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Research Trends toward Intelligent Computing
— Promotion of Multidisciplinary Research in Cognitive Science and Artificial Intelligence —

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1 | Introduction

The ubiquitous society is around the corner in Japan now that the nation's population of broadband subscribers has reached 15 million, allowing people to access the Internet faster and more cheaply than in any other part of the world. However, most information technology devices, which have traditionally been designed for professional users, are not easy for non-specialists to use, even at a time when these devices are widely available. Furthermore, the proliferation of the Internet has, on the one hand, given people access to large amounts of information, but, on the other hand, it has caused a deluge of information making the retrieval of the desired information difficult. Under these circumstances, an environment in which people can use computers effortlessly in their daily lives and computers that are user-friendly are strongly required. If this becomes a reality, smooth collaborative work between humans and computers will be facilitated, and intellectual productivity will improve as a result.

Studies to implement "Intelligent Computing," the concept of creating systems that support human beings in their intellectual activities and naturally interface with them have been conducted as part of research in artificial intelligence. Artificial intelligence studies aiming to develop machine intelligence on the computer began in the latter half of the 1950s, shortly after the invention of the computer. Since the intellectual capacity of artificial intelligence systems has been slow to increase, there has been criticism over research activities in this field.

As the computer's processing speed increases, however, greater performance on intelligent processing has become available, allowing the commercial use of artificial intelligence. Today, the results of artificial intelligence research have been embedded in many information systems in fragments, although they are not easily recognizable as artificial intelligence technologies. In the artificial intelligence research fields, data mining using machine learning algorithms has recently been attracting attention, and studies in this area have greatly contributed to advances in security technology.

However, further enhancement of intelligent processing capability is needed because the ability of current Intelligent Computing is inferior to that of humans. To this end, researchers are facing a number of problems, the resolution of some of which may elucidate the essence of human beings. In particular, it is expected that research in cognitive science, a field that clarifies human cognitive functions, will help create new ideas for Intelligent Computing.

To make Intelligent Computing a reality, many countries, especially the U.S., have been active in implementing projects to promote multidisciplinary studies of artificial intelligence and cognitive science, recently. In Japan, on the other hand, brain research has been the center of attention, generating some results for use in cognitive science. One problem is that Japanese projects often focus on basic research and therefore lag behind their U.S. counterparts in the its applied research toward artificial intelligence.

This article describes recent research trends in artificial intelligence and cognitive science, and discusses possible measures to encourage

research into Intelligent Computing, a field that appears to be slower to grow than the information technology hardware sector, which has undergone rapid progress. In this article, artificial intelligence research is including overall research activities toward the implementation of intelligent processing on computers.

2 | Research trends in artificial intelligence

2-1 The history of artificial intelligence

Research into artificial intelligence began in the latter half of the 1950s with an eye toward "creating machine intelligence." It originated through attempts by mathematicians, psychologists, and philosophers to mimic human intellectual activities by using computers. In the 1970s, researchers succeeded in describing on a computer the rules that represent expert's knowledge and demonstrated the ability to solve problems through reasoning, without the assistance of experts. They then developed and commercialized expert systems that were able to perform simple medical diagnoses and manufacturing process failure diagnoses. However, the frame problem, where a complete description of the preconditions of intelligence rules requires an infinite number of conditions, was later discovered. For this reason, rule-based expert systems have yet to achieve performance comparable to human experts. In the 1980s, researchers sought solutions by shifting their focus to studies on data processing, particularly using neural networks from traditional research on the processing of logic and symbols. These neural network studies later led to research on the brain's neural network functions. In the 1990s, agents, each of which has a program that autonomously move across the network to perform simple tasks, attracted great attention in the research community. They have evolved to become anthropomorphic agents, which enable computers to perform various functions instead of humans, and personalization agents (or simply personalization), a technology to collect information according to the user's preference. In addition, there are more advanced ongoing

Table 1 : Historic events in artificial intelligence research

			History of the computer (reference)	
			1947	ENIAC computer
latter half of the 1950s – 60s [Emergence of artificial intelligence]	1956	Proposal of "Artificial Intelligence" (J. McCarthy)	1951	UNIVAC I commercial computer
	1965	Development of Eliza, a computer program that can interact with humans	1964	IBM 360 mainframe computer
	1967	Creation of MacHack, the knowledge-based chess program		
1970s [Expert systems (Knowledge representation as engineering approach)]	1974	MYCIN expert system (medical diagnosis)	1972	i4004 microprocessor
	1974	ABSTRIPS planning program		
	mid 1970s	Graphical user interface	1976	Apple personal computer
latter half of the 1980s [Growth of neural network research]	1982	Hopfield neural network	1981	IBM Personal Computer
	1986	Establishment of the Japanese Society for Artificial Intelligence		
1990s [Agents (Trials as distributed processing)]	1990	Start of genetic programming	1991	Windows 3.1
	1995	Situated agents (Russell)	1993	Mosaic web browser
	1995	Inauguration of the International Conference on Knowledge Discovery and Data Mining	1993	Client-Server model
latter half of the 1990s – [Data mining (Second coming of machine learning)]	1997	Victory of the chess program, DeepBlue, over a chess champion		
	1999	Proposal of the Semantic Web		
	1999	Emergence of pet robots		

projects that aim to simulate social and economic systems by running a large number of agents on a network so that each agent mimics personal behavior in a society.

The data processing capacity of the computer far exceeds that of a human being. From this perspective, artificial intelligence researchers now aim to provide "assistance for the intellectual activities of humans" rather than developing artificial intelligence to replace humans through the "creation of machine intelligence on the computer". In other words, in order to increase productivity in the intellectual activities of humans, ways of allowing computers to assist human intellectual activities and to perform tasks that humans are not good at, such as processing simple but large volumes of data or extracting significant data from a huge database, are now being the research target.

## 2-2 Recent research results in artificial intelligence

Research themes in the field of artificial intelligence are extensive as shown in Fiugre 1. To provide an overview of recent research trends in this area, I explain research results in the categories of game playing, agents, data mining, visual and auditory senses, and robotics.

(1) Game playing

In the research on artificial intelligence for reasoning and thinking, some researchers have been studying games in order to develop computer software that can beat human players in games such as checkers, chess, Othello, and shogi, or Japanese chess. In the U.S., the International Computer Chess Association was founded in the 1970s, and the association has been holding Computer Chess Championships. Computers successfully beat the world champion at checkers in 1994 and then at Othello and chess in 1997. In shogi, researchers believe that the ability of the computer is now equivalent to that of an amateur 5-dan player.

These game programs have a knowledge database containing large amounts of standard move sequences and best move sequences shown by professional players so that they can make inferences according to a preset strategy and

Figure 1 : Research themes in artificial intelligence
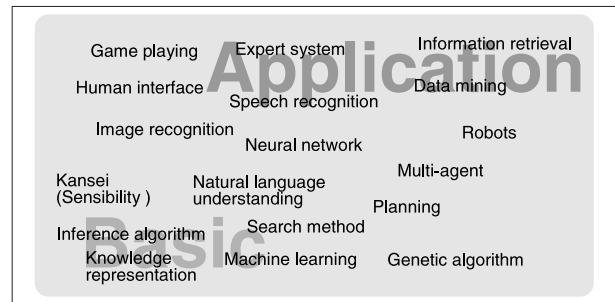
Source: Website of the Japanese Society for Artificial Intelligence

decide the next move. This means that computers can now beat human beings at relatively simple games by employing inference techniques in addition to drawing on enormous databases and having high-speed processing capacity. The next challenge for researchers is to investigate the strategies of champions to develop powerful programs that can play more complicated games such as shogi and go.

(2) Agents

In the 1990s, research on agents, which are computer programs that make the rounds of different sites on a network and perform tasks independently to assist human beings, began receiving particular attention. Capable of communicating with required sites and executing simple processing tasks, an agent autonomously moves across the network and completes jobs for specific purposes. Major research themes in this area include personalization and anthropomorphic agents. The results of these research projects have been applied to schedulers and to web navigation software.

Some projects focus on "multi-agents," and these aim to design systems that enable a large number of agents to behave autonomously on a network. Possible application areas of achievements through these activities include the simulation of social or economic systems. The scheme describes the individual elements of a social or economic system as agents, allows them to operate on the network, and analyzes their behavior. This kind of project tackles unsolved difficulties such as describing agents in a manner that properly expresses the elements of a real society or economy, and describing the interaction between individual agents.
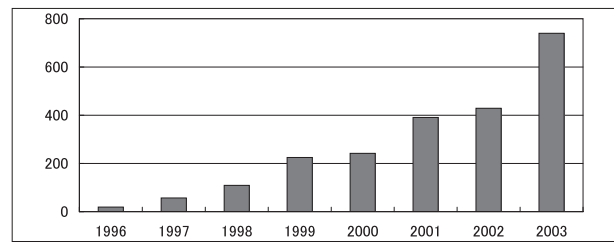
(3) Data mining

Data mining is a technology for extracting significant information from a huge set of data and has been growing as a research field since the late 1990s. Data mining uses machine learning algorithms, which have long been studied. New or improved algorithms have been proposed to meet the requirements of new application fields in data mining, including document analysis, information searching, and security.

Conventional computer security technologies such as virus detection and intrusion detection perform checks against pre-registered virus patterns or find the origins of intruders. This method, however, has the disadvantage of being unable to detect patterns that are not registered, which allows damage to occur during the time lag between the emergence of a new virus and the updating of the virus pattern file. Researchers addressed this problem by developing learning techniques that enable the flexible calculation of patterns to keep up with data changes, and they improved the ability to detect new viruses. These learning methods have proven effective in detecting network intrusions and attacks as well as computer malfunctions[1].

Another popular research area is text mining, which is a combination of data mining and natural language processing. Researchers are addressing topics such as the categorization of questionnaire sentences, reputation analysis, the automatic categorization of e-mail messages, and the categorization of purchase records; the results are in practical use as marketing tools.

Such research efforts in the field of data mining became active in the late 1990s, particularly in the U.S., as shown in Figures 2 and 3. One achievement that prepared the way was the invention of an identification technique called the Support Vector Machine, proposed in 1995 by V. Vapnik, an American mathematician. For its excellent capability to classify unknown data, this technique is widely used as a machine learning tool. Since 1997, a data-mining contest has been held in the U.S. to encourage and speed up building the practical applications based on basic theories. In 2000, three years behind the U.S., a Japanese version of this contest,

Figure 2 : Change in the number of papers on data mining

Source: Based on a search of the ISI database for "Data Mining"

Figure 3 : Number of papers on data mining by country (for 2002)
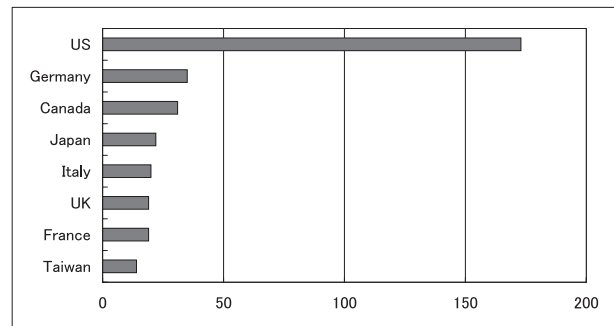
Source: Based on a search of the ISI database for "Data Mining"

"Knowledge Discovery from Common Data Sets," was hosted by the Japanese Society for Artificial Intelligence. To secure its dominance, the U.S. is further intensifying its efforts to facilitate application-oriented basic research, as indicated by the National Science Foundation (NSF), an organization that is known as to promote basic research, planning to build a Science of Learning Center (Table 4) as a comprehensive research institution dedicated to learning, which covers a broad spectrum from basic theory to practical experiment.

(4) Visual and auditory senses

Character recognition, voice recognition, and image recognition technologies are already in commercial use in suitable environments. To be usable in a wider range of environments, they need to be adaptable to varying usage conditions such as where there is ambiguous information, high ambient noise, and changes in light requiring context-based decisions or compensation by the situation. The technologies currently implemented in commercial products are in principle statistical techniques based on enormous databases. Since it is impossible to gather all data covering every possible change in the environment or the situation, or to endlessly enhance performance, extensive research is

needed in areas such as multimodal systems, which use multiple modes of information for decision making, and technologies that adapt to changes in the environment.

(5) Robotics

Recently robot researchers are developing robots having visual and auditory functions. A major challenge is how to find the target for recognition in a given environment as a preparation of recognition process. From this point of view, there are a number of research themes to be addressed, including technology to identify and keep track of the human voice or the target object in a given environment.

In addition, as research into bipedal robots and nursing-care robots proliferates, the need for human-robot interaction and robots operable in people's daily lives is increasing. To allow robots to naturally communicate with humans, some researchers have begun developing robots that use nonverbal communication tools such as facial expressions and gestures. To improve current robot brains, which are still immature, breakthroughs in artificial intelligence research are expected.

2-3   *Subsequent challenges in artificial intelligence research*

Many achievements in artificial intelligence research are already in practical use for expert systems, text recognition, voice recognition, machine translation, data mining, information searching, and so forth. Moreover, the research results of areas such as personalization and distributed agents have already been embedded in information system software which is not easily recognizable as artificial intelligence technologies.

Although commercialized, these technologies have their own limitations in terms of expansion. For example, statistical techniques that are dependent on databases, while being able to perform in the same environment as from where the obtained data cannot cope well with changes in the environment. Currently, artificial intelligence cannot make decisions based on various kinds of information as humans do, and researchers are seeking to narrow the gap of

this ability. These researchers should advance toward a fusion between a mechanical approach, which is solely dependent on large data sets and therefore limited in potential as mentioned in the section on game research, and a human-oriented approach, which intends to learn from human strategies.

3 | Research trends in cognitive science

In artificial intelligence research, described in the previous chapter, findings in cognitive science have been used as part of the human-oriented approach. The research community has high expectations to cognitive science, hoping that it will provide new ideas to overcome the limitations of mathematical and mechanical approaches for performance improvement. The sections below discuss trends in cognitive science, followed by challenges for researchers in cognitive science in pursuit of Intelligent Computing.

3-1   *The history of cognitive science*

To explore human cognitive mechanisms, research in cognitive science began in the 1970s by combining cognitive psychology and the computer. Psychologists, information scientists, neuroscientists, linguists, and cultural anthropologists participated in the study. Cognitive psychology is a research field explaining intellectual activity from a functional viewpoint using the mental state model and that developed within the framework of psychology mainly in the 1950s. In the 1980s, noninvasive technologies for observation of the brain activities were advanced, followed by the development of technologies to visualize observed brain activity data in the 1990s. These advances have allowed researchers to obtain a wide variety of observation data on brain activities. These data have been used to investigate which areas of the brain are responsible for cognitive function, a popular study known as brain mapping, and also referred to as cognitive neuroscience. In this area, there have been major findings on brain plasticity and interconnectivity between brain components.

Table 2 : Historic topics in cognitive science research

latter half of the 1950s Cognitive revolution in psychology	1956	Short-term memory structure (Miller)
	1956	Cognitive processes in concept formation (Brunner)
	1957	Universal grammar (Chomsky)
	1958	Cognitive filter theory (Broadbent)
1970s Emergence of cognitive science	1972	Problem-solving theory (Newell & Simon)
	1979	Establishment of the Cognitive Science Society in the U.S.
	1980	Twelve Issues for Cognitive Science (Norman)
1980s Development of noninvasive brain measurement technologies	1983	Establishment of the Japanese Cognitive Science Society
	1986	The Society of Mind (Minskey)
	1986	Proposal of cognitive engineering (Norman)
1990s Progress in cognitive neuroscience	1995	Neural network model based on neural plasticity
	1996	Bidirectional interaction of nerves in image generation
	late 1990s	Progress in brain activity imaging using computer graphics

Another mainstream research area is creating estimation models for brain information processing by using the neural network methodology employed in artificial intelligence research for simulating the brain's neural networks.

In the late 1980s, a new field in cognitive science was proposed, cognitive engineering, in an attempt to apply cognitive psychology to engineering. To increase attention to user needs in designing engineering products, researchers in this field study human-object (machine) interaction, such as interfaces and communication. They pursued an interface that humans can easily use without being aware of its presence.

3-2 Recent research results in cognitive science

Research themes in the field of cognitive science are diverse as shown in Table 3. Of the four main categories, studies related to central cognition focus on exploring the mechanisms of the sophisticated functions of the human mind. Even when researchers have access to technologies for observing brain activity, the information they have acquired on individual cognitive functions is still fragmented. With respect to the linguistic cognition category, key themes include the understanding of language, the generation of language, and communication. In the area of sensory cognition such as vision, researchers are trying to elucidate how external

Table 3 : Research themes in cognitive science

Central	thinking, learning, conception, memory
Linguistic	language, communication
Sensory	vision, affordance (environment and cognition)
Behavioral	behavior, interaction

stimuli cause brain activity through observation of brain activity and psychological experiment. For behavioral cognition, there are research projects to observe behavior that surfaces in psychological experiments and to predict possible cognitive behavior. There are greater amounts of data available in this area since the external observation of behavior is easier than brain activity observation conducted for the study of central or sensory cognition.

(1) Interworking between visual and auditory senses and action

Researchers have observed that the visual cognitive function for recognizing objects involves activity not only in the visual cortex but also in the motor cortex, that means interworking exists between the visual cortex and the motor cortex. This finding, in addition to helping reveal that humans use physically memorized information when recognizing objects, has recently been encouraging the study of "embodied cognition." This interworking between vision and action is not contained in the pattern recognition mechanism of current computers, and this suggests the possibility of

multimodal recognition techniques, which is an approach based on information acquired from multiple sources such as vision, hearing and physical information. Further exploration of this interworking mechanism is needed.

(2) Application of cognitive properties to products

User interfaces for information equipment have been designed to reflect in the observation results of user behavior. In addition, as information equipment proliferate, they have begun to adopt a universal design, which is a design concept to be accessible for all. While this is the case, however, the design of these devices is often prioritized by cost effectiveness rather than exploiting human cognitive characteristics. Some kinds of information equipment, for example, are equipped with a voice guidance function to ensure user accessibility. These voice guidance systems sometimes frustrate users and cause errors, suggesting the need for smarter systems that adapt to learning level of user and different usage situation. Cognitive scientists and information equipment engineers should cooperate in developing such systems.

Similarly, video conferencing systems, designed by information device engineers using cutting-edge technologies, are not sufficiently considered to cater to the needs of the user. Some researchers in cognitive science have indicated that the lack of reality of presence in video conferencing systems is attributable to the limited space information shared among participants[2]. Eye-to-eye contact and gestures do not work effectively in a small- or single-screen environment. This finding is applicable to improving user-friendliness in not only video conferencing systems but also remote control systems in general.

In the automobile field, where safe operability is emphasized, researchers have been exploring designs that consider human cognitive characteristics. For instance, they have conducted cognitive psychology experiments to study the cognitive mechanism of visual attention and discovered an inverse correlation between the depth of attention and the width of attention as well as certain characteristics of the process of shifting visual attention[3]. The relation between the depth and width of attention is reflected in guidelines for safe driving. Considering the characteristics of human vision, the finding that the process of shifting focus from distant view to near view takes longer than the reverse process has allowed researchers to point out risks associated with car navigation systems. In the area of information equipment, too, similar safety-oriented design concepts adaptable to diverse usage situations should be pursued.

(3) Designs that mirror cognitive characteristics

In much the same way that designers play an essential role in the fields of building construction and automobiles, those who design information equipment are assuming an increasingly important role. This is attributed to the increased demand for user-friendliness in information devices, which have become widely used in people's daily lives. When laying out numerous pieces of information on the Web, for example, designers should consider, in addition to appearance, cognitive aspects of the design, such as the rationality of assumed user actions and interactive capability[4].

The design process for information equipment requires the screening of user needs, design specification, and testing and evaluation of usability. An information equipment designer is expected to conduct the overall management of this process. Current information equipment are often incomplete; their appearance is good but their usability is poor, or they are attractive in their individual elements but lacking in overall design harmony. This suggests the need for integrated effort particularly in the area of interface design, which involves multiple elements such as psychology, cognitive science, human engineering, software engineering, product design, and graphic design.

3-3 Future challenges in cognitive science research

To apply cognitive science to Intelligent Computing, the utilization of findings from cognitive science research has begun, but it is not sufficient.

Knowledge of behavioral cognitive functions obtained through the study of human behavioral and cognitive mechanisms has been reflected in the design of user interfaces for some information equipment. However, these interface design activities are currently dependent on accumulated experience. The next challenge in cognitive science is achieving outcomes that can serve a wider range of purposes and further systematize cognitive properties. This requires cognitive scientists and information technologists to increase interchanges, interworking and collaboration, through which they could elucidate the essence of the cognitive properties useful for designing information devices.

Meanwhile, there is only microscopic, fragmentary understanding of the mechanisms of central and sensory cognition. Traditionally, these areas have been positioned as basic research fields and thus there has been no active effort toward application. Researchers in Intelligent Computing, however, expect new ideas to be derived from these areas, and these ideas could break through the limitations of mathematical and mechanical processing. Cognitive scientists are hopefully aware of the need for application-oriented research activities so that their results may be used for research

into Intelligent Computing. At the same time, interchanges, interworking, and collaboration between the two research fields is essential. In other words, Intelligent Computing researchers should use the achievements of cognitive science on a trial basis and provide cognitive scientists with feedback on the possibilities and problems found.

4 | Challenges in intelligent computing research

To realize Intelligent Computing capable of assisting the intellectual activities of human beings and of naturally interfacing with human beings, there must be a framework to ensure that advances in cognitive science are reflected in research in artificial intelligence. From this perspective, many counties are implementing projects to promote multidisciplinary studies in artificial intelligence and cognitive science. In the U.S., as shown in Tables 4 and 5, the National Science Foundation (NSF) and the Defense Advanced Research Projects Agency (DARPA) have been taking the initiative. NSF, which is offering funds for basic research activities in diverse fields, is particularly promoting joint research projects and multidisciplinary research

Table 4 : Major NSF projects related to cognitive science and artificial intelligence

Year	Project Name	Description
2001~	Cognitive Neuroscience	Research in cognitive neuroscience
2003~	Collaborative Research in Computational Neuroscience	Collaborative research in computational neuroscience
2003~	Artificial Intelligence and Cognitive Science	Multidisciplinary research in artificial intelligence and cognitive science
2003~	Human-Computer Interaction	Research in interfaces between humans and machines
2003~	Human Language and Communication	Research in new computational models for text and speech processing, as well as multi-modal communication
2004~	Science of Learning Center	Multidisiciplinary research center for machine learning, educational/psychological learning, and physiological learning

Table 5 : Major DARPA projects related to cognitive computing

Year	Project Name	Description
2001~	Augmented Cognition	Development of systems that can enhance human cognitive abilities in a stressful environment
2003~	Cognitive Information Processing Technology	Development of systems that can recognize and assist human activities
2003~	Real-World Reasoning	Development of practical inference engines
2003~	Architectures for Cognitive Information Processing	Development of computing architectures of cognitive information processing systems for real-time DoD applications

Table 6 : Competitively funded Japanese research projects related to cognitive science

Year		Project Name	Description
1997 ~ 2003	JST Basic Research Program (CREST)	a part of the "Creating the Brain" and "Understanding the Brain" projects	Development of brain-like devices / architectures and cognitive processing systems; elucidation of higher brain functions
1997 ~ 2000	Scientific Research in Priority Areas	Mind development: the mechanism of cognitive growth	Research in conceptual development, language acquisition and cognitive development
2001 ~ 2005	Scientific Research in Priority Areas	Informatics studies for the foundation of IT evolution: A03 Understanding human information processing and its applications	Investigation into dynamic interaction between perception and action, development of symbiotic systems, and realization of multimodal human-machine interaction
2002 ~ 2006	Exploratory / Fusional Development Program	Construction and elucidation of the emergence mechanism of communication through dynamic interaction	Research in the neural mechanism of action and facial expression, communication models, and the self-organizing function of neural circuits

projects. Recently, NSF has been intensifying its efforts to build comprehensive research centers that cover from basic research to applied research. In contrast, DARPA stresses systems development for demonstrations even in basic research, and requires more specific research target what is to be achieved. Each DARPA project, relatively large in scale, is administered by a program manager and is subject to a rigorous evaluation of the final results. For example, an ongoing project under the theme, "Cognitive Information Processing Technology," consists of members from 20 different organizations. Although geographically dispersed, the members work under the project leader in a virtual research institution.

European initiatives in the area of Intelligent Computing are made in the 6th Framework Program to the European Commission (EC), which addresses this field of study as 'Cognitive Systems'. The U.K. and Germany have selected cognitive science as a theme in their technology foresight activities and have begun discussing specific promotional plans. The technology foresight report[5] published in November 2003 by the Office of Science and Technology of the Department of Trade and Industry of the U.K. (OST DTI) states that interesting new signs were appearing in cognitive science and that, if coupled with artificial intelligence research, cognitive science would result in accomplishments applicable to the fields of information and communications as well as life science, thereby greatly contributing to society.

In Japan, too, a series of multidisciplinary research projects is in progress as listed in Table 6. In each of these projects, a sizable number of researchers work on a variety of themes. While these initiatives foster increased interchange between researchers from different disciplines, the project teams usually dissolve when the project finishes, leaving very few teams to form new organizations to continue activity. With an eye toward constructing world-leading research and educational institutions, Japan has been implementing the 21st Century COE Program since 2002, including the six projects selected in the area of cognitive science as listed in Table 7. These projects aim at, in addition to the promotion of multidisciplinary research, the development of creative human resources. It is expected that these projects will provide frameworks to nurture research personnel and to further develop and systematize research activities when these projects have finished, thus allowing research teams to grow into new organizations. In another initiative, Japan is encouraging brain research under the leadership of the RIKEN Brain Science Institute. This effort emphasizes basic research into the brain, including its cognitive functions.

In contrast, from the standpoint that multidisciplinary research in cognitive science and artificial intelligence will bring about results leading to practical application, the U.S. is promoting application-oriented basic research projects. In the U.S., when a project ends, it does not mean the end of the study, but rather, the start of an industry-academia collaborative effort toward commercialization. This approach is

significantly different from that adopted by Japan, whose projects concentrate on basic research. Although they are potentially fruitful, the outcomes of these basic research projects have not shown major progress. There is a need for a management scheme that permits the research resources of a finished project to be effectively inherited for use in a subsequent project. In addition, it is necessary that scientists will be more aggressive to lead basic research outcome to applied research so that their projects can develop into industry-academia collaboration. The business sector, for its part, should make proactive approaches to universities, such as proposing joint research projects. Research in the information and communications sector is progressing in extremely high rate so that someone across the world are quickly taking advantage of the potential opportunities found though basic studies for practical application.

5 | Conclusion

Research in Intelligent Computing to develop systems capable of assisting the intellectual activities of human beings and naturally interfacing with human beings has advanced in the area of artificial intelligence. The intelligent

Table 7 : Major centers for the 21st Century COE Program related to cognitive science

Program Title	University	Courses	Majors or Disciplines
A Strategic Research and Education Center for an Integrated Approach to Language, Brain and Cognition	Tohoku University	Graduate School of International Cultural Studies, New Industry Creation Hatchery Center, GraduateSchool of Information Sciences, Graduate School of Medicine, Medical School Hospital, Graduate School of Engineering, Graduate School of Arts and Letters	Cognitive Linguistics, Cognitive Psychology, Brain Mapping, Natural Language Processing, Linguistics, Generative Linguistics, Speech and Language Processing, Phonetics, Phonology, Neuropsychology, Neurolinguistics, Sociolinguistics, Linguistic Geography, Learning Psychology, Linguistic Anthropology, Computational Linguistics
Center for Evolutionary Cognitive Sciences	University of Tokyo	Graduate School of Arts and Sciences, Graduate School of Science, Graduate School of Humanities and Sociology, Graduate School of Agricultural and Life Sciences, University of Tokyo Hospital, Digital Museum, Information Technology Center	Human Evolution, Psycholinguistics, General Linguistic Science, Computational Linguistic Science, Cognitive Development Clinical Science
Toward an Integrated Methodology for the Study of the Mind	Keio University	Graduate School of Letters, Graduate School of Human Relations, Institute of Cultural and Linguistic Studies	Philosophy and Ethics, Aesthetics and Science Arts, History, Japanese Literature, Chinese Literature, English and American Literature, German Literature, French Literature, Library and Information Science, Psychology, Education, Institute of Cultural and Linguistic Studies
Zenjin Human Science Program (Exploration of the brain mechanisms for learning, memory, reasoning, and thinking and their application to educational technologies)	Tamagawa University	Research Institute, Graduate School for Engineering, Graduate School for Agriculture, Graduate School for Education and Letters,	Brain Science Research Center, Language and Communication Research Center
Promotion of 'Kansei' Science for Understanding the mechanism of the Mind and Heart	University of Tsukuba	Graduate School of Comprehensive Human Sciences	System Brain Science, Neural Molecular Dynamics, Behavioral Neuroscience, Psychology, Mental Disability Science, Brain-Like Information Processing Mechanics, Kansei Informatics, Art
World of Brain Computing Interwoven out of Animals and Robots	Kyushu Institute of Technology	Graduate School of Life Science and Systems Engineering	Neurophysiology, Electrochemistry, Psychology, Human Behavior, Mathematical Science, Linguistic Science, Devices, Robotics

processing capability of such systems has enhanced as the computer's processing capability has improved, and some of them have been incorporated into commercial information systems in fragments, in a manner that is not easily recognizable as artificial intelligence. However, mathematical and mechanical approaches solely dependent on the processing capacity of the computer are not sufficient for developing highly sophisticated intelligent systems.

In cognitive science, a field aiming to elucidate the mechanisms of human cognitive functions, the development of noninvasive brain observation technologies since the 1990s has brought major research advances to the mapping between cognitive function and brain activation, partially revealing the correlation between the visual/auditory senses and action. While a large part of central cognitive mechanisms, which are related to reasoning and thinking, has yet to be explained, expectations are high that this area of research will be able to propose new ideas to help overcome the limitations of mathematical and mechanical approaches in artificial intelligence research.

Traditionally, researchers in cognitive science have emphasized achievements within the framework of basic research and have not made proactive efforts toward practical application. Engineers in the information and communications sector have simply used findings in cognitive science with little interaction with cognitive scientists. The boundary between the two fields must be eliminated because new developments can be derived from such activities as addressing existing challenges in the field of information and communications in the new light of cognitive science. These efforts will lead to an application-oriented multidisciplinary research initiative. In implementing this initiative, the conventional multidisciplinary research framework must be avoided because in such a framework once a project ends, its research results disperse and stop accumulating. As a result, achievements in the project do not grow into a critical mass and further progress is inhibited. Another possible measure for multidisciplinary research promotion in cognitive

science and artificial intelligence is building a research institute that recruits a sizable research staff to work on all spectrum of research from basic to application.

Recently, the U.S. has been implementing projects to encourage multidisciplinary research in the areas of cognitive science and artificial intelligence. While promoting application-oriented basic research as well as the applied research that follows, the U.S. is planning to build a center for integrating such activities to secure its position as the world leader in this field. Since research in the information and communications sector is proceeding rapidly, positive results achieved through basic research are quickly finding its application.

Japan has not been successful in embodying or applying excellent new concepts found through basic research to engineering. Another discouraging element of Japanese research initiatives is that multidisciplinary research teams usually dissolve once the project ends, reducing the opportunity for the results to be further studied and developed. Japan should consider a program of constructing a research center dedicated to cognitive science and artificial intelligence, while seeking more the flexible operation of research organizations in universities by, for example, adopting a 'scrap-and-build' approach. Yet another weakness of Japan is its lack of effort in linking basic research with applied research. Possible solutions by the government are to increase incentives to promote interchange between basic and application initiatives and to encourage application-oriented basic research activities. In the meantime, the business sector should also make proactive approaches to universities, such as proposing joint research projects, to facilitate the commercialization of potentially fruitful findings.

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