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Converging Technologies Enabling the Information Society

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Purpose

The purpose of the project was to analyse the scientific strengths of the EU compared to the USA and Japan in the field of 'converging technologies' with the aim of informing and influencing the European research agenda.

Does Convergence Really Exist?

The US **NBIC initiative** on nano-, bio-, info- and cogno- science domains as well as the European High Level Expert Group '**Converging Technologies for a European Knowledge Society**' have identified the convergence of technologies as an important technological development that will have a significant impact on all aspects of human life.

Both reports are based on **visions** of the future rather than on a solid evidence base. Indeed the question is often posed whether convergence really is taking place or not. It is still an open issue whether a convergence of Cognitive Science with domains such as Information and Communication Technologies is actually taking place. However many experts agree on the possibility of radical breakthroughs occurring should this be the case.

Our study aimed at presenting an analysis of relevant strengths and weaknesses of the EU in the whole area of converging technologies. It took ICT as a core technology and examined the convergence of ICT with Cognitive Science, Biotechnology, Nano-technology and the Material Sciences. It also set out to identify related prospective areas of research for the European research agenda, in particular in the area of converging technologies on the boundary between cognitive science and ICT.

Statistical Findings

The first main task was a **bibliometric analysis** of the strengths and weaknesses of the EU compared to the USA and Japan. For the EU a breakdown to the EU-25 countries has been provided. The bibliometric analysis was based on sepa-

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rate sets of keywords identified for each of the following disciplines:

- ICT
- Cognitive Science
- Biotechnology
- Nanotechnology and
- New materials.

This was used to distil relevant publications from the Thomson scientific database. Publications in convergent clusters such as ICT + Cognitive Science or ICT + Biotechnology, to name but a few were matched to show the overlap and estimate the level of convergence between fields. Convergence measured in this way was analysed in terms of the:

- Level of scientific **activity** by estimating the size of the cluster of publications as well as the
- **Impact** based on figures for citation normalized each respective discipline.

A study of trends on the basis of **Vision Documents**, **Foresight Reports** and **Technology Roadmaps** complemented the bibliometric analysis.

For the convergent cluster Cognitive Science + ICT the bibliometric analysis was supplemented with a **patent analysis.**

National research programmes in the EU, the USA and Japan were **inventoried** to present an overview of national activities within the convergent clusters for each of these countries - the EU, the USA and Japan.

Gross figures regarding the **distribution of centers of excellence** within the EU-25 were presented on the basis of scientific activity and impact figures.

Possible Impact on the Future European Research Agenda

The impact of the phenomenon of technology convergence in the case of the convergent cluster of Cognitive Science + ICT was explored in detail in a dedicated **workshop** organized with the intention of building a vision for a European research agenda based on convergence.

Violating Boundaries between The Human Mind and Body

Regarding socio-economic and cultural trends the study concluded that in many converging areas study it is possible to perceive the introduction of tools and devices which are on the one hand small or very small and on the other hand cross boundaries between the human body and the human mind. For example the use of artificial neural networks for various kinds of daily ‘routines’ in which selection and identification processes are used is increasingly common. Optimistic voices refer to a ‘new renaissance’ being at hand. More critical observers express concern about the implications of these new technologies and applications. In any case the socio-economic impact of this convergent cluster is believed to be potentially very high. It is expected to provide benefits for emerging as well as growing markets, not only in the health care sector but also in areas of application such as robotics in the broad sense of the term.

Cognitive Neuroscience at the Forefront

Within the convergent cluster of Cognitive Science + ICT one can perceive the emergence of intelligent devices that mimic cognitive processes of the brain and the mind in:

- Sensing,
- Perceiving,
- Memorizing,
- Controlling,
- Acting and
- Learning.

Cognitive neuroscience supported by brain imaging techniques is at the forefront of developments in cognitive science and has strong links with developments in neurobiology.

Brain-machine interfaces coupled with robotics provide opportunities to create systems that can operate under circumstances that are difficult, dangerous or simply impossible for human beings:

- Disaster zones such as earthquake sites,
- Deep sea or
- Outer space.

Cognitive vision systems that enable intelligent monitoring processes, speech and language processing technologies also feature amongst the technological trends within cognitive science and ICT.

Within Biotechnology + ICT convergent cluster developments were identified that brought together bio-informatics and computational biology to provide technologies for:

- Non-invasive monitoring and diagnosis based on biosensors and biomarkers,
- Biological computing and the
- Development of virtual environments to manipulate genetic properties of organisms.

Within the Nanotechnology + ICT cluster developments were identified within;

- Nano-electronics for nano-scale medical diagnosis and treatment, for cleaner, safer and more comfortable transport, and for anti-terrorism and security applications,

- Nano-photonics for fiber-optic communication, optical data storage, quantum dots, simulation and modeling techniques as well as image processing and pattern recognition.

Finally, new trends within the Material Sciences + ICT convergent cluster show overlaps with other clusters. This is especially true in the terms of the attention given to simulation and modeling, image processing, pattern recognition and neural networks. The overlap with Nanotechnology + ICT is particular strong in the area of electronics.

Applications in Medicine and Robotics

These trends provide opportunities in a variety of fields including:

- Diagnosis and treatment in the field of medicine on the basis of markers and sensors,
- Brain imaging, deep neural stimulation and robotic surgery,
- The application of robotics to the exploration of outer space and deep sea as well as personal care and industrial processes,
- New modes of computing based on biological computing and nano-computing paradigms,
- New and advanced simulation and modeling techniques,
- Pattern recognition techniques based on the application of artificial neural networks in a great range of potential application domains.

The many visionary and roadmap documents that we studied, formulated challenges that remain to be overcome. These included challenges as ambitious and as inspiring as fully mimicking the human brain with the use of artificial neural network to replace the cognitive vision system. It has to be noted that many of the formulated technologically advanced challenges may not be realized for decades to come.

Europe's Comparative Advantage

Strong Input but Weak Output

Convergence is visible in all four clusters, though for now Material Science + ICT exhibits only modest convergence. Scientific activity in Europe as measured by the number of publications is overall higher than that in USA and Japan in all of the convergent clusters, except in the case of Biotech + ICT where USA has a slightly lead.

In terms if scientific impact as measured by the normalized citation score, the USA however leads in all clusters with the possible exception of Nanotechnology + ICT. In this case however reliable figures are hard to come by.

With regard to the centers of excellence, this study showed that the USA has a marked lead over Europe in terms of 'middle average' centers of excellence. In terms of high end centers of excellence however the USA and Europe are more balanced. This is especially the case for the Cognitive Science + ICT cluster and slightly less balance in the case of Biotechnology + ICT and Material Science + ICT. The figures for Nanotechnology + ICT are hard to interpret in a reliable way.

The overall conclusion is that Europe performing well in terms of input (scientific activity) but lags the USA in terms of output (scientific impact). The structural conditions reflected in the status and distribution of centers of excellence show that Europe is rather closely aligned to that in USA for the upper segment but is losing ground in the middle segment.

The position of Europe compared to Japan is quite good overall. Japan outperforms Europe only with respect to the impact score on Cognitive Science + ICT.

National Promotion of Convergent Clusters

Europe shows a relatively balanced set of research activities on a national scale and on a European scale regarding the convergent clusters. However not all European countries contribute equally well to developments within each cluster. In particular the contribution of new European member states lags that of the rest of Europe.

The new member states focus more on participation in European research programmes rather than developing their own activities. Most countries have adopted specific strategies to promote participation in research activities focused on convergent clusters.

US Ability to Commercialize Knowledge

The study showed that continued and intensified attention to the role of convergent clusters is justified. One can recognize the European knowledge paradox within these convergent clusters: Europe has a good and solid reputation regarding knowledge creation but lags the USA in terms of knowledge commercialization.

Major issues identified during the course of the study as being important for improving the European position are:

- **The role of Knowledge Centers:** To help actors to concentrate on multidisciplinary research, to balance long term visionary ambitions with realistic mid-term goals, to

adopt the European innovation model in which societal implications are part of the research strategy.

- **The role of Industry:** Moving from a technology push towards a market demand model, involve SMEs in research and application development, to develop high-risk/high-gain activities alongside more secure, robust and versatile applications.
- **The Need for Communication:** In particular there is a need for communication with the public at large concerning ethical issues that accompany convergent technologies. There is a need to appraise the socio-economic, ethical and legal dimensions of converging technologies, to involve those affected most in a dialogue on converging technologies and to develop an **ELSA** test-bed to address the spectrum of Ethical, Legal and Social aspects of these domains.

New Opportunities for SMEs

Critical factors identified in the study relate to shaping scientific challenges and bridging the gap between grand scale scientific research programmes and application oriented activities. Part of the research within converging technologies is bound to big programmes or requires huge investment in equipment and instruments. The development of applications however is often feasible for innovative SMEs despite their relatively modest resources. The successful combination of and co-operation between SMEs and research institutes is seen as a critical success factor in harnessing convergent technologies for growth and prosperity in the future.

Discussing the Social Implications

The awareness and attitude of the public at large is another critical factor. Important social, economic and ethical considerations arise in the development of convergent technologies.

To ensure a broad societal uptake of new products and services for example in areas such as health care, a broad debate involving various stakeholder groups is seen as a critical precondition for the successful dissemination and uptake of related technological innovations.

Finally the study notes that actors do not consider it necessary to establish a central large-scale research institute to coordinate all research activities in convergent technology domains. Support for mid-sized institutes requires a more decentralized approach in which not only elite research institutes are financed but a broader group of actors necessary to support the successful development of convergent technologies across all countries of Europe and all sectors of the economy.

European Discourse on Converging Technologies

The findings of the TNO study is being used by IPTS to drawing up its own conclusions and formulate the final project report.

Disseminating these findings to a broad audience is one of the ways it will contribute to the European discourse on converging technologies.

The IPTS will use these findings to influence the European research agenda in the field of converging technologies in line with the above formulated opportunities and their broader implications for society and the economy.

Sources and References

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