Chapter 2
Convergence Platforms: Human-Scale Convergence and the Quality of Life

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The greatest benefits to human knowledge and well-being will come from convergence of all fields of science, with nanotechnology, biotechnology, information technology, and cognitive science (NBIC) being the core foundational quartet of fields drawing all the others together. But at particular points in time, one field may be having disproportionate impacts on society, even as the others are gathering strength through fundamental scientific research. The NBIC field experiencing the most rapid application changes and having the most potential for continued change in its direct effects on human lives in the coming decade appears to be *information*

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technology, although nanoscience, biology, and cognitive science are also progressing rapidly and will contribute through their convergence. It is entirely possible that fundamental scientific advance is moving more rapidly at the nanoscale, whether reflected in biotechnology or nanotechnology, and information technology is merely going through a stage in its application to human problems where the impacts are both huge and highly visible.

Not only do vast numbers of people belong to online communities, but they also carry the equivalent of computers around with them, whether in the form of smart phones, handhelds, or tablets. In addition, information technology is changing the relations that ordinary people experience with governments and with corporations, as well as globalizing the relations between organizations both large and small. However, information technology cannot progress in isolation from the other NBIC fields, or in ignorance of its ethical, legal, and social implications. Therefore, this chapter examines the general topic of human–technology relationships, with a vantage point from information technology, but stressing convergence across multiple fields.

Electronics is the obvious meeting ground between information technology and nanotechnology, and the relationship between the two is rather mature at this point, although still offering many opportunities for progress. A few years ago, the nanoscale phenomenon called the giant magnetoresistance effect was exploited to give computer hard drives the ability to handle greater amounts of information and move it more quickly, but now solid-state hard drives are becoming common and inexpensive, handling input and output vastly faster in the absence of a disk that must be rotated, and employing electronic components with nanoscale dimensions. This chapter notes connections to biotechnology as well, but since its theme is the human dimensions of NBIC, much attention will be given to cognitive science and the social sciences.

Since the beginning of formal NBIC efforts over a decade ago, there has been an awareness that the social sciences need to be included, probably through their connections to information science and cognitive science. A different conception of how that might happen has arisen very recently, as increasing numbers of research projects enlist nonscientists in what is often called “citizen science.” This significant shift has positive educational implications, because the ordinary citizens who contribute their labor learn about the science. But more than that, this shift represents a convergence of science and technology with society and thus may offer an entirely new way in which the societal implications of technology progress can be addressed to achieve progress for society by embedding science and technology more solidly in society.

Convergence platforms offer an opportunity to accelerate the scaling of the benefits of new knowledge globally and rapidly (Gawer 2009). For example, industry platforms include both technological service platforms such as smart phones for scaling “new apps” globally and rapidly (e.g., Apple iPhone, Google Android) as well as organizational service platforms such as franchises for scaling “new offerings” globally and rapidly (e.g., Starbucks). In addition, IBM and other global IT businesses are working on diverse types of “Smarter Cities Intelligent Operations

Center" platforms to scale up the benefits of new urban service innovations, across industries, globally and rapidly. These platforms depend on intelligent infrastructure of converged nano-bio-info-cogno capabilities. For example, the "digital baby" offering can be deployed to identify health problems in premature babies in hospitals where the needed platform combines nanosensors, bio-pattern databases, mobile cognitive assistance alerts, all integrated in a shared healthcare cloud-computing environment. As convergence platforms enable the rapid spread of service innovations globally, the benefits of diverse crowd-funded university-based startups can more easily be compared and evaluated. The rise of convergence platforms may foreshadow an increase in faculty and student teams working on local community-based collaborative innovation and service learning projects, with the potential to positively impact local quality of life (Baldwin and von Hippel 2011). The large global vendors may then compete to be the scale-up partner of choice for these university-based startups and open service innovations (Chesbrough 2011).

This chapter explores specific investigative and transforming approaches and overall characteristics of the human-scale platform of converging advances in science and technology. Its connections to other converging platforms (foundational tools, Earth-scale, and societal-scale) also are discussed.

2.1 Vision

2.1.1 Changes in the Vision Over the Past Decade

The past decade has seen two major shifts relevant to information technology, reinforcing each other but conceptually distinct. The first major trend is captured in such buzzwords as "Web 2.0" to designate a new system in which a billion people create online content to share with each other, rather than the original situation in which a few large companies or government agencies provided the content. Of course, this term is something of a misnomer, because the original vision of the World Wide Web enunciated over two decades ago by Tim Berners-Lee imagined that content on the Web would be created by all the users (Berners-Lee and Fischetti 1999). But from the days of Colossus and ENIAC in the 1940s, the dominant computers were the largest machines, built and operated by large bureaucracies. The development of personal computers in the 1970s was a milestone on the route to democratic computing (Freiberger and Swaine 1984), but even today much online content comes from the modern equivalents of broadcasting companies. Thus the democratization of the Internet is a gradual process, but one that has made great progress since the earliest NBIC reports.

New interaction methods are being developed at the interpersonal level, and in human–environment, human–machine, and individual–social media interactions. This is particularly evident in the case of open source software (Scacchi et al. 2010; Schweik and English 2012). The most influential early example is the Linux operating system, which runs on a number of hardware platforms, which began with a kernel released in 1991 by Linus Torvalds of Finland and has since been expanded by a large community of volunteer programmers. The software infrastructure for the World Wide Web also emerged as open-source software (Jensen and Scacchi 2005) prior to its early commercialization efforts (by Microsoft, Netscape Communications, and others); through ongoing efforts by the Mozilla Foundation, Apache Foundation, and others, much of the Web still relies on open source software. Since Linux and the Web led the way, participatory open source systems and approaches to software development have become a major methodology for creating, deploying, and sustaining participatory systems for NBIC research and development communities. Open source systems and software have transformed software-intensive industries and institutions, software development practices, and global socio-technical ecosystems.

The second major trend is a reconceptualization of computing as a service, rather than as the sale of hardware and software products, foreshadowed in the original NBIC reports (Roco and Bainbridge 2003; Roco and Montemagno 2004; Bainbridge and Roco 2006a, b), but further advanced today. Technologies are owned by service system entities, such as people, businesses, universities, and nations. Service can be defined as the application of knowledge belonging to one person for the benefit of another person. Thus, service is governed not only by software and hardware, but also by the rules of the social system in which the service provider and the customer interact. Rules are a special type of symbolic knowledge that help to govern complex systems. The co-evolution of technologies and rules is key to policymaking in the future.

2.1.2 The Vision for the Next Decade

Scientific research performed according to the open source paradigm will accelerate the development, reproduction, adaptation, and replication of participatory organizational forms. A crucial goal for the coming decade is to establish open source and adaptive models, representations, and interaction protocols that can enhance converging technology discovery, education, innovation, informatics, and commercialization within a globally self-organizing and self-regulating ecosystem.

Convergence at any scale will greatly benefit from both (1) transparent, open source models and process representations that can be expressed in both human-readable and computational forms (Scacchi et al. 2010), and (2) models and representations that can be visualized and computationally simulated to help people understand and explore the features and limitations of the models and representations (Scacchi 2012). The openness realized through open-source approaches enables both reproducibility and more rapid diffusion and transfer of concepts, techniques, and tools across organizations and disciplines. Both are critical to scientific advancement. They also encourage open access to scientific results, research methods, and data for sharing, which improves the research impact (Gargouri et al. 2010; Piwowar 2011).

Investment and implementation strategies should therefore address computational tools and techniques that embrace open source expression and collective articulation of the scientific models used to convey observable principles and practices of converging technologies. Governance methods should embrace self-organizing practices in terms of the socio-technical systems that emerge to create, continuously refine, and evolve the converging technologies at different scales of interest. Thus, open source is not merely a way of harnessing the talent and energies of computer programmers outside a formal organizational structure, but a principle for doing technical work that could be applied across all NBIC fields.

An important step toward interdisciplinary work and converging knowledge will come from technology. There are limits on our capabilities to understand numerous data points and phenomena across domains and disciplines. Current tools at our disposal are information visualizations, statistical packages, and mathematical modeling to help our minds detect patterns. However, as data grow ever larger, we need better visualizations that can be used across different fields with wildly different types and amounts of data. We need easy ways to do this, rather than individuals trying to cobble these together from other tools.

2.2 Advances in the Last Decade and Current Status

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Within the field of information technology, well-established areas have seen incremental progress, and the most rapid progress seems to have been in areas related to social computing, where a number of the developments are controversial. Considering NBIC more broadly, fields are becoming increasingly interdisciplinary, but rewards for such work are not keeping up with the demand for it. There are serious barriers that must be overcome to encourage such work. Political and economic divergence is the most significant change in the wider environment in which research and development take place. That is, even as we see great opportunities for unification within science, disunity is growing in society; thus, *convergence must combat disorganization*.

For convergence to combat disorganization, the challenge will be to ensure that all major urban regions of the world have the needed convergence platforms to rapidly scale up the service innovations that positively impact quality of life. A hopeful sign is that the adoption rate of mobile phones and smart phones in developing nations is proceeding at an incredible pace (Goggin 2012). These human-scale convergence platforms (as they become enabled with more nanosensor capabilities for perception tasks) can also be used to spread skills via massively open online courses (MOOCs) that lead to the regional upward spirals of technological infrastructure and individual skills.

However, convergence is challenged by the fact that human-relevant systems tend to have multiple levels. For example, the service system entities at all levels from people (with their smart phones) to family living structures (houses, apartments, etc.) to local universities to cities, states, and nations must be able to "keep up" and to improve their convergence platform technological infrastructure and individual skill levels in a manner that preserves equity of access to the benefits of new knowledge. This will require a successful shift in policy (rule systems) at the continental level, globally. Institutional rules may not change as rapidly as technological infrastructure or even individual skill levels. The need for better rule systems is as apparent, if not more apparent, than the need for better technological systems (Spohrer et al. 2012). To achieve better equity and increase unity, the strongest must have an incentive for helping the weakest, and the weakest must have an incentive to aspire to compete with the strongest—which requires a great deal of enlightened self-interest among all stakeholders. For example, what would inspire top MIT innovators to move to Detroit, a city in turmoil and a mere shadow of its former glory, to work on urban challenges there (Rowan 2012)? Mere investment and loans cannot be the full answer, if the debtor regions fall further behind in productivity and cannot pay back the wealthier lender nations, as illustrated by the European Union's troubled strategy, where it may be that real human talent flows are needed to allow the weakest regions to compete with the strongest regions. When top talent flows out of weak regions, instead of into weak regions, it is only a question of time before the weak region falls further and further behind. The current rule systems and policies favor the concentration of talent into single winner-take-all regions (Florida 2008).

Within many of the sciences, a considerable degree of convergence has occurred through *collaboratories* and *virtual organizations*. These are partnerships linking multiple organizations and large numbers of scientists who use information and communication technology to share data, analytical tools, and results (Noll and Scacchi 1999; Olson et al. 2008). Aspects of this can be seen in the wider society as technology compresses time. There is no lag between an event and that information flowing into the world where others are made aware of the event via a display. But within a science, rigorous quality control is essential, and to accomplish that, human experts must work in cooperation with increasingly intelligent automated systems.

The Protein Data Bank and computer tomography virtual organization are convergence examples of computer-supported cooperative scientific research, which is among the main scientific and engineering advancements of the last 10 years.

The Worldwide Protein Data Bank (http://www.wwpdb.org/) illustrates how a shared information resource that was born long ago has taken on new life through information technology. Established in 1971, it became a clearing house for information about the structure and folding properties of proteins, a topic at the intersection of biology and nanotechnology, because proteins are building-blocks of life whose size is on the nanoscale. As innovative methods made it possible to decipher more quickly and reliably the structure of proteins and comparable complex molecules, the need for computer tools to manage the information also grew. This led to such crucial, but sometimes apparently mundane, developments as revising the file structure for the data, and more obviously revolutionary forms of convergence as the effort begun in 2001 to develop collaborative centers and use the Internet to unite researchers around the world (Berman 2012).

The computer tomography virtual organization (Tapia et al. 2012) is another example, but centered on a particular high-resolution system for computer tomography using X-rays to study structures such as human bone anatomy. This unofficial community has formed around one of only three high-resolution computed tomography (HRCT) scanners in the world, that at the Center for Quantitative X-Ray Imaging at the Pennsylvania State University (http://www.cqi.psu.edu/). For example, as used by the Department of Anthropology (among other departments at Penn State), the HRCT can generate 3D internal maps of physical structures in human and animal subjects, which capability has led to a number of cross-institution and international research collaborations among physical anthropologists. It is of great value to researchers at many institutions, so it is an example of one kind of scientific collaboratory, a shared instrument. But the virtual organization that hosts the instrument also provides a community data system, sustains a virtual community of practice, and functions as a geographically distributed research center.

At the present time, it is uncertain how well telecommuting and teleconferencing can substitute for traditional collaboration in which the people share a physical location, but this option does seem promising. As an example, both the National Science Foundation (NSF) and the National Institutes of Health (NIH) have been experimenting with virtual panels to review scientific research grant proposals. As part of their funding decision process, these agencies bring together scientists and engineers who have written reviews of research proposals, so they can discuss the various projects and achieve a convergence of views through group recommendations. For example, at this point NSF has held 23 review panels on a secure “island” in the virtual world Second Life, in which each person is represented by an avatar, illustrated in Fig. 2.1 (Bohannon 2011).

All NSF panels have long used groupware called the Interactive Panel System, which provides access via Internet to research proposals and individual reviews, as well as providing a text-based communication system for writing, commenting on, and approving a written summary of the panel’s discussion of each proposal. This combined virtual-groupware system reduces costs, allows convenient scheduling of meetings, and permits people who cannot travel to participate. Enhancements to facilitate transdisciplinary convergence remain to be developed.

2.3 Goals for the Next Decade

Two very different but compatible strategies suggest goals for the coming decade, based on advances in information technology in convergence with other fields. First, specific areas, of which robotics is a good example, bring together elements from different areas of science, through the engineering of new technologies, for direct application in human lives. Second, with a much more general scope, social sciences and related disciplines can be integrated with the NBIC fields, helping both to connect them and to increase the benefits they provide to society.

Fig. 2.1 One of the areas where virtual review panels are held by NSF

2.3.1 Strategy/Goal 1: Advance Information Technology in the Field of Robotics

Robotics has the potential to impact our daily lives substantially in the next decade, though perhaps not in the ways we envisioned 10 years ago. We typically have viewed the promise of robots as automated manual laborers, a vision that matches both their early capabilities (industrial automation) and fictional visions. The difficulties faced in developing these kinds of systems are well known. For example, perception is deceptively challenging, manipulation lacks flexible and compliant actuators and control algorithms, and planning requires both fine detail and extensive computational power. However, robots have the potential to offer other forms of support—cognitive, social, and behavioral. This switch is a substantial intersection for converging technology that can impact the quality of life for many individuals. Important areas of convergence in the next 20 years will be systems that offer support for the cognitively challenging society that the information revolution has produced: systems that enhance social support for individuals, that allow for a more connected and more natural experience, and that help to coach, train, and support healthy behavior and educational goals.

Robotics is seeing some of the same changes that happened to computing in previous decades. Just as the giant-room-sized computers of the 1960s became smaller, less expensive machines as they became consumer electronic devices, robotics is entering the same kind of transformation where robotics technologies are

Table 2.1 Consumer shifts in computing and robotics

	1960 Computing	2010 Computing
Cost	Institute-scale	Consumer-scale
Size	Room-sized	Desktop-sized or smaller
Training of user	Ph.D. level	None
Technology requirements	Fast, repeatable, durable	Easy to use, portable, flexible
Applications	Cryptography Scientific computing Engineering design	Social networking Entertainment Personalized search
	1975 Robotics	**2025 Robotics**
Cost	Institute-scale	Consumer-scale
Size	Room-sized	Desktop-sized or smaller
Training of user	Ph.D. level	None
Technology requirements	Fast, repeatable, durable	Easy to use, safe, flexible
Applications	Factory automation Remote sensing Dangerous materials handling	?

becoming more available and pervasive. Convergence in robotics will follow the trend of convergence in computing; that is, as robotic devices become consumer electronics, there will be a shift in the convergent areas toward areas of social and cognitive support for individuals. Table 2.1 sketches the possible future of consumer robotics by analogy with consumer computing.

The final cell of the table, representing 2025 consumer robotics applications, contains only a question mark, indicating that we can imagine several possibilities but not confidently predict which ones will become both feasible and popular. Just because industrial robots have been so successful, we cannot assume that robots in the home will be doing factory-based tasks. Robotics will initially move into consumer-driven niche markets, just as computers did, but which ones is exceedingly difficult to predict. We can, however, identify some key questions.

The traditional conception of a robot as a machine human dates back perhaps as early as the mythical ancient Greek giant made of bronze, Talos, who according to some accounts was manufactured by Hephaestus, the god of technology. Indeed, it may be very important for some consumer robots, or robots in educational settings, to take humanoid form, in order to interact comfortably with children and adult humans, or to perform certain tasks for which the human geometry is well-suited. However, we already have dishwashers, so the image of a robot standing at the sink washing dishes by hand is no more than a cartoon.

It may well be that robot applications will move from classical, physical-based to cognitive-based and social-based tasks. However, the form in which artificial intelligence is embodied will be a significant research and design question. For example, a security system to protect a home may be embodied in a humanoid robot, integrated into the dwelling itself, or located in the wider cloud of information services surrounding the home.

Robotics Application Areas

This raises the question of why consumers would need a mechanically embodied robot instead of a virtual agent, like Siri, the intelligent personal assistant and knowledge navigator that currently works on Apple mobile devices. However, many tasks do require physical movement and manipulation of physical objects. As the simple Roomba robot vacuum cleaner suggests, the ideal form for a particular physical-based task may not always be humanoid. When physical-based tasks are involved, actuators and sensors need to be in the mobile device, but the intelligence could be elsewhere. For example, in domestic applications, a central computer of a smart home could operate several robots of different kinds simultaneously and wirelessly; among them might be a humanoid robot or voice-operated intelligent agent that serves as the user interface for the entire system.

One application area of great potential and current research effort is *assistive robotics*, most obviously for people with problems of physical mobility. Personalized assistive devices available to the individual consumer will introduce a new range of services and demands for converging technologies. For example, convergence with biotechnology may often be required if the user has difficulty using hands to control a device like a wheelchair. Research progresses both on noninvasive brain–computer interfaces and on neural implants, for example, to operate artificial limbs. Understanding the human mind through behavioral science is needed to develop better noninvasive brain–machine interface design. Obviously, safety is a primary concern, but another is adaptability, because individual people differ widely in their needs and capabilities. In the context of a "smart" home, the entire environment could become assistive technology, including robotic components integrated into a unified system, greatly enhancing the autonomy and capabilities of the human being, so he or she would no longer be called "disabled." Achievement of these visions requires advanced forms of artificial intelligence, designed to handle a wide range of tasks reliably, and to do so in the manner most supportive of human freedom and dignity.

A second possible application area is in the *education of children*. Many people quickly respond negatively to this idea with concerns that childhood should be a natural period of life, filled with free play and exploration unconstrained by machinery. However, from an early age children are subjected to the regimentation of schools, and we typically give little thought to the harmful consequences of confinement to a classroom for half of each weekday. Robotic technology could be developed with great sensitivity to this issue, to increase rather than reduce the freedom of childhood, while providing proper discipline and helping a child to learn in the best way for that individual. We imagine a robot that can guide the child toward long-term behavioral goals; be customized to the particular needs of the child; develop and change as the child does; and engage the child as a peer, not as a parent, teacher, toy, or pet.

2.3.2 Strategy/Goal 2: Advance Information Technology by Integrating Social and Hard Sciences

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Opportunities for collaboration between the natural science and technology disciplines, on the one hand, and the social science and humanities disciplines, on the other, are increasing under the vision of "NBIC2," although there could be challenges in bringing them together. Some concern has been expressed by some experts that certain areas of the social sciences are perceived to have become moribund or marginalized, with the exception of economics, and more needs to be done to demonstrate their relevance and role in government decision-making.

Journals like *Science*, or magazines like *Scientific American* or *Science News*, hardly ever publish articles about solid advances in sociology or political science, and social psychology or anthropology are typically reported only if the particular work involves physical data. How much this state of affairs results from opposition to the social sciences, or from differences between social and physical sciences that may be responsible for delays in the progress of the former, we cannot say (Bulmer and Bulmer 1981; Fisher 1993). Revival of social sciences might be facilitated in several ways, notably: (1) providing extensive support for scientific fresh starts, often based on convergence of cognitive and information sciences, and (2) redesigning the currently problematic institutions of societal governance, with much greater guidance from social sciences (Bainbridge 2007b, c, 2008, 2009).

Expanding Citizen Science to Include Citizen Social Science

As one specific example of how convergence might revive social science, we can sketch an approach in which information technology assists in transferring the open source concept to sociological research, in the form of citizen social science. Of course, amateurs have played a role in several sciences since their historical beginning, including amateur astronomers who discover comets through their backyard telescopes and amateur archaeologists or paleontologists who hunt far and wide for specimens. One of the most famous examples was Francis Tully, an ordinary citizen who spent much of his spare time exploring the Mazon Creek area in Illinois picking up fossils. In the 1950s, he found the first specimen of the remarkable and as-yet not thoroughly understood animal named after him, the Tully Monster (*Tullimonstrum gregarium*), and took it to professional paleontologists for them to study (Johnson and Richardson 1969). While amateurs continue to contribute to science in this manner, today many major research projects enlist ordinary citizens in a systematic way, providing training and collecting data online.

A modern citizen-science project involving research on animals is *eBird*, centered on an Internet-accessible database (http://ebird.org/content/ebird/) where amateur bird watchers submit observations of particular species observed at specific times and places. As simple as this concept seems, it has led to significant research findings about the distribution and migrations of avian species, results that would have been next to impossible to achieve by any other means (Fink et al. 2010). Two related examples are *Galaxy Zoo* (http://www.galaxyzoo.org/) and Phylo (http://phylo.cs.mcgill.ca/eng/). *Galaxy Zoo* currently enlists thousands of amateurs to classify images of galaxies taken through the Hubble telescope and find anomalies for further study by professionals, using an online system to train the volunteers and combine their efforts to achieve maximum reliability (Smith et al. 2011). Phylo employs a game-based crowdsourcing approach for identification of multiple DNA sequence alignments (Kawrykow et al. 2012). Another example, closer to the social sciences but still using data about physical objects, is the *Field Expedition*: *Mongolia*, *Valley of the Khans* project (http://exploration.nationalgeographic.com/mongolia/), a crowd-sourced search for archaeological sites in aerial photographs of Mongolia that identified targets for ground-based expeditions to explore (Lin et al. 2011). More obviously relevant for NBIC is the *Foldit* project (http://fold.it/portal/) created by a collaboration between the Center for Game Science and the Department of Biochemistry at the University of Washington, which uses an online game to enlist nonspecialists in solving problems in protein folding. This is the most prominent example of citizen nanoscience (Khatib et al. 2011) and computer game-based approaches to scientific research (Scacchi 2012).

Ordinary citizens have long contributed to progress in the social sciences by answering survey questionnaires and volunteering as research subjects in laboratory experiments. But in the adjacent field of history, they have also contributed as oral history interviewers in addition to being respondents. For example, for 40 years the public library in Greenwich, Connecticut, in collaboration with the town's historical society, has collected documents and conducted 850 interviews with older residents to gain their observations about Greenwich throughout their lifetimes. In principle, every town should do this—but with enhancements in methods and concepts provided by the social sciences. Perhaps the most massive, high-tech example is the Shoah Foundation Institute at the University of Southern California (http://dornsife.usc.edu/vhi/), which at the time of the NBIC2 U.S. workshop announced completion of its project to digitally preserve video interviews with 52,000 survivors and witnesses of the European Holocaust.

With such oral history examples as inspiration and the many well-established citizen science projects as a guide, it is possible to imagine transformation of the social sciences, to make them not only more successful intellectually, but also more relevant for the lives of citizens. In the case of sociology, every person receiving a BA degree in sociology could be considered a bona fide sociologist in the context of collaborative citizen-science projects. For example, a graduate could remain a research associate of a favorite professor for the duration of the professor's career, collecting data, conducting analyses, and collaborating in publications, wherever the graduate happens to wind up in life. Organizations like the American Sociological Association or leading university departments in the field could set up research projects on specific topics, involving holders of sociology undergraduate degrees, or other reasonably well-prepared people.

As of July 9, 2012, the *Scientific American* website http://www.scientificamerican.com/citizen-science/ offered descriptions and links for fully 47 citizen science projects that were seeking volunteers, but none of these centrally involved the social sciences. One, Ancient Lives (http://ancientlives.org/), concerns ancient texts of value for historians and conceivably could be used to develop or test sociological theories, although that does not seem to be among its current goals. Another, the Health Tracking Network (http://www.healthtracking.net/index.php), could be adapted for sociological use or to chart sociologically significant phenomena like what is popularly called "mental health," but it currently is medically oriented. Additionally, the projects all seem to be old-style citizen science, in which the volunteers server as laborers rather than collaborators. Nonetheless, as online clearing houses of citizen science such as *Scientific American* emerge, there is no reason why social scientists could not submit their projects for inclusion.

Information technology would provide the data collection and team collaboration framework for "citizen social science." Thinking in terms of today's technology, a text-based forum and chat room would run constantly as members of the particular project share insights, advice, and access to other resources. A wiki, editable only by members of the team but visible to the whole world, could assemble their findings. Questionnaires, videos, and data in innumerable other formats could become part of the archive, and newly emerging analytical tools could be employed to achieve results. The range of potential topics is so great, and the opportunity to study the same phenomena in many different physical and cultural environments so attractive, that a very large number of such projects could be carried out simultaneously. Of course, proper attention would need to be paid to the ethics of research on human beings, yet the net result could be a huge transformation of the status of social science in society. Each participant would incorporate the research and its ideas in his or her own life, together accomplishing the convergence of social science and society.

2.4 Infrastructure Needs

A key infrastructure feature will be shared resources that allow scientists and engineers to accomplish great tasks, with special emphasis on those resources useful for multiple fields, because such multiple-field infrastructures are environments conducive to convergence. People think of infrastructure in terms of expensive hardware and physical installations, such as big telescopes, atom-smashers, and supercomputers. However, in the context of convergence we can identify four kinds of infrastructure that will contribute to and build on converging knowledge and technology:

1. *Physical infrastructure*, such as major production facilities, urban infrastructure, and instruments and laboratories
2. *Information infrastructure*, such as massive databases and the tools for using them
3. *Institutional infrastructure*, such as research universities, scientific associations, and government funding agencies

4. *Educational infrastructure*, for training the new generations of scientists and engineers

As the Protein Data Bank and computer tomography virtual organization illustrate, often these kinds of infrastructure are combined into one resource, a convergence of hardware and data resources within a cooperative social organization. But distinguishing the four infrastructure types avoids conceptualizing infrastructure entirely in terms of physical installations, and it facilitates thinking about many specific relevant issues, such as the following:

- Creation of laboratories, centers, and funding mechanisms should be designed to foster integrated, multidisciplinary research.
- Better scientific collaboration systems should include (1) informatics to assist in data collection, pattern detection, and data assimilations; (2) shortened publication cycles for research findings; and (3) wide availability of raw data and good procedures for their proper shared use.
- Converging technologies research should also provide a concurrent match in resources for public education in science and technology. We should consider that resources for converging technology research should be matched by resources for public education.
- Much of the future scientific infrastructure will take the form of Internet-based systems to support citizen science, employing transparent, open-source models and process representations that can be expressed in both human-readable and computational forms.
- Technology and access to information grow exponentially, but understanding within the human brain and mind cannot. Thus the gap is widening between our technological capabilities and our mental grasp of those capabilities; we need an infrastructure to help the individual and societal mind work with technology.
- Technology development for health sciences should have a home in focused Federal funding rather than falling between the areas funded by NIH and NSF. Other multidisciplinary areas may need similar innovations regarding institutional support.
- So that self-organizing communities of practice can flourish, government may need to focus on developing infrastructure and assuring free access to this infrastructure.

2.5 R&D Strategies

Converging technologies at the human scale require humans to work together, specifically humans with knowledge in the various converging domains and the ability to understand and incorporate the knowledge of those domains into their own individual work. Such interdisciplinary work will be required for converging technologies. One example is personalized healthcare. Various motivational, societal, and political forces influence the usefulness and acceptance of personalized healthcare. Years ago, the field of economics realized the need to incorporate social and behavioral science, because classical models failed to explain much of human behavior involving resources. Indeed, it was not enough for economists to merely work with psychologists; they also had to understand the theories and data in both fields to make progress. In converging technologies, we need to both encourage interdisciplinary work and create workers and scientists capable of transdisciplinary work, where a single worker or researcher can work in more than one field.

However, in research, there is not yet a widespread system that encourages interdisciplinary work. As with most work, it can be encouraged or discouraged through rewards and "punishments." Already, several Federal agencies offer incentives for interdisciplinary work through specifically solicited interdisciplinary programs; center competitions; interdisciplinary submissions to core programs; and through education, training, workshops, conferences, and symposiums. The National Science Foundation lists several of its own examples in three major categories:

1. **Solicited Interdisciplinary Programs**. Numerous NSF programs are designed explicitly to be interdisciplinary, often involving several NSF directorates. Program solicitations are developed for these programs and posted on the NSF website, e.g., that for Interdisciplinary Behavioral & Social Science Research (http://nsf.gov/pubs/2012/nsf12614/nsf12614.htm). Recent examples include Cyber-Enabled Discovery and Innovation; Water Sustainability and Climate; Collaboration in Mathematical Geosciences; Dynamics of Coupled Natural Human Systems; Macrosystems Biology; Emerging Frontiers in Research and Innovation 2010; and Decadal and Regional Climate Prediction using Earth System Models.
2. **Areas of National Importance**. NSF develops activity portfolios focusing on areas of national interest, often in collaboration with other Federal agencies. Because the challenges that we face as a society are often complex and require an integrative, collaborative approach, these areas are often interdisciplinary. Examples of interdisciplinary programs that NSF contributes resources to include Science, Engineering, and Education for Sustainability (SEES, http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504707); Networking and Information Technology Research and Development (NITRD, http://www.nitrd.gov/); and the National Nanotechnology Initiative (NNI, http://nano.gov/).
3. **Center Competitions**. Many of the centers funded by NSF bring together interdisciplinary research teams. Some examples include the Materials Research Science and Engineering Centers (MRSECs, http://www.mrsec.org/); the Science of Learning Centers (SLCs, http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5567); and the Science and Technology Centers (STCs, http://www.nsf.gov/od/oia/programs/stc/index.jsp).

NSF's solicited interdisciplinary programs operate in parallel and cooperation with the long-standing disciplinary programs, typically managed by teams of program officers drawn from the core programs. These programs' special competitions tend to last for 3–5 years and are designed to promote collaboration among selected sets of disciplines that are judged to have a good potential for collaborations at their current state of development. Areas of national importance are highlighted for similar periods of time, because a pressing societal need can be addressed by a concentrated but multidisciplinary effort. Based in one or more universities, centers play a key leadership role in addressing national areas of need, often spanning multiple disciplines.

A somewhat different approach has been taken by the National Institutes of Health in its Common Fund (http://commonfund.nih.gov/):

> The NIH Common Fund was enacted into law by Congress through the 2006 NIH Reform Act to support cross-cutting, trans-NIH programs that require participation by at least two NIH Institutes or Centers (ICs) or would otherwise benefit from strategic planning and coordination. The requirements for the Common Fund encourage collaboration across the ICs while providing the NIH with flexibility to determine priorities for Common Fund support. To date, the Common Fund has been used to support a series of short term, exceptionally high impact, trans-NIH programs known collectively as the NIH Roadmap for Medical Research [http://commonfund.nih.gov/aboutroadmap.aspx]. The Common Fund is coordinated by the Office of Strategic Coordination, one of the six offices of the Division of Program Coordination, Planning, and Strategic Initiatives (DPCPSI) within the Office of the Director.

Occasionally, several Federal agencies combine their resources in a special convergence effort. Among the most promising current examples that place human beings in the context of technology is the National Robotics Initiative (NRI; http://www.nsf.gov/pubs/2011/nsf11553/nsf11553.htm, "Synopsis of Program"):

> The goal of the National Robotics Initiative is to accelerate the development and use of robots in the United States that work beside, or cooperatively with, people. Innovative robotics research and applications emphasizing the realization of such co-robots acting in direct support of and in a symbiotic relationship with human partners is supported by multiple agencies of the federal government including the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), the National Institutes of Health (NIH), and the U.S. Department of Agriculture (USDA). The purpose of this program is the development of this next generation of robotics, to advance the capability and usability of such systems and artifacts, and to encourage existing and new communities to focus on innovative application areas. It will address the entire life cycle from fundamental research and development to industry manufacturing and deployment. Methods for the establishment and infusion of robotics in educational curricula and research to gain a better understanding of the long term social, behavioral and economic implications of co-robots across all areas of human activity are important parts of this initiative. Collaboration between academic, industry, non-profit and other organizations is strongly encouraged to establish better linkages between fundamental science and technology development, deployment and use.

At the core of the NRI is the concept of co-robot, the design of intelligent machines that will be optimal partners with human beings. Figure 2.2, from the multiagency program solicitation, suggests the convergence of multiple disciplines in achieving this synthesis.

These examples of existing government activities reflect three somewhat different but apparently equally successful strategies: (1) creation of well-focused temporary competitions within one agency; (2) development of an over-arching convergence mechanism uniting all divisions of an agency, and (3) cooperation between agencies in a convergence area of mutual interest. All three mechanisms must be designed to emphasize areas that are technically suitable at the given point

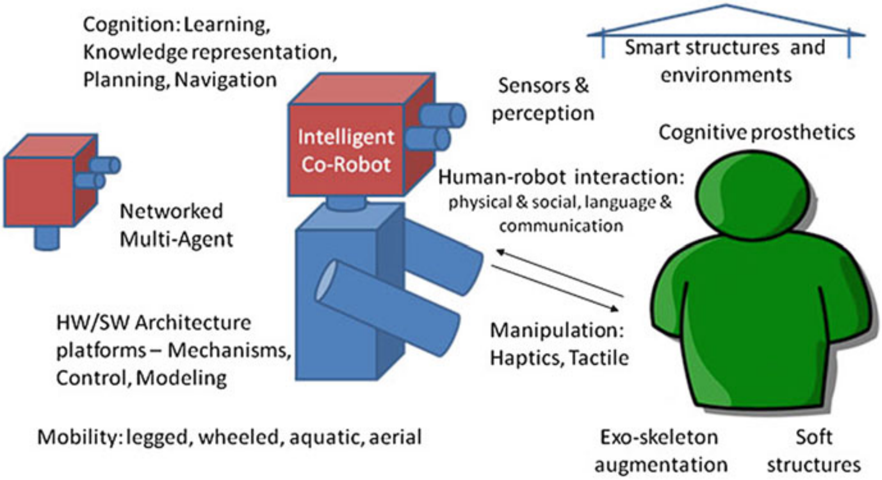

Fig. 2.2 The "co-robot" concept in the National Robotics Initiative (Open source: National Science Foundation, http://www.nsf.gov/pubs/2011/nsf11553/nsf11553.htm)

in time for rapid progress and where both the leadership and the rank-and-file employees in the agencies are prepared to work together.

It is not uncommon for universities to create multidisciplinary programs, although their functionality and longevity may often be inferior to those of departments representing single disciplines. Some examples happen on an ad hoc basis because they do not give the fields in question high priority, as some teaching institutions combine sociology and anthropology, and it is a rare research university that separates archaeology from cultural anthropology.

Reward systems differ by discipline. For example, a computer scientist gets high value from proceedings papers at conferences, while a psychologist benefits most from journal publications, and in the view of many, sociology is a book-based discipline. Even author order can be problematic: psychologists list the primary author first, mathematicians provide authors in alphabetical order, and biologists list the primary author last. In short, an interdisciplinary *curriculum vitae* is a difficult one to evaluate.

At the university level, even with the advent of interdisciplinary hires, there are still hurdles to interdisciplinary work. First, as the systems stand, there is little reward for interdisciplinary work. In the day-to-day life of the academic, it is difficult to work with researchers outside of one's discipline. Their offices or laboratories may be in different locations, requiring tedious travel to meet. Sharing data is difficult, because of a need for privacy and security in human behavioral data and the different data formats and analysis software used by different physical sciences. If researchers in two disciplines submit a grant proposal together, they may need to deal with the rules of two offices of sponsored programs that have different deadlines and requirements. It is much easier to collaborate with colleagues at the same location, with the same reward structure, and speaking the same technical and administrative languages.

Institutional Review Board approvals for human subjects research is a challenge that must be addressed for interdisciplinary teams that engage physical, natural, and social scientists. The complexity of research design around the issues of human subject protection is not always immediately appreciated by researchers whose past experience has not involved human subjects. While social scientists need to become more familiar with the language and landscape of contemporary science and technology research priorities, STEM (science, technology, engineering, and mathematics) researchers (outside medicine) also need to gain an appreciation of Federal regulations related to protection of human subjects and to become more familiar with protocols that involve these regulations if NBIC convergence is to progress.

Some solutions for these problems involve small changes to culture "at the human scale." Implementing rewards such as interdisciplinary funding from funding sources and university hiring across areas, is valuable in itself. However, success can also occur at a smaller scale by removing barriers to interdisciplinary work on a daily basis. This requires leadership in universities and government agencies, but also initiative-taking by all the people who work within these organizations.

2.6 Conclusions and Priorities

Contact: *W. S. Bainbridge*, *National Science Foundation*

2.6.1 Economic Effects Associated with Technological Innovation

In the economic sphere, information technology is creatively disruptive, offering marvelous new jobs for workers and profits for investors, yet also destroying or downsizing old occupations and industries. There is widespread concern that the current economic problems are more than merely the aftermath of an unusually severe downturn in the regular economic cycle, but a transition to a "new normal" with permanently higher unemployment rates (Brynjolfsson and McAfee 2011). We could even have entered a long-term decline in the prosperity of most citizens of post-industrial societies, in a "race to the bottom" as per capita incomes equalize across nations without sufficient growth to keep the rich nations rich. Clearly, we need much better-quality social science in order first to answer such disturbing questions with any confidence, then to invent the best responses to the problems we face.

Computers may be cutting-edge, but they are also double-edged swords that can cause harm as well as provide benefit. Extreme technological unemployment may come about as intelligent machines replace more and more human workers in an increasing number of sectors of the economy, which we already see as mass-market stores install automatic check-out machines, bookselling moves away from local bookstores to online services, and journalistic careers vanish as newspaper subscriptions plummet and people read blogs instead of magazines. Information technology facilitates off-shoring of jobs, for example, of local telephone help operators in Indiana who are replaced by workers in India.

A standard concept in the economics of innovation is creative destruction, the principle that innovations often destroy old industries and jobs, but the net result is creation of more and better-paying jobs in new industries (McKnight and Kuehn 2012). The usual criticism of this postulate is that it does not take account of the suffering of people who lose employment in old industries, especially those unable to get jobs in the new industries. But if we think of creative destruction in terms of a production function in which old industries are the input and new industries are the output, we cannot in fact specify exactly what the function is, especially when innovations of different kinds may have different consequences. Some scholars suggest that innovation has a declining utility function, such that in earlier stages of human history the new jobs gained from creative destruction outnumbered the old jobs lost, but later on in history, the jobs lost outnumber the jobs gained. They postulate we may have passed the inflection point, after which innovation is more destructive than creative.

The current situation with information technology may illustrate a different point, conceptualizing innovation as a staged process, in which creation and destruction occur at different times, following a complex coupling function. For example, the two could proceed in surges like two sine waves of the same frequency but out of phase with each other, or even of different frequencies and thus causing a third kind of wave like a beat frequency that occasionally causes either creation or destruction to predominate without that fact marking a long-term trend. This metaphor suggests that the current unusually severe economic distress could be partially caused by an extreme but temporary dissonance in the rates of progress in different fields of science and technology, which convergence could harmonize.

2.6.2 Social Effects Associated with Technological Innovation

While today we commonly think of scientific and technological progress as a gradual improvement in knowledge and abilities, convergence can unleash sudden advances with profound implications that can be realized quickly. A classical view of scientific and technological progress stressed decisive innovations that have great consequences, but too much emphasis on day-to-day management may currently blind science and technology leaders to the very real possibility of technical revolutions. Ninety years ago, William F. Ogburn (1922; cf. Bimber 1994) outlined a four-step “technological determinism” model of human history that gave special prominence to rare, decisive innovations:

1. *Invention*: the appearance of a new technological form that does not depend upon the genius of any one inventor, because major inventions are made roughly simultaneously by several different people
2. *Accumulation*: the process in which new inventions are added to the general store of culture more rapidly than they are forgotten or rendered obsolete
3. *Diffusion*: the transfer of knowledge, skills, and technology from one geographic location to another, and from one domain of application to another
4. *Adjustment*: the process by which nontechnical aspects of a culture adapt to invention, usually happening with greater difficulty for the more significant innovations

Ogburn was especially worried about *cultural lag*, a tendency of society’s institutions to resist change, thus hindering adjustment. On the positive side, he noted that accumulation of inventions could feed back into the invention process via diffusion, as new inventions combined old ones in new ways. Thus, Ogburn was an especially early theorist of convergence. A rather different episodic theory of scientific progress was offered by Thomas Kuhn (1957, 1962), who wrote about historical paradigm shifts in which a new generation of scientists brought with them a radically different conception of their field than that possessed by their elders. It is possible that convergence represents a *metaparadigm*—a paradigm about the combination of existing paradigms across fields, leading eventually to a wholesale reconceptualization that transcends many of the older paradigms.

Information technology relates to these ideas in three ways. First, it offers tools for rapid diffusion of innovations around the globe and across fields of science and technology. Second, it is an example of disjunctive progress, just as the invention of integrated solid-state circuits half a century ago made possible a true revolution across many areas of human accomplishment. Third, we may be experiencing severe cultural lag as a consequence of this technological revolution, and we have hardly begun to decide which traditional societal institutions need significant adjustment, let alone in which direction. Thus, the overarching themes of this report—(1) improved economic productivity, (2) increased human potential, and (3) sustainable life security—are themselves areas for research and public debate.

2.6.3 Relationship of NBIC Convergence to Economic and Social Aspects of Technological Change

Economic competiveness can be analyzed on several levels: individual, community, corporate, national, and global. For individuals, a key dimension of competitiveness is education, not only the formal schooling early in life, but life-long learning to keep up-to-date in terms of work skills and to enhance the quality of life outside of work. Communities, such as cities and states or provinces, compete for industries against other communities, but at any given time only a few can be centers of technical innovation, while other geographical areas may rely upon extractive industries, agriculture, or commerce—leaving many geographic regions at a competitive disadvantage unless new institutions can be developed that compensate for their disadvantages. Corporate competitiveness is harsh but often highly rewarded in new industries, while innovation in well-established companies can be especially difficult. On the global level, the question may become how to emphasize cooperation and mutually beneficial division of labor across nations, or else the world economy may become "a race to the bottom" in which the nation with the lowest labor costs yet sufficient technical competence undercuts the prices of all other nations for goods and services.

Increasing human capacity today often means giving people technologies that effectively increase the scope of their memories and their capacity to process more information, for example, through the Internet, personal computers, and mobile devices. In the past, human physical capacity was increased through motor-driven machines that ranged from water pumps to drill presses to automobiles. We can ask whether we might stand at the threshold of another phase of technology-assisted human development, that of increasing human capacity not at the physical or mental levels, but at the social level of communities, corporations, and families.

Security and sustainability cannot be achieved through resistance to change, but only through *wise management of innovation*. This is not to suggest that we would continue a technocratic, typically hierarchical, top–down policy-setting and management approach in which people who consider themselves knowledgeable help the resisters see the benefits of change. Resistance provides information that may often be valuable and sometimes correctly advises against a particular course of action, or for a better one that technocratic managers may not have noticed. If viewed in this way, resistance provides data for a scientific and reflective observation about what underlies the lack of enthusiasm or even active resistance. Today's concepts of management may be supplemented by emerging management forms that can arise as a result of the increased connectivity among people possessing a range of perspectives and interests.

Wise management may often mean defining environments in new ways, such as redesign of the workplace to balance the human needs of the workers with increased productivity. Smart homes may be both more comfortable and more cost-effective than big homes, integrating sensors, machines, and computation into unified habitats. Information-integrated transportation systems can be more satisfying than exhausting traffic jams or waiting lines, avoiding both accidents and unnecessary costs in time and money. It is easy to name problems and suggest superficial solutions, but it is extremely difficult to preserve the beneficial aspects of customary life while enhancing human capabilities in profound ways. A proper balance requires very significant research and development efforts, bringing together the methods and insights of all relevant fields, in technology-enhanced human convergence.

2.7 R&D Impact on Society

To properly assess the impact of NBIC convergence on society, we need to develop better models and approaches for prospectively gauging social impacts of new technologies. A difficulty here is assessing impacts that are beyond economic and quantitative assessment. We may want to consider looking toward governance concepts that are less oriented than currently toward utilitarian concepts like risk/benefit analysis. This is true for at least three reasons. First, we know from social science research that economic models do not adequately account for how broad populations of people evaluate prospects put before them. Second, as NBIC emerges in the applied world, it will interact with other cultures, many of which are based on traditionalism that would reject utilitarian thinking in favor of more holistic or morality-based ideas. Third, priorities for research and development in converging technologies should take account of broad social needs, as opposed to allowing commercialization to be heavily driven by market forces.

The impact depends on the state of society, as well as upon the nature and application focus of the technologies. Today, the world faces unprecedented aging of its population. The stakeholders, workers, and even the scientists will be increasingly older. In consequence, the focus of much medical work will shift from curing diseases to managing chronic conditions and degeneration. Aging is not a disease; evolution shaped humans to live long enough to complete the task of being parents, given the long duration of human childhood—one of the prices for our high intelligence—and not much longer. At present, we lack a consensus about priorities concerning how much society is willing to invest in adding a few months to the life of an elderly person versus investing in universal good nutrition and healthcare for children. We also lack a clear understanding of what new "nano-bio" methods might increase not only the average life span, but the years during which a person can be productive.

One idea considered by the Quality of Life working group at the U.S. NBIC2 conference was the antagonistic pleiotropy hypothesis (Williams 1957), postulating that the expression of a gene results in multiple competing effects, some beneficial but others detrimental to the organism. Some genes responsible for increased fitness in the younger, fertile organism contribute to decreased fitness later in life. This means declining forces of natural selection. Antagonistic pleiotropy can conceivably be fought by up-regulating the repair mechanisms we already have, which decay with time. Using molecules derived from the large inventory of substances generally recognized as safe might open pathways to use genomic information, perhaps in the form of dietary supplements. Genomics focused on finding repair mechanisms, rather than disease precursors, would contribute to progress in this area, as would attacking aging holistically as a complex system of disorders requiring convergence of the relevant sciences and technologies.

One of the attractive features of the antagonistic pleiotropy hypothesis, quite apart from the ultimate determination of its correctness within the science of biology, is that it can be applied by analogy to features of social evolution. Characteristics of societal institutions that served us well earlier in history may be dysfunctional now, and we may seek other analogies from across the spectrum of convergent sciences to suggest cures for the maladies of an aging civilization. For example, comparison of winner-take-all (WTA) and improve-weakest-link (IWL) policies are needed. Shifting the competitive framework to accelerate learning from regional competitions and experiments has great potential for improving quality of life. Improvements in innovativeness, equity, sustainability, and resiliency will result from converging technologies. A shift may be required in the competitive framework to balance WTA and IWL policies to accelerate learning in and between geographic regions so as to improve quality of life for all.

A cornerstone of this session is quality of life. Yet, quality-of-life research has, over several decades, moved from "standard-of-living" types of (economic) measures in the direction of concepts such as "happiness." We need to develop ways to identify how the concept "quality of life" can be brought into the risk-based decision processes associated with new theories of risk governance. This may require higher synergies between funding agencies, academia, and industry: the funding agency defines parameters of the problems, and industry and academia receive funding to solve them. That could imply creating generally higher rewards for scientist-practitioners. In education, convergence R&D can promote learning based on creative synthesis rather than learning based on facts and problem decomposition, with increased emphasis on philosophy and values.

A crucially important area where convergence has failed to take place concerns the ethical, legal, and social implications (ELSI) of information technology. Both nanotechnology and biotechnology have well-established ethical codes, and one of the original sources of government NBIC efforts was the concentrated consideration of the social implications of nanotechnology. Two areas of clear public concern having implications for the economy as well as for human well-being are information privacy and intellectual property rights. A third area not often discussed but of real significance is the possibly excessive regimentation of daily life by information technologies. With guidance from social science, cognitive science, and public debate, these are three very high priorities for the next few years:

1. *Information Privacy*. Legitimate concerns focus on government surveillance of personal communications, justified by a national-security ideology that includes data mining, Internet scraping, computer vision through ubiquitous cameras, and requirements that many kinds of records in such areas as health and education be stored in central databases. At the opposite extreme, movements like WikiLeaks publicize government secrets, and irresponsible individuals can post online harmful, false, or defamatory information about other individuals in a manner that makes it impossible to prove who is responsible and difficult to remove the material from public view. Whether or not there exist technological solutions for these problems, a fresh look at public policies is needed.
2. *Intellectual Property Rights*. There has been much recent focus on online file-sharing practices by ordinary citizens that violate existing copyright laws, and on actions by legislatures to increase the penalties for such violations. The legal structure is the result of centuries of accidental historical accretion, leading to many anomalies. For example, why is the duration of a patent so much shorter than the duration of a copyright? Or, why can engineers patent their inventions,

but scientists cannot patent their discoveries? A social movement in Europe represented by the Pirate Parties International, originating in Sweden but currently popular in Germany, advocates radical reduction or even elimination of intellectual property laws. Whatever the right course may be, information technology has changed the realities surrounding intellectual property rights, so fresh thinking should be a high priority.

3. *Computer Regimentation*. Computer technology permits imposition of harsh control over every detail of worker behavior, for example in white-collar jobs where everything must be done through computers, imprisoning the worker by rigid and poorly designed software. As an illustration, medical professionals have complained about new government regulations promoting electronic health records, indicating that requirements were too aggressive, not all laboratories have the technology to send clinical lab tests into electronic health record technology as structured data, and that the new requirements will force providers to engage in too much manual data entry (Fiegl 2012a, b). There is a similar concern about increasingly dogmatic indoctrination of students in schools, which often require computer-based lessons and tests that include artificial intelligences serving both as teachers and graders, structured within an increasingly rigid ontology of permissible ideas. The relative dearth of public discussion of such possible threats leaves open the question of how real they are, but innovators developing new information technologies for work and school need to be cognizant of the dangers of inappropriate application.

Even as information technology presents such dangers, in convergence with the cognitive and social sciences, it can help us navigate past the dangers to a bright new future for humanity. New online forms of public decision-making can be developed, involving all sectors of society impacted by technological changes, in a manner that combines expert analysis with the consent of the governed. This could not only prevent potential negative consequences of improper application of information technology but also unleash human creativity to overcome cultural lag while safeguarding the well-being of the general public. Expanding on the success of the virtual organization scientific collaboratories developed over the past decade, and building through increasing involvement of the general public in citizen science, the ultimate convergence could be achieved, uniting science with society.

2.8 Examples of Achievements and Convergence Paradigm Shifts

2.8.1 Case Study: Arts, Humanities, and Culture

Contact*: W. S. Bainbridge, National Science Foundation*

Human artistic creativity almost invariably uses tools, so throughout history, technology advances have facilitated the development of new artforms. While the first novels were written in the ancient world, novel-writing did not become a popular artform until the development of the printing press and widespread distribution of manufactured goods. Today, as so many forms of art are moving to digital media, we forget how technically demanding color and sound motion pictures were, using three microscopically thin photographic layers on the film to record the colors, and one or more separate optical sound tracks. Yet this exceedingly complex technology was completely mature by 1939, as demonstrated by *Gone With the Wind* and *The Wizard of Oz* that date from that year.

Today, the relatively new digital media are already influencing artistic creativity in at least two ways: (1) by enabling new artforms that were either impossible with earlier technologies, or so difficult they could not be widely adopted, and (2) by establishing new forms of distribution that not only reduce costs and facilitate speedy diffusion of new artforms, but also call into question traditional norms concerning intellectual property. Convergence of all the NBIC fields has the potential for a third, related transformation: (3) inclusion in many arts of themes derived from progress in science and technology, whether in the plots of stories or in other artistic dimensions such as images and background metaphors.

A new medium that illustrates all three of these factors is massively multiplayer online role-playing games (MMOs), which are actually far more than mere "games" but total works of art that include music, drama, and visual arts—even in many cases allowing the player's avatar to dance. Players can team up with each other despite being thousands of miles apart and belonging to different cultures. *Second Life* includes the Google Translate system that facilitates communication across languages, and *Final Fantasy XI* includes an extensive phrase book for communication between English, French, German, and Japanese players. *World of Warcraft* reached a peak subscriber population of 12,000,000. *EVE Online* has "only" 400,000 subscribers, yet for them it is a realistic economy based on exploitation of virtual natural resources, manufacturing of virtual goods, and economic exchange (Bainbridge 2011; Plumer 2012). Already, MMOs have shown promise for education, and now innovative mobile educational games are being developed (Steinkuehler 2007; Scacchi et al. 2008; Scacchi 2010), as well as enabling advances in the arts and humanities, social sciences, and broader scientific research (Scacchi 2012).

The ease of distributing MMOs over the Internet has facilitated the rapid emergence of major companies in China and South Korea, often using a free-to-play but pay-to-win economic strategy very different from the Western subscription model that is in rapid decline. Many MMOs, and smaller games for mobile devices as well, are more-or-less direct copies of existing successful ones, so there have been many lawsuits, and intellectual property protections seem to be breaking down. The Chinese MMO *Perfect World* reverse-engineered *World of Warcraft*, but filled it with Chinese culture, so no laws were broken. The company operating *Perfect World* has bought *Star Trek Online*, thereby taking possession of a major product of American culture. Among the most innovative features of some MMOs, including *Star Trek Online*, is the freedom they give players to create their own missions, which itself erodes intellectual property protections, because the players lose control over their own creations and have no property rights, at the same time that some players create game missions that violate franchise copyrights. A new convergent discipline is emerging that might be called *virtual socio-legal studies*, that examines the radical implications of MMOs and other revolutionary communication developments (Lastowka 2010).

Many MMOs have begun to feature culture based on technological convergence. For example, nanotechnology is the central metaphor of the Norwegian MMO, *Anarchy Online*, in which players may simulate building human-sized robots from nanobot components, and use fictional nanomedicine to improve their avatars' functions. *Fallen Earth* is a survivalist MMO set in the future around the Grand Canyon, where a convergence of biotechnology and information technology has caused the collapse of civilization but also offers the possibility of rebuilding it. Of course, many NBIC convergence ideas have appeared in other artforms. For example, Neal Stephenson's (1994) novel, *The Diamond Age*, conceptualizes nanotechnology in terms of information technology, while Kathleen Ann Goonan's tetralogy (1994, 1997, 2000, 2002) conceptualizes nanotechnology in terms of biotechnology in convergence with music.

Research and policy reconsiderations are desperately needed in the area of intellectual property rights. Intellectual property norms have varied across cultures and throughout history, so the copyright regulations of the past two centuries may become outmoded as future culture evolves away from traditional assumptions. The sharing of data files such as movies and music tracks has become trivially easy via online computers, so why should people not be free to share any artworks they wish? From the perspective of copyright law, Sophocles and Shakespeare were plagiarists, because they freely borrowed from other authors. Yet, they might argue that culture belongs to the entire society, and dramatists are adequately rewarded with either honor or money by being directly involved in theater productions. Under current U.S. law, the movie version of *The Wizard of Oz* will not enter the public domain until perhaps 2034, but the novel the movie was based on is already in the public domain, having been published in 1900, and both are easy to share online.

Information technology is blurring the practical distinctions among three conceptually and legally different forms of art: (1) folk art that is associated with an historical or ethnic culture but not owned by individuals, (2) classical high art that may be owned by its creators for a brief period but then passes into the cherished cultural heritage of humanity, and (3) popular art that is commercially created and distributed by mass media companies but loses value when the stylistic fad and associated celebrities pass from the scene. Whether or not this conceptualization is adequate, the new communications technologies can be the basis for a new science of art, as researchers develop new tools and consider their impact.

The humanities can be conceptualized either as scholarship oriented toward the arts, or as humanistic scholarship about non-artistic aspects of human culture. Both dimensions of the humanities link to the social sciences and are an interesting focus for cognitive science research. Developing a new convergence science of the arts need not inhibit aesthetic creativity, and indeed, the merging technology can nourish artistic innovation. Likely areas of innovation include:

- Comprehensive entry points to a particular cultural complex, especially useful for students, such as The Perseus Project gateway to classical civilization (Crane 2012)
- Digital preservation projects, which need not only to archive cultural works and provide ways of searching and comparing them, but also to manage the intellectual property context for each one (Caroli et al. 2012)
- New methodologies to transform the humanities into sciences, for example, quantitative analysis of changing artistic patterns, adapting the recommender system technology currently used to advertise products the user is predicted to like (Bainbridge 2007a)
- Adaptation of traditional theories and methods from cultural anthropology to post-modern culture, for example, participant observation ethnography of MMOs (Nardi 2010)

2.8.2 Case Study: Digital Government 2.0

Contact: *W. S. Bainbridge*, *National Science Foundation*

The form and structure of government has varied greatly across the time dimension of history and the cultural dimensions around the globe. Thus, there is reason to doubt that our current institutions of government are the best ones possible, or the ones best adapted to the unique conditions of the twenty-first century. However, there is every reason to preserve our current institutions, as they are, until we have solid evidence that improvements are both needed and feasible. Many current research projects are exploring alternative possibilities, based on convergence of social science and information technology, to offer feasibility assessments and design innovations for consideration by the citizenry.

The concept of *digital government* originated in the 1990s, initially with a goal of improving dissemination of government information between agencies and to the general public, but increasingly also seeking ways in which ordinary citizens could participate more actively in government decision-making. Thus, "Digital Government 1.0" emphasized information flow in one direction, from government to citizens, whereas "Digital Government 1.5" increased input from the citizens. Now, "Digital Government 2.0" seeks to go further, also developing ways in which citizens can use information technology for self-governance, especially on the local level, without necessarily any involvement by formal governmental agencies.

Soon after U.S. Federal Government agencies had set up websites and started using the Internet extensively for both internal and external communication, the revolutionary potential of the technologies began to dawn on sophisticated users. Already in 2002, a workshop to develop a research agenda in this area noted such innovative possibilities: "The fundamental restructuring of government from bureaucratic structures joined through oversight bureaucracies and Congress to greater use of horizontal arrangements using, at times, less formal governance mechanisms, market mechanisms, and temporary configurations signals an emergent change in the structure of the state and policymaking capacity" (Fountain 2002, 5).

An excellent example of recent Digital Government 1.5 research is a study at Cornell University aimed at achieving wider public involvement in the rule-making process of conventional government agencies (Farina et al. 2011). Often the legislation passed by Congress outlines steps to be taken but does not specify the details, so a complex technical process of drafting specific rules must follow before the legislation can be fully enacted. The goal often may be regulation of technology, in such areas as the environment, transportation, workplace safety, or now even intellectual property rights in the information sphere. Government agencies are under a legal obligation to include stakeholder groups and citizens in the process of evaluation of proposed rules, but exactly how to do this both fairly and efficiently has been a difficult challenge. It is one thing to set up an online forum where people may post comments, but quite another to do so in a manner that objectively classifies the diverse contributions to achieve a high-quality consensus. Current research systematically charts participation trends and identifies problems of message content, with the hope that future research will develop methods based on computerized natural language processing to cluster the inputs and measure their quality.

Several very recent projects have begun developing communication tools that citizens can use in their local communities to undertake joint projects and perform tasks that otherwise government might need to do at greater cost and lesser flexibility, or that lie outside the traditional domain of government responsibilities. Janne Lindqvist at Rutgers University and Winter Mason at Stevens Institute of Technology are developing a system called Myrmex to facilitate local community crowdsourcing of physical tasks, like package delivery, optimizing such variables as efficiency, privacy, usability, and motivation for people to participate. John Carroll at Pennsylvania State University is studying time banking, a form of community-based volunteering in which participants provide and receive services, to develop new design principles in human-centered computing. Loren Terveen at the University of Minnesota is developing algorithms and interaction mechanisms to improve the functioning of social media technologies through which members of a community can assist each other with very personal goals, such as parenting and bicycling for good health. Such Digital Government 2.0 research often faces surprisingly difficult intellectual challenges, and makes unexpectedly profound discoveries, despite the apparently humble and "down-to-earth" nature of the applications in ordinary people's lives.

Digital Government 2.0 also includes research projects to examine or prepare for major changes in political processes. Many researchers have focused on the role of new Internet-based communication technologies in the so-called "Arab Spring," although their research has shown that the Internet is not necessarily a powerful force that operates only to promote democracy (Howard 2010; cf. Howard and Jones 2004). Rolf Wigand at the University of Arkansas and Merlyna Lim at Arizona State University have begun to study factors leading to success or failure in collective online action, using the global female Muslim blogosphere as their case study. Philip Howard at the University of Washington studied online communications around the historic 2011 Tunisian election.

Other researchers are examining the changing dynamics of American politics in the Internet era. Jason Thatcher at Clemson University is developing techniques for understanding the impacts of the social web on political polarization, in the context of Congressional elections. Geraldine Gay at Cornell University and Francesca Poletta at University of California, Irvine, are developing computational tools to support citizens in framing political issues in the ways most conducive for reasonable public deliberation, as opposed to mere partisanship. In two separate projects using different methods to achieve convergence between social and information sciences, Robert Mason at the University of Washington and John Jost at New York University are developing new research techniques, theories, and design principles related to online social movements, using the case study of the "Occupy Wall Street" movement.

Digital Government 2.0 research has as yet produced very few publications and is among the very newest areas of science and engineering. Thus, there is a great need for contributions from all the many disciplines that might help establish this new field of convergence.

2.8.3 Case Study: Post-industrial Society

Contact: *W. S. Bainbridge*, *National Science Foundation*

While nanotechnology and biotechnology give new life to manufacturing industries, for decades it has been clear that the economy has been shifting toward services, in which innovation may require very different approaches, including new ways of managing information (Bell 1973; Spohrer et al. 2012). As noted earlier, a new discipline called *services science* has been emerging, beginning first with reconceptualization of computing as a service provided to the user by companies specializing in advanced information processing, rather than primarily thinking in terms of hardware possessed by the user.

If the economy continues to evolve away from industrial production to provision of services, there will be great challenges for the social and information sciences, and we may not yet be clear about what the most difficult problems or greatest opportunities will be. Communication between users and the organizations providing the services will be essential, and the users may initially lack a full technical appreciation of the requirements for using the service or of the benefits from using it competently. This line of thought implies that tools and procedures for collaboration between people possessing different kinds and levels of expertise will be important, and this is a classical convergence issue. One solution may be professional *convergence consultants*, independent from the major service-providing corporations, able to help the corporation's customers gain the best possible service in the context of their own special needs.

Other issues may arise at the societal level. Outside the specific area of information technology services, there is some concern that service industries are less profitable than manufacturing ones, having less to invest in research and development, and less to pay employees who therefore will have lower salaries. To the extent that many kinds of services are optional, even luxuries, they may exaggerate the magnitude of economic recessions, even during the normal economic cycle. This is somewhat true already for manufactured durable goods, as people continue to drive their old cars during economic recessions rather than buy new ones, and factories put off installing or do not install new equipment. But services that are not essential for survival may suffer almost complete loss of business during economic hard times, thus exaggerating the depth of a recession and even prolonging it (Keynes 1936).

The NBIC2 workshop in Seoul, Korea, contributed a number of ideas that relate to the economic shift from physical production to services, suggesting three related dimensions of this transformation:

1. The aging of the population shifts the balance of both the labor force and human needs.
2. Many challenges will be presented, in moving from an economy based on physical production, to one emphasizing entertainment and psychological well-being.
3. Numerous factors combine in complex ways to require fundamental redesign of the healthcare system.

The fundamental goal becomes enhancing the quality of human life, in a context that is ubiquitous in three senses: (1) society is global rather than local, (2) information technology connects people wherever they happen to be, and (3) achievement of the most important goals requires broad convergence across multiple domains of science and technology rather than narrow specialization.

The world is evolving beyond industrial society, precisely because it has been so successful in providing food, housing, and other material goods required for life. Especially in the context of an aging population, health priorities shift to improved management of incurable chronic conditions, then beyond physical well-being altogether to mental health. Scientific progress in understanding the human brain clearly has an important role to play. Psychiatric disorder can be treated, based on the development of new methods, by finding the root cause of problems such as alcohol abuse, mental diseases, and impaired physical functions. To the extent that the causes are physical, whether chemical or structural, we can reasonably hope that effective new treatments can rely upon convergence technology. But mental health is more than simply cure of “mental illness” following a medical paradigm. It is also well-being in terms of social relationships, engagement in pleasurable activities, and a sense of intellectual and spiritual growth.

During such a massive societal change away from industrial production to services, the entertainment industries become more important, both as a fraction of the economy and in the functions they perform for human beings (Scacchi 2012). An entertainment-driven society can spoil human beings and distract them from important responsibilities they have for human progress, a complex set of problems that science needs to tackle. One clear example is how much Japan has contributed to worldwide entertainment, through popular videogames, manga, and cartoons, even as it has faced industrial stagnation and all the problems attendant to an aging population. Korea has become a major center for the computer gaming industry, illustrating how different nations around the globe can play creative roles for the benefit of all nations. A key research question becomes how to elevate the quality of entertainment so that it becomes art, not merely diverting people but also ennobling their experience of life.

2.8.4 Mimicking Avatar*: Uploading Your Experience*

Contact: *J.-W. Lee*, *Department of Convergence Nanoscience*, *Hanyang University*, *Korea*

Preserving one's memories or even living eternally has been among the most interesting subjects in popular culture. In 2009, *Avatar* became the first motion picture ever to gross two billion dollars, by using advanced computer graphics to depict the transfer of human consciousness into an alien body (Bainbridge 2011: 190–194). The scene was a densely forested habitable moon in another solar system, Pandora, where humans developed software to transfer the soul of a physically disabled human into a cloned body of a member of the Na'vi—a humanoid but very alien species. In so doing, humans created Na'vi–human hybrids with human sprits, called *Avatars*. They can be controlled remotely by genetically matched humans, communicating with each other via a neural network. The background for the creation of Avatars is the following. In the middle of the twenty-second century, humans try to mine a valuable mineral, "unobtanium," on Pandora in order to cope with the exhaustion of natural resources on earth. However, humans face great difficulty in obtaining unobtanium, because Pandora's atmosphere is poisonous to humans. The implication is that advanced avatar technology could be used here on Earth, for other equally radical purposes.

For decades, science fiction writers have speculated about the possibility of transferring human memories and personalities to artificial platforms based on information technology (Clarke 1956; Brunner 1975), and *Avatar* expanded this concept through bio–info convergence. However, some fantasies of the past can become realities of the future, and technically competent visionaries have begun to write serious nonfiction books on this radical possibility (Moravec 1988; Kurzweil 1999). In February 2011, Dmitry Itskov, a Russian media billionaire, announced the "2045 Initiative" to disembody our conscious minds and upload them into holograms (http://2045.com). This is intended to achieve cybernetic immortality and the artificial body as conceptualized in *Avatar*. A research team of leading Russian scientists will be engaged in R&D on humanoid robots, modeling of the brain and consciousness, and so on. They have sketched the following technology roadmap:

2015~2020 (Avatar A); A robotic copy of a human body is remotely controlled via brain–computer interface (BCI). This robot could work in hazardous environments and for rescue operations.

2020~2025 (Avatar B); An avatar in which a human brain is transplanted at the end of the human's life. Achieving this technology could result in another IT revolution by the materialization of hybrid bioelectronics systems.

2030~2035 (Avatar C); An avatar with an artificial brain in which a human personality is transferred at the end of one's life. This really expands human capability by restoring and modifying one's brain at will.

2040~2045 (Avatar D); A hologram-like avatar. This is the time when a humanoid robot exceeds the capability of ordinary humans, called singularity, as predicted by a futurist Ray Kurzweil. It is forecasted that humans will coexist with humanoid robots at that time.

Over the past century, scientists and engineers have tried to make machines that would be able to think, learn, or behave like a human being. The key benchmark in the history of *artificial intelligence* (AI) was a workshop held at Dartmouth College in 1956 (McCarthy et al. 1955). In 1970, *Life* magazine quoted one of the organizers, Marvin Minsky, as saying, "In from three to eight years we will have a machine with the general intelligence of an average human being" (Darrach 1970, 58). Later, Minsky said he was misquoted, but it appears that progress was slower than he and many other Dartmouth participants had expected (Crevier 1993; McCorduck 2004). One reason may be that for them *intelligence* meant the ability to solve complex but well-defined puzzles, such as the technical design challenges faced by engineers, rather than the ability to behave exactly as a human being does (Simon 1996). However, progress has constantly been achieved in AI, and already 15 years ago, affective computing was developing means for allowing machines to understand human emotions (Picard 1997).

AI was one of the fields that converged to create cognitive science, and a full NBIC convergence can accelerate progress. A major challenge in duplicating the human mind is the fact that nobody fully grasps how our brains work. Nevertheless, in the past few years, there have been real advances in several fields of research in the building of an AI system. For example, neuroscientists have gained considerable knowledge about how learning occurs at the level of a single synapse. Computer scientists have modeled and simulated the neural mechanisms to obtain the behavior of neurons using supercomputers. Engineers have investigated nanoelectronics with some promising results such as more computation power, higher density, and less power consumption.

What kinds of AI systems will we introduce in the future? A first approach to get thinking machines is to develop the technology that can let us control a machine simply by thinking. This is called either *brain–machine interface* (BMI) or *brain–computer interaction* (BCI). BCI has had reasonable success in moving parts of the human body like arms, legs, and wrists. BCI technology could be further extended into stimulating brain and muscles simultaneously to restore the movement of physically disabled people. Nevertheless, real enhancement of the physically disabled still has a long way to go in that researchers all over the world are still struggling to find the basic principles of neural activities in the motor cortex, a part of the brain controlling movement.

In the long-term future, we could directly feed a much denser stream of information to our retinas by optical implants, including contact lenses, and to nanosystems implanted on our cerebral cortexes. An app will tell you what to do and will guide your work. As illustrated in *Avatar*, brain waves from thinking thus would control all the machines and even yield person-to-person communication via a shared neural network.

After 2020, we expect to have AI robots substantially better in performance than present humanoid robots. However, if we use conventional CMOS integrated circuits for them, the power consumption may surpass 100 kW, which is almost one-third of that of the IBM Watson computer that beat a human expert in the game Jeopardy (Markoff 2011). The human brain runs on about 20 W, while the power for the robot as smart as the human brain (100 petaFLOPS) requires 100 MW—a small nuclear power plant if you use conventional CMOS utilizing von Neumann-based software. Thus, energy efficiency fundamentally limits our ability to realize AI systems unless we do not use CMOS for the AI hardware. Furthermore, other big technological obstacles in today's CMOS integrated circuits are unacceptable variations in properties, size, noise, defects, and density of devices. Up to now, no solution to overcome these barriers has been found, regardless of the form in the name of beyond-CMOS.

In addition, computer-based computation is very inefficient at human tasks such as adaptability, pattern recognition, and error tolerance. This is because the human brain processes information in parallel mode even 10,000,000 times slower than today's desktop computer. Thus, the R&D priority for the materialization of AI systems could be given to brain-inspired neuromorphic devices. Mimicking the function of human brain through hardware development could be the first prerequisite to the successful buildup of AI systems. Fortunately, recent advancements in nanoelectronics including phase change memory (PCM) and metal oxide resistive switching (random-access) memory (RRAM) and other memories have allowed renewed hope in emulating the human brain, because they offer much higher memory density and lower power consumption, which are essential for artificial synapses in neuromorphic hardware. Nevertheless, the development of brain-inspired neuromorphic devices is still in the early stage of research.

From this perspective, mapping the entire brain of an individual would be required for complete preservation of the brain, and perhaps even to understand the mechanisms of brain functions. This is called the *connectome*, a comprehensive map of neurons to fully catch up with learning, recognition, and reasoning mechanisms (Kasthuri and Lichtman 2010). However, there is an insurmountable technological difficulty associated with mapping the entire human brain, since our brain consists of perhaps 10^{11} neurons and 10^{14}–10^{15} synapses. More than 1 zettabyte (10^{21} bytes) of random access memory (RAM) would be needed to store all the mapping information. To put that figure in perspective, IBM's Watson computer—the winner of Jeopardy—contains only 16 terabytes (1.6×10^{13}) of RAM, and the year 2012's total digital data produced from all over the world was 2.8 zettabytes.

An alternative viewpoint argues that the information defining an individual human's mind with reasonable fidelity is much, much smaller, for example encompassing perhaps only 50,000 episodic memories of life events, each of which consists of a very small net of connections to memories of concepts, which themselves number only in the tens of thousands (Bainbridge 2002, 2003). Perhaps the large number of neurons in the human brain is merely evolution's way of compensating by means of massively parallel processing for how slowly each neuron reacts compared to computer components. Thus, while neurons are the fundamental units in the brain, perhaps much larger modules encompassing many neurons actually represent concepts at a far grosser scale, and only they would need to be emulated by a computer. Or, it may be that nanoscale processes inside each neuron are crucial, and the previous paragraph even underestimates the difficulty of the challenge. These debates are among many that can be resolved only through convergence across many fields of science.

2.8.5 Human–Robot Interaction: An Emerging Field Dependent Upon CKTS

Refer to: *WTEC Study on R&D in Human–Robot Interaction* (http://www.wtec.org/reports.htm)

In the last decade or so, robotics research has become increasingly focused on understanding and defining the dynamic interactions between human and robot, to help make robots easier for people to use in a wider variety of situations. Many emerging applications of robotic systems are being based on models of human intelligence and behavior. In general, robotic applications trend today toward *proximate* interactions of humans with robots, and "*toward peer or mentor roles*" (Goodrich and Schultz 2007, 234–235).

These trends have pushed the development of a new field, that of human–robot interaction (HRI), where clinical and rehabilitative medicine, biomedical engineering, social psychology, neuroscience, cognitive science, human factors research, artificial intelligence, organizational behavior, anthropology, linguistics, and even standards-setting governance, all have become essential to advancing the ability of robots to meet human needs.

As the U.S. Office of Naval Research puts it, HRI aims to "develop the underlying principles and technology that will enable autonomous vehicles and robots to work with people as capable partners."[1] Prestigious university, industrial, and national laboratories across the United States, Europe, and East Asia are investigating and refining myriad applications for HRI, including the ones listed below. Each has different human–robot interaction paradigms and interface modalities, depending on the robot's role:

- Robotic assistance for seniors and persons recovering from injuries or with disabilities to provide physical, cognitive, safety, occupational and physical

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[1] http://www.onr.navy.mil/en/Media-Center/Fact-Sheets/Human-Robotic-Interaction.aspx

therapy, and/or social support, where it is critical for the human to feel safe, comfortable, and “in control” when interacting with the robot

- Robotic devices for microsurgery and telesurgery where the communication between surgeon and robot must be seamless and intuitive and the mechanical capabilities must be intricate
- Robots that provide teaching, interaction, and therapy for individuals with autism spectrum disorders or trauma, who may respond better to mechanical devices than to social interaction
- Service robots that perform innumerable, mostly precise, automated tasks in manufacturing, mining, inventory management, agriculture, even as receptionists
- Robots for entertainment and education, as dance partners, tour guides, storytellers, even pets
- Unmanned intelligent or autonomous space, air, naval, underwater, and ground vehicles for military, academic, private, and public use under a variety of complex operating conditions
- Robot-assisted search and rescue operations in which human–robot interactions must be capable of considerable complexity because of the inherently unstructured nature of such work
- Robot-assisted space exploration with specific challenges due to extreme operating conditions. Interactions include both time-lag and proximal interactions such as the robot assisting a human to transport equipment, perform physical tasks, and/or provide sensing and information

2.9 International Perspectives

The following are summaries relevant to this chapter of discussions at the international regional WTEC NBIC2 workshops held in Leuven, Belgium, September 20–21, 2012; in Seoul, Korea, October 15–16, 2012; and in Beijing, China, October 18–19, 2012. Further details of those workshops are provided in Appendix A.

2.9.1 United States–European Union NBIC2 Workshop (Leuven, Belgium)

Participants: *Elements of all three EU working groups’ deliberations had relevance for this topic, as presented in the final plenary session. Participants in the Leuven workshop are listed in Appendix B.*

This workshop’s participants identified three major interrelated themes where convergence could achieve great continued progress: (1) productivity, (2) human capacity, and (3) education. Increased productivity can create many new jobs, even as some older jobs become obsolete, so long as human capacity is also increased, and transforming education is one of the best ways to accomplish this.

NBIC-enhanced automation, carefully designed standardization across fields, and more efficient use of time and materials will be essential for future productivity. Techniques such as neuromorphic engineering and transformational communication media can employ machines to increase human capabilities, thereby improving both ourselves and the tasks we can perform. Essential for success will be changes in education at all levels—vocational, continuing education, undergraduate, and graduate education. This is not just a zero-sum game, but progress with a positive sum in which the entire world can participate, through knowledge-sharing, creative imagination, and new approaches to economic challenges, prominently including social justice and issues of negative externality defined in terms of the limited resources of the planet.

Nearly limitless productivity growth can be achieved through convergence of a wide range of new technologies, from nanomaterials, to robotics, to knowledge-based manufacturing that enables personalized production. Immersive technologies, based on sensors and adaptive human–machine interaction systems, can render robots more autonomous and human-like, even as the human experience of work can be improved on the basis of anthropomorphic interactions between psychology and cognitive science on the one hand, and robotics and machine learning on the other hand. Education must empower people to act—democratizing the ways to play and to experiment, while permitting appropriate standardization—in the context of a rethinking of high-school education to include vocational training in machine–human interfaces because of the changes in the job market. Ph.D. training could be reconceptualized as a team effort, or always involving more than one field, to escape the inhibiting constraints of assuming higher degrees are based on one lone person in one narrow field.

2.9.2 United States–Korea–Japan NBIC2 Workshop (Seoul, Korea)

***Panel members/discussants*:**

Wonjong Yoo (*Co-Moderator*), *SKKU Advanced Institute of Nanotechnology* (*Korea*)
Takeshi Kawano (*Co-Moderator*), *Toyohashi University of Technology* (*Japan*)
H.-S. Philip Wong (*Co-Moderator*), *Stanford University* (*U.S.*)

***Others*:**

Sung Ha Park, *Sungkyunkwan University* (*Korea*)
Jiyoung Kim, *Kookmin University* (*Korea*)
Mitsuo Kawato, *ATR Brain Information Communication Research Laboratory* (*Japan*)
Kazunobu Tanaka, *Japan Science and Technology Agency* (*JST*, *Japan*)
Myung-Ae Chung, *Electronics and Telecommunications Research Institute* (*ETRI*, *Korea*)

S. Kawamura, *JST* (*Japan*)
Young-Jae Lim, *ETRI* (*Korea*)
Yong-Joo Kim, *Korea Electrotechnology Research Institute* (*KERI*, *Korea*)
Changhwan Choi, *Hangyang University* (*Korea*)
Sanghee Sun, *Korea Institute of Science and Technology* (*KIST*, *Korea*)
Young Jik Lee, *ETRI* (*Korea*)

This group emphasized the ubiquitous nature of communications, globally, and the shift from a world economy based on industrial production to one giving greater emphasis to services such as healthcare and entertainment. It identified some specific convergence trends, including collaboration between electronic and biological research, nanobiotechnology, and the increasing role for social science as the economy shifts further toward services. The volatility of new industries poses challenges for people pursuing careers in science and engineering, even as research and development become global enterprises. The economically advanced nations must provide adequate healthcare and other services for their aging populations but must look beyond merely physical survival to mental and emotional well-being. Some forms of mental disorder may be cured or at least managed by new methods resulting from nano-bio-cogno convergence, but it will also be crucial to support improved mental functioning through life-long education and forms of entertainment designed to be substantively beneficial rather than merely diverting.

2.9.3 United States–China–Australia–India NBIC2 Workshop (Beijing, China)

***Panel members/discussants*:**

Shushan Cai (*Co-Moderator*), *Tsinghua University* (*China*)
Tanya Monro (*Co-Moderator*), *University of Adelaide* (*Australia*)
H.-S. Philip Wong (*Co-Moderator*), *Stanford University* (*U.S.*)

***Others*:**

Jonathan Manton, *University of Melbourne* (*Australia*)
Tianzi Jiang, *Academy of Sciences* (*China*)
Tingshao Zhu, *Academy of Sciences* (*China*)
Chen Chen (*China*)

This group emphasized issues directly or indirectly connected to health. In recent years, convergence between fields has begun but is incomplete. Medical patients have greater knowledge about their conditions, and there exists increased public concern about the environmental impact of new technologies, coupled with a general social acceptance of technological change. In the near future, we can expect improved mental health and general quality of life improvements from convergence. Mental health will benefit from far more comprehensive understanding of the causes of problems, for example, based on data mining of information about large numbers of cases and more advanced diagnostic methods, leading to improved treatments. Personalized medicine can especially advance through ubiquitous diagnostics, using sensors and other information technologies to collect data about peoples' individual health as they go about their daily activities. New assistive medical devices may replace and augment functions. Outside the domain of health, the quality of life can benefit from improved social well-being, including social management and appropriate intervention, in a safe environment with secure and efficient access to food, water, and other necessities. We can create an NBIC-technologically literate society by bringing together clinicians, scientists, and engineers to create a common language and train the next generation to be real-world problem solvers, through transdisciplinary research and education.

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