

CONVERGING TECHNOLOGIES FOR IMPROVING HUMAN PERFORMANCE

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In the early decades of the 21st century, concentrated efforts can unify science based on the unity of nature, thereby advancing the combination of nanotechnology, biotechnology, information technology, and new technologies based in cognitive science. With proper attention to ethical issues and societal needs, converging technologies could achieve a tremendous improvement in human abilities, societal outcomes, the nation's productivity, and the quality of life. This is a broad, crosscutting, emerging and timely opportunity of interest to individuals, society and humanity in the long term.

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 [1]; (b) biotechnology and biomedicine [2], including genetic engineering [3]; (c) information technology, including advanced computing and communications; (d) cognitive science, including cognitive neuroscience.

Timely and Broad Opportunity:

Convergence of diverse technologies is based on *material unity at the nanoscale and on technology integration from that scale*. The building blocks of matter that are fundamental to all sciences originate at the nanoscale. Revolutionary advances at the interfaces between previously separate fields of science and

technology are ready to create key *transforming tools* for NBIC technologies. Developments in systems approaches, mathematics, and computation in conjunction with NBIC allow us for the first time to understand the natural world, human society, and scientific research as *closely coupled complex, hierarchical systems*. At this moment in the evolution of technical achievement, *improvement of human performance through integration of technologies* becomes possible. Examples of payoffs may include improving work efficiency and learning, enhancing individual sensory and cognitive capabilities, revolutionary changes in healthcare, improving both individual and group creativity, highly effective communication techniques including brain-to-brain interaction, perfecting human-machine interfaces including neuromorphic engineering, sustainable and "intelligent" environments including neuro-ergonomics, enhancing human capabilities for defense purposes, reaching sustainable development using NBIC tools, and ameliorating the physical and cognitive decline that is common to the aging mind. The government envisions important breakthroughs in NBIC-related areas in the next 10 to 20 years. Fundamental research requires about the same interval to yield significant applications. Now is the time for everyone to anticipate the research issues and plan an R&D

approach that would yield optimal results.

Key Issues: What are the implications of unifying sciences and converging technologies? How will scientific knowledge and current technologies evolve and what emerging developments are envisioned? What visionary ideas can guide research to accomplish broad benefits for humanity? What are the most pressing research and education issues? How can we develop a transforming national strategy to enhance individual capabilities and overall societal outcomes? What should be done to achieve the best results over the next 10 to 20 years?

This paper underlines several broad, long-term implications of converging technologies in key areas of human activity, including working, learning, aging, group interaction, and human evolution. If we make the correct decisions and investments today, many of these visions could be addressed within 20 years' time. Moving forward simultaneously along many of these paths could achieve an age of innovation and prosperity that would be a turning point in the evolution of human society. The right of each individual to use new knowledge and technologies in order to achieve personal goals, as well as the right to privacy and choice, are at the core of the envisioned developments. This paper is based on exploratory research already initiated in major research organizations and on the opinions of leading scientists and engineers using research data.

Strategies for Transformation: It is essential to prepare key organizations and societal activities for the changes made possible by converging

technologies. Activities that accelerate convergence to improve human performance must be enhanced, including focused research and development, increased technological synergy from the nanoscale, developing of interfaces among sciences and technologies, and a holistic approach to monitor the resultant societal evolution. The aim is to offer individuals and groups an increased range of attractive choices while preserving such fundamental values as privacy, safety, and moral responsibility.

Education and training at all levels should use converging science and technology and prepare people to take advantage of them. We must experiment with innovative ideas to motivate multidisciplinary research and development, while finding ways to address ethical, legal, and moral concerns. In many application areas, such as medical technology and healthcare, it is necessary to accelerate advances that would take advantage of converging technologies.

Towards Unifying Science and Converging Technologies: The evolution of a hierarchical architecture for integrating natural and human sciences across many scales, dimensions, and data modalities will be required. Half a millennium ago, Renaissance leaders were masters of several fields simultaneously. Today, however, specialization has splintered the arts and engineering, and no one can master more than a tiny fragment of human creativity. The sciences have reached a watershed at which they must unify if they are to continue to advance rapidly. Convergence of the sciences can initiate a new renaissance, embodying a holistic view of technology based on

transformative tools, the mathematics of complex systems, and unified cause-and-effect understanding of the physical world from the nanoscale to the planetary scale.

Major Themes: Scientific leaders and policy makers across a range of fields prepared written statements for a December 2001 workshop, evaluating the potential impact of NBIC technologies on improving human capabilities at the microscopic, individual, group, and societal levels. During the workshop, participants examined the vast potential in six different areas of relevance:

Overall potential of converging technologies: Representatives of government agencies and the private sector set forth the mission to explore the potential of converging technologies and research needs to improve human performance, as well as the overall potential for revolutionary changes in the economy and society. They identified the synergistic development of nano-, bio-, information- and cognition-based technologies as an outstanding opportunity at the interface and frontier of sciences and engineering in the following decades, and proposed new visions of what is possible to achieve.

Expanding human cognition and communication: Highest priority was given to “The Human Cognome Project,” a multidisciplinary effort to understand the structure, functions, and potential enhancement of the human mind. Other priority areas are: personal sensory device interfaces; enriched community through humanized technology; learning how to learn; and enhanced tools for creativity.

Improving human health and physical capabilities: Six priority areas have been identified: nano-bio processors for research and development of treatments, including those resulting from bioinformatics, genomics and proteomics; nanotechnology-based implants and regenerative biosystems as replacements for human organs or for monitoring of physiological well-being; nanoscale machines and comparable unobtrusive tools for medical intervention; multi-modality platforms for increasing sensorial capabilities, particularly for visual and hearing impaired people; brain-to-brain and brain-to-machine interfaces; and virtual environments for training, design, and forms of work unlimited by distance or the physical scale on which it is performed.

Enhancing group and societal outcomes: An NBIC system called “The Communicator” would 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. Other areas of focus are in enhancing group creativity and productivity, cognitive engineering and developments related to networked society. A key priority will be revolutionary new products and services based on the integration of the four technologies from the nanoscale.

National security: Given the radically changing nature of conflict in this new century, seven opportunities to strengthen national defense offered by technological convergence deserve high priority: data linkage and threat

anticipation; uninhabited combat vehicles; war fighter education and training; responses to chemical, biological, radiological and explosive threats; war fighter systems; non-drug treatments to enhance human performance; and applications of human-machine interfaces.

Unifying science and education: To meet the coming challenges, scientific education needs radical transformation from elementary school through postgraduate training. Convergence of previously separate scientific disciplines and fields of engineering cannot take place without the emergence of new kinds of people who understand multiple fields in depth and can intelligently work to integrate them. New curricula, new concepts to provide intellectual coherence, and new forms of educational institutions will be necessary. Beyond the 20-year time span, or outside the current boundaries of high technology, convergence can have significant impacts in such areas as: work efficiency, the human body and mind throughout the life cycle, communication and education, mental health, aeronautics and space flight, food and farming, sustainable and intelligent environments, self-presentation and fashion, and transformation of civilization.

Recommendations

The recommendations of this paper are far-reaching and fundamental, urging the transformation of science, engineering and technology at their very roots. The new developments will be revolutionary and must be governed by respect for human welfare and dignity. Building on the suggestions developed in the five topical groups, and the ideas in the more

than 50 individual contributions, the federal NBIC workshop recommended a **national R&D priority area on converging technologies focused on enhancing human performance**. The opportunity is broad, enduring, and of general interest.

a) **Individuals.** Scientists and engineers at every career level should gain skills in at least one NBIC area and in neighboring disciplines, collaborate with colleagues in other fields, and take risks in launching innovative projects that could advance NBIC.

b) **Academe.** Educational institutions at all levels should undertake major curricular and organizational reforms to restructure the teaching and research of science and engineering so that previously separate disciplines can converge around common principles to train the technical labor force for the future.

c) **Private Sector.** Manufacturing, biotechnology, information and medical service corporations will need to develop partnerships of unparalleled scope to exploit the tremendous opportunities from technological convergence, investing in production facilities based on entirely new principles, materials, devices and systems, with increased emphasis on human development.

d) **Government.** The Federal Government should establish a national research and development priority area on converging technologies focused on enhancing human performance. Government organizations at all levels should provide leadership in creating the NBIC infrastructure and coordinating the work of other institutions, and must accelerate convergence by supporting new multidisciplinary scientific efforts while sustaining the traditional disciplines that are essential for success.

Ethical, legal, moral, economic, environmental, workforce development, and other societal implications must be addressed from the beginning, involving leading NBIC scientists and engineers, social scientists and a broad coalition of professional and civic organizations. Research on societal implications must be funded, and the risk of potential undesirable secondary effects must be monitored by a government organization in order to anticipate and take corrective action. Tools should be developed to anticipate scenarios for future technology development and applications.

e) **Professional Societies.** The scientific and engineering communities should create new means of interdisciplinary training and communication, reduce the barriers that inhibit individuals from working across disciplines, aggressively highlight opportunities for convergence in their conferences, develop links to a variety of other technical and medical organizations, and address ethical issues related to technological developments.

f) **Other Organizations.** Non-governmental organizations that represent potential user groups should contribute to the design and testing of convergent technologies, in order to maximize the benefits for their diverse constituencies. Private research foundations should invest in NBIC research in those areas that are consistent with their unique missions. The press should increase high-quality coverage of science and technology, on the basis of the new convergent paradigm, to inform citizens so they can participate wisely in debates about ethical issues such as unexpected effects on inequality, policies concerning diversity, and the implications of transforming human capabilities. A vast opportunity is

created by the convergence of sciences and technologies starting with integration from the nanoscale and having immense individual, societal and historical implications for human development. The outcomes of these researches recommend *a national research and development priority area on converging technologies focused on enhancing human performance*. This would be a suitable framework for a long-term, coherent strategy in research and education. Science and technology will increasingly dominate the world, as population, resource exploitation, and potential social conflict grow. Therefore, the success of this convergent technologies priority area is essential to the future of humanity.

References:

- [1] <http://www.wtec.org>
- [2] <http://www.betterhumans.com>
- [3] <http://research.mednet.ucla.edu/pmts>

General References:

- <http://www.ornl.gov/hgmis/faq/compngen.html>
- <http://www.wired.com>
- <http://www.transhumanism.org>