanotechnology from Drexlerian "utopias" and "dystopias".

This seeming paradox might be resolved, if we take into account the specific preconfiguration of the discourse on nanotechnology and convergence. We may interpret posthumanism as a "hostile brother" of its "dystopian" critique which together prevail in the discourse (cf. Coenen 2007). From this perspective, the exclusion or marginalisation of social scientists and humanists as actor-groups that could be observed in the early US discourse on nanoconvergence is reflected in an ideological configuration which systemically impedes the testing of assumptions that underpin the techno-social visions: The "social implications" of NBIC convergence are then "knowable and the ethical dimensions negligible because given the way that the narrative re-ontologises the past, present and future (e.g. […] NBIC makes possible the increases in productivity and human performance that have always been the motive force of human evolution) no other future is desirable or even conceivable" (Lopez 2005, p. 26). In this context – which is not the one of the European debate on convergence –"what would be unethical" or " qualify as a negative social outcome", would be "the failure to proceed forward", even absent any serious foresight and deliberation efforts. While it might be worthwhile to also use CT "to imagine radically different futures" (Lopez 2005, p.24), these futures should not be constructed in a fashion "that the only way to criticize them is to introduce a virus into their core" and adapt the posthumanist ontology "to assemble a dystopian future" (Lopez 2005, p. 26).

If the SSH want to avoid that trap, they should take a closer look at the posthumanist worldview and elucidate from a historical perspective its potential for defining 21 century subject positions. In the following, we can only make some preliminary remarks concerning possible directions of such a research (cf. also Coenen 2006, 2007). However, we would also like to point out that, notwithstanding their often highly speculative and ethically problematic character, posthumanist visions are to be taken seriously as assumptions which deeply underlie debates on the technosciences and their wider implications.

3.2 The genesis and historical antecedents of the visions

Key players of the NBIC initiative and its transhumanist supporters are reconstructing our world as the cradle of a transhuman civilisation. Strong tendencies of techno-determinism (cf. Coenen et al. 2004; Grunwald 2006, 2007a, 2007b) – for example, with regard to the prospects of technologies that are still largely in their infancy or visionary (e.g. several neuro-enhancement technologies) – are combined with ideas for a societal mobilisation in favour of "human enhancement" and other favourite transhumanist technologies. NSF's Bainbridge writes in his latest pertinent publication: "The scientific and engineering community can accomplish much, but their energies are currently not harnessed to the task. Therefore, a social movement must arise to weld individuals together, creating a community dedicated to human transcendence of mortality through colonization of the solar system in the form of advanced robots" (Bainbridge 2007, p.231). In Bainbridge's view, organised transhumanism can be the avant-garde of such a social movement (Bainbridge 2006). His first public announcement of an alliance between the NBIC initiative and organised transhumanism culminated in the following sentences: "Transhumanists everywhere, whether they recognize the name, (…) or not, must join together to break the chains that bind science. The captivity of science, prevented from transcending human physical limitations: This is the challenge. Creating a new civilization, both inside and outside standard institutions: This should be our response" (Bainbridge 2003).

Interestingly, this speech to members of the World Transhumanist Association (WTA) took place during a banquet given on the occasion of the WTA's J.B.S. Haldane award. Haldane is one of the key figures in a technofuturist tradition of thought which informs much of today's transhumanism. This early biofuturism or posthumanism (cf. Coenen 2006, 2007) was shaped in the West by a circle of eminent natural scientists and intellectuals, such as the famous author H.G. Wells, the biologists Haldane and Julian Huxley, and the crystallographer John Desmond Bernal (cf. e.g. Parrinder 1995). All of them are held in high esteem by the transhumanists who, for example, named another award after Wells and often refer to the early use of the term "transhumanism" by Huxley (1957). In their futurist texts, they have envisioned civilisations that control evolution, create improved humans or new species, and colonise outer space. In Bernal's essay "The World, the Flesh, and the Devil" (Bernal 1970), we encounter the vision of an ever-progressing man-machine hybridisation which leads to the construction of a network of disembodied brains and egos in outer space that leaves behind and secretly controls unaltered humanity on earth. Since this network can create artificial life and bio-machine hybrids ("angels"), it possesses tremendous powers to explore, control and manipulate the observable universe up to the stars.

Finally, consciousness itself may end or vanish in a humanity that has become completely "etherealized" and ultimately perhaps will resolve itself entirely "into light".

While Bainbridge does not refer to Bernal or Haldane, their early posthumanist visions clearly resonate in his flights of fancy in which, for instance, he opines that we may learn in the distant future "to conceptualize our biological lives on Earth as extended childhoods preparing us for the real life that follows in cyberspace", that "the transition from flesh to data will not be so much metamorphosis as liberation" and that as "information contained in a star-spanning database (…) we will travel across immensity, create new bodies along the way to dwell in every possible environment, and have adventures of the spirit throughout the universe" (Bainbridge 2004b, p. 119). Bainbridge himself traces such ideas back to the first report of the NBIC initiative (in particular: Robinett 2003) and to a 1993 essay on religion, science, and secularization by himself (cf. Bainbridge 2007). And he refers to another source of inspiration of organised transhumanism, namely the visions of posthumanist visionary engineers such as Hans Moravec, an expert in robotics, who proposed that deep-space exploration would be carried out entirely by intelligent machines, and that humans will soon be succeeded by machines as the dominant intelligent species. However, Bainbridge suggests that machines will not replace humans. Rather, humans would realize that "they are by nature dynamic patterns of information, which can exist in many different material contexts, some of which are suitable for travel to the stars" (Bainbridge 2007, p. 211).

While most of posthumanism's younger roots lie within technophiliac "fringe" groups (such as "cryonicists" and other off-shoots of the anti-ageing movement, enthusiasts of space colonisation, certain cybercultures, and Drexlerian nanofuturism), the worldview of today's transhumanists can also be traced back to Bernal, Haldane and Wells, on the one hand, and to early cybernetics, on the other. Cybernetics put forward the vision of engineering non-biological intelligence and, by privileging "informational pattern over material instantiation", reinforced the posthumanist perspective of the human "embodiment in a biological substrate" as an "accident of history" (Hayles 1999, p. 2). The cybernetic naturalisation of the mind is also an element of the metaphysical underpinnings of both posthumanism and the NBIC initiative. It tends to end up paradoxically in a new ontological dualism, if not spiritualism (Dupuy 2007; cf. Coenen 2006; Dupuy 2000). From the early 1960s on, posthumanist-biofuturist and cybernetic visions converge (cf. Coenen 2006, 2007) and are influenced by a new wave of "eugenics". Much of this visionary discourse was inspired by real and interrelated progress in the life and information sciences, partly accomplished by the visionaries themselves and fuelled by funding for space and military research (mainly in the US). This technofuturist tradition, whose core ideas were melded by organised

transhumanism into a fully fledged worldview, was maintained by a continuous interplay of, on the one hand, rational speculations and non-fictional technological visions, and, on the other hand, science fiction. Among the key figures of this tradition – which neatly fits into an overall technofuturism (fuelled by promoters of the life, information and nano sciences) – are the physicist Freeman Dyson (e.g. 2002) and the author Arthur C. Clarke (e.g. 1983).

If we sum up the core features of the posthumanist worldview, we may better understand the role it plays in the ontological politics of convergence: Early Western posthumanism saw science as "man's gradual conquest, first of space and time, then of matter as such, then of his own body and those of other living beings, and finally the subjugation of the dark and evil elements in his own soul" (Haldane 1995, p. 46), Bernal's "world", "flesh" and "devil" (Bernal 1970). The human race has to "prove that its destiny is in eternity and infinity" (Haldane 1927, p.41), it has to conquer outer space to evade ultimate destruction. Converging sciences and technologies are to be used to prepare the ground for this techno-evolution. They should also guarantee a non-catastrophic transition to the new techno-civilisation, by way of "cultural engineering" (Bainbridge 2004a) and by means of a new social technology, based on visionary neurotechnology and drugs (e.g. Hughes 2007). An overall "human enhancement" and the creation of a new species (wholly artificial or cyborgian) are seen as preconditions of successful expansion into outer space. Promising a kind of immortality and outlining a destiny of humanity, posthumanism has self-consciously become a rival of Christianity and other religions, a fact which fuels quite a few of the recent ethical debates on the CT.

But not only religious critics of NBIC posthumanism may feel provoked by such visions: Sober, more cautious engineers and natural scientists are sometimes worried about negative consequences for the public image of their research fields and professions, and a wide range of critics are irritated by elitist, scientistic and misanthropic overtones in the posthumanist flights of fancy. Haldane himself in his day held that "the value of the individual is negligible in comparison "with the cosmic destiny of mankind (Haldane 1927, p. 41). And the idea of a separation of humanity into a backward species living in a low-tech civilisation on earth and a technoscientific, cyborgian or wholly artificial, extraterrestrian avant-garde can be found in works of Bernal, Haldane and Bainbridge. The last of these writes, without reference to the pertinent visions of Moravec (although he is obviously aware of them) that "(w)e can agree that the planet Earth should remain a refuge for traditional humanity, living in a variety of low-tech societies in what technophiles would call a perpetual Dark Age. (…) The meek will inherit the Earth, but the bold will go elsewhere" (Bainbridge 2007, p. 216).

Vested with the credentials of political, scientific and ethical authority, the posthumanists meld in their visions fact, realistic and fantastic projections as well as contested values into an ontological landscape which is presented as the world as it is and as it should be in the future. Human beings are reduced to their brains, ultimately to their egos, and society to a network of brains in need of enhancement (e.g. Hughes 2006). While the "transhuman condition" functions as a lure for the (post)modern individual, the crypto-totalitarian visions of an hive-like "global brain" (Roco/Bainbridge 2002) remain present in the background. In the far-reaching cosmic visions of some posthumanists (e.g. Bernal 1970, Kurzweil 2005), humanity's destiny culminates in a kind of immanent unio mystica made feasible by mankind's symbiosis with intelligent machines. While much less visible in public than the anti-posthumanist polemic by Bill Joy (2000), the publications of the NBIC initiative and its supporters have contributed to a highly visionary and value-laden framing of the ontological politics of convergence.

What challenges are raised for the social sciences and humanities by this "transhumanisation" of research policy and the ethics of S&T? On the one hand, it remains important to engage critically with the research and technology policy ambitions of the transhumanists inside or outside the NBIC initiative and to analyse how realistic their visions are and how urgent their claimed needs for action (Grunwald 2007a, 2007b, Nordmann 2007a). On the other hand, there is a need for a broader assessment of the worldview which underlies and is expressed in the NBIC initiative's core visions and similar ideas. What we have to deal here with is a worldview which apparently exerts influence on the public understanding of S&T (largely by way of its intense interplay with science fiction) and which is an important element of recent ethical and political debates about the CT. While many of the ethical debates appear to be "show fights" of "hostile brothers" in which (traditional) religious and quasi-religious posthumanist authors compete together for public and political attention, they indeed at least touch upon central questions of how the relationships between science, technology and society are shaped by techno-visions of various kinds. Questioning the specific worldview of posthumanism cannot be equated with carrying out boundary work in terms of the ontological politics of convergence. On the contrary, the recognition of posthumanism as a relevant actor and current of thought in debates about S&T may help us to gain a more accurate and nuanced picture of the diverse ontological landscape of convergence. Besides helping to bring in perspectives derived from the rich tradition of European thought about the future prospects of S&T and their societal relevance, the analysis of posthumanism may also help to shed light on other, more or less related visions of "enhancement" by man-machine interaction (cf. e.g. Friedewald 2005) and of technoscientific convergence (cf. e.g. Bunge 2003), some of

them to be found in the NBIC initiative's publications (e.g. Spohrer/Engelbart 2004; Turkle 2002).

The distinction drawn (HLEG 2004) between an engineering of the human mind or body and an engineering for the human mind or body may help us to assess the various visions of "enhancement" and "convergence" and specific trajectories of man-machine interaction. While not rashly to be taken as a kind of threshold which it should forever be forbidden to cross (in the sense of a "tampering" with human nature), it may serve us in analysing more and less radical modes of enhancement (Khushf 2005) in a differentiated manner. A high degree of physical man-machine symbiosis, for example, does not necessarily indicate a loss in human autonomy, as some assistive implants demonstrate. On the other hand, ontological concepts of "enhancement" that subsume inter alia the effects of chewing-gum, brain implants, computer use, and education (Sandberg/Bostrom 2006) will only obfuscate nuances and fundamental differences. Moreover, the history of man-machine interaction shows that the intention to free human beings of natural constraints by the use of (body-external) machinery often results in new necessities. Such dialectics of emancipation and mechanisation have been analysed in detail with regard to many specific technologies, and the SSH will increasingly have to do this with regard to the new converging sciences and technologies.

4 Performing the ontological landscape of converging technologies

We have thus far considered some of the historical and institutional origins of the ontological landscape of CT, focusing especially on transhumanism. But it is important also to know: to what extent and in what ways are these ontologies enacted, kept alive and performed in contemporary discussions about CT? In order to address this question we looked in detail at the transcripts of four interviews with CT participants, and at the transcript of an international live webcast conference[2].

The analysis of the materials presented in this section is informed by techniques for textual analysis developed by Dorothy Smith (1978, 2001) that suggests that a text (the interview transcripts; the cyberchat protocol) is constitutive of the phenomenon it describes (converging technologies) as it introduces certain entities and performs relations - communities of actants/the moral order - between them. We examine in detail the ways in which CT are constituted by (re)defining boundaries between different constituencies/actants. The individual and collective actants to which various kinds of agency are ascribed include, for instance, individual scientists, policy making bodies, corporations, and members of expert/public domains. Our participants sometimes explicitly drew on the language of boundaries when, for instance, referring to the CT-related processes as **"***… a sort of intellectual/capitalist frontier that has yet to be negotiated and/or defined* (CT cyberchat)*,* or as being about *"fundamentally blurring the boundaries between discipline-based science" (KatherineL).* The revolutionary claims associated with CT manifest themselves in these materials as a profound redefinition of boundaries. Some boundaries are rendered as having particularly important consequences for other processes of knowledge creation and for the very condition of humanity. For instance, the blurring of disciplinary boundaries ("interdisciplinarity") is said to bear "*on our whole notion of research, development, and thinking, and knowledge.* (KatherineL). The frontier of the human skin is spoken about as being equivalent to the whole redefinition of the social (CT cyberchat). Means of transition from the "present" human condition to some "future" state are offered and contested. In this section we offer a critical assessment of these claims to boundary redefinition.

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2 The webcast conference moderated by Steve Fuller is referred to as the "CT cyberchat" in this paper. The protocol of the session that took place on 15 May 2007 is available online at http://www.converging-technologies.org/cyberconference/Chat/tabid/55/Default.aspx, last visited 18 September 2007.

Our materials indicate that a notable current feature of CT is the lack of obvious or commonly agreed patterns of responsibility for the revolutionary transitions expressed in some of the literature on CT (see section 3 above). Neither did we observe much agreement on the definition of converging technologies. It seemed instead that the question of which entities are assigned accountability and/or accept responsibility is a significant and (as yet) unresolved matter of concern for our participants. What we observe is rather a range of contested claims out of which various modes of governance were articulated and questioned.

4.1 Performing expert membership in CT

Uncertainty about the status of the expert in CT was a recurrent theme. KatherineL characterises CT as a "strange field" when speaking about the task of assembling a pool of "experts" for an policy-making research exercise: "*It is a strange field… how do you define the stakeholders in CT?"*. A similar opinion was expressed in the CT cyberchat: "*Luckily or not, it's not clear who the experts are in matters relating to converging technologies -- lots of different expertise simply run up against each other*." (CT cyberchat) How then is expert membership in CT performed? We asked our four respondents to explain their affiliation and involvement with CT and to reflect on the various roles associated with CT. We were also interested in the accountability structures in and through which such expert affiliations are articulated. The answers varied with regard to the closeness/distance of the respondents' activities and forms of affiliation with CT.

KatherineL does not regard herself as a key person in CT. She sees herself, not as an expert on convergence, but on some future studies methods. KatherineL has been working on a research council project helping to build scenarios on the futures of CT. The deliverables for this project include a set of questions to be included in a next call for research funding. But KatherineL is not happy with such framing. She sees her work as providing "a tool to provide the research council with CT conversations" but she can not provide the research council with a set of questions.

KatherineL distinguishes between natural and social sciences involved in CT.

> *The social sciences getting involved seem to be the social sciences that have always been involved with technology, as opposed to economics. Economists have not touched CT (but there is research estimating the market for nanotechnology). Some social scientists shape the conversation – is it ethical? These are CT and these are the issues that we have to take into account. But*

> *very disparate, more disparate than natural scientists who tend to be working in this area.* (KatherineL)

PaulM reported that he was involved in CT "to a significant extent". As a philosopher, he is generally interested in such topics as "future implications of technologies, human enhancement and nanotechnology". He is working on a project connected to CT, concerning the ethics of human enhancement. It is a collaboration between several universities, and his focus is cognitive enhancement. PaulM does not think the project is specifically "branded" as CT:

> *I am not sure if the phrase "converging technologies" featured … if it occurred in the funding proposal it was in passing somewhere. As you know, these proposals…* (PaulM)

PaulM distinguishes between those who "do" (make, do the science of) CT and those who "talk" (reflect, write) about them, in anticipation of possible objections to CT (by "some people"):

> *People who would have an objection to CT or to human modifications, they would be happy with philosophers thinking about that, or with social scientists wondering about the implications. Their concern will be with people who actually make these things available. Only a few people who may think that all the money should go into the development of the technologies and not wasted on people who are not actually building anything.* (PaulM)

Thinking about CT is thus presented as a harmless exercise provoking no real impact on the world or consequences for (stopping) funding. On the other hand, doing CT in the form of philosophising and writing can have some real impact:

> *If I saw something like that {I disapproved of} I would try to speak up against that trying to explain why that is such a bad idea. ... I wouldn't stop doing philosophy because I thought that some of the CT would be catastrophic. It would be more writing and critique.* (PaulM)

The boundary between the scientific and social scientific/humanities expertise blurs as projects form. The work of "wondering about the implications" of emerging and converging technologies requires recruiting some kind of natural scientific expertise. In PaulM's project, a neuroscientist by background was recruited, a philosopher needs to

dust off his medical credentials, and a famous neurophysiologist (MarthaB) is another member:

> *The work on ethics is clearly from a philosophical point of view, not from the technical, natural scientific kind of perspective?*
>
> *No, we are trying to do both, trying to understand exactly what is feasible – medically, technologically, right now, in the future, and trying to build some ethical analysis on top of that. We are not having a lab. But we are trying to dig into science, and into specific techniques as well.*
>
> *Are there any scientists in your team?*
>
> *Yes, in December we hired a neuroscientist by background. And James Smith.*
>
> *But is he not a philosopher?*
>
> *Yes, but he is a doctor by training. And I have science background as well. MarthaB was involved in some of it…* (PaulM)

GeraldK says his involvement with the CT is "very limited", but that his project on regenerative medicine could be categorised as CT-related: *"the work that I've been developing in the area of stem cells has led to some collaboration between universities in the field of regenerative medicine."* (GeraldK). It is a "possible candidate" for CT:

> *But to be honest if someone asked was it designed as a converging technologies project per se – I'd say no. It's a sort of converging technologies project.* (GeraldK)

The convergence aspect of the project is apparent in that the field of regenerative medicine "brings together a number of technologies in a convergent way: biology, engineering, informatics, clinical expertise, surgery and so on", whereby "converging technologies" is defined as a "sub-field":

> *Our involvement with that is trying to anticipate the sort of regulatory dynamics of this field over the next five-ten years. We are doing some work on regulation for this particular sub-field which is called converging technologie*s. (GeraldK)

According to GeraldK, such involvement is subject to evaluations and redefinitions in the context of funding decision-making as social scientific expertise becomes recruited as a part of a natural science project. The role of such social science expertise in these instances is relatively marginal:

> *If you define social sciences and the work we do on regulation as a form of expertise and techniques that could be incorporated into the field of regenerative medicine, you could say that there's some sort of contribution that we are making. But it's very much seen as a service role rather than a fundamental role. Who are funding, they need to partly redefine our own work on regenerative medicine in order to get funding from the regional development agency that is supporting all that*. (GeraldK)

He also claims an indirect affiliation with CT through his involvement, "wearing a different hat", in the House of Commons Science, Technology and Health committee. He admits that his initial source of authoritative knowledge about CT was discussions *"with some of the civil servants there who introduced me to converging technologies."* (GeraldK).

A striking feature of interviewees' responses was their use of the distinction between on the one hand, real CT (the actual doing of CT, practical involvement in CT) and, on the other hand, (merely) talking about, debating, discussing and promoting CT.[3] Interviewees did not consistently categorise themselves as situated on one or other side of this distinction, but rather shifted during the interview.

MarthaB sees herself as both "involved in" CT and in commenting upon it. As a natural scientist, she "is involved in experimentation". She acknowledges however that whether scientific activities she is involved with can be seen as CT can be questioned. MarthaB claims that the research into "how the brain generates consciousness" in her lab involves a combination of different knowledges: *"the use of optical imaging requires the knowledge of physics and chemistry, biology and psychiatry. IT as well – modelling in a hypothetical, collective mathematical model. Knowledge of relativity, and time and space to understand how these things may come together".* However, she recognises

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3 This may be an artefact of the make up of our sample of 4 interviewees. The interview sample for CONTECS project as a whole comprised three groups: Social Sciences and Humanities; Natural Sciences and Research Policy. Of the 4 interviewees considered here, 3 were from SSH; and 1 from Natural Sciences.

that describing this as convergence could be challenged (by "some"): *"One may argue that this is straightforward biotechnology, but what we are doing is convergence"* (MarthaB).

With equal commitment, she is actively involved in debates on CT. She is especially keen to talk about CT in the context of policy debates about improving the future of scientific education. For her, CT are about the need to promote cross and interdisciplinary education for scientists. As a public figure, she acknowledges it is as a duty and an opportunity to be able to speak publicly about CT: *"In my position in the House of Lords I am able to talk about it".* She has established herself in a role which enables her to comment on CT, to articulate definitions, as well as relevant and pressing concerns and ways of solving those: *"You need something the ethicians should worry about"?* (MarthaB to interviewers). She is writing a book about identity in 21st century and how it is going to be affected by CT (MarthaB). MarthaB also acknowledges her special position as a privileged spokesperson about CT:

> *I am privileged to be able to speak about these things. As compared to an average academic I can have access to journalists rather quickly, I know who to talk to, and I can get things out more efficiently than any average speaker or academic (perhaps, with all modesty). That's one of the things I am very lucky I am able to do* (MarthaB).

We see then that the status of the expert in CT is uncertain. The extent of participants' involvement varies and this variation is explained by appeal to a hierarchy of disciplines. A central characteristic of this performance of expertise is the use of a distinction between "talking about" and "doing" CT. This distinction is used flexibly, in that participants can characterise their own activities as falling on either or both sides of the divide. This perhaps suggests that the difference between doing CT and just talking about CT is itself constitutive of the field.

4.2 The dynamics of NBIC components

4.2.1 The trouble with definitions

We noted earlier a general lack of agreement about what "converging technologies" comprise. This section looks at what it takes and what it means to articulate a definition of CT. We suggest the work of articulating a definition of CT reflects the currently unstable patterns of accountability. Thus, participants frequently acknowledge the possibility of challenges (either by some named entities or by the generic actant *"some people"*) to definitions of CT.

KatherineL reported that she personally had no definition of CT. In her profession concerning future scenario building she tends not to hold a view. Otherwise she starts becoming partisan, and she stops listening. Her source of authority on CT is "the report from the US" she read a year and a half ago. The report defined CT in terms of NBIC, but KatherineL assumes that "this might have changed since". KatherineL shared with us her observation that she encountered a number of different, and contradictory definitions:

> *Some people understand it in terms of nano, bio, information and cognitive science, and hold to the fact that each of those hold the key to the development of each other.*
>
> *And some people think that this has nothing to do with convergence. It is not about convergence, it is about divergence, about intersection. You find different words for it. It is not about coming together at a single point, but about coming together and getting apart, about weaving in and out of technology and science. (KatherineL)*

One of the tasks of her CT project was to assemble a constituency of experts to debate various definitions of CT. This constituency comprised a range of social scientists, economics, natural scientists, and also potential investors and users of CT. KatherineL was asked to go and find, not the usual suspects, but rather individuals outside pure academia, including business, commerce, and the military. A consistent feature of the scenario-building exercise was "the invocation of future horizons by different epistemic communities fighting for legitimacy".

MarthaB did not hesitate to provide a solid definition of CT defining it through two NBIC components: *"if you think of invasive and pervasive technologies that would embrace nanotechnologies with IT, you would have a converging technology"* (MarthaB). But

other definitions are possible. For instance, in her new book, convergence is defined as a market driven phenomenon:

> *As I understand technologies can traditionally be distinguished as … crudely, my view… nanotechnology, biotechnology, information technology. Now, the demands on the market, for products and services and so on, that people may want, mandating these things all coming together.* (MarthaB)

Some respondents were reluctant to give a definition, even preferring to shift responsibility for a definition to the interviewers. The assumption seemed to be that at least some definitions are available somewhere. Respondents seemed to imagine that the interviewers knew "what is going on in CT".

Participants' definitions of convergence employed different mentions and combinations of the elements of the NBIC acronym. PaulM suggests that NBIC is a useful "buzzword" that assumes that "a lot of interesting work can be done at the interface of those different disciplines". However, NBIC also represents a current choice of a focus for the application of the term "converging technologies": *"Whether there's something specific about these four different disciplines that makes it a suitable unique focus, as opposed to any other disciplines that you may like to cross-fertilise. It also depends on which specific product in the CT…"* (PaulM)

Participants in the CT cyberchat were similarily conscious of the variations:

> *What I find interesting is that NBIC discussion is often just NB, or as Steve just put it, "nano-biotechnology stuff"... I also got that impression on the workshop. Where is I and C? (I admit I'm kind of biased toward I and C, I'm a psycholinguistics grad...)* (CT cyberchat)

Sometimes CT discourse featured the idea that "nano" was at the heart of the convergence. However, the place of "nano" in CT was also performed differently.

> *I was thinking of not just nanotech, but the whole NBIC spectrum. (I also said people were prone to identifying the two, which I don't like.)* (CT cyberchat)

MarthaB acknowledged a problem in defining "nano" as the pivotal component of CT. First, "nano" is a troublesome component: *"what is nano is clear to some and not to others"* (MarthaB). Secondly, in order to "converge", the technologies must be recognised as sufficiently "different". Another definition uses two NBIC components – biology and IT – to constitute "convergence" in more general terms of "traditional" disciplines coming together. GeraldK spoke of the "mantra" which characterises current discussions of CT in terms of the NBIC components.

In general CT discourse deploys the term NBIC as a label, an acronym, and as the scientific practice that sustains NBIC convergence. These deliberations involve, on the one hand, figuring out the correspondence between the label and what is going on in practice, and, on the other hand, strategising and assessing how well the label does the work of "converging" the disciplinary components. PaulM put it in terms of a more general problem for the organisation of scientific research:

> *It's very difficult perhaps to have a debate at the abstract level without having these simplifying buzzwords and rubrics (like should we push "nanotechnology", "medicine").*
>
> *Do you need a kind of big language, meta-language, high-level rubric?*
>
> *I don't think it will ever go away. But I think it's more important to ask what's the role of that hi-level language is, and to what extent it kind of connects to a mid-level language.* (PaulM)

4.2.2 Performing communities

The interviews reveal attempts to strategise about the use of the CT label. What is achieved by use of the CT label? Some respondents find it problematic:

> *I have a problem with the word "converging technologies". I really do not see what it brings to those conversations that are already there.* (KatherineL)

MarthaB, as an active public speaker on behalf of converging technologies finds the label useful:

> *I like it personally. It is what it says on the tin. It's converging, it's technology. Singularity – I don't like, you need to understand what's the vertical. With CT everyone pretty much knows what it is- different disciplines, and that is coming together in a way that you can't disentangle. You get much more value than from each of the smaller parts* (MarthaB).

In her view, the term functions not just as a label for existing trends in scientific research, but as a banner to encourage people join under it:

> *Is there a danger it's too wide, too broad? So it loses coherence?*

> *It depends on what you want to achieve. Yeah? If you want to look at trends, then it's very important, because the more you narrow stuff down, the more you are prohibitive and constraining, and determining what people need to be thinking and doing. Whereas I think it's broad enough to allow a diversity of activities and inventions that are going on, but nonetheless in a common theme. I am very comfortable with that. It may be that the technocrats and the bureaucrats are uncomfortable with something that hasn't got a greater specificity, and more constraints.* (MarthaB)

However, KatherineL questions the need for such an "ambiguous" term that turns the debate into a debate about "everything":

> *…if it's too ambiguous, it recruits to it every conversation that is going on into the same space. So you have the sustainability conversation, and the human extension conversation, and the human embryo fertilisation, and stem sell – they all come into the same space. It's a convergence – it's about coming together. You've already got all these conversations within the biological sciences area, and you have all these conversations in the material sciences area. … It can be too ambiguous, but it becomes everything. The debate about everything.* (KatherineL)

Other respondents said it is unclear to what extent the label is actually used on the ground, in scientific labs, that the hype and excitement about CT in the public domain has little to do with the practice of CT.

> *– it's a political effort to get funding, to generate public support or enthusiasm.* (PaulM)

Active researchers do not themselves use the term at all. It is instead a label that is used strategically and opportunistically:

> *They don't actually use it at all. I wouldn't be surprised if in the final pitch they do. Perhaps to get some additional European money ……* (GeraldK)

> *The European Union has been scanning around – they had this CT scenarios last year. Don't know what happened, what debate they stimulated. ESRC has been producing reports on nano. The UK Foresight project. I don't know what policy debates they stimulated, except for, perhaps a mistaken, belief that there is such promise in this area that the UK should be involved somehow.* (KatherineL).

In sum, our analysis indicates little or no agreement about what CT actually are. Participants themselves noted the "trouble" associated with defining CT and could only do so by nominating specific kinds of expertise as relevant to the particular activities under discussion at that moment. We found repeated concern about possible requests for definition from various unspecified organisations or agencies. In all this, participants give much attention to the different components of the NBIC acronym, to the ways these interrelated, and to the relation between this label and the scientific practice which sustains NBIC.

4.2.3 Bringing scientific constituencies under the CT banner

The term "converging technologies" or NBIC can be understood as an element of discourse that can be used to redefine boundaries between, and sometimes unite perceivable different, scientific communities. *"Traditional disciplines come together in a new type of discipline, so that you cannot say this is biology, this is IT"* (MarthaB). However, respondents acknowledged various practical difficulties when speaking about technological convergence in practice. These accounts constituted a kind of folk sociology of the tensions that stand in the way of greater interdisciplinarity. MarthaB spoke of the inertia and discomfort experienced by scientists who venture into "interdisciplinary" work: "*There's inertia because people like to be in their comfort zones. … and research councils, they are the same. They like to be able to say: this is medical research, this is biological research, this is social science research. …… People are traditional, especially academics are uncomfortable out of their comfort zones"* (MarthaB).

PaulM elaborates the same point, drawing on his own experience of "being interdisciplinary": *It's easy to say let's do something in an interdisciplinary way. It's harder to make it work in practice."* KatherineL stressed the importance of accountability systems in providing or refusing incentives for interdisciplinary exchanges:

> *There is no incentive for doing that. It is not that there is no research money for that. But where will you get it published? How is it going to appear in the RAE assessment report? So, why do it? Lock out: the existing system won't accommodate it, but nobody wants to change the existing system. There are vested interests – lot of people benefit from the current system.* (KatherineL)

The proposed solutions to these tensions speak of research contexts in which interdisciplinarity "can happen", either as a response to a breakthrough achieved by China (KatherineL), or through strengthening an educational system that encourages learning practices which stimulate a *"creative, and imaginative, and reflective"* outlook to engaging with the world (MarthaB), or as an outcome of informal exchanges between scientists "on the level of individuals" (PaulM).

We see that participants engage in a dynamics of inclusion and exclusion through bringing together and dividing constituencies under the banner of CT. In the interests of furthering "interdisciplinarity", NBIC is invoked as a way of redefining boundaries between scientific communities. Participants noted various practical difficulties which stand in the way of interdisciplinarity and suggested various aspects of accountability structures which sustain or hinder interdisciplinary exchange.

4.3 Redefining human "essence"?

How does CT discourse articulate the boundary between technology and the human body? CT are claimed to be able to produce a significant impact on the notion of humanness and to stimulate a radical change in actual physical bodily constitution. In the cyberchat "skin" is spoken about metaphorically as "the final frontier" of the intervention into human nature. This intervention is isomorphic with the social organisation of changes which will affect every member of the population ("will affect the life of everyone quite significantly"):

- *Well, JMR, the frontier for surplus capital in converging technologies is the human body itself, what some transhumanists call (euphemistically) 'morphological freedom'. Seen in the round, NBIC can be seen as trying to push stuff currently outside the body (and often between people in social relations) inside the body, typically changing its form in subtle and not so subtle ways. 'Skin, the final frontier...'*
- *LOLOL*
- *As we all know … life at the frontier can be an uneasy one.. and I particularly think that this frontier is one that will affect not just the life of the first pioneers, but rather the life of everyone quite significantly. Especially when the NBIC discourse is rolled up in a economic framework…i.e., border security, passports etc…*
- *Steve.. LOL.. yes you are right... skin...*
- *it *is* kind of Freudian...*
- *Or, to paraphrase Microsoft, "Who do you want to be today?"*

This proposed change is cast in terms of various degrees of interference by technologies in the human body ("human enhancement") that can eventually surpass the conventional notion of the human. While all participants seem to agree that some socio-technical reconfiguration will be achieved in some future[4], the degree of appropriate transformation (in the example below associated with the notion of "everyone's" perfection) is contested:

> *I think one has to be alert to the implications of what you are doing. And already there are things I disapprove of, like transhumanism. This notion that we should all be physically and mentally perfect. We live in this sanitised society. Everyone so happy and everyone cheerful. Everyone looks like Tony Osman. (*MarthaB)

Through these processes certain subject positions will assumingly be achieved as humans would adopt and comply with the new modifications. The questions of to what extent humans will be different, and how to achieve and assess the difference were discussed in the interviews. Below we will try to understand patterns of responsibility associated with the social production of such subject positions. We will look more closely at the proposals and assessments of processes purportedly capable of achieving a redefined humanness, and of the moral ordering of such change.

Unlike the previously mentioned statement that entering the "skin frontier" is equivalent to "everyone's" inclusion into the transformative movement, some statements are more cautious in this respect. The repeated production of social categorisations when the transformation is spoken about puts limits onto the process of inclusion. It is clear that the human enhancement/transhumanism talk employs all sorts of categorisations and their assessments:

> *You find these immensely sharp, polarised perspectives about whether it is a bad or a good thing* (KatherineL).

The assumed production of some of the social categories ("techno-haves" vs. "techno have-nots"; "healthy" vs. "sick") associated with CT is pushed into the domain of "ethics"[5]:

> *First of all to come to this transhumanism, is the first ethical issue, if we have the ability to enhance our mental and ethical powers technologically, this becomes an ethical issue of course, it is about techno-haves versus techno*

4 Except for GeraldK who said he could do it a bit which was taken as a joke.

5 Sometimes when prompted by the interviewers.

> *have-nots. Why would need to be stronger than you are, stronger than most human beings are. What are you going to do with these abilities? Is it because you want the differential compared to someone else? Or do you want all the humanity to be so enriched and empowered, and if so, why?* (MarthaB)

In the example below the degree of adoption of enthusiasm towards the transformation is shown to be a contestable matter - "where we draw the line" - predicated upon the notions of what the human (body; functions; capacities; appearance) is. MarthaB advocates difference, diversity and individuality as the cornerstone concepts commonly recognised and validated in the societal discourses. Going against such assumingly wholesome beliefs is seen as a challenge - "no one will make those claims" to the recognised as conventional discourse:

> *You indicated earlier that you are a little reticent about adopting all sorts of enthusiasm for making humans better?*
>
> *Physically (not about the brain, but all these other things), why would we all want to be stronger? In a sense, where do we draw the line … does that mean that everyone is being perfect? And it doesn't if someone cannot run for a certain amount of minutes, or lift certain amount of weights? Is it all sanitised with no deviations tolerated? … No one will make those claims. And the appeal of being individual is a diversity. And this notion that there is a norm to which we should all aspire, I find it rather depressing. Should we be of a certain height? Of a certain strength? Wouldn't it be a bit boring?*
>
> *What if they say to you this is about improvement?*
>
> *What is improvement for a healthy person? Might be therapy for a sick person, but how can you choose one over the other?* (MarthaB)

The examples above introduce the intervention and modifications of the human associated with the promise of converging technologies as a matter of concern and deliberations regarding the content of the promise of CT. From a different angle, according to KatherineL, CT also provoke questions about some of the currently adopted social ordering mechanisms:

> *CT is not only just about regulating what comes out of the pipe. Is that anything that we have not known before? But it is about organising the way we do research and understand things in the way we haven't done before. (KatherineL)*

Accomplishing this work of figuring out the mechanisms of social ordering of CT, the actors are engaged in identifying and *configuring* (GeraldK, quoting Woolgar, 1991) other actors and the audiences (e.g. "public user") for converging technologies:

> *It's not really been in the public domain in that sense yet. The only thing in this regard was the reflexivity of the advancement of sciences involved, not to overhype the stuff. The papers I've been drafted have been about the long-term, and about the expectations not to be raised too quickly and too rapidly. So there's intent, as you would say, to configure the public user in the anticipation of what might happen when the materials hit its roots (GeraldK).*

PaulM's talk established the "EU" as an actor that may be interested in or have power to endorse or disapprove of the use of the label of "converging technologies". As a banner (high-level concept) circulating in scientific-political circles CT can serve as a useful reference point for promoting high quality research in some alternative ways:

> *If the wider goal for EU if to use it as a concept, or not, it is better to have a discussion on a different ground, not as a yes or not to converging technologies, but if there are any alternatives of other exciting higher concepts that could be used. To focus on creative vision of what a European research can develop. There have to be alternative visions from creative people on alternative ways of organising things. Then one can choose between rather than saying yes or no.* (PaulM)
>
> *I see them in Europe doing that. In as much as I can see there is a desire to make that happen in Europe. To make it more responsive to human needs, and to accommodate a wider range of stakeholders. The EU may decide to go ahead with CT or some other word that gives funding to cutting edge research, and also distributes the slice of the pie to the social sciences and humanities perhaps.* (PaulM)

The participants suggested, assessed and dismissed various versions of the mechanisms of moral ordering of converging technologies. Public debates, or engagement, were a prominent part of the interviews. The respondents actively took issue with the forms and the applicability of various ordering mechanisms. The respondents acknowledged that the phenomenon of converging technologies may

provoke questions about the nature of currently adopted forms of engagement and may even provoke a change in the accountability systems.

We have thus seen how discussions about redefining the boundary between technology and the human body involve deliberations about the dynamics of moral order. These, in turn, involve the specification of which entities have the power to promote redefinitions and which become subjected/get access to the transformation. The questions of to what extent humans (or new subject positions in relation to CTs) will be different (and how to achieve and assess the difference) remains open. Participants articulated and contested patterns of responsibility associated with the social production of such subject positions. We need to look more closely at the proposals and assessments of processes purportedly capable of redefining humanness, and of the moral ordering of such change.

The efforts of different constituencies actively to shape CT related discourses can be seen as a form of mutual "configuration" (Woolgar, 1991). At the moment it is not clear who configures whom. We can see that participants are currently engaged in making converging technologies *tellable* (Simakova/Neyland forthcoming) by creating both "internal" (disciplinary, policy-making) constituencies and representations of the "outside" agencies through which CT discourse might be spread. So the focus of current deliberations is on which are the "right" circumstances of storytelling (for example, public consultations) and on the most appropriate entities to perform tellable stories.

5 Conclusions

We have argued that ontological politics are key to understanding the origins, direction and fate of converging technologies. The upshot of ontological politics is no less than the very nature and range of the entities which are thought to fall under the purview of CT. These include determinations of matters such as the character of humans in a posthuman world, the sources of relevant expertise, appropriate interdisciplinary collaborations, likely applications and developments, and determinations of ethical implications and societal impacts, to name but a few.

In this paper we have introduced two ways in which ontological politics can be analysed.

First, we examined the historical and institutional origins of CT, focussing in particular on the genesis and currency of visions of transhumanism. These visions serve as powerful instruments in the ontological politics of convergence. Indeed, it is important to note that these visions - "utopian" as well as "dystopian" ones - often function as central elements of worldviews with deep roots in the Western history of ideas and a political significance which exceeds research and technology policy in a narrow sense. One important consequence is that decisions about which social sciences and humanities approaches are appropriate to understanding CT, are themselves shaped by the ontological politics in play. Thus, for example, the political construction of "nanoconvergence" in the US provides evidence of the decisive role that major funding institutions play in setting the agenda and even in determining the goals and major contents of ELSI-related activities. The contribution of individuals within these institutions has been so substantial and determinant that overall the ELSI-related activities appear to largely reflect their personal ideological inclinations.

EU activities on CT have not been marked by the same marginalisation of academic and other non-governmental contributors as was largely the case in the US (cf. TAB 2008). The strongly ELSI-oriented concept of "Converging Technologies for a European Knowledge Society (CTEKS)", developed by external experts (HLEG 2004), was subsequently seen as the official EU approach to the topic and inspired a range of other research activities. However, several experts on the Commission staff have played or still play very active roles in shaping the EU discourse on convergence, some of them with ideas which are largely unconnected to the CTEKS ideas and goals.

The European debate on converging and emerging technologies is characterised by a greater degree of diversity of actors and views than does the political debate in the US. An important role is played by the European Group on Ethics in Science and New Technologies (e.g. EGE 2005). Thematically persistent EU-funded research activities

and discussions range from state-of-the-art reports by leading transhumanists (Bostrom/Sandberg 2006) through explorations of the wider philosophical aspects of cognitive enhancement (Lüttenberg 2006), analyses of the role of social sciences and humanities in and with regard to processes of techno-scientific convergence and foresight studies and debates on CT (e.g. STOA 2006), to investigations concerning the actual relevance and potentials of convergence with regard to its socio-economic impacts and R&D in the NBIC fields (e.g. Van Lieshout et al. 2006), or the ethics of emerging fields of S&T. Much of this discourse is informed by the work of the expert group (HLEG 2004) that developed the first European CT concept and thereby adheres to their critical stance towards an "engineering of the mind" and the posthumanist overtones of the US NBIC initiative. However, not only are transhumanist perspectives and actors integrated in the discourse, but highly visionary or radical aspects of HET and convergence are thematicised by policy actors (e.g. Bonazzi 2007)

Second, we have shown that by using methods of textual analysis we can understand some of the ways in which ontological politics are enacted in contemporary discussions and debates. These discussions do not explicitly feature visions of CT; they are not intended as contributions to policy debates about CT. Instead, they articulate questions and concerns about what, after all, CT might be, who is doing what kinds of work under the CT rubric, whether this entails substantial realignments of disciplinary practices, to which organisations or agencies one is accountable, and so on.

These more down to earth, everyday discussions and exchanges are nonetheless vital to the evolution of a discourse on CT. These are the practices and processes whereby participants offer and tell stories about CT could be. They are the means by which academics, scientists, policy makers and others learn how to speak about CT. In exchanging and communicating views, they contribute to emerging narratives about what, for example, are the promises and pitfalls of tranhumanism. By engaging in these discussions they come to enact and perform the essential ingredients of what CT actually comprise. One result of all this, as we hinted earlier, is the emergence of what Foucauldians might call the CT subject position. The CT discourse makes available appropriate ways of thinking and being a CT subject.

Of course, in sketching these two ways of apprehending the ontological politics of CT, we have hardly scratched the surface. By exposing, analysing and demystifying ontological politics, especially those associated with the technofuturist background of the most heatedly discussed visions (cf. Nordmann 2007b), the social sciences and humanities may be able to draw more attention to issues that are largely neglected in the debates on CT, such as (a) more realistic or ethically urgent uses of "human enhancement technologies" (e.g. drugs, deep brain stimulation, or future "mandatory

enhancements" for soldiers and other groups), (b) artistic, lifestyle and identity-political forms or visions of "enhancement" and modification (e.g. in architecture, media art, science fiction, and queer politics), and (c) to distil socially accepted and individually required enhancements of man-machine interactions out of the totalizing visions of individual and societal perfectibility which is characteristic of posthumanist and some cybernetic visions. Such small steps in identifying and tackling pressing ethical questions and needs for political and societal action might be less attractive for any research and technology policy which focuses on a strategy of "hype and hope". They would also require a widening of the societal and ethical discourse on convergence (HLEG 2004). The ontological politics of convergence might then become more difficult to handle, but also reflect more accurately the diversity of European cultures and societies.

However, posthumanism and closely related worldviews are obviously here for a long time and will probably stay, even if the NBIC initiative, organised transhumanism or their alliance dissolves. Europe — which displays a strong and overall healthy scepticism towards any secular ideologies of salvation — will therefore need to be more aware of the ethical aspects, political claims, and social relevance of these ideologies, above all with regard to the social shaping and the imaginary of technoscientific progress. An externalisation of the issue, its identification with "US culture" or "fringe groups" alone, will most probably not work, because the ideologies in question are firmly embedded into the European history of ideas, cultures, and modern societies (including the technosciences themselves).

The kind of close examination of ontological politics which we have applied in this paper to CT may help inform our understanding of the interplay of society and S&T more generally. To develop a programme of analysis along these lines, the social sciences and humanities will need to

- analyse what is derived from "speculative ethics" (Nordmann 2007a) and what refers to real innovations in debates about actual technoscientific developments, looking for their antecedents, but also for new qualities (e.g. Nordmann 2006)
- assess NBIC and other visions of the perfectibility of life (Knorr Cetina 2004) and "human enhancement" against the background of traditions such as humanism, enlightenment thought and utopianism (cf. e.g. Coenen 2007, Kettner 2005, Saage 2006), taking into account the insight of the contingency of the *conditio humana* (cf. Grunwald 2007a, 2007b) and religious views of human corporeality and mortality; and

- analyse in what ways and to what extent the designers, developers, advocates and users of CT "reinforce specific assumptions about the nature and operation of concepts such as individuality, humanness and 'cognition'" (Woolgar 2006, p. 19f.).

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Appendix D

Current trends in RTD policy on Converging Technologies

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Converging Technologies and their impact on the social sciences and humanities (CONTECS)

Deliverable D3.3

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Table of contents

1 Introduction 1

2 Converging Technologies in RTD Policy Worldwide 5

2.1 North America 5

2.2 Europe 10

2.3 Asia/Oceania 13

2.4 Latin America 14

2.5 Africa 15

3 Analysis of Policy Documents 17

3.1 Canada 17

3.2 European Union 21

3.3 France 31

3.4 Germany 33

3.5 International 35

3.6 Japan 38

3.7 Spain and Latin American Countries 39

3.8 United Kingdom 42

3.9 United States of America 44

4 Conclusion 49

Overview table of country activities 53

List of Abbreviations 67

1 Introduction

Converging Technologies (CT) emerged as an issue of scientific and political discussion in the US. The term takes up the notion of 'convergence in the digital world' which was developed in the IT, multimedia and entertainment industries in the nineties, and applies it to a current technological trend: Nanotechnology enables many new approaches, processes and materials at the nanoscale as well as analytical access to and theoretical understanding of fundamental chemical, physical and biological processes at atomic and molecular level. The implications of these trends and their synergies with information technology are described in a RAND report published in 2001[1]. On December 3-4, 2001, the National Science Foundation (NSF) and the US Department of Commerce (DoC) at the request of the National Science and Technology Council (NSTC), Subcommittee on Nanoscale Science, Engineering and Technology (NSET), organised a workshop on "Convergent Technologies to Improve Human Performance". The outcomes of this workshop and contributions submitted after that meeting were published in June 2002 in a report with the same title (see scheme 16).

According to the report, "the phrase 'convergent technologies' refers to the synergistic combination of four major "NBIC" (Nano-Bio-Info-Cogno) provinces of science and technology, each of which is currently progressing at a rapid rate: (a) nanoscience and nanotechnology; (b) biotechnology and biomedicine, including genetic engineering; (c) information technology, including advanced computing and communications; (d) cognitive science, including cognitive neuroscience. Accelerated scientific and social progress can be achieved by combining research methods and results across these provinces in duos, trios, and the full quartet. (…) This progress is expected to change the main societal paths, towards a more functional and coarser mesh instead of the less organised and finer one we have now."

Since then, the label *Converging Technologies* (or *NBIC*) has been used by scientists, politicians and other stakeholders in research and technology development (RTD) policy worldwide to discuss new technological developments in the "converging" fields of nanotechnology, biotechnology, information technology and cognitive science, their conditions for realisation and their implications. A first analysis of documents within that field shows diverging notions of what exactly *Converging Technologies* are. Depending

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1 Antón et al.: The global technology revolution: bio/nano/materials trends and their synergies with information technology by 2015. Santa Monica: Rand 2001

on the concrete definition of the term, different actors point out different paths for the development of *Converging Technologies*. Notwithstanding those differences, governmental institutions worldwide plan and support a huge number of activities to establish and strengthen *Converging Technologies* as key technology(ies) of the future, although some of these activities are not labelled as such.

First of all, the present background report is intended to show how activities in the field of *Converging Technologies* are already reflected in current RTD policy around the globe. It will highlight aims and hopes associated with this development as well as specific projects and research programmes planned for the coming years. Furthermore, the authors of the paper examine if and to what extent questions related to social sciences and humanities (SS&H) are finding their way into the research agendas and programmes of governmental actors at this early stage of technological development.

Aim of the deliverable is to give an overview of activities by governments and other political actors in the field of *Converging Technologies* worldwide. Therefore, the project group had a deeper look at RTD policy programmes, specific research projects and foresight activity results that were identified with the help of desk research analysis. These "policy documents" include reports and position papers dealing with converging science and technologies that were produced by, or on behalf of, political institutions. They also include reports and papers with major contributions on content by such institutions or their staff (including reports in response to official documents). The results of this deskwork were complemented by a series of interviews with actors and stakeholders in converging technologies done by the entire CONTECS team during the Summer of 2007.

In the second part of this report RTD policy activities throughout the world are outlined briefly. The details of all documents that were reviewed in order to draw a picture of the current state of affairs can be found in a table attached in the annex. Thereafter, the analysis focuses mainly on visionary statements and mid- or long-range foresight within the policy documents, particularly with respect to cognitive science and technology, but also on ongoing programmes and projects with relevance for convergence. Therefore, the third section of the paper lists especially documents, programmes and reports from the U.S.A., Canada, Japan and the European Union (and its member states). They are analysed in further detail with the help of a template to explore which

- technological and scientific challenges and areas of convergence are mentioned in the policy documents
- societal and ethical aspects or implications of convergence are identified
- consequences or impacts are anticipated

- roles are seen for SS&H
- SS&H research challenges are identified
- policy implications of convergence exist (in particular for science and technology policy, but also regulatory legislation etc.)

In some cases, the data on these aspects has been derived from passages implicitly dealing with them rather than from explicit statements or even recommendations. The systematic analysis of publicly available documents reveals the current context of RTD policy regarding *Converging Technologies* and examines whether the visions of governments and stakeholders are followed by research programmes and projects that aim at the realisation of these visions. The last chapter of the report sums up first evidence for possible "hot topics" of research in the SS&H field.

It is important to bear in mind that the analysis was restricted by a number of factors, such as language, public availability of documents, publications and dissemination policies, military secrecy, so that there may well be important developments missing from this review. In some cases we may hope that its publication will encourage experts to provide new information or to modify any wrong or biased perceptions contained in this report.

2 Converging Technologies in RTD Policy Worldwide

For the following review of policy documents on *Converging Technologies* a huge number of websites of governmental institutions, research organisations, "watchdog" associations and internet communities related to one or more fields of nanotechnology, biotechnology, information technology and cognitive science were scanned for documents and further information. The starting points for this analysis were overviews provided in reports by the Etc Group (see annex 9) and the Canadian Foresight directorate (see scheme 2). Table 1 in the annex shows all RTD policy documents that have some sort of reference to one of the above mentioned research fields. The following section will not mention any of these documents in detail, but will rather give a broad overview over the policy context of *Converging Technologies*.

2.1 North America

Current interest in *Converging Technologies* is largely the result of the publication of a report called "Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science" which was compiled on behalf of the National Science Foundation and the US Department of Commerce in the aftermath of a workshop (see scheme 16). Subsequently, there have been annual conferences on convergence organised by the National Science Foundation. Since 2003 "converging technologies", "convergence of nanotechnology with information technology, modern biology and social sciences", and "improving human performance" are regularly mentioned in NSF budget requests. Nevertheless, funding specifically on these topics was relatively small and largely confined to the activities within the context of the National Nanotechnology Initiative (NNI). Moreover, the concept of NBIC convergence originally was (and still to a large degree is) a by-product of the NSF's and NNI's activities on ethical, legal, and societal implications of nanotechnology. One of its most active promoters (Roco) is one of the key architects of the NNI and senior NSF advisor on nanotechnology.

The concept of NBIC convergence does not necessarily mean that all four elements are present in all combinations. The unifying element is the nanoscale, which is seen to be the key to progress. Nevertheless, some of the projects and visions covered in the NBIC reports have nothing to do with nanoscale activities. The new, and possibly defining, element in NBIC convergence is the (re-)discovery of cognitive science: awareness of potential synergies between biotechnology, nanotechnology and information technology had already existed for some period of time before the conference. Cognitive science has a two-fold role to play in NBIC convergence, the first as an "enabler" for the necessary renaissance of (unified) science by building bridges between isolated

communities, the second as a part of convergence itself by exploring fundamental processes.

At least two distinct motivations may be assumed to be at the root of US interest in NBIC convergence:

- There is a strong military interest, in particular in the aftermath of September 11 2001 and the subsequent "War on Terror". Even without this, there is strong interest in retaining US military supremacy, perhaps for the sake of securing the continued existence of humanity, as the report by Roco/Bainbridge (see scheme 16) insinuates.
- Even in a wealthy society like the US, there is intense competition for funding of research. In recent times, the winner of funding competitions had often been the life sciences at the expense of the physical sciences. The NNI changed that competitive situation. The NBIC initiative, originally conceptualised as a potential successor to the NNI [2], might have been the attempt to repeat this political success, by pointing out applications in such prioritised policy fields as health and environment. This assumption was reinforced by the results of the interviews for CONTECS, particularly those in the USA, which created the impression that, with NBIC convergence, the NNI was defining its own "man to the moon" project.

To underline the central importance of converging technologies for the US and its future position in an increasingly globalised world, Roco/Bainbridge develop a grand vision of a "new renaissance" of science which will overcome all of the divides of disciplinary science: "Convergence of diverse technologies is based on material unity at the nanoscale and on technology integration from that scale. Science can now understand the ways in which atoms combine to form complex molecules, and how these in turn aggregate according to common fundamental principles to form both organic and inorganic structures. Technology can harness natural processes to engineer new materials, biological products, and machines from the nanoscale up to the scale of meters. The same principles will allow us to understand and, when desirable, to control the behaviour both of complex microsystems, such as neurons and computer components, and macrosystems, such as human metabolism and transportation vehicles" (see scheme 16, p.2):

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2 Bainbridge, W.S., Roco, M. (eds.): Managing Nano-Bio-Info-Cogno Innovations – Converging Technologies in Society. Dordrecht: Springer 2006. p. 347.

The National Science Foundation is largely independent of government so that its policies have no direct impact on US government positions on technology. In the case of converging technologies, there are intensively conflictive positions: for example, while there has never been any official debate on converging technologies within the President's Council on Bioethics or between members of the council and proponents of human enhancement through converging technologies, the majority position of the council is obviously opposed to such enhancement. In fact the work by the President's Council on Bioethics, which resulted in the publication of its report "Beyond Therapy"[3], was done largely before the publication of the Roco/Bainbridge opus, even if it could be interpreted as being opposed to the positions in that work. The position of "official America" vis-à-vis converging technologies, at least when used to "improve human performance", can therefore be assumed to be cautious. Publicly funded activities in the area are thus at best rudimentary and fragmentary.

In the 21st Century Nanotechnology Research and Development Act (March 2003)[4], one of the programme activities is: "ensuring that ethical, legal, environmental, and other appropriate societal concerns, including the potential use of nanotechnology in enhancing human intelligence and in developing artificial intelligence which exceeds human capacity, are considered during the development of nanotechnology". This clause in the act is the main reason that STS activities on converging technologies are at all taking place in the USA at such institutions as Arizona State University or the University of South Carolina.

Nevertheless, it is to be assumed that in military, space and other RTD sectors a specific interest in converging technologies continues to exist. Visions like the idea of a "new renaissance" have yet taken root in mainstream thinking on science and technology in the US, in fact the interviews for CONTECS revealed that there is not even any noticeable debate on this topic and that converging technologies are largely absent from general public and mass media attention.

In the dispute between the so-called "bio-conservatives" (the label has a derisive intent) and the "transhumanist" movement in the US, NSF officers do not shy away from enlisting the support of the "transhumanist" camp to further the cause of convergence. To give but a few examples: James Hughes, the Secretary and Executive Director of

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3 The President's Council on Bioethics (2003): Beyond Therapy – Biotechnology and the Pursuit of Happiness. Washington D.C. http://www.bioethics.gov/reports/beyondtherapy/

4 "21st Century Nanotechnology Research and Development Act" (108th Congress, 1st Session, S.189, Signed by the President on December 3, 2003).

the World Transhumanist Association is among the authors of a recent publication on convergence by Bainbridge and Roco[5], and NSF officer William Bainbridge has participated in activities organised by the transhumanist movement, e.g. as a celebrated key note speaker of major transhumanist conferences and as a member of the editorial board of the transhumanist "Journal of Evolution and Technology".

Despite some uncertainty as a result of the controversy on the ethics of enhancement on the current strategic assessment of converging technologies for the USA as a whole, NSF has not abandoned the concept. Moreover, research projects in the NBIC fields will most probably continue to play an important role: Bainbridge/Roco [6] contains an annex, listing 96 NSF funded research projects that (in Bainbridge's view) combine Information Technology with one or more of the other three NBIC-areas.

To some extent, the debate on convergence has been fuelled by work done by the RAND Corporation of Santa Monica, Ca. for the US National Intelligence Council (NIC). The latter regularly gathers intelligence on developments in the different regions of the world, broadly to inform US foreign policy. RAND is entrusted with work on science and technology. In 2001, RAND published a book entitled "The global technology revolution: bio/nano/materials trends and their synergies with information technology by 2015"[7]. The book virtually addresses NBIC convergence, but without giving special focus to the cognitive sciences or using the term "convergence". RAND's most recent paper on the subject, also for NIC, has the title "The Global Technology Revolution 2020, In-Depth Analyses" (see scheme 18). It is claimed that, "as RAND found in its prior study for the NIC, technology will continue to accelerate and integrate developments from multiple scientific disciplines in a 'convergence' that will have profound effects on society." Among the convergence-based "integrated technology applications (TAs)" that in RAND's view may be feasible by 2020 are new implants.

Regardless of these and other, widespread activities from a number of institutions, (most of them close to, but not part of the US government), there seem to be few plans for specific CT programmes and projects today. It appears that the very spectacular

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5 Bainbridge, W.S., Roco, M. (eds.): Managing Nano-Bio-Info-Cogno Innovations – Converging Technologies in Society. Dordrecht: Springer 2006.

6 Ibid.

7 Philip S. Antón • Richard Silberglitt • James Schneider: The global technology revolution : bio/nano/materials trends and their synergies with information technology by 2015. Santa Monica: Rand 2001.

launch of the converging technologies concept within the framework of the NNI was due more to a need to attract attention to the potential of nanotechnology in a future process of convergence with other key technology than to the development of any coherent programme to make such convergence reality.

The NBIC initiative in the US caught the attention of its Northern neighbour, Canada, almost immediately, initially mainly from the perspective of foresight, but also that of military research institutions. Convergence under the heading of "Biosystemics" (see scheme 1) was the subject of one of two studies for the Science and Technology Foresight Pilot Project (STFPP). The foresight directorate, which has since moved to the Office of the National Science Advisor at the Privy Council Office of the Government of Canada is apparently watching developments both in the US and Europe closely and has a further project "Understanding Convergence" in hand.

A paper from this project explicitly mentions societal and ethical aspects of the emerging field of technology and aims at finding a "Canadian framework of values" (see scheme 2). The documents examined for CONTECS point out research areas for SS&H that might be relevant for a future European research agenda for the field as well and therefore should be taken into further consideration during the course of the ongoing project.

The label used by the National Science Advisor's Office for convergence is now BIND – Bio, Info, Nano and Design – reflecting on the one hand the relative absence of cognitive sciences from Canada's research agenda, but also focusing on the importance of design as an element in a convergence of the key technologies in question. Examples for design technologies are automatic design, computer supported development, and imaging.

Activities have most recently tended to focus on the nano-bio pair, with an element of information technology always present at least in the background. There is hardly any public debate on CT in Canada, Gregor Wolbring is active in the field, but is more of a lonel voice. The public debate is microscopically small ,as is the debate on emerging technologies in general. If there is any discussion then it is due to citizen movements like the ETC group, which is probably meeting with greater interest in Europe than in Canada, which is its home country. The current Conservative minority government is concentrating strongly on commercialisation of technology which is not yet very visible for CT and that is the reason why there are hardly any financial resources. The Foresight office is actively discouraged from seeking and leading a public discourse.

There is an SSH Research Council. The Foresight Unit has undertaken an initiative for discussions with this, but the message has not yet reached the funding institutions. There are no Advanced Technology Studies

Even so, Canada is apparently taking convergence as an ongoing development seriously, since the National Research Council has commissioned so-called cluster studies on "ICT/Life Sciences Converging Technologies". These are comparative studies "of the Information and Communications, Life Sciences, and Converging Next Generation Technology Clusters in Vancouver, Toronto, Montreal and Ottawa"[8].

2.2 Europe

Prior to the diffusion of the notion of NBIC convergence, actors from the field of European RTD policy participated in a number of joint workshops on nanotechnology and its social implications with the National Science Foundation of the United States. These events amongst others focused on the convergence of disciplines such as physics, chemistry, biology, life sciences, information technology, and materials research.

In view of the strategic importance attached to convergence by such organisations as the National Science Foundation in the US, the concept soon attracted attention at the EU level and elsewhere in Europe. Beside the aspect of the potential of converging technologies for global competitiveness, the interdisciplinary character of convergence particularly caught the imagination of the European Commission.

Beginning in 2003, the European Commission started its foresight activities in the field of *Converging Technologies* with the setting up of a High Level Expert Group "Foresighting the New Technology Wave" (see scheme 4) which published its final report "Converging Technologies for the European Knowledge Society" (CTEKS) in Autumn 2004. The paper was immediately understood as a reaction and alternative to the previously mentioned U.S.-American document, broadening the scope of disciplines involved and emphasizing the role of SS&H for future development.

Another High Level Expert Group "Key Technologies" came into life from 2004 onwards, one of its tasks being to advance the concept of *Converging Technologies*. The

8 Voyer, R., Makhija, N.: ICT/Life Sciences Converging Technologies Cluster Study: A Comparative Study of the Information and Communications, Life Science, and Converging Next Generation Technology Clusters in Vancouver, Toronto, Montreal and Ottawa. Ottawa 2004. (http://strategis.ic.gc.ca/epic/internet/inict-tic.nsf/en/it07730e.html)

term is used in a number of reports, press releases, speeches and opinions on new and emerging technologies, but its high relevance is yet not adequately reflected in concrete projects that are funded by European RTD institutions. However, the concept is incorporated in research agendas for the 7th Framework Programme, e.g. in the fields of nanotechnology and information and communication technologies. Furthermore, special emphasis is put on research and perspectives of social sciences and humanities, the role of cognitive science and the identification of "converging clusters" where specific CT projects have already been funded.

Since 2005, the field of *Converging Technologies* has been addressed by events such as the annual conference of the European Parliamentary Technology Assessment (EPTA) network. An assessment of the visions related to convergence was the topic of one of the first projects commissioned by the European Parliament's Scientific Technology Options Assessment panel (STOA) under its new framework contract and a workshop titled "Converging Technologies in the 21st Century: Heaven, Hell or Down to Earth?" was organised in the European Parliament in July 2006. The main focus of the debate among experts was on *Converging Technologies* and the contrasting positions of the (mainly derisively) so-called "bio Luddites" and the "transhumanists" on human enhancement. Human enhancement is likely to be the subject of further work for the European Parliament in connection with technologies for disabled persons.

A report published by the National Intelligence Council in 2004 (see annex 83) states that despite the previously mentioned RTD activities of European policy institutions within the field of *Converging Technologies* "Europe risks slipping behind Asia" (pp.12), especially when compared to India and China (see 2.3). This assessment is based on impressions from workshops attended by restricted numbers of experts, who might well be arguing in their own interests, so that the statement is to be taken with a pinch of salt.

Apart from the political institutions of the European Union, some EU member states have developed their own national strategies and activities in relation to Converging Technologies (see for more details sections 3.3, 3.4, 3.6, 3.7 and 3.8). Not surprisingly, national differences in the handling of the concept of convergence can be observed. Over all, the grander visions of NBIC convergence are absent from European initiatives, which are generally closer to the component technologies, e.g. nanotechnology or brain research. Topics linked with convergence have been the subject of foresight studies, for instance in Great Britain (cognitive sciences, brain science, addiction and drugs) and Germany (guiding vision "Understanding Thinking" - see annex 33 -, developed in the foresight activity "Futur", in which NBIC convergence was one of the topics for discussion). The German government is aware of the US and EU activities on CT

and has integrated the concept in the Microsystems Framework Program (2004 - 2009). While there is some social science research on converging technologies, mainly in connection with nanotechnology, in Germany, there is no specific programme or focus for social science research on the topic.

In workshops the role of Cognitive Science in convergence was discussed. In Spain, US NBIC and EU CTEKS activities have aroused interest and led to NBIC initiatives that were started by academic institutions and funded or sponsored by RTD policy institutions or companies. A Converging Technologies Institute was founded in close collaboration with Latin American partners (see 2.4).

In France, where the US NBIC initiative and their visionary goals are discussed in various media, a joint task force of the Conseil général des mines (CGM, general mine engineering council) and the Conseil général des technologies de l'information (CGTI, general council on information technology) prepared a report on "main orientations for assessment of French public policy with respect to nanotechnologies, based on an analysis of the European and international contexts, taking into account all aspects, particularly their societal and ethical implications" (see scheme 9). The report employs the term "meta-convergence" for what for the purposes of this project is being called *Converging Technologies*. Moreover, one of the research departments of the Commissariat à l'énergie atomique (CEA; a major interdisciplinary research centre) has published dossiers on nanotechnology with special emphasis on the NBIC concept and on extreme visions of technological convergence. In two interviews conducted for the CONTECS project, doubts are expressed regarding the authenticity of many R&D projects sailing under the banner of nanotechnology. One of the interviewees put it bluntly that physicists had invented "nanoscience" to be able to enjoy the same kind of funding that biologists had received for the Genome project.

In the UK, the James Martin Institute at the University of Oxford is helping the Economics and Social Science Research Council (ESRC) to build a set of scenarios on the future of converging technologies. The goal here is to set up an agenda for the research council and to engage with the other research councils in the UK, notably the Technology Strategy Board (TSB), a newly created body.

Russia and the countries of Eastern Europe have strong traditions in scientific disciplines important for converging technologies and thus it is to be expected that there will be activities in the field. It is unlikely that there will be a strong role for the Social Sciences and Humanities in these developments, but CONTECS will endeavour to determine the situation in the course of its activities. A workshop on "Converging Technologies - Promises and Challenges" in Budapest (December 2005) brought together natu-

ral scientists, other academics and RTD policy experts from Eastern Europe and other parts of the world.

2.3 Asia/Oceania

Looking at RTD policy in the four NBIC disciplines, no consistent picture can be drawn for Asia. A highly developed country such as Singapore invests huge sums in one or more of the areas, while developing countries are trying to keep step with global development, but have fewer resources to spend. Furthermore, information on research strategies and programmes is not easy to access due to language problems and lack of English documents.

Most of the countries, whose RTD policy was examined, devoted considerable effort it developing nanotechnology and biotechnology and often have initiatives or networks in this regard. Nevertheless, cognitive science as well as the whole concept of convergence does not make an appearance in national research strategies or programmes - with the exception of Japan. The same holds true for mid to long term visions on new technology fields. Often a huge number of concrete programmes and projects does exist (e.g. in India), but no overall development strategy is made explicit.

Those that, besides Japan, are investing notable parts of their RTD budget in nanotechnology, biotechnology and information technology (e.g. Singapore, South Korea, India and supposedly China) do not take societal or ethical aspects into consideration (at least they do not mention them in official documents). This might be due to lack of resources and thus giving priority to funding basic research in the various disciplines and only in a second step financing research on the meta-level.

Looking further at individual countries, especially China and India might be of some interest for the global development of *Converging Technologies*. The above mentioned report of the U.S.-National Intelligence Council speculates that both countries will become world leaders in several NBIC fields due to ongoing or projected basic research. It furthermore states that this "will help China’s and India’s prospects for joining the "First World"" (see annex 83; p. 34). Whereas India´s RTD strategy is more or less transparent, this does not hold true for China. With the instrument of desk research analysis, the only information available was that on the website of the Asia Nano Forum. The most concrete statement to be found on Indian policy on research on convergence was a passage in the Tenth Five Year Plan 2002-2007 (see annex 39), which supported CT as an area for international cooperation.

Japan as the sole Asian country is explicitly dealing with *Converging Technologies.* European experts even claim that the nation is stronger in this new field than the U.S.

(as mentioned at the STOA workshop "Converging Technologies in the 21st Century: Heaven, Hell or Down to Earth?" in June 2006), most likely due to its long tradition in the development of robotics. Whereas a number of countries focus on research in nanotechnology, biotechnology and information technology, Japan is also taking the cognitive science component into account. It considers SS&H aspects in its national Science and Technology Basic Plan as well and is active in the field of foresight (see scheme 12).

For Australia not much information was available. There is research on nanotechnology and biotechnology and there is awareness of potential chances and risks, but no overall strategy seems to exist. New Zealand documents show an emphasis on biotechnology and nanotechnology with strong funding of projects in these disciplines. Roadmaps for these high-level goals are supposed to be finished by the beginning of 2007. Additionally, New Zealand has a number of foresight activities on new and emerging technologies mainly organised in the Navigator Network Project.

A number of countries from Asia and the Pacific Rim are members of the Asia Nano Forum (ANF), a network organisation that was founded in May 2004 to promote excellence in research, development and the economic uptake of nanotechnology within the Asian region (see annex 2). Main aim of the network is to bundle financial, human and infrastructure resources in order to strengthen the global impact of Asian countries. Although nanotechnology is closely linked to areas such as biotechnology and information technology *Converging Technologies* or convergence in general is not a visible topic for the organisation.

Israel and its Interdisciplinary Center for Technology Analysis and Forecasting (ICTAF) situated at Tel-Aviv-University work on the topic of emerging technology such as nanotechnology, biotechnology and information technology, but RTD policy documents about projects, programmes or strategies are not publicly accessible. However, since ICTAF is a member of the "NBIC Knowledge" project team working concurrently with CONTECS, it is expected that a clearer picture of Israel's position on convergence will emerge soon.

2.4 Latin America

Most of the countries in Latin America focus especially on the development of nanotechnology in combination with applied materials research. Furthermore, the important role of biotechnology and information technology for the future development of the countries is stressed. Most of the national research strategies mention these disciplines as key areas of development and invest considerable sums compared to other

research areas. For few of the analysed countries a number of current research projects in the three disciplines could be found. Notwithstanding official statements on the importance of the emerging technologies, our desk research has shown that in some countries research programmes and projects e.g. in the field of biotechnology were funded a few years ago, but there is no more recent information on widely accessible sources like the Internet. Thus Cuba apparently last funded projects in its biotechnology programme in 2003 (see annex 15) and no further projects seem to have been initiated since then.

The concept of *Converging Technologies* does not appear explicitly in the analysed national documents. Although three of the four relevant disciplines, nanotechnology, biotechnology and information technology, are ranked high in the RTD policies of the Latin American countries, cognitive science is apparently not. Furthermore, as is the case for most Asian countries, specific research projects in the fields are set up, but it seems that no mid or long term visions have been developed.

Despite the national situation as described above, there is joint collaboration between the mostly Spanish-speaking countries of South America with Spain. A Converging Technologies Institute was founded on the initiative of the University Autonoma of Barcelona (UAB), Spain. It was created "with the aim to ignite and develop projects and activities with other Science and Technology centres within the European Union and Latin America"[9]. In March 2005 the "Barcelona's Declaration on Converging Technologies" was adopted by the community (see scheme 13) and there was a follow-up conference on the topic in September 2005. It is stated that especially in Latin America, where relatively limited funding and sources are available, there is an increased need to focus the efforts from science correctly and tactically in order to secure a realistic position at the academic and market levels.

2.5 Africa

Virtually the only information on the NBIC technologies from the entire African continent to be found via desk research was from the Republic of South Africa. This most likely reflects the true situation to some extent, since several documents point out the danger of a "new divide" as the result of converging technologies, with developing countries in Africa mainly on the "losing side". South Africa is the most likely exception due to its comparatively well-developed research infrastructure.

9 http://nbic.org.es/institute/gb-home.html

In all South African national strategy and research papers, the development of biotechnology and nanotechnology is seen as priority area for research and funding. In some of the analysed documents information technology was added as key technology platform of the modern age. The fourth discipline belonging to the NBIC quartet, cognitive science, is not mentioned in any of the strategic papers. The term "convergence" is mentioned in a document called "The National Nanotechnology Strategy" (see annex 64) published by the Department of Science and Technology. Neuroscience is mentioned in this context as well, but no future applications that include all four disciplines are mentioned. There are no long term visions to be found. Apart from that the South African governmental institutions state that the country cannot ignore the new global technologies but on the other hand only has a limited capacity to respond to these developments. In relation to the field of nanotechnology the concern is voiced that this will cause another technology-based divide between developed and developing countries. This aspect might be relevant in the course of the CONTECS project and could be addressed by SS&H research on the topic.

3 Analysis of Policy Documents

3.1 Canada

1. Bio-Systemics Synthesis (Science and Technology Foresight Pilot Project)

Programme/ paper	Bio-Systemics Synthesis, part of the Science and Technology Foresight Pilot Project, June 2003
Country	Canada
Institution	National Research Council of Canada. ***Note***: *the foresight directorate has since moved to the Office of the National Science Advisor. This currently has a project "Understanding Converging Technologies" – cf. Smith, J.: S&T Foresight: Provocateur for Innovation Policy? INNOVATION PRESSURE - Rethinking Competitiveness, Policy and the Society in a Globalised Economy, Tampere, 15-18 March 2006* http://www.proact2006.fi/chapter_images/298_Ref_A10_Jack_Smith.pdf
URL	www.moyak.com/researcher/nrc/BioSystemics.doc; 2100.org/Nanos/biosystemics-canada.pdf
Scope and characterisation of the study	▪ Strongly influenced by US NBIC initiative. ▪ Particular emphasis on materials science, management of public systems for biohealth, eco and food system integrity, disease mitigation. ▪ Five characteristics creating sense of urgency: convergence, fundamentality, replication, distribution, public interest. ▪ Technology commercialisation gap ▪ Natural environment as asset of Canada – orientation toward environmental applications ▪ Emphasis on "niches":
Converging Technologies considered	▪ The foresight study considers "the convergence of nanotechnology, ecological science, biotechnology, information technology and cognitive science" (Bouchard 2003, p.8). Extends NBIC to include ecological science. ▪ Areas are largely considered separately, but there was a panel on Info/Cogno, a section on Information and Cognitive Technology Observations. ▪ Translation mentioned in several places (particular relevance for Ca. due to two official languages. ▪ Advances in imaging techniques as key to understanding – possibility of "reverse engineering of brain functions" explicitly mentioned. ▪ Tailored medication possible.

Societal/ethical aspects and impacts, risks related to CT	▪ Trust ▪ Reliability ▪ Intrusion/surveillance ▪ Dependency on technology ▪ Mechanisms for public debate (e Government as possible application area) ▪ Responsibility/accountability ▪ Human self-esteem ▪ Discusses Moravec vision of strong AI with benign and hostile versions. ▪ Not all technologies expected to be beneficial – criminal use and security aspects mentioned. ▪ Public interest in use and misuse. ▪ Capability to modify human behaviour via nano drug delivery systems.
Potential role and research questions of SS&H	▪ Breakout group on "Science and Society" ▪ Risk management, informed choice ▪ Mechanisms for public debate ▪ Creation of "The Observatoire" to assess direction and impacts of science.
Policy implica-tions	▪ Largely speculative, ▪ Recommendation for the creation of "The Observatoire" to assess direction and impacts of science.

2. Toward Understanding Science and Technology Convergence

Programme/ paper	Toward Understanding Science and Technology Convergence, draft version 2005.
Country	Canada
Institution	Science and Technology Foresight Directorate, Office of the National Science Advisor, Privy Council Office, Government of Canada.
URL	none
Scope and characterisation of the study	▪ Definitions of convergence and converging technologies ▪ Rationale for understanding convergence ▪ Socio-ethical dimensions ▪ Other countries ▪ Tools for foresight in CT ▪ Situation of foresight in Canada.
Converging Technologies considered	▪ NBIC (US), CTEKS (EU) as benchmarks for Canada ▪ Advanced modelling, visualisation, adaptive heuristics, manipulation of matter at a fine scale ▪ Genomics/Information Technology as two sides of a coin ▪ Assemblers ▪ Military applications ▪ Examples: FabLabs, synthetic biology, open source development, evolutionary computation, autonomous vehicles.
Societal/ethical aspects and impacts, risks related to CT	▪ Education of workforce ▪ Understanding of risks, proposals for mitigation ▪ "appropriate" use of CT to further aims of civil society ▪ Overlap of ethical issues in advanced biotechnology and nanotechnology ▪ Legal decisions in IT presage those emerging in bio and nano ▪ Human and constitutional rights, public moral, social identity, "self" ▪ Economical and institutional S&T pressure on society ▪ Possible threats to culture, tradition, human integrity, political and economic stability ▪ Divide between rich and poor countries ▪ Environmental impacts ▪ "Falling into the wrong hands" easy due to size ▪ Benefits could be improved health, better environmental protection, increases in human comfort, ability and dignity.
Potential role and research questions of SS&H	▪ Distinguishing between science fact and science fiction ▪ Communication of impacts and risks ▪ Table 5 on p. 49 of the Annex contains a list of societal impacts projects (usually from the US) ▪ Foresight as ongoing task ▪ "Canadian framework of values" proposed ▪ Need to bring ethical debate into the realm of public discourse ▪ Privacy rights ▪ Kind of human enhancements that should be allowed.

Policy implications	▪ Need to define specific niches for Canada ▪ Enlightened innovation policies ▪ Legal and regulatory frameworks (anticipatory, not reactive) ▪ Establishment of accountability framework ▪ How to engage private sector collaboration ▪ Evaluation of interdisciplinary research.

3.2 European Union

3. Converging Applications enabling the Information Society - Trends and Prospects of the Convergence of ICT with Cognitive Science, Biotechnology, Nanotechnology and Material Sciences

Programme/ paper	R. Campañó (ed), Marc van Lieshout, Christien Enzing (TNO), Andreas Hoffknecht, Dirk Holtmanspotter (VDI), Ed Noyons (CWTS): Converging Applications enabling the Information Society - Trends and Prospects of the Convergence of ICT with Cognitive Science, Biotechnology, Nanotechnology and Material Sciences, 2006.
Country	European Union/Netherlands/Germany/Spain
Institution	European Commission, Directorate General Joint Research Centre, Institute for Prospective Technological Studie
URL	www.jrc.es
Scope and characterisation of the study	▪ Based on patent and publications analysis, assessment of scientific position and potential of Europe compared to global competition ▪ Nanoelectronics as key application: pattern recognition, neural networks ▪ Many ICT-Cog-Sci Applications in sight, but sophisticated applications only in the long run. ▪ ICT important enabler for materials science and vice-versa ▪ Bioinformatics and computational biology exist, non-invasive monitoring/diagnostics and biodevices on the horizon ▪ Most attention paid to convergence of cog-sci with ICT (least studied area!).
Converging Technologies considered	▪ Addresses NBIC quartet plus material sciences, mainly from the angle of ICT. ▪ Intersections between ICT-Cog-Sci, ICT-Biotech; ICT-Nanotech, ICT-Material Sciences ▪ Implantable electronics (cochlea, retina) ▪ Large section on development of cognitive science ▪ Shift in cognitive science toward studying the brain.
Societal/ethical aspects and impacts, risks related to CT	▪ Technology complex, danger of losing control.
Potential role and research questions of SS&H	▪ Not addressed, not subject of report.
Policy implications	▪ Ranking of EU research on worldwide scale.

4. Foresighting the New Technology Wave

Programme/ paper	Foresighting the New Technology Wave
Country	European Union
Institution	High Level Expert Group convened by Foresight Unit in DG Research. There is a main report, edited by Alfred Nordmann. Additionally, there are several reports by special interest groups (SIGs)
URL	ftp://ftp.cordis.europa.eu/pub/foresight/docs/ntw_report_nordmann_final_en.pdf; other publications at: http://cordis.europa.eu/foresight/ntw_expert_group.htm; Conference material at: http://cordis.europa.eu/foresight/ntw_conf2004.htm
Scope and characterisation of the study	▪ Response to US NBIC initiative ▪ Exploring potential and risks of CT by delineating areas of interest and fields of application of CTS, relating CT to European environment and policy goals ▪ Improve the understanding of human knowledge and cognition at large ▪ Identification of role of CT within Lisbon Strategy, common goals in European policy framework ▪ Explicit awareness and study of limits needed ▪ Applications in health, education, ICT infrastructure, environment, energy.
Converging Technologies considered	▪ "Embedded" devices and applications ▪ Unlimited reach challenging boundaries between nature and culture ▪ Engineering mind and body ▪ Specificity (e.g. targeted products) ▪ Not restricted to nano, bio, info (cogno).
Societal/ethical aspects and impacts, risks related to CT	▪ Alarm about ambitions to turn humans into machines by improving human performance ▪ CT may undermine conventions for warfare (e.g. Geneva Convention). ▪ Public acceptance of CT limited by transformative potential ▪ Economic risks (lost investments in R&D) ▪ Risk that consumer acceptance will outpace consideration of consequences ▪ Inherited risks of component technologies.

Potential role and research questions of SS&H	▪ Needed to inform and accompany CT research and to serve as intermediaries. Create settings for mutual learning. ▪ Societal feedback to the agenda-setting process via "Begleit-forschung" ▪ Real time technology assessment ▪ Should be integrated into CT development (promoted through Begleitforschung) ▪ Understanding resistance to new technology ▪ Cognitive science, evolutionary anthropology, economics, philosophy ▪ Impact of technological environments on cognitive processes ▪ "Societal observatory of Converging Technologies" (standing committee) ▪ Vision assessment.
Policy implica-tions	▪ Cognitive science research needed for assessment of best enabling specific NBIC technologies ▪ Regulatory framework might require an overhaul ▪ Widening Circles of Convergence Initiative (WiCC) as central driving force in EU ▪ Strong multidisciplinarity for CT(EKS) research ▪ Proactive education policy ▪ Transparent governance process ▪ EuroSpecs research process to develop European design specifications for CT.

5. Converging Technologies – Literature Study and Vision Assessment

Programme/ paper	Berloznik, R., Casert, R., van Est, R., Enzing, Ch., van Lieshout, M., Versleijen, A.: Converging Technologies – Literature Study and Vision Assessment
Country	European Union: Belgium/Netherlands
Institution	European Parliament, Scientific Technology Options Assessment panel/ETAG
URL	
Scope and characterisa-tion of the study	▪ Examine different approaches to convergence in US (Roco/Bainbridge) and Europe (CTEKS – Nordmann (ed.)
Converging Technologies considered	▪ Defence, military requirements ▪ Health, aging ▪ Ambient intelligence ▪ Nanoscience will deeply influence other domains vs. blurring of boundaries between nature and technical artefacts. ▪ Quotes on technology from IPTS/TNO report
Societal/ethical aspects and impacts, risks related to CT	▪ Creation of artificial intelligence superior to humans ▪ Evolutionary struggle ▪ Human enhancement ▪ Examines transhumanist and "bio-Luddite" positions, arguing for medium road, such as proposals for CTEKS
Potential role and research questions of SS&H	▪ Not addressed
Policy implica-tions	▪ Need for timely debate on NBIC Visions.

6. Ethical Aspects on ICT Implants in the Human Body

Programme/ paper	Ethical Aspects on ICT implants in the human body. Opinion No 20. (2005)
Country	European Union
Institution	European Group on Ethics in Science and New Technologies to the European Commission (EGE)
URL	http://ec.europa.eu/european_group_ethics/avis/index_en.htm (03.08.2006)
Scope and characterisation of the study	▪ Information and communication technologies (ICT) implants: Implantation of microchips inside the human body, accessible via digital network ▪ medical devices: monitoring of body parts, simulation of biological and psychic functions, restore or substitute of bodily functions, restore or enhancement of memory, stimulation or performance of brain activity ▪ surveillance and tracking devices for identification and location purposes ▪ enhancement or commodity devices: neural interfaces to increase and enhance human capabilities
Converging Technologies considered	▪ implants for functional electrical stimulation ▪ implants for bypassing damaged body parts ▪ implantable neurostimulation devices modifying electrical nerve activity ▪ chip-controlled body parts (artificial chip-controlled leg) ▪ biosensors monitoring inaccessible parts of the body ▪ implantable brain chips ▪ identification and location devices with an storage of data, programmable at distance, with tracking capabilities.

Societal/ethical aspects and impacts, risks related to CT	▪ "Contemporary society is confronted with changes that have to do with the anthropological essence of individuals." (p 21) ▪ technology modifies the body and its relationship with the environment ▪ individuals are being observed, modified, turned into networked individuals ▪ need for an extended grasp of a body that is physical and electronic ▪ transformation of the human race ▪ erosion of personal prerogatives ▪ threat of the dignity of the human body, its identity and its basic capabilities ▪ elimination of the human body by an artificial one ▪ body controlling by means of technology ▪ reduction of the body to a device or tool: dispossession of the own body and the own autonomy ▪ there are no reliable scientific investigations concerning the long-term health impact of ICT implants in the human body ▪ value conflicts between economic values and the respect for human dignity, between personal and societal claims, between the freedom of researchers and the health of research subjects ▪ implants that will influence biologically and/or culturally future generations.
Potential role and research questions of SS&H	▪ Social and political debate about kinds of applications, particularly concerning surveillance and enhancement ▪ education and constructive, well-informed debates ▪ precautionary approach: research on the long term social, cultural and health impact of different types of ICT implants with a particular focus on risk characterisation, risk assessment, risk management, risk communication (kept in mind for the Seventh EU Research Programme) ▪ preoccupation with the background of the idea of an 'enhanced' human being and the perfectibility of human beings ▪ feasible dependence of humans with ICT implants on market forces and even on the possibility of their use in the work place ▪ risk benefit assessment and the problem of fair access to ICT implants ▪ social exposure to humans whose body parts – particularly the brain - are substituted and/or supplemented by ICT implants, particularly when they are networked with or even guided by external devices.
Policy implications	▪ Legal framework and the lawfulness of ICT implants can be derived from general principles underlying national legislation and international instruments ▪ implanting ICT for profit-related purposes should be prohibited ▪ no use to manipulate mental functions or change personal identity ▪ need for regulation: "non-medical implants in the human body are not explicitly covered by existing legislation, particularly in terms of privacy and data protection" (p.35).

7. Meeting of Minds. European Citizens´ Deliberation on Brain Science

Programme/ paper	Meeting of Minds. European Citizens´ Deliberation on Brain Science. Synthesis Report on National Assessment. (December 2005)
Country	European Union
Institution	Project-coordinator: King Baudouin Foundation (with a consortium of 12 European research institutions)
URL	http://www.meetingmindseurope.org/europe_default_site.aspx?SGREF=15&CREF=5229 (08.08.2006)
Scope and characterisation of the study	▪ Treatment of brain-related diseases
Converging Technologies considered	▪ Brain Sciences as opposed to all sciences in general or health issues in general
Societal/ethical aspects and impacts, risks related to CT	▪ Rising needs and health care costs will aggravate the dilemma between freedom of individual choice and the common good ▪ actual and possible stigmatisation of the mentally ill or those who differ from a perceived normality
Potential role and research questions of SS&H	▪ Ethical control of research; need for extension of the reach of ethical oversight to non-experimental research ▪ preoccupation with patient rights ▪ questions of determination or free will ▪ terms of norms and values linked to brain sciences ▪ preoccupation with the grasp of normalcy and the distinction between normalcy and diversity taking into account "that diversity is ‘normal’ and positive for the development of society, the arts and science" (p 10) ▪ investigation of societal and individual demands and ways and means to balance them ▪ preoccupation with the challenge of a long-term increase in neurodegenerative diseases in the context of the definition of normalcy, the financing of health systems, the equal access to expensive treatments ▪ agency of the moral imperative value of involving citizens in the discussion ▪ inclusion of societal and environmental aspects of brain disease in the scientific and public debates.

Policy implications	▪ Requirement of high levels of information for public regulation as well as individual freedom of choice ▪ need for emphasizing patient's autonomy and individuality ▪ need for availability and promotion of alternatives to conventional treatments such as drug free-alternatives like music, sport, psychotherapy ▪ need for strengthening prevention: "better prevention could solve many of the challenges presented to health systems much more efficiently than the current dominant treatment approaches" (p 6) ▪ need for fostering interdisciplinary cooperation and holistic approaches ▪ need for cooperation of natural scientists with humanities ▪ need for the regulation of brain sciences and treatments coordinated on an European level ▪ need for safeguarding scientific research from politics, interest groups and other material factors that could divert and streamline research to the disadvantage of medical progress and patients' well-being.

8. What it Means to be Human. Origins and Evolution of Human Higher Cognitive Faculties

Programme/ paper	What it means to be human. Origins and Evolution of Human Higher Cognitive Faculties, 2005
Country	European Union
Institution	NEST (New and Emerging Science and Technology) High Level Expert Group. Research activity under the European Community's 6th Framework Programme.
URL	ftp://ftp.cordis.europa.eu/pub/nest/docs/whatitmeanstobehuman_b5_eur21795_en.pdf (04.08.2006)
Scope and characterisation of the study	Establishment of a research program called 'Human Mind Project' through collaboration of numerous disciplines (see 'Converging Technologies considered') concerning research on ▪ the genetics of human cognition ▪ the developing mind ▪ the process of thinking ▪ Motivation and decision making ▪ the cultural context of human and environmental phenomenon.
Converging Technologies considered	Convergence in the academic fields of ▪ Genetics ▪ Neurobiology ▪ Cognitive Science ▪ Human Behaviour Science ▪ Animal Behaviour Science ▪ Paleoanthropology ▪ History ▪ Modelling ▪ Philosophy of mind.
Societal/ethical aspects and impacts, risks related to CT	▪ Support of "policy makers interested in persuading people to adopt healthy lifestyles, improving industrial relations, encouraging children to learn, or even minimising institutional corruption" (p.16) ▪ "solutions to problems such as the best way to persuade people to invest in pensions and how to present public information so that it will be meaningful to people" (p.16).

Potential role and research questions of SS&H	▪ Call for aggregation of different philosophical traditions and approaches concerning theories overlapping with the theoretical aspects of cognitive psychology, the exploration of the structure and character of common-sense thinking, theories focusing on the metaphysics of mind ▪ evidence of links between philosophy of mind and philosophy of psychology and cognitive and behavioural science ▪ high relevance of current research in moral philosophy, philosophical logic, the philosophy of language ▪ evolutionary analysis of culture, mental connections and cultural and ecological influences on human evolution through collaboration of anthropologists, psychologists, archaeologists, geneticists, linguists, economists, mathematicians (examples for collaborative ventures in UK: the British Centenary Project 'Lucy to Language' and the Centre for the Evolutionary Analysis of Cultural Behaviour) ▪ identification of factors that influence and motivate us in the field of neuroeconomics managing by an integration between social and natural science ▪ historical research on evolutionary processes of cultural change and continuity, on the historical mapping of cultural traits, on interplay between natural and cultural processes, and on the relation between innovation and learning for the understanding of how we build culture done in collaboration with geographers, evolutionary biologists, archaeologists, evolutionary anthropologists further philosophical research on ▪ the standards of rationality and correctness (creation of a model of rationality) ▪ the relations between philosophical models of consciousness and explorations of different types of non-consciousness awareness in scientific psychology ▪ comparisons of the nature of explanation in folk psychology and scientific psychology ▪ the implications of philosophical accounts of the norms of cognitive functioning and the ways in which these norms break down in psychiatric disorders ▪ the extension of philosophical accounts of the nature of thought to the types of non-linguistic thinking attested to by cognitive ethnologists and developmental psychologists.
Policy implications	▪ Creation of research institutes along the lines of the Max Planck institutes ▪ establishment of series of conferences, summer schools ▪ creation of a system of medium-sized, grant-funded research projects that bringing together researchers from several different disciplines and at least two European countries ▪ exchange programs for researchers from different disciplines ▪ integration of journalists in the research progress by getting them into the lab to increase public interest and to keep policy makers informed.

3.3 France

9. Nanotechnologies: Ethics and Industrial Prospectives

Programme/ paper	Les Nanotechnologies: Ethique et Prospective Industrielle. Nanotechnologies: Ethics and Industrial Prospectives, November 2004
Country	France
Institution	Conseil General des Mines/Conseil General des Technologies de l'Information. Jean-Pierre Dupuy; Françoise Roure
URL	
Scope and characterisa-tion of the study	▪ "Meta-Convergence": combinations from at least two distinctive sectors. ▪ Lower costs in ICT as driver ▪ France is setting up 5 major technology centres specialised on nano.
Converging Technologies considered	▪ Convergence by simple combination (NB, NI, etc.) ▪ Convergence by multiple combinations (NBI), special role for cognitive science and neurotechnologies ▪ Repairing vital functions ▪ Bio-compatible nano-implants ▪ Evolution from microelectronics to nanoelectronics.

Societal/ethical aspects and impacts, risks related to CT	▪ Use of technologies intended to restore vital functions to "increase capacities" ▪ "Dual use" ▪ Ethical assessment criteria needed for EU projects ▪ Promotion of ethical aspects of nanotechnologies within STOA ▪ International dialogue based on precautionary principle (suggested by Roco): "Alexandria Process." ▪ Disorganisation of economy and international relations ▪ Competitive advantage by military funding of civilian outlets ▪ Accidents, diseases (potential leads to need for standards) ▪ Social sciences and humanities not currently involved in OMNT (Observatoire des micros et nanotechnologies).
Potential role and research questions of SS&H	▪ Determine needs of various stakeholders taking into account the subsidiarity of various players ▪ *Comité consultative national d'éthique* should be provided with resources to fulfil mission with regard to nano and convergence, to liase with national ethical committee of the CNRS ▪ Due to commitment of USA to devote 1% of Federal money allocated to nanotechnology to research on social and ethical implications, authors expect that US will lead field in such research. ▪ Ongoing "normative assessment" (according to Grinbaum/Dupuy)[10] ▪ Research platforms on ethical and societal implications of nanotechnologies.
Policy implications	▪ Need to assess technology before it is disseminated: impact studies, permanent monitoring. ▪ Law unsuitable: need to change regulatory framework (but practical implications still unknown) – need to find a balance between over-regulation and absence. ▪ Patents, IPR: need for standards ▪ Public awareness of risks essential ▪ Nanotechnology societal monitoring unit at EU level ▪ Applying accountability principle.

10 Jean-Pierre Dupuy and Alexei Grinbaum, "Living With Uncertainty: Toward a Normative Assessment of Nanotechnology", Hyle/Techne, in press.

3.4 Germany

10. "Computational Neuroscience" and "Innovative Facilities" (Research Programmes)

Programme/ Paper	Several different programmes, e.g. Nationales Netzwerk "Computational Neuroscience", August 2003; BMBF-Förderung "Innovative Facilities", August 2006
Country	Germany
Institution	Federal Ministry of Education and Research (BMBF)
URL	www.bmbf.de; http://www.bernstein-zentren.de/de/77.php (26.07.2006); http://www.gesundheitsforschung-bmbf.de/de/1340.php (07.08.2006)
Scope and characterisation of the study	▪ Computational Neuroscience: systematic study of the neural basis of cognitive processes (from the processing of complex sensory stimuli to learning processes; from the retrieval of stored information to the planning and precise coordination of motion patterns relevant to behaviour); elucidate the interaction between neural dynamics and information processing at the level of individual neurons, local networks and large-scale neural systems; relevant subject areas: - principles and mechanisms of the neural integration of multimodal information - neural coding and representation of the temporal structures of sensory stimuli and/or motor programmes - fundamental neural processes involved in spatial perception and spatial memory - modular structure, hierarchy and cooperation in the nervous system - dynamics of neural systems: mechanisms and function - acoustic communication and speech: from sub-symbolic information to cognition - neural basis of attention and conscious perception - plasticity in the nervous system: from signal cascades to learning processes. ▪ In BMBF-support programme "Innovative Facilities" development of innovative, technical facilities, that reconstitute, train, support or substitute functions and abilities such as mobility or motor abilities, sensory, cognitive, communicative and controllable vegetative abilities; projects in two subjects areas: - neuroprosthetics (e.g. brain-computer-interfaces) - assistive and restorative systems.

Converging Technologies considered	▪ Establishment of four Bernstein Centres for Computational Neuroscience in line with the FUTUR lead vision "Understanding thought" with research in areas such as information technology, biomedicine, learning and research ▪ Working together of disciplines such as neurobiology, cognitive science, systems biology and information technology to develop a common scientific language ▪ Support and funding of projects developing neural implants, prostheses or external devices.
Societal/ethical aspects and impacts, risks related to CT	▪ Legal and ethical aspects as well as questions related to safety, benefit, quality managements etc. of the devices that are supposed to be developed in the proposed projects have to be included in the projects from the beginning onwards.
Potential role and research questions of SS&H	▪ Not addressed.
Policy implications	▪ Bernstein Centres: development of interdisciplinary training programmes in the field of computational neuroscience and the establishment of expert counselling resources.

3.5 International

11. White Paper on Nanotechnology Risk Governance

Programme/ paper	White Paper on Nanotechnology Risk Governance, June 2006
Country	International
Institution	International Risk Governance Council (IRGC)
URL	www.irgc.org/irgc/_b/contentFiles/IRGC_white_paper_2_PDF_final_version.pdf (07.08.2006)
Scope and characterisation of the study	▪ Nanotechnology and related short-term ("frame one") and medium-to-long term ("frame two") risk issues ▪ Converging technologies central part of so called "third and forth generation nanotechnology developments" within frame two NT: "New applications will develop based on the convergence of nanotechnology, biotechnology, information technology and the cognitive sciences (NBIC) (Gen 3) ... Fundamentally new functions and processes begin to emerge with the behaviour of applications being based on that of biological systems (Gen 4)".
Converging Technologies considered	▪ Use of various synthesis and assembling techniques such as bio-assembling ▪ the creation of macromolecules "by design" to self-assemble on multiple scales ▪ directed and multiscale self-assembling ▪ evolutionary bio- and hybrid- nanosystems (later with emerging functions); ▪ artificial organs built from the nanoscale ▪ improved cell-material interactions for cell conditioning ▪ nanoscale genetic therapies, cell ageing therapies, and nanoscale controlled stem cell therapies ▪ emerging behaviour robotics ▪ evolutionary artificial organs and cells ▪ modified viruses and bacteria ▪ self-replication of large nanostructured systems ▪ brain modification ▪ nanorobotics ▪ brain-machine interface, human-machine interface ▪ nano-engineering in agriculture ▪ (molecular) nanosystems used for manufacturing and product processing ▪ neuromorphic engineering.

Societal/ethical aspects and impacts, risks related to CT	▪ Interested parties are considering the social desirability of anticipated innovations ▪ Debates are focused on the process and speed of technical modernisation, changes in the interface between humans, machines and products, and the ethical boundaries of intervention into the environment and living systems (such as possible changes in human development and the inability to predict transformations to the human environment). ▪ The primary concern of Frame 2 is that the societal implications of any unexpected (or expected but unprepared for) consequences and the inequitable distribution of benefits may create tensions if not properly addressed. These concerns about technological development may not be exclusively linked to nanotechnology but are, at least partially, associated with it and will impact upon stakeholder perceptions and concerns ▪ Knowledge uncertainty and ambiguity: "The main risk governance deficits for the second to fourth generations of nanoproducts (including active nanodevices, nano-bio applications and nanosystems) is the uncertain and/or unknown implications of the evolution of nanotechnology and its potential human effects (e.g. health, changes at birth, brain understanding and cognitive issues and human evolution) and the lack of a framework through which organisations and policies can address such uncertainties." ▪ Risk of changing human condition, human identity and human development. ▪ Society structural risks ▪ Educational gap risk ▪ Political and security risks.

Potential role and research questions of SS&H	▪ "The primary concern of Frame 2 is therefore characterised by a mixture of beliefs, values and visions that are not exclusively linked to nanotechnology but are, at least partially, associated with it. (...) To study these concerns and visions and to provide meaning to the often fragmented public voices is the domain of the social sciences and the humanities: traditional impact assessment or risk analysis will have no bearing on the arguments that are exchanged in this debate. The evidence that is required for this debate is narratives that show plausible (or implausible) links between social and perception threats and a combination of technologies including nanotechnology. Examples are neurochips to be implanted in the human brain, nanomachines used in warfare, plants with biochips, and other futuristic applications. The main message is: Stop this process before it is too late." ▪ "Research for Frame 2 questions, however, requires a more holistic and transdisciplinary approach. This should include a strong involvement of the social sciences and the humanities, the incorporation of stakeholder preferences and intense reflections by legal and ethical scholars." ▪ New approaches for the societal infrastructure and legal system to handle the potential broad changes in daily human activities (such as learning, working, increasing life expectancy, neuromorphic engineering and brain-machine interface). ▪ Investigation of the long-term effects on human development that have not been well addressed so far ▪ Development and implications of major equity conflicts if CT are targeted at individual customers ▪ Heuristics and biases relating to cognitive processes that may affect CT risk governance.
Policy implications	▪ Stakeholders must achieve understanding, engage in discussion about ethical and social responsibility for individuals and affected institutions and build institutional capacity to address unexpected risks ▪ Projected scenarios need to be explored that show plausible (or implausible) links between the convergence of technologies and the possible social, ethical, cultural and perception threats.

3.6 Japan

12. Eighth National Japanese Science and Technology Foresight

Programme/ paper	Eighth National Japanese Science and Technology Foresight, 2005 General findings, life sciences, information and communications, nanotechnology, social technology fields
Country	Japan
Institution	NISTEP - The National Institute of Science and Technology Policy and MEXT – The Science and Technology Foresight Center, Ministry of Education, Culture, Sports, Science and Technology.
URL	www.nistep.go.jp
Scope and characterisation of the study	▪ Is the eighth study in a series ▪ Mind-machine interfaces based on brain waves ▪ Nearly complete elucidation of the molecular mechanisms for neural network formation ▪ Elucidation of neural mechanisms for dreaming ▪ Brain as a metaphor: emulation of mechanisms vs. replicating functions irrespective of architecture ▪ Artificial limbs with sensation, technology to voluntarily control prostheses ▪ Nanoscience for a safe and secure society ▪ Traffic, transportation, environmental technologies ▪ Artificial organs, retinas
Converging Technologies considered	▪ Brain research – advanced and untapped. Japan trailing US and Europe ▪ Nanobiology (Japanese lead) ▪ Translation (Japan lags) ▪ Social application of brain science (anticipated to take long to achieve application)
Societal/ethical aspects and impacts, risks related to CT	▪ No major change in average longevity, but extension of healthy life phase. ▪ "Social technology" added as new field compared to earlier foresights (safe and secure society, aging society, knowledge society) ▪ Entertainment technology, cultural technology and knowledge production systems have low expert priority
Potential role and research questions of SS&H	▪ Not addressed explicitly
Policy implications	▪ Brain research must be strengthened ▪ Resources development in biology and bioinformatics is urgent task.

3.7 Spain and Latin American Countries

13. Barcelona´s Declaration on Converging Technologies

Programme/ paper	Barcelona´s Declaration on Converging Technologies, 2005
Country	Spain (cooperation with Europe & Latin America)
Institution	Converging Technologies Institute
URL	http://www.nbic.org.es/forumnew/gb-f-download.html (03.08.2006)
Scope and characterisation of the study	▪ Design of new devices that will enable cognitive and communicative capacity expansion, improve health and the physical capacities of humanity and its social welfare
Converging Technologies considered	▪ Synergy between Nanotechnology, Biology, Information Technology and Cognitive Sciences.
Societal/ethical aspects and impacts, risks related to CT	▪ Prospect of major social and economical impacts from the fields of Health and Education.
Potential role and research questions of SS&H	▪ Education Programmes should emphasise such aspects as bio-security, bio-ethics, regulation ▪ Creation of support structures and networks in consideration of doctors, scientists, engineers, patient associations, ethics specialists ▪ Study of the development of NBIC technologies and their social and ethical implications to ensure social freedom.
Policy implications	▪ Proposal for the establishment of a pilot programme of education not later than 2006 ▪ foundation of a specific Institute for CT, encompassing scientists and centres from all Technology and Science orientations ▪ need for promotion of convergence of technologies as a new tool for research and investigation and as an engine for innovations and development.

14. Tecnologías Convergentes NBIC. Situación y Perspectiva 2005

Programme/ paper	Tecnologías Convergentes NBIC. Situación y Perspectiva 2005, November 2005
Country	Spain
Institution	Consejo Superior de Investigaciones Científicas (CSIC - National Research Council)
URL	http://nbic.org.es/institute/sp-home.html (09.08.2006)
Scope and characterisation of the study	▪ NBIC Converging Technologies as "the interdisciplinary study of interactions between living and artificial systems in different scales (nano-macro) for the design of artefacts that improve or expand human cognitive and communicative capabilities, health and social well-being ▪ Reference to Roco/Bainbridge 2002 (see 3.9) and Nordmann (see 3.2) ▪ Report as answer to a call from the EU inviting member states to identify their needs, strengths and opportunities ▪ Based on four workshops with Spanish and foreign scientists ("CT and Neurotechnology", "CT and Information Technology", "CT and Genomics", "Education and CT"), the "Converging Technologies Forum 2005", in-depth interviews with heads of Spanish research centres and a survey of scientists of CSIC and deans of research of some Spanish universities ▪ Analysis of different documents on CT (USA, Canada, European Union) ▪ Chapter 3 on state-of-the-art of NBIC in Spain.
Converging Technologies considered	▪ Neuroprosthetics (including case study on artificial organs and intelligent prostheses) ▪ Implants to help people with severe neural damage or restricted mobility ▪ Lab-on-a-chip applications ▪ Diagnostics and therapy (including case study on tumours) ▪ microarrays and microchips ▪ nanotubes for medical applications ▪ molecular imaging ▪ simulation of biological processes and the functioning e.g. of organs and organelles ▪ NBIC technologies for human enhancement ▪ Telepresence ▪ Personal intelligent assistants (including case study) ▪ Storage and generation of energy ▪ Largest short-to-mid-term impact of NBIC technologies in health and education ▪ Expert survey identified areas of biomedicine as primary application of NBIC, followed by pharmaceutics, energy, environment, food, communication, transport, agriculture, education, ocean science and tourism.

Societal/ethical aspects and impacts, risks related to CT	▪ Restrictions on personal freedom (e.g. through personal intelligent assistants, interconnected environment) ▪ Ethical questions related to use of artificial organs and intelligent prostheses (who sets the norms? for whom? who benefits? Etc.) ▪ In expert interviews some called for ethics commission on CT.
Potential role and research questions of SS&H	▪ Involve academics from various disciplines such as ethicists lawyers, different public groups (such as disabled persons) to develop good practices.
Policy implications	▪ In setting up a NBIC strategy topics such as biosecurity, bioethics, regulations etc. to be taken into account ▪ Recommendation to found a Converging Technologies Institute similar to the Santa Fe Institute (U.S.A.) ▪ Set up educational and research infrastructure to support NBIC development.

3.8 United Kingdom

15. Applications and Impact. (Paper for the UK Foresight Cognitive Systems Project)

Programme/ paper	Bill Sharpe: Applications and Impact. Paper for the UK Foresight Cognitive Systems Project, 2003
Country	United Kingdom
Institution	Foresight directorate of the Office of Science and Innovation. This has also performed a project on "Brain Science, Addiction and Drugs" which is of relevance to CONTECS. Both the Cognitive Systems and the "Brain Science" projects have produced scientific reports with connections to the topics of CONTECS., all available from the website at: www.foresight.gov.uk [11].
URL	www.foresight.gov.uk for all publications. http://www.foresight.gov.uk/Previous_Projects/Cognitive_Systems/Reports_and_Publications/General_Reports/Applications%20and%20Impact/Applications_and_Impact.html for Applications and Impact Paper.
Scope and characterisation of the study	▪ If Moore's law continues, it is foreseeable that computing power equivalent to that of natural cognitive systems (humans) will be within reach soon. ▪ Ubiquitous, pervasive computing, ambient intelligence, consisting of 3 components: 1. core computing (getting cheaper), 2. WWW, 3. agent based computing ▪ Mind-body relationship: central model of symbolic computing disconnected from demands of natural environment. ▪ Embodied cognitive tasks are astonishingly difficult. ▪ Transportation (Foresighted driving, automated control).

11 e.g. Berridge, V. & T. Hickman: History and the Future of Psychoactive Substances; Room, R.: Social Policy and Psychoactive Substances; Ashcroft, R., Campbell, A.V., Capps, B.: Ethical Aspects of Developments in Neuroscience and Drug Addiction, Jones, R., Morris, K, Nutt, D.: Cognition Enhancers; Garavan, H., Lingford-Hughes, A., Jones, T., Morris, P., Rothwell, J., Williams, S.: Neuroimaging; McKeganey, N., Neale, J., Lloyd, C., Hay, G.: Sociology and Substance Use.

Converging Technologies considered	▪ Cognitive systems can be pursued from the perspectives of the life sciences, physical sciences and real-world engineering. People in these fields are studying essentially the same problems. ▪ Interfacing directly between living neurons and electronics ▪ Neuroprosthetics ▪ Neurofeedback ▪ Cognitive prosthetics, assisted cognition, distributed cognition "Things that make us smart". ▪ Exoskeletons (military at present).
Societal/ethical aspects and impacts, risks related to CT	▪ Responsibility in complex, interacting systems ▪ New forms of dependence; ownership and governance ▪ Technology is ahead of legal structures ▪ New vulnerabilities as barriers to deployment ▪ Emergent properties ▪ Implanted chips will challenge regulatory regimes ▪ Distinctions between treatment, enhancement and recreation will blur ▪ Level of equivalence to permit testing ▪ Permanent augmentation as a lifestyle choice ▪ Greater competence of cars than humans for driving: how to take a driving test? Will cars limit ability of driver to control them? ▪ Robots in healthcare as replacement for humans? ▪ Impact of use of "intelligent toys" and virtual environments on social skills. ▪ Social backlash, e.g. against nanotechnology ▪ Unanticipated emergent effects (unwelcome surprises) ▪ Technology and cognitive intervention will take place in world of alternative medicine: problems for regulation of practice. ▪ Dependence on cognitive assist technologies: liability, responsibility.
Potential role and research questions of SS&H	▪ Not addressed.
Policy implications	▪ New legislation, regulatory framework ▪ Liability, responsibility ▪ Governance ▪ Intellectual property regimes.

3.9 United States of America

16. Converging Technologies for Improving Human Performance

Programme/ paper	Roco, M.C.; Bainbridge, W.S. (eds.): Converging Technologies for Improving Human Performance, 2002
Country	United States of America
Institution	National Science Foundation, Department of Commerce.
URL	http://www.wtec.org/ConvergingTechnologies
Scope and characterisation of the study	▪ NBIC convergence: directed at improving human performance with distinct military orientation ("invincible soldiers) ▪ Expanding human cognition and communication ▪ Improvement of human health and physical capabilities ▪ Enhancing group and societal outcomes ▪ National security ▪ Unifying science and education.
Converging Technologies considered	▪ "Convergence of diverse technologies is based on material unity at the nanoscale and on technology integration from that scale. Science can now understand the ways in which atoms combine to form complex molecules, and how these in turn aggregate according to common fundamental principles to form both organic and inorganic structures. Technology can harness natural processes to engineer new materials, biological products, and machines from the nanoscale up to the scale of meters. The same principles will allow us to understand and, when desirable, to control the behaviour both of complex microsystems, such as neurons and computer components, and macrosystems, such as human metabolism and transportation vehicles" (p.2) ▪ Cognitive science can help computer scientists develop software inspired by growing understanding of the neural architectures and algorithms actually employed by the human brain ▪ "Human Cognome Project" to "chart the structure and functions of the human mind" (p. 98), this project is not only to include a "complete mapping of the connections in the human brain" (p. 98) but also "new kinds of rigorous research on the nature of both culture and personality" (ibid.). ▪ In the field of Improving Human Health and Physical Capabilities, the report identifies six priority areas: (1)nano-bio processors for research and development of treatments, (2) nanotechnology-based implants and regenerative biosystems as replacements for human organs or for monitoring of physiological well-being; (3) nanoscale machines and comparable unobtrusive tools for medical intervention; (4)multi-modality platforms for increasing sensorial capabilities, particularly for visual and hearing impaired people; (5) brain-to-brain and brain-to-machine interfaces; and (6)virtual environments for

	training, design, and forms of work unlimited by distance or the physical scale on which it is performed (Roco, Bainbridge (eds.) 2002, p. xi). ▪ "The Communicator", designed to remove barriers to communication caused by physical disabilities, language differences, geographic distance, and variations in knowledge, thus greatly enhancing the effectiveness of cooperation in schools, corporations, government agencies, and across the world" ▪ Applications to ensure security (military) ▪ Unification of science and education (reference to EO Wilson's concept of "consilience").
Societal/ethical aspects and impacts, risks related to CT	▪ Executive summary mentions ethical issues and societal needs ▪ Need for representation of public addressed ▪ Subject of 21st Century Nanotech. R& D act, 2003, thus probably not major concern.
Potential role and research questions of SS&H	▪ Proposal for new science or discipline "memetics" ▪ Social sciences regarded as "stagnant" ▪ Sciences of human culture "lack formal paradigm and rigorous methodology" ▪ Interdisciplinary nanotechnology research centres to ensure consideration of ethical, legal, environmental and other appropriate societal concerns. ▪ Involvement in addressing ethical, legal, moral, economic, workforce development and other societal implications ▪ Challenges to American cultural supremacy ▪ Discover products to make the information economy profitable ▪ Identify forms of social institutions most conducive to social and economic progress.
Policy implications	▪ Top-down approach to foster the emergence of "memetics". ▪ Establishment of national R&D priority area on converging technologies focused on enhancing human performance ▪ Research on societal implications must be funded. ▪ Monitoring of potentially undesirable secondary effects by government organisation in order to anticipate and take corrective action.

17. Nanotechnology: Societal Implications – Maximizing Benefits for Society

Programme/ paper	Nanotechnology: Societal Implications – Maximizing Benefits for Society, December 2003
Country	United States of America
Institution	National Nanotechnology Coordination Office and National Science Foundation
URL	http://www.nano.gov/html/society/home_society.html (07.08.2006)
Scope and characterisation of the study	▪ Outcome of an expert workshop on societal implications of nanotechnology, breakout sessions in 10 different areas – theme 3: quality of life, theme 5: converging technologies ▪ Much of the impact of NT will occur through its convergence with other technologies (bio – info – cogno) ▪ Take up the NBIC concept ▪ Each breakout session is summarised with anticipated developments, key areas of research, methods and evaluation of research and action recommendations.
Converging Technologies considered	▪ Statement by P. Bond (Department of Commerce): brain implants, interconnected environment, DNA customisation ▪ Statement by M. Roco (NNI): potential developments by 2015 in the area of CT such as hybrid manufacturing, neuromorphic engineering, artificial organs, expansion of the life span, and enhanced learning and sensorial capacities ▪ Breakout session on theme 3: in their everyday lives people will benefit from greatly enhanced tools for cognition and communication ▪ Breakout session on theme 5: treating fatal diseases (e.g. AIDS, cancer); improving crop yields and nutritional value to feed the world; turning almost any water into an affordable source of potable water; energy production from clean, renewable sources; remediating existing environmental damage; enabling the blind to see, the deaf to hear, the lame to walk; NBIC technologies may contribute greatly to human health, longevity, and the easing of medical hardships, pain and suffering, and handicaps.
Societal/ethical aspects and impacts, risks related to CT	▪ P. Bond: societal and ethical challenges through CT such as privacy, humanness, enhancement (for commercial and military advances of nations); Nano-divide between regions that benefit from CT and those that do not; risks such as change of occupational world, loss of industries, misuse of CT (e.g. by terrorists) ▪ Breakout session on theme 5: change in industrial structure with impacts on individuals, companies, regions and nations ▪ Related to restoring lost brain functions or treatments of mental illness: what kinds of treatments are appropriate, at what levels, for whom and under what circumstances ▪ Variety of legal privacy issues raised.

Potential role and research questions of SS&H	▪ P. Bond: holistic approach to address challenges of NT including ethicists, philosophers, historians etc., but with engineers and scientists playing a key role ▪ Breakout session on theme 5: strong, ongoing, open and honest dialogue among all stakeholders ▪ Understand and quantify risks associated with NT materials, products and processes ▪ Communication with the public on NBIC technologies (two-way-communication) – for effective communication knowledge of the various public perspectives on new technologies necessary; engage the public to provide a citizens´ perspective ▪ Needs for better models for risk analysis, characterisation and quantification; for more effective models to do risk-based cost-benefit analysis; for improved dissemination of "lessons learned" in risk management.
Policy implications	▪ Need for regulatory decision-making covering development, manufacturing, use, disposal and reuse of NBIC products and materials ▪ NBIC technologies and products require regulators to be contrained in areas outside their core expertise ▪ May necessitate legislative changes to regulatory agencies´ mandates and spheres or authority and/or restructuring of regulatory review and approval process ▪ Exploring proactive, non-regulatory approaches to achieving regulatory objectives; expanded cooperation between industry and government ▪ New challenges to existing law and educational preparation of legal professionals.

18. The Global Technology Revolution 2020, In-Depth Analyses Bio/Nano/ Materials/Information Trends, Drivers, Barriers, and Social Implications

Programme/ paper	Silberglitt, R., Antón, P. S. , Howell, D. R., Wong, A. with Gassman, N. , Jackson, B.A. , Landree, E., Pfleeger, L.S., Newton, E.M. and Wu, F.: The Global Technology Revolution 2020, In-Depth Analyses Bio/Nano/Materials/Information Trends, Drivers, Barriers, and Social Implications
Country	United States of America
Institution	Rand Corporation, Santa Monica, prepared for the National Intelligence Council (NIC)
URL	http://www.rand.org/pubs/technical_reports/TR303/
Scope and characterisation of the study	▪ In contrast to an earlier RAND report on the same subject, published in 2001, convergence is explicitly mentioned. The passages on "implants" are the most relevant for CONTECS. ▪ Aim is to quickly identify promising movements with potentially significant effects on the world. ▪ NIC addresses director of the CIA and key policy makers on foreign policy priorities.
Converging Technologies considered	▪ Implants and prostheses mimicking biological functions ▪ Functional nanostructures for controlled drug delivery and improved performance of implants and prosthetic devices. ▪ RFID, human surveillance and monitoring, implantable RFID chip ▪ Implants connected directly with brain and nervous system ▪ Robots that look and move in very human fashion ▪ Improved IT devices to control bodily functions and prostheses.
Societal/ethical aspects and impacts, risks related to CT	▪ Implants designed to repair lost functionality that are used for other purposes or enhancement. ▪ What does it mean to be human? (Line between correction of deficiency and augmentation or modification) ▪ Military uses ▪ Implications for personal privacy and freedom ▪ Not all conflicts on technological issues can be resolved (conflicting values etc.) ▪ Laws, public opinion, investment in R&D, and education and literacy should be drivers for, and not barriers to, technology implementation.
Potential role and research questions of SS&H	▪ Not explicitly addressed.
Policy implications	▪ Need for debate to resolve conflicts.

4 Conclusion

Based on an analysis of policy papers, with the caution that these are mainly restricted to documents publicly available on the Internet, the general picture is that there was initially a great deal of interest in Converging Technologies, very largely as a result of the visions contained in the first NSF/DOC report on the topic (Roco/Bainbridge 2002 – see scheme 16).Following the first rush of euphoria, assumed more "normal" proportions: Nano-related convergence is an important, but not outstanding item on the research agenda.

In the U.S.A., the concept of converging or convergent technology was linked strongly with the National Nanotechnology Initiative - NNI) and was in fact conceived as a successor to the NNI. The really new element in this concept of convergence is the addition of the cognitive sciences to nanotechnology, biotechnology and information and communication technologies, all of which had already achieved widespread recognition as key technologies for the future. One interviewee put forward much the same idea: "…cognition is held apart – it provides some form of superstructure. It's at the same time the ultimate goal of convergence and a metaphysical superstructure".

Progress in technologies for the visualisation of such things as brain signals (neuroimaging) coupled with progress in neurosciences, in parallel with the anticipated continued validity of Moore's law, gave birth to high hopes that it will be possible in the foreseeable future to replicate, amplify or surpass human intelligence, be it in separate machines, or be it in implants intended originally to provide or restore sensory, motor or cognitive capacities to humans severely impaired when compared to the average of humankind. The potential to "improve human performance" which is part of the NSF/DOC's report's title suggests that it will be possible to go well beyond only restorative applications.

The term "converging technologies" is frequently used, but not uniformly and in a number of different senses. Thus there is need to develop a working definition for CONTECS and a broader societal debate.

Another vision contained in the NSF/DOC report is that of a "new renaissance" of science based on unity: "Convergence of diverse technologies is based on material unity at the nanoscale and on technology integration from that scale. Science can now understand the ways in which atoms combine to form complex molecules, and how these in turn aggregate according to common fundamental principles to form both organic and inorganic structures. Technology can harness natural processes to engineer new materials, biological products, and machines from the nanoscale up to the scale of meters. The same principles will allow us to understand and, when desirable, to control

the behaviour both of complex microsystems, such as neurons and computer components, and macrosystems, such as human metabolism and transportation vehicles" (Roco/ Bainbridge 2002, p.2 – see scheme 16).

The vision of a systematic integration of all sciences and technologies is a topic with a long-standing tradition in the history of ideas. The US NBIC initiative's ideas about this subject owe much to the concepts of "consilience" and a new "unity of knowledge", which were developed in a book by the biologist E.O. Wilson[12] and in turn are based on Wilson's older and controversial ideas on "Sociobiology". This aspect of the debate has not drawn as much attention outside the US as the notion of Converging Technologies or enhancement. However, some scepticism was aroused by a rather vague vision, developed within the US NBIC initiative, to fuse social and behavioural sciences, ICT, empirical cultural studies, "memetics", and cognitive and brain sciences into a new and predictive science of social behaviour and to develop a kind of new social technology with the aim to politically "engineer culture". As the interviews for CONTECS in the USA revealed, this aspect of the NBIC vision has not triggered any kind of major debate in the country and was dismissed by at least one interview partner as a "goofy idea".

With respect to the visions of a new renaissance and unity of knowledge, the EU HLEG on the New Technology Wave and others reacted rather cautiously. They argued instead for more interdisciplinary work that integrates natural sciences, engineering disciplines and SS&H. However, such a strong interdisciplinarity has its own problems. The ongoing discussions on this issue in European RTD policy and academia deserve to be intensified and related activities should become more concrete.

Over all, and despite a wave of enthusiasm for convergence of key technologies, most countries and regions seem rather hesitant in embracing the concept wholesale while reinforcing efforts in selected areas such as the cognitive sciences, in particular brain research, or nanobiotechnology.

The cognitive sciences had previously played a major role in the debate on artificial intelligence which took place worldwide mainly in the late 1980s and early 1990s. At that time, the cognitive sciences were regarded mainly as a supplier of knowledge to artificial intelligence whereas today, artificial intelligence seems to be regarded widely as a part of the cognitive sciences. These are themselves interdisciplinary in that they involve scientists from a whole range of natural, physical and life sciences in addition to social sciences and the humanities.

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12 Wilson, E.O.: Consilience. The Unity of Knowledge. New York: Vintage Books, 1999 (originally published in 1998)

There are two basic approaches to artificial intelligence which are reflected in the cognitive sciences: "one as an engineering discipline concerned with the creation of intelligent machines, the other as an empirical science concerned with computational modelling of human intelligence" [13]. Other branches of the cognitive sciences, such as neuroscience, are expected to deliver the insights into the biochemical foundations of cognitive processes to enable progress in understanding human intelligence to the extent that it can be accurately analysed to be translated into functionally, and ultimately "physically" modelled.

A major question in this context is the degree of coherence between the various disciplines forming the cognitive sciences, i.e. whether results of research in one discipline or area are at all noted and then employed by the others. Experience from the beginning of the UK Cognitive Systems foresight project suggests that there was, and possibly still is, a lack of awareness of possible cross-benefits of research by the various disciplines in the field. While many exciting and promising discoveries due to the availability of new techniques are being made, particularly in the neuroscience branches of the cognitive science, there is still need for much research to translate the discoveries into technology. Military secrecy aside, this probably applies as much to the USA as to other regions, despite very optimistic predictions being made by futurists[14] and in foresight-like studies[15].

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13 Jordan, M.I., Russell, S.: Computational Intelligence, in Wilson, R.I., Keil, F.C. (eds): The MIT Encyclopedia of the Cognitive Sciences. Cambridge Mass.: MIT Press, 1999, pp. lxxi – xc; citation p. lxxiv

14 e.g. BT Futurist Ian Pearson, who expects first electronic artificial life between 2006 and 2012, an AI entity to pass it's a levels by 2015 and human knowledge to be exceeded by machine knowledge by 2020. Cf. Neild, I., Pearson, I. (Eds): 2005 BT Technology Timeline. http://www.btinternet.com/~ian.pearson/

15 The Korean VISION 2025 expects that by 2020, 30% of human brain functions will be understandable and that neurocomputers modelling brain functions for logical thinking will be possible. By 2030, the report expects that it will be possible to understand logical inference in human brains and human cognitivemechanisms, enabling their adoption by computer science. **Vision 2025 (2000):** VISION 2025 – Korea's Long-term Plan for Science and Technology Development. Ministry of Science and Technol ogy, June 2000. http://unpan1.un.org/intradoc/groups/public/documents/APCITY/UNPAN008040.pdf, accessed 1 October 2007

The debate taking place in the social sciences and philosophy is in part a debate on the ideological foundations of converging technologies and on technology underpinning current R&D trends at the interface between nature and technological development. It is at the same time a pattern for discussions on general issues of the governance of science and technology in the 21st century. The assessment of visions can play a crucial role in this context[16].

Such a general debate on converging technologies is currently restricted to a still small but growing number of actors, but there are many contributions from social sciences and ethics on narrower topics, such as genetic engineering and reproductive medicine, and, more recently, neuroimaging and the related neuroethics. Health technology assessment studies have been performed on individual sensor-based prostheses and "enhancement" has been quite widely discussed, mainly in regard to illegal substance use and psychopharmaceutics for improving performance.

The obvious affinity of the topic of improving human performance with the agendas of a number of other societal fringe groups beside the trunshumanists, such as spokespeople for the complete liberalisation of drug-taking, "cognitive liberals", "cryonicists", "extropians", "singularitarians", "life-extensionists" etc., with positions perceived as extreme by the majority of society, may possibly contribute either to the instant rejection of corresponding technological developments perceived as "too hot to handle" by active science and technology policy ("bio-conservatism") or to muddling through by not openly addressing or supporting a topic for the time being.

Despite such high expectations in some areas of society, the notion of NBIC is not a leading vision for society at large and in research and technology policy in particular, if public policy documents and the broad societal debate are reliable indicators. This does not mean that everything related to converging technologies is hype and unrelated to practical applications. Far from it: there are many activities under the separate headings of nanotechnology, biotechnology and information technology, many in conjunction with one of the other two and with the cognitive sciences, which are interdisciplinary in nature and pointing strongly in the direction of convergence. This means that there is sufficient time for a broad societal discourse on desirable applications and to develop research programmes taking advantage of the ongoing developments in research and technological development.

16 Grin, J., Grunwald, A. (eds.): Vision Assessment: Shaping Technology in 21st Century Society: Towards a Repertoire for Technology Assessment. Berlin et al.: Springer, 2000

Overview table of country activities

More detailed information on documents that are highlighted in grey colour can be found in section 3 of the deliverable.

N°	Country	Name	Institution	Content	URL/document
1	Argentina	Bases para un Plan Estratégico de Mediano Plazo en Ciencia, Tecnología e Innovación	Ministry of Education, Science and Technology	In Spanish; nanotechnology, biotechnology and information and communication technology as key areas for the development of Argentina; broad outline of science and technology policy 2005 to 2015	http://www.secyt.gov.ar/bases_plan_estrategico_05_15/intro_bases_plan_estrategico.htm
2	Asia		Asia Nano Forum (ANF)	"ANF Network" lists the members of ANF, for each of which information is provided e.g. on policy summary, government's programs	www.asia.nano.org
3	Australia		ANF	Not much information available yet, Australian Research Council Nanotechnology Network (ARCNN), The Nanostructural Analysis Network Organisation (NANO)(Major National Research Facility)	http://www.asia-nano.org/CountryHome.php?CN=2
4	Brasil	Desenvolvimento da Nanociencia e da Nanotecnologia	Ministry of Science and Technology	In Portuguese; detailed plan for the development of the field of nanotechnology including budget, short, mid- und long-term aims, but no visions	http://www.mct.gov.br/upd_blob/2361.pdf
5	Brazil	Programa de Biotecnologia e Recursos Genéticos	Ministry of Science and Technology	In Portuguese; detailed strategy for further developing biotechnology, also in cooperation with nanotechnology and information technology; including overall strategy, description of infrastructure and next steps; no real visions	http://www.mct.gov.br/upd_blob/450.pdf
6	Canada	A Brave New World: Where Biotechnology and Human Rights Intersect	Department of Justice	Mid-term report of the Biotechnology and Human Rights Framework Project, human rights issues with respect to current and future applications in the field of biotechnology are examined, ethical, moral and novel legal issues with regard to biotechnology are discussed. Not directly on convergence, but possible relevance through analogy.	http://www.biostrategy.gc.ca/HumanRights/HumanRightsE/toc_e.html
7	Canada	Bio-Systemics Synthesis	Science and Technology Foresight Pilot Project	Description of four NBIC technologies and their implications and impacts with detailed lists of possible application fields; compared to other documents quite detailed about cognitive science developments as well	http://2100.org/Nanos/bio-systemics-canada.pdf
8	Canada	Toward Understanding Science and Technology Convergence	Science & Technology Foresight Directorate	Definition and key characteristics of CT, reasons for their importance, developments in other countries (including the U.S.A., the European Union, Asian countries, further developing countries and the – expected - role in Canada)	

N°	Country	Name	Institution	Content	URL/document
9	Canada	The Big Down: Atom-tech.Technolo-gies Converging at the Nano-Scale	ETC Group	Stakeholder document with relevance especially for nanotechnology	http://www.etcgroup.org/documents/TheBigDown.pdf
10	Chile	Fondo de Innvación Tecnologica de la Región del BíoBío (INNOVA BIOBIO)	Regional government BíoBío, Ministry of Economy and CORFO	In Spanish; regional initiative with national model character, fostering development and transfer of innovations into enterprises; supporting research and development in areas such as biotechnology, information technology and related areas	http://www.innovabiobio.cl/
11	China		ANF	Not much information available yet, a number of projects carried out within the Shanghai Municipal Government Project, Priority Research Areas during the Tenth Five-Year Plan Period (2004-2009) (only accessible with login); The National Center for NanoScience and Technology, China (NCNST), The National Natural Science Foundation of China (NSFC), Nano Science and Technology Networks (nanotech.com.cn), Shanghai Nanotechnology Promotion Center (SNPC), National Nanotechnology Industrialisation Base of China (NIBC)	http://www.asia-nano.org/CountryHome.php?CN=6
12	Colombia		Consejo Nacional de Nanociencia y Nanotecnología	According to document No. 42 council's website under www.nanocolombia.org, but this has expired; no other information about CT or any of the four disciplines could be found	
13	Costa Rica	Programa Nacional de Ciencia y Tecnología 2002-2006	Ministry of Science and Technology	In Spanish; short outline of the national R&D policy, biotechnology, information and communication technology as important areas	http://www.micit.go.cr/docs/PNCYT_01.pdf
14	Cuba		Observatorio Cubano de Ciencia y Tecnología (OCCYT)	In Spanish; most of the paper describes the plans, programmes, ideas and visions of the U.S. (and less prominently: the European Union and few other countries); only one small part (chapter 7) refers to the situation in Cuba, huge potential for Cuba – has to be developed, concrete plan has to be developed (as of 2002)	http://www.occyt.cu/ (Pulicaciones/Informe Nanotecnología (PDF))
15	Cuba	Biotecnología Agropecuaria (Programa 003)	Programas Nacionales de Ciencia y Técnica (PNCT)	In Spanish; list of numerous projects in the field of biotechnology, mainly specific research projects from the area of agriculture, last projects finished in 2003 (not visible whether there are current projects within the programme)	http://www.redciencia.cu/geprop/resultados3_1.html

N°	Country	Name	Institution	Content	URL/document
16	European Parliament/ STOA	Technology Assessment on Converging Technologies – Literature Study and Vision	European Parliament, Scientific Technology Options Assessment panel. Study by viWTA and Rathenau Instituut.	Different approaches to convergence (USA – Europe), map several areas of convergence such as military, health, nanoscience, mention societal aspects such as creation of artificial intelligence superior to humans, enhancement, etc.	http://www.itas.fzk.de/eng/etag/document/doc1.pdf
17	European Union	Ethical Impacts of ICT Implants in the Human Body	European Group on Ethics in Science and New Technologies (EGE)	Paper on the scientific and technical background of different sorts of implants, on the legal background (including human dignity, human violability, the precautionary principle) and the ethical background (including value conflicts); p24ff.: list of knowledge gaps in relation to ICT implants – questions that could be on a research agenda as well!!!; last section of the paper contains the opinion of the EGE, also on ICT implants for non-medical purposes	http://ec.europa.eu/european_group_ethics/avis/index_en.htm
18	European Union	Envisioned Developments in Nanobiotechnology	Nano2Life (European Network of Excellence)	Expert survey; supposed to reveal perspectives on future developments in nanobiotechnology (NBT) and to contribute to a shared vision regarding the future of NBT research, taking into consideration barriers, ethics and public acceptance, commercialisation prospects and the state of basic and applied research; one possible application discussed: "theranostic nanomachines practically used inside the body"	http://www.ictaf.tau.ac.il/N2L_expert_survey_results.pdf
19	European Union	Research Projects	Nano2Life (European Network of Excellence)	12 strategic research programmes (SRPs), officially initiated in 10/2005, one of the application driven SRPs: Nano-bio-info-cogno applied to neurodegenerative medicine	http://www.nano2life.org/scripts/home/publigen/content/templates/show.asp?P=205&L=EN
20	European Union	Converging Technologies – Shaping the Future of European Societies	HLEG Foresighting the New Technology Wave	History, definition, implications, risks of CT as well as a specific European approach towards CT; new concept of CTEKS is introduced	http://ec.europa.eu/research/conferences/2004/ntw/pdf/final_report_en.pdf
21	European Union	State of the Art Reviews and Related Papers	HLEG Foresighting the New Technology Wave	Reviews and summaries of related documents from various aspects (as of June 2004), papers on each of the four areas of NBIC as well as on ethical, social and legal aspects, risks and state policies (see also SIG 1 -4)	http://ec.europa.eu/research/conferences/2004/ntw/pdf/soa_en.pdf
22	European Union	Converging Applications enabling the Information Society	Institute for Prospective Technology Studies (IPTS)	Patent and publications analysis, nanoelectronics as key application, mentions applications with cognitive component, NBIC quartet plus material science addressed, implants as example for CT	www.jrc.es

N°	Country	Name	Institution	Content	URL/document
23	European Union	What it means to be Human. Origins and Evolution of Human Higher Cognitive Faculties	HLEG New and Emerging Science and Technology	Convergence not only in NBIC fields, but in disciplines such as neurobiology, human behaviour science, history, philosophy of mind, modelling, etc.; supports a rather philosophical approach to the topic; strong focus on cognitive component	ftp://ftp.cordis.europa.eu/pub/nest/docs/whatitmeanstobehuman_b5_eur21795_en.pdf
24	European Union	Meeting of Minds (European Citizens´ Panel)	International group of 12 organisations, coordinated by the King Baudouin Foundation	overall objective: involve European citizens in assessing and publicly discussing the issue of brain science with relevant research, policy and ethics experts, various stakeholders as well as representatives of European decision-making organisations; as a result citizens' conclusions on the use of new technology, medicines and techniques are offered to policy-makers at the European, national and transnational level	http://www.meetingmindseurope.org/europe_default_site.aspx?SGREF=14
25	European Union	Scenarios for Europe in 2020	HLEG Foresighting the New Technology Wave	Four different scenarios (1. Competitive Europe, 2. Alternative Lifestyles, 3. Global Capitalism, 4. Regional Calm) for Europe in 2020 are described, compared and their implications are compared	http://ec.europa.eu/research/conferences/2004/ntw/pdf/scenarios_report_en.pdf
26	France	Les Nanotechnologies: Ethique et Prospective Industrielle	Conseil General des Mines/ Conseil General des Technologies de l´Information	Label of "meta-convergence" for combinations of at least two distinctive sectors; within converging technologies cognitive science and neurotechnologies play special role, applications e.g. in the field of nano-implants; important to determine needs of various stakeholders at an early stage; ongoing "normative assessment"	http://www.cgm.org/themes/deveco/develop/nanofinal.pdf
27	Germany		Federal Ministry of Education and Research (BMBF)	Information on funding for research and development of the nanotechnology sector	www.bmbf.de/de/nanotechnologie.php
28	Germany	Kompetenznetze Nanotechnologie	BMBF	Extended overview over 9 competence networks funded mainly by the BMBF, working since 1998, additional information on funding of nano projects and further governmental initiatives	http://www.kompetenznetze.de/navi/de/Innovationsfelder/nanotechnologie.html
29	Germany	Nationale Kontaktstelle Nanotechnologie	BMBF	Information on the 6th Framework Programme, organisation of workshops, support for applications etc.	www.vditz.de/nks
30	Germany	Fördermaßnahme "Nanobiotechnologie"	BMBF	Funding of projects in the field of nanobiotechnology since 2000, numerous projects and their websites can be found at this page; organisation of conferences on nanobiotechnology	www.nanobio.de
31	Germany	Rahmenprogramm IT-Forschung 2006	BMBF	Programme on information und communication technology, funding of research and technology transfer	http://www.it2006.de/

N°	Country	Name	Institution	Content	URL/document
32	Germany	Rahmenprogramm Biotechnologie	BMBF	Funding 2001 – 2005: 802,1 million Euro; strategic vision, fields of interest, research projects	http://www.biotechnologie.de/bio/generator/Redaktion/PDF/de/bmbf-broschuere-rahmenprogramm-biotechnologie,property=pdf.pdf
33	Germany	FUTUR-Leitvision "Das Denken verstehen"	BMBF	Short outline of the FUTUR lead vision "Das Denken verstehen" ("understand the thinking") including vision and aims, description of the field and its importance for economy and society, a scenario (for an unspecified year, however) and priorities for future research; no mention of CT either	http://www.bmbf.de/futur/de/dateien/LV_gesamt.pdf
34	Germany	Förderung "Innovative Hilfen"	BMBF	Funding of projects (probably from 2007 onwards) that work on the development of innovative, technical facilities that reconstitute, train, support or substitute functions and abilities such as mobility, sensory, cognitive, communicative and controllable vegetative abilities; taking into account legal and ethical aspects as well as questions related to safety etc.	http://www.gesundheitsforschung-bmbf.de/de/1340.php
35	Germany	Microsystems Framework Program 2004-2009	BMBF	Microsystems technology to bridge the gap between the nano and macro worlds, important for developments on nanotechnology and biotechnology; important area of application: life sciences (health, diagnosis, therapy, intelligent implants)	http://www.bmbf.de/de/5701.php
36	Germany	Nationales Netzwerk "Computational Neuroscience"	BMBF	Funding of projects that systematically study e.g. the neural basis of cognitive processes, the neural basis for attention and conscious perception, acoustic communication and speech; establishment of four Bernstein Centres for Computational Neuroscience	http://www.bernstein-zentren.de/de/77.php
37	Hong-Kong		ANF	No information on general policy, number of government projects on nanotechnology and biotechnology, focus on applications in textile development	http://www.asia-nano.org/CountryHome.php?CN=9
38	India		ANF	India National Nano Science and Technology Initiative (NSTI) launched 2001 by Department of Science and Technology (DST), 2005 new Center for Nanomaterials in Hyderabad, from 2002 to 2005: $ 23 million spent by DST; objectives of NSTI: support of research, infrastructure and education in the field of nanotechnology; 90 listed government projects, NSTI organised International Conference on Nanoscience and Technology (ICONSAT 2006) in March 2006	http://www.asia-nano.org/CountryHome.php?CN=1

N°	Country	Name	Institution	Content	URL/document
39	India	Tenth Five-Year Plan 2002-2007	Department of Science and Technology	CT as areas in which international cooperation is supported; nanotechnology identified as one field in which mission mode programmes should be set up, in the Tenth FY Plan CT named as field for new initiatives, belongs to the national priority areas, also focus and R&D, national centres of excellence are to be set up (see above); within the Tenth FY Plan programme on biotechnology and IT	http://planningcommission.nic.in/plans/planrel/fiveyr/10th/volume2/v2_ch10_1.pdf
40	India	India Science Budget 2006-2007		Increase in budget for the financial year 2006-07: 17%, gains for biotechnology, nanotechnology and pharmaceutical research, funding for biotechnology research increased by 25%; £22.5 million for national nanotechnology programme	
41	India		Department of Biotechnology	Strong focus on biotechnology, with funded projects in the fields of biodiversity conservation, medical biotechnology, stem cell research, bioinformatics, agricultural and marine biotechnology, seribiotechnology	http://www.globalwatchservice.com/Pages/ThreeColumns.aspx?PageID=608
42	Indonesia		ANF	Not much information available yet, National Nanotech program (Ministry for Research Sciences and Technology Development), in April 2005 first workshop on nanotechnology with c. 100 participants,	http://www.asia-nano.org/CountryHome.php?CN=28
43	International	White Paper on Nanotechnology Risk Governance	International Risk Governance Council	Nanotechnology and related short-term and medium-to-long term risk issues, number of areas of convergence mentioned such as artificial organs, nanoscale cell therapies, nanorobotics, brain-machine interfaces, nanoengineering in agriculture; role of SS&H to study concerns and visions, impact assessment	www.irgc.org/irgc/_b/contentFiles/IRGC_white_paper_2_PDF_final_version.pdf
44	Israel	The Israeli Science and Technology Foresight Study towards the 21st Century	The Interdisciplinary Center for Technology Analysis and Forecasting (ICTAF) at Tel-Aviv-University	Executive Summary of an expert delphi survey conducted 1999/2000; topics in 12 science/technology fields, identified as significant for the long-term future of Israel had to be evaluated by the experts; under the headline "life sciences and health care" allusions to CT	http://www.ictaf.tau.ac.il/scitech_foresight.pdf
45	Japan		ANF	No information on general policy, number of governmental projects, NEDO nanotechnology program, in December 2005 Nano and Society Initiative was launched	http://www.asia-nano.org/CountryHome.php?CN=3
46	Japan	Science and Technology Basic Plan	Government of Japan	Development, strategy and goals for RTD policy 2006-2010; more structural development of research sector than strategy as regards content	www.8.cao.go.jp/cstp/english/basic/index.html#third

N°	Country	Name	Institution	Content	URL/document
47	Japan	Eighth National Japanese Science and Technology Foresight 2035	Ministry of Education, Culture, Sports, Science and Technology; Science and Technology Council Japan	Mind-machine interfaces, artificial limbs with sensation, nanoscience for security of society, nanobiology and brain research as key areas of research (Japan leading according to expert assessments)	www.nistep.go.jp (NISTEP Report No.97)
48	Japan	Innovationsorientierte Technologiepolitik	Ministry of Economy, Trade and Industry, Japan et al.	All CT identified as key areas for R&D activities of the government, reference to "Third Term Science and Technology Basic Plan" of the "Council for Science and Technology Policy" from 2006 onwards	http://www.jetro.de/d/ub.pdf
49	Latin America	Nanociencias y Nanotecnologia en America Latina	Conference "Converging Technologies & Latin America", 29.08.-09.09.2005, Colombia	In Spanish; state-of-the-art on nanotechnologies in Latin America (Brazil, Mexico, Argentina, Costa Rica, Chile, Colombia, Cuba), including some figures and governmental programmes (conference presentation)	http://nbic.org.es/jornadasnew/downloads/Nano%20en%20LA1.pdf
50	Malaysia		ANF	Malaysian Nanotechnology Forum since 2005, no information on general policy, governmental programs: Malaysian Science and Technology Centre	http://asia-nano.org/CountryHome.php?CN=10
51	Mexico	División Materiales Avanzados para la Tecnología Moderna	Instituto Potosino de Investigación Cientifica y Tecnologica (IPICYT)	In Spanish; list of projects that are carried out within the division, most of these are related to nanotechnology; postgraduate and Ph.D. programmes in nanoscience and nanotechnology, also other divisions like molecular biology; no documents on visions, plans, budgets etc. could be found	http://www.ipicyt.edu.mx/Proyectos/ProyectosMateriales.htm
52	Multinational (but especially USA)		International Council on Nanotechnology (ICON)	Up-to-date news on nano research, links e.g. to governmental organisations with R&D budgets for nanotechnology, Environmental, Health and Safety database, participation of government agencies	www.icon.rice.edu
53	New Zealand		ANF	MacDiarmid Institute for Advanced Materials and Nanotechnology funded by Ministry of Education (also work on nanobiotechnology), main funding in the field also from Ministry of Research, Science and Technology; no national nanotechnology initiative yet, but to be launched in 2006; several governmental projects e.g. New Zealand Nanoscience Network	http://asia-nano.org/CountryHome.php?CN=4

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54	New Zealand	Statement of Intent 2006-2009	Ministry of Research, Science and Technology (MoRST)	Biotechnology and emerging sciences as key areas (strong focus on biotechnology – Biotechnology Strategy of the Government to encourage the growth of the sector); cooperation agreement with France in the field of biotechnology and nanoscience; within the Futurewatch programme: Navigator Network Project – scanning of developments in fields like biotechnology and nanoscience, roadmaps for high-level goals e.g. in CT (for nanotechnoloy and biotechnology finished by the beginning of 2007); nanotechnology, information and communication technology as sciences of the future, workshops for stem cell research (September 2006) and nanotechnology (June 2007) to be organised by MoRST	http://www.morst.govt.nz/Documents/publications/soi/MoRST-SoI-2006.pdf
55	New Zealand	Biotechnologies to 2025	MORST (within the Futurewatch foresight programme)	Overview over developments and possible applications of biotechnology and linked sciences like information technology and nanotechnology, mainly written for NZ government agencies to guide their work; convergence of sciences as meta-trend – is seen as one key factor for growth	http://www.morst.govt.nz/Documents/work/biotech/FutureWatch-Biotechnologies-to-2025.pdf
56	New Zealand	Navigator Network	MORST (within the Futurewatch foresight programme)	Set up to identify emerging science trends and innovations, particularly in biotechnology and nanotechnology, and to explore those that may raise significant economic, social or environmental issues for New Zealand, findings from the network will provide input for policy and operations across government, including guidance for science policy and research directions	www.navigatornetwork.net.nz
57	New Zealand		MORST	Government funding of biotechnology in 2004: (NZ???)$ 141,4 million	http://www.stats.govt.nz/NR/rdonlyres/1026BF02-EFE2-4349-8EF4-82983D8773F4/0/Alltables_web.pdf
58	Singapore		ANF	National University of Singapore Nanoscience and Nanotechnology Initiative (NUSNNI) officiated in 2004, no information on general policy, some government projects on applications in the field of nanotechnology	http://asia-nano.org/CountryHome.php?CN=7

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59	Singapore		Agency for Science, Technology and Research (A*STAR)	Science & Engineering Research Council (SERC) oversees initiatives of seven research institutes, e.g. Institute for Infocomm Research (information and communication technologies), Institute for Materials Research and Engineering (nanomaterials, nanoparticles, etc.), Singapore Institute of Manufacturing Technology (artificial intelligence applications, etc.), five biomedical science institutes: BioInformatics Institute (BII), the Bioprocessing Technology Institute (BTI), the Genome Institute of Singapore (GIS), the Institute of Molecular and Cell Biology (IMCB) and the Institute of Bioengineering & Nanotechnology (IBN), no mention of social or ethical implications of CT	www.a-star.edu.sg
60	Singapore	Science & Technology 2010	Ministry of Trade and Industry Singapore	CT identified as technologies that are needed by industry clusters and for industry growth, Biopolis and Fusionpolis (focal points for public and private research in the biomedical, physical, chemical etc. technologies) as cradle for knowledge convergence and CT	http://app.mti.gov.sg/data/article/2461/doc/S&T%20Plan%202010%20Report%20(Final%20as%20of%2010%20Mar%2006).pdf
61	South Africa	Annual Report 2004/05	Department of Science and Technology (DST)	Recent initiatives e.g. establishment of Biotechnology Regional Innovation Centres (BRICs), establishment of a programme to promote nanoscience and nanotechnology; working together with India and Brazil (IBSA Agreement) - key areas: nanotechnology, biotechnology	http://www.dst.gov.za/publications/annual_reports/annualreport-05.pdf
62	South Africa	South Africa´s National Research and Development Strategy (2002)	Government of the Republic of South Africa	Biotechnology mentioned as THE priority area of research and development; biotechnology and information technology as the two key technology platforms of the modern age; SA has a limited capacity to respond to new areas of technology that are regarded critical in the global economy; no further visions or areas of convergence	http://www.dst.gov.za/publications/reports/sa_nat_rd_strat.pdf
63	South Africa	A National Biotechnology Strategy for South Africa	Government of the Republic of South Africa	"most startling innovation will occur at the confluences of these three profound scientific currents (quantum mechanics, information technology and biotechnology" (p.4), no connection to neuroscience etc.	http://www.pub.ac.za/resources/docs/biotechstrategy_2002.pdf
64	South Africa	The National Nanotechnology Strategy	Department of Science and Technology (DST)	Nanotechnology (as biotechnology and information technology) will cause another technology-based divide between developed and developing countries; research and development together with biotechnology, information technology etc.; NBIC convergence mentioned (p.15); South Africa cannot afford to ignore the development in nanotechnology; funds (2006-2009): R 450 million	http://www.dst.gov.za/publications/reports/Nanotech.pdf

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65	South Korea		ANF	Korea National Nanotechnology Initiative launched in December 2000 by the National Science and Technology Council (NSTC); 10 Year Plan (2001-2010, 3 phases, to be modified in 2004) - total funding $1.485 million (983,5 million from government, 501,5 million from private), Law of Accelerating Research for Nanotechnology Development registered in 2002 (Operation Rules for the Development of Nanotechnology in 2003); government policy aims to fuse the 3 main fields Information Technology (IT), Biotechnology (BT) and Nanotechnology (NT) to upgrade cutting-edge technology and develop basic technology in the future; by 2010, Korea aims to narrow the gap between Korea and other leading countries such as USA and Japan in its Nanotech R & D level to almost zero; number of government programmes (including the construction of a nanotechnology database and cooperation between research, industry etc.), listed more than 150 key centres for nanotechnology; seemingly huge efforts in education in the field of nanotechnology as well	http://asia-nano.org/CountryHome.php?CN=11 Korea_NNI_2004.pdf
66	South Korea	Nanonet South Korea		Nanotech information site operated by the Centre of Nanotech Information (CNI) of the Korea Institute of Science and Technology Information (KISTI), part of national infrastructure establishment for supporting R&D activities in the nanotech sector	www.nanonet.info/engweb/
67	South Korea			Ca. 30 government research institutes; four main sectors: information technology, biotechnology, radiation technology and nanotechnology. A total investment of 18.4 trillion won was made between 1973 and 2004; a November 2005 Lux Report ranked Korea 4th globally in the nano area	http://www.globalwatchservice.com/Pages/ThreeColumns.aspx?PageID=148
68	South Korea	21st Century Frontier Science Programme	Ministry of Science and Technology (MOST)	10 year effort to develop core technologies in near to market areas by 2010; supports 23 projects in areas such as bioscience, nanotechnology, space technology, etc at a total cost of over US$3.5 billion, projects launched by September 2003 (see detailed list on the website)	http://www.globalwatchservice.com/Pages/ThreeColumns.aspx?PageID=372
69	South Korea		MOST	Government plans to invest 800 million won to advance biotechnology R&D in 2006, another 430 million won to support stem cell research in the next ten years; aims at Korea becoming one of the leading three countries in stem cell research by 2015	http://www.oti.globalwatchonline.com/online_pdfs/36604X.pdf
70	Spain (Europe & Latin America	Barcelona's Declaration on Converging Technologies	Converging Technologies Institute	Non-governmental platform for access, study, diffusion and development of the synergy between Nano-Technology, Bio-Technology, Information Technology and Cogno-Technology (NBIC) from academic to industrial level.	http://www.nbic.org.es/forumnew/downloads/Declaration.pdf

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71	Spain (Europe & Latin America	Tecnologías Convergentes NBIC. Situación y Perspectives 2005	Spanish National Research Council	Converging Technologies Institute founded (situated and on initiative of Universidad Autonoma, Barcelona); activities in and with Latin America	http://nbic.org.es/institute/downloads-eu/Summary-NBIC05.pdf
72	Taiwan		ANF	Taiwan National Science Council (NSC) approved National Science and Technology Program for Nanoscience and Nanotechnology (NSTP-Nano S&T) at its June 2002 board meeting; NSTP Nano S&T coordinates various government agencies with budgets dedicated to nanotechnology R&D; total budget: US$622 million over six years (2003–2008) – 74% from the Ministry of Economic Affairs (MOEA), 20% from NSC; various government programmes and projects	http://asia-nano.org/CountryHome.php?CN=8
73	Taiwan	National Science and Technology Program for Nanoscience and Nanotechnology	National Science Council (NSC)	Divided into Academic Excellence Programme, Industrialisation Nanotechnology Programme, Core Facilities Programme and Education Programme, detailed budget information for 2003-2008, huge number of projects within these four programmes	www.nano-taiwan.sinica.edu.tw
74	Thailand		ANF	National Nanotechnology Centre (NANOTEC) founded in 2003 (autonomous agency of the National Science and Technology Development Agency (NSTDA), Ministry of Science and Technology (MOST)), aim: funding and conducting research in the field of nanotechnology, some government programmes in this sector	http://asia-nano.org/CountryHome.php?CN=5
75	Thailand		National Nanotechnology Centre (NANOTEC)	Mission: establish National Nanotechnology Strategic Plan, provide R&D funding and support human resource development, promote public awareness and understanding	http://www.nanotec.or.th/nanotec/eng/index.php
76	Thailand		National Centre for Genetic Engineering and Biotechnology (BIOTEC)	Established 1983, in 2005 (1 October 2004 - 30 September 2005), operational budget of $18,48 million, which was sourced from government direct funding, revenue from providing services and commercial projects, as well as competitive grants from both national and international sources; $ 16.37 million devoted to R&D funds (for detailed budget information see website)	http://www.biotec.or.th/biotechnology-en/index.asp

N°	Country	Name	Institution	Content	URL/document
77	Thailand	National Biotechnology Policy Framework 2004-2009	BIOTEC	Six goals for biotechnology development: 1. emergence and development of new Bio-Business, 1. biotechnology promotes Thailand as kitchen of the world, 3. Thailand represents healthy community and health care centre of Asia, 4. utilizationisation of biotechnology to conserve the environment and to produce clean energy, 5. biotechnology as the key factor for self-sufficient economy, 6. development of qualified human resources; detailed description of and strategies within the goals laid out in the framework document	http://www2.biotec.or.th/document/W-Eng/FrameWork9-11-2548.pdf
78	The Netherlands	Nanotechnology in medical applications: possible risks for human health	Dutch Ministry of Health, Welfare and Sports	Nanotechnology and current medical applications as well as future applications are described; neuronal implants and brain-machine-interfaces are described, but it is stated, that "(a)lthough human studies demonstrate the feasibility of using brain signals to command and control external devices, many years of development and clinical testing will be required."	http://www.rivm.nl/bibliotheek/rapporten/265001002.pdf
79	United Kingdom	Cognition Enhancers	Office of Science and Technology (commissioner of the report)	Quite detailed description of current cognition enhancers (mainly on a chemical base) and their effects on the human brain and body, at the end outlook on future cognition enhancers and what their use would mean for society	http://www.foresight.gov.uk/Brain_Science_Addiction_and_Drugs/Reports_and_Publications/ScienceReviews/Cognition%20Enhancers.pdf
80	United Kingdom	Ethical Aspects of Developments in Neuroscience and Drug Addiction	Office of Science and Technology (commissioner of the report)	Focus on cognitive science and its relation the life sciences, physical sciences and real-world engineering, number of applications such as neuroprosthetics with their social and ethical aspects mentioned	http://www.foresight.gov.uk/Brain_Science_Addiction_and_Drugs/Reports_and_Publications/ScienceReviews/Ethics.pdf
81	USA		Converging Technologies Bar Association	Vision and Mission Statements, Honorary Members from National Science and Technology Council, U.S. Department of Commerce, N.Y. State Assembly	www.ctba.us
82	USA	Converging Technologies for Improving Human Performance	National Science Foundation	Roco/Bainbridge – especially Introduction can be seen as "policy document on CT	http://www.wtec.org/ConvergingTechnologies/Report/NBIC_report.pdf
83	USA	Mapping the Global Future	National Intelligence Council (NIC)	NBIC convergence mentioned e.g. pp. 16 and 38	http://www.foia.cia.gov/2020/2020.pdf
84	USA	The Global Technology Revolution (2006)	RAND Corporation	Convergence mentioned in key passages	**ISBN:** 0-8330-2949-5

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85	USA	Nanotechnology: Societal Implications – Maximizing Benefits for Humanity	National Science Foundation	Visionary aspects (e.g. comment by P. Bond), one of the Breakout Sessions on Converging Technologies (Theme 5)	http://www.nano.gov/nni_societal_implications.pdf
86	USA	National Science Foundation Strategic Plan 2003-2008	National Science Foundation	NSF priority areas: Information Technology Research, Nanoscale Science and Engineering; Federal Cross-cutting activities: National Nanotechnology Initiative (NNI); Center Programmes: Information Technology Centers, Nanotechnology Centers; Facilities: Nanofabrication (National Nanofabrication Users Network (NNUN) / National Nanotechnology Infrastructure Network (NNIN)), Network for Computational Nanotechnology (NCN)	http://www.nsf.gov/pubs/2004/nsf04201/FY2003-2008.pdf
87	USA		National Nanotechnology Initiative (NNI)	NanoNews, all sorts of up-to-date information on research, funding, activities, institutions involved, also on related science and technologies; useful links and databases under "Resources"	www.nano.gov
88	USA	Research and Development Funding in the President´s Budget 2007	National Nanotechnology Initiative (NNI)	2001, 2006 and 2007 figures for funding of the NNI by several governmental institutions; 2007: $ 1.2 billion	http://www.ostp.gov/html/budget/2007/1pger_NNI.pdf
89	USA	The National Nanotechnology Initiative – Strategic Plan	National Nanotechnology Initiative (NNI)	Vision, Goals and Plans of the NNI; Program Areas, Cross-cutting Activities, organisational structure	http://www.nano.gov/NNI_Strategic_Plan_2004.pdf
90	Vietnam		ANF	In 2003 formulating of National Strategy for S&T development until 2020 (nanotechnology as one of the high priority fields), Ministry of Science and Technology (MOST) launched infrastructure-building National Program on Nanoscience and Nanotechnology (2004-2006); budget $ 0.35 million; main research areas in the fields of physics and chemistry of new materials;	http://asia-nano.org/CountryHome.php?CN=12
91	Vietnam	National Program on Nanoscience and Nanotechnology	MOST	short description of the programme, funding of various technology programmes; current research and education activities on materials science including nanoscience and nanotechnology are mainly conducted by groups of physicists and chemists at the Institute of Materials Science (IMS), Institute of Physics (IP), Institute of Chemistry (IC) and at some universities	

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92	Vietnam		Ministry of Agriculture and Rural Development (MARD)	Focus of research in biotechnology on agriculture, forestry and fishery; state offers tax and credit incentives to both domestic and foreign investors in the bio-technology sector with the aim of creating a market for biotechnology; further governmental investment in biotechnology in the next 5 years to set up a strategy to develop human resources by 2015 and a master plan for bio-technology development by 2020; statements of different scientists or investors from the biotechnology sector; target of the government: increase the contribution of biotechnology in agricultural production development by 50 per cent during the period 2006-2010; total capital for biotechnology development during the period of 2006-25 will be $63.2 million, mainly for research and trial production; so far 1,500 bachelors of biotechnology, 400 masters and 90 doctorates; 10 bio-technology laboratories, six national laboratories and 44 technological science and biotechnology institutions	http://www.vnast.gov.vn/index.asp?m=SK&bydate=&lan=1&page=1&layID=529

List of Abbreviations

AI	Artificial Intelligence
CT	Converging Technologies
CTEKS	Converging Technologies for the European Knowledge Society
DOC	Department of Commerce (U.S.A.)
EC	European Commission
EPTA	European Parliamentary Technology Assessment
HLEG	High Level Expert Group
ICT	Information and Communication Technologies
NBIC	Nanotechnology, Biotechnology, Information Technology and Cognitive Science
NIC	National Intelligence Council (U.S.A.)
NNI	National Nanotechnology Initiative (U.S.A.)
NSF	National Science Foundation (U.S.A.)
NT	Nanotechnology
PCBE	President's Council on Bioethics (U.S.A.)
R&D	Research and Development
RFID	Radio Frequency Identification
RTD	Research and Technology Development
S&T	Science and Technology
SSH	Social Sciences and Humanities
STOA	Scientific Technology Options Assessment (European Parliament)

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