Chapter 6
Implications: Human Cognition and Communication and the Emergence of the Cognitive Society

James L. Olds, Philip Rubin, Donald MacGregor, Marc Madou, Anne McLaughlin, Aude Oliva, Brian Scassellati, and H.-S. Philip Wong

6.1 Vision

6.1.1 Changes in the Vision over the Past Decade

Over the past 10 years, the vision of how convergent technologies can be utilized to positively affect society has undergone many changes (Adamson 2012). Among them are the deployment of ubiquitous noninvasive brain visualization technologies, the recognition of nonverbal communication (spatial cognition, alternative sense modalities, brain–brain, and brain–machine), and the emergence of neuromorphic engineering. At a societal level, these changes to the vision have manifested

---

Corresponding editors M.C. Roco (mroco@nsf.gov) and W.S. Bainbridge (wbainbri@nsf.gov).

J.L. Olds
Krasnow Institute for Advanced Studies, Fairfax, VA, USA

P. Rubin
Office of Science and Technology Policy, Washington, DC, USA

D. MacGregor
MacGregor-Bates, Eugene, OR, USA

M. Madou
University of California, Irvine, Irvine, CA, USA

A. McLaughlin
North Carolina State University, Raleigh, NC, USA

A. Oliva
Massachusetts Institute of Technology, Cambridge, MA, USA

B. Scassellati
Yale University, New Haven, CT, USA

H.-S.P. Wong
Stanford University, Stanford, CA, USA

M.C. Roco et al. (eds.), *Convergence of Knowledge, Technology and Society: Beyond Convergence of Nano-Bio-Info-Cognitive Technologies*, Science Policy Reports,
DOI 10.1007/978-3-319-02204-8_6, © Springer International Publishing Switzerland 2013

themselves in the viral nature of social networking, the popularity of functional brain images in the mass media, and the ability to use nanoelectronics to emulate some aspects of how the brain functions. This change in vision has made it possible to massively enhance the readily assessable computational power of human brains: the current meme that one's smartphone "has more computing power than all of NASA did when it put a man on the moon in 1969" (Otellini 2012) reflects not only massive change in American society but a qualitatively different perspective on what convergent technologies mean for everyday life. This evolution in our perspective, then, is that convergent technologies are fully embedded in ordinary life, where they augment individual human connections, access to domain knowledge, and cognition in profound ways that their inventors (e.g., Google's Larry Page, and Facebook's Mark Zuckerberg) never conceived of at the time of their invention. In this chapter, we argue that this evolutionary trajectory is profound and use the term "The Cognitive Society" to represent a future global cognitive awareness that is emerging from the current progression.

6.1.2 Background: The Emergence of Cognitive Science as a Discipline

***Contact**: W. S. Bainbridge, NSF*

The convergence of subdisciplines from the multiple fields that created cognitive science three or four decades ago had the effect of distancing this new discipline from others, notably clinical psychology and psychiatry, with which a rapprochement may now be in order. Founded in 1979, the Cognitive Science Society (http://cognitivesciencesociety.org/) lists the main constituent fields of cognitive science as artificial intelligence, linguistics, anthropology, psychology, neuroscience, philosophy, and education—but not such highly cognitive social sciences as sociology and political science. The inclusion of "psychology" refers primarily to cognitive psychology, which leaves ambiguous how deeply involved social psychology should be—and the Cognitive Science Society does not really include personality psychology and clinical psychology. The inclusion of neuroscience has not meant a strong connection to psychiatry, but it serves as a second bridge to applications of cognitive science in the general area of mental well-being.

By the mid-1980s, despite its great accomplishments and high prestige, the American Psychological Association came to be seen by many research psychologists as too heavily influenced by mental health practitioners, whose perspective may on occasion be unduly oriented toward what their clients or patients accept, rather than toward the results of rigorous research (Pinker 1997). In 1988, a group initially calling itself the American Psychological Society—now the international Association for Psychological Science—sought to establish the field on a more scientific basis, but without the convergent quality of the Cognitive Science Society. Now that cognitive science is well established as a field, and the leaders of many nations have come to recognize the need for reform of many aspects of their healthcare systems, cognitive science could make a major contribution in the area of mental and emotional well-being, whether or not this is conceptualized as a convergence with clinical psychology and psychiatry.

Applied mental health fields tend to follow a *disease model* of the problems they face, except to some extent in dealing with cases of mental retardation and autism where a *disability model* also comes into play. Conceptualizing a mental problem as a disease asserts that proper treatment could return a person to normal, and thus that a clear definition of normal exists. Critics have called the excessive imposition of the disease model *medicalization* and have suggested that despite the great benefits medicine often can offer, many kinds of "cases" could better be conceptualized as a poor fit between the innate mental characteristics of a person and the expectations of the surrounding society (Conrad and Schneider 1980). Unfortunately, most problems faced by psychiatrists can be diagnosed currently only by listing behavioral symptoms, which is superficial, imprecise, and makes it difficult either to select the correct treatment from the range of remedies currently available or to develop new and more appropriate treatments.[1] Here, cognitive science may often be in a better position than psychiatry to develop really rigorous modes of diagnosis to identify the kinds of cases where a medical model is inappropriate, whether through the use of sophisticated brain scan methods or genetic testing, both of which combine information technology with biotechnology. Principles from cognitive science could better decide when efforts to help a person should concentrate on new assistive technologies, educational programs to give the person new skills that can compensate for an incurable disability, and perhaps even make adjustments in society's expectations.

By listing anthropology among its constituent fields, the Cognitive Science Society chiefly included a number of theory-oriented anthropologists, but that wing of cognitive science can play a key role now by reversing a divergence that occurred decades ago, when the *culture and personality* school in anthropology, and a subfield within it called *ethnopsychiatry*, faded from prominence. Anthropologists had observed that societies differed significantly—but certainly not completely—in what they defined as normal (Benedict 1934; Ackerknecht 1943). By the 1960s, a considerable body of literature in ethnopsychiatry had developed, some of it incorporating rather sophisticated cognitive theories (Opler 1959; Kaplan 1961). However, the significance of this approach faded, because it did not offer practical treatments to assist maladapted people in adjusting to the lives in which they find themselves. A defining feature of this approach is the *variance model* of mental and emotional problems that some people currently suffering greatly could make a very satisfactory adjustment in a different society that happens to value the innate characteristics they possess. To provide the best modern response to the full range of problems, the three models—disease, disability, or variance—must converge (e.g., the spectrum disorder model, Wurzman and Giordano 2012; Kendler and Parnas 2008). A competent diagnostician must be ready to select the right model for the

---

[1] See Haslam (2002) and associated references for examples of articles that discuss psychiatric taxonomy and the ontological assumptions of the medical model.

particular case: disease, disability, or variance. Cognitive science can play the central role in developing rigorous diagnostic methods, and perhaps in designing new social environments, that would be especially helpful for people whose problems fit either the disability model or the variance model.

6.1.3 The Vision for the Next Decade

Below the level of human cognition, but subserving it, is the neurobiology of the brain. The neurobiology of the human brain plays out in the micro-domain of neurons and the nano-domain of synapses. While nanotechnologies are maturing along the trajectory laid out in the "NBIC" process (see Chap. 4), the vision for how they will change society has been altered by the new discipline of neurotechnology, which seeks to build on new knowledge of the brain's natural neural code to create brain–machine interfaces far more powerful than what had once been thought possible. In particular, nanotechnologies offer the vision of bringing the power of the smartphone and the social network into direct physical contact with brains, in sharp contrast to the current touchscreen interfaces that we now use. Such hybridization or blurring of the distinction between machines and biology, formerly the stuff of science fiction, will in the future create very significant and new governance challenges for humans, while at the same time offering up new potential for an enhanced human response to global challenges. It may also be possible to construct neuromorphic machines that complement and subsequently emulate the functions of the brain.

Furthermore, deeper knowledge of natural brain processes will usher in the possibility of reprogramming some of that inherent biology to open up new vistas. Sensory channels (such as gustation) may acquire new additional cognitive "meaning" through the use of artificial sensor–neural communication systems (Bach-y-Rita et al. 2003). Neural code translation devices may make possible direct brain-to-brain communication channels in addition to the ones that have been used for millennia, that is, language and culture.

The development of sophisticated brain–machine interfaces that make full use of neural coding will increase human capacity. New information channels with greater bandwidth will be a central characteristic of the technological driver for capacity growth. As capacity grows for individuals, it will also be reflected at the societal level. New modes of communication that take advantage of the above-described advances will change the very nature of group decision-making processes. Almost certainly they will add an unprecedented level of transparency. Such changes will affect education, markets, and policies. There will be both opportunities and risks associated with such a sea change.

In essence, the vision for the next 10 years moves beyond the notion of connectome (the wiring blueprint for the brain) to a new concept: the "cognome", a blueprint for higher cognition in both individual and socially interacting brains (Horn 2002). This new concept of cognome in turn will lead to a new science of "mind", which will bring together disciplinary threads that include most of the physical and social sciences. In short, the vision for the next 10 years is for a transdisciplinary Renaissance in human cognition and social communication.

6.2 Advances in the Last Decade and Current Status

6.2.1 Advances in Converging Technologies

The first decade of the twenty-first century saw a number of significant advances in convergent technologies that affected human cognition, communication, and quality of life. The common denominator in these advances was not so much qualitative shifts to new technologies but rather the notion of ubiquity: formerly cutting-edge technologies became smaller, faster, and embedded in the day-to-day life of Americans, particularly in the five specific domains of cognitive science of science, computing/cloud/social networking, functional brain imaging, social "enabling" of big data, and widespread general access to "maker" technologies such as 3D printing.

Cognitive Science of Science

Scientists in different fields, and researchers with different dispositions or backgrounds within each field, use different modes of cognition to do their work, and cognitive science has begun to identify alternative ways of thinking scientifically. For example, one tradition in the artificial intelligence branch of cognitive science conceptualizes engineering problems in terms of a predefined design space, with each dimension representing a different class of alternative choices, and then uses rigorous computer methods to search the design space for one or more optimal solutions (Simon 1996). This method assumes that the design space is already well defined, so it does not prepare a researcher well for making entirely fresh discoveries, yet many scientists may use a similar rubric even in pure research, whether or not they employ computers.

A standard view in the philosophy of science is that formal hypotheses must be stated within a rigorous theoretical structure and tested empirically, although debates have raged about whether true hypotheses can be unambiguously confirmed, and how cognitive habits may bias the process of evaluation (Popper 1959; Klayman and Ha 1987). But many scientists—in fields as diverse as paleontology and linguistics—spend most of their time collecting and categorizing specimens rather than searching a design space or testing hypotheses. Many of the difficulties that members of the general public have in understanding science may stem not so much from ignorance as from the fact that the modes of cognition that evolved to serve everyday needs are very different from those required in science. For example, much of the resistance to the theory of evolution by natural selection from random variation may reflect the human propensity to think in terms of narrative stories centered on protagonists who seek goals, face challenges, and gather resources to help them (Abbott 2003). Even among scientists, this may bias thinking about evolution, instinctively seeing it as goal-oriented, and possibly deterring convergence between evolutionary biologists and scientists in other fields where the human propensity to think in terms of conscious goals is insufficiently counteracted by their training.

Cognitive science needs to take a new and comprehensive look at the varieties of scientific cognition, and as each variety is better understood, cognitive science should develop an increasingly rigorous map to chart their variations and potential convergence. Positive results could include:

- Better designs for the tools used by the scientists
- Improved education of future scientists
- Insights that can help practicing scientists understand their own mental processes
- New principles for convergence between sciences based on much better understanding of how the various different kinds of scientists think

Computing/Cloud/Social Networking

What used to be called “high-performance” computing in the 1980s is now present in hand-held computers used by a majority of U.S. consumers (Lunden 2012). This ubiquity has been made possible by advances in semiconductor technologies as projected by Moore’s Law and underlying innovations in nanotechnologies, particularly with regard to device density improvements of computer chips (Fig. 6.1).

With the “smartphone” revolution has come the advance of cloud computing and the deployment of mobile social networking applications that enhance human communication, knowledge retrieval, and citizen journalism. Regime change on a multinational scale via the “Arab Spring” appeared to be enhanced considerably by these convergent technologies.

Functional Brain Imaging

The current gold standard for noninvasive imaging of human brain activity remains the same: functional magnetic resonance imaging (fMRI) (Fig. 6.2). The use of high-field magnets, sophisticated multichannel receiver coils, and advances in analytical imaging methodologies have all enhanced fMRI’s sensitivity, yet the essential challenge of mismatch to the neural code, both spatially and temporally, remains.[2] What has changed in the past 10 years is the use of fMRI in cognitive research. This technology has come to

---

[2] fMRI detects functional neuronal activity with a spatial resolution of millimeters and a temporal resolution of seconds. By contrast, neurons have spatial dimensions on the order of microns and fire action potentials that last milliseconds.

Fig. 6.1 The evolution of computation: An early 1980s image-acquisition board and an iPhone 4 (Photo by J. Olds)

Fig. 6.2 Functional magnetic resonance imaging (fMRI) remains the most common method for imaging human brains as they think (Photo by J. Olds)

dominate cognitive and neurophysiological studies (Cabeza and Nyberg 1997, 2000; Rosen and Savloy 2012). The technology has also been widely adopted (potentially inappropriately) by the private sector in areas ranging from marketing to deception detection (e.g., see Farah and Wolpe 2004).

Social Enabling of Big Data/Social Networking

What has made Facebook a global phenomenon was not software innovation but rather its ability to engage users. As of 2012 Facebook had 500 million mobile users and 901 million monthly active users (SEC 2012). That engagement was compelling enough that users willingly enabled "Big Data" approaches to mining their personal information. A similar "value proposition," writ large, was also crucial to Google's success in the search domain—at least as important as its page rank algorithm. In May of 2011, Google had a U.S. audience of 155 million unique visitors (Machlis 2011).

What is the nature of that "value proposition"? At its most basic level, it is an exchange of information. Users exchange their own personal information (within a heterogeneous ecosystem of privacy protection schemes) for information about the world, including most importantly their own social networks.

The emergence of the above-described exchange has resulted in massively coupled social networks. These networks played central roles in the Arab Spring, the "Occupy" movement, and recovery efforts after the earthquake in Haiti. The field of Computational Social Sciences is a new discipline that has arisen, at least partly, because this "enabled" Big Data has become both available via public APIs (application programming interfaces) and amenable to computational approaches.

Widespread General Access to "Maker" Technologies

The "maker" phenomenon, a grassroots movement that represents a technology-based extension of the do-it-yourself culture, has been accelerated by the advent of inexpensive 3D printing, genomics, and microcontroller chips. While chip fabrication facilities (fabs) are still beyond the reach of the maker culture, a vast array of other technologies is now within the reach of the motivated lay public: a low-end 3D printer costs about $1,500 (Peck 2012). In a sense, science and engineering skills are being democratized in the same way that software engineering was several decades ago. The societal implications of this shift are not yet clear but promise to be profound.

6.2.2 Relationship of Advances to the Tools for Converging Technologies

Each of the above-described advances acts to enhance the impact of converging technologies on the American polity. Thus, while the societal value of these advances is still open to debate, they each act as an "amplifier". Taken together, the common denominator of these advances is to accelerate societal change.

6.3 Goals for the Next Decade

The overarching goal is to enrich individual human lives while at the same time sustaining the biosphere that humans share with all other living things.

6.3.1 Goal 1: Assistive Robotic Technologies in a New Context: Cognitive and Social Support

Robotics has the potential to impact our daily lives substantially in the next decade, although perhaps not in the ways we envisioned 10 years ago (Tapus et al. 2007). 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 support. This change in vision offers a substantial intersection for converging technology that can impact quality of life for many individuals. An important area of convergence in the next 20 years will be of robotic systems that (a) offer support for individuals to navigate the cognitively challenging society that the information revolution has produced; (b) enhance social support for individuals to allow for a more connected and more natural personal life experience; and (c) help to coach, train, and support healthy behavior and educational goals.

Embodied robotic systems that provide social and cognitive support to individuals have the potential to address a diverse range of populations and some of the most critical societal issues facing the world today. For example, consider the following three target areas:

1. *Aging populations*: It is estimated that in 2050 there will be three times more people over the age of 85 than there are today (UN/POPIN 2012). A significant portion of the aging population is expected to need physical and cognitive assistance. Yet, space and staff shortages at nursing homes and other care facilities are already an issue today. As the elderly population continues to grow, a great deal of attention and research will be dedicated to assistive systems aimed at promoting "aging in place," i.e., living independently in one's own home for as long as possible. Assistive robotic systems for the elderly, therefore, require technologies capable of being commanded through natural communication (e.g., speech, gestures), of fetching items, and of assisting with daily activities (e.g., dressing, feeding, moving independently).
2. *Early childhood education*: Early caretaker interaction with prekindergarten children helps to promote healthy life habits, raises the quality of the future work force, enhances the productivity of schools, and helps to reduce crime, teenage pregnancy, and welfare dependency (Campbell et al. 2002). While many studies

support the societal benefits of early childhood education, there is surprisingly little technological innovation enabling new and distributed forms of such training for young children, especially outside of traditional classroom settings or for children who need aid in areas not covered by typical classroom instruction. Furthermore, increases in class size, decreases in the availability of trained pre-K teachers, and the increasingly hectic pace of life for many parents have resulted in opportunities for technology to supplement existing formal and informal educational programs. Robotics technology has the potential to augment the skills of parents and educators rather than supplanting them. Technologies for tracking skill development, assessing skill competence, and individualizing behavior and habit shaping and instruction could have substantial benefits for this young population.

3. *Individuals with disabilities*. Individuals with cognitive disabilities, developmental disabilities, and social disorders constitute another growing population that can benefit from socially assistive robotics through special education, therapy, and training (Scassellati et al. 2012). Current research suggests that an average of 1 in every 110 children in the United States will be diagnosed with autism spectrum disorder (ASD) (DHHS/CDC 2012). Early intervention is critical for a positive long-term outcome, and many individuals with ASD need high levels of support throughout their lives (Volkmar et al. 2004). Robotics offers the potential for long-term supportive interactions that motivate individuals to maintain appropriate therapeutic activities, support human–human interactions through novel technological interfaces, and enrich human experience throughout an individual's lifespan.

One of the primary challenges in providing these kinds of technological support for social and cognitive tasks is the development of systems that adapt to the individual needs of their users. Just as there is no single educational approach or training technique that is guaranteed to succeed with all students, a single constant design for a cognitive support technology will fail if it cannot adjust to the unique needs, personality, and capabilities of each individual user. The converging technology solution to this requirement relies upon leveraging the collective information of many users, identifying commonalities among groups of users, and applying likely approaches from one user to "jump start" the interaction options for a new user, all while maintaining the privacy and identity of each of the users.

Over the longer-term, one might have a vision for assistive software/machine interfaces that assist individuals' ability to understand the world around them. Such interfaces might customize in real-time approaches to communicate scientific information. An application might be to communicate information about medicine and treatments. Such interfaces might also distill and synthesize Internet communications about an issue of importance (e.g. climate change) using words and concepts appropriate for the user. Analogous tools might help users better perceive the world around them (e.g., perception of the feelings of family members, friends, co-workers; of potential hazards—while driving, recreating, eating; of sounds and electromagnetic stimulus beyond normal human senses).

6.3.2 Goal 2: Cognome: A Theory-Based Rule Set for Understanding Human Cognition

By any account, humanity's rate of progress is breathtaking: in 1969 we celebrated mankind's first walk on the moon. Fifty years later, we could have billions of people "reaching into the cloud" to access a compendium of human knowledge via noninvasive mind–machine interfaces.

Today, we are standing at the threshold of producing paradigm-shifting discoveries by taking what we learn from basic sciences to address practical problems so as to drastically improve quality of life and augment personal capacity. However, an immense obstacle remains: we are surrounded by an exponential growth of processing units connected with the outside world (via web-enabled devices), yet we do not know how our own "smart device", the human mind, works. We are rapidly approaching an era in which the benefits of living in a highly technologized society will be put at risk unless we are able to understand how we, as a single individual or a group, process and retain information, make decisions, and perform actions. Getting to that point will require a much deeper understanding of the rule set that subserves decision-making. We term that rule set "cognome".

Cognitive technologies have started to inundate our everyday life: the Internet and wireless access put the world's information in the hand of the individual. The availability of mobile web-enabled devices—noninvasive artificial interfaces between a user's mind and the external world (e.g., smartphones)—is enabling everyone to accomplish tasks that used to take days or minutes in a fraction of the time. As web-enabled technology compresses time, there is zero lag time between an event's occurrence in the world, that information flowing to the world, and the world's response. At such a time scale, errors can also be corrected with no lag, which will revolutionize personal medicine, the global economy, and education, and force us to reconsider issues of national and international security.

But as technology and access to information have grown exponentially, our understanding of the human brain and the human mind has not. The wider the gap grows, the harder it will be to close, and the harder it will become to create the next technology wave. Hence, closing the gap is necessary in order to realize the potential utility of convergent technologies.

There are, however, ways forward. For instance, noninvasive intelligent mind–machine (and body–machine) interfaces will become increasingly beneficial when we know the code used by the brain to communicate with the external world—to improve both physical and mental capabilities. But it will be necessary to first significantly expand our understanding of how the brain interfaces with the world.

In the direction of devising assistive devices that can enhance human physical capabilities, a breakthrough is underway in a surgery-free method for treating blindness by Dr. Sheila Nirenberg (Nirenberg and Pandarinath 2012; Nirenberg et al. 2012). By cracking the retina's code—that is, the code the retina normally uses to communicate with the brain—Dr. Nirenberg designed a noninvasive neuroprosthetic that allows the restoration of quasi-normal vision for completely blind retinas, by producing normally coded signals of faces, landscapes, people walking, etc., that the brain can understand. Another breakthrough is underway in integrating human perceptual science with material engineering. Dr. Edward Adelson (Johnson and Adelson 2009) has developed a new tactile sensing technology able to sense the shape of the surface it touches with extremely high spatial resolution and with compliance similar to that of a human fingertip. Such a technology has direct applications for medical, robotic, and industrial domains where the mechanical properties of material or tissues touched needs to be recovered with fine detail and in a minimally invasive manner (e.g., robotic applications with sensitive gripping surfaces, surgery, brain–machine tactile interfaces, and wearable computing). With similar implications, recent advances in computational data sciences (Torralba et al. 2008), can allow smart devices to "see" better than we are currently able to, remembering massive amounts of information that we cannot store in our brain. Augmenting our memory capacity can potentially be achieved by improving the perceptual and cognitive capabilities of our smart devices so that they can "perceive" the world without our assistance and in sensory modalities that we do not naturally possess.

Considering the evolution of assistive devices that can learn from the human brain, our ability to build very-large-scale nanoelectronic systems will let us emulate functions of the brain. Further advances in nanomaterials and nanodevices enable such brain simulations to reach capabilities at the functional level. At that point, the notion of reverse-engineering the brain to find out how it works may become reality.

As perceptual, cognitive, and social sensors and technologies become increasingly ubiquitous, they will enable us to transcend current human limitations and improve life from birth until old age.

6.3.3 Goal 3: "My Own Genomics": Convergent Technologies to Enhance Wellness, Quality of Life

When considering human cognition, communication, and quality of life in converging technologies it is critical to include individual empowerment through tools and systems designed to allow such empowerment. Understanding the self at all levels, from the nanoscale level up through one's behavior within a society, requires access to data and the ability to interpret and comprehend those data. With the advent of low-cost technologies, citizen scientists with access to low-cost education can build tools to collect massive datasets and analyze them at the individual level. But better tools need to be created (Fig. 6.3) as well as an educational infrastructure supporting the minds that will build and utilize such tools, as described below.

There are numerous current examples of individual data easily available to the layperson and inexpensive or free tools for interpreting these data. For example, the 23andme Company (http://23andme.com) can provide a complete genotype given just a cheek swab. This can reveal health and ancestry information. Further, the data provided are not only of the individual's DNA results, but those results in the

Fig. 6.3 Current gene sequencer; next version the size of a thumb drive? Current genomic technology is undergoing a rapid transition. Microfluidics and other nanotechnologies may radically reduce the footprint and cost for human genomics (Photo by J. Olds)

context of others; for example, a user might learn that s/he possesses a genetic variant linked to hemochromatosis. In addition, the context would also be provided, namely, that it is the most common genetic disease in the United States (Siddique and Kowdley 2012). Finally, that user would gain access to educational materials about genetics in general.

As an example of what may lie ahead in the near future, the SpikerBox technology has opened electrophysiology to citizen scientists. Created by Timothy Marzullo and Gregory Gage through Backyard Brains (2012; http://backyardbrains.com/), the device allows one to record single-neuron activity from an insect, using a smartphone as a data-visualization device. In the future, such do-it-yourself technology may be applicable to human brains using noninvasive sensors.

Another example is the personalized health record. Via smartphone apps and other devices, it is possible to record real-time health information, from heart-rate to skin cancer identification, from blood sugar readings. Although summary information of these and other vital signs is helpful for bringing to the attention of a doctor, this information will be most helpful in context, for example, in helping people to understand the relationships between differing foods and activities and their blood sugar levels and in exploring patterns of reactions to foods, hormones, and environmental stimuli. There are concerns about such data, from privacy and security issues to misinterpretation and medical errors (El Boghdady 2012). In this case, the ability to collect data has outstripped the ability of most users to analyze it. There are specialized programs for a few variables, but these data need to be examined in context with each other, in spatial context, in temporal context, and in social context.

The barriers to a lay understanding of combining genetics, current and historical vital statistics, and other individual variables are the same barriers as for scientists: not only are the data sets large, but one must have advanced knowledge in the many areas from genetics to behavior in order to comprehend and correctly interpret the data. Tools for analysis that make data more comprehensible to humans (Halford et al. 2005) should be created. An initial step is to enable analysis across converging domains. Interpretation will require extensive knowledge and logical skills by scientists capable of asking the right questions and comprehending the answers.

Training such scientists is currently an expensive process, for both the students and the educators. However, online courses may be one avenue toward reducing education costs for students and the costs of time on the part of instructors. Faculty members at prestigious universities have created online courses that allow them to have in a class hundreds of thousands of students from across the globe (Friedman 2012; see also Chaps. 4 and 8). Dissemination of knowledge on such a scale has literally never before been possible. It remains to be seen what forms of knowledge are best disseminated this way (i.e., can critical thinking skills and research methods be taught online as well as machine learning or algorithm design?). Further, as the United States generally lags in math and science education (WEF 2011), interventions will likely have to occur before the college level.

In conclusion, deep understanding and empowerment of the individual and society may come from assisting human cognition and communication through technological tools as well as educational opportunities across disciplines.

6.3.4 Goal 4: It's Time to Lead Again: CKTS Can Provide a Means and a Trajectory for National Renewal

With globalization has come a need for our nation to focus on maintaining and advancing its competitive edge in the world order. When we look to our assets for accomplishing this objective, convergent knowledge, technology, and society (CKTS) offers itself as a potential trajectory we can follow that provides both a means for sustaining economic growth and a resource for national renewal. The full power of the potential of convergence can only be manifested by addressing the wants and needs of stakeholders from all walks of life, perhaps best characterized as the broad population of the nation. In short, CKTS provides an opportunity to increase global leadership by improving quality of life on a large and demonstrable scale. How it does this and the pathways it takes will determine its success as a platform for providing heretofore unattained life benefits that transform our nation through richer lives that are characterized by both longevity and prosperity. Of course, for this to happen, society must view supporting such renewal as a critical investment.

When we look at human life span over the past century, we see a continuing increase in longevity. If we define quality of life in terms of numbers of years (quantity) of potential life, our quality has been increasing. Over these same years, however, we have come to gauge quality of life less by its quantity and more by other dimensions that relate to life's meaning and its enjoyment (e.g., MacGregor 2003). Living longer needs to be accompanied by living well and happily, extending not only the number of years we live but also the number of productive and socially engaged years we live (e.g., Veenhoven 1996). In addition, these longer life spans need to be experienced in terms of states of mind and emotion that are enriched by positive affect that promotes human flourishing (Fredrickson and Losada 2005). It is in this realm of human needs that CKTS offers real potential to improve quality of life through technologies and their implementation that accomplish objectives along the lines of the following:

- Extend the range of *productivity* of individuals to include what we now consider the retirement years, thereby providing not only income streams that supplement (or supplant) our current Social Security system, but also provide *meaningful* engagement with our society
- Increase levels of safety and security so that that normal decline of physical abilities is either lessened or ended in key areas, with a longer life being translated into longer independent living, perhaps through robotics, social networking, and computerized health maintenance
- Improve methods of wealth development and attainment that rely on large-scale computerized systems to improve personalized financial planning and that reduce sources of uncertainty in wealth accumulation and distribution
- Develop enhanced modeling of social milieus that provide both continued opportunities for social experiences and a meaningful contribution to people's emotional lives

6.4 Infrastructure Needs

To meet the promise of convergent technologies in the area of cognition, communication, and the quality of life, significant investments must be made over the next decade in the enabling infrastructure.

First, we must prime the pipeline of new scientists and engineers with the transdisciplinary training that is needed to understand these new convergent technologies and then exploit them. NSF's Integrative Graduate Education and Research Traineeship (IGERT) program is an excellent example of past successes. These types of investments must continue.

Second, the tools for understanding the human cognome must be developed. This includes noninvasive brain imaging better matched to the neural code, but it also encompasses new methodologies for interacting with ensembles of neurons—such as via optogenetics, transcranial direct current stimulation, and transcranial magnetic stimulation—and the ability to build large-scale nanoelectronic systems with sufficient power efficiency to enable large-scale simulations of the brain. These developments must be guided by theoretical advances in our understanding of the fundamental psychological and physiological principles that underlie behavior.

Third, the governance structures to support massive data-sharing between research groups must be developed. Not only will they enhance the economic efficiency of research and development, they also will make possible a great acceleration in the pace of deployment of convergent technologies.

6.5 R&D Strategies

Over the course of the next decade, significant sustained (or renewable) investments are needed in the following areas:

- *Research and development funding gaps that currently exist need to be filled.* There is a critical intersection of technology development that falls in between current funding coverage by the National Institutes of Health (NIH) and the National Science Foundation (NSF), that is, technology development for cognitive, behavioral, and social support. This includes research aimed at cognitive support for aging populations as well as support for individuals with disabilities and support for day-to-day activities of typical adults. While basic technology development (without evaluation) can often be funded via NSF, and clinical evaluation of an extant technology can be funded via NIH, it is often difficult to develop technology aimed specifically at a clinical application, because it cannot be both developed and evaluated under the same funding programs.
- *Researchers in academia need to be properly incentivized.* Truly interdisciplinary work can be difficult to conduct and maintain in an academic setting, for both cultural and funding reasons. While early career funding programs can be found in nearly every Federal funding agency, early career researchers are not well positioned to conduct interdisciplinary or integrative work. Tenure processes as well as expectations from departmental and professional organizations tend to favor disciplinary success, in part because interdisciplinary work can be difficult to evaluate. Investment in mid-career researchers (rather than in specific research projects) would boost exploratory and “high-risk, high-reward” investigations in converging technology and interdisciplinary areas. In short, we need more mid-career research awards.
- *Stakeholders* (*such as the large aging population*) *need to be properly involved* in the ethical, legal, and social issues, and given a voice to respond to proposed lines of convergent research.
- *Metrics of success need to be standardized across disciplines*. Incentives and rewards vary enough across disciplines that it discourages interdisciplinary work. As an example, in the humanities, a book is valued; in the social sciences, a journal article is valued; in computer science, a conference paper is valued: If these three types of academics work together on a project, who decides how it get published?

- *Participatory governance will be critical for an open-ended system.* No one can foresee the regulations that would be required by emerging technologies, so there must be another way than simply regulations to guide decisions.
- *Funding should lead a transdisciplinary project to develop a new* "*science of the mind*" aimed at understanding higher cognition and behavior (of humans and animals) on the basis of the biological activity of brains.
- *An international effort begun in 2007 aimed at evolving a science of the mind should be continued.* The complexity and scale of the problem requires the same "big science" approaches as those used in high-energy physics and polar exploration.
- *The White House neuroscience initiative should continue to encourage coordination and cooperation* across the agencies of government and the creation of public–private partnerships to accelerate progress in neuroscience, cognitive science, and related areas.

6.6 Conclusions and Priorities

The human brain has, throughout human history, interacted with other human brains and the biosphere with vast effect. The emergent phenomena of culture, history, agriculture, technology, and anthropogenic planetary changes are all the results of human brains interacting as agents. Now, convergent technologies are making it possible for human brains to interact with each other in entirely new ways that may well shape the future of human cognition, communication, and the quality of life (Carr 2008). Such a future would be characterized by a greater cognitive awareness as emerging from the processes described above. We call that future *The Cognitive Society*. The priority must be to shape this future to be positive, for individuals and also for society at large.

The four goals listed in Sect. 6.3 provide a roadmap for creating this positive future (Fig. 6.4): (1) Augmented and embodied cognition will enhance and support human interaction and understanding of society and planet. (2) The human cognome will enable a fuller understanding of our own human potential and limitations. (3) "My Own Genomics" will enhance human wellness as well as the aspects of our biology that play a role in our individual phenotype. Finally, (4) "It's Time to Lead Again" creates an agenda for national renewal that leverages convergent technologies towards a better national future.

Above all, the overarching vision is that a deeper understanding of human cognition will play a central role in how human beings live and how they interact, both in the biosphere and then later, perhaps, during sustained human space exploration, on spacecraft, and in other solar system locales. The idea that our interacting cognitive brains represent an "information field" that can be explored using the same scientific principles that we have used to explore other fields may have a deep significance for how humans collaborate to solve complex problems in the future. As such, the study of cognition and its related convergent technologies represents a grand opportunity for humanity.

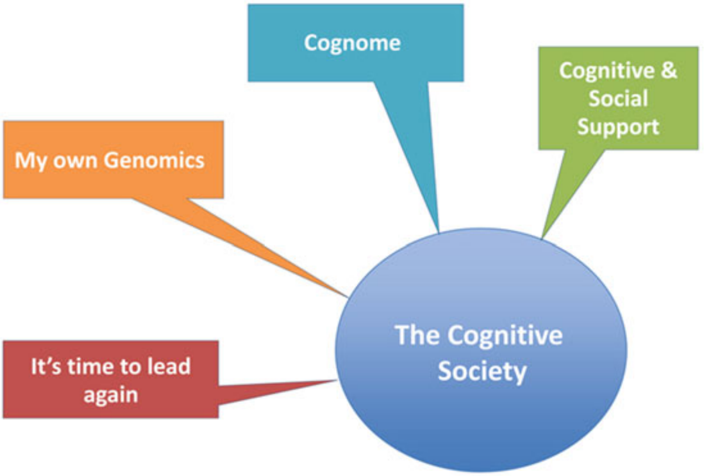

Fig. 6.4 Four goals, cognitive and social support, the cognome, "My Own Genomics", and "It's time to lead again" all play a role in creating the Cognitive Society (Figure courtesy of J. Olds)

6.7 R&D Impact on Society

Human society faces massive cognitive, communicative, and physical challenges over the next decades. Fundamentally, human decision processes, whether at the level of the individual or the collective, now affect the sustainability of the entire biosphere. The quality of human decision-making is both a function of natural human cognitive capabilities and the emergent effects of human-to-human interactions. The welfare of humans, in turn, feeds back onto human cognitive capabilities and hence to human decision-making. Thus, the converging technologies that affect human cognition, communication, and quality of life have very significant broad societal implications for the future.

As the new generation of convergent technologies becomes fully embedded within the science of cognition, it is inevitable that our own view of what it means to be a human being will change fundamentally (e.g., see Giordano 2012). This change in view will be a central characteristic of *The Cognitive Society*. At an obvious level, the boundary between brain and machine will become increasingly blurred as machines are increasingly made out of materials that mimic those of the brain. At a deeper level, as humans become increasingly more deeply connected to one another, the notion of "self" may evolve in as yet unpredictable ways that could have profound effects on society. The ethical, social, and legal implications for such trajectories in human development will be extraordinarily important for serious consideration—by scientists, policymakers, and the larger global human polity.

6.8 Examples of Achievements and Convergence Paradigm Shifts

6.8.1 Possibilities for a Cognitive Society Initiative

Contact person*: James Olds, George Mason University*

The Problem and Background

In the first two decades of the twenty-first century, the general recognition of the brain as the main engine of human behavior and thought has converged with advances in cerebral sensor–activator technology. This convergence has resulted in a now-ubiquitous technological ecosystem whereby the relationship between functional brain activity and human behavior can be routinely studied, not in some animal model, but in conscious human subjects. This new ecosystem of tools has qualitatively changed how we view cognition as a society.

In future decades, as this convergence accelerates innovation cycles, it can be expected that a much deeper knowledge of the human cognition will be elucidated. This deeper understanding will be enabled by the same technological advances (e.g., Moore's Law) that are driving Big Data and the various "-omics" fields. At the same time, brain sensor–activator technologies will improve to the point where they are better matched to the actual spatial–temporal dynamics of the human brain neural code. These sensor–activator technologies will become increasingly integrated into biological brain tissue as brain–machine interfaces become both smaller and more sophisticated. Jointly, we term these "cognitively enabled technologies." At some point soon, human societies, including our own, will begin to consider deploying this new knowledge and these new convergent technologies beyond the simple goal of creating new brain knowledge. This emergence will be catalyzed by the complexity and span of human challenges, ranging from public health to climate change.

The sustained societal conversation about the ethical, legal, and social issues related to future use of cognitively enabled technologies and knowledge will constitute the early stages of what we term The Cognitive Society. A cognitive society is a human society that engages with deep knowledge about human cognition and brain sensor–activator technologies in order to more fully realize its potential. The Cognitive Society Initiative ("SCI-C") is a program designed to assure that the arrival of a cognitive society here in the United States is both accelerated and a positive development.

What Is Proposed

It is proposed that SCI-C begin the process of facilitating and understanding how twenty-first century America will be transformed as it becomes a truly cognitive society. SCI-C will engage with scientists, ethicists, and philosophers across many disciplines—it will be transdisciplinary. SCI-C will also reach out to members of the lay public and their elected representatives so that societal consensus will emerge from SCI-C activities. The SCI-C will have three major scopes:

1. Access and forecast trends for the embedding of cognitive knowledge and technologies into American society
2. Fund transdisciplinary research designed to enhance this embedding
3. Consider the ethical, legal, and social issues

In (1), SCI-C will bring together scientists, technologists, and futurists to perform a cognitive forecast for American decision-makers. These activities will facilitate situational awareness about the processes by which cognitively enabled technologies are becoming embedded in current-day America while at the same time establishing a variety of forecasting methodologies to elucidate likely futures. The forecasting function will be dually focused on both challenges and opportunities.

In (2), SCI-C supporting agencies will come together to fund projects that can catalyze the enhancement of American potential through advances in either cognitive knowledge (e.g., hierarchal linked frameworks for brain architectures) or brain sensor–activator technologies. Such research funding will require cross-cutting agency support and will be designed to fill the "gaps" between the classical funder portfolios.

In (3), SCI-C will convene members of the lay public, ethicists, politicians, philosophers, scientists, technologists, and decision-makers at all levels to engage with the ethical, legal, and social issues regarding the migration of cognitively enhanced technologies into the "wild."

Rationale

The rationale for SCI-C stems from the challenges presented by the already ongoing rapid introduction of convergent technologies related to cognition into American society. These current technologies include functional brain imaging, transcranial brain stimulation, and brain–machine interfaces. Their successors may include human optogenetics, nano-level computing, and advanced robotics. Because individual human experience and all human social interactions are driven by cognitive processes, the introduction of these technologies could pose a systemic risk to society. A primary aim of SCI-C is to avoid unintended consequences, or tripping hazards. As convergent technologies accelerate the innovation cycle, this risk will only grow. Rather than respond reactively, SCI-C is a proactive approach to addressing an American future as a cognitive society.

At the same time, SCI-C represents a national opportunity to both shape and accelerate the implantation of these cognitive technologies in such a way as to optimize their potential for positive impact on American society. Whether it be by enhancing social communication capabilities or ameliorating the effects of traumatic brain injury through novel brain–machine interfaces, SCI-C can play a crucial role in catalyzing America's worldwide leadership as a cognitive society.

Deliverables

There are several key objectives for SCI-C:

- *Marked improvement in brain health with a resultant public health and economic benefit for the United States*. Brain diseases represent an enormous drag on national well-being. This drag will only increase as the Baby Boomer generation enters retirement and becomes vulnerable to chronic neurodegenerative disorders such as Alzheimer's or Parkinson's disease. Central to SCI-C initiatives are the development of new therapies, technologies, and interventions to reduce this public health and economic load on American society.
- *Deployment of cognitively enabled technologies to improve the well-being of seniors so that productive lifespan increases significantly*. As America ages, life can retain meaning and productivity for seniors with the embedding of assistive technologies. Many of these technologies (e.g., assistive robots) represent the convergence of cognitively enabled machines or software with sensor–activators. SCI-C investment in these technologies will create concrete opportunities for the enhancement of geriatric care so that a greater proportion of the American life-span will be spent enjoying good health.
- *Improved outcomes for K–20 education* (*and beyond*) *as a result of embedding cognitively enabled technologies in our schools and colleges*. Learning across the human lifespan constitutes one of the most obvious cognitive activities, and yet currently there has been little movement for educators to take advantage of what cognitively enabled technologies may have to offer. SCI-C research investments will seek to catalyze the use of such technologies in lifespan learning to enhance the competitive edge of American citizens as they compete in a globalized world.
- *Avoidance of strategic surprise over the next decade in the area of cognitive enabled technologies*. Formal cognitive forecasts that engage with ethical, legal, and social implications will be performed by SCI-C supported researchers. The lay public and decision-makers at all levels of government will also play key roles in this process. Success will be measured by the discovery and societal avoidance of tripping hazards related to the transition of the United States to a cognitive society.

6.8.2 Possibilities for a Cognitive Technology Initiative

Contact person*: R. Stanley Williams, Hewlett-Packard Laboratories*

Advancing the nascent discipline of cognitive science into engineering and development practices from which economically and societally important technology can be launched will require a concerted transdisciplinary effort. A successful model for achieving critical mass in an emerging field and applying a wide range of expertise to create commercial outlets has been established by the U.S. National Nanotechnology Initiative (NNI).

Cognition is now recognized as a critical component of future applications ranging from healthcare to information technology. Just one example is that information

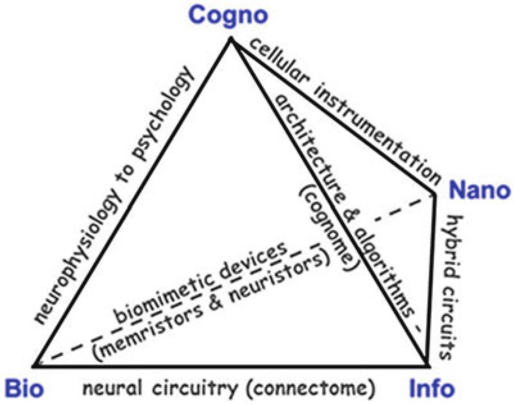

Fig. 6.5 The cognohedron (Adapted from R. W. Leland, Sandia National Laboratory, with permission) illustrates the nano-bio-info-cogno (NBIC) convergence to address the challenge of understanding how cognition arises in biological systems and how that understanding can be applied to advances in human health, economic competitiveness, and national security

analytics is moving from mainly arithmetical operations on highly structured databases to finding meaning in vast quantities of unstructured data. This requires a new computation paradigm in which cognitive systems and algorithms recognize context and intent without having to be programmed by experts in arcane software languages, but rather learn in an uncertain and changing environment. The one successful example we know that is capable of such analysis is the human brain. However, at this point, cognitive science, which includes quantitative psychology, is a highly specialized research field that is mainly focused on fundamental understanding of an incredibly complex system. To bring the insights developed from cognition to information technology (IT) and other fields will require encouragement in the form of research funding that is specifically targeted at transdisciplinary teams (see Fig. 6.5). Given the realities of the funding of today's disciplinary silos and agencies, the only way to break down the barriers to collaboration is to fund an effort that is specifically tasked to dramatically advance cognitive technology through focused research programs.

What would such an effort look like? Taking the successful example of the NNI, we understand that there are two important components for accelerating a field and encouraging applications.

The first critical component of a focused cognitive technology initiative is targeted research funding for transdisciplinary groups—which may include participants from academia, national laboratories, and commercial entities—to address fundamental discovery, national needs, and economic development. The primary goal here is to address the "Pascal quadrant" of research with specific goals—in the IT example, building systems based on new hardware and software that address real-world problems far more efficiently than present computing platforms by emulating models of brain function. At this stage, the two major U.S. institutions with portfolios related to cognitive technology are NIH and NSF, but the Department of Energy (DOE), the Department of Defense (DOD), and the intelligence communities are major stakeholders in the outcomes of such efforts, so coordination in funding efforts across these agencies is critical to success. However, new methods of encouraging collaborative efforts should be explored. An example could be to use expert crowd sourcing to identify, prioritize, and fund some research programs. A sponsoring agency would host a website on which researchers describe their expertise and recent results. Other researchers could then propose projects that would advance the state of the art in a dramatic way if particular experiments could be performed and/or theories be developed. The participants in such a forum could vote on which ideas they believe are most important, and motivated research groups from appropriate institutions could sign up to obtain starter grants to deliver tangible results based on predetermined statements of work. Those groups that deliver high-quality results, as determined by the research community, would then receive longer-term grants to complete a project.

The second critical component of a focused cognitive technology research initiative is establishment of a core research and user facility that can act as a center of excellence in transdisciplinary research, builder of prototype systems, first user of the technology that is created, and supplier of the technology and facilities to individual investigators until commercial markets are established (similar to a DOE Nanoscale Science Research Center). Such a center (which can be geographically distributed) should be hosted by an organization that has a strong foundation in a broad range of relevant disciplines, for example, expert capabilities in cognitive science; computer architecture; algorithms and modeling; facilities for designing, building, and testing instrumentation and hardware; and ability to host researchers from all the required disciplines to interact with each other to advance the field. A center can provide a focus for the grand challenges faced by the cognitive science community, such as the question of multiscaling—how to measure and model critical aspects of cognition from the ion channel and synapse to memory and learning. The tools for probing brain function are now developed in academic research labs on an individual basis—everything from reporter nanoparticles to multiwire electrical probes to miniature wearable microscopes to functional MRI. What is needed is serious engineering development of some of these tools to standardize and integrate them into systems so that results from multiple scales can be correlated to specific behavior.

Just as important are theoretical models of what happens at each scale in the brain, how these models can be connected together to provide a unified picture of function across scale, and most importantly, how the models compare with the multiscale experimental results. For example, one of the more intriguing models of memory involves sparse coding: What lower-level models of neuron function can provide additional insight to the mechanism of long-term memory storage, and what experimental measurements are required to confirm or refute the model? The relevant comparison is to the multiscale modeling painstakingly developed by the nanotechnology community over the past dozen years to bridge the length scales from atoms to nanoparticles, to composite materials, to aircraft fuselages. Development of multiscaling tools and theories is greatly advanced by providing smaller-scale research groups the opportunity to interact with user communities and centers; however, the primary focus of the centers should be the support of, rather than replacement of, the individual research groups.

What are the desired outcomes? The long-range goals for any national-scale initiative must be measured in terms of dramatic improvements in the lives of the people who support the initiative through their taxes. Three significant areas will be impacted by cognitive convergence:

- *Health*. At present, there are a large number of brain-based diseases that afflict people, and they are becoming more prevalent as the population ages. Greatly improved understanding of human cognition and preventing the biological factors that degrade it will mean that increased quantity of life can also translate into increased quality of life and productivity.
- *Security*. As our world both shrinks and becomes more complex, the number and severity of threats to our security are increasing dramatically. We need cognitive tools that can exponentially improve our ability to sense our cyber and physical environments, and enable us to respond to threats before they become incidents.
- *Economic opportunity*. We now live in a global technological society, where the most important economic assets of a nation are the inventiveness and productivity of the people. The countries that successfully understand and harness cognition to amplify their human assets will be far more competitive than those that do not. In a world of exponential technological advances, not being the leader risks becoming irrelevant.

6.8.3 List of Examples

Major achievements in addressing issues of cognition, communication, and human quality of life are illustrated in Table 6.1.

6.9 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.

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

Facilitator and Rapporteur: *Laura Ballerini*

Discussants**:**

Milos Nesladek, Academy of Sciences of the Czech Republic (EU)
Mira Kalish, Tel Aviv University (EU)
Sylvie Rousset, CNRS (EU)
Jian Cao, Northwestern University (U.S.)
James Olds, George Mason University (U.S.)
Mark Lundstrom, Purdue University (U.S.)
Christos Tomakanis, EC (EU)

Table 6.1 Major achievements in the areas of cognition, communication, and human well-being

CKTS Domain	Example
Communications	*Smartphone revolution*: The release of Apple's iPhone in 2007 brought about a qualitative change in the use of mobile computing across the globe
Quality of Life	*Personal genomics*: The massive reduction in the marginal cost of DNA base sequencing has brought whole genome analysis within the reach of ordinary citizens
Cognition	*Transcranial magnetic stimulation*: The ability to noninvasively activate (and inhibit) specific human brain areas has opened up new avenues for neural therapies
Quality of Life	"*Maker tools*": New additive manufacturing technologies are profoundly affecting innovation and the ability of empowered individuals to bring new intellectual property to market
Communications	*Twitter*: The searchable and real-time nature of Twitter has altered the definition of who is a journalist and greatly reduced the importance of the 24-h news cycle. Real-time twitter feeds played a major role in the Arab Spring and have the potential to have major political influence in the future
Communications	*Facebook*: With over 500 million users, Facebook represents one of the most ubiquitous examples of how the convergence of computing and social networking has changed the world
Cognition	*Brain imaging technologies*: The embedding of brain imaging technologies into medicine has brought new diagnostic tools and therapies to the fore

This group of scientists assessed the role of convergences in nano-bio-info-cognitive science on human development. Consensus emerged around three main topics:

1. Use of molecular and personalized information to enhance treatment of disease and improve human cognition
2. Quality-of-life enhancement, including prosthetic devices and regenerative medicine
3. Personalized innovative education

In the area of molecular and personalized information to enhance treatment and cognition, the core idea was that the technology for developing dynamic and personalized molecular profiles for medical treatments will emerge over the next 10 years. Diseases that might be better treated include cancer, neurodegenerative illness, and spinal lesion. The convergent technology tools that will make this possible include:

- Data optimization (in the sense of innovative and enhanced data harvesting, sharing, analyzing)
- Improvement of technological tools for information management at the molecular level (genome, proteome, bioinformatics, contactless tools, biomarkers, sensors, cellular imaging)
- Tools for improving accuracy and efficacy towards predictive diagnosis
- Cost-effectiveness (including personalized manufacturing of drugs)
- A distributed system for delivery of care

Thinking about enhancement of quality of life, the central idea was engineering "of" and "for" the human body, including human bionic machine/organ interfaces as new frontiers in personalized regenerative medicine. The convergent technologies that are emerging to make this possible include:

- Advances in nanotechnology (including nanomaterials and nanoelectronics)
- Artificial restoration of functions
- Development of multidirectional therapeutic interfaces
- Improved knowledge of intracellular signal transduction codes
- Addressing cognitive enhancement
- Restoring function to restore human productivity

Turning to personalized innovative education, the group saw that the next decade will bring a paradigm shift in addressing formal and informal education with adaptive life-long learning systems. The convergent technology tools that will make this possible include:

- Targeting aging needs for continuous education through informal pedagogical processes
- Micro-education learning platforms based on personal needs ("I teach you in your own personal learning style")
- Adaptability of workstations to the needs of each individual in terms of a human–machine "relationship"
- Haptic platforms for text-based sensory motor feedback
- Connecting informal with formal education via science centers on convergent technologies
- Reframing formal education systems to promote convergence of disciplines by mutual enabling—improving disciplines' awareness of their limits and needs
- Enabling "smart" information distribution channels using synergies with public media
- Developing a market for targeted personal education

Cross-cutting across each of these topics was the notion that governance is critical for enabling the technological convergence necessary for societal improvement in each of the above three topics.

The joint NSF–EC workshop held in Leuven also highlighted that convergence can provide new job opportunities for a competitive and sustainable economy by promoting responsible innovation, which is an increasingly important challenge for diverse policies in the EU, United States, and beyond. Promoting *new skills for "scientific social responsibility"* could contribute to progress towards this goal. Research, innovation, and education are a living ecosystem, where education contributes to bridging the gap between research and innovation. So, there is a need to enable the next generation of scientists to meet the needs of industry by developing the appropriate skills and competencies. In this context, society at large is showing a progressive need to better understand the pros and cons of converging technologies so as to make informed responsible choices about their new products and processes, while young people are becoming increasingly inclined to engage in studies on converging technologies. This requires adapting both education and training by developing inter- and cross-disciplinary education to develop an inter- and cross-disciplinary "*scientific social responsibility*" scheme for future scientists and technologists, by integrating generics (e.g., nanosciences, nanomoleculars, nanoengineering, nanophotonics) with specifics (e.g., nanoelectronics, nanomaterials, nanobiotechnology, nanomedicine, ethicalities, safety, standards, regulation, entrepreneurship). This can be done by conceiving, designing, and developing new ways to promote paradigm shifts by addressing formal and informal education with adaptive life-long learning systems; disseminating and developing versatile learning/teaching materials for multipliers (e.g., teachers, trainers, science communicators, explainers); including innovative learning methods and scientific experimentation; and designing new formats for staff exchanges between labs, academia, and industry.

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

Panel members/discussants

Myung Joon Kim, Electronics and Telecommunications Research Institute (ETRI, Korea)
Mitsuo Kawato, ATR Brain Information Communication Research Laboratory (Japan)
James Olds, George Mason University (U.S.)
H.-S. Philip Wong, Stanford University (U.S.)
Byoung-Tak Zhang, Seoul National University (Korea)
Young Jik Lee, ETRI (Korea)
Jon-Won Lee, Hanyang University (Korea)
Tsuyoshi Hasegawa, National Institute for Materials Science (NIMS, Japan)
Takanori Ichiki, Tokyo University (Japan)
Takeshi Kawano, Toyohashi University of Technology (Japan)
Shinya Nakamoto, Japan Science and Technology Agency (JST, Japan)
Takahiro Fujita, NIMS (Japan)
Wan Seok Kim, ETRI (Korea)
Hong Soon Nam, ETRI (Korea)
Young-Jae Lim, ETRI (Korea)

The group reached consensus around five core ideas:

- The concept of a "Trust Society" (e.g., computer-enhanced privacy)
- The concept of the Aging Society and the need to provide a meaningful and healthy aging experience
- The notion of bricks-and-mortar "convergence centers" bringing multidiscipline investigators together under one roof

- The coming ubiquity of brain–machine interfaces to cure brain diseases
- The utility of national buy-in to support NBIC technologies through policies and grant support

The team saw both risks and the potential for enhanced well-being from the advent of convergent technologies. Specifically, the team noted the potential for the systematic erosion of privacy as a result of Big Data and the commoditization of computing. With those risks in mind, the team advocated for the development of a Trust Society built upon novel CKTS tools that act to enhance privacy, such as novel easy-to-use encryption schemes.

There was also the general agreement that all of the participating nations (Korea, Japan, and the United States) face an increasingly aging population as a result of demographic shifts. This realization led to consensus around the notion of an Aging Society—where CKTS is deployed from NBIC technologies to not only enhance health but also a sense of life having real meaning during the last decades of the human lifespan.

The team learned about Seoul National University's Advanced Institute of Convergent Technology (AICT) that brings together NBIC researchers under a single, non-virtual "roof." The institute, formally supported by both national and provincial governments, serves as an excellent model for promoting the types of paradigmatic changes so critical to cognitive well-being and communication. There was strong consensus that such examples should be facilitated elsewhere.

It was also felt that brain–machine interfaces were on a trajectory to become ubiquitous (and therefore embedded) in society in such a way as to completely change the nature of both cognition and communication between individual humans and machine artefacts. The team felt that, if pursued in a careful manner that is sensitive to the relevant legal, ethical, and social issues, such interfaces would be very positive.

Finally, there was a realization among team members that a formal recognition of the positive role for CKTS in promoting a healthy society would be a good thing. The Korean members of the team brought up the idea of formal legislative support, and such a notion was endorsed by the group.

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

Panel members/discussants

Tingshao Zhu, Academy of Sciences (China)
Jonathan Manton, University of Melbourne (Australia)
James Olds, George Mason University (U.S.)
Tanya Monro, University of Adelaide (Australia)
Xioming Wang (China)
H.-S. Phillip Wong, Stanford University (U.S.)
Tianzi Jiang, Academy of Sciences (China)

This group came together over a shared vision for how NBIC advances might improve human cognition and communication in the next decade. That vision included:

- An increased focus on educating the public about mental health issues
- Leveraging communications and wearable devices to improve decision-making and patient management
- Increasing recognition of the *Aging Society*, supported by technologies and services to enable people to remain in their communities
- Novel approaches to diagnosis and therapy of psychiatric and neurological diseases
- Transdisciplinary focus
- Open access to learning

Scientists and research agency directors from China, Australia, and the United States discussed NBIC in the context of cognition and communications. Consensus was reached over the following achievable goals for the next decade:

- Embedding of transdisciplinary education into research and vice versa, leading to improved health outcomes
- Establishing the physical underpinning of cognition, i.e., understanding how cognition emerges from the chemical, physical, and biological activities of brains
- Wearable devices for personalized medical services and monitoring
- Reduced cost and increased efficiency of access to medical services
- Reduced incidence, medicalization, and impact of autistic spectrum disorders and other cognitive challenges in children

The group felt that the following R&D strategies would be critical towards achieving the above goals:

- Investing in programs that address “bigger” scientific problems
- A significant increase in prioritization of government support
- Educating government and political decision-makers about NBIC scientific priorities
- Application-oriented R&D targeted towards real societal problems
- Filling interagency gaps
- Creating a new “brand” for NBIC science in the area of cognition and communication
- Improved communication to the general public about NBIC science.

References

Abbott, H.P.: Unnarratable knowledge: the difficulty of understanding evolution by natural selection. In: Herman, D. (ed.) Narrative Theory and the Cognitive Sciences, pp. 143–162. Center for the Study of Language and Information, Stanford (2003)

Ackerknecht, E.H.: Psychopathology, primitive medicine and primitive culture. Bull. Hist. Med. **14**, 30–67 (1943)

Adamson, G.: Socially beneficial technology: can it be achieved in practice? IEEE Technol. Soc. Mag. (Summer): 20–27 (2012)

Bach-y-Rita, P., Tyler, M.E., Kaczmarek, K.A.: Seeing with the brain. Int. J. Hum. Comput. Interact. **15**, 285–295 (2003)

Benedict, R.: Anthropology and the abnormal. J. Gen. Psychol. **10**, 59–80 (1934)

Cabeza, R., Nyberg, L.: Imaging cognition: an empirical review of PET studies with normal subjects. J. Cogn. Neurosci. **9**(1), 1–26 (1997)

Cabeza, R., Nyberg, L.: Imaging cognition II: an empirical review of 275 PET and fMRI studies. J. Cogn. Neurosci. **12**(1), 1–47 (2000)

Campbell, F.A., Ramey, C.T., Pungello, E., Sparling, J., Miller-Johnson, S.: Early childhood education: young adult outcomes from the Abecedarian Project. Appl. Dev. Sci. **6**(1), 42–57 (2002)

Carr, N.: Is Google making us stupid? Atlantic Magazine (July/August). Available online:http://www.theatlantic.com/magazine/archive/2008/07/is-google-making-us-stupid/306868/ (2008)

Conrad, P., Schneider, J.W.: Deviance and medicalization. Mosby, St. Louis (1980)

DHHS/CDC (Department of Health and Human Services, Centers for Disease Control and Prevention, National Center of Birth Defects and Developmental Disabilities). How many children have autism? (based on 2006 statistics). Available online: http://www.cdc.gov/ncbddd/features/counting-autism.html (2012). Accessed 7 Sept 2012

El Boghdady, D.: Health-care apps for smartphones pit FDA against tech industry. *The Washington Post* Business section. June 22 (2012)

Farah, M.J., Wolpe, P.R.: Monitoring and manipulating brain function: new neuroscience technologies and their ethical implications. Hast. Cent. Rep. **34**(3), 35–45 (2004). Published online 6 March 2012: http://onlinelibrary.wiley.com/doi/10.2307/3528418/full

Fredrickson, B.L., Losada, M.: Positive affect and the complex dynamics of human flourishing. Am. Psychol. **60**, 678–686 (2005)

Friedman, T.L.: Come the revolution. *The New York Times* Op-Ed, 15 May 2012

Giordano, J. (ed.): Neurotechnology: premises, potential and problems. CRC Press, Boca Raton (2012)

Halford, G.S., Baker, R., McCredden, J.E., Bain, J.D.: How many variables can humans process? Psychol. Sci. **16**(1), 70–76 (2005)

Haslam, N.: Kinds of kinds: a conceptual taxonomy of psychiatric categories. Philos. Psychiatr. Psychol. **9**(3), 203–217 (2002). http://dx.doi.org/10.1353/ppp.2003.0043

Horn, R.E.: Beginning to conceptualize the human cognome project. A paper prepared for the National Science Foundation Conference on Converging Technologies. Available online: http://www.stanford.edu/~rhorn/a/topic/cognom/artclCncptlzHumnCognome.pdf (2002)

Johnson, M.K., Adelson, E.H.: Retrographic sensing for the measurement of surface texture and shape. In *Proceedings*, *IEEE Conference on Computer Vision and Pattern Recognition* 1070–1077 (2009)

Kaplan, B. (ed.): Studying Personality Cross-Culturally. Harper and Row, New York (1961)

Kendler, K.S., Parnas, J. (eds.): Philosophical Issues in Psychiatry: Explanation, Phenomenology, and Nosology. Johns Hopkins University Press, Baltimore (2008)

Klayman, J., Ha, Y.-W.: Confirmation, disconfirmation, and information in hypothesis testing. Psychol. Rev. **94**(2), 211–228 (1987)

Lunden, I.: Nielsen: Smartphones used by 50.4% of U.S. consumers, Android 48/5% of them. AOL Tech online: http://techcrunch.com/2012/05/07/nielsen-smartphones-used-by-50-4-of-u-s-consumers-android-48-5-of-them/ (2012)

Machlis, S.: Google vs. Facebook by the numbers. Computerworld (July 7). Online: http://www.computerworld.com/s/article/9218177/Google_vs._Facebook_by_the_numbers (2011)

MacGregor, D.G.: Psychology, meaning and the challenges of longevity. Futures **35**, 575–588 (2003)

Marzullo, T., Gage, G.: The SpikerBox: a low cost, open-source bioamplifier for increasing public participation in neuroscience inquiry. PLoS ONE **7**(3), e30837 (2012). http://dx.doi.org/10.1371/journal.pone.0030837

Nirenberg, S., Pandarinath, C.: Retinal prosthetic strategy with the capacity to restore normal vision. PNAS Published online before print, August 13. http://dx.doi.org/10.1073/pnas.1207035109 (2012)

Nirenberg, S., Pandarinath, C., Ohiohenuan, L.: Retina prosthesis. WO Patent WO/2012/030625 (filed under the international Patent Cooperation Treaty) (2012)

Opler, M.K. (ed.): Culture and Mental Health. Macmillan, New York (1959)

Otellini, P.: As quoted by M.J. Miller. Intel enters smartphone chip race for real. PC Magazine, Forward Thinking, online: http://forwardthinking.pcmag.com/ces/292745-intel-enters-smartphone-chip-race-for-real (2012)

Peck, M.E.: 3-D printing revolution stymied by high prices. Txchnologist (August 27). Online: http://txchnologist.com/post/30829846467/3-d-printing-revolution-stymied-by-high-prices (2012)

Pinker, S.: How the Mind Works. Norton, New York (1997)

Popper, K.R.: The Logic of Scientific Discovery. Basic Books, New York (1959)

Rosen, B.R., Savloy, R.I.: fMRI at 20: has it changed the world? Neuroimage **62**(2), 1316–1324 (2012)

Scassellati, B., Admoni, H., Matarić, M.: Robots for use in autism research. Annu. Rev. Biomed. Eng. **14**, 275–294 (2012). http://dx.doi.org/10.1146/annurev-bioeng-071811-150036

SEC (U.S. Securities and Exchange Commission): Amendment Number 4 to Form S-1 Registration Statement: Facebook, April 2012: http://www.sec.gov/Archives/edgar/data/1326801/000119312512175673/d287954ds1a.htm (2012)

Siddique, A., Kowdley, K.V.: Review article: the iron overload syndromes. Aliment. Pharmacol. Ther. **35**(8), 876–893 (2012). http://dx.doi.org/10.1111/j.1365-2036.2012.05051.x

Simon, H.A.: The sciences of the artificial. MIT Press, Cambridge (1996)

Tapus, A., Matarić, M., Scassellati, B.: The grand challenges in socially assistive robotics. IEEE Robot. Autom. Mag. **4**(1), 35–42 (2007)

Torralba, A., Fergus, R., Freeman, W.T.: 80 million tiny images: a large dataset for non-parametric object and scene recognition. IEEE Trans. Pattern Anal. Mach. Intell. **30**, 1958–1971 (2008)

UN/POPIN (United Nations Population Information Network, United Nations Population Division, Department of Economic and Social Affairs). United Nations Statistical Yearbook. http://www.un.org/popin/, http://unstats.un.org/unsd/syb/ (2012). Accessed 7 Sept 2012

Veenhoven, R.: Happy life-expectancy: a comprehensive measure of quality-of-life in nations. Soc. Indic. Res. **39**, 1–58 (1996)

Volkmar, F.R., Lord, C., Bailey, A., Schultz, R.T., Klin, A.: Autism and pervasive developmental disorders. J. Child Psychol. Psychiatry **45**(1), 1–36 (2004)

WEF (World Economic Forum): Global competitiveness index. Available online: http://reports.weforum.org/global-competitiveness-2011-2012/ (2011)

Wurzman, R., Giordano, J.: Differential susceptibility to plasticity: a ‘missing link’ between gene-culture co-evolution and neuropsychiatric spectrum disorders? BMC Med. **10**, 37 (2012). Available online: http://www.biomedcentral.com/1741-7015/10/37