Converging Technologies (NBIC)

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ABSTRACT

The convergence of nanotechnology, biotechnology, information technology, and cognitive science can greatly improve human performance over the next ten to twenty years. The chief areas of application include: expanding human cognition and communication, improving human health and physical capabilities, enhancing group and societal outcomes, strengthening national security, and unifying science and education. Convergence will be based on the material unity of nature at the nanoscale, technology integration from the nanoscale, key transforming tools, the concept of reality as closely coupled hierarchical complex systems, and the goal to improve human performance.

Keywords: nanotechnology, biotechnology, information technology, cognitive science, science policy.

1 TECHNOLOGICAL CONVERGENCE

A study sponsored by the National Science Foundation and the Department of Commerce has examined the progress that could be achieved by combining four "NBIC" fields: Nanotechnology, Biotechnology, Information technology, and Cognitive science [1]. Nearly a hundred contributors conclude that this technological convergence could vastly increase the scope and effectiveness of human activity, thereby improving human performance and well-being.

Convergence of diverse technologies will be 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. That is the scale at which complex inorganic materials take on the characteristic mechanical, electrical, and chemical properties they exhibit at larger scales. The nanoscale is where the fundamental structures of life arise inside biological cells, including the DNA molecule itself. Soon, the elementary electronic components that are the basis of information technology will be constructed at the nanoscale. Understanding the function of the human brain requires research on nanoscale phenomena at receptor sites on neurons, and much brain research will be facilitated by nanoscale components in microsensor arrays and comparable scientific tools. Thus, nanotechnology will play an essential role in achieving progress in each of the four fields and in unifying them all.

The challenge of integrating fields, disciplines, and subdisciplines will stimulate both theoretical creativity and empirical discovery. Measurement techniques developed in one area will accelerate progress elsewhere, as will innovative tools of all kinds, from nanoscale sensors to cyberinfrastructure. Investment by government and industry cannot be entirely justified by the anticipated intellectual benefits, however. The great promise of technological convergence must attract the interest of policy makers and ordinary citizens through the practical applications it can achieve. Converging technologies will make people healthier, stronger, smarter, more creative and more secure.

2 APPLICATION AREAS

Five workshop groups of experts in appropriate fields considered the research challenges associated with highly valuable applications that could enhance human performance along five different dimensions. Their conclusions follow.

2.1 Expanding Human Cognition and Communication

The human mind can be significantly enhanced through technologically augmented cognition, perception, and communication. Central to this vital work will be a multidisciplinary effort to understand the structure and function of the mind, which means research not only on the brain, but also on the ambient socio-cultural milieu, which both shapes and is shaped by individual thought and behavior. Specific application areas include personal sensory device interfaces and enhanced tools for creativity. A fundamental principle is putting people fully in command of their technology, which will require socio-technical design to humanize computers, robots, and information systems.

2.2 Improving Human Health and Physical Capabilities

In the absence of new approaches, medical progress is widely expected to slow markedly during the coming century. To increase longevity and well-being throughout the life span, we will need to innovate in fresh areas. Nano-bio sensors and processors can contribute greatly to research and to development of treatments, including those resulting from bioinformatics, genomics and proteomics. Implants based on nanotechnology and regenerative biosystems can replace human organs, and nanoscale machines can unobtrusively accomplish needed medical intervention. Advances in cognitive science will provide insights to help people avoid unhealthy lifestyles, and information technology can create virtual environment tools both for training medical professionals and for enlisting patients as effective partners in their own cure.

2.3 Enhancing Group and Societal Outcomes

Peace and economic progress require vastly improved cooperation in schools, corporations, government agencies, communities, nations, and across the globe. However, communication is too often blocked by substantial barriers caused by physical disabilities, language differences, geographic distances, and variations in knowledge. These barriers can be overcome through the convergence of cognitive and information science to build a ubiquitous, universal web of knowledge, automatically translated into the language and presentation media desired by diverse users. Nano-enabled microscale data devices will identify every product and place, and individuals will merge their personal databases as they choose which groups and interaction networks to join. Group productivity tools will radically enhance the ability of people to imagine and create revolutionary new products and services based on the integration of the four technologies from the nanoscale.

2.4 National Security

The rapidly changing nature of international conflict demands radical innovation in defense technology, strategic thinking, and the capabilities of professional war fighters. Both mental and physical enhancement of human abilities can achieve significant gains in the performance of individual military personnel, and new battlefield communication systems employing data linkage and threat anticipation algorithms will strengthen armies and fleets. The combination of nanotechnology and information technology will produce sensor nets capable of instantly detecting chemical, biological, radiological and explosive threats and able to direct immediate and effective countermeasures. Uninhabited combat vehicles and human-machine interfaces will enhance both attack capabilities and survivability. As was true historically in the development of computer technology, developments initially achieved at high cost for defense purposes will be transferred over time to low cost civilian applications, for the general benefit of society.

2.5 Unifying Science and Education

To meet the coming challenges, scientific education needs radical transformation from elementary school through post-graduate training. Convergence of previously separate scientific disciplines and fields of engineering cannot tak place without the emergence of new kinds of people wh understand multiple fields in depth and can intelligentl work to integrate them. New curricula, new concepts t provide intellectual coherence, and new forms of educationa institutions will be necessary.

3 TRANSFORMING TOOLS

Revolutionary advances at the interfaces betwee previously separate fields of science and technology ar ready to create key *transforming tools* for NBI technologies. These include scientific instrument analytical methodologies, radically new materials, and dat sharing systems. The innovative momentum in thes interdisciplinary areas must not be lost but harnessed t accelerate unification of the disciplines. Progress ca become self-catalyzing if we press forward aggressively; bu if we hesitate, the barriers to progress may crystallize an become harder to surmount.

Developments in systems approaches, mathematics, an computation in conjunction with NBIC allow us for the firs time to understand the natural world, human society, an scientific research as *closely coupled complex, hierarchica systems*. At this moment in the evolution of technica achievement, *improvement of human performance throug integration of technologies* becomes possible. Applied bot to particular research problems and to the overa organization of the research enterprise, the complex system approach provides holistic awareness of opportunities fo integration, in order to obtain maximum synergy along th main directions of progress.

One reason sciences have not merged in the past is tha their subject matter is so intellectually complex. It will ofte be possible to rearrange and connect scientific findings based on principles from cognitive science and informatio theory, so that scientists from a wider range of fields ca comprehend and apply them within their own work Researchers and theorists must look for promising areas i which concepts developed in one science can be translate effectively for use in another. For example, computationa principles developed in natural language processing can b applied to work in genomics and proteomics, and principle from evolutionary biology can be applied to the study o human culture.

4 HUMAN PERFORMANCE

The aim of NBIC convergence is to offer individual and groups an increased range of attractive choices whil preserving such fundamental values as privacy, safety, an moral responsibility. It can give us the means to dea successfully with the often unexpected challenges of th modern world by substantially enhancing human mental physical, and social abilities. Everyone wants to be healthie and to live longer. Everyone wants prosperity, security, an creativity. By improving the performance of all humans technological convergence can help us all achieve these goals together.

However, as the challenge of national security illustrates, human performance is often competitive in nature. What may matter is the relative military power of two contending armies or the relative economic power of two competing corporations, not their absolute power. At the present time, technologically advanced nations like the United States, Japan and the countries of western Europe maintain their position in the world order in significant part through their rate of technical progress. Other nations, often called developing countries, provide raw materials and relatively low-tech manufactured commodities in exchange for the cutting edge products and services that the advanced nations alone can offer. If a rich nation were to cease moving forward technologically, a much poorer nation could fairly quickly match the quality of its exports at lower cost. This would be fine for businesses in the poorer nation, but the rich nation could see its standard of living drop rapidly toward the world average. The result could be not merely disappointment and frustration, but social chaos.

For example, a significant fraction of the prosperity of the United States depends upon the continuing superiority of its information technology, including the components manufactured by its semiconductor industry. In 1965, co-founder of the Intel corporation, Gordon Moore, observed that the density of transistors on the most advanced microchip doubles about every 18 months. Called "Moore's Law," this observation has proven to be true ever since, but the transistors on conventional chips are nearing physical size limits that could repeal the "Law" within a decade. If that happens, the US semiconductor industry may evaporate, as other nations catch up to the current US technical lead and produce comparable chips at lower cost. Thus, there has been great interest recently, in both American government and industry, concerning nanotechnology approaches that could extend the life of Moore's Law another decade or two, notably molecular logic gates and carbon nanotube transistors [2].

These radically new approaches require development of an entire complex of fresh technologies and supporting industries, so the cost of shifting over to them may be huge. Only a host of new applications could justify the massive investments, by both government and industry, that will be required. Already, there is talk in the computer industry of "performance overhang," the possibility that technical capabilities have already outstripped the needs of desirable applications. For example, the latest models of home computers are just finally able to handle the speed and memory demands of high-quality video, but no more demanding application is currently on the horizon that would require a new generation of hardware.

During the twentieth century, several major technologies essentially reached maturity or ran into social, political, or economic barriers to progress. Aircraft and automobiles have changed little in recent years. The introduction of high definition television has been painfully slow, and one would predict that consumers will be content to stick with the next generation of television sets for many years. Spaceflight technology has apparently stalled at about the technical lev of the 1970s, and nuclear technology has either halted c been blocked by political opposition. In medicine, the rat of introduction of new drugs has slowed, and the grea potential of genetic engineering is threatened by increasin popular hostility. In short, technological civilization face the very real danger of stasis or decline unless something ca rejuvenate progress.

The Converging Technologies report suggests that th unification of nanotechnology, biotechnology, informatio technology, and cognitive science could launch a Ne Renaissance. Five centuries ago, the Renaissance infused a fields of creative endeavor with the same holistic spirit an many shared intellectual principles. It is time to rekindle th spirit of the Renaissance, returning to the holistic perspectiv on a higher level, with a new set of principles. Then, a ver few individuals could span multiple fields of productivit and become "Renaissance men." Today, technologica convergence holds out the very real hope that all people o the planet could become "Renaissance people," throug enhanced abilities, tools, materials, knowledge, and human institutions.

5 SOCIAL AND ETHICAL PRINCIPLES

A September 2000 conference on the societa implications of nanoscience and nanotechnology, organize by the National Science Foundation, concluded that it i essential to involve the social sciences early in th development of these fields [3]. For example, it is importar to understand the evolving socio-cultural context in whic research at the nanoscale is funded, the societal needs tha nanotechnology may satisfy, and the popular misconception that nanoscience education will have to overcome. A simila sensitivity to social and ethical principles must be th hallmark of converging technologies.

Enhancement of human performance should serve th legitimate hopes of human beings, who in return will suppo the scientific and engineering work required to achiev technological convergence and the unification of science.

REFERENCES

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