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Cognitive Science as Science of the Mind

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1 Introduction

Of the various means of studying the mind, cognitive science and neuroscience both explain the mind of the individual through her/his physical conditions including those of the brain. Cognitive science, in particular, examines mental aspects as 'software' to acquire, modify, maintain and utilise information. It aims to elucidate the mechanisms concerning thought, linguistic capacity, learning, consciousness, the concept of the self as distinguished from others, evaluation, and communication with others.

In the West, cognitive science has appeared as a continuum from Greek philosophy as a science of the mind, a refutation of Cartesian mind-body dualism, a psychology split from philosophy as a positive discipline, a backlash against behaviorism and the establishment of cognitive psychology under the influence of computational theory. Meanwhile, Japan has had no mind-body dualism exerting extensive, long-lasting influence such as Descartes' theory. Instead, it has long been thought that the mind and body are inseparable. Traditionally, the Japanese were proficient in handling ambiguous ideas and non-verbal thoughts, and in guessing the mental states of others. In other words, the resources obtained through cognitive science have already been applied in Japan. However, without the custom of consciously analysing one's own thought processes and explicitly describing them, Japan now finds the challenge of dealing with the loss of traditional social structures over the last few decades, as well as the recent demand for the promotion of science, considerable. It is necessary to understand one's own thought processes to establish new solutions to such issues.

The general history of cognitive science and its potential industrial applications have already been reported by Watari[1]. With this in mind, this report summarizes the development of cognitive science through interdisciplinary interaction and discusses its potential to supply knowledge of the mental functions of human beings and to provide solutions to mental and social issues.

2 The formation of cognitive science

2-1 Constituent areas

When the U.S. Cognitive Science Society was founded in 1979, cognitive science was defined as "a multidisciplinary field embracing artificial intelligence, psychology and linguistics"[2]. As represented by the theme of the first conference, "knowledge, internal and logical representations, symbolic information processing, functionalism", the main early interests were topics related to computer science[3]. Later, emphasis was also placed on the biological brain as an indispensable entity, or actual experiences and knowledge as an essential part of cognitive function. Researchers from various disciplines such as computer science (or information technology (IT)), psychology, linguistics, neuroscience, philosophy, education, sociology and anthropology, take part in research in cognitive science (Table 1). The Japanese Cognitive Science Society was established in 1983, with membership of around 1,500 as of 2004 (Table 2)[4]. Researchers in brain science and neuroscience are not obvious in the society but rather participate in the Japanese Society of Cognitive Neuroscience, where they interact

Table 1 : Constituent disciplines defined by cognitive science societies in various countries

	Year of foundation	Computer science	Psychology	Linguistics	Neuroscience	Philosophy	Sociology	Education	Anthropology	Ergonomics	Logic	Cognitive science
AISB (UK)	1964	○										
CSS (USA)	1977	○	○	○								
	1984*	○	○	○	○	○						
	1997*	○	○	○	○	○		○	○			
ARCo (France)	1981	○	○	○	○	○	○				○	
JCSS (Japan)	1983	○	○	○	○	○	○					
ESSCS (Europe)	1983	○	○	○	○	○		○		○		
KSCS (South Korea)	1987	○	○	○	○	○						
GK (Germany)	1994											○

*: Turning point
AISB: the Society for the Study of Artificial Intelligence and the Simulation of Behaviour
CSS: Cognitive Science Society
ARCo: Association pour la Recherche Cognitive
JCSS: the Japanese Cognitive Science Society
ESSCS: the European Society for the Study of Cognitive System
KSCS: the Korean Society for Cognitive Science
GK: Gesellschaft für Kognitionswissenschaft

among relatively close subdisciplines such as neuropsychology, neurophysiology, neuroscience, brain imaging, education, psychology, neurosurgery, neurology and psychiatry.

Table 2 : Number of members of cognitive science societies in various countries

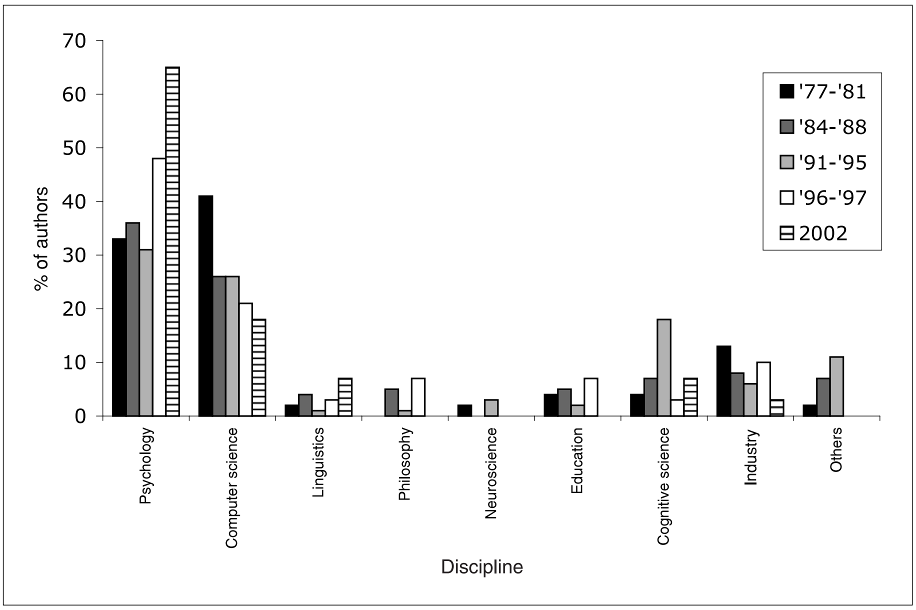
	Approximate membership
AISB in the U.K.	500
CSS in the U.S.	1100
ARCo in France	350
JCSS in Japan	1500
KSCS in South Korea	500

2-2 Benefits of multidisciplinarity

In many countries, societies for cognitive science have defined themselves as multidisciplinary since their foundation, and two decades hence, they continue to emphasize their multidisciplinary nature. The reason that cognitive science is still considered to be a multidisciplinary field is due to the change of its constituent disciplines over time (Table 1) and the influx of human resources from different disciplines through educational and research institutions. Therefore, the contribution of the methodology or expertise of each discipline in cognitive science changes, and so do the contents of academic output in the field of cognitive science.

Currently, more than half of the researchers in the cognitive science field belong to one of two domains, namely, psychology or IT. In many countries, the number of researchers in IT is decreasing, while the number of psychologists and linguists is increasing. Focusing on the first authors of the papers published in the Journal of Cognitive Science and their institutions, the proportion of researchers in psychology and IT was 33% and 41% (1977-1981), 48% and 21% (1996-1997) and 65% and 18% (2002), respectively[2]. In terms of methodology, information processing, which analyses human cognition by analogy with functions of the computer, has long been mainstream. However, with the growth of situation theory, emphasizing context-dependent cognition, or the socio-cultural approach from sociological and cultural perspectives, use of the descriptive method based on on-site data has also increased

Figure 1 : Percentage of first authors of articles published in the Journal of Cognitive Science with given departmental affiliations



Source: Based on the report by Schunn, Crowley & Okada, (1998)[2]. The latest data ('96-'97, 2002) is also shown for reference.

in the last decade. Corresponding to the increasing participation of neuroscientists, the physiological activity of the brain has also been actively considered in recent years. The rise of these new approaches and methodologies is also reflected in the research subjects themselves. Since its foundation, the main subjects of cognitive science were the processes of thought, reasoning and memorisation in the individual. Recently, however, research has been conducted on interpersonal perception, collaborative cognition and thought processes within groups. Moreover, there is increasing demand for research results to be more socially applicable. When journals accept articles for publication, researchers from different disciplines are employed to conduct peer review. This helps to avoid articles focusing only on traditional disciplines that are preoccupied with academic interests, and favours articles compatible with various disciplines as well as with society.

3 Methodologies in cognitive science

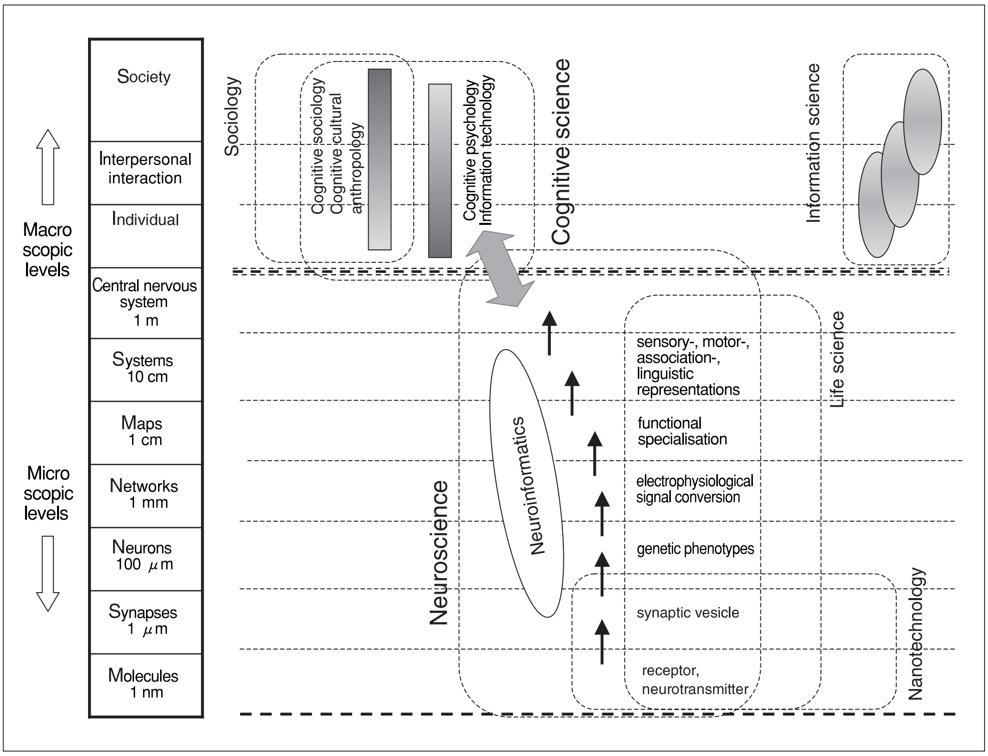
3-1 Hierarchical structure of science of the mind

The functions of the human mind involve various phenomena over different levels, from molecules, cells, neural networks, brains, individuals to groups of individuals (Figure 2). Cognitive science analyzes mental software from a macroscopic standpoint and therefore targets individuals and more global entities. Meanwhile, neuroscience, a life science, analyzes mental hardware from a microscopic standpoint and deals with molecules (such as neurotransmitters and neuron-specific gene expression), cells and electrophysiological signal transduction, etc.

3-2 Is psychology literature?

Because psychology targets macroscopic subjects such as individuals or society and often employs descriptive approaches, researchers from other empirical disciplines working at the microscopic level often perceive psychology as lacking the strictness or rationality required in the natural sciences. Although psychology originally split from philosophy, aiming to be an empirical discipline, certain schools in this domain indeed created their own speculative terms and conceptual systems that could only be understood by people within the same school and that could not be verified. Cognitive psychology deals with the cognitive process that takes place within the bodies of human subjects or experimental animals, which are practically 'black boxes'. Therefore, researchers have coped with this difficulty by enhancing the strictness or rationality of experimental constraints

Figure 2 : Hierarchy of phenomena concerning the mind



The constituent disciplines of cognitive science, cognitive sociology and cognitive anthropology place relatively strong emphasis on the analysis of society, while cognitive psychology and IT place relatively strong emphasis on the analysis of individuals. The gap between psychology and information science within the cognitive science field and neuroinformatics or non-invasive cerebral activity measurement within the neuroscience field is decreasing, which increases the potential for a fusion of the knowledge and methodologies of both fields.

when inputting information to the subjects or processing and interpreting the output. Due to the large limitation of experimental studies conducted on human subjects, such studies were almost exclusively performed in the medical field, such as comparison between pathological and healthy subjects. Through the development of cognitive psychology, the possibility of cooperation among medicine, psychology and IT is increasing.

In 1876, the Meiji government started to appoint returnees as instructors in the Faculty of Literature of the Imperial University as part of its efforts to encourage the development of a westernized general education. Here, psychology was taught in the philosophy class of the liberal arts course. In 1893, Yujiro Motora, who had studied experimental psychology in the U.S., opened a department of psychology within the faculty. Thereafter, psychology gradually became institutionalized in the Faculty of Literature[5]. During 1875-78, as part of a widespread general education drive, the Meiji government dispatched delegations to the U.S. where psychology was included in teacher-training courses. After returning, they also established psychology in teacher-training courses in normal schools, which explains the link between psychology courses and faculties of education in Japan. Psychology was originally influenced by physiology, departing from speculative philosophy. In Cambridge University in the U.K. for example, the psychology domain derived from physiology. In Japan, neither psychologists nor scientists from other disciplines, including medicine and physiology, are aware that they can share and fuse their methodologies. This has prevented their mutual interaction. It is first necessary to reconsider the research situation in experimental psychology in Japan and improve it so that researchers in the discipline can cooperate with their counterparts in other disciplines.

3-3 Cooperation between psychology and IT

In the field of cognitive science, psychological experiments have been often combined with simulations based on computational theory.

In IT, the cognitive process is translated into programmes where parameters can be set and altered on demand. Here, the researchers emphasise the types of programme or parameter selected to create explanatory systems detailing the processing that takes place between input and output. When psychologists begin cooperating with IT researchers, their different perspectives often stand as obstacles. However, as their collaboration progresses, they revise their strategies by mutually incorporating other viewpoints. For example, for their simulation studies, IT researchers may choose parameters as close as possible to those of observations using psychological approaches. When data obtained through psychological experiments are considered to be effective but insufficient in sample size for statistical processing, IT can provide simulation studies to complete the validity of a hypothesis. The difference between the mutual viewpoints can be therefore advantageous in creating new scientific concepts.

4 Research subjects in cognitive science

Some examples of the subjects studied in the cognitive science field are shown.

4-1 Verbal/non-verbal thinking

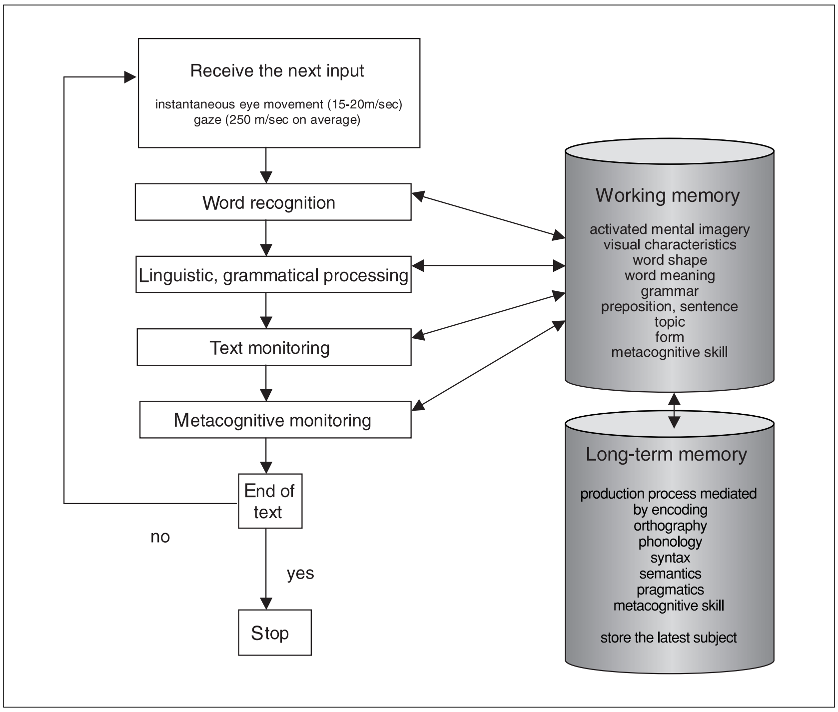
Noam Chomsky, a linguist, further advancing his analysis on the universal structure of language, presented the hypothesis that "the human being is born with an innate ability to spontaneously acquire language"[6]. This biological insight suggests that "even higher mental functions in humans can be elucidated through empirical science" and has inspired a number of new studies in various areas. When there were no means of empirically analysing thought, perspectives based on linguistic determinism claiming that 'language rules thought' did exist. However, important concepts have actually occurred in the minds of many scientists and artists by pondering in mental imagery. Michael Faraday visualized the 'lines of force as narrow tubes curving through space' and thus formed the concepts of the electric and magnetic fields. James Clerk Maxwell, an abstract theoretical mathematician, manipulated mental imageries of thin foil and a fluid to generate the mathematical concept of electromagnetic fields[7]. Cognitive science has demonstrated that non-verbal thinking processes employing mental imaging does exist and that the process involving language is only a part of the overall thought process. In the earliest experiment, subjects were shown the letter 'F' or its mirror image rotated at various angles and were asked to discriminate the stimuli. The time required for their responses correlated with the rotation angle of the images, indicating that the subjects made their judgments by rotating the given images to an upright position in their minds[7]. Meanwhile, human language processing is an effective means of analysing cognitive functions, and a vast volume of research has been conducted on the process.

4-2 Cognitive mechanisms of reading

As can be seen in learning the Analects of Confucius in Japan or that of the Koran in Islamic societies, reading the written/printed form of a language is an important aspect of training in traditional learning processes. Even today, children with reading problems find it difficult to proceed in terms of the learning process, even if other abilities are at a normal level or more advanced There is a huge amount of information in the modern world, and people find an increasing need to read documents for meetings, manuals for working procedures, contracts, etc. The resource of populations with high vocational and professional legibility should greatly influence the foundation of science and technology.

Meanwhile, about 5-10% elementary and secondary school children either have reading difficulties or understand the meaning of written sentences only with difficulty, although they can normally communicate through speech and have no specific disabilities otherwise. Those who have already mastered reading, such as teachers or parents, may be unaware, but from the viewpoint of cognitive science, reading is composed of multiple parallel steps involving the complex, rapid processing of information (Figure 3). It has been found that children with reading difficulties encounter problems in one or

Figure 3 : Diagram showing the cognitive processes performed in reading



source: Prepared by the author based on Bruer's report[8]

more of these steps. For example, normal reading requires information processing in the order of milliseconds, but children with problems in the rapid processing of sensory information exhaust their efforts in recognizing the elements of words and can hardly encode them into semantic elements. Now it has been conceived that reading ability may be improved by strengthening certain weak steps in cognitive processes.

4-3 Learning theory

(1) Domain-specific knowledge

In the field of cognitive science, "the process by which a beginner becomes an expert", i.e., the mechanism of learning, has been analyzed through comparison of problem-solving between experts and beginners[8]. Initially, artificial intelligence was successful in solving formal, logical problems such as those in mathematics, geometry and chess, but in the 1970s, they showed a weakness in solving problems requiring large amounts of factual knowledge to solve them, such as those in physics and medicine. It was shown that human beings use an abundance of domain-specific knowledge when solving certain actual problems. Considerable portions of domain-specific knowledge can be neither compensated for by other knowledge specific to different domains nor deduced from resources of general knowledge shared by multiple domains. Based on such findings in cognitive science, a scholar of English who was worried about the lack of basic cultural knowledge among teenage students wrote "Cultural Literacy: What Every American Needs to Know"[9] in 1987, and it has been used since as a book helping foreigners to understand general aspects U.S. culture.

(2) Metacognition

Around 1980, cognitive scientists suggested that the mature cognitive process in an individual involves metacognition, the ability to think about thought itself. In other words, it is the ability to consciously recognize problem-solving behaviour in oneself or in another person and to monitor and control one's own mental processes. When infants are told to memorise all the items on a list taking as much time as they need and to inform the examiner when they think they have memorised the list, the actual level of performance is much lower than their evaluation, even when their memories are tested immediately after they declare they have completed the task. When children are told to memorise and recite a story, younger children's memories tend to be dispersed and incoherent, lacking the vital elements required to reproduce the main plot of the story. Meanwhile, when children over 12 years declare that they have learned a certain task, they can generally reproduce it to a level similar to their evaluation, indicating that they can recognize their own achievements. In addition, they know that they must find associations between various elements in the story, judge which parts are important and pay attention to these parts when memorising the story. Once metacognition has been acquired in one domain, it can facilitate learning in novel domains.

Metacognition is required not only during growth but also at any stage of human life facilitating our learning efficiency. As Karl Popper said, scientific theories are elaborated on by successive modification of an existing immature hypothesis by proposing opposing hypotheses and by verification[10]. Metacognition is, therefore, equally important in pursuing scientific research. It is also used for providing advice on others' activities, or in collaborative work, when team members have different tasks they are good at or work at different paces. A lack of metacognition concerning performance of either oneself or one's teammates often reduces working efficiency.

4-4 Theory of mind

We unconsciously guess the mental status of other people or adjust our own thoughts and comportment to theirs. Because most guesses are adequate, interpersonal relationships can proceed relatively smoothly without much need for minute verbal explanations. This ability to recognize the mental status of oneself and others, 'theory of mind', is firmly established by 3-5 years of age. Using theory of mind, children come to understand that someone's belief is not always a representation of the actual facts of the external world but may merely be a misrepresentation that the person holds in her/his mind. The development of this ability can be tested by showing a child a picture of a simple story and verifying whether the child can detect the character(s) having 'false belief'.

Even a newborn baby has the neurological properties to distinguish between self and non-self environments, but the subjective recognition of self and non-self first appears at the age of 18-24 months. As the first step in the development of joint attention ability, pointing behavior intended to attract others' attentions to oneself or to an external target appears by the age of 12 months. From this point, babies start to follow the glance of another person to a point away from the person, and by the age of around 18 months, they learn that when someone is staring at a certain target, "the person is thinking about the object" and, in this sense, they relate the person and the object. Autistic individuals, however, have difficulty in guessing their own mental status and that of other people. Psychological examination using 'theory of mind' tasks has enabled the early diagnosis of autism. Moreover, by combining 'theory of mind' tasks with the non-invasive imaging of brain activity, the functions of the frontal lobe responsible for the ability to guess one's own and others' mental status are being extensively analysed.

5 Involvement of brain science and neuroscience areas

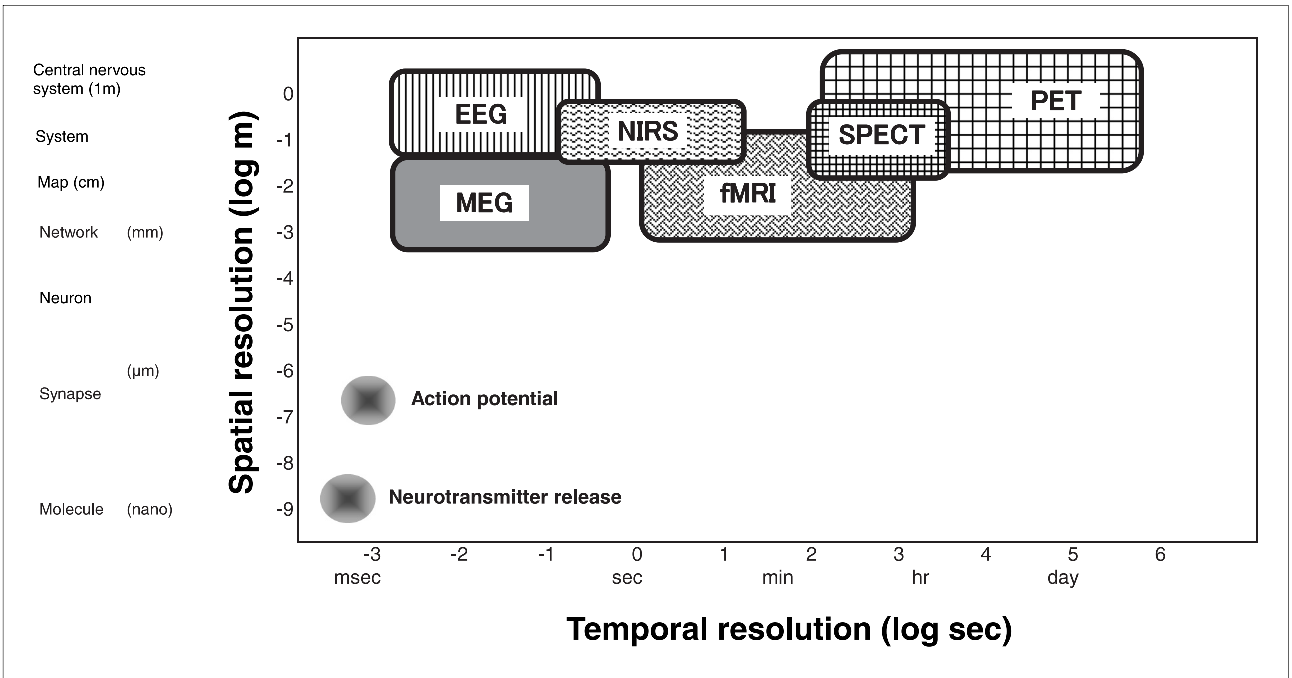
5-1 Microscopic neuroscience and macroscopic cognitive research

Neuroscience dealing primarily with the brain involves numerous researchers; in Japan for example, the total membership of the Japan Neuroscience Society and the Japanese Society for Neurochemistry is 5,600, and that of the U.S. Society of Neuroscience is around 32,000 including overseas members. Although a considerable number of these researchers have the intention to elucidate the cognitive process, they rarely participated in cognitive science societies because neuroscientists were primarily interested in the biological aspects of the brain, 'hardware' in the cognitive process. They start by accumulating the 'focal' findings concerning molecules, cells or local neural networks, with little in common with cognitive scientists' 'global' analyses of individuals (Figure 2). However, neuroscientists also aim at global understanding at levels such as the brain system, the central nervous system, and the individual. This is because (i) sensory recognition of vision, hearing, temperature, smell, taste and posture is perceived only after physical stimuli (light, vibration, pressure & distortion) or chemical stimuli of some hundreds of thousands of molecules such as acids and salts by the sensory organs are converted into electric signals and transmitted to the brain, and integrated in the cerebral cortex, (ii) human beings can autonomously create a new idea and utilize stored memories even in the absence of external stimuli, and (iii) the aforementioned global status of the brain controls microscopic phenomena. The existence of the top-down control mentioned in (iii) can be understood from the fact that a person perceives the same stimulus differently at different times according to attentional level, expectation, anxiety or combination of stored memory contents. Unlike machines, human beings make good use of the top-down mechanism in their smooth, flexible processing of information.

For the experimental establishment of the concept of long-term depression in the cerebellum, Dr. Masao Ito was inspired by the Marr-Albus theory in which, by hypothesising a special synaptic plasticity in the cerebellum, the learning potential of the neural network was deduced. Since then, theoretical strategies have been adopted for analysis at the microscopic level. In particular, methods employing IT, neuroinformatics, are effective for such analysis in dealing with the convergence and divergence of electrophysiological signals in the neural network, and for integrating several findings at the microscopic level for a global understanding. Here, neural information rather than biological entities are simulated.

In recent years, the sensitivity, resolution and scanning rate have dramatically improved in the non-invasive measurement of cerebral activity, such as functional magnetic resonance imaging (fMRI), cerebral blood flow measurement through near-infrared spectroscopy (NIRS) and magnetoencephalography (MEG), and in the relatively low-invasive single photon emission computed tomography (SPECT). Thus, analysis of smaller, more discrete loci of the brain can be conducted in healthy individuals under natural conditions (Figure 4). This has raised expectations that understanding cerebral hardware in neuroscience and software in cognitive science will fuse in the near future. This is reflected in the increasing participation of neuroscientists in the U.S. Cognitive Science

Figure 4 : Temporal and spatial resolution of the measurement of brain activity



Non-invasive methods: fMRI: functional magnetic resonance imaging, NIRS: cerebral blood flow measurement through near-infrared spectroscopy, MEG: magnetoencephalography, EEG: electroencephalography
Less invasive method: SPECT: single photon emission computed tomography
*The time required for the synaptic release of neurotransmitters form a vesicle and the duration of an action potential at a synapse are indicated for reference.

Society in last 5 years.

5-2 IT of the brain and the nervous system

The human brain has about 1012 nerve cells, and each cell receives input from other nerve cells at a few thousand to 10,000-20,000 synapses. As a signal transporter at the synapse, more than a few dozen neurotransmitters and neuromodulators have been identified so far. Each neurotransmitter has multiple specific receptors, which by themselves are coupled to multiple intracellular second signaling pathways, contributing to diversification of signal transduction. Researchers refer to ‘a grandmother cell’ only as a metaphor for the concept that “a single nerve cell in the brain may be able to evoke an image of (for example) grandmother’s face”. In fact, however, the contents of the neural information are determined by temporal and spatial changes in neural activity within the network. Moreover, neural information processing involves, in addition to the bottom-up conversion from sensory input, top-down regulation in which attention, expectation, memory and autonomous inspiration may select or modify on-going information.

Since the information processed in the brain is so huge and complicated, it was necessary to incorporate strategies of IT, informatics, for a comprehensive description of neural information processing. At the RIKEN Brain Science Institute, a research group is surveying advances in neuroinformatics and developing a neuroinformatics system for visual processing[11].

At its early stage, neuroinformatics was considered to be “just a means of storing and integrating experimental data”. Recent progress in neuroinformatics is reaching global analysis of brain function, and may fuse with the IT-based analysis of cognitive processes of the individual conducted in cognitive science. Supporting a subject studied both in neuroinformatics and cognitive science separately reduces efficiency and wastes funds. It is necessary to promote interaction between the two fields so that materials, facilities and knowledge can be exchanged and shared effectively.

6 Application to society

6-1 The case of Stephen Mobley

In 1991, Stephen Mobley killed an employee of a pizza parlor and was accused of murder and robbery. No particular medical, psychological or sociological predispositions were observed. He had no previous record of violence and showed normal intellectual potential. His personality could be described as impulsive, cunning and self-centered. There was a history of pyromania and animal abuse. His lawyer found an article[12] by Brunner et al. published in 1993 suggesting that “a point mutation in the gene encoding monoamine oxidase, which metabolizes neurotransmitters such as serotonin, dopamine and noradrenalin, may be related to an inherited disposition of aggressive behaviour among members of a Dutch family with a marked familial history of crime”. He checked Mobley’s family line and found records of impulsive, antisocial behaviour through three generations. The question as to whether Mobley should be subject to genome analysis for the presence of this particular mutation and whether its presence was a reason for commutation was strongly debated. However, finally, genetic testing was not conducted, and Mobley was sentenced to death.

Mobley’s case has raised two questions: whether individual or a small number of genetic traits can determine human behaviour, and whether a person with such a genetic alternation for a substance influencing brain activity would be exempt from legally responsibility for a crime. Later, in 1996, Brunner presented his view that “the concept of a gene that directly encodes behaviour is unrealistic”[13]. Meanwhile, monoaminergic neurotransmissions are significantly implicated in diverse mental disorders such as depression and anxiety, and are always studied intensively in both the medical and pharmaceutical domains. To develop effective diagnosis methods and therapies, a plausible relationship between genetic alternation and phenotypic expression at an individual level must be demonstrated[14]. The critical debate avoided in Mobley’s case will confront us again in the near future. We must be prudent in relating issues at the microscopic level such as genes, neuromodulators, cells and tissues, with those at the global level such as individuals or society. Based on new findings obtained in cognitive science, the concepts of judgment ability or responsibility for an individual's own acts have to be reconsidered.

7 Support system for cognitive science

7-1 Dissemination

Being a science of the mind, cognitive science should have enormous influence on society. We must disseminate cognitive science as a discipline to help us understand mental functions and improve public understanding. Once interested, people may have unreasonably high expectations of the discipline. It is then necessary to explain what cognitive science can and cannot offer, and to continually discuss what and to what extent we should know about the mind. It is better to start by dispatching understandable information so that at least those who are interested and understand will take notice. Appointing a science writer may be helpful for large organizations. Moreover, informatics is an effective tool for people fromdiverse fields to access such information..

7-2 Opportunities for verification

Because research in cognitive science is oriented to the social application of its fruits, cooperation with society is essential in the first place. In science, the process from "setting a hypothesis, its evaluation, to restructuring of the hypothesis" is taken as a regular strategy in which trial and error is accepted. On the other hand, where new scientific findings are applied, e.g., in school curricula, development of commercial products, diagnosis and drug administration, an error once made can never or rarely be compensated for or retrieved. Scientists must recognize that society also has its own strict criteria of evaluation although they may be different from theirs. Therefore, coordinating different evaluation criteria is required.

Through efforts to improve public relations, cognitive scientists must win social understanding and opportunities to verify their findings in actual situations. For instance, hypotheses in cognitive science concerning personal learning, collaborative learning or a particular teaching method would be verified in university-affiliated elementary or secondary schools. Once such a hypothesis is proven to be valid, strategies for its wide application would be discussed. As for the development of commercial products in companies, there are opportunities to make a good use of and to evaluate findings in cognitive science[1].

7-3 Application of results versus scientists' autonomy

At present, the major outcomes in cognitive science are from the U.S., where the NSF (National Science Foundation) as well as military organizations such as DARPA (Defense Advanced Research Projects Agency), ONR (Office of Naval Research) and AFOSR (Air Force Office of Science Research) have been sponsoring research in this field. Each country should have its own policy on the application of scientific findings. It is better that Japan not be overwhelmed by enumerative information but to select and utilize the information that it really needs. Private U.S. foundations such as McDonnell, Mellon and Spencer explicitly demand applications for the results of the research projects they sponsor. In 1983, the United States National Committee on Excellence in Education published the report, 'A Nation at Risk'[15], which triggered in society significant concerns about public education, which resulted in a demand for proposals for the innovation of teaching and learning techniques that have a firm theoretical and empirical background. Around this time, cognitive studies of learning processes were beginning to produce new theories. Since then, cognitive science has offered influential knowledge and theories for educational strategies in the U.S. Some people worry that cognitive science, on the other hand, disproportionately emphasises the research subjects of education and that researchers are concentrated in the domain. In Japan, it is necessary to represent social needs to scientists, but it would be better if the actual choice of research subjects and approaches were left in the hands of the scientists themselves. In 2002-2003, the U.K. Office for Science & Technology conducted a "Foresight Cognitive Systems Project" to establish frameworks for promoting cognitive science. However, 'they placed the activity firmly in the hands of the scientific community[16].'

7-4 Worldwide database

The enormous amount of scientific findings on the brain can be hardly integrated by a single country's efforts, and international cooperation is essential. Since 1996, a subgroup in the OECD Megascience Forum (currently known as the Global Science Forum) Working Group on Biological Informatics has been studying issues in neuroinformatics, and Japan has actively contributed to it from the beginning. In January 2004, the OECD Committee for Scientific and Technological Policy met at ministerial level and decided to establish the International Neuroinformatics Coordinating Facility (INCF), which will take charge of the development and management of comprehensive database systems for brain research[17]. The project has reached the stage where participating nations are being asked to sign the agreement and to establish national nodes. As mentioned previously, Japan has developed a neuroinformatics platform in certain areas. Promotion of such projects should encourage research within the nation and raise the technological and intellectual contribution of Japan on the international stage.

7-5 Promotion of original research in Japan

During the Annual Forum of the AAAS (American Association for the Advancement of Science) Science and Technology Policy in 2004, the importance of cognitive science was emphasized in the context of the converging project in nanotechnology, biotechnology, information technology, cognitive science and sociology (NIBCS)[18,19]. A plan to understand the human mind through the collaboration of the aforementioned disciplines was named The Human Cognome Project. It is obviously an analogy to the Human Genome Project and is expected to involve a series of large-scale support programmes. The combination of nucleotide sequences or codons that can infinitely generate variable information, resembling the grammatical combinations of a language, are processed with IT relatively easily. On the other hand, information in cognitive science differs in nature and requires significantly greater labour compared to the Genome Project. Moreover, even if a single highly comprehensive database system is established, it may not necessarily be as effective as expected. The different pathways of information processing in the brain, although heavily interconnected each other, are also unique. A database unified by standardising the diverse pathways may seem like an encyclopedia, and may not be able to cope with actual individual problems. In Japan, it is wise to use foreign knowledge only if it is useful, as well as to pursue independent support of projects that really meet Japanese needs.

8 Conclusions

The attempt to explain the human mind with physical conditions including that of the brain involves two scientific areas. One of them, cognitive science, analyses the 'software' of the mind at the macroscopic level such as individuals or groups, while the other, neuroscience, analyses the 'hardware' of the mind such as molecules, cells and neural circuits in the biological brain at the microscopic level. As the distance between these two areas has been decreasing in recent years, physical and physiological bases of the human cognition should be elucidated in the future. The approaches of the two areas can be mostly attributed to the vast findings accumulated in each area, the employment of IT to integrate them and advances in the non-invasive measurement of brain activity. Now, it is essential to enrich research environments for the efficient accumulation, storage and utilization of findings obtained in the two areas, and to elaborate on systems for cooperation among constituent disciplines such as psychology, medicine and IT, so that experimental data, e.g., that of the non-invasive measurement of brain activity, can be interpreted and integrated into an effective understanding of the mind.

Cognitive science is necessary for current Japanese society, and we must promote this science in a unique way.

(1) Explicit presentation of thoughts

For more than a millennium, the Japanese have been achieving high levels of intellectual and economical production, and undoubtedly have high cognitive abilities. They are not accustomed to being explicitly aware of their thinking processes or to expressing them straightforwardly. However, now that it is necessary to invent new concepts and problem-solving strategies, the lack of explicit recognition of their own processes of conduct is often a hindrance to the Japanese. Scientific research in particular is made up of such processes as 1) focusing on a worthwhile question, 2) setting a goal after evaluating whether the actual tools to reach it are or will be available, 3) pursuing research while evaluating the process by oneself, 4) verifying the results and 5) advancing a theory. Thus, metacognitive excellence is required. In a society lacking metacognitive excellence, researchers can hardly explain the meaning of their own research, seek and find the most efficient solution available, or apply particular knowledge under differing circumstances. This is a serious obstacle for a nation aiming at social development by promoting science and technology. It is an urgent issue for the Japanese to form the habit of explicitly recognizing their thinking processes and consciously controlling their thoughts.

(2) Best use of traditional wisdom

On the other hand, according to cognitive science, human thinking does not exclusively consist of "rational, logical processes that are consciously managed through our own free will" as Westerners have often taken for granted (see note). A social system and production system that can cope with ambiguous, context-dependent affairs and that considers human emotions and needs is required for the future world. The Japanese tend to refrain from rigid formularisation and to make use of reservation and flexible adjustment of comportment. Traditional Japanese communication utilizes not only the spoken language but also subtle facial and physical expressions or even the duration of silences, as well as timing of utterance. These are sophisticated cognitive functions to pass on and for understanding subtle feelings. The Japanese have long attached importance to guessing others' feelings, which has subsequently allowed them to predict, prepare and supply what others expect. Fine sensitivity and discrimination of different colors and forms, and hand dexterity are representative of excellent cognitive patterns, and characteristic of that for which the Japanese have a good reputation. The Japanese already have the abundant cognitive resources required to invent new social structures and production systems, and it would be a grave loss if Japan did not make the best use of its traditional cognitive faculties.

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Note

As a surgical operation for epilepsy, patients may receive separation of neural connectivity between the right and left hemispheres. Studies in cognitive psychology have been conducted after such operations. When a certain object was described verbally and the patient was asked to pick it up from among several objects, the patient could make the right choice and pick up the corresponding object without being consciously aware of it. This demonstrates that unconscious thinking processes do exist. The contents of unconscious thinking tend to be expressed through physical and facial expressions rather than words. Moreover, some patients with certain brain defects after injury or tumor may preserve the manipulation of intellectual concepts but lack certain control of emotions. Because these patients cannot integrate individually correct pieces of intellectual information into a meaningful task, it is indicated that emotions are inevitably important for judgment or conduct. The judgment of healthy individuals can be modified by expectation and speculation when they are exposed to distracting stimuli before or at the same time as the target stimulus. Some conditions of stimuli presentation may make subjects perceive non-existent stimuli. This reflects the cognitive function used in actual life when we deduce the entire features of a target even when it is partially hidden, or when we rapidly recognize a particular target from a perceptually confusing background. When a subject is asked to talk freely in the laboratory and the questioner favourably responds only to a certain word, the usage of the word by the questionee increases. On the other hand, when the questioner ignores a word, the questionee uses the word less frequently. In neither case is the questionee aware of the fact that s/he is performing auto-correction in line with the alluded to preference of the interlocutor. When performing collaborative work in actual society, these cognitive processes work for a conformity bias in which the statements or performances of a person are adjusted to synchronize with others' opinions or acts.

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