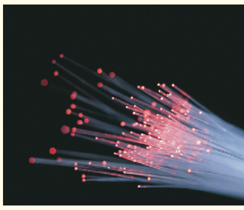
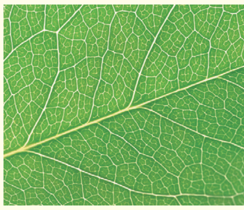
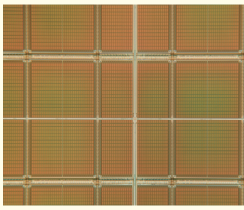
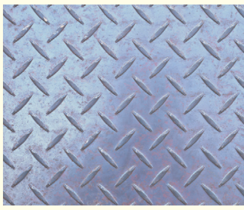
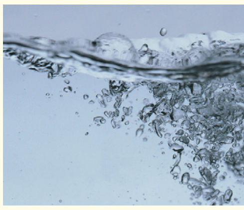
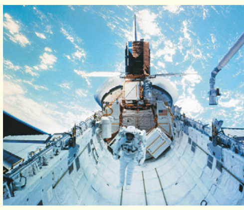
ISSN 1349-3671

Science & Technology Foresight Center of NISTEP

Science & Technology Trends
Quarterly Review

No.14
January
2005

Foreword

This is the latest issue of "Science and Technology Trends — Quarterly Review".

National Institute of Science and Technology Policy (NISTEP) established Science and Technology Foresight Center (STFC) in January 2001 to deepen analysis with inputting state-of-the-art science and technology trends. The mission of the center is to support national science and technology policy by providing policy makers with timely and comprehensive knowledge of important science and technology in Japan and in the world.

STFC has conducted regular surveys with support of around 3000 experts in the industrial, academic and public sectors who provide us with their information and opinions through STFC's expert network system. STFC has been publishing "Science and Technology Trends" (Japanese version) every month since April 2001. The first part of this monthly report introduces the latest topics in life science, ICT, environment, nanotechnology, materials science etc. that are collected through the expert network. The second part carries insight analysis by STFC researchers, which covers not only technological trends in specific areas but also other issues including government R&D budget and foreign countries' S&T policy. STFC also conducts foresight surveys periodically.

This quarterly review is the English version of insight analysis derived from recent three issues of "Science and Technology Trends" written in Japanese, and will be published every three month in principle. You can also see them on the NISTEP website.

We hope this could be useful to you and appreciate your comments and advices.

TERUTAKA KUWAHARA
Director
Science and Technology Foresight Center

Contact us: Science and Technology Foresight Center
National Institute of Science and Technology Policy
Ministry of Education, Culture, Sports, Science and Technology (MEXT)
2-5-1, Marunouchi, Chiyoda-ku, Tokyo 100-0005, Japan
Telephone +81-3-3581-0605 Facsimile +81-3-3503-3996
URL http://www.nistep.go.jp/index-e.html
E-mail stfc@nistep.go.jp

Executive Summary

Life Sciences

1 Cognitive Science as Science of the Mind

p.13

Cognitive science and neuroscience both explain the minds of individuals through their physical states, including their brains. In particular, cognitive science analyzes mental ‘software’ such as the acquisition, modification, maintenance and utilization of information, and studies the mechanisms concerning thought, linguistic capacity, learning, consciousness, the concept of the self as distinguished from others, evaluation, and communication. Cognitive science involves researchers from various fields including computer science, psychology, linguistics, neuroscience, philosophy, education, sociology and anthropology. There are great expectations of recent advances in the non-invasive measurement of cerebral activity, but the acquisition of concrete knowledge using such methods requires solid inter-disciplinary collaboration among cognitive psychology, computer science, clinical medicine and neuroscience. In Japanese universities, psychology is confined to departments of literature or education, which has prevented close interaction between this discipline and others such as medicine, science and engineering. We must reexamine the position of empirical psychology and create a system to facilitate its cooperation with other scientific disciplines.

Knowledge of the mind potentially has a large influence on society, so we have to be prudent in rationalizing the global phenomena of individuals or society using microscopic subjects such as genes, neuroregulators, cells and tissues. Based on the knowledge accrued in cognitive science, the concepts of individual judgment or responsibility for one’s own acts may have to be reconsidered.

In the West, cognitive science has its roots in traditional philosophy and psychology. For the Japanese, who have a different concept of mind and body, way of thinking, and social demands, it is better to set research subjects according to their original reasoning. Mental mechanisms revealed by cognitive science should help the Japanese to understand the characteristics of their traditional way of thinking. Accordingly, they will offer effective measures to reexamine and reconstruct ways of problem solving and communication that were destabilized by the effeteness of the traditional social system. Now, the Japanese have a number of problems to solve mainly because they are not used to consciously controlling their own thoughts. For the time being, therefore, it is essential to introduce the western way of pondering one’s own thinking processes consciously and explicitly describing one’s own thoughts.

Neuroscientists, who also attempt to explain the mind through the physical conditions of human beings including those of the brain, handle the hardware rather than the software of the mind through microscopic analysis of the structure and function of the biological brain. To integrate and analyse the enormous, complex findings on the brain, neuroinformatics has emerged as a new discipline using information technology. Mathematical simulations are used for theoretical advancement where microscopic findings are translated into global knowledge. The distance between cognitive science and neuroscience is now narrowing, and physical bases for cognitive processes have a good chance of being realised.

In January 2004, the OECD Committee for Scientific and Technological Policy met at ministerial level and decided to establish a comprehensive database system for brain research and an International Neuroinformatics Coordinating Facility (INCF) as an administrative system. Japan has been developing its own neuroinformatics systems and is now ready to contribute to the international system.

At the 2004 Annual Forum on Science and Technology Policy of AAAS (the American Association for the Advancement of Science), emphasis was placed on the importance of converging nanotechnology, biotechnology, information technology, cognitive science and sociology into a comprehensive knowledge system (NIBCS). In this context, an enterprise to understand the human mind through cooperation among multiple disciplines was named the Human Cognome Project. Following in the footsteps of the successful Human Genome Project, it is supposed to have large-scale support. In regard to the enormous workload demanded in cognitive science, making good use of foreign findings in the fields that Japanese researchers cannot cover is an efficient method. However, Japan has to select the necessary information and implement projects of great priority without being overwhelmed by information.

(Original Japanese version: published in July 2004)

Information and Communication Technologies

2 R&D Trends in Flat Panel Display Technology

p.26

As terrestrial digital broadcasting is beginning, CRT TVs are about to be displaced by TVs with higher resolution and larger screen size. To seize this huge business opportunity, manufacturers have developed various next-generation display technologies such as the liquid-crystal display (LCD), plasma display panel (PDP), and organic EL display (OLED for Organic Light-Emitting Diode), to name only a few flat panel types, and they are now being introduced onto the market.

These technologies, although initially considered not applicable to consumer TVs, have been improved by Japanese manufacturers, who have overcome technical hurdles over the years. Among these are the LCD and PDP technologies that have already become the two major camps splitting the large-screen TV market. Thus, Japan has led the world in display panel technology development.

Despite their success in technological development, Japanese companies have fared poorly in business. Korean and Taiwanese competitors have rapidly caught up since the launch of the LCD and PDP markets. Furthermore, there has recently been a move among Korean universities that could threaten Japan's position even in the area of R&D.

Because the current display industry is primarily based on horizontal labor division, manufacturers are increasingly emphasizing manufacturing costs to gain a competitive edge. Under these circumstances, rather than vying with Korea and Taiwan only in the panel manufacturing arena, Japan should widen its scope of development and pursue next-generation high-performance display technologies with high added value and systems that exploit such technologies.

Display is expected to advance toward the production of images closer to reality. For example, to achieve a wider color reproduction range, display researchers will probably need to revise not only display devices but all technologies for image signal input and output, including cameras, image pickup devices, and image processing functions. Higher color reproducibility could even spur the demand for higher definition. The R&D activity required to tackle these challenges is too extensive for a single company to handle. In a development project that involves diverse research themes and a number of businesses, the government should coordinate development efforts across participating firms, while providing R&D subsidies.

Japan's strength lies in a combination of comprehensive capability in display technology and imaging systems, including peripheral technologies, where Japan has accumulated knowledge, and the Japanese consumer who is highly demanding in terms of image quality. Japan should take advantage of this strength to develop high value-added technology for the next generation.

(Original Japanese version: published in August 2004)

3 The Two Rationalities and Japan's Software Engineering

p.41

Despite many years of priority funding by the government, the international competitiveness of Japan's software sector is almost hopelessly weak. This article explores the causes of this weakness from the perspective of "theory on rationality."

The structural weakness of the Japanese software industry is attributable to a presumable lack of rationality and logicality among the Japanese. However, this does not mean the Japanese have no rationality and logicality. Rationalities vary as much as cultures do, and Japanese have a different type of rationality than that of Westerners. From this sociological viewpoint, "building-in quality," a common practice in the Japanese manufacture industry, is also a form of rationality.

Similar approaches are being adopted by the world's leading software consultants for the agile and flexible development of software to meet the demands of the modern business world. These approaches defy traditional methodology in software engineering that is based on "up-front rationality." The tide in software engineering is about to change its direction, and the situation is favoring Japanese methodology.

This article argues that Japan can dramatically improve its competitiveness in software engineering and the software industry by analyzing this emerging situation with the assistance of production engineers and using the results to review its policies for developing the software industry and software-related human resources.

(Original Japanese version: published in September 2004)

Nanotechnology and Materials

4 Issues and Prospects of Materials Databases
— Aiming to Develop a Materials Database to be Used around The World —

p.54

It is necessary to consolidate data and information to make progress in science and technology. However, database development poses many problems, and thus there has been little progress in this area. This paper analyzes the characteristics and issues of materials databases developed in Japan, examines efforts to develop a materials database by leading organizations both at home and abroad, suggests measures to increase the availability of a materials database, and outlines the direction for database development.

It is extremely important to create a database that is visible. In other words, easy access must be ensured. It is also imperative that a database offer valuable contents so that it will be widely used. Development efforts should focus on creating a visible database to be used by anyone who requires information.

In Japan, technologies are developed to meet the needs of the shop floor, which calls for the development of a database that is geared to these needs. In this respect, it is essential to create a comprehensive materials database that offers highly professional information to meet the needs of researchers and engineers. It is also important to develop software that enables the effective use of information so that the availability of a database increases.

In Japan, a highly professional materials database is offered by the National Institute for Materials Science (NIMS), the National Institute of Advanced Industrial Science and Technology (AIST) and other organizations. Systematic effort and time have been invested in the development of databases that now have a good reputation. Public research institutes should lead these development efforts to create and establish a truly original materials database that appeals to the world.

There are various materials databases around the world. These databases offer a wealth of highly professional information, but often specialize in a narrow field. Thus, a single materials database cannot satisfy the needs of users with varying needs. However, it is difficult to consolidate existing databases without an understanding of the intention behind their development. In general, because users of professional information only want to know where they can find information, it is extremely useful to build a network that connects materials databases and help users locate information.

It is important to create an environment in which materials experts lead efforts to develop a highly professional materials database and where information technology experts provide assistance. Once developed, a database must be maintained and improved. This means establishing a framework to secure funds for maintenance.

(Original Japanese version: published in September 2004)

Energy

5 Trends and Prospects for Japan-China Technical Assistance in Energy and the Environment
— From the Viewpoint of Global Environmental Problems and Energy Security —

p.69

Achieving 3E – Energy security, Environmental preservation and sustainable Economic growth – is the biggest challenge facing the international community in the 21st century. With Asian countries having achieved high economic growth and beginning to have a substantial impact on the world's energy market, the Asian region is most likely to represent a considerable burden on the global environment in coming years. In particular, it is estimated that China's primary energy consumption will account for some 45% of total Asian consumption in 2020.

World CO_2 emissions, meanwhile, are expected to increase by 50% between 2000 and 2020, a projected increase which some estimates attribute as much as half to Asian countries. A mere 2% of this increase is attributable to Japan, whose economy is expected to grow modestly, in contrast to around 53%, to China. In addition, air pollution in the shape of sulfur and nitrogen oxides, etc. in China, will probably have serious effects on neighboring countries, including Japan.

The 3E issue, therefore, goes beyond a Japan-specific problem and emphasizes the need for cooperation with Asian countries (particularly China) in addressing forthcoming challenges.

Japan has made significant contributions to Chinese environmental conservation through technical assistance and research exchange. However, there have been considerable recent problems concerning inappropriate technology transfer and a shortage of local maintenance engineers. This article summarizes the trends and prospects for Japan-China technical assistance from the viewpoint of a cooperative framework, coal exploitation, clean coal technology, environmental conservation technology and the utilization of natural gas and nuclear and renewable energy, suggesting various means by which Japan and China should cooperate with each other in addressing the 3E issue. As guidelines, the following four themes were identified.

(1) Transfer of Japan's commercialized technologies

Japan's commercialized technologies should be transferred to China to solve the country's 3E issue, focusing on coal utilization and clean coal technologies (high-efficiency coal-based power generation, coal gasification, coal liquefaction, etc.), environmental conservation technologies and technologies for utilizing natural gas and nuclear and renewable energy. In order to facilitate this transfer and develop human resources (maintenance engineers), moreover, Japanese experts should be dispatched on a long-term basis, based on a bilateral agreement, to establish and promote an energy and environmental technology center through which technical training can be offered and first-hand information exchanged.

(2) Creation of a bilateral framework for reducing greenhouse gas emissions

A system based around a Clean Development Mechanism (CDM) should be created and managed between the two countries, where Japan earns CO_2 emission credits from emissions reduced in China through the technology transfer stipulated above. Such a system requires a framework in which the CO_2 emissions reduced by technological transfer are quantified and certified. The Japanese and Chinese governments should establish this framework based on mutual political cooperation and agreement.

(3) Development of strategic joint research and development projects

Strategic joint research and development projects in the fields of energy and the environment should be promoted between Japan and China, based on cooperation between industry, academia and government. Specifically, advanced technologies with clear objectives should be jointly developed- e.g., air pollution prevention technologies to be applied in the East Asian region, high-efficiency coal gasification, combined power generation and clean coal technologies including the utilization of coal ash. Any achievements resulting from the projects shall be protected as intellectual property rights, based on a mutual bi-lateral agreement.

(4) Development of human resources on a medium- to long-term basis

A program to exchange students in the fields of science and technology should be promoted between universities and graduate schools in Japan and China to develop human resources sufficiently aware of the 3E issue. Specifically, it is recommended that the Japanese and Chinese governments create independent scholarships for students of their partner countries.

The above themes will be of interest to China in terms of (i) diversification of its power supply, (ii) development of inland areas including coal-producing regions and (iii) exploitation and proliferation of advanced technology. Meanwhile, benefits to Japan would likely be (i) effective reductions of CO_2 emissions and (ii) maintenance or improvement of its industrial competitiveness. In addition, both countries would benefit through improvements in (i) environmental conservation and (ii) sustainable economic growth.

(Original Japanese version: published in July 2004)

Infrastructure

6 3-D Full-Scale Earthquake Testing Facility (E-Defense)

p.83

The current Enforcement Ordinance of the Building Standards Act is based on the revision to introduce a new earthquake-resistant design, which was made in 1981 in the wake of the Miyagi-Oki Earthquake, which occurred in 1978. The Enforcement Ordinance has undergone revisions concerning the design seismic coefficient, the earthquake-proof criteria and other items repeatedly after large-scale earthquakes.

In the Kobe Earthquake, which occurred in January 1995, the earthquake epicenter was located directly beneath the Kobe area and exhibited strength surpassing conventional assumptions, resulting in large-scale damage. A great number of structures were destroyed including reinforced concrete buildings and expressway bridges that had been thought immune from destruction in an earthquake thus far imagined, causing more than 6,400 deaths and an economic loss amounting to 12 trillion yen.

To protect human lives from earthquakes, it is necessary to design structures that will not collapse completely or to reinforce existing building to prevent them from collapsing completely. This demands not computer-simulation-based analyses, but the development of an experiment facility that allows a full-scale structure on a shaking table to be put under conditions of three-dimensional shaking identical to actual earthquake shaking. The development of such a facility will allow the process of structural collapse to be recorded and analyzed experimentally, thereby leading to dramatic improvements in technologies concerning earthquake resistance and reinforcement.

The world's largest 3-D Full-Scale Earthquake Testing Facility (E-Defense), which the National Research Institute for Earth Science and Disaster Prevention, an independent administrative institution, started building in Miki City, Hyogo Prefecture in 2000, is currently undergoing its final overall performance test; it will be completed in 2005, 10 years after the occurrence of the Kobe Earthquake.

The E-Defense has the following features:

(i) The size of the shaking table is 20 meters by 15 meters, allowing a structure weighing up to 1200 tons to be tested;
(ii) Capability of reproducing three-dimensional motion identical to actual earthquake motion; and
(iii) Capability of performing experiments on the basis of the records of nearly all earthquakes observed the world over.

Structures for which the improvement of earthquake resistance is needed range widely in fields such as buildings, civil engineering work, and machinery. In the two-year period beginning in Fiscal 2005, earthquake resistance experiments for (i) reinforced concrete buildings, (ii) wooden buildings, and (iii) foundation ground are planned.

The E-Defense facility will be used in three ways: for the Research Institute's own research activities, for joint research activities, and for consigned research activities.

To avoid catastrophic damage caused by an earthquake and protect human lives even if a certain degree of damage is unavoidable, it is necessary to clarify the process of collapse of buildings (why, how, and to what extent buildings collapse). The role that the E-Defense facility is expected to play is to realize the collapse of a full-scale structure on a shaking table, and thereby contribute to designing structures not susceptible to catastrophic damage.

(Original Japanese version: published in August 2004)

Frontier

7 The Rapid Progress of China's Space Development

p.92

In October 2003, China successfully launched and recovered a manned spacecraft, becoming the third country, subsequently to the United States and Russia, to do so. Underlying the feat are not only technical achievements steadily accumulated over 40 years of aiming towards space, but also rapid transformation of social systems, including reforms in science and technology systems.

The organization leading China's space development planning is the China National Space Administration (CNSA), but actually performing research and development is the state-owned enterprise the China AeroSpace Corporation (CASC). Development of artificial satellites is centered on the Chinese Academy of Space Technology (CAST), which is under CASC.

Since its first launch in 1970 through April 2004, China has successfully placed 60 of its own satellites in orbit, relying mainly on Changzheng (Long March) launch vehicles. Including commercial launches, Changzheng have succeeded 76 times with 8 failures for a launch success rate of 89.5 percent. From the last failure, in August 1996, through April 2004, there have been 34 consecutive successful launches.

China's own satellites include recoverable satellites, meteorological satellites, Earth observation satellites, communications and broadcast satellites, navigation satellites, and manned spacecrafts. In its plans for future space development, China includes goals for implementing various spacecraft projects connected with burgeoning national power, among them the development of mission instruments, standardization of satellite platforms, and advanced satellite design. In addition, new concepts such as lunar probes and space environment monitoring are also included. China is also cooperating with the nations of the Asia-Pacific region to reduce the impact of disasters.

In order to discover actual trends in Chinese space development, this article examines the journal China Space Science and Technology published by the Chinese Academy of Space Technology. Issues published during 2003 are analyzed for distribution of research sectors, author affiliations, and sources of citations. The journal incorporates articles in a wide range of fields, including Single Stage To Orbit (SSTO) systems for manned spacecraft, space rendezvous, human error in the operation of manned spacecraft, and methods of analyzing Earth observation images, demonstrating that China undertakes ambitious research on a par with that in the United States of America, Russia, Europe, and Japan.

China has begun working on reform of its science and technology systems with an eye to completion by 2010. It is also proceeding on the path of reform in its national economy, including antiquated practices, and is attempting to maintain sustainable economic growth.

Rather than merely observing the rapid progress of China's space development as it has been doing for the past several years, Japan should be asking what it can learn from Chinese research and development trends and changes in social systems.

(Original Japanese version: published in July 2004)

Science and Technology Policy

8 Scientific Research and Intellectual Property in the Public Interest : "Status of the Research Use Exemption" —A contributed article from AAAS

p.104

Policymakers should determine the proper scope of intellectual property protection coverage so that scientific research can progress and lead technological innovation.

In 2002, the American Association for the Advancement of Science (AAAS) in the US launched a project to explore the relationship between scientific research and intellectual property from a public interest perspective. At its annual meeting in February 2004, AAAS held a symposium entitled "Intellectual Property and the Research Exemption: Its Impact on Science."

Japanese policymakers also recognize the necessity of clarifying the scope of the exemption from patent rights at experiments and research activities. The Intellectual Property Policy Headquarters claims that this clarification is necessary in its "Intellectual Property Promotion Plan 2004" (dated May 27, 2004) and has been conducting related studies.

Dr. Audrey R. Chapman, co-director of the above-mentioned AAAS project, sent us the article outlined below to clarify the "Status of the Research Use Exemption."

Outline of Dr. Chapman's Article

Since the Bayh-Dole Act in 1980, the United States has tended to protect scientific research outcomes under intellectual property rights. This phenomenon has impaired the freedom to search, the freedom to access data and the freedom to disclose results, which are essential for progress in science, and has caused new problems in scientific research activities.

In terms of the applicable scope of patent rights, some nations legislate that non-commercial, personal and experimental research activities are exempt from patent right protection if certain conditions are satisfied. However, because many of these legal exemptions are excessively narrow and vague, it is necessary to set out the proper scope of such exemptions.

Many US scientists traditionally assume that they can use a patented invention without obtaining explicit approval from the patent holder if their research activities are not for commercial profit. However, in June 2003, the US Supreme Court made the ruling that "Patent rights would cover even research activities that do not have a commercial purpose." This ruling may have significant adverse impact on researchers. For example, researchers may avoid important research activities because of licensing obstacles; they may enter into unnecessary contracts to use research tools; and they might relocate their research activities in a nation that legally exempts their research activities from patent right coverage.

Addressing this problem requires a clear definition of "Exemption from patent rights." It is also effective in harmonizing domestic law in various nations in accordance with the TRIPS Agreement, which sets out the minimum requirements for WTO member nations in terms of intellectual property protection. I believe that using a patented invention for research purposes should be exempted from patent right protection.

(Original Japanese version: published in August 2004)

1

Cognitive Science as Science of the Mind

KAYOKO ISHII
Life Science and Medical Research Unit

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.

2-2 Benefits of multidisciplinarity

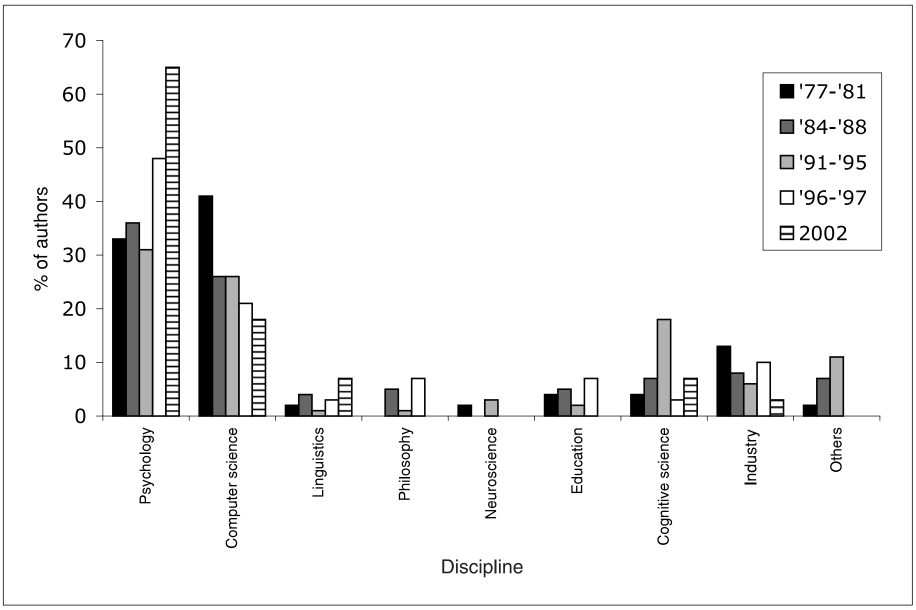
In many countries, societies for cognitive science have defined themselves as multidisciplinary since their foundation, and two decades hence, they continue to emphasize their multidisciplinary nature. The reason that cognitive science is still considered to be a multidisciplinary field is due to the 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

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

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

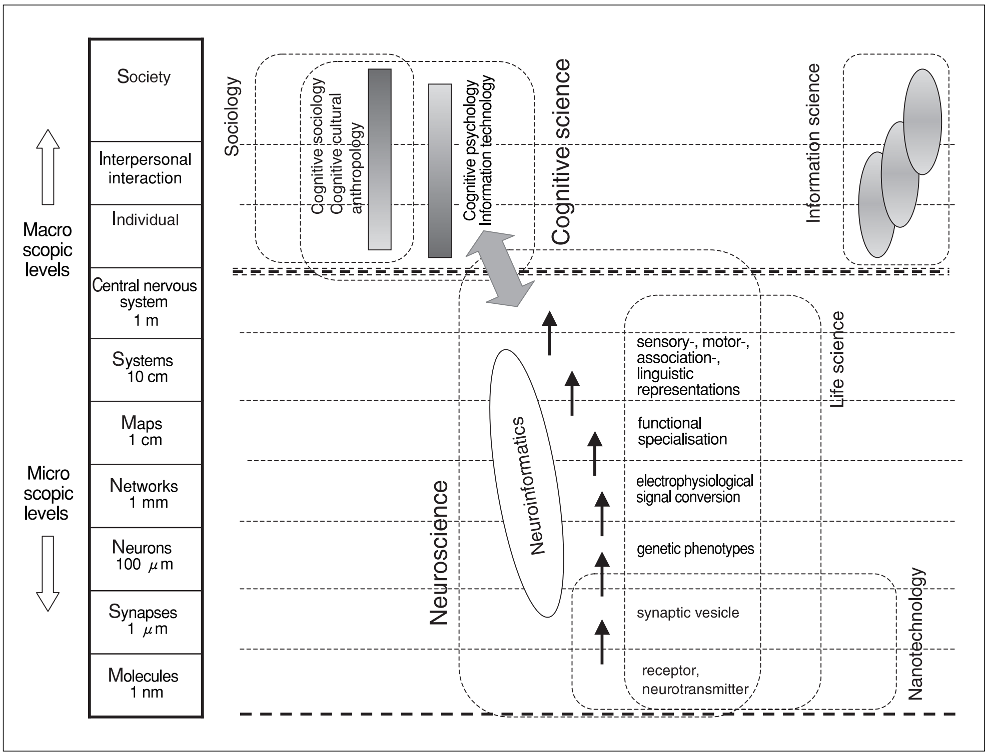
3-1 Hierarchical structure of science of the mind

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

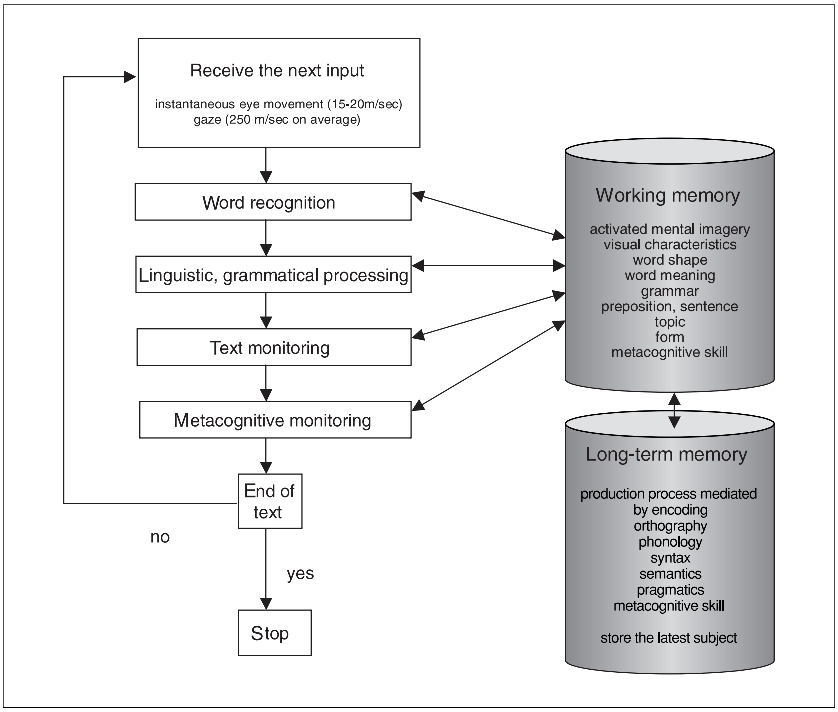
Noam Chomsky, a linguist, further advancing his analysis on the universal structure of language, presented the hypothesis that "the human being is born with an innate ability to spontaneously acquire language"[6]. This biological insight suggests that "even higher mental functions in humans can be elucidated 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

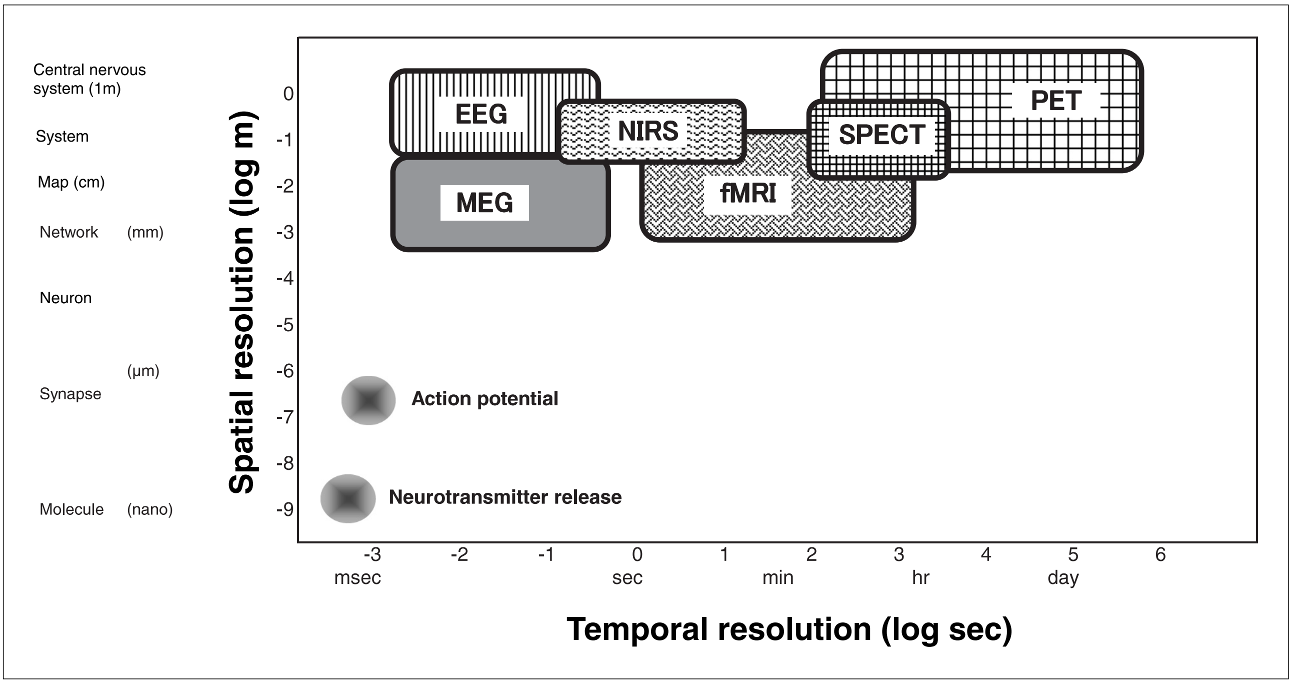
5-1 Microscopic neuroscience and macroscopic cognitive research

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.

References

[1] Masao Watari; "'Research Trends toward Intelligent Computing — Promotion of Multidisciplinary Research in Cognitive Science and Artificial Intelligence —" Science and Technology Trends- Quarterly Review No.13 (October 2004). : http://nistep.go.jp/index-j,html

[2] Schunn, C.D, Crowley, K, & Okada, T 'The Growth of Multidisciplinarity in the Cognitive Science Society' Cognitive Science 22, 107-130 (1998)

[3] http://www.cognitivesciencesociety.org/

[4] http://logos.mind.sccs.chukyo-u.ac.jp/jcss/

[5] Tatsuya Sato, Miki Takasuna "Reading the History of Psychology: In Japan and the World)." Yuhikaku, Tokyo 2003

[6] Chomsky, N. 'Language and mind' Thomson Learning, Harcourt Brace Jovanovich, Inc. New York 1972

[7] Steven Pinker 'The Language Instinct' Penguin Books 1994

[8] John T. Bruer, 'Schools for Thought. A Science of Learning in the Classroom' The MIT Press, 1993, "jyugyou ga kawaru-ninchi shinrigaku to kyouiku jissen ga tewo musubutoki" Japanese translation by Fumiko Matsuda, Toshiaki Mori. Kitaohji Shobo

[9] Hirsch, E.D. 'Cultural Literacy: What Every American Needs to Know,' 1987 Houghton Mifflin "kyouyou ga kuni wo tsukuru" Japanese translation by Yasuo Nakamura. TBS Britannica

[10] Popper, K. The logic of scientific discovery, Routledge Classic, London 2002

[11] Shiro Usui “Neuroinformatics: trends and prospects.” Seitai no kagaku. October 2003. Feature article “Genomic and informatics in drug development” (in Japanese)

[12] Brunner H.G., Nelsen M., Breakefield X.O., Ropers H.H., van Oost B.A., ‘Abnormal behavior associated with a point mutation in the structural gene for monoamine oxidase A.’ Science 1993, 262, 578-80

[13] Brunner H.G. ‘MAOA deficiency and abnormal behaviour. Perspectives on an association.’ Ciba Found Symp. 1996, 194, 155-64

[14] “A big project for the genetic resolution of depression.” Science and Technology Trends: June 2004 (in Japanese) : http://nistep.go.jp/index-j.html

[15] United States National Committee on Excellence in Education “A Nation at Risk-Challenge to Japanese Education.” Japanese translation by Sadao Hashizume. Reimei Shobo

[16] http://www.foresight.gov.uk/cognitive.html

[17] http://www.oecd.org/document/15/0,2340,en-2649-201185-25998799-119690-1-1-1,0,html

[18] http:/wtec.org/ConvergingTechnologies/

[19] http://www.aaas.org/spp/rd/forum.html Masatsura Igami; “Science and Technology Policy Trends in the United States - Report on the AAAS Annual Forum on Science and Technology Policy -”,Science and Technology Trends — Quarterly Review No.13 (October 2004) : http://nistep.go.jp/index-j.html

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.

(Original Japanese version: published in July 2004)

2

R&D Trends in Flat Panel Display Technology

HIROSHI KOMATSU
Information and Communications Research Unit

1 Introduction

1-1 The most familiar information terminal

Of the five senses, sight contributes most to the human ability to gather information, accounting for over 80% [1]. Personal computers and mobile phones are usually operated through display. In years to come, human interfaces based on visual recognition, typically graphical user interfaces (GUI), will play an increasingly important role in enabling people to operate electronic equipment loaded with an increasing number of functions. The most important key device of these visual interfaces is the display.

The black-and-white television, which appeared in the 1950s, once constituted together with the washing machine and the refrigerator, the “three sacred treasures” of the household. During the Izanagi Boom, a major economic boom in the 1960s, these three were replaced by the “3Cs”-the color TV, the air conditioner, and the car. Recently, a new version of the three sacred treasures has emerged among the digital household appliances that are driving consumer spending: the flat panel TV, the digital camera, and the DVD (Digital Versatile Disc) recorder (Table 1). Each generation of these treasures includes TV, so TV has, since its advent, been a central consumer product.

TV has recently undergone a transformation because of the development of display technology. The digitization of TV broadcast signals improves resolution and other image quality aspects. In a move toward digital broadcast, TV displays are required to show high-definition image without degrading the quality of the original image. High-definition pictures are at the same time spurring demand for larger screens. Since conventional TVs with a Braun tube, also known as a cathode ray tube (CRT), cannot adequately meet this demand because of depth dimension and weight constraints, liquid crystal display (LCD) and plasma display are attracting attention as key devices for next-generation flat panel TVs.

Table 1 : Changes in the three major consumer products

Three sacred treasures	3Cs	The new three sacred treasures
Monochrome TV	Color TV	Flat panel TV
Washing machine	Cooler (air conditioner)	Digital camera
Refrigerator	Car	DVD recorder

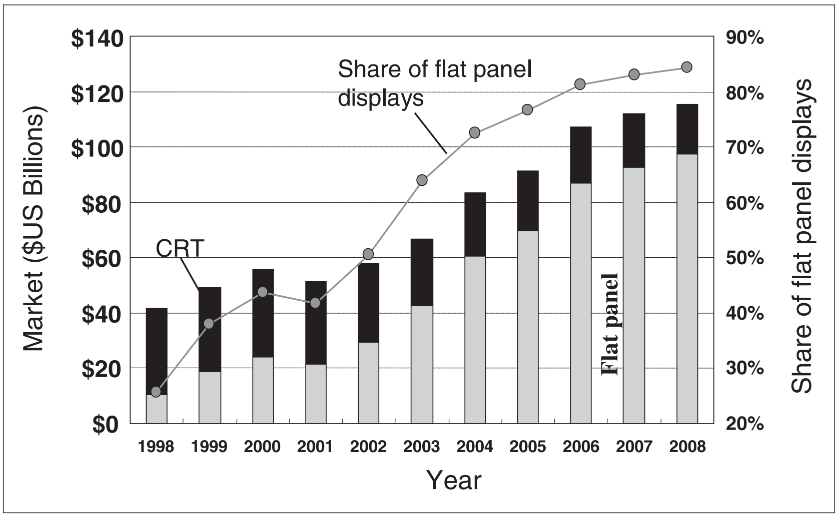
1-2 A hopeful market

The worldwide display market was valued at approximately ¥7 trillion in 2003 and is projected to grow to roughly ¥12 trillion by 2008 (Figure 1). The share of flat panel models in all display products was over 50% in value terms in 2002, surpassing CRT displays. The proportion is expected to continue growing, exceeding 80% by 2006.

The rapid growth of the flat panel display market since 2003 can in part be attributed to replacement demand for large-screen TVs in response to the expanded coverage of terrestrial digital broadcasting. Lured by the growth forecasts, more companies are moving into the flat panel TV market. One of them is Dell Inc. (Dell Computer Corp. until last November), which announced its entrance into this market in a tradeshow held in the U.S. in early 2004.

This article describes R&D trends in flat panel display technology, an element that supports the

Figure 1 : Display market size by type of technology



Source: A report by DisplaySearch

evolution of the TV toward higher definition and larger screen size, and examines the challenges faced by this technology.

2 What is a flat panel display?

2-1 Principle and characteristics

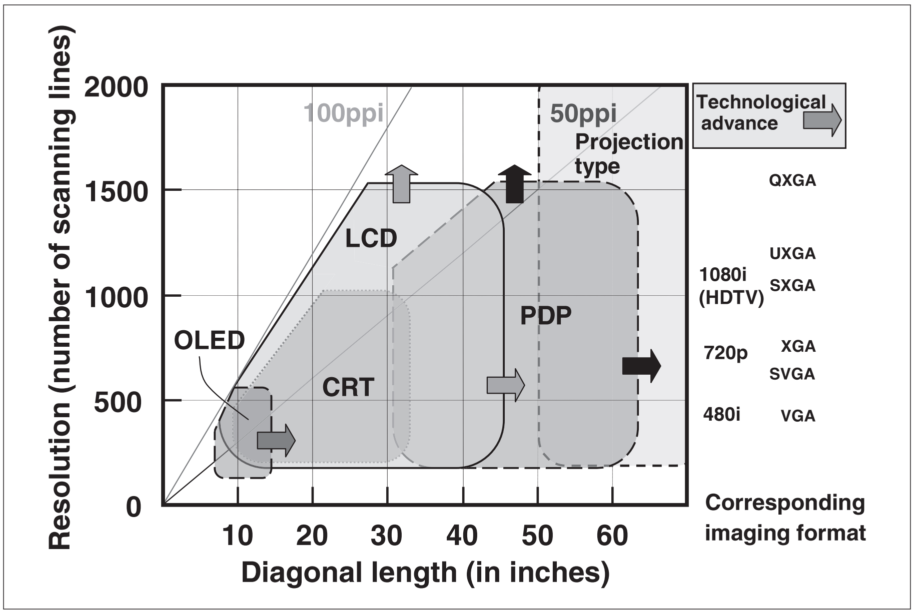
Among the other display technologies, this report primarily discusses, compared with traditional CRT displays, flat panel display technologies that have been, or are officially planned to be, commercialized as TVs. Table 2 summarizes the principle and characteristics of the display technologies covered. Figure 2 shows the area of strength for each type of display in terms of screen size and resolution. Table 2 describes each display technology from the viewpoint of the light source and the dimming (luminance) control mechanism. In CRT technology, fluorescent materials, or phosphors, are excited by electron beams and jump to a high-energy state; they then emit light when returning to the low-energy ground state. On the other hand, an LCD panel carries a fluorescent lamp called the backlight. For luminance control, it electrically changes the orientation of the liquid-crystal film placed in front of the backlight. A plasma display, which has an array of numerous miniature discharge tubes that form pixels, emits light by exciting phosphors by ultraviolet light generated by plasma discharge. A plasma display lights up based on the same principle as an ordinary fluorescent lamp and uses xenon (Xe) as the inert gas, whose resonance line is at a wavelength of 147 nm. On the other hand, the fluorescent lamp in an LCD display uses 254 nm ultraviolet rays, which correspond to the resonance line of mercury (Hg). Therefore,

Table 2 : The principle and characteristics of display technologies

Technology	Abbreviation	Light source	Luminance control	Thinner panel	Larger screen	Mass production	Power consumption
Liquid Crystal	LCD (Liquid Crystal Display)	Backlight (fluorescent lamp, non-emissive)	Change in liquid crystal orientation	○	△	○	○
Plasma	PDP (Plasma Display Panel)	Light emission from phosphors excited by ultraviolet light	Intensity of the light emission of plasma	○	◎	△	△
Organic EL	OLED (Organic Light-Emitting Diode)	Light emission during recombination of excited electrons	Intensity of light emission by injected electrons	◎	×	×	○
Braun tube	CRT (Cathode Ray Tube)	Light emission from phosphors excited by electron beams	Intensity of electron beams	×	△	◎	○

◎ : Very good ○ : Good △ : Fair × : Difficult

Figure 2 : Display technologies and their useful ranges



* For details of the corresponding imaging formats, see the appendix at the end of this article

these two technologies usually use different types of phosphor. The light source of an organic EL display is the light emitted when the electrons injected into organic light-emitting diodes recombine with the holes. LCD panels are called non-emissive displays because of their dependence on an external light source.

In plasma display technology, the larger the pixel size, or the screen size, the easier the manufacturing process, due to the luminous efficiency of the discharge tubes that constitute the pixels. On the other hand, large-screen LCD panels that are constrained by the need to ensure the uniformity of optical films and bottlenecks in the liquid crystal injection process during manufacturing, for example, have been considered difficult to produce at a reasonable cost. Therefore, it was expected that LCDs and plasma displays would form separate markets in terms of screen size with LCDs thriving in the under-30-inch market and plasma products dominating the over-30-inch market. Recently, however, production lines for so-called sixth-generation LCD panels have been in operation, allowing manufacturers to launch LCDs with screens of over 40 inches. Moreover, even some makers of organic EL displays have announced plans to develop technology aiming at large-screen TVs. Nowadays, screen size is no longer a critical issue in discussing flat panel technologies.

2-2 History of technological development

Table 3 lists major events in the development of display technology, including the discovery of display principles, the invention of basic technologies for application, the introduction of the first commercial model, and the launch of the first color TV.

As Table 3 shows, Japanese scientists have not necessarily been involved in early breakthroughs such as the discovery of the fundamental display principles and the invention of basic technologies for electronics application. The quality of each display type immediately after fundamental technology development was far from sufficient for application to TVs. For example, digital watches and calculators, the products for which LCD technology was first applied as display devices, initially showed numbers and characters using pixels called segments. The response of these displays was very slow, taking almost 1 second depending on ambient temperature. Likewise, early plasma displays consumed so much power per luminance that they were dubbed “flat panel heaters.” Japanese companies, however, made persistent efforts to improve these quality problems and successfully introduced these technologies onto the market.

Organic EL displays are already in commercial use for some mobile phone models. However, there are still some technical hurdles such as support for larger screens and improved endurance. In addition, their operating lives, which are currently between 1,000 and 2,000 hours, are insufficient for application to TVs. In May 2004, Seiko Epson Corporation announced that it would release a large-screen (40-inch) TV based on organic EL technology in 2007, which will probably have a longer life.

Since Kenjiro Takayanagi, who successfully demonstrated an electronic television system for the first time in 1926, Japanese researchers have been pioneering the application of new technologies to TV, and have improved the characteristics of LCD and PDP technologies, leading to commercialization. Even in the field of organic EL displays, the next potential technology, Japanese companies currently lead the world in commercialization, including application to mobile phones, and promote R&D activities for application to TVs.

Thus, in every type of technology, Japan's R&D efforts to commercialize new display technologies have been successful.

2-3 The recent state of technological development

(1) Lower power consumption

The power consumed by a display increases in proportion to the screen size, provided that the luminous efficiency of the light source and the display surface luminance remain the same. By increasing screen size and definition, it is necessary to reduce power consumption. Table 4 shows a roadmap of display technologies in terms of lower power consumption and other properties, assuming application to current TVs.

Table 4 includes the power consumption target in each technology. Improving the luminous efficiency of the light source is essential for reducing display power consumption. The

Table 3 : History of display technology development

Decade	Year	LCD	Year	PDP	Year	Organic EL
1880	88	Discovery of liquid crystals (F. Reinitzer, Austria)				
1910			10	Invention of the neon tube (G. Claude, France)		
1950					53	Discovery of light emission by applying an electric field to thin polymer films containing organic dye (A. Bernanose, France)
1960	62	Discovery of electro-optical properties of LCs (R. Williams, RCA, U.S.)	64	Development of a surface discharge AC-PDP (Bitzer & Slottow, Univ. of Illinois, U.S.)	63	Start of research in charge-injection EL using the monocrystals of anthracene, etc.
	68	World's first liquid crystal display (RCA, U.S.)			67	Formation of conductive polymer film (Shirakawa et al.)
1970	73	Commercial application to watches (Seiko)	79	Electrode structure for surface discharge to prevent phosphor degradation (Fujitsu)		
		Commercial application to calculators (Sharp)				
1980	87	Introduction of 3" color TV (Sharp)	83	Cell structure for 3-electrode surface discharge (Fujitsu)	87	High-efficiency, solid-state light-emitting device using multilayer films (C.W. Tang, Eastman Kodak, U.S.)
1990			92	Introduction of 21" color TV (Fujitsu)	90	Observation of charge-injection EL using conjugated polymer monolayer film of polyphenylene vinylene (D.D.C. Bradley et al., Cambridge Univ.)
			96	Introduction of 42" color TV (Fujitsu)	97	Commercialization of a green monochrome display for cars (Tohoku Pioneer)
2000					99	Commercialization of a 3-area color display for mobile phones (Tohoku Pioneer)

Table 4 : Display technology roadmap

Year of achievement		2000	2005	2010
Screen size Diagonal (inch)		32	50	50
Definition (ppi)		15-40	40-50	50-100
Luminous efficiency (lm/W)	LCD	2	3	4
	PDP	1.2	5	10
	OLED	1-2	7	14
	CRT	2	2	2
Power consumption (W)	LCD	140	120	100
	PDP	300	200	120
	OLED	-	60	30
	CRT	200	230	230

Source: Excerpted partly from the display technology roadmap published by the New Energy and Industrial Technology Development Organization (NEDO)[2]

luminous efficiencies target indicated in the above roadmap will be 4-14 lm/W*1 by 2010, from 1-2 lm/W (current actual values) although slightly varying from one technology to another in 2000.

Approaches to improving luminous efficiency differ depending on display technology. In the case of LCDs, ongoing attempts include changing the backlight from the current multiple cold-cathode fluorescent lamp (CCFLs) to a single flat lamp for higher light source efficiency and using multiple light-emitting diodes (LEDs) as the light source.

For plasma display, improvement in efficiency is considered in three stages, namely, the emission of ultraviolet light through electrical discharge, visible light emission from fluorescent materials irradiated with ultraviolet rays, and the extraction of visible light. Researchers are taking approaches such as improving discharge cells and the electrode structure, finding a better voltage application sequence for plasma operation, optimizing xenon partial pressure, and optimizing the characteristics of red, green, and blue phosphors.

In the area of organic EL display, fluorescent materials have been the major consideration in improving luminous efficiency. When excited by the recombination of electrons and holes, fluorescent materials produce two high-energy states, which are called the triplet and singlet excited states. However, it is only substances in the singlet state that contribute to light emission. For higher luminous efficiency, phosphorescent materials in which substances contribute to light emission even in the triplet excited state, have been studied as a substitute for fluorescent materials. Since the energy density of the triplet excited state is theoretically three times greater than that of the singlet excited state, a four-fold increase in luminous efficiency can be expected using phosphorescent materials.

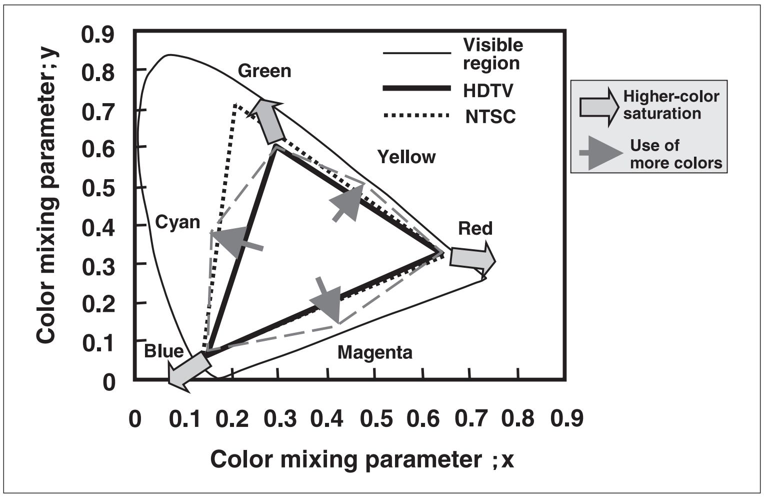
(2) Wider color gamut

The NTSC*2 color TV standard was established in 1953 in the U.S. In the 1970s, NHK (Japan Broadcasting Corporation) began developing a provisional standard for high-definition TV (HDTV), a next-generation TV technology for a wider, larger screen with high-resolution pictures. In contrast to these advances in resolution, the color gamut[3] has fallen short of the level initially set by the standard. This refers to the range of colors that an entire imaging system, including the display, can reproduce. The HDTV standard supports a narrower color gamut than NTSC, which is more feasible. However, the need for the accurate reproduction of actual colors has significantly increased recently, for such purposes as desktop publishing (DTP) in the printing industry, film-making, e-commerce, and telemedicine. In the XY chromaticity diagram, conventional displays can reproduce a color range no more than roughly 70% of Adobe RGB*3, the color space standard for high-end digital cameras. In these application fields, operators, who often need to print out designs and digital images created on computers and check the color of input data, want to perform color checking on their displays.

To meet this demand, researchers are examining two approaches to expanding the color gamut of displays. One is to increase the color saturation of red, green, and blue (RGB), which are the primary colors of light. For LCDs, for example, some researchers are considering using an array of high-power RGB LEDs as the light source, instead of traditional cold cathode fluorescent tubes, to increase backlight color saturation, which can help reproduce the original color[4].

The other is to use more basic colors, in addition to RGB, to expand the range of color

Figure 3 : Two approaches to a wider color gamut



* For details on this graph (CIE-xy chromaticity diagram), see the appendix at the end of this article

reproduction. Samsung Electronics Co, Ltd., of Korea presented at the 2004 SID exhibition*4 an LCD panel featuring six-color*5 filters, which use the standard RGB plus cyan (C), magenta (M), and yellow (Y). The company demonstrated that the color reproduction range of this panel is as wide as 98% of NTSC[5].

(3) Hoped-for features of future displays

In 2002, NHK displayed a prototype of the "Super Hi-Vision"*6 system, which consists of both a camera and a display that support 4,000 scanning lines. Sony, on the other hand, introduced this year a projector-type LCD offering a vertical resolution of 2,160 lines (4096 horizontal pixels x 2160 vertical pixels, or 8.85 megapixels)[6].

A new imaging format requires not only the expansion of the color reproduction range through the use of more colors, but also the review of all related technologies including cameras, imaging devices, image processing methods, and displays. Meanwhile, despite long-time efforts to develop better display devices based on different technologies, none of the current display technologies meets all the requirements. Therefore, technological development needs to continue in pursuit of the reproduction of more realistic images. R&D for higher image quality to achieve ultimate imaging technology will remain the primary theme for researchers in years to come.

One of the drawbacks of display is the presence of the "frame" around the screen, a factor that makes people aware that they are looking at an artificial image. To solve this, a technology that shows borderless pictures throughout the viewer's visual angle, similar to a panoramic vision system, is discussed as a future direction of display technology [7]. Furthermore, some believe that large-screen displays will evolve to create a living environment, rather than just TVs. For example, a large paper-thin display could be hung on the wall like a painting. It might even be used as an intelligent lighting system, if hung on the wall of a windowless room or the window of an urban apartment, which shows panoramic pictures of natural scenery with luminance that automatically changes as if it were natural light according to the intensity of sunlight. As a display, while providing input and output functions as an information terminal, it could become a part of the human living environment, helping people feel refreshed by showing them a background image'; this would be considered a true evolution of human interfaces.

3 The flat panel display industry

3-1 Change in the market share

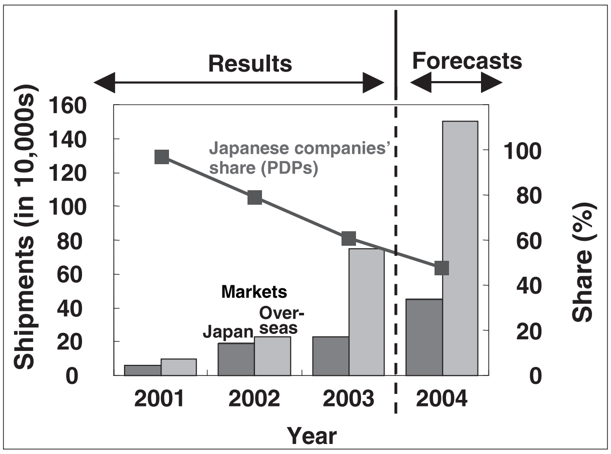
Figure 4 shows the size of Japanese and overseas plasma display panel (PDP) markets and the combined share of Japanese companies in these markets.

Currently, there are only PDP manufacturers outside Japan in Korea, where Samsung SDI and

LG Electronics account for the majority of the output.

Year 2001 marks the beginning of the plasma TV era, because multiple plasma TV models supporting HDTV were released that year. Since then, the market has been growing at an annual rate of over 100%. As the PDP market grew, however, Korean companies made a full-scale entry, resulting in a sharp decline in the market share of Japanese companies. This is also the case with the LCD market. Taiwanese and Korean companies becoming dominant in the worldwide market[※1] is typical as the technology matures. However, some experts argue that Japanese manufacturers' share of the PDP market will not easily be surpassed by their Korean counterparts because several Japanese PDP makers announced earlier this year their plans to invest in PDP production plants[8]. Nevertheless, from a long-term perspective, it is very likely that Japanese companies will face an uphill battle in competing with their Korean and Taiwanese rivals who will market products of a similar quality at lower prices.

Figure 4 : Trends in PDP production and Japanese companies' market share

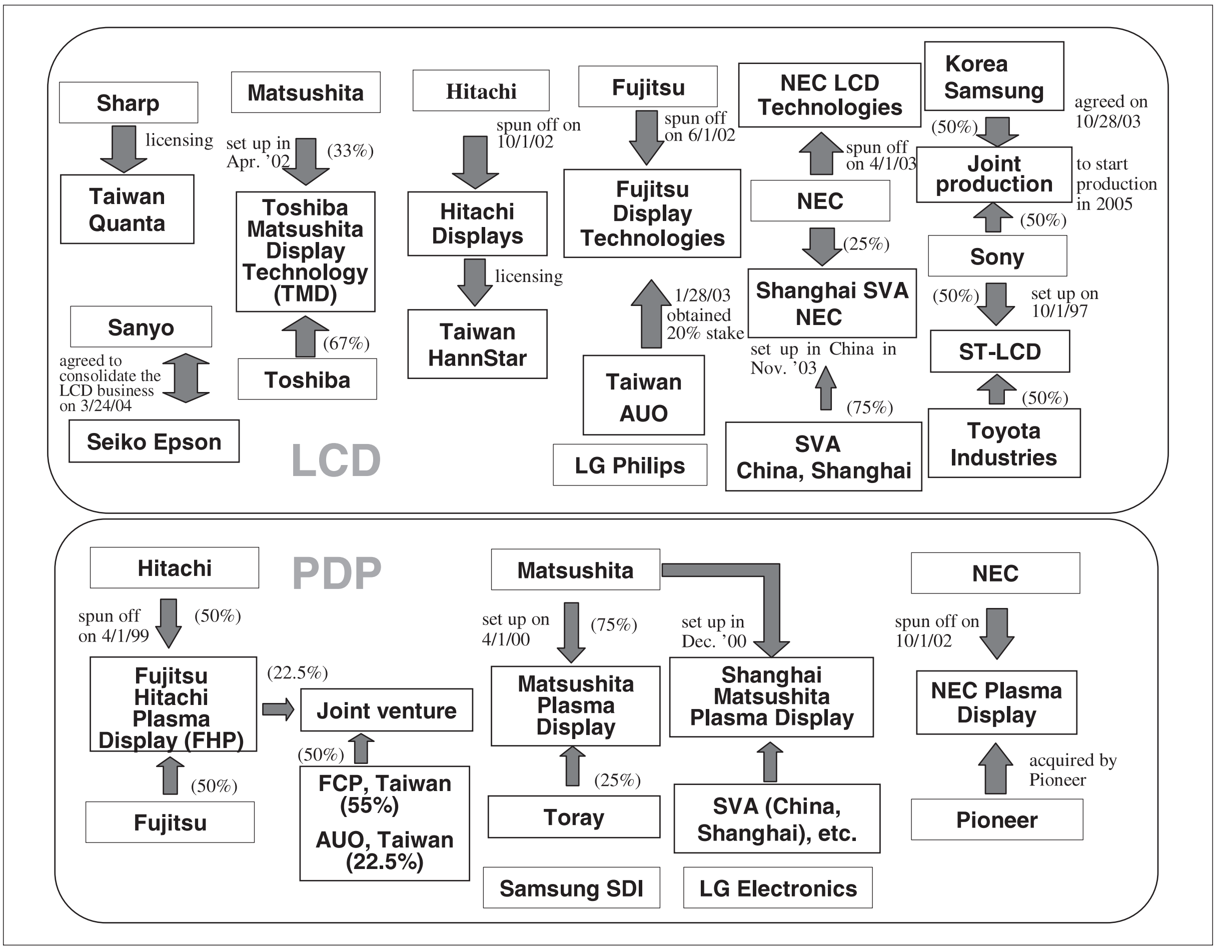


Source: Prepared by the author based on material published by the Japan Electronics and Information Technology Industries Association and DisplaySearch

3-2 Restructuring status in the industry

Figure 5 shows the major alliances that have been recently formed, leading to the restructuring

Figure 5 : Partnerships among display manufacturers



Source: Prepared by adding data to material published by the Development Bank of Japan[9] of the LCD and PDP industries. In the LCD industry, the restructuring process has advanced to a stage at which even Taiwanese and Chinese companies, in addition to Korean companies, are involved. In contrast, in the PDP industry, which has just emerged, Taiwanese and Chinese manufacturers have yet to make an entry. Corporate strategy varies by country. Korean companies can be characterized as primarily targeting the domestic market and having the capacity to perform technological R&D. On the other hand, Taiwanese companies do not engage in technological R&D and seek, as manufacturers specializing in displays, the lion's share of the global market in mature products.

In the LCD manufacturing business, Japanese companies were once compelled to accept capital from Korean and Taiwanese rivals whose low-cost strategy proved successful. Here, there is debate about how to prevent "technology drain" from Japan. However, it is a welcome move for consumers that, based on economic principles, companies are reorganizing and Taiwanese makers have begun using technologies that originated in Japan, making products that excel in price as well as quality available. The PDP industry will also see more technology licensing, investments, and alliances across the border, as its market grows and matures.

3-3 Comparison with the semiconductor industry

The once-dominant semiconductor, especially the DRAM[*7]-manufacturing sector in Japan rapidly lost its competitiveness in the latter half of the 1990s and was forced to reorganize and consolidate. Again, Korean and Taiwanese companies displaced Japan. Japan's fast decline in the share of the LCD market is often compared with its similar experience in the DRAM industry. The display panel is more similar to DRAM than CPU[*8] among the sectors in the semiconductor industry. LSI technology is multi-layered, consisting of technologies for architecture, circuit design, manufacturing, and testing. While CPUs do not allow each technology layer to be distributed independently, DRAMs do. In the DRAM market, each layer of technology is supplied by vendors specializing in that specific area. In addition, it is impossible to differentiate products by performance because DRAM standards are expressly defined and certified by CPU manufacturers.

In the case of display panels, while the interface is determined by standards, product performance varies slightly because they are analog products. Nevertheless, because displays are manufactured based on materials and devices supplied by specialized vendors, there should be no significant difference in performance among the final products.

Since Japan has led the world in R&D in display technology, its patent position in this field is different from that in DRAM, for which Japan had to play catch-up with technology leaders. The display market is also dissimilar in its growth trends from the DRAM market, which leveled off in value terms by 1995. If differentiation by performance is not feasible, manufacturers will eventually move toward price competition. When price becomes an issue, Japanese manufacturers will have to fight an uphill battle against their Korean and Taiwanese rivals. This process is not affected by changes in market size or the country's technological position, and the challenge that Japanese companies face in seeking commercial benefit from successful technological development will remain.

Recently, there has been an increasing number of patent lawsuits filed by Japanese companies against Korean and Taiwanese companies. The Customs Tariff Law[10], which was amended last year, appears to benefit Japanese companies in that it allows them to seek legal measures at an earlier stage, such as bans on imports of the product in question. While claiming the rights granted is the right course of action, victory in patent disputes will not improve the situation in which Japanese companies face a continuing struggle in the display manufacturing business. If companies compete only in the display manufacturing sector, which is horizontally divided, the industry leader will probably keep changing on a short-term basis as in the DRAM industry.

4 The State of R&D

4-1 The number of presentations at academic conferences

Figure 6 shows the trend in the number of presentations on PDP technology at recent SID conferences by country and region. In the first half of the 1990s, when Fujitsu Limited and other companies released plasma TVs, followed by the development of larger-screen models, Japan gave the largest number of presentations, with little contribution from elsewhere. However, the number of presentations from Korea sharply increased between 1996 and 1998, exceeding that of Japan in 1998, and has remained the largest for the remainder of the selected period.

According to Reference[11], which reports the detailed analysis results of the number of presentations by institution, the majority of Korean presentations have been made by universities, the business sector**2 providing meager input. This analysis also reveals that the ratio of presentations jointly delivered by businesses and universities to the total business presentations is high in Korea: 83% for LG Electronics and 42% for Samsung SDI, compared with an average 24% among the top presenting companies in Japan.

4-2 National projects in Japan

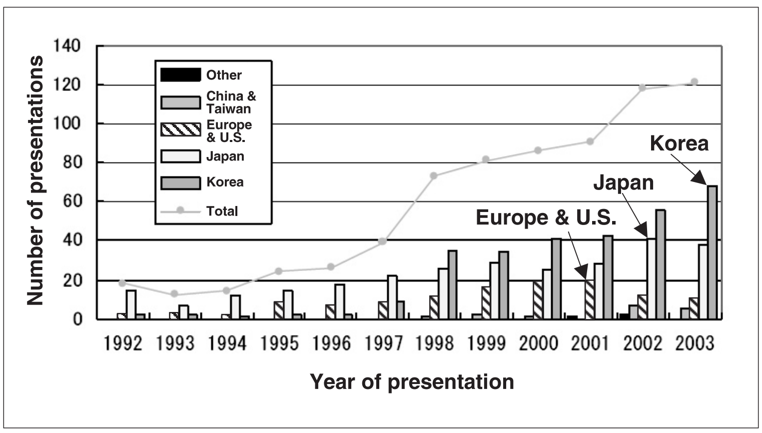
Table 5 lists major national projects ongoing in Japan with respect to display technology. They pursue, for example, display devices with lower power consumption and energy-efficient manufacturing processes for displays. With the exception of the project on the construction of facilities for joint research, all of the projects in Table 5 are small-scale, operating with an annual budget of less than ¥1 billion. In addition, all of them have been launched recently; this means that there were no display-related national projects in Japan previously. Therefore, it will be some time before these projects produce results.

In the field of display technology development, where no single technology is anticipated to be mainstream, it is difficult to forecast what will happen next. To complicate matters, researchers in LCD technology, considered by most to be a mature technology, still face many challenges, including not only improving characteristics through higher-efficiency light sources, a wider viewing angle, and faster response, but also advancing manufacturing technology. Given this nature of display technology development, small, distributed projects seem more appropriate in this area than large-scale comprehensive projects, which are common in semiconductor technology development. In any case, national display technology projects should provide long-term support for research themes that are too challenging for private-sector institutions and scientists. Current national projects are conducted close to this ideal, except that they tend to demand outcome too soon.

4-3 The situation in the U.S.

At one time, U.S. companies, namely, RCA and Zenith, dominated the market with color CRT TVs equipped with a technology called the shadow

Figure 6 : Trends in the number of presentations on PDPs at SID conferences by country/region



Source: Japan Patent Office, Report on the Technological Trends in Industrial Property Rights Applications [11]

Table 5 : Major national projects for the development of next-generation display technology

Years	Project	Budget (in ¥100 millions)	Developing technologies	Remarks
'03-05	Next-Generation Energy-Saving PDP	7.7	High-efficiency light emission mechanisms, phosphors for a higher luminous efficiency, energy-efficient manufacturing process	
'02-06	High-Efficiency Organic Devices	7.8	Constituent technologies including high-efficiency light-emitting devices and materials, large-area formation technology, organic transistors	
'03-05	Polymer Organic EL Materials	4.7	Technology to form, refine, and mass-produce new conjugated polymer organic EL materials	
'03-05	High-Strength Nano Glass for Displays	2.3	Technology to strengthen substrates by forming heterogeneous phases in glass; Technology for the short-time processing of large substrates	
'03-05	Carbon Nanotube (CNT) FED	7.4	Technology to produce homogeneous CNT film and micro emitters	
'03-05	Construction of Facilities for Joint Research on Next-Generation Low-Power Display Manufacturing Technology	153 for 3 years	Technology to manufacture low-cost, low-power large LCD panels	FY 2001 supplementary budget
'01-04	Liquid Crystal Device Process for the Rational Use of Energy	5.1	50% reduction of power consumption in the manufacturing process of low-temperature polysilicon TFTs	Grants-in-aid for R&D

*The budgets without remarks refer to the annual budget for FY 2003

mask. In the 1970s, however, Japanese CRTs that excelled in both quality and cost emerged to rapidly weaken the competitiveness of U.S. CRT manufacturers. Until today, there has been no remarkable display-related industry in the U.S. This does not necessarily mean that the U.S. has failed to take measures; for instance, alarmed by the Japan-led progress of flat panel display technology, the U.S. government and the private sector jointly established the United States Display Consortium (USDC)[12] in 1993. The USDC, with over 100 member companies, devoted its energies to developing the LCD and FED*9 display technologies, which were then considered likely to be next-generation display devices for military and medical purposes. In reality, however, none of the USDC efforts have yielded remarkable results, with Japanese companies dominating in R&D on LCD technology and FED panels that are nowhere near commercialization. In another attempt to gain strength in the display industry, the U.S. Army and others are reportedly planning to set up a consortium[13] in imitation of SEMATECH*10. Yet another initiative is to establish a scientific society dedicated to the application of displays[14] to explore new technologies. However, the effectiveness of these activities is uncertain, given that the U.S. lacks a major technology leader in this field and that there is little reason for the business sector to invest in new display technology, said to take at least five years to develop.

The U.S. has no presence in the display industry. By contrast, Korea has a growing presence worldwide, thanks to successful collaboration among industry, government, and academia. In Korea, the display industry, positioned by the government as a future key industry, is an area where the business sector is eager to hire a large amount of personnel and to make sizable investments. Furthermore, universities are active in supplying human resources and research results.

5 How to maintain technological competitiveness

As described in the previous chapter, Japan's national research projects to develop display panel manufacturing technology generally matches the nature of this development field. However, in the same field, Korea began their efforts much earlier to intensify R&D as a national strategy. This increases the need for Japan to explore technologies in areas other than panel manufacturing.

A possible strategy is to shift focus to developing high value-added technologies, as U.S. companies did when they were caught up with by their Japanese counterparts in DRAM manufacturing technology. The strategy of these U.S. chip makers, in specializing in CPU and DSP[*11] development, has proven successful, and they currently dominate a market that is very difficult to enter.

As far as the fields in which Japan has accumulated industry-leading technologies are concerned, the country can utilize such technologies for a transition to display systems that are more advanced. However, the expansion of the color gamut through the use of more basic colors, for example, cannot be realized merely by improving the performance of display devices, because the current color technology is built on the basis of RGB combination. To allow for the use of more than three colors, all technologies for image signal input and output, including display devices, cameras, imaging devices, and image processing function, must be revised. A wider range of color reproduction can even raise the need for higher resolution, possibly leading to the proposal of a next-generation imaging format. These are goals that encompass such a broad range of R&D activity and such high risk that a single firm cannot handle. This is exactly the case where government should provide support. In a development project involving such diverse research themes and so many businesses, the government should act as a coordinator of development efforts across the participating companies, while providing R&D funds.

Considering the recent numbers of presentations at academic conferences, it is highly likely that Korea will eventually overtake Japan as the industry leader in another display panel manufacturing arena: PDP. Japan could counter this possible move by utilizing its existing technological position to develop higher value-added technologies, such as a next-generation high-performance imaging system and a broadcast format after HDTV.

Another possible measure is to launch long-term initiatives to develop future display technologies such as the one applicable to a display that can create a comfortable environment, as mentioned at the end of Chapter 2. Displays will become part of the infrastructure that supports a maturing society. They are expected to evolve to an intelligent system that can cater to national, local, or even personal preferences. With respect to consumers, Americans usually watch TV in relatively low light, while Japanese often watch TV in bright light and therefore prefer crisp pictures. Japan's strength lies in the combination of these Japanese consumers, who are highly demanding in terms of image quality, and display and imaging systems, including peripheral devices, in which Japan has accumulated knowledge. Japanese display researchers should take advantage of this national strength to develop high value-added technology for the next generation.

6 Conclusions

As terrestrial digital broadcasting starts, CRT TVs are about to be displaced by TVs with higher resolution and larger screen size. In an effort to seize this huge business opportunity, manufacturers have developed various next-generation display technologies such as liquid-crystal (LCD), plasma (PDP), and organic EL (OLED) displays, to name only a few flat panel types, and are now introducing them onto the market.

These technologies, although initially considered not applicable to consumer TVs, have been improved by Japanese manufacturers, who have overcome technical hurdles over the years. Among them, LCD and PDP technologies have already become the two major camps that split the large-screen TV market. Thus, Japan has led the world in display panel technology development.

Despite their success in technological development, Japanese companies have fared rather poorly in business. They have seen Korean and Taiwanese competitors rapidly catching up with them ever since the launch of the LCD and PDP markets. Furthermore, in recent years, research in Korean universities is advancing at a pace that threatens Japan's position in the area of

R&D.

Since the present display industry is primarily based on horizontal labor division, manufactures are placing growing emphasis on manufacturing costs to gain a competitive edge. Under such circumstances, Japan should, rather than vying with Korea and Taiwan only in the panel manufacturing arena, widen its scope of development and pursue next-generation high-performance display technologies with high added value and systems that exploit such technologies.

Displays are expected to advance toward the ability to produce images closer to real things. For example, to achieve a wider color reproduction range, display researchers will probably need to revise not only display devices but all technologies for image signal input and output, including cameras, image pickup devices, and image processing function. Higher color reproducibility could even spur the demand for higher definition. These challenges, which are too extensive for a single company to handle, should be tackled in a large framework that involves a large number of companies. In a development project that covers such diverse research themes, the government should act as a coordinator of development efforts across the participating companies, while providing R&D funds.

Japan's strength lies in the combination of its comprehensive capabilities in display technology and imaging systems, including peripheral technologies, where Japan has accumulated knowledge, and Japanese consumers who are highly demanding in terms of image quality. Japan should take advantage of this national strength to develop high value-added technology for the next generation.

Acknowledgements

I would like to express my deepest gratitude to the following people for their invaluable opinions and advice on this article: Prof. Yoshifumi Shimodaira, Department of Electrical and Electronics Engineering, Shizuoka University; Prof. Shigeo Mikoshiba, Department of Electronic Engineering, the University of Electro-Communications; Prof. Heiju Uchiike, Department of Electrical and Electronics Engineering, Saga University; Prof. Tatsuo Uchida Graduate School of Engineering, Tohoku University; and Mr. Yukichi Deguchi, General Manager of the PDP Technical Department, Toray Industries Inc.

Glossary

*1 lm/W

The unit of luminous efficiency calculated by dividing the amount of light expressed in lumens (l m) by the power consumption of the light source, which is expressed in watts (W).

*2 NTSC

Abbreviation for the National Television Standards Committee. It refers to either the U.S. organization that has set the standard for analog terrestrial color TV broadcasting, or the standard itself. NTSC TVs have 525 horizontal scanning lines (of which 480 are active) and use interlaced scanning at 30 frames per second.

*3 Adobe RGB

The color spectrum standard adopted by Adobe Systems Inc. of the U.S. for its "Photoshop" image editor. It supports a range wider than the sRGB standard (see below). Adobe RGB is widely recognized as the de facto standard in the printing and publishing industry.

sRGB (standard RGB)

The international standard for color space defined by the International Electrotechnical Commission (IEC). Many computer peripheral devices such as digital cameras, printers, and monitors adjust colors based on sRGB to minimize color difference between input and output.

*4 SID

Abbreviation for the Society for Information Display. Based in the U.S., it is the largest academic society in the field of display technology.

*5 Use of six colors

Even though magenta is not monochromatic (saturated color), such non-saturated colors are sometimes added to increase the number of basic colors.

*6 Super Hi-Vision
A imaging format with 7680 x 4320 pixels (16 times more than HDTV) and 60-Hz frame rate progressive scanning.

*7 DRAM
Abbreviation for Dynamic Random Access Memory, a type of semiconductor memory chip. Being freely readable/writable and allowing relatively high density, DRAMs are primarily used for the main memory of computers.

*8 CPU
Abbreviation for Central Processing Unit. This is a device that executes programs stored in the memory of a computer. It receives data from input and storage devices, computes and processes this data, and outputs the results to output and storage devices.

*9 FED
Abbreviation for Field Emission Display. FED is a display that glows by releasing electrons from numerous horizontally-arranged electron emitters into a vacuum where electrons collide with phosphors. FED technology is similar to CRT in the principle of light emission, but is dissimilar in having no deflection system for electrons, a property that allows for a thinner panel.

*10 SEMATECH
Abbreviation for SEmiconductor MAnufacturing TECHnology. This is a consortium jointly established by the U.S. Department of Defense and four private-sector semiconductor manufacturers for R&D in the semiconductor manufacturing technology, to reinvigorate the competitiveness of the U.S. semiconductor industry, which was on the decline in the mid-1980s.

*11 DSP
DSP is an abbreviation meaning Digital Signal Processor. This processor is designed for processing specific signals such as audio and image signals and is often embedded in devices such as a modem, or in a PC to offload some of the processing tasks from the CPU.

Notes

**1 Market share of matured products
Of the CRT and 19-inch or smaller LCD panels available on today's market, roughly 60% are made in Taiwan and 30% are produced in Korea.

**2 Number of presentations by institution
The top institutions in the number of presentations in Japan are four business enterprises, three universities, and one public research institute, whereas those in Korea consist of one business enterprise and seven universities, suggesting the overwhelming leadership of universities in development activities.

References

[1] (e.g.) Shin Hasegawa, "Image Engineering", the University Series of the Institute of Electronics, Information and Communication Engineers, Corona Publishing Co., Ltd. (in Japanese)

[2] The display technology roadmap on the website of the New Energy and Industrial Technology Development Organization (NEDO):
http://www.nedo.go.jp/nanoshitsu/project/loadmap.pdf

[3] SID Japan Chapter Newsletter No. 23 (May 17, 2003):
http://www.sidchapters.org/japan/letter/SID-NL23.pdf

[4] (e.g.) Press releases by Mitsubishi Electric Corporation:
http://www.mitsubishielectric.co.jp/news/2004/0322-a.htm
http://www.mitsubishielectric.co.jp/news-data/2004/pdf/0322-a.pdf

[5] An article released by Nikkei Business Publications, Inc.:
http://ne.nikkeibp.co.jp/members/NEWS/20040526/103584/

[6] A press release by Sony Corporation:
http://www.sony.co.jp/SonyInfo/News/Press/200406/04-0604/

[7] EDF 2004 display tutorial lecture collection

[8] (e.g.) A press release by Matsushita Electric Industrial Co., Ltd.:

http://www.matsushita.co.jp/corp/news/official.data/data.dir/jn040518-2/jn040518-2.html
[9] Development Bank of Japan's website: http://www.dbj.go.jp/beginners/why_dbj/about/files/
[10] http://www.mof.go.jp/jouhou/kanzei/ka160415a.htm
[11] Japan Patent Office, "Report on the Technological Trends in Industrial Property Right Applications": http://www.jpo.go.jp/shiryou/index.htm
[12] USDC's website: http://www.usdc.org/index.html#
[13] Japan Electronics and Information Technology Industries Association's survey and research report: "2003 Update on the U.S.: Trends and Development in Information Policies to Promote IT/Digitization and the Current State and Policy Issues on Internet/E-Commerce Rules Development": http://it.jeita.or.jp/infosys/report/2003-04usreport/chapter3.pdf
[14] SID's website: http://www.sid.org/conf/adeac04/adeac04.html

<Appendix>

i) Imaging formats

Table 6 lists the major imaging formats mentioned in the article.

ii) Color gamut diagram (CIE XY chromaticity diagram)

International color standards are managed by the International Commission on Illumination (CIE from its French name "Commission Internationale de l'Eclairage"). In 1931, the CIE created a standard for color specification. As the three primary colors, it defined red (R), whose light has the largest wavelength perceivable by the human eye, at 700 nm, and green (G) and blue (B) at 546.1 nm and 435.8 nm respectively, which correspond to the mercury lamp's emission line spectrums. This CIE system allows colors to be represented by coordinates on a diagram, based on the mixing ratio of the three primary colors.

The CIE 1931 RGB system defines chromaticity by this method. This system expresses any color as a point in 3D space. The CIE XY chromaticity diagram was derived by converting this RGB 3D color space including the entire color gamut into an easy-to-handle XYZ space in a manner that all parameters remain positive, and normalizing and projecting the results onto a 2D space.

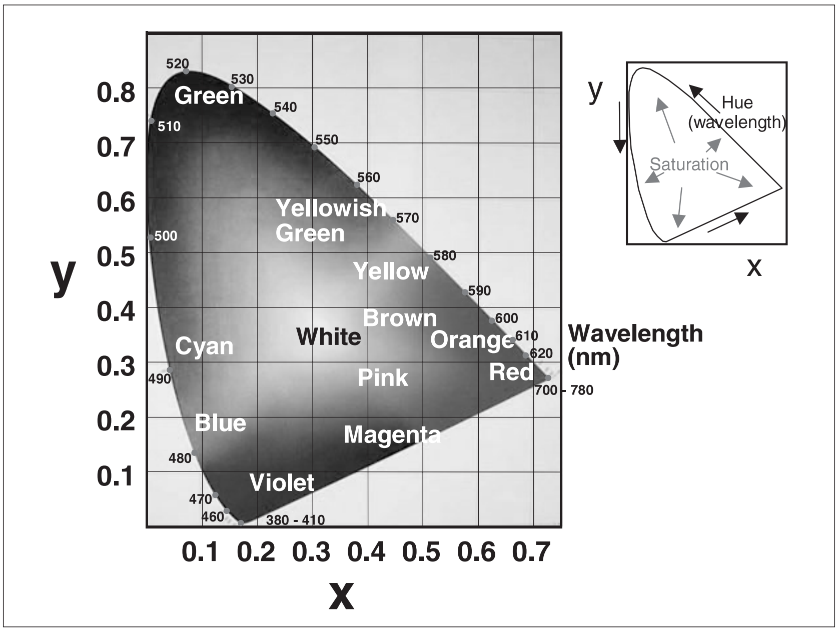
The CIE XY chromaticity diagram is currently used for the most common and precise color reproduction. In this diagram, spectral (monochromatic) lights

Table 6 : Major imaging formats

Application	Format Name	Resolution: Horizontal	Resolution: Vertical	Pixels (in 10,000)	Aspect Ratio
PC	VGA (Video Graphics Array) ; Basic	640	480	31	4:3
	SVGA (Super-VGA)	800	600	48	4:3
	XGA (eXtended-VGA)	1024	768	79	4:3
	SXGA (Super-XGA)	1280	1024	131	4:3
	SXGA+ (SXGA at 4:3 aspect ratio)	1400	1050	147	5:4
	UXGA (Ultra-XGA)	1600	1200	192	4:3
	QXGA (Quadruplet-XGA: quadrupled XGA)	2048	1536	315	4:3
	QSXGA (Quadruplet-SXGA: quadrupled DXGA)	2560	2048	524	5:4
	QUXGA (Quadruplet-UXGA: quadrupled UXGA)	3200	2400	768	4:3
TV	480i (interlaced) / 480p (progressive)	720	480	35	3:2
	720ps	1280	720	92	16:9
	1080i (HDTV)	1920	1080	207	16:9
	1080p	1920	1080	207	16:9

are distributed along the outline of the figure (visible region), and the figure includes all colors that can be produced by mixing monochromatic lights. Color purity (saturation) increases toward the center of the figure. The colors reproducible through the additive mixing of given basic colors are limited to those within a polygon joining the coordinates for the basis colors on the CIE XY chromaticity diagram. In general, monochromatic lights are not reproducible by additive mixing. The CIE XY chromaticity diagram implies that vivid green and the complementary colors of RGB-namely, cyan, magenta, and yellow-are not reproducible through the additive mixing of RGB.

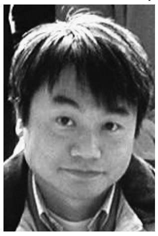
Figure 7 : CIE-xy chromaticity diagram

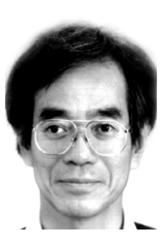


(Original Japanese version: published in August 2004)

3

The Two Rationalities and Japan's Software Engineering





Susumu Hayashi *(Affiliated Fellow)**
Toshiaki Kurokawa *(Affiliated Fellow)***

1 Introduction

Japanese people are often said to lack logicality and rationality. Until recently, this well-known characteristic of the Japanese has been linked to the weakness of the Japanese software industry and software engineering. For example, researchers have considered this trait to be related to the structural weakness of the Japanese software industry. They have also attributed the failure of the Japanese software industry and software engineering to gain a strong position in the global market, even though it has received priority funding by the government, to Japanese society's weakness in rational and logical thinking.

The Japanese industry cannot compete with its U.S. and European counterparts in the software sector unless rational thinking takes root in Japanese society as it has in Western societies. The Japanese software sector cannot thrive unless rational and logical thinking is disseminated in Japanese society, but it may be impossible for the Japanese to become rational and logical. Therefore, it is hardly likely that the Japanese software industry can thrive. The only way to overcome this problem is to teach rational and logical thinking in schools, which means the further Westernization and Americanization of Japan.

Until recently, many experts have made all of the above assumptions. However, the U.S., the leader in the software sector, has seen a change that defies them. During Japan's "lost decade," the world's-leading American software consultants began introducing Japanese methodologies such as the Toyota Production System into their software engineering schemes.

"Rationality" is not exclusive to Western, especially American, society, and there is no single legitimate form of rationality, or absolute rationality. Rationalities vary as much as cultures do, and United States has found one kind of "Japanese-style" rationality. This rationality is becoming an essential software engineering technique that allows engineers to cope with a rapidly changing business environment.

A deep understanding and the effective application of this technique could dramatically strengthen the Japanese software engineering community and industry. This is an unparalleled opportunity to enhance Japan's software engineering capabilities to world-class level, and Japan must not miss it.

2 Japan's software technological capabilities

The term "software" has a number of meanings ranging from pop culture items, such as manga (comics) and anime (animation), to computer software. Japan's competitiveness in the manga and anime fields is unsurpassed. However, as far as business software and its development and production technology are concerned, excluding pop cultural products such as game software, Japan has very weak capability in

* Susumu Hayashi Professor at the Department of Computer and Systems Engineering, Faculty of Engineering, Kobe University, http://www.kobe-u.ac.jp/
** Toshiaki Kurokawa CSK Fellow, e-Solution Technology Division, CSK Corporation • http:www.csk.co.jp/index.html

software technology. In this article, "software" and "software technological capability" refer only to business software, a sector in which Japan is weak. When considering software from the viewpoint of Japan's industrial and technological policy, this sector draws major attention because of its scale and the seriousness of the problems it faces.

The software industry and software engineering in this sense are divided into two types. This division is important when applying our analysis to policy-making because the two types call for different kinds of human resource. These two types are explained from the viewpoint of industrial structure.

2-1 The two types of software technological capability

Michael Cusumano of the Massachusetts Institute of Technology splits software companies into two models: products companies such as Microsoft and Adobe Systems and service companies such as IBM and NTT Data[4]. Generally speaking, the former business model involves developing software intended for a mass market and selling copies in high volume. On the other hand, the latter engages in designing and constructing custom software and computer systems to satisfy specific customer needs. These are simplified models, and in reality, many software companies either fall between the two types or as a combination of both. However, these intermediate cases are disregarded in our discussion because our focus is on the software development business.

We refer to Cusumano's scheme, which is a classification by business model, in an article that explores technological capabilities because his two business models depend on dissimilar software development technologies by which we can categorize software technologies. Engineers working for software products companies are expected to develop software as marketable "products," including operating systems and business applications such as Excel, Java, Windows, Linux, Oracle, and GNU, and sometimes even game software. In this regard, the Ministry of Economy, Trade and Industry's "Exploratory Software Project" looks for individuals with this software development capability. Software engineers in products companies develop software in the same way that cars and home appliances are developed.

On the other hand, there are different expectations of engineers in software service companies. They need to be familiar with software development methodologies, including the waterfall and spiral models, agile methods, and requirement-specification engineering, and they must use such methodologies to define customer requirements, design quality custom software at low cost in a short time, and manage and operate them. Software engineers in service companies create software in the same way that civil engineers design and construct buildings. In terms of industry size, this second type of software business far exceeds the first type, which consists of software products companies.

We should consider thired aspect when discussing the technology of software service companies. In the U.S. software industry, software engineers have been devising original software development methodologies that are so innovative that they have become a source of corporate competitiveness, and they are selling these techniques as knowledge. Many of the leading software enginners are not university researchers but software consultants. They are directly connected to industry, and can be compared to industrial engineering consultants who "sell" production techniques, or former Toyota engineers who now advocate the Toyota Production System, for example. Although it seems that these technologies have only little impact on industry because they contribute to production technology rather than directly to products, they do influence the competitiveness of software technology.

This article groups these three aspects of software technology into the following two types:

- P type: This refers to technological capability that software products companies are required to have and is the first aspect among the three.
- S type: This refers to the technological capability that software service companies

are required to have and is a combination of the second and third aspects.

When discussing Japan's software technological capability, it is important to be explicit on which type is considered, especially for policy-makers for the software industry.

Software companies do not need large capital investment because only computers and communications infrastructure are required. In other words, the software industry is highly labor-intensive and the software industry's largest, most important production resource is people, or engineers. The most effective promotional measure, then, is human resource development. However, P-type and S-type technological capabilities demand different kinds of engineer, and can be mutually contradictory.

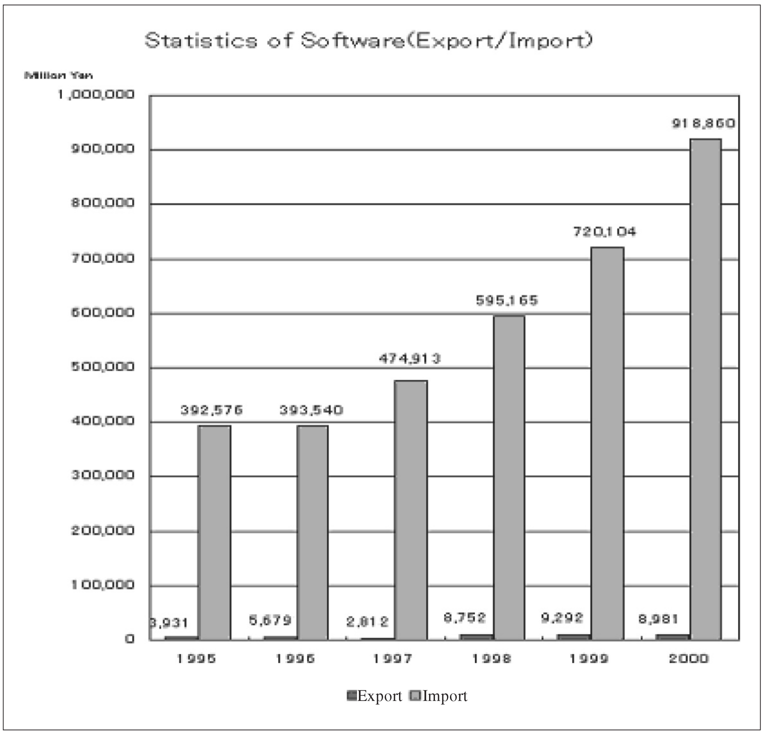
Therefore, there should be two different methods of human resource development. In his talk[4], Cusumano suggests that the best strategy for software companies to ensure steady growth even in bad economic times is to combine the two capabilities. Although this is possible for an enterprise, or a group of individuals, it is very difficult for a single person to excel in both P- and S-type capabilities. Developing human resources with hybrid capabilities is a challenge. An important consideration in developing national strategies for nurturing human resources is to decide which approach to take, either focusing on the P type, as in the case of the Exploratory Software Project or providing funds for educational programs intended to foster human resources who can combine the two capabilities.

2-2 An analysis of Japan's technological capabilities

Both types of Japan's software technological capability in our classification measure up very poorly. In the P-type field, except for a few remarkable developments such as Ruby, the Japanese software market is dominated by foreign products, as demonstrated by the Japan Electronics and Information Technology Industries Association's statistics on software imports and exports[10], which shows a great excess of imports over exports at a ratio of 100 to 1 (Figure 1). Note that the data exclude game software.

Since S-type development capability involves methodology, it cannot be easily statistically analyzed. Like Cusumano, who onece praised the Japanese software industry calling it a

Figure 1 : Japan's Software Imports and Exports



* Year 2000 results

Source: http://it.jeita.or.jp/statistics/software/2000/4.html software factory, some experts say that Japan has moderate competitiveness in this field. However, the industry is still immature, especially in one of the two sub-categories of the S type. These are technological capability provided by consultants. First of all, software consultancy is not yet an established profession in Japan, and both academic and corporate researchers have a long way to develop technologies that are directly applicable to industry.

The U.S. dominates the software sector, and the rest of the world, including Japan, is in a weak position. However, Japan's capability in software technology is inferior even to Europe's. Europe has invented many notions in software engineering, especially those belong to the S-type category, ranging from basic theories like formal methods[*1] to practical techniques such as the use case model[*2], while Japan has no such achievements. However, Japan is ranked after the U.S. in the hardware sector despite its presumable weakness in information technology. This is a remarkable achievement for Japan in the IT industry, where both the hardware and software markets are highly oligopolistic. In the console gaming business, Japan leads in both hardware and software. These strengths of Japan highly contrast the country's weakness in the overall software industry except the gaming sector. This situation has occurred for some specific fundamental reasons.

3 Exploring the causes of weakness

What has weakened Japan's software technological capability? There are a number of different views, but our analysis shows that the primary cause is Japanese society's "lack of rational thinking."

3-1 Software and rationality/logicality

Japanese society is said to be poor at rational and logical thinking. We partly agree with this and attribute the weakness of the Japanese software industry to this weakness in Japanese society.

Some oppose this perception and instead cite the poor language skills of the Japanese, especially in English, as the primary cause. Language is the best instrument to describe, record, manipulate, and communicate knowledge. Even graphical tools such as the Unified Modeling Language (UML)[*3] are referred to as graphical language. "Language" is a collective term and describes, records, manipulates, and communicates knowledge. Therefore, poor language skills seem to show a lack of rationality and logicality and, if our theory is correct, may eventually weaken the software industry. There is no contradiction between this theory and our own.

Japan's weakness in the software industry and software engineering is attributable to a lack of rationality and logicality among the Japanese. Because software is by nature rational and logical, a lack of rationality and logicality leads to a weak software industry.

How is software rational and logical? This question requires analysis of the nature of software. Software's nature can be described as follows:

- Software is artificial rules that control cyberspace.
- Software is built for specific purposes.

3-2 Software and logicality: Verification

In short, software is "artificial rules that control cyberspace." Alistair Cockburn, a renowned software consultant, explains software using the philosopher Wittgenstein's concept of a "language game"[3]. On a computer, one can create anything, even a virtual universe that defies physical laws, through game software and simulation systems, for example. In computer cyberspace, a programmer can be like God and create physical laws. Everything is artificial and is free from real-world rules and laws. Although hardware capacity is a major constraint in reality, the software world is a theoretically "unrestricted space" governed only by logic (This article uses the term "logic" in a broad sense, including, for example, algorithm efficiency).

Like abstract mathematics, software exists in a conceptual world and is hardly governed by rules in this world such as physical laws. Software only follows the few laws that abstract concepts must follow, such as logical rules. This creates a major difference between software and other artificial objects such as physical machines. Developing software is like drawing a picture with a pencil on white paper, where the pencil represents logic and the paper, the conceptual world.

Truth defined by artificial rules (formal rationality, instrumental rationality) is governed by logic in a broad sense. Technically, it is embodied by mechanical reasoning methods such as formal and term-rewriting systems[*4] in mathematical logic. This is why formal verification is fundamental to software engineering and computer science[6].

3-3 Software and rationality: Requirements engineering

"Validation" is a term often used in contrast to "verification." Although they have similar meanings, there is a major difference between the two terms. Verification refers to checking whether software conforms to its predefined specifications. This process does not involve changing the specifications, which is a description of the software requirements and an absolute axiom. Verification can be compared to proving a theorem from an axiom in demonstrative geometry and can be performed within cyberspace (Table 1).

By contrast, validation requires actually running the finished software to check whether it meets the requirements set before specification, that is, the initial purpose of the software development. This also includes checking whether the specification conforms to the purpose (Table 1). Unlike verification, specifications are no longer axioms but are instead treated like differential equations expressing physical phenomena. When a differential equation expressing a phenomenon is solved, and the solution is discovered to contradict reality, it must be incorrect if there is nothing wrong with the numerical analysis. Consequently, the differential equation must be changed. In other words, when specifications are defined as formalizing the purposes and programs are written as "solutions" to these purposes, validation checks and reviews programs against their initial purpose. Verification and validation are two major interrelated elements of software development.

In cases of actual validation, specifications as formalized purposes and programs are checked in parallel, although this is not possible until the programs are completed. In a software development project, the last-minute discovery of bugs in the specifications is the worst situation. Most of these bugs are not a result of contradictions in the program, which may be solved within cyberspace, but the disparity between the expected functions of the finished software and the original purpose or requirements. This is why software developers are placing increasing importance on ensuring a close agreement between specifications and purposes as well as clarifying the purposes and translating them into specifications as accurately as possible. Software engineering researchers have responded to this problem by launching a discipline called requirements engineering (Table 1). Requirements engineering contributes to identify the one of the nature of the software, that is, "Software is built for specific purposes".

4 Is the Japanese software industry really hopeless?

We have already explained that one aspect of software, or software as artificial rules, depends on logicality. Another aspect, however, is not about logicality. Requirement definition as the formalization of the purpose and requirement analysis necessary for that are areas that modern logic has abandoned. This can be explained

Table 1 : Verification, validation, requirement engineering

Verification	Checking a system against its specifications, where specifications are defined as preexisting explicit descriptions of the requirements of a system.
Validation	Checking how well a system conforms to the requirements set before the specifications, or checking how well it conforms to the original requirements. Interpretations of this term are more varied than those of verification, and this article uses the term in a broad sense.
Requirements engineering	A technology to identify the requirements of the software to be developed. This is essential, especially for custom software development.

using terms that Max Weber, one of the fathers of sociology, defined in his (unfinished) theory on rationality. The first aspect of software, artificial rules, represents the concept that Weber calls formal and instrumental rationalities. He says that solving the second aspect using requirements engineering means building and analyzing the starting point of formal rationality and instrumental rationality, based on value rationality and substantial rationality. In other words, software consists of “rationality and logicality,” and construction naturally requires rational and logical thinking.

In his analysis of the strength of Japan’s automotive industry[5], Takahiro Fujimoto defines the architecture of industrial products in two dimensions using four types: “modular versus integral types” and “open versus closed types.” He argues that Japan shows strength in products with closed-integral architecture such as automobiles and game software, which require the integration of elements in a closed environment. However, Japan suffers weakness in products with open-modular architecture such as personal computers and packaged software.

Fujimoto’s theory is based on the “design information transfer theory,” which regards design and manufacturing as processes of “information transfer.” For example, the stamping press of car body panels is considered as a transfer of shape information to sheet steel. Fujimoto says that Japan excels in handling “media with poor writability” such as sheet steel. Although his argument on this point is weak, he demonstrates that making good transfers to media with poor writability requires “building-in quality,” and the final product quality depends on the manufacturer’s capability in closed-integral activity, including care about detail and craftsmanship.

In Fujimoto’s concept of information transfer, requirements engineering is transferring implicit information to formal information, and specification-based programming is transferring requirements, or formalized purposes, to executable programs. In this regard, cyberspace is a medium with ultimate writability because it is governed solely by logic. Therefore, a product can be made simply by writing software design information rationally and logically in a formal language such as a programming language. Unlike car production, no further transfer is required. In the software development, designing can be considered almost synonymous with producing (although software designing is actually divided into multiple stages).

Fujimoto explains that because Japan’s technology is less competitive in areas where information transfer is easy, the Japanese software industry lacks international competitiveness. Software is a product that can be transferred simply by writing on a storage medium. In this sense, there is a similarity between our argument that software solely depends on rationality and logicality and Fujimoto’s explanation that the software sector is driven by media with greater writability. We focus on structure while Fujimoto centers on how structure is written.

If our assumptions that the Japanese are culturally irrational and illogical and that software is a combination of rationality and logicality were both correct, the weakness of the Japanese software industry could be attributed to cultural characteristics. This leads to the conclusion that the Japanese software industry will not thrive unless Japan changes its culture. This is supported by the similarity between our theory and Fujimoto’s, which explains the weakness of the Japanese software industry from a different perspective, adopting the industrial engineering (production engineering) concept of transfer to media. This could also account for “the lost decade of Japan”.

5 The paradox of agile methods

Reality is not so simple, however. Fujimoto points out that it was during this lost decade that the U.S. discovered the value of the Toyota Production System, a lean production in worldwide use as an effective Japanese production technique[5]. However, it was not only industrial engineering technology that the U.S. learned from Japan during this period.

Shortly after realizing the strength of the Japanese production technique, the U.S., the leading country in software engineering, started to pay attention to a set of new software development techniques called agile methods. With no connection with earlier Japanese techniques by industrial engineers, agile methods have been created to help custom software developers.

In traditional software engineering, it is usual among software developers that, once a development plan has been made, it should not be changed. It is assumed that a project should be split into modules and distributed, and the interface between each module should be defined by a detailed "contract." In any field of software engineering, this has been so fundamental a principle that deviating from it has been impermissible. Software engineering has been how to correct development processes that easily deviate from this principle.

Agile software development methods have successfully defied this principle by demonstrating higher productivity and improved quality. Their impact is as strong as the influence of the Toyota Production System on Detroit, which had long stuck to scale- and plan-oriented production systems. In software engineering, however, revolutionary change came from inside, rather from outside.

How completely these agile methods defy traditional common sense in software engineering is shown by the bold name given to one of them: Extreme Programming. Known as XP, this programming technique has become increasingly popular in the U.S. and even in Japan over the past few years. Other well-known agile methods are Scrum, Crystal, Adaptive Software Development, and recently, Lean Software Development. Software industries worldwide are struggling to find the right ways of handling these new technological methodologies that have emerged against traditional approaches.

These new software development methods allow a project involving up to about 10 people to be carried out with great efficiency. These approaches have been dubbed collectively by their inventors "agile methods" after the industrial engineering method introduced by the Iacocca Institute. Thus, the name "agile" derives from a methodology intended to flexibly and speedily meet the demands of end users and cope with change in these demands.

Over the past few years, some American researchers have argued that agile software development is closely related to Japanese production techniques and business administration. A typical example is Mary Poppendieck, who advocates Lean Software Development. Her monograph on this methodology[8], which begins by referring to Toyota, mentions people and terms associated with the Toyota Production System such as Ohno (Taiichi Ohno) and software kanban. Scrum, another methodology, is a term first used by Ikujiro Nonaka, a well-known Japanese business management professor. Moreover, in a panel discussion at XP 2003, an international conference on Extreme Programming, Kent Beck, the father of XP, used a concept known in lean production as "muda" (waste) to explain test cases in test-driven development, which constitutes XP's core technology[1].

The media used to use expressions like "the information technology industry = an emerging next-generation industry," "the machine industry = a declining old industry," "a country at the forefront in new industries = the United States," and "a country with old industries and falling behind the times = Japan," showing a simplified picture. Paradoxically, however, knowledge originating from Japan's "traditional industries" such as the automotive industry is highly valued as cutting-edge concepts in the core sector of the IT industry, which symbolizes the victory of the U.S.

Let us provide a brief description of agile development methods to show how they are "Japanese". XP rejects completed specifications because having specifications and implementing them is a two-fold process, and managing it interferes with efficiency. A development scheme that defines detailed requirements and formulates a meticulous plan before starting is called up-front development. In this approach, the majority of the cost is spent at the initial stage of development, or up front. In a coordinate system whose horizontal axis represents time elapsed, the cost of an up-front development project draws a curve that sticks up like the prow of a boat during the early period.

Figure 2 : The Agile Manifesto

Source: http://agilemanifesto.org/

If we assume that systems are nonlinear and emergent and that customers' minds and environments change, agile methods are more suitable. This concept is exactly same as "ex-post rationality," a rationality Fujimoto argues to be inherent in Toyota-style thinking (as opposed to up-front development, which corresponds to Fujimoto's "ex-ante rationality").

XP does not emphasize tools. In fact, XP ingeniously incorporates the specification process in a manner that places a minimal load on total development. Because of this design, it is suggested that XP users avoid specific tools except the compiler. For specification, XP employs CRC, a technique that uses paper cards with simple formats printed on them. It resembles the kanban scheme, which also uses paper cards, in the Toyota Production System, as opposed to Detroit's heavy computer-aided systems for production and inventory management.

In agile development, teamwork is more important than individual activity. XP requires programming to be conducted in pairs. As a result, team members work in an open room rather than in private rooms. This environment allows them to hear what others are discussing, promoting a common understanding of the entire project.

Agile development encourages delaying decision-making, avoiding forced premature decisions.

Agile development also emphasizes interaction with customers. "The customer is God" is a familiar phrase among agile developers. Some teams even practice Onsite Customer, a technique that involves customer representatives as on-site team members so that the team can consult them for decisions or instructions when a change or a postponed decision must be made.

These are only a few examples of the similarities between agile methods and Japanese thinking. This is not a result of Japanophile because it was not until the value of agile methods was recognized that their inventors noticed the resemblance between their approaches and Japanese approaches.

6 Elephant-type and monkey-type approaches and a fusion between them

Because of their practical benefits, skilled programmers, especially those familiar with the specific style of thinking known as the UNIX culture, can easily appreciate and accept agile methods, but software engineers who rely on traditional up-front development are confused by them. Barry Boehm, the well-known inventor of the spiral model, published in early 2004 "Balancing Agility and Discipline"[2] to clarify how discipline in up-front development relates to agility. The book starts with an allegory about an elephant and a monkey, which perfectly explains the relationship between agility and rationality. Here is a summary of the story.

Once upon a time, an elephant lived in a village near a jungle. For many years, the elephant served the village by bringing back bananas from the jungle and was appreciated by the villagers. One day, a monkey appeared and began bringing exotic fruits that no one had ever seen to the village. Tired of bananas, the villagers were very pleased with the monkey's services and grew indifferent to the elephant. However, as the population of the village increased, the demand for food grew so large that the monkey could no longer support it alone. Criticized by the villagers, the monkey visited the discouraged lonely elephant and suggested a plan; the monkey would find exotic fruits quickly with its agility and the elephant, with its strength, would carry them in bulk. This way, they could together bring sufficient quantities of various fruits back to the village. They lived together happily ever after.

The elephant represents methods such as Fordism[*5], Taylorism[*6], and up-front development that intend to achieve system rationality by careful planning. The monkey corresponds to methods such as agile development, and the Toyota Production System. Boehm's conclusion is that, like the elephant and the monkey in the allegory, both agility and up-front discipline are equally important. However, this does not mean that up-front methods surrendered to agile methods upon their practical success or that irrationality surrendered to rationality.

There are many different types of rationality. Sociologist Yoshiro Yano[11] points out that Weber contrasts the up-front rationality of the "systematiker" (system builder) and the rationality that seeks to gradually adapt to reality through ceaseless improvement. The former is the rationality of Fordism and Taylorism, which Fujimoto calls ex-ante rationality, and the latter is the rationality of agile methods and the Toyota Production System, which Fujimoto calls ex-post rationality. The story of the elephant and the monkey implies not a compromise between rationality and irrationality but a fusion between elephant-type rationality and monkey-type rationality.

An industrial engineering expert says that the concepts underlying new production methods such as lean production[*7], agile production[*8], and TOC[*9] are actually Fordism and Taylorism, and they are blended in various ways to serve different purposes. This also applies to software engineering. An in-depth analysis of agile methodology shows that it includes the same mechanism as the basic theory of up-front development. For example, some software engineers, including the first author, have noted that test-driven development (TDD), a core concept of XP, cleverly exploits a programming technique based on Hoare logic, which is fundamental to up-front development[7].

Today's society is highly complex and changing rapidly. To rationally meet its demands, software developers should not depend only on up-front development but should also exploit what sociologists and philosophers call "reflection", or "ex-post rationality" in Fujimoto's terminology. Problems are often so complicated that developers cannot find a promising solution. They are also frustrated over "clients who do not understand the difficulty of software development," because the moment a solution is given, the clients change the initial requirements because of the solution itself. However, the clients are not to be blamed. Software developers should meet these demands. Failing to do so means lack of competitiveness.

An investigation of UML modeling methodology shows that one of the most efficient approaches to collecting requirements in the modeling process of specification acquisition is to use agile methods[7]. This exactly represents a fusion between the elephant-type and monkey-type approaches.

These discussions lead to an unmistakable conclusion about the Japanese software industry. The monkey-type approach that Japanese companies have been taking is rationality, although a rationality dissimilar to elephant-type rationalities such as Taylorism. Unlike when Taylorism and Fordism dominated the world, today's companies must combine elephant-type and monkey-type rationalities. Therefore, the U.S., an elephant-type country, has learned from the monkey-type approach of Japan. Although

Japan lacks elephant-type rationality represented by ex-ante rationality or the rationality of the Systematiker, if modern society requires two rationalities and one is a universal rationality originating in Japan, Japan has already reached half of its goal. All Japan has to do is learn the remaining elephant side of rationality just as the U.S. has learned the monkey side.

7 Conclusion

The Japanese software industry is enormous. Its sales of custom software such as online banking systems are huge. This market has remained highly domestic because of language and cultural barriers. However, as the much-talked-about recent project on the Shinsei Bank system shows, the presence foreign systems engineers, especially Indian engineers, is rapidly increasing in Japan. If Chinese engineers join them, this highly domestic industry may be conquered by foreign companies.

Even if this does not become a reality, Japan may still be left behind the U.S., Europe, and Asian countries in the performance of information systems, particularly those that play a key role in defining future social competitiveness. This could result in a major decline in the competitiveness of Japanese society. Signs of this are already everywhere.

The cause of this situation is not simple. It is most likely derived from the way of thinking inherent in modern Japanese society, predominantly ignorance and misunderstanding of rationality and logicality. This can be traced back to the Japanese social system, especially the educational system, since the Meiji Era. We have been conducting research from this perspective. This article adopts the same perspective for analyzing software engineering as a technological aspect of the software industry.

7-1 Acquiring elephant-type rationality and strengthening monkey-type rationality

Of the two rationalities required for software development, Japan needs to be complemented by elephant-type rationality. In doing so, Japan should recognize, retain, and improve its monkey-type rationality and integrate it with elephant-type rationality.

Traditionally, software engineering has emphasized only the elephant-type approach. However, researchers of software engineering are revealing that the right solution is a combination of both. This principle has proven effective in not only software engineering but also many other fields related to production and design. This is confirmed by the fact that agile methods in software engineering have been inspired by ideas in industrial engineering and business administration, two fields whose design and production processes are completely different from those in software engineering.

When faced with foreign methods, many Japanese often show one of two extreme responses: accepting them as if they were axioms or neglecting them as unrealistic. This attitude, however, is a fundamental weakness in Japan's competitiveness when the answer is somewhere between the two extremes. For example, Japanese software engineers tend to criticize the monkey-type approach as irrational, thereby denying the advantages of their own society.

Software engineers are beginning to accept the idea that the monkey-type approach and a fusion between the monkey- and elephant-type approaches are the key to software engineering. Japan should take this opportunity to catch up in the area of . The secret of the Toyota Production System has yet to be fully elucidated even after the formulation of the lean production theory. No other automotive manufacturer in the world, after adopting lean production, has achieved productivity as high as Toyota's. Even Toyota itself cannot entirely understand and explain its system[5]. The Japanese software industry exists in the same culture as Toyota, and the solution is within its reach. Not using it would be irrational; it may enable the industry to catch up with the world leaders and perhaps even overtake them.

7-2 Policy-oriented research activities

Today's move toward a fusion between the elephant- and monkey-type approaches presents the Japanese software industry with an ideal opportunity to seize the top position in the world. To take advantage of this opportunity, Japan should identify and implement the policies necessary for performing the three following tasks:

(i) Perform complete research in techniques in software engineering and industrial engineering including the Toyota Production System from the viewpoint of Boehm's elephant- and monkey-type approaches, and use the results to compare Japan's software industry and other industries such as the automotive industry to identify the structural problems of the Japanese software industry.

(ii) Examine whether Japan's technological capabilities in areas where Japan is competitive, such as gaming and mobile technologies, can be evidence against our theory or not.

(iii) Elucidate the potential similarities between automobile production and software production, which have both been considered completely different in production system, and extend the results to other engineering fields and business administration. In other words, identify the infrastructure of production and design issues in these engineering fields and formulate a theory.

Let us elaborate on the above three items. In terms of immediate benefit to the software industry, the first two are more important. Both refer to research in areas where Japan is competitive, namely, the first task is in automobiles and the second is in gaming and mobile technologies. In particular, the first research task once started is likely to make rapid progress since there are numerous research resources available. There are other encouraging factors that imply the potential benefits of this attempt. Neither Cusumano nor Fujimoto have addressed on these fields. Comparing software engineering with industrial engineering is an unconventional approach, and custom software production, the main field in software engineering, has not received much attention in government programs. Research on Fujimoto's theory on information transfer will play a guiding role in the first research task.

Japan's strong competitiveness in the gaming and mobile industries can be powerful evidence against our theory. Unless we can produce a proper explanation of this, our theory is unrealistic. However, we can infer that these two IT industries are very different from the custom software industry, the primary target of our theory; the volume of logical information to be exchanged between users and computer systems is much smaller in gaming and mobile communications devices than in ordinary office computers, for example. When we can explain Japan's competitiveness in these two industries, our conclusion will gain a much more solid foundation and our theory will be advanced into a new stage.

In the mobile phone industry, the interfaces of Japanese products in the early days were obviously ad hoc and therefore inferior to the products of Nokia and other overseas competitors who employed software design principles. Japanese manufacturers are, however, rapidly overcoming this weakness. On the other hand, game software production is reportedly moving to the U.S. from Japan. Finding reasons behind these changes will be a start in the second research task.

The third and last research task is to elucidate the infrastructure. Its potential impact on future research makes it the most important among the three. Telelogic, a Swedish firm, addresses the requirement development process using a multi-layer structure consisting of customers and suppliers, which resembles a concept in supply chain management[12]. This is in contrast to Fujimoto's approach[5] that assumes production as the transfer of design information. These different approaches suggest that areas that do not seem to be related are in fact closely related and that their relationships may be theoretically explainable. It is still possible that the traditional two-fold definition of software development, design and production, must be abolished.

7-3 Possible policy directions

The last phase of the project on a fusion between monkey- and elephant-type approaches may lead to a fundamental reform of the entire Japanese educational system, instead of merely a change in software and information education.

This reform should start not at school but at a social level and extend to school.

We suspect that Japan's fundamental weakness in software capability stems from Japanese society's poor thinking power that forces people to choose between one of two extremes. In addition, there is a lack of conceptual understanding of "information," as demonstrated by how easily Japanese people assume building an information system is simply ordering and buying computers and software.

It is very difficult for Japanese society to break away from these traditional thinking patterns only through government-led school reforms. Unless triggered by society itself, efforts to reform the school and educational systems will fail. In this regard, Japan should not take an up-front approach where policy-oriented research must be completed before society can start developing elephant-type capability. A preferable approach is applying findings to actual production and education and checking the results for problems while research is ongoing. In other words, by assuming that information engineers are customers and the educational institutions that produce them are suppliers, Japan should address both in a industrial engineering framework similar to the Toyota Production System. This allows the nation to review, from the viewpoint of supply chain management, its educational institutions as well as its companies and society that receive the "produced" human resources.

While society should continuously inform universities of the types of human resource needed, universities should develop such human resources and supply them to society. These two processes should be improved concurrently. In this effort, research tasks (i) to (iii) should progress in parallel. Radical educational reforms could occur unintentionally through these research activities.

These reforms should be led by the public, not by the government. However, the government can support them and plant the seeds of such a movement. Education to foster "good customers," who are scarce in current society, is one of these reforms. This means fostering chief information officers (CIOs). However, perhaps even industry does not yet have a clear vision of what a good customer or a CIO should be like, and Japanese universities are far from ready to provide education for these purposes. Guiding both industry and academia to their goals is a role that the Japanese government should play through its policies.

Glossary

*1 Formal methods
These refer collectively to software engineering methods that use formal language, formal logic and so forth. Program verification theory, a notion that assures a program's compliance with the specifications through logical and mathematical verification, is a major field of formal methods.

*2 Use case
Invented by Ivar Jacobson of Sweden, use cases are a technique for describing the requirements of a system (or sets of described system requirements).

*3 UML
A semi-formal language that may become the de facto standard in modeling languages, which make a "blueprint" of software. It was invented by "Three Amigos", including Ivar Jacobson.

*4 Formal systems and term-rewriting systems
A formal system is a set of mechanical rules defined by syllogism and other logical systems. A term-rewriting system, a formal system, expresses mathematical rules such as equation transformations and calculations rather than logic.

*5 Fordism
A mass production system introduced by Henry Ford, also known as the Ford Production System

*6 Taylorism
Also called Scientific Management, this approach was initiated by Frederick Winslow Taylor, an American engineer, and aims to improve productivity through the scientific analysis of a production or operational system. It is the origin of TQC (Total Quality Control) activities in Japan. It is also significant in the history of thought for having initiated rationalism in technology

soon after the end of rationalism in science.

*7 Lean production

This was developed at MIT, the U.S., from the Toyota Production System. It emphasizes the elimination of "muda," or waste.

*8 Agile production

Although associated with lean production, this concept originates in the U.S. Instead of eliminating "muda," it stresses flexibility and agility.

*9 TOC (Theory of Constraints)

A production management system proposed by Eliyahu Goldratt. It is similar to lean production but focuses on the performance of the whole system.

References

[1] A panel at XP 2003, "Test Driven Development (TDD)," Steven Fraser, Kent Beck, Bill Caputo, Tim Mackinnon, James Newkirk, Charlie Poole : http://www.xp2003.org/panels/fraser.html

[2] Barry Boehm and Richard Turner, "Balancing Agility and Discipline: A Guide for the Perplexed," 2004; A Japanese translation, UL Systems, Inc., 2004

[3] Alistair Cockburn, "Agile Software Development"; A Japanese translation, Pearson Education Japan, 2002

[4] Michael Cusumano, "Strategy for Software Companies: What to Think About," An invited talk at XP 2003, http://www.xp 2003.org/keyspeeches/cusumano.html., cf. Michael Cusumano, "The Business of Software: What Every Manager, Programmer, and Entrepreneur Must Know to Thrive and Survive in Good Times and Bad," Free Press, 2004

[5] Takahiro Fujimoto, "Capability-Building Competition: Why Is the Japanese Auto Industry Strong?", Chuko shinsho 1700 (in Japanese)

[6] Susumu Hayashi, "Program Verification Theory", Kyoritsu Shuppan Co., 1995 (in Japanese)

[7] Susumu Hayashi, Pan YiBing, Masami Sato, et al., "Test Driven Development of UML Models with SMART Modeling System," in Proceedings of UML 2004, Lecture Notes in Computer Science, Springer-Verlag, 2004.

[8] Mary Poppendieck and Tom Poppendieck, "Lean Software Development: An Agile Toolkit for Software Development Managers."

[9] James P. Womack, et al., "The Machine That Changed the World: The Story of Lean Production"

[10] Japan Electronics and Information Technology Industries Association, "Software Exports and Imports of 2000," July 31, 2002 : http://it.jeita.or.jp/statistics/software/2000/

[11] Yoshiro Yano, "Max Weber's Methodological Rationalism", Sobunsha Publishing Co., 2004 (in Japanese)

[12] Elizabeth Hull, Ken Jackson, Jeremy Dick, "Requirements Engineering," Springer-Verlag, 2002

(Original Japanese version: published in September 2004)

4

Issues and Prospects of Materials Databases
— Aiming to Develop a Materials Database to be Used around The World —

KOICHI YAGI *(Affiliated Fellow)*

1 Introduction

When we start something new, we research to obtain useful information. Here is a familiar example. Before you go on a trip, you buy a travel guide, obtain tourist information about your destination and find out other details such as the hotels, restaurants and shopping available.

Likewise, when we develop new materials, we must obtain information to determine the combination and composition of materials, as well as a manufacturing process. We may also require data for simulation. When we use new materials for a product, we must obtain material property information or data to ensure the selection of the suitable materials to achieve the intended performance. In this respect, material information and data are essential in providing a base for product development.

The Science and Technology Basic Plan[1] presents a vision for the creation of an intellectual infrastructure to promote science and technology. It states that the government should strategically and systematically improve the intellectual infrastructure, such as research materials, measuring standards, measuring/analyzing/testing/evaluating methods, advanced devices, and related databases. Following the announcement of the Basic Plan, the Intellectual Infrastructure Development Committee, a working group of the Technology and Research Foundation Section that operates under the Council for Science and Technology issued a report[2], entitled "Intellectual Infrastructure Development Plan - Towards the Development of One of the World's Best Infrastructures in 2010" to propose specific measures for database development.

Consolidating material information and data is important for various occasions, and the same problems and issues recur. This is probably because these problems create even more complicated issues that cannot easily be solved or that stem from barriers too difficult to overcome. This paper presents issues concerning the current state of materials databases, suggests measures to overcome these issues, and presents one of the goals of a materials database.

In this paper, the term "materials" does not mean a mere substance, but materials used for product. Data and information are based on materials that are actually used (in engineering), rather than experimental data such as the physical or chemical constants of a pure substance.

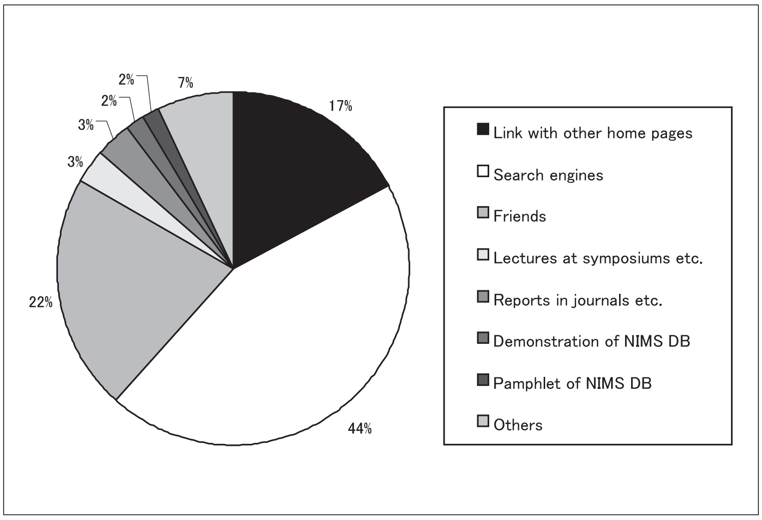
2 Issues concerning databases

2-1 *Invisible database*

A report entitled "Follow-up and Review of the Intellectual Infrastructure Development Plan (Report)"[3] states that 128 materials databases (open to the public) have been created by research institutes and universities, and that the number has increased by 30 since 2002. The number of material property data items has reached approximately 980,000 as it has increased by 180,000 since 2002. These databases are offered by various organizations including the

Koichi Yagi Director General, Materials Information Technology Station, National Institute for Materials Science, http://www.nims.go.jp/jpn/

Figure 1 : How domestic registered users came to know about the polymer database*



*One of the NIMS Materials Databases

National Institute of Advanced Industrial Science and Technology (AIST), the National Institute for Materials Science (NIMS) and the Japan Science and Technology Agency (JST). If progress continues at this rate, there will be yearly improvement in the development of materials databases.

The National Institute of Informatics (NII) issues a report every year based on its investigation of the actual conditions of academic information databases. This paper conducted a follow-up investigation of Japanese academic databases using a report issued by NII. The following are findings from the follow-up investigation based on the NII report for 2002[4]. Firstly, 30 samples, which appeared to be from a materials database, were drawn from the databases listed under the category of engineering. It was found that 5 of the 30 databases belonged to NIMS. I searched the remaining 25 databases on the Internet, of which only 12 databases could be located. No information was found about the remaining 13 databases. Surprisingly, they were not accessible from the homepage of the institute or laboratory in question. Most of the 13 databases were created by universities, and it seems that these universities are not aware of people using the database created by their researchers.

Figure 1 shows results of a survey conducted on users of the Polymer Database, which is one of the materials databases offered by the National Institute for Materials Science (NIMS). In this survey, users were asked how they found out about the Polymer Database. Of all domestic users, 44% said that they knew about it via a search engine, 22% from a friend/acquaintance, 17% through a linked page, and 7% through a lecture at symposiums held by an academic society. Of all newly registered users abroad, 72% of them came to know about the database via Internet, and 12% via a linked page. As just described, many users came to know of its existence via a search engine. These days, general-purpose search engines are widely used at home, so it is natural that researchers use a search engine to find information or data at the initial stage of research. The results of the NIMS survey on database users confirmed this trend.

What can we learn from the results of the follow-up investigation based on the data available in the NII report? When we use general-purpose search engines like Yahoo and Google, and enter “material” or “database” for a keyword search, most of the databases listed in the NII report do not appear on the screen. Even though the keyword may not be appropriate, these databases are not user-friendly despite the fact that they are open to the public. In fact, they are not specifically designed to serve outside users. They are only private materials databases used among colleagues, and are not open to the public. Many existing databases have been created by researchers for their own use, and thus are not visible to general users. If a database is to be open to the public, it should be designed to be seen and used by general users. A database has significant meaning only after it is open to the public and widely used.

2-2 Japanese databases struggling for survival

Together, the Japan Aluminum Association and the Japan Research and Development Center for Metals published a report on the development of a non-ferrous metals database, entitled "Study of the State of Intellectual Infrastructure in the Field of Materials"[5], which states the findings of a survey conducted in 1999 to investigate the circumstances surrounding non-ferrous metals and other materials databases. The report provides a list of recommended materials databases. The list consists of 8 databases created in Japan and 9 databases developed overseas. The lineup gives the impression that some of them have been selected in an arbitrary manner because of the personal connections of those who conducted the survey. Five years on, a question has been raised regarding the databases created in Japan. Of the 8 databases, 2 databases suspended operation. NIMS offered 3 databases (including a database taken over from JST), and companies and universities continued operating 3 databases. In the meantime, all of the 9 databases developed overseas remained in good condition.

As indicated in the report issued by the Intellectual Infrastructure Development Committee and as frequently pointed out, many domestic databases do not live long. In Japan, a research budget is allocated for database development, but it is not easy to secure a budget for database maintenance. Two databases that suspended operation make a good example. Considering the large budget required for database maintenance, this is understandable, but we must create ways to maintain a database.

There is another reason that many materials databases do not last long. As already mentioned, a materials database is often developed as part of a research project. A researcher who has created a database tends to see it as his/her own property, which makes it difficult for an organization to interfere with its operation. The design of a database often reflects the individuality of the researcher who created it, making it difficult for another researcher to take over its operation. Given this, an organization must make coordinated efforts to develop a database from the initial stage so that it can be taken over smoothly. It is important to educate researchers so that they are aware of their responsibility to return a database to society because it has been funded with taxpayers' money. Database development largely depends on the ability and efforts of researchers, and this calls for an assessment system that rewards researchers on the basis of their efforts to develop a database.

3 Materials databases in Japan

3-1 NIMS Materials Database

In April 2003, NIMS launched the NIMS Materials Database[6] on the Internet by consolidating the databases from 3 resources: materials databases created and opened to the public when it was known as the National Research Institute for Metals, an electronic form of Structural Materials Data Sheets, and databases that NIMS took over from JST. Currently, the NIMS Materials Database is offered by the Materials Information Technology Station, one of the units of NIMS. NIMS has published creep and fatigue data sheets since 1966. It has been making a coordinated effort to publish these data sheets, and their quality control system fully complies with ISO9001. At NIMS, databases are developed in the same way as the Structural Materials Data Sheets.

As Table 1 shows, the NIMS Materials Database consists of eleven databases. These databases can be categorized into two groups; (i) those based on original test data (e.g. electronic form of the Structural Materials Data Sheets such as the Creep, Fatigue, Corrosion, and Space Use Materials Strength Data Sheets) and (ii) those consisting of data taken from scientific literature and thoroughly examined by specialists for relevance (e.g. Polymer Database, Diffusion Database, Superconducting Materials Database). Creep Data and Fatigue Data are the unique databases in the world that offer highly reliable and professional information. Data in the Polymer Database are taken from scientific literature concerning polymers in accordance with basic principles. For this reason, NIMS Materials Database offers a wide variety of highly professional information. It is useful for materials specialists, but it is difficult for non-professional users to make good use of the data. As a result, engineers of small and medium companies have asked for more detailed explanation.

Figure 2 shows the number of registered users of and the number of visits to the NIMS Materials Database. The number of registered users was about 13,800 as of the end of July 2004 (about 10,600 domestic users and about 3,200 overseas users). Researchers and engineers from companies account for 60 to 70% of the registered users, and about 80% of the registered users for highly professional databases such as the Structural Materials Database and Polymer Database. The NIMS Materials Database is aimed at delivering a "materials database that is commonly used." In this paper, a "materials database that is commonly used" does not mean a "materials database that is easy to use," but a "database with valuable contents that attract users."

Table 1 : Outline of the NIMS Materials Database

Database	Content	Number of Data Items(as of June 2004)
Structural Materials	Creep, Fatigue, Corrosion, Space Use Materials Strength	Creep and Fatigue Data Sheets in PDF files (50 files for Creep Data, 96 files for Fatigue Data), Fact Data
Nuclear Materials	Nuclear change, neutron irradiation	Mechanical properties data, Approximately 15,000
Pressure Vessel Materials	Strength properties of Cr-Mo alloy steels	Strength properties data, Approximately 4,800
Welding	CCT diagram for welding	CCT diagram for welding, 370 steel types
Polymer	Sample property, dictionary	Polymer, Approximately 10,000 Property Point, Approximately 100,000
Basic Crystal Structures	Crystal structure, X-ray diffraction	Crystal structure, Approximately 27,000 X-ray Diffraction, Approximately 27,000
Electronic Structures	Electronic structure, elemental property	Electronic structure, Approximately 160
Diffusion	Diffusion data of metals, alloys and intermetallic compounds	Diffusion coefficient, 3,500
3D Demo System for Ternary Phase Diagrams	Phase diagrams of alloys	5 types
Superconducting Materials	Superconducting properties	Properties of superconducting materials, Approximately 30,000
High Magnetic Field Engineering and Cryogenics	Low-temperature properties	Thermal and superconducting properties, Approximately 10,200

Figure 2 : Number of registered users of and number of visits to the NIMS Materials Database

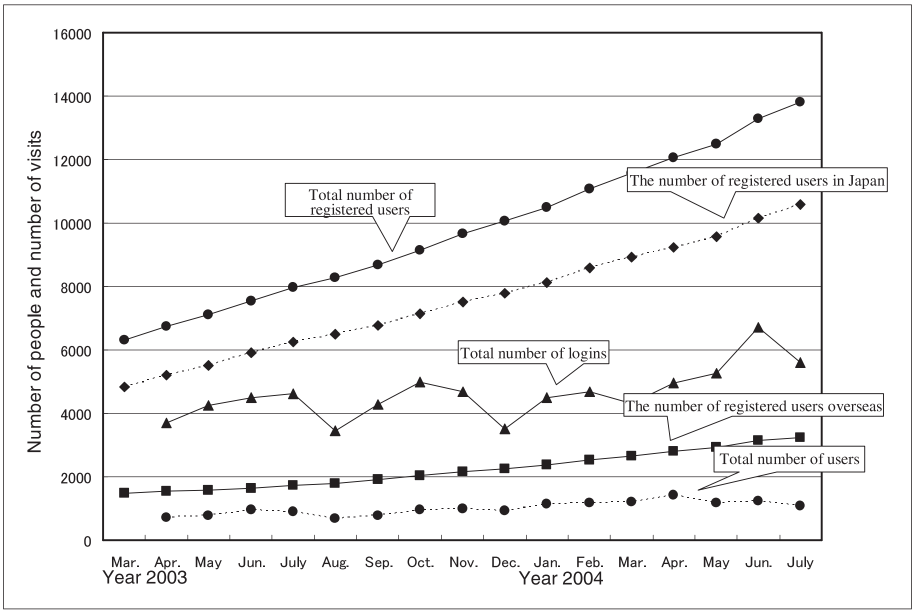
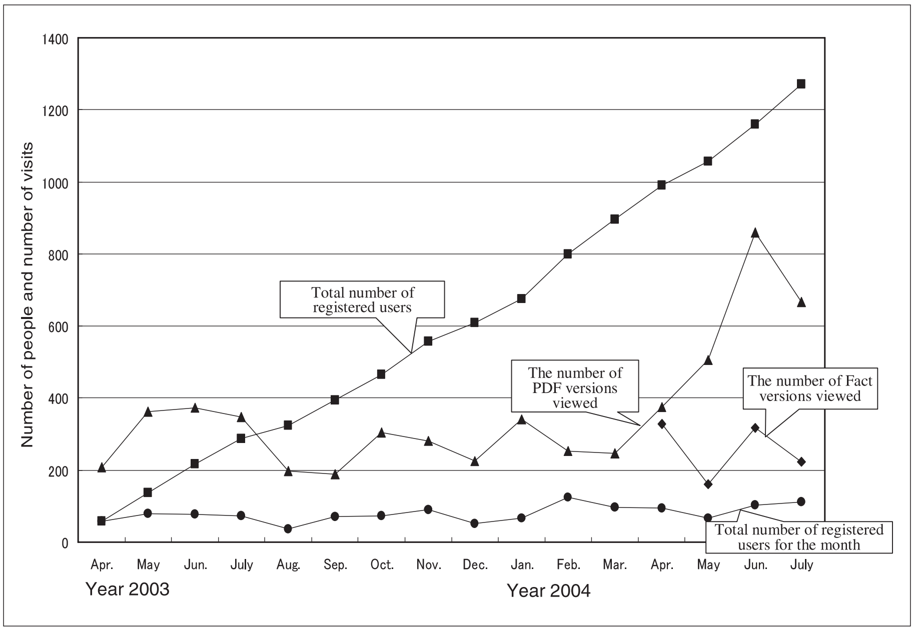


Figure 3 : Number of registered users of and number of visits to the Structural Materials Database*



*One of the NIMS Materials Databases

Figure 3 shows the number of registered users of and the number of visits to the Structural Materials Database. This database is centered on a project to offer structural materials data sheets, which makes it different from other databases. Since its launch in April 2003, the Structural Materials Database has been offering structural materials data sheets in the form of PDF documents. Its Fact version, which adopted a common database design, was launched in April 2004, enabling users to select materials and conditions to design their own products. Although it was expected that the Fact version would attract more users, the PDF version continued to be in greater demand. The PDF version comes as a printed data sheet containing detailed information and data. On the other hand, the Fact version offers major data and avoids complex database structures. Instead, it offers the function of browsing factual data retrieved from the database and describing relationships between different materials using diagrams. Detailed analysis has not yet been conducted. However, this trend suggests that users expect a database to provide detailed information rather than be a function enabling them to present data as a diagram.

There is no point in comparing the number of registered users or databases viewed for different databases because we do not know how institutes interpret these figures. However, a comparison with commercial databases in the US reveals a huge gap between the number of databases viewed in the US and that in Japan. Even a highly professional database like the NIMS Materials Database has fewer users than a general-purpose commercial database in the US.

3-2 Materials database offered by AIST

The National Institute of Advanced Industrial Science and Technology (AIST) developed a research information database (RIO-DB)[7] in 1995 to contribute to technological advancement and to foster industry growth by providing research results and factual data. At its onset in 1996, RIO-DB had 22 databases open to the public with the total number of visits (the number of databases viewed) being 310,000. In 2003, the number of databases open to the public increased to 77, with the total number of visits exceeding 30 million. Table 2 shows RIO-DB databases open to the public by category[8]. To select areas suitable for databases and meet the strong demands of academic societies and the industrial community, AIST places particular emphasis on three types of database: a large-scale database that takes a long time to develop, a geology-related database, and a unique database that can only be offered by AIST.

Table 3 shows outlines of materials databases

Table 2 : Number of databases for the AIST Research Information Database RIO-DB by category

Category	Number of databases	Number of archived databases (stored without updates)
Life Science	8	0
Information Communication	5	0
Nanotechnology, Material, Manufacturing	16	2
Environment, Energy	19	6
Social Infrastructure (Geology, Marine)	16	1
Social Infrastructure (Standard)	10	2
Other (Publicity)	3	2
Total	77	13

Table 3 : Outlines of materials database in the AIST Research Information Database RIO-DB

Database	Content
Materials-LCA Data Base for Ecomaterials Design	Research and development of composite materials based on LCA
Optical Properties of Ceramics and Ceramics Thin Films	Optical properties such as transmittance, reflectance, and emissibility of ceramics and ceramic thin films
Superconductivity Papers Database	This database mostly covers articles on superconductivity after the advent (1987) of the high-temperature superconductor. It contains high-temperature superconductors (49,852 entries), C60-related (3,233 entries), organic conductors (2,377 entries), non-oxide superconductors including conventional superconductors (7,973 entries), oxide conductors (3,272 entries), theory (6,556 entries)
Database for Metallic Material Design	This database covers the development of implant materials at AIST
Manufacturing Database	Data on welding, electronic grinding and cutting
Ceramic-Color Database	Ceramic glaze data, Number of data: 1488
Database for Assessments of Metals in Aggressive Environments	Mechanical property data for metallic materials used in harsh environments such as high-pressure hydrogen gas, high temperatures and ultracold temperatures (e.g. tensile properties, fatigue properties, fatigue crack growth, fracture toughness/elastic plastic fracture toughness, creep properties and fracture surfaces of metallic materials)
Electronic System Integration Technology Database	Technical papers and data related to next-generation packaging technology (3D packaging, optical packaging), Total number of data items: Approximately 7,700
Light-Metal Composite Material Database	Superplastic deformation of aluminum composite materials, Materials properties (mechanical properties, thermal properties, abrasion resistance)
Database for DDS Nano-Materials Applying Complex Carbohydrate Ligands	DDS nano-materials data that can be applied to drug delivery systems (e.g. molecule design/synthetic method, disposition of tumor-bearing mice, model for sugar chain molecular structure, assessment of molecular recognition/function)
Ceramic Materials in Japan	Data can be searched by category, such as type/category, area, chemical composition and other properties, and supplier
Underwater Technology Database	This database consists of underwater welding, underwater cutting and ultrasonic databases
Database of Plastic Thermophysical Properties	Specific heat for every 10 degrees centigrade, thermophysical properties such as required enthalpy in the solid, fusion, thermal cracking or vaporization area
Network Database System for Thermophysical Property Data	Thermophysical property data such as thermal conductivity, thermal diffusion rate, specific heat capacity, coefficient of thermal expansion, and radiant heat. This database system allows access to the databases of independent research institutes on the Internet. Number of data items: 765
Integrated Spectral Data Base System for Organic Compounds	This is an integrated spectral database system for organic compounds (SDBS), which includes 6 different types of spectrum under a directory database of the compounds. (Compound dictionary: Approximately 32,200 compounds, Mass spectrum: Approximately 22,600, 1H NMR spectrum: Approximately 14,000, 13C NMR spectrum: Approximately 12,300, Infrared spectrum: Approximately 49,200, Raman spectrum: Approximately 3,500, ESR spectrum: Approximately 2,000)
Raman Spectra Database of Minerals and Inorganic Materials	This is a spectra database of minerals and inorganic materials based on research and development data on ceramics. (Minerals: 485, Inorganic compounds: 396, Reference literature: 100)

offered by AIST. Some of them are already archived because no-one oversees or updates them. On the other hand, coordinated effort and time are devoted to large-scale databases. For example, the Integrated Spectral Data Base System for Organic Compounds[9] is a large-scale database that attracts many users, accounting for slightly more than 80% of the total number of visits to RIO-DB. This organic compounds database includes 6 different types of spectrum. Its development began in the 1970s. A general-purpose host computer was used to accumulate data from the 18 years of its history. Today, a personal computer is used to add and update the data in RIO-DB.

AIST is devoting time and coordinated effort to developing a database based on its years of research experience. They have a clear vision of the database to be developed, and they are developing it based on an understanding of user needs. This is only possible at public institutes like NIMS and AIST that can afford the continued effort. If Japan intends to develop and establish a unique intellectual infrastructure around the world, public research institutes must play a central role in creating a clear vision for databases to be developed and formulating strategies to maintain them.

3-3 Other materials databases

In Japan, non-public organizations also open their databases to the public. In 1991, the first edition of the INTERGLAD International Glass Database[10] was launched in the form of CD-ROM. The New Glass Fiber Forum, the development body of INTERGLAD, was established in 1985 by a number of leading companies in glass-related fields to encourage businesses specializing in fiber optics or high-tech, new glass industries to promote the collection and provision of information and international exchange for technological development. The Internet edition was launched later. INTERGLAD International Glass Database Ver.5 was also launched with the support of the Measurement and Intellectual Infrastructure Division, the Ministry of Economy, Trade and Industry. It has been reported that there were nearly 1,000 users at home and abroad.

The Society of Materials Science, Japan, has various databases that cover structural materials properties, and the Japanese Fatigue Bibliographic Database is a representative example. The concept of this database dates back to the 1970s, and it was published in 1982 and 1992. Consisting of a wide variety of metallic materials fatigue strength data collected in Japan, it is available as a book and a computer-readable database[11]. It covers a range of materials including steel materials and non-ferrous metals, but consists only of data collected before 1991. The data has not been updated since then.

Meanwhile, industry associations published a materials catalogue featuring data on aluminum, magnesium, titan or other materials[12]. However, these catalogues are small in scale. There are also a small number of databases offered by companies for a fee (e.g. the electronic version of the “Kikai Sekkei (Machine Design)” handbook [13]).

Except for the INTERGLAD International Glass Database, there are only a few materials databases which are offered by non-public research institutes and are truly original on a worldwide scale.

4 Materials databases around the world

4-1 Private sector databases with a large number of users

When we enter “material” as a search keyword to search for information via a general-purpose search engine, one database always appears at the top of the screen: MatWeb[14]. It is offered by a US company called Automation Creations established in 1996. The company offers database applications and business software solutions for governments and companies, and MatWeb is one of their business operations. Through e-mail exchange, I realized how interested they are in database architecture with growth potential. They appeared to be unenthusiastic about improving existing materials databases. However, they are enthusiastic about developing and improving materials databases.

MatWeb is a materials property database containing more than 40,000 entries for more than 400 material properties, and is periodically updated. About 85% of the data is supplied directly from materials manufacturers. Some data and information are taken from scientific literature or handbooks, but most data are the data of materials products from a catalogue. Automation Creations does not perform laboratory experiments to offer data through MatWeb.

Most property information is on plastics, metals, ceramics and fibers, but there are some data on fluxing materials, lubricant agents and liquids. MatWeb offers data for free, but advanced features such as associated tools are only available to registered users for a fee. MatWeb has a large number of users, the average number of users per day being 10,000, and the average number of newly registered users per week being 14,000. It consists of data taken from catalogues published by materials-related companies; thus, there is no guarantee of the accuracy of the data. It offers data on usual materials only.

Nonetheless, MatWeb is very well known throughout the world, and many organizations provide a link to MatWeb. It could make a good model for Japan as it provides a foundation for consolidating materials databases. If we try to compete with MatWeb, we must deliver original features such as functions, quality and reliability that are not offered by MatWeb. However, we must be aware that we could be defeated if we lose in terms of the number of visits to the database.

4-2 Characteristics of materials databases around the world

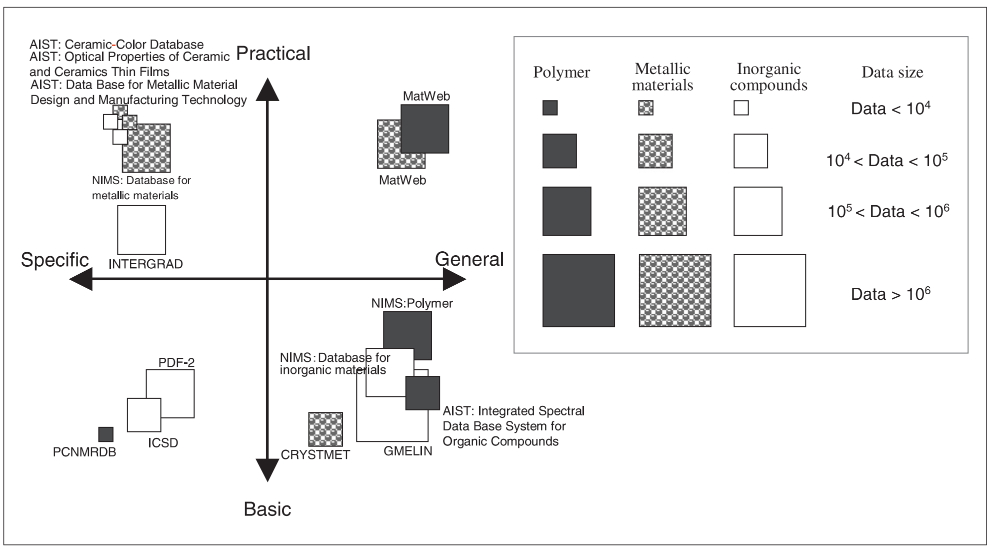
Figure 4 is based on the diagram[15] by Nagasaka et al. It shows the characteristics of materials databases by scale, diversity (whether properties are specific or general) and applicability of data (whether properties are basic or practical).

Japanese databases can be categorized into two groups; databases that focus on specific fields for practical use, and others that cover general fields to provide basic data. The databases tend to be relatively small. On the other hand, European databases such as BEILSTEIN (an organic compound database) and GLEMIN (an inorganic compound database) have data and information collected over nearly 200 years. European databases tend to focus on basic properties.

Based on the above-mentioned conditions, databases can be categorized into roughly three groups: (i) those that have a tradition and contains the basic property data of materials and substances collected over years, (ii) those that have professional information for a specific field and are thus truly original on a worldwide scale, and (iii) large-scale databases that contain information taken from catalogues.

The three categories of materials database show the potential direction of Japan. Because Japan has a short history of science and technology and is behind its overseas counterparts in terms

Figure 4 : Scale and objective of materials database



Source: Prepared by the author based on the diagram drawn by Nagasaka et al.[15]

of the quantity of basic data and information, it is difficult to compete with large-scale European databases of the first category. It is also a challenge to establish a distinct business model and create a large-scale commercial database as described in the third category because success depends on how innovative the idea is. It is difficult, but not a hopeless task, to create such a database. However, this is not what a public research institute ought to do. This leaves one possibility; Japan can only aim to create a database that offers highly professional information and that cannot be rivaled by any other organization.

5 Ideal contents for materials databases that promote manufacturing

5-1 Materials databases that promote manufacturing

Takahiro Fujimoto, a professor at the University of Tokyo, says that the Japanese manufacturing industry is good at developing technologies based on the ideas of the shop floor. He stresses that it is necessary to continue strengthening the institutional capacity and develop architecture (design philosophy) based on this premise[16].

The figures specified by the standards (data found in a catalogue) are not sufficient to develop a product with the most suitable materials. Product development requires a database that contains detailed materials information. As already mentioned, public research institutes such as NIMS and AIST have highly professional databases with a substantial amount of data to meet the needs of a specific field. These databases certainly support the development of manufacturing technologies in Japan.

The following examples show that a materials database must consist of detailed information obtained from research or firsthand experience instead of figures specified by the standards. To create a materials database with detailed information, materials experts must lead efforts to design and build databases, with information technology experts providing technical support. Meanwhile, it is important that a database like MatWeb, which allows users to combine data taken from catalogues, is easy to use. It may well be that information technology experts will lead development efforts in developing a database similar to MatWeb.

5-2 Example of information obtained from an accident

In November 1999, the launch of the H-II Launch Vehicle No.8 from Tanegashima Island failed because of engine malfunction. To investigate the cause of the failure, the engine parts were recovered from the bottom of the Pacific Ocean using cutting-edge technologies. The investigation revealed that the engine stopped when a part of the inducer blade attached to the turbo pump, which pumps liquid hydrogen into the engine, fell off due to metal fatigue. The breakdown of the metal originated on the surface of the inducer blade where there was a tiny scar caused during metal processing. It was found that the fatigue strength of the materials used for the inducer blade was different from that specified in the design, and this became a major issue. The inducer was made from domestically produced titanium alloy. However, NASA's data on the same type of material was used for the inducer design because data on the material in question was not available in Japan. The grain size of domestically produced titanium materials was larger than that of the titanium materials which NASA used for its experiment. Fatigue strength depends on grain size. The larger the grain size, the lower the fatigue strength. The inducer did not have sufficient strength because it was produced according to design values set by NASA. Since this incident, the importance of obtaining space-related materials property data at home has been recognized. It was decided that NIMS will develop Space Use Materials Strength Data Sheets with the cooperation of the Japan Aerospace Exploration Agency (JAXA). As this example shows, materials do not depend on the elements of the basic components alone. Materials properties data are not necessarily applicable even if the material in question has the same standard name. If you accept the name at face value and use that data in design, unexpected accidents may occur. To use materials safely, we must carefully examine information and knowledge such as the manufacturing conditions and microstructure of the metal.

5-3 Examples of information obtained from materials development and the manufacturing process

(1) Example of auto sheet steel

Japanese sheet steel manufacturers have the technology to produce excellent auto sheet steels. Auto body sheet processing requires materials that change shape homogeneously because these materials do not crack, and they deliver an even thickness when they are formed in suitable dies. The production of such materials requires information sharing and close cooperation among steel engineers, die press engineers and auto body designers. In Japan, engineers from steel manufacturers and auto manufacturers have worked together to develop high-performance auto sheet steels[17]. Because we have to reduce the environmental burden of auto steels, there is a growing demand for the high-strength steel materials required for lighter vehicles and steel materials that are easy to recycle. Materials engineers, auto design engineers and auto manufacturing engineers are expected to work together to develop materials and processing technologies. As just described, it is necessary to develop a database that covers not only information about materials but also the information required for machine design, if materials development and machine design are promoted for products development in tandem.

(2)Example of heat-resistant steel for boilers

Heat-resistant steels used for boilers in thermal power plants must withstand high pressure and high temperature. This means that they must have high creep strength. Boiler design is based on the allowable stress determined by creep strength that ensures 100,000 hours of operation, thereby requiring an experiment to obtain creep rupture strength for 100,000 hours. Currently, such an experiment is being conducted by NIMS and some European research institutes only, because it requires funds, human resources and relevant facilities. Creep strength is sensitive to the microstructure of the metal and is influenced by a very small amount of minor chemical elements. For example, stainless steel properties vary depending on the quantity of boron contained, although there is no standard that specifies the quantity of boron in stainless steels. There is a significant difference between stainless steels containing a few ppm of boron and those containing more than a dozen ppm of boron[18]. Stainless steels with more than a dozen ppm of boron have high creep strength but are brittle, and thus are unsuitable for practical use. A few ppm of boron is added to improve strength and to give appropriate ductility to stainless steels for practical use. Such information, which cannot be found in a catalogue, is indispensable for professionals.

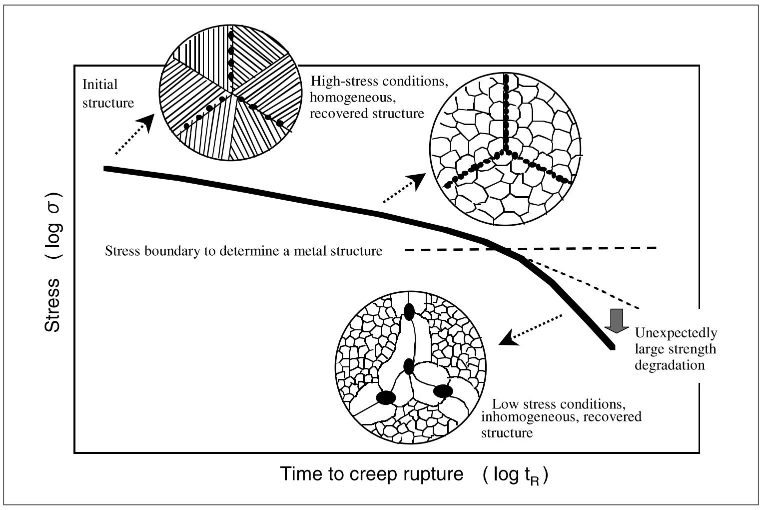
(3) Example of heat treatment simulation

Steel microstructure changes due to temperature and deformation processing, which affects its strength. This is how Japanese swords are strengthened and given a subtle difference in properties. Knowledge and data concerning the mechanics of materials and metal materials science are required to simulate this phenomenon. The development of a database that enables steel heat treatment simulation was conducted by the Society of Materials Science, Japan, under the initiative of Tatsuo Inoue, a professor at Kyoto University. The stress-strain curve was obtained and accumulated for steels that show a significant difference depending on temperature and composition change[19]. This example shows that a strong leadership and cooperative framework are required for the development of a database that features a large amount of diverse data.

5-4 Information obtained from research

Figure 5 shows the creep strength of high-chrome steel. High-chrome steel was developed as a structural material for future fast breeder reactors in the US during the 1980s. It was then diverted to thermal power plants, but efforts continue to deliver high-chrome steel which withstands higher temperatures. Japan developed high-chrome steel with increased strength based on this material. When exposed to high temperatures, the microstructure of the metal changes, leading to a change in strength.

Figure 5 : Stress dependency and effects on creep strength by the microstructure of heat resistant steel during high-temperature creep[19]



This also applies to high-strength heat-resistant steel because its microstructure changes and strength deteriorates over time. Figure 5 shows that recovery is observed in all parts of a material when there is high stress (when creep life is short), but recovery takes place in areas close to the grain boundary only when there is low stress (when creep life is long)[20]. This presents a problem; when a creep test is conducted under high-stress conditions, recovery takes place in all parts of the material. If creep life over time is extrapolated and strength is estimated using test data, the obtained strength will be higher than the actual strength of high-strength heat-resistant steel. If a plant is designed based on the obtained strength, creep rupture is imminent.

6 To build a partnership on a worldwide scale for materials databases

Databases are expected to organize accumulated knowledge and information to help researchers and engineers. They must also provide information to help people locate the source of information. Many materials databases feature highly professional information, but the scale and the quantity of data are relatively small. In addition, materials databases must cover many measurement items, which makes it impossible for any single organization to develop a database that contains data on all of these measurement items.

There is another aspect to a database. Because they are the culmination of research, researchers are especially attached to them. Databases lack compatibility because their creators often use different forms. Despite efforts towards establishing international standards for databases, there has not been much progress. This may be a problem in making effective use of existing databases. The people involved in the existing databases may be reluctant to cooperate if the consolidation of database formats is pushed forward in a high-handed manner.

Professor Ashby of Cambridge University in the UK is a famous materials researcher and author of course books on materials selection for product design, based on a concept developed over years. He has developed electronic materials for teaching materials selection at Cambridge University, created a materials database, and built a materials database network that connects the world’s most famous materials databases. He claims that the standardization of database formats or the integration of databases does not matter, and that researchers and engineers only want to know the location of the data and information that they require. He says that they can collect, organize and use data and information once they know their locations. Based on this belief, he has developed a search engine called the Material Data Network by collaborating with Granta Design[21], a venture business originating from Cambridge University.

Table 4 shows a list of databases included in the Material Data Network and database providers (research institute and company).

The Material Data Network consists of various databases provided by the world's leading institutes such as the American Society for Metals (ASM International), Automation Creations that provides MatWeb, the National Physical Laboratory (NPL), The Welding Institute (TWI) and the National Institute for Materials Science (NIMS). This network system functions as a tool to locate data and information and a search engine for professional materials information. Users visit the site based on search results, register for the database and obtain information on their own.

Table 5 shows the amount of information that can be obtained from the Material Data Network. The data obtained from any database that comprises the Material Data Network is one-sided because each database specializes in certain

Table 4 : Outlines of databases Linked to the Material Data Network

Database	Provider		Outline
	Organization	Country	
ASM Handbook	ASM International/Granta Design Ltd.	US/UK	Online metal materials handbook
ASM Alloy Center	ASM International/Granta Design Ltd.	US/UK	Metal alloy properties
ASM Micrograph Center	ASM International/Granta Design Ltd.	US/UK	Collection of micrograph images of metals
IDES Resin Source	IDES Inc.	US	Data on US (ASTM class) plastics provided by resin suppliers
MatWeb	Automation Creations, Inc.	US	Data on metals, polymers, ceramics and other composite materials provided by suppliers
MetalsUniverse. com	National Metals Technology Centre	UK	Properties of materials that meet the standards such as steels, metal-based composite materials and non-ferrous metal alloys, and environmental burden data
MIL-HDBK-5H	Granta Design Ltd.	UK	Property data on aircraft materials
NIMS Materials Database	National Institute for Materials Science	Japan	8 kinds of database in NIMS Materials Database
NPL MIDS	National Physical Laboratory	UK	Material and measurement information
SteelSpec II	UK Steel	UK	Steel data provided by suppliers
TWI JoinIT	The Welding Institute	UK	Welding technology information

Table 5 : Number of data items per database linked to the Material Data Network

Database	Ceramic	Composite	Fibres & Particulates		Form	Metal	Natural	Polymer	Total
			Fibres	Particulates					
ASM Handbook	1629	1909	16	136	263	7816	1063	1010	13842
ASM Alloy Center	1676	449	1	32	13	7685	232	237	10325
ASM Micrograph Center	3	1670	None	1	None	972	36	None	2682
IDES Resin Source	4	678	16	None	33	9	481	13849	15070
MatWeb	2780	834	31	5	254	9990	532	29443	43869
MetalsUniverse.com	2	63	11	None	11	215	3	6	311
MIL-HDBK-5H	20	107	56	None	133	322	6	672	1316
NIMS Materials Database	16563	None	None	None	None	12029	2	10973	39567
NPL MIDS	263	153	31	1	11	351	147	1900	2857
Steel Spec II	None	1	None	None	None	5	4	1	11
TWI Join IT	450	448	171	42	63	500	268	433	2375
Total	23390	6312	333	217	781	39864	2774	58524	132225

As of August 12, 2004

areas. However, these databases make up for each other's deficiencies and allow users to locate data and information that cannot be obtained from a single database. With this network, users can use approximately 140,000 pieces of data.

It is important to remember that the quality of a database cannot be judged from the amount of data. A large collection of data does not provide valuable analysis results if the data quality is not consistent. Rather, a collection of data of various quality increases the data uncertainty, which may lead to negative results or mislead.

7 Requirements for the increased availability of a materials database

This section offers suggestions regarding requirements for a materials database to be developed by materials researchers, based on the above discussion and considering that it is necessary to increase the availability of a materials database and to expand the areas in which a materials database can be utilized.

(1) Developing a materials database that can be used

In Japan, technologies are developed to meet the needs of the shop floor. If we are to continue developing technologies in the same way and lead the world's manufacturing scene, we must develop a materials database suitable for this style of technology development. To develop such a materials database, we should reflect the needs of potential users and exclude the personal feelings of individual researchers. It is necessary to establish a system that enables an organization, instead of an individual researcher, to address database issues. Establishing such a system should be led by public research institutes.

It is also important to develop a "visible database" that enables users to find out about its existence via a general-purpose search engine.

(2) Coordinating database development and software development for effective database use

A database with a simulation facility enables materials property estimation. It is, therefore, essential to coordinate database development with software development that aims to deliver software that enables the more effective use of a database. Software development efforts should be led by database users because different users use data differently.

(3) Seeking partnerships to establish an international data network

A materials database, especially featuring highly professional information, often covers only limited areas. Therefore, it is necessary to combine several materials databases to meet the needs of users. However, each database has a different background and is based on different ideas, which calls for a network system that can accommodate such differences among databases. One possible solution is to establish a system on a worldwide scale similar to the Material Data Network, which enables users to locate the data and information that they require.

(4) Introducing databases in the field of education

In Japan, efforts to promote E-education have just begun as software development has started. As already described, Professor Ashby at Cambridge University took a long time to write course books on materials selection on his own. These course books are truly original and they all initially present an example and a case study. They are designed to help students gain basic knowledge as they analyze each example. Students require certain data and information to analyze an example, so they access a database to obtain the data and information that they require. In this way, the university students have an experience similar to that of materials engineers on the shop floor. If we are to provide the same kind of education, we must first develop educational materials. It is also necessary to develop software for students.

(5) Using databases on the shop floor

Today, materials and products move across borders. This trend is expected to accelerate in the future, and to catch up, it is necessary to develop a business-oriented database that enhances convenience and assistance for the purchase and use of materials around the world. Such a database must offer data and information to be used not only in the technology field but also in various business fields around the world. It must also be based on the common knowledge of those engaged in these fields.

8 Conclusion

Critics often say that databases cost a lot of money but do not pay for the investment. However, the systematic accumulation of data and information provides a basis for the science and technology indispensable for socioeconomic activities and untroubled living conditions. This paper examines the situation regarding databases and discusses what is to be done to develop a database that can be widely used. This paper focuses on user-friendliness in database development from the standpoint that databases have true value only if they are used. Thus, it points out problems in database development, presents ideas to attract more users, and recommends measures to develop a desirable materials database.

The following are the points raised in this paper that require special attention.

- Japan's strength in technology development lies in shop-floor technology. A materials database must be designed to meet the needs of shop-floor technology. Furthermore, it must also meet the needs of users, and be established as a truly original database around the world. It is also important that users can find it easily. Japan should invest funds and human resources to develop a materials database that meets the above needs and to show its strength to the world.
- Each materials database specializes in a certain area. If several databases are combined, they can meet more diverse user needs. The development of a worldwide materials database network provides a key to addressing this issue. However, it is unwise to consolidate existing databases in a high-handed manner. What matters most for professional users is the location of information. Japan should aim to develop a worldwide materials database network system that enables users to locate information. All of us must work to develop a truly original materials database to accomplish this goal.

The following are the points that require attention in developing and improving a database.

- It is necessary to introduce a database in the classroom to give students the firsthand experience of engineers on the shop floor. For this purpose, it is necessary to develop educational materials that reflect the reality of the shop floor, and create a system to support the development of educational materials that incorporate a materials database.
- Once developed, a materials database must be maintained and improved. It is essential to secure a budget for the maintenance of the database, in addition to the budget for its research and development.

To conclude, materials databases that provide mere figures are not sufficient. They have true value only if they provide information about materials. Materials researchers and engineers must lead efforts to develop a materials database that offers highly professional materials information. Their motivation and effort are essential for the creation of a truly original materials database. We expect to see such materials databases as valuable national assets and establish mechanisms to maintain and improve them on a long-term basis.

References

[1] The Council for Science and Technology Policy: Recommendation Concerning the Deliberation No.1 "Comprehensive Strategy to Promote Science and Technology," March 22, 2001 : http://www8.cao.go.jp/cstp/output/toushin1.pdf

[2] The Council for Science and Technology, the Ministry of Education, Culture, Sports, Science and Technology: "Intellectual Infrastructure Development Plan - Towards the Development of One of the World's Best Infrastructures in 2010 (Recommendation)," August 20, 2001 :

http://www/mext.go.jp/b-menu/shingi/gijyutu/gijyutu0/toushin/010803.htm
[3] The Intellectual Infrastructure Development Committee: Follow-up and Review of the Intellectual Infrastructure Development Plan (Recommendation), March 2004 : http://www.mext.go.jp/b-menu/shingi/gijyutu/gijyutu8/gaiyo/04040801.htm
[4] The National Institute of Informatics (NII): Report on Fact-Finding Survey on Academic Database in 2002, March 2003 : http://www.nii.ac.jp/publications/DBDR/H14dbdr.pdf
[5] The Japan Aluminum Association, The Japan Research and Development Center for Metals: Report on Results of Infrastructure Development Commission Concerning Materials Information in 1999, entitled "Study of the State of Intellectual Infrastructure in the Field of Materials" for the development of a non-ferrous metals database, March 2001 (in Japanese)
[6] The Materials Information Technology Station, The National Institute for Materials Science: NIMS Materials Database : http://mits.nims.go.jp/
[7] The National Institute of Advanced Industrial Science and Technology: A research information open database RIO-DB : http://www.aist.go.jp/RIODB/
[8] Yoichi Hamasaki: "Research Information Database RIO-DB," AIST Today, Vol.4, No.7, 2004, 17-21, The National Institute of Advanced Industrial Science and Technology (in Japanese)
[9] National Institute of Advanced Industrial Science and Technology: The Integrated Spectral Data Base System for Organic Compounds : http://www.aist.go.jp/RIODB/SDBS/menu-j.html
[10] Toru Iseda: "Introduction for New Version on International Glass Database INTERGLAD - (Easy Glass Structure Design)," NEW GLASS, Vol.16, No.2, 2001, 76-81 : http://www.ngf.or.jp
[11] Tatsuo Sakai: "Outline of Materials Databases Offered by The Society of Materials Science, Japan and Their Public Use," The 26th materials seminar of the Society of Materials Science, entitled "New Developments Concerning Various Materials Databases and CAE Technologies," 2003, 1-6 (in Japanese)
[12] For example,
http://210.225.184.19/alumi/
http://210.225.184.19/nagne/
http://www.src-serve-unet.ocn.ne.jp/titanium/
[13] Hitachi, Ltd.: Electronic version of "Machine Design" handbook : http://www.englink21.com/i-eng/guest2/0m0315.htm
[14] Automation Creations, Inc.: MatWeb Material Property Data : http://www.matweb.com
[15] Kyosuke Nagasaka et al.: "Chemical and Material Databases: Current Status and Future Directions," Journal of Information Processing and Management, Vol.44, No.4, 2001, 245-257
[16] Takahiro Fujimoto: "Japan's Manufacturing Philosophy," Nihon Keizai Shimbun, Inc., June 2004 (in Japanese)
[17] Compiled by Tetsuro Nakaoka: "Technology Formation in Post War Japan - Imitation or Creation?," Nihon Keizai Hyoron Sha, 2002, pp.193-227 (in Japanese)
[18] Hideo Tanaka, Masaharu Murata, Fujio Abe, Koichi Yagi: "Effects of Grain Boundary Precipitates on Long-Term Creep Rupture Properties for SUS347H Steel," Tetsu-to-Hagane Vol.83, No.1, 1997, 72-77
[19] Sub-committee on Material Database, the Committee on Engineering Plasticity: "Material Database for Simulation of Metallo-Thermo-Mechanical Field," Materials, Vol.51, No.3, 2002, 350-355
[20] Kazuhiro Kimura, Hideaki Kushima, Fujio Abe: "Improvement of Creep Life Prediction of High Cr Ferritic Creep Resistance," Journal of the Society of Materials Science, Japan, Vol.52, No.1, 2003, 57-62
[21] Granta Design Limited: Material Data Network : http://matdata.net

(Original Japanese version: published in September 2004)

5

Trends and Prospects for Japan-China Technical Assistance in Energy and the Environment
— From the Viewpoint of Global Environmental Problems and Energy Security —

TATSUYA OHIRA
The Environment and Energy Research Unit

1 Introduction

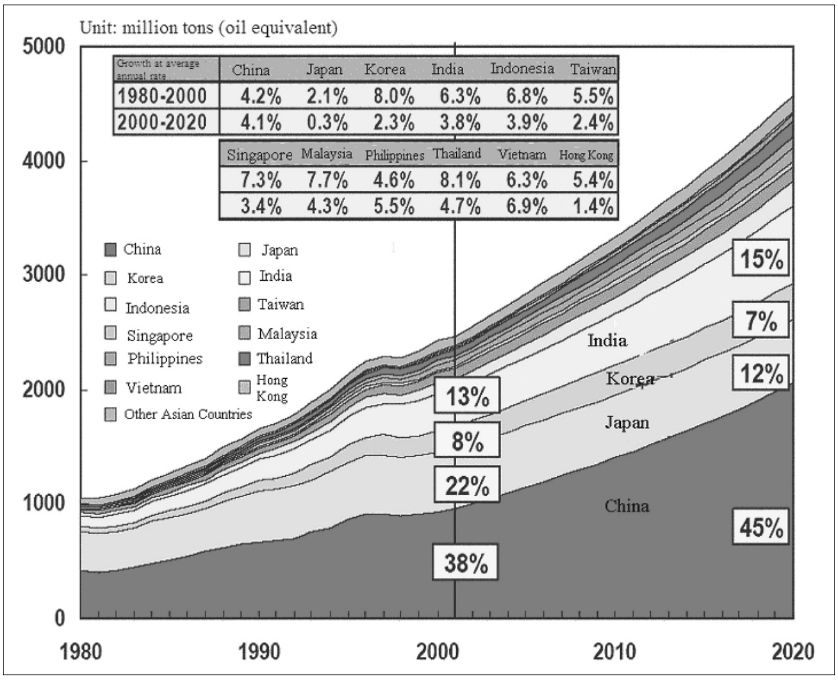
Achieving 3E - Energy security, Environmental preservation and sustainable Economic growth - is the biggest challenge to be faced by the international community in the 21st century. While the world economy has globalized rapidly in the post-Cold War period with the progress of IT, the Asian "tigers" (countries that have achieved high economic growth) are beginning to exert a considerable impact on the world's energy market. With these countries expected to continue rapid growth and consuming more energy, the Asian region is the most likely to place a huge burden on the global environment in coming years. In particular, it is estimated that China's primary energy consumption will account for some 45% of Asia's total consumption and 50% of its CO_2 emissions in 2020[1]. Worse still, air pollution involving sulfur and nitrogen oxides, etc. in China will probably have serious effects on neighboring countries, including Japan. It is thus critical that Japan work together with China in addressing the 3E issue by securing energy supply and tackling energy-related environmental problems.

In the meantime, China's remarkable economic growth, a product of the government's reform and liberalization policy, is resulting in power shortages, depletion of natural resources and serious environmental disruption. Alarmed at the present situation, since these problems represent a potentially serious undermining of national economic and social development, the Chinese government is beginning to reorient itself to a "recycling economy," considering a revision of the current economic development model as part of its strategy for sustainable development. The international community has been insisting on the need to create such an economy in China in view of global environmental conservation, placing high expectations on technical assistance from Japan, which has been striving to develop environmental conservation technologies.

Japan has been offering technical assistance to China through the ODA (Official Development Assistance) in the fields of energy and the environment. Major independent administrative agencies engaged in international technical assistance include the Japan International Cooperation Agency (JICA), the Japan External Trade Organization (JETRO) and the New Energy and Industrial Technology Development Organization (NEDO), all of which are making substantial contributions to China in their respective fields. However, considerable recent problems have surfaced such as inappropriate technology transfer and a shortage of local maintenance engineers.

This article provides an overview of the 3E issue, based on the present situation in China and Japan. It also summarizes trends and prospects for Japan-China technical assistance from the perspective of a cooperative framework, coal exploitation, clean coal technology, environmental conservation technology and the utilization of natural gas, and nuclear and renewable energy, thereby providing some suggestions as to how Japan and China should

Figure 1: Asia's primary energy consumption by region



Source: The Institute of Energy Economics, Japan[1]

cooperate with each other in addressing the 3E issue.

2 Status in Japan and China concerning energy, the environment and economy

2-1 Status in China

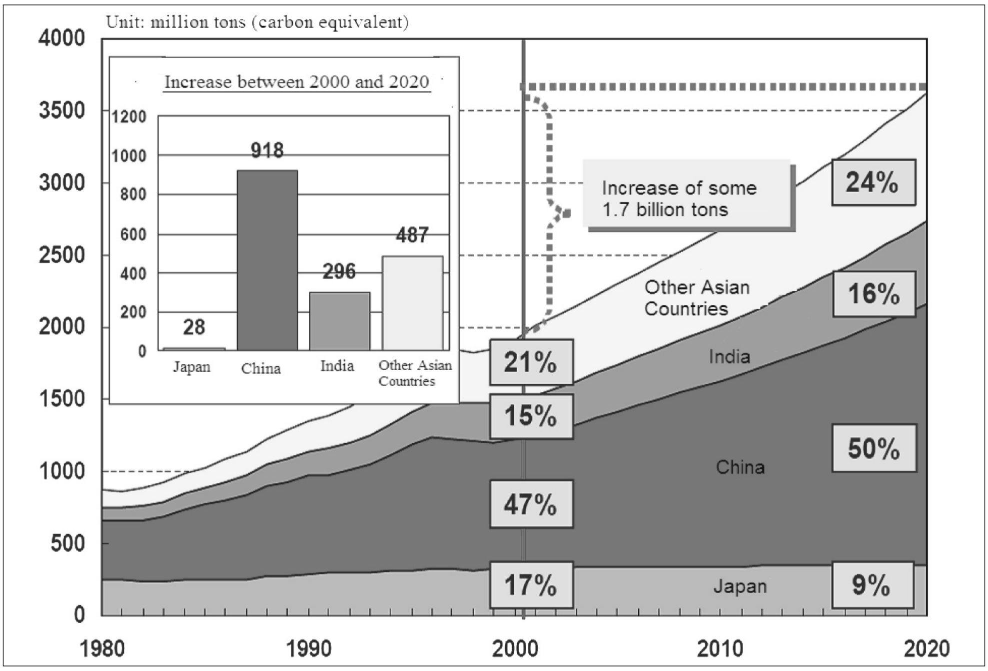
The Chinese economy, which expanded dramatically in the 1990s thanks to robust domestic demand, has experienced 7-9% annual growth since accession to WTO in 2001. Despite uncertainties associated with internal economic disparities, ongoing reforms of state-owned companies, unemployment and non-performing loans, the economy is expected to continue growth at an average annual rate of 7.2% provided the current macro-economic policy remains in place[1].

Energy demand in China, meanwhile, has increased dramatically due to the rapid economic growth and advancing motorization. Indeed, China is now the world's second largest consumer of primary energy and is expected to consume an amount equivalent to 2.06 billion tons[1] of oil in 2020 (or 1.7 billion tons, according to the World Energy Outlook 2002 of IEA). It is estimated that China's consumption of primary energy will account for some 15% of total global consumption, or as much as 45% of Asia's total 2020 consumption (as compared to 38% in 2000), as shown in Figure 1[1].

Coal and oil account for about 70% and 20%, of the primary energy in China respectively - a situation attributable to the country's abundant coal resources, ensuring a stable supply of low-cost coal. Coal continues to be a major energy source in China, though its share of the energy mix is expected to decrease to 56% in 2020 due to increasing dependence on natural gas and nuclear energy. Coal is also an essential energy source for power generation: coal-fired power generation made up 78% of the total in 2000; hydraulic power generation, 16%; oil-fired power generation, 3.4%; and nuclear power generation, 1.2%[1,5]. The share of coal-fired power generation is estimated to be 70% for 2020[1].

On the other hand, some estimates predict global CO_2 emissions to increase from 6.5 billion tons in 2000 to 9.9 billion tons in 2020 (both on a carbon equivalent basis) and emissions from Asian countries are expected to account for about half of the increase. In particular, those from China are estimated at 1.8 billion tons (carbon equivalent) [1] for 2020 (or 1.5 billion tons, according to reference[2]), second only to the U.S.A. As shown in Figure 2, the proportion

Figure 2 : Trends in Asia's CO_2 emissions



Source: The Institute of Energy Economics, Japan[1]

of China's emissions as part of Asia's total will increase from 47% in 2000 to 50% in 2020. Asia's total emissions, meanwhile, are expected to increase by 1.7 billion tons (carbon equivalent) between 2000 and 2020, about 53% of which will come from China. Major emission sources in China are the power generation and industrial sectors, while emissions from the transport sector are increasing due to motorization. Increased CO_2 emissions from China will likely have a substantial impact on global warming.

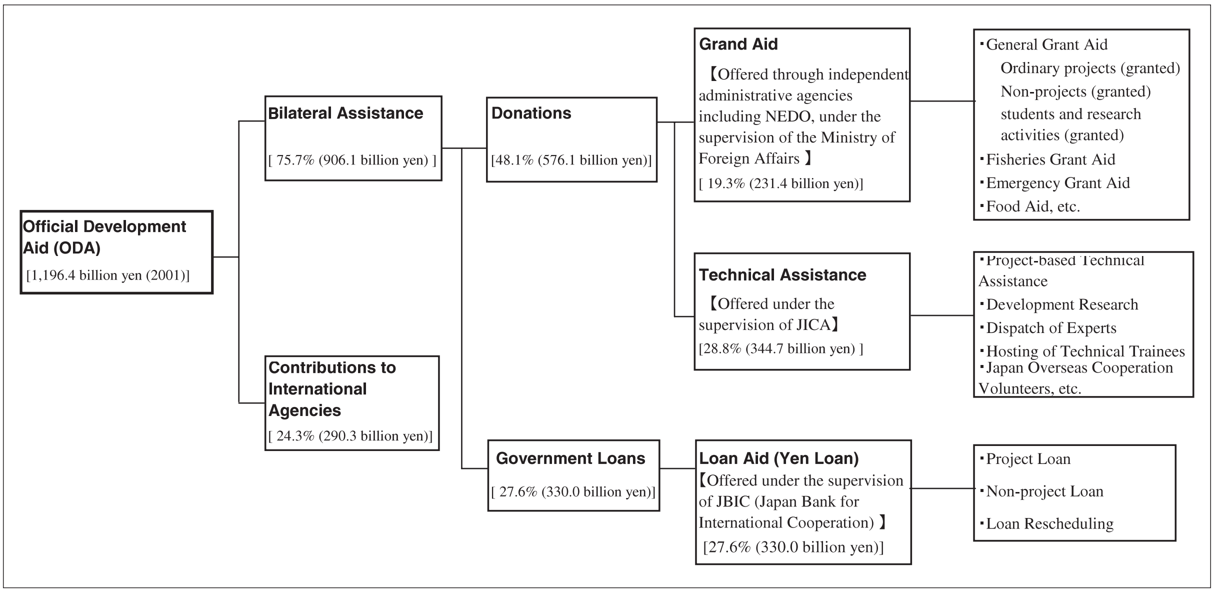
In contrast, emissions of sulfur oxides, which experienced an upward trend in the 1980s and the first half of the 1990s, peaked in 1996-1997 and have since been decreasing due to altered industrial structure, improved energy efficiency and tightened environmental regulations[2]. Nevertheless, seven cities in China were ranked among the world's 10 most seriously polluted cities, according to a survey conducted by WHO in 1998. Air pollution continues to be a major concern in China, while its antipollution measures have yet to prove effective. As mentioned earlier, moreover, the country is experiencing rapid motorization and the serious air pollution resulting from such economic growth may have a substantial impact on neighboring countries, including Japan[17].

2-2 Status in Japan

Because of the policy prioritizing energy security above all, a fuel shift (from oil to nuclear energy, natural gas and coal) and energy-saving measures (adopted primarily by the industrial sector) have made dramatic headway over the past three decades. As a result, the proportion of oil in the total energy mix has decreased from 77% to 49%. With the economy growing modestly (at an average annual rate of 1.3%), and a declining population due to a falling birthrate and an aging population as well as progressive energy-saving measures progressing, Japan's energy consumption is expected to level off or decrease in the future. Accordingly, its predicted share of Asia's primary energy consumption will decrease from 22% in 2000 to 12% in 2020 (see Figure 1).

While the prevention of global warming has become a key issue, Japan seems unable to reduce its greenhouse gas emissions by 6% (from the 1990 levels, taken from a five-year average) between 2008 and 2012 in accordance with the Guideline of Measures to Prevent Global Warming (the Kyoto Protocol). As shown in Figure 2, however, the proportion of Japan's CO_2 emissions as part of Asia's total is expected to decrease from 17% in 2000 to 9% in 2020. By contrast, China's

Figure 3 : Framework of Japan's ODA



Source: Prepared by the author, based on the website of ODA : http://www.mofa.go.jp/mofaj/gaiko/oda/

emissions will increase, as mentioned in Chapter 2-1. In addition to reducing domestic emissions, therefore, Japan should work together with Asian countries (particularly China) to curb the regional greenhouse gas emissions.

Specifically, it is essential that Japan offer its advanced technologies in terms of coal utilization and clean coal technologies, environmental conservation technologies, and technologies for utilizing natural gas and nuclear and renewable energy to these countries.

3 Trends and challenges in Japan-China technical assistance

3-1 Previous trends in Japan-China technical assistance

This chapter addresses trends in Japan-China technical assistance from the viewpoints of economic assistance, research cooperation and private investment.

(1) Economic assistance

Japan has been offering technical assistance to China through ODA (Official Development Assistance) in the fields of energy and the environment[10]. As shown in Figure 3, Japan's ODA is comprised of bilateral assistance (direct assistance to developing countries) and multilateral assistance (assistance through international agencies). The former includes donations (grant aid and technical assistance) and bilateral loan (loan aid or yen loan). Figure 3 shows the total amount of assistance in 2001 and the proportion of each assistance program in the total; grant aid and technical assistance, when combined, account for around half the total amount.

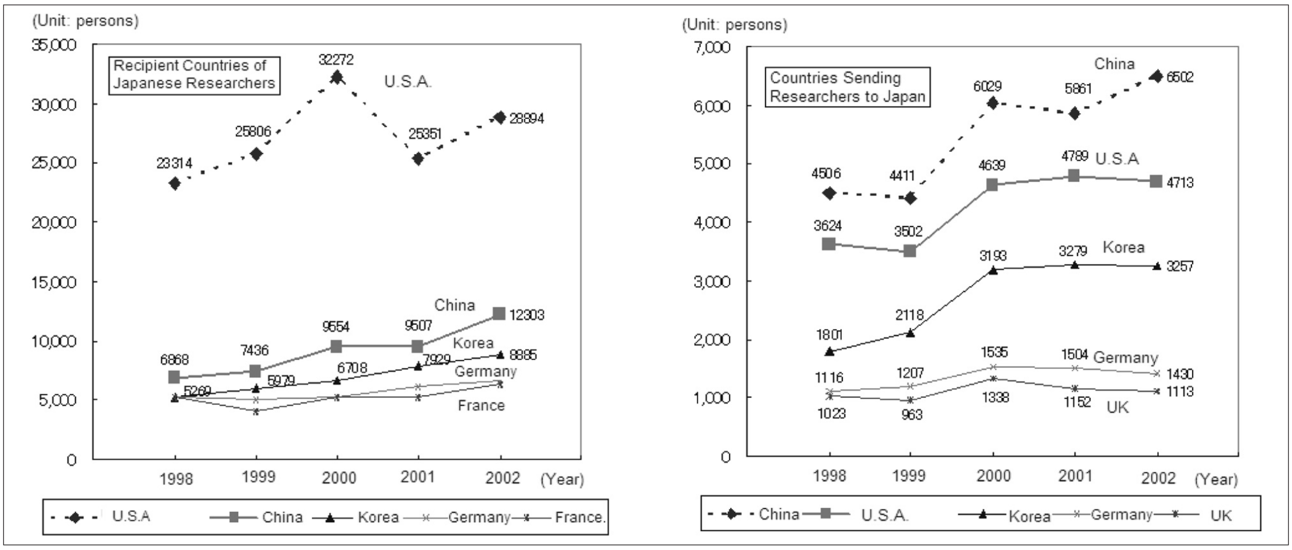
Table 1, meanwhile, shows examples of ODA-based technical assistance to China in the fields of energy and the environment. In the energy field, NEDO plays a leading role in offering technical assistance in the effective use of coal, natural gas and hydraulic power. Specifically, programs for the effective utilization of coal, China's major energy source, have commenced with the introduction of circulating fluidized bed boilers and desulfurizing agent-added CWM (Coal Water Mixture) systems. In the environment field, meanwhile, a variety of environmental conservation measures are in place under the initiative of the Ministry of Environment and JICA to tackle air pollution, acid rain, water treatment, domestic waste disposal, chemical substance management, environmental management policies, etc. Citing the transfer of desulfurization technology as an example, however, the ongoing assistance programs are designed to set up pilot plants rather than commence commercial runs - a situation that makes it difficult to quantify the achievements of Japan's technical assistance[2].

Table 1 : Examples of ODA-based technical assistance to China in the fields of energy and the environment*1

Field		Project Name	Organizations Involved		Loan or Grant	Period
			Japan	China		
Energy	Eco-friendly coal utilization	• Introduction of circulating fluidized bed boilers	NEDO	Fangshan Garments Group Co.,Ltd., etc.	Grant	1993-1998, 2002-2004
		• Demonstration of desulfurizing agent-added CWM (Coal Water Mixture) systems	NEDO	Beijing Yanshan Petrochemical Co.	Grant	1998-2002
	Natural gas utilization	• Construction of natural gas distribution facilities (Henan air environment improvement project)	JBIC*2	Henan Provincial Government (the Finance Agency)	Loan	2002
		• Construction of natural gas distribution facilities (Anhui air environment improvement project)	JBIC	The State Development Planning Committee	Loan	2002
	Hydraulic power utilization	• Hubei small-scale hydropower plant	JBIC	Huber Provincial Government (the Finance Agency)	Loan	2000
		• Gansu small-scale hydropower plant	JBIC	Gansu Provincial Government (the Finance Agency)	Loan	2000
	Power network	• Harbin power network extension	JBIC	The State Power Corporation of China	Loan	1999
	Effective energy use	• Coke dry quench model project (AIJ)*3	NEDO	The State Development Planning Committee	Grant	1996-2000
		• Energy-efficient ferroalloy electric furnace model (AIJ)	NEDO	The State Development Planning Committee	Grant	1997-2000
Environment	Air pollution	• Development of manuals for measures to prevent air pollution from fixed sources	JICA, The Ministry of the Environment	The State Environmental Protection Administration	Grant	1996-1997
		• Measures to alleviate regional air pollution (including acid rain, yellow sand and particle contaminants)	JICA	The State Environmental Protection Administration	Grant	2002-2006
	Acid rain	• Development of model strategies and plans for acid rain monitoring networks	JICA, The Ministry of the Environment	The State Environmental Protection Administration	Grant	1996-1999
		• Development of measures to reduce emissions of pollutants causing acid rain in East Asia and research into assessments of its environmental impact	JICA	The State Environmental Protection Administration	Grant	1998-1999
	Urban	• Measurement and calculation of auto-emission coefficients in relation to Dalian environmental model city surveys	JICA	The State Environmental Protection Administration	Grant	1997
		• Japan-China environmental development model cities plan	The Ministry of Foreign Affairs	The State Environmental Protection Administration	Grant	1998-1999
	Water treatment	• Research cooperation in coal mine wastewater biotreatment	NEDO	The State Development Planning Committee	Grant	1993-1998
		• Suzhou water environment conservation plan	JBIC	Suzhou Provincial Government	Loan	1999
	Domestic waste disposal	• Joint research on domestic waste disposal in Beijing City	JICA	The State Environmental Protection Administration	Grant	1998-2000
	Chemical substance management	• Management of new hazardous chemical substances such as dioxins and EDCs	JICA	The State Environmental Protection Administration	Grant	2002-2006
	Environmental management policies	• Improvement of environmental information networks	The Ministry of Foreign Affairs, JICA	The State Environmental Protection Administration	Grant	1998-1999
		• Improvement of environmental management standards (measures to promote ISO 14000, trial introduction of a pollution control manager system	JICA	The State Environmental Protection Administration	Grant	2002-2006

*1: Prepared by the author, based on the websites of ODA http://www.mofa.go.jp/mofaj/gaiko/oda/, New Energy Development Organization (NEDO) http://www.nedo.go.jp/kankobutsu/nenshi/3color/1999_2000/kokusai/01tojyou.html and the Sino-Japan Friendship Center for Environmental Protection Project (Japan International Cooperation Agency) http://www.zhb.gov.cn/japan/fulezu2syoukai.html
*2: Japan Bank for International Cooperation
*3: A joint implementation project in accordance with UNFCCC (U.N. Framework Convention on Climate Change)

Figure 4 : Top five countries in international research cooperation (universities, research institutes, etc.)



Universities include national universities, inter-university research institutes, national junior colleges, national technical colleges, public universities and private universities. Research institutes refer to national research institutes, independent administrative agencies and government-affiliated research institutes. Public and private universities, and national junior colleges were included in the survey as from 1997; national technical colleges, national research institutes and government-affiliated research institutes, as from 2000.

Source: Prepared by the autohr, based on Reference[19]

(2) Research cooperation

A survey was conducted on the number of exchange programs agreed between Japanese and overseas universities (as of October 1, 2002, covering technical fields including energy and the environment) to keep track of research cooperation between universities and research institutes in Japan and China[19]. Japanese universities primarily cooperate in research activities with counterparts in Asia, Europe and North America. In particular, Chinese universities account for some 44% of the Asian universities currently in partnership with Japanese counterparts.

Since the conclusion of the “Science and Technology Cooperation Agreement” in May 1980, the Japanese and Chinese governments have held regular meetings of the Joint Science and Technology Cooperation Joint Committee. The latest gathering took place in February 2003 to exchange views in four priority fields including energy and the environment; producing an agreement concerning cooperation in research on “science and technology to conserve the environment and create an eco-friendly society.”

Another survey was conducted on the number of Japanese researchers sent overseas and foreign researchers accepted (by country), with the aim of clarifying the extent of international research cooperation among Japanese universities and research institutes. Figure 4 shows recent trends in the top five countries. Japan has accepted the largest number of researchers from China, which itself is second in terms of the destination of Japanese researchers sent overseas (about 40% of those are sent to the U.S).

(3) Private investment in China

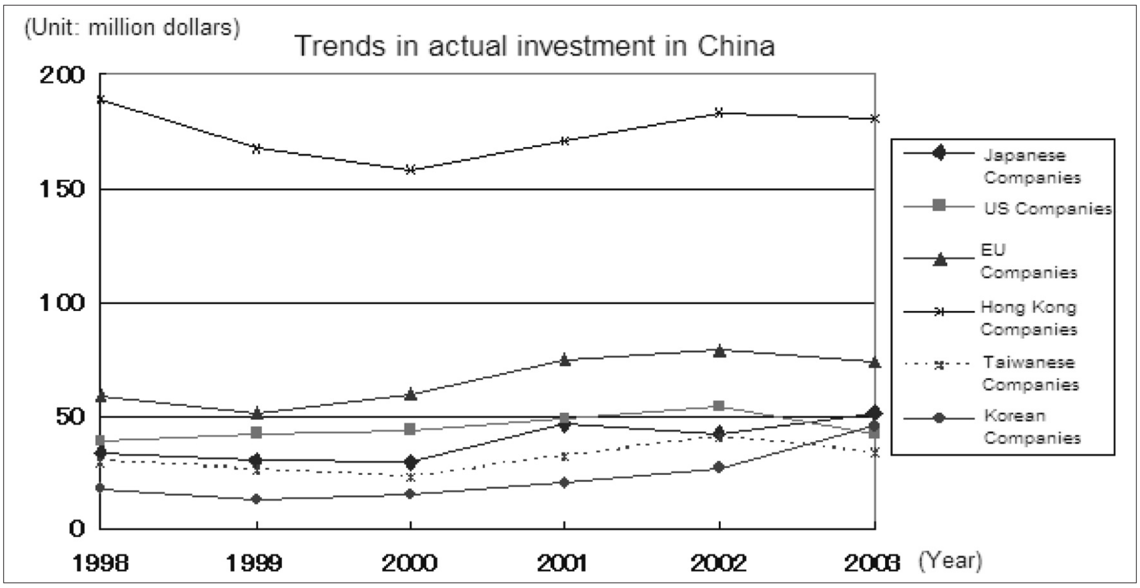
A survey was conducted to monitor Japanese companies’ investment in China (in comparison with EU, US and Asian companies). Figure 5 shows trends in actual investment in China in all technical fields including energy and the environment. Japanese companies have been less aggressive than those in Hong Kong and EU countries. Jin Jianmin, a chief researcher at Fujitsu Research Institute who summarized an interview survey conducted in China, suggests that this is attributable to resources in information gathering, sales and distribution -which tend to be lacking in Japanese companies as compared to their EU rivals[11].

3-2 Challenges and measures for cooperation between Japan and China

A closer look at trends in Japan-China technical assistance from the viewpoints of economic assistance, research cooperation and private investment reveals progress in a variety of fields including energy and the environment. As shown in Table 2, however, there have been challenges posed to both the public and private sectors to further advances in cooperation[2,3]. One is the transfer of appropriate technology and the other is the training of maintenance engineers. The former involves discrepancies between Japan's cooperation programs and the present situation in China. Specifically, (i) China's infrastructure has yet to be fully developed due to financial and institutional constraints and (ii) the dwindling resources of Japanese companies in terms of information gathering, sales and distribution are resulting in inappropriate technology transfer. The latter concerns Chinese engineers and researchers working on site, to whom techniques and expertise have yet to be passed on. Specific problems include (i) insufficient training programs due to a shortage of experts sent from Japanese companies and universities and (ii) a lack of training facilities.

An energy and environmental technology center should thus be established and promoted, based on a Sino-Japanese governmental agreement. Accordingly, it is recommended that training institutes be set up all over the country, each of which will serve as a base to demonstrate the specialties and products of Japanese companies and universities, offering training programs in energy (including energy-saving measures) and environmental management respectively. Middle-ranking on-site engineers are expected to develop expertise (which will then be passed on to workers) through such institutes. On the other hand, it may also be advisable for Japanese companies to conduct field trips to gather first-hand information to ascertain what is really needed. The center will also function

Figure 5 : Private investment in China



Source: Prepared by the author, based on statistical data of Japan-China Investment Promotion Organization (http://www.jcipo.org/)

Table 2 : Challenges and measures for cooperation between Japan and China

Subject	Challenges	Measures
Transfer of appropriate technology	• Japan's cooperation programs (technology transfer) do not correspond to the present situation in China. ◦ Inefficient infrastructure due to financial and institutional constraints ◦ The dwindling resources of Japanese companies in terms of information gathering, sales and distribution	• Establishment of an energy and environmental technology center to: ◦ Demonstrate the specialties and products of Japanese companies and universities ◦ Offer training programs in energy management and environmental management ◦ Conduct field trips to gather first-hand information on site (ambient surroundings, basic requirements, etc.) ◦ Work with the Chinese government to protect the intellectual property rights of commercialization technology to be transferred and to improve the investment climate for the transfer
Training of engineers	• Techniques and expertise have yet to be passed on to Chinese engineers and researchers working on site. ◦ Both the number of Japanese experts and the frequency of their dispatch have been insufficient. ◦ There are not many training facilities in the country.	

as a hub to protect the intellectual property rights of Japan's commercialized technologies and to improve the investment climate for future technology transfer.

While both the Japanese and Chinese governments should address global environmental problems and energy security from a broad perspective, it is critical that Japan's proprietary expertise in coal utilization, clean coal technology, environmental conservation technology and the utilization of natural gas and nuclear and renewable energy be promoted through the center.

4 Japan's advanced clean energy and environmental technologies to be offered

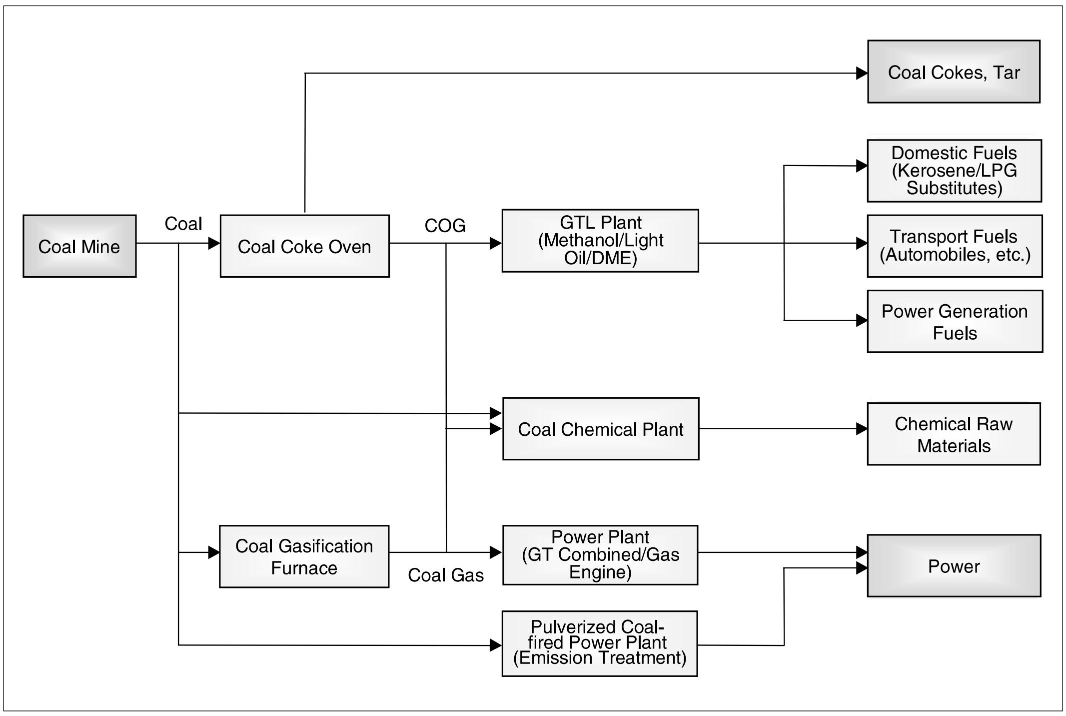
The following are Japan's advanced clean energy and environmental technologies that can be offered to China to solve the country's energy and environmental problems.

4-1 Coal utilization and clean coal technologies

Clean coal technologies are essential to China, which continues to depend on coal for its power supply[7]. These particular technologies include (i) thermal-efficiency improving technology (ii) desulfurization and denitration technologies (iii) coal treatment technology (coal liquefaction, gasification and slurrying) and (iv) coal ash utilization technology. As for technologies relating to (i) and (ii), "supercritical pressure pulverized coal-fired power generation" has already been in practical use in Japan, while "ultra supercritical pressure pulverized coal-fired power generation" and "pressurized fluidized bed combustion combined-cycle systems" are nearing commercialization. In addition, "integrated coal gasification combined-cycle systems" are scheduled for commercialization around 2010, and "coal gasification fuel cell systems," by 2020[2].

High value-added items (methanol, ammonia, activated carbon, etc.), liquid auto fuels, domestic fuels (light oil, kerosene, LPG substitutes such as dimethyl ether, etc.) can be produced through coal treatment technology. Coupled with thermal-efficiency improving technology, moreover, it can create an energy/chemical chain that is based on coal utilization (see Figure 6). With coal gasification plants producing 0.8-1.2 million t/y of liquid methanol operating in Japan,

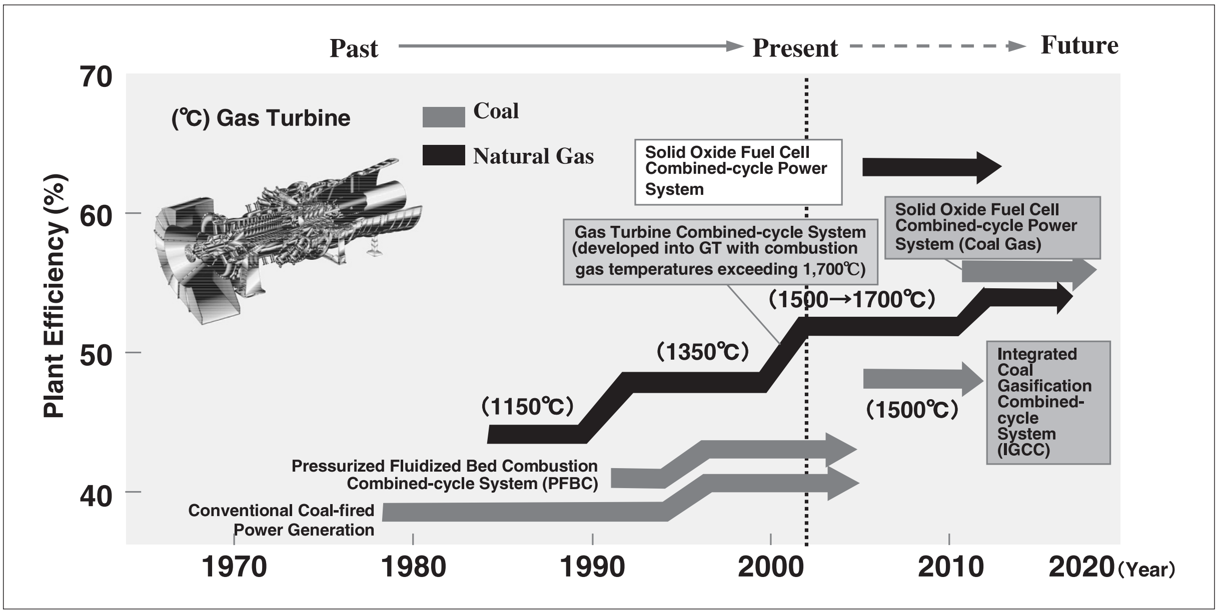
Figure 6 : Coal-based energy/chemical chain



COG: Coke-oven Gas, GTL: Gas to Liquid, GT: Gas Turbine, DME: Dimethyl Ether

Source: Prepared by the author, based on Reference[8]

Figure 7 : Efficiency of natural gas-fired and coal-fired power generation systems



Source: Reference[15]

its expertise in constructing 0.4-0.6 million-t/y methanol plants can be offered to China.

Specific plans are underway in China to develop high value-added industries based on new applications of coal other than those for fuel. Clean coal technology is expected to gain in importance in China.

4-2 Natural gas utilization technologies

Though demand for natural gas constituted a mere 2.7% of overall primary energy consumption in China as of 2002, the government's energy security policy emphasizes the promotion of natural gas as a substitute for oil[4]. It is yet to be seen whether the use of this energy source will expand as dramatically as expected, but natural gas-fired power generation is expected to grow in the country, with power rates in coastal areas stabilizing and environmental regulations tightening[5].

As domestic technologies for natural gas power generation are not available, there is every chance that China will be dependent on overseas technologies. Thus lies the opportunity for Japan to contribute substantially to the construction of natural gas-fired power plants in China, offering its gas turbine technology including gas turbine combined-cycle systems with dramatically improved power generation efficiency, with the temperatures of combustion gas at the inlet of a gas turbine increasing. The third-generation gas turbine combined-cycle systems, for instance, maintain an efficiency level exceeding 50%, with the temperatures of their combustion gas ranging from 1,450 to 1,500 degrees Celsius. At the same time, research is underway to develop a gas turbine with combustion gas temperatures exceeding 1,700 degrees Celsius. Figure 7 shows the power generation efficiency of natural gas-fired power generation, compared with that of coal-fired power generation.

Other categories relevant to natural gas utilization include air conditioning, transportation and distributed power sources such as fuel cells. Japan has the potential to contribute in these categories as well.

4-3 Nuclear energy utilization technology

The National Development and Reform Commission (founded in March 2003) specifies nuclear power generation as one of the principles in developing China's power industry, aiming to set up about 31 nuclear power plants by 2020 to generate 4% (or 36 million kW) of the country's total power supply[6,12]. With domestic technologies for nuclear reactors unavailable, China continues to depend on overseas technologies, as in the case of the aforementioned natural gas utilization technologies. Japan, meanwhile, began to operate light-water reactors (LWR) in 1970, the total output of which account for some 15% of the country's primary energy production, or as much as one third of its total power supply. Japan is thus capable of contributing to China's nuclear power generation through its LWR technology.

The Chinese government decided to sign the London Guidelines[*1](an international framework for the nonproliferation of nuclear technology, controlling imports and exports of nuclear power facilities) in 2004, which will enable Japan to export its nuclear power technology and products to China. With the EU and U.S.A. also poised to offer their expertise, however, full support of the Japanese government is critical to beat the competition.

4-4 Renewable energy utilization technologies

Despite its low energy density, the significance of introducing extremely eco-friendly renewable energy is widely acknowledged. In fact, China began to address renewable power generation technologies in 2000, focusing on solar energy, wind power and biomass[9]. Japan is still taking the lead in this particular area with its commercialized technologies[14], and hence great potential remains to contribute to China's environmental conservation efforts.

With small- to medium-scale systems constituting a major part of renewable energy power generation, they can be installed individually or collectively at a variety of locations, from dwellings to medium-scale power plants - a feature that diversifies the cooperation frameworks and broadens the scope of potential recipients. Japanese companies and trading houses engaged in energy and environmental businesses are thus shifting their focus from the sluggish domestic market to the promising Chinese market. There is every chance that small-scale renewable energy projects involving minimal business risks and considerable flexibility will serve as their means to gain a foothold in China[2].

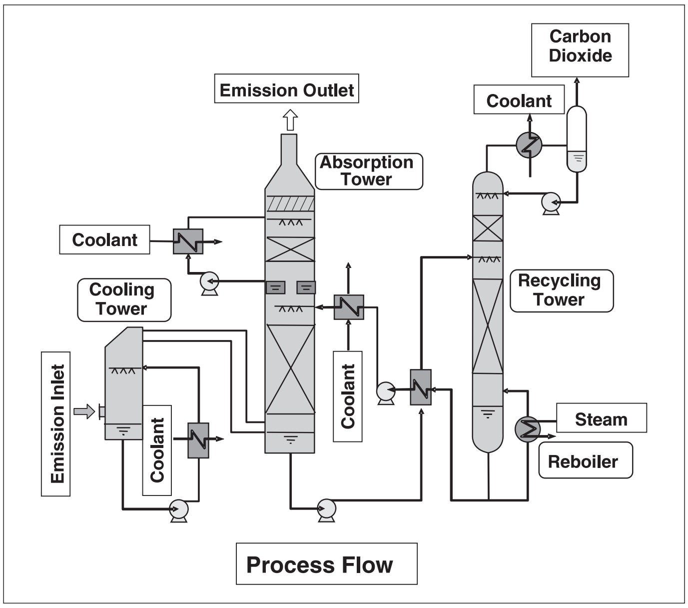
4-5 Environmental conservation technologies

This chapter addresses desulfurization/denitration technologies to reduce the levels of sulfur and nitrogen oxides (major air pollutants in China), and CO_2 separation technologies applicable to thermal power plants. Japan began to develop environmental conservation technologies more than 20 years ago, ahead of Western industrialized countries, and is continuing to take the lead in this area.

Desulfurization technologies[13] can be broadly categorized into (i) pre desulfurization technology, (ii) furnace desulfurization technology, and (iii) flue-gas desulfurization technology, which includes wet and dry methods. The wet method using limestone slurry, a commonly used process in Japan, is the most efficient desulfurization technique. Likewise, denitration technologies can be broadly categorized into (i) low-NOx combustion technology, (ii) furnace denitration technology, and (iii) flue-gas denitration technology. As in the case of flue gas desulfurization technology, flue-gas denitration technology comprises wet and dry methods, while the selective catalyst method combining low-NOx combustion technology and catalysts is currently the mainstay of the denitration process. When transferring Japan's desulfurization and denitration technologies to China, techniques best suited to the present situation in China should be selected.

Japan is also heading the field in CO_2 separation technologies using alkanolamine, a liquid that readily absorbs CO_2[16]. Figure 8 shows the flow of CO_2 separation technologies applicable to thermal power plants: flue gas (from a thermal power plant or boilers) is cooled down to 45 degrees Celsius through a cooling tower; amines in an absorption tower absorb CO_2; and a recycling tower heats the amines containing CO_2 up to 130 degrees Celsius to recover the gas. An enhanced oil recovery process using CO_2 injection appears to be a promising application of recovered CO_2. CO_2 separation technology is of interest to both Japan and China since it contributes to reducing CO_2 emissions in China.

Figure 8 : CO_2 separation technology for thermal power plants



Source: Reference[15]

5 Recommendations on policies

As mentioned at the outset, achieving 3E - Energy security, Environmental preservation and sustainable Economic growth - is the biggest challenge to be faced by the international community in the 21st century. It is critical that this issue be addressed in the Asian region, where energy demand and the resulting environmental load are expected to increase. In particular, comprehensive and cooperative approaches should be adopted for China. This chapter provides an overview of the 3E issue, based on the present situation in China and Japan, summarizing trends and prospects for Japan-China technical assistance from the viewpoint of a cooperative framework, coal utilization and clean coal technologies, environmental conservation technologies and the utilization of natural gas and nuclear and renewable energy.

- It is estimated that global CO_2 emissions will increase from 6.5 billion tons in 2000 to 9.9 billion tons in 2020, with as much as half of this 50% increase coming from Asian countries. A mere 2% of the increase is attributable to Japan, with modest predicted economic growth but as much as 53% to China, with a rocketing economy.
- In addition to reducing domestic emissions, Japan should collaborate with Asian countries (particularly China) to curb regional greenhouse gas emissions. It is also essential that Japan make the most of its commercialized technologies in the fields of coal utilization (including clean coal utilization), natural gas, nuclear power, renewable energy and environmental conservation to assist China and other Asian countries.
- Japan has been offering technical assistance to China through ODA (Official Development Assistance) in the fields of energy and the environment, emphasizing coal utilization technologies and measures to guard against air pollution. However, there have been considerable recent problems: (i) discrepancies between Japan's cooperation programs and the present situation in China, and (ii) techniques and expertise that have yet to be passed on to Chinese engineers and researchers working on site.

In view of the abovementioned trends and challenges present in Japan-China technical assistance, the following four approaches are recommended to solve the 3E issue of Japan and China: (i)Transfer of Japan's commercialized technologies; (ii) Creation of a bilateral framework for reducing greenhouse gas emissions; (iii) Development of strategic joint research and development projects; (iv) Development of human resources on a medium- to long-term basis

These approaches are designed to transform the conventional "cooperation," from unilateral "assistance" into bilateral "collaboration," which benefits both Japan and China.

(i) Transfer of Japan's commercialized technologies

To solve China's 3E issue, it is recommended that Japan's commercialized technologies in the fields of energy and the environment - coal utilization and clean coal technologies (high-efficiency coal-based power generation, coal gasification, coal liquefaction, etc.), environmental conservation technologies and technologies for utilizing natural gas, nuclear energy and renewable energy - be transferred to China. While investment funds are financed primarily by the private sector, public funds (Development Bank of Japan, Japan Bank for International Cooperation, etc.) should be used for projects involving high risks. To facilitate technology transfer and training of maintenance engineers, moreover, Japanese experts should be dispatched on a long-term basis, based on a bilateral agreement, to establish and promote an energy and environmental technology center through which technical training would be offered and first-hand information exchanged. This center would be a base in China allowing a sufficient number of nationwide training institutes to be subsequently set up. It would also function as a hub to protect the intellectual property rights of Japan's commercialized technologies when transferred, and to improve the investment climate for future technology transfer.

(ii) Creation of a bilateral framework for reducing greenhouse gas emissions

A system based on Clean Development Mechanism (CDM)[*2] should be created and managed between Japan and China, where Japan earns CO_2 emission credits from emissions reduced in China through the aforementioned technology transfer. Such a system requires a framework in which CO_2 emissions reduced by technological transfer are quantified and certified. The Japanese and Chinese governments should establish this framework based on mutual political cooperation and agreement.

(iii) Development of strategic joint research and development projects

Strategic joint research and development projects in the fields of energy and the environment should be promoted between Japan and China, based on cooperation between industry, academia and government. Specific projects may include research into air pollutants such as SOx and NOx in East Asia (a survey of emission sources and their distribution through aerial observations)[18], and development of advanced technologies with clear objectives (high-efficiency coal gasification combined power generation, clean coal technology including coal ash utilization, etc.). Achievements of the projects shall be protected as intellectual property rights, based on a mutual bi-lateral agreement.

(iv) Development of human resources on a medium- to long-term basis

A program to exchange students in the fields of science and technology should be promoted between universities and graduate schools in Japan and China to develop human resources sufficiently aware of the 3E issue. Specifically, it is recommended that the Japanese and Chinese governments create independent scholarships for students of their partner countries.

Through the recommendations mentioned above, China's coal resources will be exploited domestically to their fullest potential by taking advantage of Japan's commercialized technologies and technologies to be developed jointly by Japan and China. The 3E will also be achievable in Japan and China alike through the implementation of antipollution measures and the reducing of CO_2 emissions in China. Benefits for China include (i) diversification of power supply, (ii) development of inland areas including coal-producing regions and (iii) exploitation and proliferation of advanced technology. Those for Japan, meanwhile, will be (i) effective reductions in CO_2 emissions and (ii) maintenance or improvement of industrial competitiveness. Moreover, the two countries will benefit from (i) environmental conservation and (ii) sustainable economic growth.

Acknowledgements

I would like to thank everyone who provided invaluable support in creating this article, particularly Professor Ryoichi Yamamoto (Institute of Industrial Science, University of Tokyo), Associate Professor Atsushi Sunami (National Graduate Institute for Policy Studies), and Dr. Ohki, Mr. Furuya and Mr. Fujimura (Technology Planning Department, Technical Headquarters, Mitsubishi Heavy Industries, Ltd.)

Glossary

*1 The London Guidelines

With nuclear weapons testing in India as a turning point, seven countries including Japan, the U.S. and the former Soviet Union met together in London in 1975 to discuss measures to prevent nuclear materials from being diverted into weapons. This international meeting later expanded to include a total of 15 countries, mapping out guidelines for the export of nuclear-related items to non-nuclear weapon countries - i.e., the London Guidelines, which were officially announced by IAEA in 1978 (with 27 countries currently taking part). The guidelines are designed to: (i) secure a commitment from countries importing nuclear materials not to divert them into weapons, (ii) apply IAEA safeguards against any misapplication of nuclear materials, (iii) implement appropriate measures to protect nuclear materials, (iv) regulate the transfer of enrichment and reprocessing technologies, and (v) regulate the retransfer of nuclear materials. The disclosure of Iraq's clandestine nuclear program resulted in the tightening of export regulations. The revised version of these guidelines was agreed on and enforced in Warsaw in 1992

*2 Clean Development Mechanism (CDM)

A system through which the parties to the Kyoto Protocol implement greenhouse gas reduction projects in host countries (not participating in the protocol) to earn emission credits. This system is considered to be of interest to host counties since investment by the parties to the Kyoto Protocol is expected to promote environmental conservation measures and technology transfer.

References

[1] The Institute of Energy Economics, Japan. "Asia and World Energy Outlook: Rapidly Growing Asian Economy and Changing Energy Supply-Demand Structure." March 2004 (in Japanese)

[2] The Northeast Asia Eco-friendly Energy Use Workshop, National Institute for Research Advancement (NIRA). "Environmental Strategies in Northeast Asia." Nihon Keizai Hyoron-sha, 2004 (in Japanese)

[3] Ogawa, Y. The Institute of Energy Economics, Japan. "Energy and Environmental Problems in East Asia." (in Japanese) : http://www.esri.go.jp/jp/tie/ea/ea4.pdf.

[4] Keii Cho, "Demand and Supply Trends in China's Natural Gas Market." J. Jpn. Inst. Energy. Vol. 83:109-117, 2004

[5] Zhang JiWei "Trends in China's Power Industry." Energy Economy. Vol. 30-2 (Spring in 2004) (in Japanese)

[6] Morooka, H. and Funakoshi, F. "Trends in China's Electricity and Nuclear Power Generation". Overseas Office Report 1:4-20, 2004 (in Japanese)

[7] Qu XiaoGuang "Survey of Policies for Energy and Supply-demand Stabilization in China after the Era of the National People's Congress." NEDO Overseas Report. No.928, 2004 (in Japanese)

[8] Tsuge, A. "Towards the Creation of the 21st Century Energy-environment Society." Preliminary Report for the 42nd National Symposium on Atomic Energy: 59-68, 2004 (in Japanese)

[9] Yusheng Xie, Shufent Ye, Kuniyuki Kitagawa, and Kali Wang, 2004. "The Developing Strategy and Research for Chinese Energy Resources." J.Jpn. Inst.Energy, Vol. 83: 207-211 (2004)

[10] The website of the Ministry of Foreign Affairs :

http://www.mofa.go.jp/mofaj/gaiko/oda/
[11] Jin Jianmin "Comparison of Strategies and Management of Japanese, US and European Companies Towards Investment in China." 2001 (in Japanese) : http://www.rieti.go.jp/jp/events/bbl/010620_03.pdf.
[12] The Chugoku Shimbun (May 25, 2004) : http://news.searchina.ne.jp/2004/0526/business_0526_001.shtml
[13] Global Environmental Engineering Handbook. Ohmsha, 1991 (in Japanese)
[14] Ju QiaoXu "New Energy: Creation and Promotion." The Nikkan Kogyo Shimbun, 2004 (in Japanese)
[15] Mitsubishi Heavy Industries Technical Review. Vol. 38-1 (2001), Vol. 40-1 (2003) and Vol. 40-4 (2003)
[16] "Honmei Gijutsu: The Most Likely Technology: Separation and Fixation of Carbon Dioxide." Nikkei Ecology, p.138-141. July 2004, Nikkei Business Publications (in Japanese)
[17] Ichikawa, Y., Hayami, H., Markus Amann, and Sugiyama, T. "Forecast for the Amount of Acid Deposits in Japan." Report of Central Research Institute of Electric Power Industry, Report No. T00022, 2001 (in Japanese)
[18] NIES Research Booklet. No.12. April 2004. The National Institute for Environmental Studies.
[19] Council for Science and Technology. The Ministry of Education, Culture, Sports, Science and Technology. Agenda for the 2nd Phase Committee on International Affairs (the 3rd Meeting in 2004). (in Japanese)

(Original Japanese version: published in July 2004)

6

3-D Full-Scale Earthquake Testing Facility (E-Defense)

KATSUTOSHI SUGANUMA
General Unit

1 Introduction

In the Kobe Earthquake, which occurred in January 1995, a great number of structures were destroyed including reinforced concrete buildings and expressway bridges that had been thought immune from destruction in an earthquake thus far imagined.

In November 1995, the then Science and Technology Agency established the Round-table Conference for the Study of Bases of Research into Earthquake Disaster Prevention. The conference recommended, in May 1996, that a new research base be created to carry out "comprehensive research aiming at the reduction of earthquake-caused disasters mainly in urban areas" and that a large-scale three-dimensional earthquake testing facility be installed at the new research base.

This article outlines the world's largest 3-D Full-Scale Earthquake Testing Facility (E-Defense), which the National Research Institute for Earth Science and Disaster Prevention, an independent administrative institution, started building in the Miki Earthquake Memorial Park (name provisionally given to the park) in Miki City, Hyogo Prefecture in March 2000 and is to be completed in 2005, 10 years after the occurrence of the Kobe Earthquake. The article outlines also the planned experiments as well as the future prospect of the facility.

The nickname of the facility, E-Defense, which has the letter 'E' to represent the word 'Earth', is a selection from the nicknames collected through a public contest to suggest the best nickname.

2 Kobe Earthquake

The Kobe Earthquake caused more than 6,400 deaths and an economic loss amounting to 12 trillion yen.

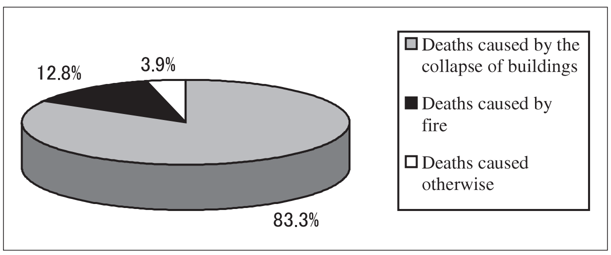
Should the predicted Tokai earthquake occur, damage of 37 trillion yen is estimated.

Most of the deaths in earthquakes since the Great Earthquake of 1923 were considered due to earthquake-related fires. However, more than 80% of the deaths in the Kobe Earthquake were suffocation and crushing due to the collapse of buildings.

This has made it necessary to clarify the process of collapse of buildings (why, how, and to what extent buildings collapse) and to develop and verify new technologies, such as reinforcement methods to prevent buildings from collapse and disintegration, to provide public safety and a sense of security.

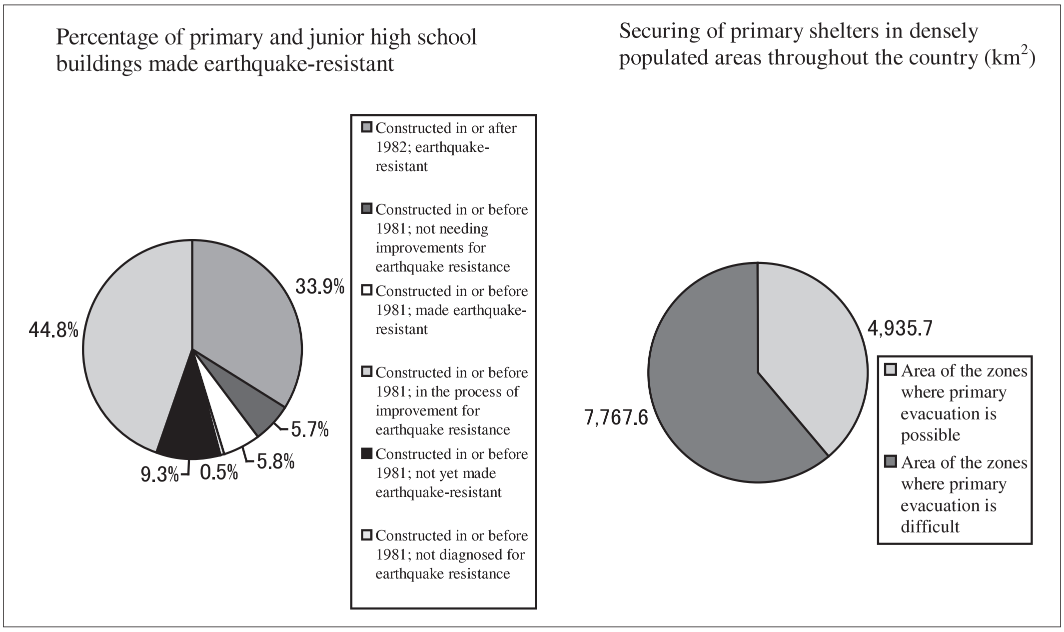
The current Enforcement Ordinance of the Building Standards Act is based on the revision to introduce a new earthquake-resistant design, which was made in 1981 in the wake of the Miyagi-Oki

Figure 1 : A breakdown of the deaths caused by the Kobe Earthquake



Source: A document prepared by the Cabinet Office on the basis of the Statistics of the Results of Autopsies in Kobe City (by the coroners of Hyogo Prefecture - 1995)

Figure 2 : Nationwide investigation of the status of earthquake disaster prevention facilities



Earthquake, which occurred in 1978. The Enforcement Ordinance has undergone revisions concerning the design seismic coefficient, the earthquake-proof criteria and other items repeatedly after large-scale earthquakes.

More than 3,800 school buildings were damaged in the Kobe Earthquake, with those school buildings constructed before the introduction of the new earthquake-resistant design (1981) being most severely damaged. This indicated the necessity of pressing ahead with a plan to make school buildings constructed before the introduction of the new design method earthquake-resistant.

To grasp and analyze the actual situation of the country's measures taken against earthquakes, the Cabinet Office made the first general investigation of the status, as of the end of Fiscal 2001, of earthquake disaster prevention facilities throughout the country, with the final report of the investigation summarized in January 2003.

It turned out that only 46 percent of 151,624 primary and junior high school buildings had been made earthquake-resistant. This points out the urgency of measures such as the making of human-life-related buildings earthquake-resistant and the securing and provision of shelters and evacuation routes.

3 Special project for earthquake disaster mitigation in urban areas

In Fiscal 2002, the Ministry of Education, Culture, Sports, Science and Technology started a program in which subjects of research and development are preliminarily selected in five fields consisting of the four strategic fields of "Life Sciences," "Information and Communication Technologies," "Environmental Sciences," and "Nanotechnology and Materials" plus "disaster prevention" to be consigned as projects to selected execution organizations. These consigned projects are handled under the collective designation of "Research Revolution 2002 (RR2002)."

Among them, the RR2002 consigned project in the "disaster prevention" field is a Special Project for Earthquake Disaster Mitigation in Urban Areas (to be executed 2002 through 2007 with a total budget of 15 billion yen).

The Special Project for Earthquake Disaster Mitigation in Urban Areas consists of the four programs that follow:

(i) Prediction of earthquake motion (strong motion): Regional Characterization of the Crust in Metropolitan Areas for Prediction of Strong Ground Motion;

(ii)Dramatic improvement of earthquake resistance: Research Aimed at the Improvement of Earthquake Resistance Using a Shaking Table;
(iii)Optimization of disaster-handling strategies such as rescue of disaster victims: Research into Disaster-addressing Strategies; and
(iv)Incorporation into earthquake disaster prevention measures.

Program (ii) will be carried out by using the 3-D Full-Scale Earthquake Testing Facility with the aim of contributing to the improvement of earthquake resistance and to the verification of simulation technology.

4 3-D Full-Scale Earthquake Testing Facility (E-Defense)

4-1 Purpose

The Kobe Earthquake of 1995 made us realize the impossibility of designing structures immune from damage. To avoid catastrophic damage caused by an earthquake and protect human lives even if a certain degree of damage is unavoidable, it is necessary to clarify the process of collapse of buildings (why, how, and to what extent buildings collapse).

This is the very purpose of the E-Defense: to shake a full-scale structure on a shaking table three-dimensionally as in an actual earthquake and to record and analyze the process of collapse of the structure with the aim of improving the earthquake resistance of structures.

4-2 Outline of the facility

E-Defense is the world's largest shaking table facility, built on a six-hectare site at the total construction cost of about 45 billion yen. It is configured as shown below.

4-3 Features of the facility

E-Defense, the world's largest shaking table facility, has the following features:

(i)The size of the shaking table is 20 meters by 15 meters, allowing a structure weighing up to 1200 tons to be tested.

Most of the existing three-dimensional shaking test units, which are said to total nearly 30 in the world, are small-to-medium ones allowing a test structure weighing not more than 50 tons to be tested.

The shaking table of the E-Defense facility is capable of being loaded with a four-storied reinforced-concrete condominium building or an expressway bridge pier, allowing a structure to be put to a breaking experiment or an earthquake-resistant reinforcement technique to be put to experimental verification.

(ii) Capability of reproducing three-dimensional motion identical to actual earthquake motion

The X- and the Y-axis on the horizontal are each equipped with five actuators, with the Z-axis on the vertical equipped with 14 actuators, and flexible three-dimensional joints are provided to avoid interference between the axes. These arrangements have lead to the realization of the world's largest full-scale three-dimensional failure-of-earthquake-ground-motion experiment facility with the world's highest performance.

(iii) Capability of performing experiments on the basis of the records of nearly all earthquakes observed the world over

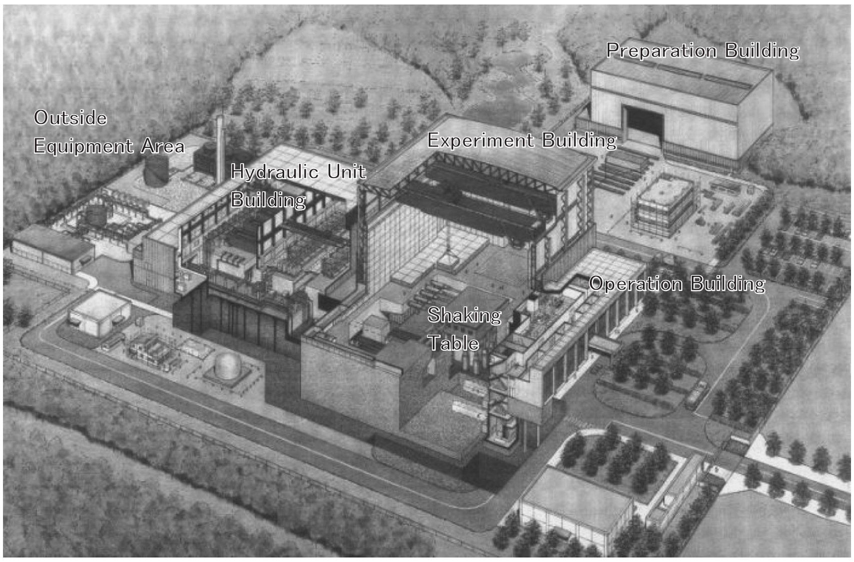
The facility is capable of reproducing the earthquake motion that occurred in the Kobe Earthquake, or in the Northridge Earthquake that occurred near Los Angeles immediately before, allowing the process of collapse accompanied with these earthquakes to be tracked down.

The Kobe Earthquake of 1995 recorded a maximum speed of 138 cm/sec and a maximum displacement of 42 cm, both on the horizontal.

The occurrence of damage to and destruction of a structure is greatly affected by the maximum acceleration; however, the maximum speed and the maximum displacement play important roles in the progress of damage toward the final collapse.

To clarify these effects, four gas-engine-driven oil hydraulic pumps and 20 accumulators (pressure accumulating devices) are installed in the hydraulic power source building, which have been used in the research and development

Figure 3 : Facility layout of the E-Defense



Building name	Description	Type of structure	Total floor area Building height
Experiment Building	Equipped with two 400-ton cranes for assembling and disassembling the main parts of the 3D Full-Scale Earthquake Testing Facility (E-Defense) and test structures	Steel structure, one-storied building	About 5,200 m^2 43 m
Operation Building	Equipped with experiment instrumentation devices and the control system unit for the centrally-operable three-dimensional shaking table	RC structure, two-storied building	About 1,300 m^2 11 m
Hydraulic Unit Building	Equipped with the hydraulic pumps, accumulators and gas-engines that provide the power source for the three-dimensional shaking table	Steel structure, two-storied building	About 4,700 m^2 21 m
Preparation Building	Facility for preparing a test structure; equipped with a 150-ton crane for assembling a test structure	Steel structure, one-storied building	About 2,200 m^2 29 m

Table 1 : Specifications of the major shaking tables in Japan

Organization (location)	Maximum Payload (tonf)	Size (m × m)	Shaking Direction	Maximum Acceleration(G)	Maximum Velocity (cm/s)	Maximum Displacement (cm)	Year of Completion
3D Full-Scale Earthquake Testing Facility (E-Defense) (Miki City, Hyogo Prefecture)	1200	20 × 15	Three-dimensional (X,Y,Z)	Horizontal: 0.9 Vertical: 1.5	Horizontal: 200 Vertical: 70	Horizontal: 100 Vertical: 50	To be completed in 2005
Tadotsu Engineering Laboratory, Nuclear Power Engineering Corporation (Tadotsu Town, Kagawa Prefecture)	1000	15 × 15	Two-dimensional (X,Y)	Horizontal: 1.84 Vertical: 0.92	Horizontal:75.0 Vertical: 37.5	Horizontal: 20 Vertical: 10	1982
National Research Institute for Earth Science and Disaster Prevention (Tsukuba City, Ibaragi Prefecture)	500	15 × 14.5	One-dimensional (X)	Horizontal: 0.5	Horizontal: 75	Horizontal: 22	Completed in 1970 Renovated in 1988
Public Works Research Institute (Tsukuba City, Ibaragi Prefecture)	300	8 × 8	Three-dimensional (X,Y,Z)	Horizontal: 2.0 Vertical: 1.0	Horizontal: 200 Vertical: 100	Horizontal: 60 Vertical: 30	1997

Source: National Research Institute for Earth Science and Disaster Prevention, an independent administrative institution of control methods for generating oscillations faithful to input signals in the electro-hydraulic servo system. Currently, the verification experiment is in progress on the shaking table.

To vibrate the total weight of nearly 2000 tons consisting of that of a test structure and that of the shaking table at a maximum displacement of ±100 cm, the horizontal actuator requires a total length of about 16 meters with the length of the three-dimensional joints added.

In the course of the development of elemental technologies using the simulated shaking table of the actuator, the performance characteristics of the actuator such as its maximum displacement and speed have been confirmed.

4-4 Problems to be studied by means of the E-Defense facility

Structures for which the improvement of earthquake resistance is needed range widely in fields such as buildings, civil engineering work, and machinery.

In the Kobe Earthquake, a great number of structures were destroyed including reinforced concrete buildings and expressway bridges that had been thought immune from destruction in an earthquake thus far imagined, with huge damage resulting from the earthquake.

The greater part of the deaths was due not to fire but to the collapse of wooden houses that had not been improved for better earthquake resistance.

Liquefaction, a phenomenon confirmed in the Niigata Earthquake 40 years ago, caused damage to roads, embankments, sewage drains, and the like. Most large urban areas of Japan are situated in alluvial plains and are therefore susceptible to liquefaction.

In the Tokachi-Oki Earthquake 2003, storage tanks were damaged due to the earthquake, with additional fire accidents caused by sloshing (liquid surface fluctuation) and long-period

Figure 4 : Shaking table and actuator system

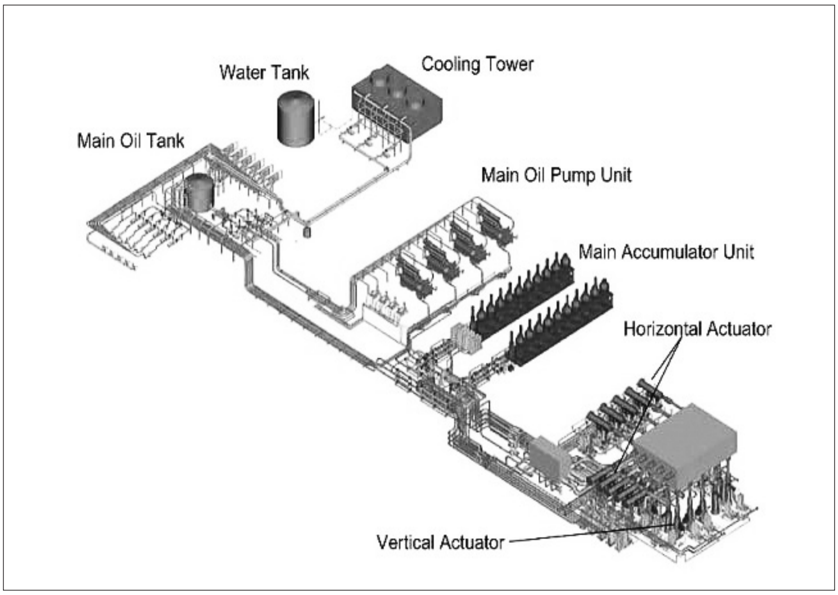
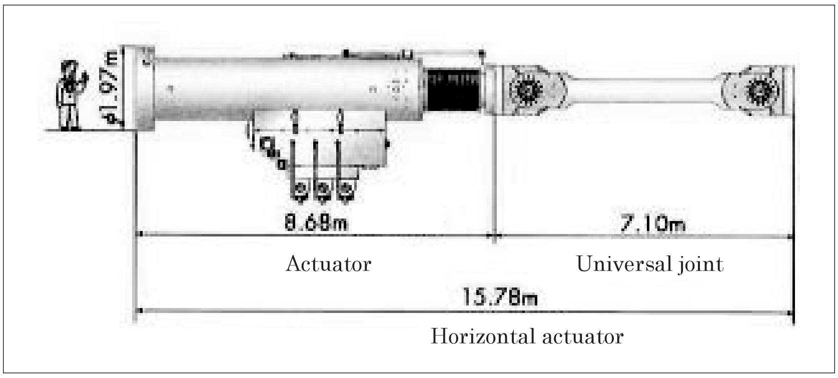


Figure 5 : A schematic diagram of a horizontal actuator



seismic motion.

For the structures mentioned below, the use of the E-Defense facility will allow us to verify the process of their collapse as well as the relevant earthquake resistance technology at full scale and in three-dimensional motion:

(i) To reproduce the process of collapse of a reinforced concrete structure by an earthquake to estimate the damage;
(ii) To reproduce the process of collapse of a bridge by an earthquake to develop and verify new reinforcement technologies;
(iii) To reproduce how industrial facilities like dangerous article storage tanks behave during an earthquake to verify their earthquake resistance;
(iv) To reproduce liquefaction using the ground model created in a special box to assess damage; and
(v) To contribute to the assessment of overall safety of a housing environment and to the development of new earthquake resistance technologies by performing shaking experiments covering the ground, foundation, furniture, and domestic equipment for various types of wooden housing.

4-5 Execution plan (a five-year plan)

The performance test on the 24 actuators of the E-Defense facility has been finished. In May, the 750-ton-weighing shaking table was hoisted using two 400-ton cranes to be installed in the pit. With the joint connection work and the connection of the shaking table with the actuators finished, the facility has been put to test runs and adjustment since July; it will be completed in the coming spring.

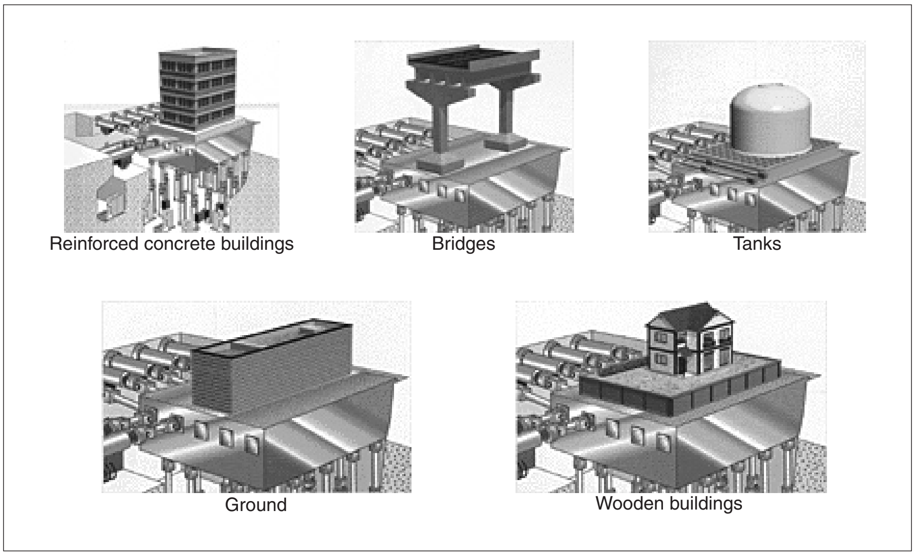
For the two years beginning in 2005, the experiments for the Special Project for Earthquake Disaster Mitigation in Urban Areas are planned, with earthquake resistance experiments on reinforced concrete buildings, wooden buildings, and foundation ground being scheduled.

Preparatory research, planned in view of the E-Defense-based full scale experiment to be started in Fiscal 2005, has been in progress using the existing shaking table since Fiscal 2002.

(i) Experiments on reinforced concrete buildings

- Experiment on the collapse of a one-third-scale reinforced concrete building on a large-scale shaking table (December 2003)
- Experiment for verifying the vibration-migrating performance of a one-half-scale four-storied model building built according to a new construction method enabling easy assembling and disassembling (February 2004)
- Experiment for clarifying the dynamic collapse

Figure 6 : Structures for which the process of collapse and earthquake resistance technology can be verified on the E-Defense facility



mechanism of an earthquake-resisting wall frame structure (scheduled in September 2004)

(ii) Experiments on ground and foundations

- Experiment on the liquefaction and lateral flow of ground arising from a sheared slope soil layer (July 2004)

(iii) Experiments on wooden buildings

- Experiment on the collapse of a wooden building using the shaking table (March 2003)
- Experiment on the collapse of a two-storied wooden building (March 2004)

Earthquake resistance designs and design standards for structures have undergone revisions and reforms repeatedly after large-scale earthquakes.

According to our plan, the findings obtained from the experiments carried out using the existing shaking tables will be reflected in the development of design methods for building and civil engineering structure foundations and of computer simulation programs. In this way, the findings will be fully used in the experiments on collapse scheduled for the E-Defense facility and thereby contribute to earthquake-related estimations.

It is impossible to predict the entire process from the destruction to the collapse of a building by computer simulation. To establish methods of design or reinforcement of structures immune from total collapse to protect human lives from earthquakes, it is necessary to record and analyze the process of collapse of a full-scale structure shaken three-dimensionally on a shaking table.

4-6 Usage patterns for the E-Defense facility

According to the current plan, the E-Defense facility will be owned by a research institution like an independent administrative organization and used in the same manner as existing large-scale research facilities that external organizations are allowed to use.

Three types of usage pattern are available: self-action-based research, joint research, and consigned research. A joint research work is conducted by a domestic or overseas research organization in cooperation with the National Research Institute for Earth Science and Disaster Prevention, with the usage charge split between the former and the latter; the usage charge for a consigned research work is fully borne by the consignor.

In the future, usage charges will be determined on the basis of the expenses necessary to operate and maintain the shaking table and the related facilities.

Applications for usage, to be solicited on the

Table 2 : Special Project for Earthquake Disaster Mitigation in Urban Areas

	Fiscal 2002 to Fiscal 2004	Fiscal 2005 to Fiscal 2006
Experiments on reinforced concrete buildings	Preparatory research 1. Clarification of destruction mechanisms using the existing shaking tables 2. Development of a numerical simulation system 3. Formulation of a full-scale experiment plan	Full-scale destruction experiments Fiscal 2005 Comparison between the new and the old design guidelines Fiscal 2006 Earthquake-resistant reinforcement
Experiments on ground and foundations	Preparatory research 1. Earthquake resistance of ground-pile foundations 2. Earthquake resistance of lateral flow 3. Assessment of three-dimensional behavior 4. Experiment plans and preparation/arrangement of facilities	Experiments on the destruction of pile foundations by an earthquake Liquefied ground and non-liquefaction Clarification of the destruction mechanism of pile foundations Experiments on the lateral flow of bulkheads Establishment of design methods
Experiments on wooden buildings	Preparatory research 1. Observation of earthquake responses 2. Numerical simulation 3. Experiment on collapse 4. Tests on structural elements and investigation of their strength	Determination of earthquake resistance strength and verification of the effect of earthquake-resistant reinforcement • About-30-year-old dwellings • Town houses (build by traditional construction methods) • Group of stores and large-scale stores

homepage of the National Research Institute for Earth Science and Disaster Prevention, will be reviewed by the Committee on the Utilization of the E-Defense to determine whether an application is to be approved and how long the facility is allowed to be used for the purpose of such an application.

Invitations for the application of use of the facility will start in Fiscal 2006 to prepare for the use by external organizations to be started in Fiscal 2007 when the current five-year program is expected to be completed.

4-7 Framework for the management of the E-Defense facility and international cooperation

In June, the Network of Science and Technology experts conducted a questionnaire survey concerning the use of the facilities such as the World's Largest Third-Generation Synchrotron Radiation Facility (Spring-8) and the Earth Simulator, facilities that are unique to Japan or best-performing in the world such as the E-Defense facility. The survey collected various opinions toward the widely open, maximized utilization of the functions of such facilities, summarizing them as follows: (i) dissemination of information on the facility; (ii) establishment of a system allowing easy access to the facility; (iii) enhancement of a supporting framework; and (iv) protection of results obtained using the facility.

The homepage of the National Research Institute for Earth Science and Disaster Prevention has publicized the outline of the E-Defense facility and the progress of its construction work; in the future, the homepage will publicize the data of experiments obtained using the facility and the results of experiments using the facility in the form of reports on research experiments. Further improvement of the environment for the usage by external research organizations will promise the E-Defense's contribution to dramatic improvement of earthquake resistance of buildings.

A plan is under study to run the E-Defense facility as an internationally shared facility that is open for access domestically and internationally alike. In addition, the E-Defense facility will be used to promote and support new experiments and research works under the cooperation of researchers both in Japan and abroad.

In 2002, a management conference and a committee on the utilization of the facility were created. The National Research Institute for Earth Science and Disaster Prevention will set up the Research Center for Earthquake Resistance Engineering (provisional name) prior to the start of the operation of the facility with the aim of carrying out research into improvement of earthquake resistance of structures by using the shaking table and of managing the operation of the facility.

(1) Management Conference forthe 3-D Full-Scale Earthquake Testing Facility

The conference was created with the aim of obtaining advice and guidance on the management of the E-Defense facility from 18 members representing the industrial, governmental, and academic sectors:

(i) Management of the E-Defense facility; and
(ii) Promotion of utilization of the E-Defense facility and medium-to-long term plans for the utilization of the facility

(2) Committee on the Utilization of the 3-D Full-Scale Earthquake Testing Facility

The committee was created with the aim of having 19 people of experience or academic standing formulate experiment programs and coordinate with related organizations:

(i) Programs for experiments using the E-Defense facility; and
(ii) Preparatory research for experiments on full-scale destruction.

(3) Conference on Japan-US joint research into disaster prevention against earthquakes using the shaking table

The conference consists of members of the four organizations below: the Ministry of Education, Culture, Sports, Science and Technology and the National Research Institute for Earth Science and Disaster Prevention, an independent administrative institution, on the Japan side and the National Science Foundation and the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES Program) on the US side. The conference will take up subjects such as the verification of results of E-Defense-based full-scale experiments by means of those based on computer simulation to discuss how to dramatically advance research into disaster prevention against earthquake. In April this year, a basic agreement was reached to explore a new direction of research into earthquake resistance by integrating computer-simulation-based research with E-Defense-based full-scale experiments.

5 Conclusions

The idea of a "minimized disaster" has been proposed meaning that efforts should be made to minimize a disaster to avoid a catastrophic one, though it is impossible to prevent a disaster completely by means of hardware measures.

The improvement in the performance of concrete and reinforcing bars has probably made it technically feasible to build a building immune from collapse. However, it is impossible to design and rebuild all buildings so that they may be free from destruction. The world trend is toward performance design specifying allowable damage corresponding to the strength level of earthquake motion.

To avoid catastrophic damage caused by an earthquake and protect human life even if a certain degree of damage is unavoidable, it is necessary to clarify the process of collapse of buildings (why, how, and to what extent buildings collapse). The role that E-Defense is expected to play is to realize the collapse of a full-scale structure on a shaking table, and thereby contribute to the designing of structures not susceptible to catastrophic damage.

References

[1] Cabinet Office: White Paper on Disaster Management

[2] Fire and Disaster Management Agency: White Paper on Fire and Disaster Management

[3] National Research Institute for Earth Science and Disaster Prevention, an independent administrative institution: Research for the Improvement of Earthquake Resistance of Structures through the Utilization of Shaking Tables (in Japanese)

[4] National Institute of Science and Technology Policy: Survey material - 106, "Survey of Research Institutions and Facilities"

(Original Japanese version: published in August 2004)

7

The Rapid Progress of China's Space Development

TERUHISA TSUJINO
General Unit

1 Introduction

In October 2003, China successfully launched and recovered a manned spacecraft, becoming the third country, subsequently to the United States and Russia, to do so. Underlying the feat are not only technical achievements steadily accumulated over 40 years of aiming towards space, but also rapid transformation of social systems, including reforms in science and technology systems. Under policies for sustainable economic growth, ambitious research and development and operation of manned space flights can be expected to continue into the future. This article will analyze the organizational systems behind China's thriving space development, its past achievements, and its future prospects. In addition, this article will look at a journal published by a major Chinese space technology research institution and examine the spread of themes and the regional distribution of authors in order to uncover a cross-section of trends in China's space technology research.

2 China's space development systems and research organizations

China's space development system formerly centered on the Ministry of Aerospace Industry, but in June 1993 the China National Space Administration (CNSA) was established directly under the State Council. In addition, the implementation sector for space activities was separated from the government and transferred to the state-owned enterprise China Aerospace Corporation. Following further reorganization and name changes, CNSA ceased to be under the State Council and was placed under the Committee on Science and Technology Industry for National Defense (COSTIND), as shown in Figure 1. The China Aerospace Corporation was divided into the China Aerospace Corporation (CASC) and the China Aerospace Science and Industry Corporation (CASIC).

CASC became a special enterprise assuming all responsibility for research and development and manufacture of the spacecrafts that are at the center of China's space activities, including manned spacecrafts and geosynchronous satellites. Under its umbrella are heavy industrial manufacturers such as China Great Wall Industry Company (CGWIC) and research organs such as the Chinese Academy of Space Technology (CAST) and the China Academy of Launch Vehicle Technology (CALT). CAST publishes the journal that this article examines.

The organization in charge of launching satellites into orbit by launch vehicles is the China Satellite Launch and Tracking Control General (CLTC), which is under the umbrella of the General Equipment Department of the People's Liberation Army, which in turn is directly under the National Central Military Commission. It has three launch bases in Xichang, Jiuquan, and Taiyuan and tracking control centers in Xi'an.

Other research organs related to space include the Institute of Remote Sensing Applications (IRSA), which is under the umbrella of the Chinese Academy of Sciences (CAS) directly under the State Council, and the National Remote Sensing Center under the Ministry of Science and Technology (MOST).

3 Overview of achievements in Chinese space development

3-1 Chinese satellite launches

Table 1 shows the situation of Chinese satellites launches, most of which utilized Changzheng (Long March) launch vehicles, from the first (1970) through the most recent (April 2004). China has successfully placed 60 satellites in orbit during this period.

From Table 1, we can see that the types of missions have greatly increased since 2000. In addition, China also has satellites except for those shown in the Table 1. They include commercial communications satellites owned by Hong Kong corporations launched via Changzheng or foreign launch vehicles (US Atlas, etc.) and a small satellite launched by Russian Cosmos launch vehicle.

Turning next to the number of Changzheng launches by launch site, in Table 2 we see that Xichang, which launches geosynchronous satellites has launched 36; Taiyuan, which launches polar-orbit satellites, has launched 15; and Jiuquan, which launches low-altitude orbit

Figure 1 : The organization of Chinese space development

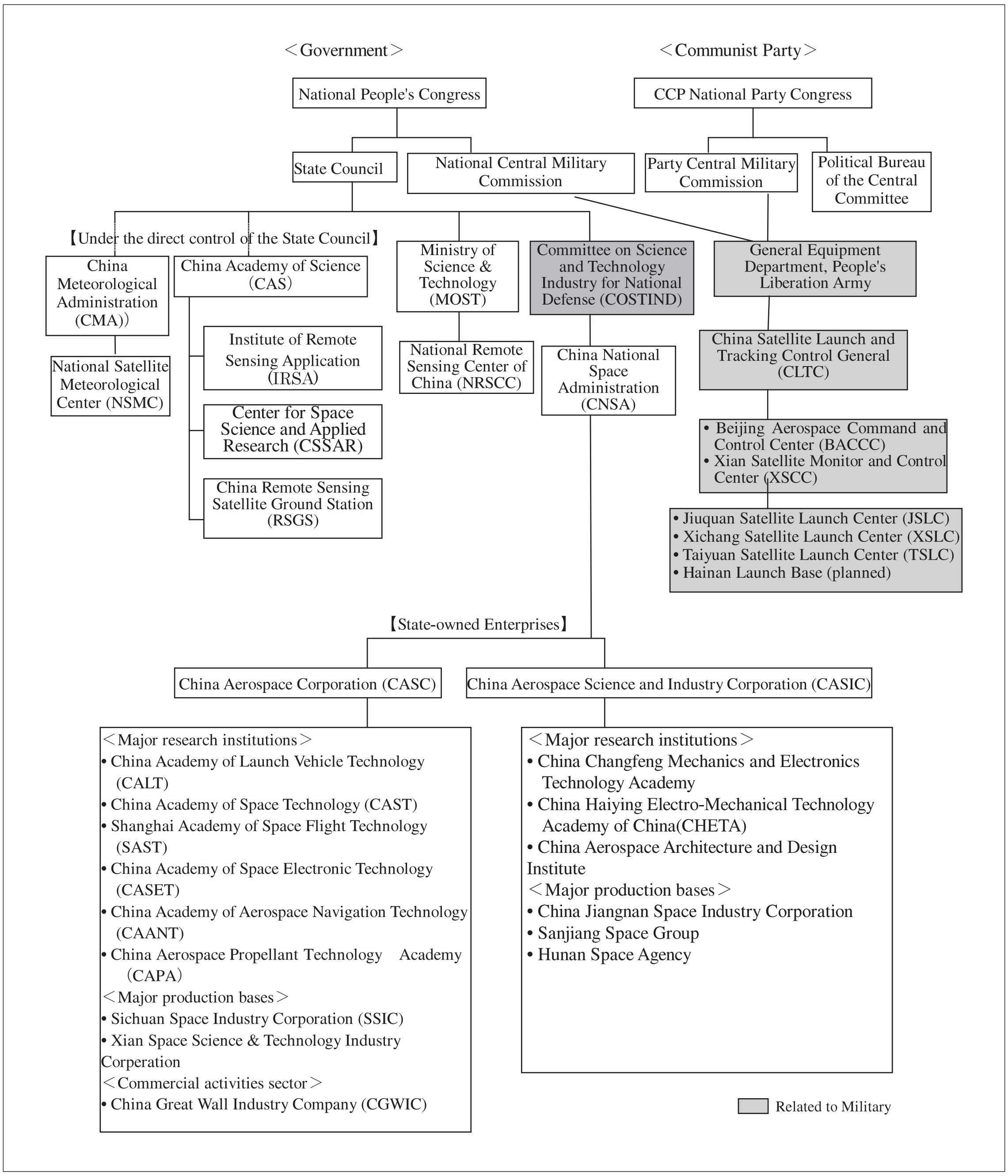


Table 1 : Number of satellites launched by China by 5-year period

Period	Satellites launched (number failing to achieve orbit)	Names of successful satellites (number)
1970-74	2	Dongfanghong 1 Shijian 1
1975-79	3	Fanhuishi (3)
1980-84	8 (1)	Dongfanghong 2, Fanhuishi (3), Shijian 2 (3)
1985-89	9	Dongfanghong 2A (3), Fengyun 1A, Fanhuishi (5)
1990-94	11 (1)	Dongfanghong2A, Dongfanghong3, Fengyun1B, Shijian 4, Fanhuishi (5), Atmosphere(2)
1995-99	10 (1)	Dongfanghong 3, Fengyun 1C, Fengyun2A, Fanhuishi, Shijian 5, Ziyuan1 (CBERS1), Shenzhou, Communications satellites (2)
2000-04 (through April)	20	Shenzhou(4), Fengyun1D, Fengyun2B, Beidou (3), Sino Star (2), Fanhuishi, CBERS2, Ziyuan 2 (2), Haiyang 1, Chuangxin 1, Tance 1, Shiyan 1, Naxing 1
Total	63 (3)	

Table 2: China's rocket launches (launch sites)

Period	Xichang	Taiyuan	Jiuquan	Total launches
1970-74			3 (1)	3(1)
1975-79			3	3
1980-84	3(1)		2	5(1)
1985-89	3	1	5	9
1990-94	10 (3*)	1	5	16 (3)
1995-99	12 (3)	9	2	23 (3)
04 (through April)	8	4	5	17
Total	36 (7)	15	25 (1)	76 (8)

Parentheses ( ) represent failed launches.
* In July 1990, one of two satellites in a payload failed.

satellites, has launched 25. There have been 8 failed launches (including a partial failure), giving the Changzheng a success rate of 89.5 percent (In case count 7.5 failures for a success rate of 90 percent). Through April 2004, there have been 34 consecutive successful launches since the last failure, in August 1996.

Figure 2 presents the successful launch rates of major launch vehicles so that we can compare China's launch vehicle with those of other countries. So that they can be compared under the same conditions, the launch vehicles are compared every 10 launches. We can see that like US's and European launch vehicles, China's launch vehicle has overcome some early failures and raised its success rate.

3-2 Overview of missions to date

(1) Recoverable satellites

China launched 18 Fanhuishi (recoverable) satellites from 1975 through November 2003. Their missions were photography (film recovered) and microgravity experiments (materials science and life science samples recovered). China carried out not only their own microgravity experiments but also French and German experiments. The method of firing retro engines at orbital separation to reduce speed and descending by parachute is the same used by the Russian Soyuz manned spacecraft. No doubt the achievement of the Chinese manned spacecraft Shenzhou(Magic Vessel) owed much to China's experience with recoverable satellites.

Advances in technology have lengthened the mission duration of recoverable satellites from their original 3 days to 15 days. Because recoverable satellites do not have solar batteries, that was achieved through increases in primary battery capacity.

Of the 18 recoverable satellites, 1 was not recovered. Launched in 1993, the 15th recoverable satellite, the Jianbing, entered an uncontrollable orbit farther from the earth when the retro engine fired to deorbit for reentry. The world was faced with the crisis of being unable to predict where a spacecraft that would not completely burn up in the atmosphere would fall to the Earth. Finally, it landed in the Southern Pacific and caused no damage.

(2) Earth observation

China has launched four Fengyun (Wind and Cloud) 1 meteorological satellites and two Fengyun 2 geosynchronous satellites. In addition, recently China has launched a succession of Earth observation satellites such as the Ziyuan(Resources) and the Haiyang(Ocean) developed from the joint China-Brazil Earth Resources Satellite (CBERS). Those satellites are relatively small, but are loaded with multiple observation instruments such as multiband CCD cameras.

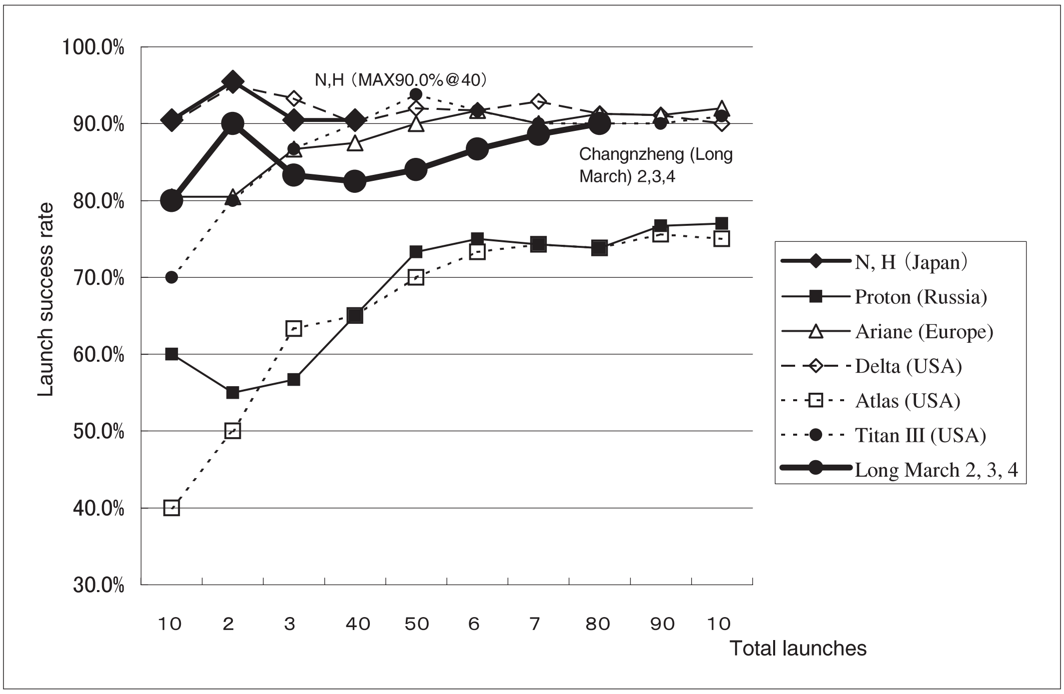
In December 2003, China launched the environmental observation satellite Tance (Probe) 1 that it jointly developed with the European Space Agency (ESA) into equatorial orbit. Together with Tance 2 in polar orbit, the project is called Shuangxing (Double Star)[1]. In April 2004, the Ministry of Science and Technology and the ESA held a symposium to open the Dragon Program, which utilizes data provided by the ESA's ENVISAT environmental observation satellite to study water and air pollution, and forest, marine, and water resources, and so on[2].

(3) Communications and broadcasting

As for its own geosynchronous communications satellites, since 1984 China has launched the Dongfanghong(East is Red) 2, Dongfanghong 2A, and Dongfanghong 3. Within China, they are held to have contributed to the development of China's spacecraft technology and satellite communications utilization technology. The Dongfanghong 3 is a full-scale geosynchronous communications satellite utilizing triaxial attitude control and carrying 24 transponders. Although operation of the first one, launched in 1994, was abandoned due to a fuel leak in the following year, the second one, launched in 1997, has already been operating for seven years. Its planned life is eight years.

Communications demand in China is growing rapidly. For eample, 5 million new mobile phone subscribers being added every month. For satellite communications, China does not rely solely on satellites it launches itself, but actively pursues a full satellite lineup by purchasing new foreign made satellites, leasing them from foreign corporations, and purchasing ownership rights to satellites already in orbit.

Figure 2 : Success rates for rockets from various countries at every 10 launches



(4) Navigation satellites

The satellites currently utilized for the Global Positioning System (GPS) are the US NAVSTAR and the Russian GLONASS. In addition, Europe is working on the Galileo program. China has launched three Beidou (Dipper) geosynchronous satellites as its own navigation satellites. China has not made public detailed information about the satellites, but they are positioned at 80°, 110°, and 140° east longitude and are used for navigation work in road, railway and marine traffic. In contrast to orbiting satellites, there is no need to send positioning data to geosynchronous satellites, so their systems are quite different. It is also thought that those satellites are unable to carry out positioning alone.

(5) Manned spacecraft

China launched the first experimental Shenzhou spacecraft in 1999 and completed preparations for a manned mission with three more launches through 2002. In October 2003, China successfully launched and recovered a manned spacecraft. China's first astronaut was Yang LiWei, a 38-year-old lieutenant colonel in the Astronaut Team of the People's Liberation Army.

The Shenzhou 5 comprised of four modules, an orbital module, a reentry capsule, a propulsion module, and additional parts. The orbital module remained in orbit after separating from the reentry capsule, and spent the next approximately six months carrying out experiments in space environment measurement, completing them in March 2004[3].

(6) Engineering test satellites

The Naxing(Nanosat) satellite launched in April 2004 is a 25-kilogram microsatellite developed at Tsinghua University. It utilizes a CMOS camera for topographical scanning, testing the creation of high-resolution topographical maps[4]. Other engineering test satellites include the Chuangxin(Innovation) and the Shiyan(Test).

4 Future prospects for space development

Xu FuXiang of the Chinese Academy of Space Technology believes that space technology and space applications will be industrialized and marketized and that the development and use of space resources will meet broad demands in economic growth, national security, and science and technology development in the long-term outlook for space development [5]. China's goal is to combine various functions and orbits in diverse systems to create a complete space infrastructure and build a network system that integrates space and Earth. With that sort of outlook, several missions and the development of satellite technologies can be expected to move forward in the near future.

4-1 Development goals by mission

Looking at media such as the People's Daily, Beijing Review, and China News, various mission plans are enthusiastically reported.

(1) Earth observation satellites

Launch of the Tance 2 global environmental observation satellite jointly developed with the European Space Agency (ESA) is planned for the end of July[6]. Launch of the third and fourth CBERS resource monitoring satellites jointly developed with Brazil is also planned in order to bring them into constant use[7]. In the future, China can be expected to work towards stable monitoring centered on the National Remote Sensing Center under the Ministry of Science and Technology and utilizing data from various types of Earth observation satellites.

(2) Communications and broadcast satellites

China is currently developing the Dongfanghong 4 for launch in 2005. It is projected to carry 38 C-band (telephone use) and 16 Ku-band (television broadcast use) transmission devices, a large increase over the Dongfanghong 3. Its expected mission life is to be 15 years, double that of the Dongfanghong 3[8].

(3) Satellite positioning systems

In addition to its own Beidou geostationary satellites, China has begun cooperating with the European Galileo project. With the USA and Europe reaching an agreement in June 2004 to cooperate on navigation satellites, worldwide use of navigation satellites, including by China, is expected to accelerate.

(4) Manned space flight and microgravity experiments

China plans a manned space flight with a two-person crew lasting several days in 2005. China's goal is a three-person flight lasting several days in about 2006. Currently 14 astronaut candidates are training[9]. On future manned flights, scientific experiments in space materials science and life science carried out on unmanned flights are expected to be carried out with the support of astronauts.

(5) Space environment monitoring

In June 2004, the Chinese Academy of Sciences announced a plan to place three solar wind observation satellites in differing orbits at altitudes of 700, 50,000, and 150,000 kilometers with a single launch by 2011. It would study solar winds and other aspects of the space environment in conjunction with the joint US-Russian-European-Japanese International Solar-Terrestrial Physics (ISTP).

(6) Deep space exploration

In February 2004, the Committee on Science and Technology Industry for National Defense announced a planned December 2006 launch for the ChangE(name of goddess ascended to the moon) 1 lunar surface probe[10]. It said that the plan for the first probe is entirely produced in China, without foreign cooperation, and that manufacture and testing of measuring instruments are already complete. It is considering joint development with foreign countries from the second probe onwards. The Committee said that China will land a lunar rover by about 2010, and by 2020 it will reach the stage of returning. In the future, China plans to harvest useful resources such as helium-3 and use them as energy sources. The United States and Europe are showing interest in Chinese lunar exploration from the second probe on.

Deep space exploration missions farther than the Moon are still a matter for the future, but China has indicated it will launch a Mars probe by 2020. For the long-term, China's goals are to stake out a relatively weighty position in the world's space science field and to develop its own characteristic research.

4-2 Technical goals for satellite development

China has following technical development goals in mind common to satellite missions[5].

(1) Prioritize development of technologies for satellite onboard mission equipments.

(2) Develop commonized platforms for satellites. By choosing from several types of platforms for satellite series such as geosynchronous satellites, polar-orbit satellites and recoverable satellites, time required for satellite development could be reduced, costs lowered, and reliability improved.

(3) Optimal design for the satellite as a whole, precision attitude control, new solar battery technology, space microelectronics technology, space data safety technology, autonomous satellite flight, space lightweight structures and mechanisms, large deployable and multiband antennas, advanced freezers for use in space, etc.

(4) Strengthen research and development in space application technologies such as GPS and communications and broadcasting.

4-3 Provision of data obtained by satellites to Asia-Pacific countries

At the 60th meeting of the Economic and Social Commission for Asia and the Pacific (ESCAP) in April 2004, Luan EnJie, the head of the China National Space Administration indicated China's intention to provide observation data to developing nations in the Asia-Pacific region from its constellation of small Earth observation satellites in order to lessen damage from disasters and so on. China states that in 2003 alone, 200 million people were victims of natural disasters that did over 180 billion yuan in damage[11]. China is attempting to actively use data obtained through satellite technology to lessen such damage. Having already become a "possessing country" through the rapid development of its space development activities, China is attempting to spread those blessings not only to its own disaster policies, but also to its neighbors in the Asia Pacific region.

5 Analysis of papers on space development

We need to know what kind of technical research underlies China's achievements and future prospects as described above. Below are the results of an examination of that aspect.

5-1 Overview by technical sector

The journal of China Space Science and Technology (published by the China Academy of Space Technology) is the medium for the most advanced space-related articles in China in terms of content. Published since 1981, it appeared bimonthly last year, with six issues. By examining at it, we can see a sample of the research being carried out around China.

There were 71 articles published in the six issues that appeared in 2003. Table 3 shows their distribution by field.

Below I also introduce some of the interesting research found in individual articles.

(1) Finding optimal parameters for engines for Single Stage To Orbit (SSTO) systems

Single Stage To Orbit systems utilize a single-stage rocket to place satellites in orbit, with the rocket recovered on the ground keeping its figure. In research performed at Northwestern Polytechnical University (Xi'an City, Shaanxi Province) Tan SongLin (age 37) and collaborators are considering Vertical Ttakeoff/Horizontal Landing (VTHL). It requires main wings and so on for horizontal landing. With a weight of 1,007 tons, propulsion comes from seven tripropellant engines utilizing two types of propellants, a petroleum-based one and liquid hydrogen, and liquid oxygen as oxidant, with 200 tons of thrust each. A US corporation invented tripropellant engines. Near the ground, where the atmosphere is thicker, they utilize petroleum-based fuel, while in the upper atmosphere they switch to hydrogen in order to efficiently obtain thrust. Utilizing the mass of the body, tank, and other parts, thrust, combustion time, fuel changeover timing, and so on as variables, the researchers carried out optimal design, finding the possible parameters for placing a 15-ton satellite in Low Earth Orbit (LEO)[12].

(2) Manned spacecraft rendezvous

China has not yet actually performed a space rendezvous in which two or more spacecraft approach each other. However, it is possible that in the future it will have its own space station to which it will send manned spacecraft and resupply vehicle that will require rendezvous and docking. Zhu RenZhang (age 62) of Beijing University of Aeronautics and Astronautics and collaborators carried out research on acceleration and deceleration during approach for manned spacecraft rendezvous. They are unique in studying the use of engine firing to reduce the astronaut's field angle (equivalent to the angle of attack as an aircraft lands) as the chaser satellite draw near the target satellite[13].

(3) Analysis of human errors in manned spacecraft

With Chinese manned space activities soon to become longer in duration, Zhou QianXiang (age 34) of Shanghai JiaoTong(Transportation) University and collaborators analyzed human errors in US Apollo and Soviet Soyuz spacecrafts. They suggest that measures against human errors should be taken in spacecraft design[14].

First, they introduced case studies of human errors in space activities and statistics concerning their timing. Next, they evaluated the process of human awareness and ability of attention. They are studying topics such as the sharing of works between human and machine, response times for display, as means to prevent human errors. While it is inevitable that astronauts must perform some work, the authors believe that the roles of robots and artificial intelligence as "helpers" should be optimized, leaving astronauts as much as possible to make only high-level decisions.

A point worthy of notice is their study of personal spatial separation aboard spacecraft for stranger who is not known by astronauts. That is a suggestion useful less for the case of the three astronauts not only Chinese army colleagues but also ordinary people joining missions for some purpose.

There is nothing technically new in the article, but the research is related to improving reliability in China's manned space flights beyond minimum necessity.

(4) Wavelet transform

In recent years, wavelet transform that can simultaneously analyze time data and frequency data is being used in various applications. Zhong Ping (age 24) of the National University of Defense Technology (Changsha City, Hunan Province) and colleagues carried out research on applying wavelet transform to find meaningful outlines in image data with much noise. They were able to obtain more detailed outlines than with conventional analysis methods such as Sobel filters[15].

Even though it is a graduate student article, it seems unusual for a military-related research institute to publish research on image analysis that it directly applicable to reconnaissance.

5-2 Distribution of author affiliations

The top five affiliated institutions for authors are shown in Table 4.

The top five institutions account for about 60 percent of the articles. The institution accounting for the most articles is the National University of Defense Technology, which is under the People's

Table 3 : Fields and major keywords of articles appearing in China Space Science and Technology during 2003

Field		No. of articles	Major keywords
Overall 1	Overall plans	1	◎ Achievements and prospects (authored by Xu FuXiang)
Mission-critical systems 19	Manned flight	1	◎ Human error
	Propulsion	3	◎ Single stage to orbit (SSTO) ◎ Tripropellant engines ◎ Liquid oxygen, Liquid hydrogen Microdetonation thrusters
	Parachutes	2	Rigid models Expansion simulation
	Reentry vehicles	9	Reentry vehicles
	Tracking control	4	Orbit-determining algorithms
Systems utilized in space 18	Satellite design	2	Fuzzy logic
	Space experimentation	3	Mutants
	Earth observation	3	◎ Wavelet transform
	Communications	3	Column-array despun antennas
	Orbital design	7	Formation flight, Genetic algorithms
Technical research 33	Reliability	1	Neural networks
	Sensors	1	Synthetic aperture radar
	Electricity	1	Solar battery panels
	Space environment	2	Atomic oxygen, Space debris
	Structure	2	Modal cost analysis
	Information processing	2	Asynchronous transfer models (ATM)
	Heat control	3	Heat contact resistance, Coatings
	Attitude control	4	Secondary nonlinear filters, Kalman filters
	Mechanisms	4	Flywheels, Pulse tube freezers
	Guidance and control	13	◎ Space rendezvous ◎ Chaser satellite, Target satellite

◎ :described in text.

Table 4 : Number of the 71 articles published in 2003 by institution (top 5)

National University of Defense Technology (Hunan Province)	15
Chinese Academy of Space Technology (Beijing)	10
Beihang University (Beijing)	9
Harbin Institute of Technology (Heilongjiang Province)	7
Nanjing University of Aeronautics and Astronautics (Jiangsu Province)	6

Liberation Army. The journal's publisher, the Chinese Academy of Space Technology (CAST) is second. It is notable that the three universities ranking third through fifth are all affiliated with the Committee on Science and Technology Industry for National Defense. Most of the universities ranked sixth and below, such as Beijing University, are affiliated with the Ministry of Education.

Although it may seem as if CAST is not a military organization, one can see that its actual research involves close industry-academia-military cooperation beyond dual use.

Looking at the research of the military-related universities, they engage in an extremely wide range including not only guidance control and information processing related launche vehicles, but also Earth observation technology and satellite mechanisms related to early warning satellites.

5-3 Analysis of works cited

Result of cited reports divided into types in the 71 articles is shown in Table 5.

The number of Chinese domestic reports cited is approximately 200, with the number of domestic journal articles and books and other publications cited about the same.

Of the foreign articles cited, particularly common were those of the Institute of Electrical and Electronics Engineers (IEEE) with 52 citations and the American Institute of Aeronautics and Astronautics (AIAA) with 30, as well as 7 from NASA reports. No citations of reports with Japanese authors were found.

In the past it appeared that China obtained much of its space technology from the Soviet Union, but recently with many students returning from study abroad like the USA and engage research works in home country, it seems that they have great interest in the latest information from Europe and US where technological innovation is so remarkable.

Table 5 : Number of cited reports divided into types

Chinese domestic journals	102
Chinese domestic publications	103
Foreign articles	191
Foreign publications	30
Conference proceedings	21

6 Social changes underlying the rapid progress of space development

China is undertaking to reform its science and technology systems, improve its antiquated customs in state-run enterprises, achieve sustainable economic development. Furthermore, it is actively working to upgrade its trade control systems. We must not overlook the fact that underlying the rapid progress of China's space development are rapid changes in social systems. Below I will introduce some of those trends.

(1) Reformation of science and technology policies

In August 2003, Shen Hua of the Bureau of Science and Technology Policies, China Academy of Sciences, gave an address in Tokyo regarding China's aim to reform its science and technology systems[16]. In her address, she spoke of China's drive for all-out reform to optimize national research institutes by 2010 and the goal of upgrading about 80 research bases. Along with those reforms, China will implement policies to attract outstanding human resources. In its personnel systems it will carry out evaluation systems designed to bring out the positiveness of human resources such as compensation based on results and competitive selection.

(2) Improvement of antiquated customs in state-run enterprises

In China they refer to the vested interests of the state-run enterprises that are harming national economic development as the "three irons". The "three irons" are the "iron rice bowl" (no bankruptcies), the "iron wage" (guaranteed wages), and the "iron armchair" (lifetime employment). In the past China's state-owned enterprises in the space sector also suffered those ills. Since we hear of the outcry of those losing their vested interests even in Japan, we can be sure that reform is actually taking place.

(3) Sustainable economic development

Regarding China's rapidly developing domestic economy, there is concern both at home and abroad that constraints on resources such as energy, water, and food will limit growth. With large numbers of the rural population moving to cities, energy and other major problems are expected to become even more serious. In response, the Chinese government has made sustainable economic growth a national strategy and is providing political guidance wherever possible. Utilization of space technologies such as Earth observation and positioning will become even more important.

(4) New trade control systems

Beginning January 1, 2004, the Ministry of Commerce and the Customs General Administration jointly implemented a "sensitive commodities and technology export permit control register" based on the Foreign Trade Law. That was a necessary revision of domestic law allowing China to join the Nuclear Suppliers Group (NSG) and the Missile Technology Control Regime (MTCR). At the NSG meeting in Sweden in May, China became a member. In June, China formally declared its intention to join to the MTCR. Once membership is achieved, even technology that can be directly applied to the manufacture of missiles and reentry vehicles can be exported from Japan to China or from China to Japan with permits.

7 Conclusion

In this article, I have outlined the achievements of approximately 40 years of Chinese space development, current organizational systems, current and future goals, and the background of social change. As exemplified by the impressive achievement of manned space flight, in recent years in particular space development and space utilization have begun exhibiting results amidst China's rapidly growing economy.

Types of satellite missions are increasing rapidly, with new projects in previously untested fields such as lunar probes and space environment monitoring making swift progress. In space transportation, the continuous successes of the Changzheng (Long March) launch vehicle are expected to bring its successful launch rate above 90 percent.

In the field of international cooperation, China has already jointly manufactured and launched an Earth observation satellite with Brazil. In the future, its cooperation with the European Union (EU) will also be noteworthy. From the perspective of contributing to the international community, how to allow the nations of the Asia-Pacific region to utilize the results of China's space technologies will be an issue for China as a "possessing country". Already China has made clear its intention to provide information to Asia-Pacific countries from its constellation of small satellites to reduce the impact of disasters.

In addition, through research papers on space development, China is carrying out broad research on its own space development and utilization that ranks with that of the United States, Russia, Europe, and Japan. In the field of manned space flight in particular, one receives the impression that China is carrying out its research more ambitiously than other countries. If innovative space transportation systems such as SSTO begin to be realized, the impact on the world's space development will be great.

China's progress in the field of space development cannot be explained solely through increased technical prowess. Underlying that progress are reforms in personnel systems in science and technology, maintenance of the nation as a whole on the path of sustained economic growth, revision of trade control systems, and other changes in social systems that make China remarkably different from how it was in the end of 20th century.

Rather than merely observing the rapid progress of China's space development as it has been doing for the past several years, Japan should be asking what it can learn from Chinese research and development trends and changes in social systems.

Acknowledgments

In writing this article, I benefited from the advice and discussion of Assistant Professor Atsushi Sunami of the National Graduate Institute for Policy Studies, the International Relations Department and the Institute of Space Technology and Aeronautics of the Japan Aerospace Exploration Agency, and numerous others. I hereby express my deep gratitude to them.

References

[1] "First satellite of the Double Star Program to be launched by end of this year", Beijing Review 2003, no. 49 (In Japanese) : http://www.pekinshuho.com/JP/2003.49/200349-week6.htm

[2] " 'Dragon Program' begins: Project of China and the ESA is of the largest scale ever in the remote sensing field", Eastday.com, April 28, 2004 (In Japanese) : http://jp.eastday.com/node2/node3/node15/userobject1ai8918.html

[3] " Shenzhou 5: success in experiments aboard orbital module", Searchina, March 16, 2004 (In Japanese) : http://news.searchina.ne.jp/2004/0316/national_0316_007.shtml

[4] "Launch of small satellites succeeds: For science experiments by two science and technology universities", Nikkan Kogyo Shimbun, April 20, 2004 (In Japanese)

[5] Xu FuXiang, "The Achievements and prospects of Chinnse Spacecraft Engineering", China Space Science and Technology, pp. 1-6, no. 1, 2003 (In Chinese)

[6] "China's Tance 2, towards launch at end of July", Japanchinaeic.net, June 30, 2004 (In Japanese) : http://nikkeibp.jp/wcs/leaf/CID/onair/jp/mech/316170

[7] "China/Brazil, towards development of third and fourth CBERS satellites", People's Daily, Japanese edition : http://nikkeibp.jp/wcs/leaf/CID/onair/biztech/mech/310152

[8] "All technical problems cleared for the Dongfanghong 4 communications satellite", People's Daily, Japanese edition, July 3, 2003

[9] "Shenzhou 6 astronaut team chosen, to begin training after Chinese New Year", People's Daily, Japanese edition, December 19, 2003

[10] "Lunar surface exploration, towards a satellite launch before 2007", Searchina, February 26, 2004 (In Japanese)

[11] "China confesses to support Asia Pacific Countries in decreasing calamity through its Aerospace Resources", Ministry of Science and Technology of China Trends and Key News (In Chinese) : http://www.most.gov.cn/dtyyw/t20040429_13327.htm

[12] Tan Song Lin, "The Parameter optimization of Tri-propellant's Engine for SSTO", China Space Science Technology, Issue 3 2003 PP19-26 (In Chinese)

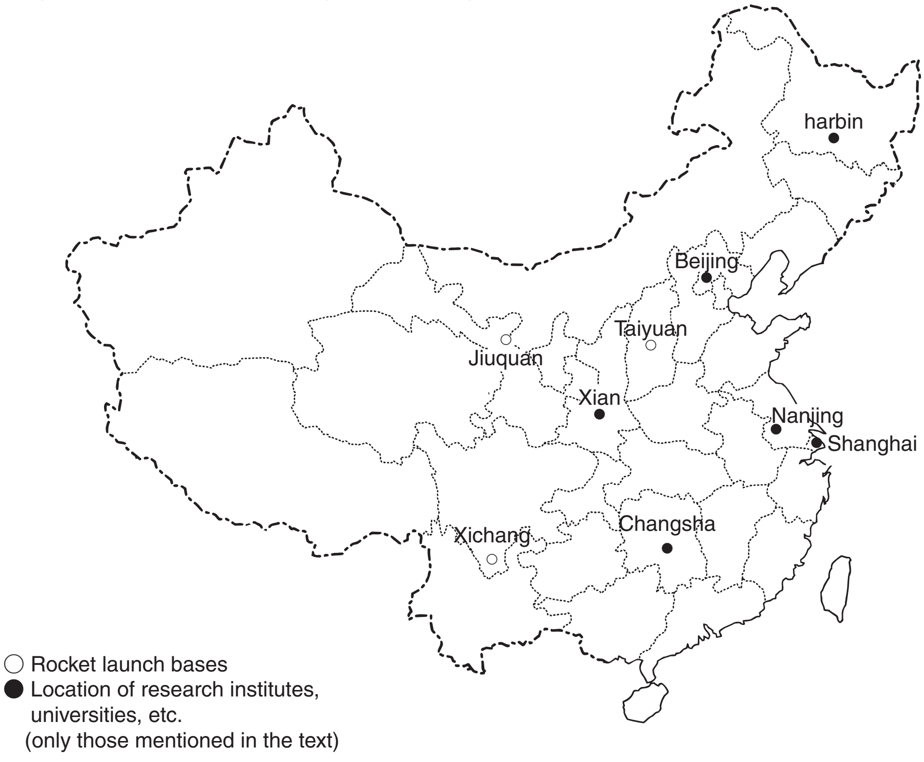
[13] Zhu RenZhang, "Analyses of the Absolute Motion and Relative Motion for Space Rendezvous V-Bar Approach Using impulsive Maneuver", China Space Science Technology, Issue 3 2003 PP1-6 (In Chinese)

[14] Zhou QianXiang, "Study on Human Errors in manned Space Flight and their Solution", China Space Science Technology, Issue 6 2003 PP52-57 (In Chinese)

[15] Zhong Ping , "Wavelet-based Self-Adaptive Edge Detection for Noisy Aerial Image", China Space Science Technology, Issue 5 2003 PP45-50 (In Chinese)

[16] Speech manuscript "China National Creation System and China Acadmy of Science", Bureau of Science & Technology Policy of China Acadmy of Science, August 2003 (In Chinese)

Map of centers of China's space development activities



(Original Japanese version: published in July 2004)

8

Scientific Research and Intellectual Property in the Public Interest : "Status of the Research Use Exemption" — A contributed article from AAAS

* **


JUNKO SHIMADA *(Life Science and Medical Research Unit)**
MASAO WATARI *(Information and Communications Research Unit)***

Intellectual property is important because it contributes to science and technology utilization, which in turn encourages economic growth. Policymakers should set out the proper scope of intellectual property protection so that scientific research progresses, leading to technological innovation.

According to Article 1 of Japan's Patent Law, intellectual property protection should "encourage inventions by promoting their protection and utilization so as to contribute to the development of industry." In this sense, the Patent Law rewards inventors and provides incentive for new inventions by granting exclusive license to inventors or their successors for 20 years after patent application to compensate them for their disclosure of patented inventions and their contribution to technological progress[1]. If patent protection is excessively narrow, researchers will lose their incentive to invent as well as their motivation to seek legal protection as compensation for their patent application or information disclosure. On the other hand, patent protection that is too extensive will prevent researchers from creating new inventions and commercially feasible products based on modifying other researchers' inventions. Thus, it is necessary to protect intellectual property rights at the proper level.

Exploring the proper patent protection level, the American Association for the Advancement of Science (AAAS) in the US launched a project to examine the relationship between science and intellectual property from a public interest perspective (SIPPI: Science and Intellectual Property in the Public Interest) in 2002. This project examines proper intellectual property protection in the science field, guaranteeing equity in access to the benefits of science and encouraging debate on intellectual property-related public policy[3]. At its annual meeting in February 2004, AAAS held a symposium entitled, "Intellectual Property and the Research Exemption: Its Impact on Science" to discuss this topic[4,5].

On the other hand, Japanese policymakers recognize the urgent necessity of clarifying interpretation of Article 69, Paragraph 1 of Japan's Patent Law, which stipulates that "the effects of patent right shall not extend to the working of patent right for the purposes of experiment or research." There are a number of arguments that favor this patent exemption. Influential scholars argue that such exemption should apply to "activities that aim at technological progress,"[2] but the Japanese courts have not yet clearly expressed a ruling in this regard.

With rapid technological innovation and deeper collaboration among universities, industries and government, it is increasingly necessary to clarify experiments and research activities beyond patent right protection. The "Intellectual Property Promotion Plan 2004" (dated May 27, 2004) states that the government will provide a clear guideline in FY2004. The Intellectual Property Policy Headquarters has been studying this issue.

Dr. Audrey R. Chapman, co-director of the above-mentioned AAAS project, kindly sent us her paper on the "Status of the Research Use Exemption" as a contributed article for the Journal of Science and Technology Trends.

** Until June 30, 2004

[A contributed article from AAAS]

Status of the Research Use Exemption

AUDREY R. CHAPMAN, PH.D.
Science and Intellectual Property in the Public Interest / AAAS

1 Background

Because science is one of the most international of all activities, advances in science require the freedom of inquiry, the full and open availability of scientific data on an international basis, and the open publication of results. Growing tendencies to seek copyright and patent protections for scientific data, research tools, and materials, as well as for discoveries, are therefore imposing new costs and problems for scientific research.

Until recently, most developed countries provided extensive public funding for basic scientific research to assure widespread availability of and access to the findings.[*1] Large government investments in basic research and development made it possible to argue that the conduct of scientific research, including the maintenance and distribution of scientific data, was a public good. Traditionally, research scientists actively pursued the dissemination of research results through the sharing of data and publication and were disinclined to patent their discoveries.[*2]

However, the landscape, which encouraged the open availability and sharing of scientific discoveries has changed in major ways. Government policies, beginning in 1980 with the adoption of the Bayh-Dole Act in the United States, have encouraged the commercial development of publicly funded research. Universities, particularly in the United States and to a lesser extent elsewhere, now regularly patent the results of government-sponsored research and consider their research work to be an important intellectual property asset. Increasingly, basic as well as applied research is being funded by the private sector. In turn, these developments have affected science's tradition of open publication. In many scientific fields, particularly the life sciences, scientists are delaying publication and withholding data so as to secure their intellectual property rights. A 1997 survey indicated, for example, that a substantial portion of researchers in the life sciences in the United States had delayed publication or withheld results and materials from colleagues to protect their intellectual property.[*3]

Researchers and universities are now seeking intellectual property protection for research tools and other "upstream" research discoveries, especially in the area of genomic research, which would have been considered too far removed from the commercial marketplace to qualify for patent protection a generation ago. As universities have become increasingly aggressive patent owners, this has imposed restrictions on the transfer of research tools, materials, and reagents.

Within many sectors of science, the ownership of intellectual property rights is becoming fragmented across institutions in both the public and private sectors and, in the view of many, is becoming an "anticommons." [*4] This fragmentation or "patent thicket" often requires that researchers spend a significant amount of time locating a multitude of patent rights to pursue a project. This results in increased legal costs and financial burdens as scientists bundle licenses together licenses in order to conduct research or develop new products. Efforts to develop vitamin A enriched "golden rice," by an international team of researchers for example, required more than 40 separate licensing agreements.[*5]

2 Existing Research Use Exemption Provisions

The general rule is that there is an infringement of a patent when an unauthorized use of the claimed invention takes place in the jurisdiction covered by the patent during the period of its life. However, this rule is subject to exceptions, one of which is an experimental use exemption. Several countries have statutes that in some circumstances provide exemptions for research carried out in private for non-commercial purposes and acts done for experimental purposes. Many European Union countries as well as Japan recognize a limited experimental use exemption, but the scope of the exemption is often quite narrow and in some instances unclear. In some jurisdictions, including the United States, Canada, Australia, and New Zealand, limited experimental use defenses are recognized in case law, although there remains a dispute over the scope.

There is significant variation in the scope and nature of the experimental use exemption. One key consideration is the difference between a right of experimentation on a patented invention and experimentation using a patented invention for broader research purposes. The patent laws of the United Kingdom and many other countries in the European Union explicitly limit the research exemption to the subject matter of the patented invention for purposes of research that "builds upon the knowledge provided by the patent, and aims to discover something unknown about the subject matter of the patent or to test a hypothesis about it."[*6] Similarly, Japanese patent law states that "the effects of the patent right shall not extend to the working of the patent right for the purposes of the experiment or research."[*7] This definition generally excludes the permissible application of the invention for broader researcher purposes, such as the development of new products. Another important distinction in national laws concerns the extent to which the applicability of the research exemption depends on whether there is some commercial motivation involved.

The U.S. Patent Act has no statutory exemptions for noncommercial or research uses of an invention with the exception of legislative provision for clinical testing related to the development and submission of information for regulatory approval of generic pharmaceutical products.[*8] Nonetheless, many U.S. scientists had assumed that it was permissible for them to use patented information and resources without seeking explicit permission to do so if they did not intend to commercialize the products. A 2002 decision by the U.S. Court of Appeals for the Federal Circuit, however, rejected an "experimental use defense" in a patent infringement lawsuit against Duke University. The Court of Appeals ruled that neither U.S. law nor judicial precedent provided for such a research exemption. The Court also held that the non-profit or educational status of Duke University did not determine the availability of the experimental use defense because research projects with arguably no commercial application unmistakably further the institution's legitimate business objectives.[*9] In June 2003, the Supreme Court denied a petition for review of the case[*10].

The decision in this case is likely to have major implications for the research community in the United States. Faced with this situation, many researchers and firms may choose to invest resources in less promising projects with fewer licensing obstacles and lower initial start-up costs. In addition, some researchers and developers, especially in universities, may be ill equipped to handle the multiple transactions necessary for acquiring the rights to research tools. It may also encourage academic research to be diverted to foreign institutions in countries with broader experimental use exceptions or the absence of patent coverage.

3 Reform Options

Given the situation noted above, instead of spurring investment and product development, more intellectual property rights may lead to fewer useful products for improving human welfare. At the least there is a need to clarify the scope of the experimental use exception in many jurisdictions so as to eliminate uncertainty. There would also be many advantages in establishing more uniform provisions across countries consistent with the requirements of the TRIPS Agreement. It is the view of this author that the provisions of a statutory research use exemption should also be broadened to cover research using a patented invention. Options for reform of experimental use defenses are under consideration in several jurisdictions. The American Association for the Advancement of Science has recently initiated a project to evaluate these proposals so as to ascertain which would be the most conducive to encouraging scientific research and innovation.

Notes

*1 Committee on Issues in the Transborder Flow of Scientific Data of the National Research Council, Bits of Power: Issues in Global Access to Scientific Data, (Washington, D.C.: National Academy Press, 1997), pp. 17, 133.

*2 Amy E. Carroll, “A Review of Recent Decisions of the United States Court of Appeals for the Federal Circuit: Comment: Not Always the Best Medicine: Biotechnology and the Global Impact of U.S. Patent Law,” The American University Law Review 44 (Summer, 1995): n.24.

*3 Eliot Marshall, “Secretiveness Found Widespread in Life Sciences,” Science 276 (25 April 1997), p.525

*4 Michael A. Heller and Rebecca S. Eisenberg, “Can Patents Deter Innovation? The Anticommons in Biomedical Research,” Science 280 (1 May 1998), pp. 698-701.

*5 Travis J. Lybbert, “Technology Transfer for Humanitarian Use: Economic Issues and Market Segmentation Approaches,” IP Strategy Today 5 (2002): 18.

*6 Quoted in Australian Law Reform Commission, Gene Patenting and Human Health, Discussion Paper 68 (February 2004), p. 388, 14.43.

*7 Patent Law No. 121 of April 13, 1959, as amended by Law No. 220 of December 22, 1999, cited in Nuffield Council on Bioethics, The ethics of patenting DNA: a discussion paper (London, 2002), p. 61.

*8 35 U.S.C. 271(e) (1).

*9 Madey Duke 307 F 3rd 1351 (2002).

*10 Duke University v Madey No. 02-1007 (Supreme Court of the United States 2003).

(End of Dr. Chapman’s paper)

Acknowledgments

In drafting this report, Dr. Koichi Sumikura, Associate Professor at the National Graduate Institute for Policy Studies, provided valuable input. We express our gratitude to Dr. Sumikura.

References

[1] Ryu Takabayashi, “Standard Patent Law,” Yuhikaku, 2002 (in Japanese)

[2] Ichiro Nakayama, “The Relationship between Patent Right and ‘Freedom of Experiment’ from a Japan-US comparative perspective; History and Problems in ‘Exemptions in Experiments/Research Activities,’” AIPPI, Vol 48, No.6, pp.436-472 (2003)

[3] AAAS, Science and Intellectual Property in Public Interest (SIPPI): http://sippi.aaas.org/about/

[4] “Impacts from Narrower Scope of Experiment/Research Use Exemption from Intellectual Property Right Claims in the US: How We Should Reconcile Intellectual Right Protection with Smooth Research Activities?” Science & Technology Trends, March 2004 Issue (in Japanese) :

[5] AAAS Annual Meeting: http://www.aaas.org/meetings/

[6] Michael A. Heller and Rebecca S. Eisenberg, “Can Patents Deter Innovation? The Anticommons in Biomedical Research,” Science, Vol.280 pp.698-701 (1998)

[7] Japanese script of Michael A. Heller and Rebecca S. Eisenberg, “Can Patents Deter Innovation? The Anticommons in Biomedical Research” translated by Masako Wakui, Journal of JIPA, Vol.51, No.10 (2001)

[8] Bio Venture. Vol.2, No.2 (2002)

[9] The 6th and 7th document materials circulated at Patent Strategy Planning-related Issues Working Group, Patent System Subcommittee, Task Force on Intellectual Property Policy, Industrial Structure

Council, METI (January 20, 2004) 8 (in Japanese)

Explanation

• *(The tragedy of) The anticommons*

"The tragedy of the anticommons" means that excessive private property right protection of research outcomes will fragment intellectual property rights and prevent their effective utilization because there will no right holders who are able to utilize them effectively[6,7].

• *Bayh-Dole Act*

The "Bayh-Dole Act" is officially the "Patent and Trademark Act Amendments of 1980" proposed by US senators Birch Bayh and Robert Dole. This legislation allows university, NPO and small- and medium-sized enterprises to entitle their federal-government-funded inventions. In addition, if they obtain a patent and license their invention to a third party, they are required to spend their royalty income on scientific R&D activities for inventors. Because of the Bayh-Dole Act, many universities started to establish Technology Licensing Organizations (TLO) inside or outside universities. This legislation has also paved the way for universities to obtain patents for government-funded research outcomes and also to transfer their technologies based on license agreements with private corporations[8].

• *International comparison of legal frameworks in terms of "research activities exempted from patent right protection"*

Patent rights usually have certain limitations and are not applicable to research activities from the viewpoint of the patent's characteristics and of public interest[1]. Major nations have the following legal patent limitations.

i) The United States

In the United States, "experimental use exemption" originates not from statute law but from case law. "Experimental use exemption" is not applicable if the use of the patented invention is "in furtherance of the alleged infringer's legitimate business" and is not "solely for amusement, to satisfy idle curiosity, or for strictly philosophical inquiry."[9]

ii) The United Kingdom

Section 60(5) of the UK Patents Act states that "An act which...would constitute an infringement of a patent for an invention shall not do so if (a) it is done privately and for purposes which are not commercial; or (b) it is done for experimental purposes relating to the subject-matter of the invention..."

iii) Germany

Article 11 of German Patents Act stipulates that "The effects of a patent right shall not extend to (a) acts done privately and for non-commercial purposes; or (b) acts done for experimental purposes relating to the subject-matter of the patented invention..."

iv) France

Article 613, Paragraph 5 of France's Intellectual Property Act sets out that "The effects of a patent right shall not extend to (a) acts done privately and for non-commercial purposes; or (b) acts done for experimental purposes relating to the subject-matter of the patented invention..."

v) Japan

Patent rights are only applicable for using patentable inventions for "business purposes." This concept refers to the use of patentable inventions that do not fall under the "use of patentable inventions that is unrelated to industry, in other words, for personal use or family use."

Article 69, Paragraph 1 of Japan's Patent Law states that "the effects of the patent right shall not extend to the working of the patent right for the purposes of experiment or research." While the Japanese courts have not yet clearly expressed an interpretation in this regard, influential scholars argue that experimental use exemption should apply only to "activities that aim for technical progress," such as patentability investigation, the investigation of functions and experiments for improvement/development purposes[9].

• *Madey v. Duke University*

In this court trial, the US Supreme Court expressed its judgment on "experimental use exemption." The plaintiff filed for an injunction on the grounds that Duke University's experiments and research activities would infringe another person's rights.

Professor Madey at Duke University installed some equipment in his laboratory. Several pieces of equipment in Madey's laboratory were covered by patents owned by Madey. Duke continued to use the laboratory's equipment even after his resignation. Based on this unauthorized use of his patents, Madey sued Duke for patent infringement. However, Duke argued that the university is a non-profit organization that provides education and that its continued use of the equipment falls under "experimental use exemption."

The district court judged that Duke's use of the equipment fell under "experimental use exemption," but at appeal court level, the Federal Circuit Court denied Duke's logic. In short, making clear its intent to limit the "experimental use exemption" strictly to activities that are "solely for amusement, to satisfy idle curiosity, or for strictly philosophical inquiry," the court noted that, regardless of whether a particular institution or entity is engaged in endeavors for commercial gain, as long as the act furthers "the alleged infringer's legitimate business," the act does not qualify as the very narrow and strictly limited "experimental use exemption." (See Madey v. Duke University, 307 F.3d 1351 (Fed.Cir2002).)

In response to this ruling, Duke University filed a final appeal to the US Supreme Court, but the Supreme Court refused to grant a review in June 2003. (See Duke University v. Madey No. 02-1007 (Supreme Court of the United States 2003).)[9]

• *The TRIPS Agreement (Agreement on Trade-Related Aspects of Intellectual Property Rights)*

The TRIPS Agreement, which became effective on January 1, 1995, sets out the minimum requirements for WTO member nations in terms of patents and other intellectual property protection.

In terms of experiment/research exemptions, Article 30 stipulates that there are "Exceptions to Rights Conferred," stating, "members may provide limited exceptions to the exclusive rights conferred by a patent, provided that such exceptions do not unreasonably conflict with normal exploitation of the patent and do not unreasonably prejudice the legitimate interests of the patent owner, taking account of the legitimate interests of third parties."

(Original Japanese version: published in August 2004)

About SCIENCE AND TECHNOLOGY FORESIGHT CENTER

It is essential to enhance survey functions that underpin policy formulation in order for the science and technology administrative organizations, with MEXT and other ministries under the general supervision of the Council for Science and Technology Policy, Cabinet Office (CSTP), to develop strategic science and technology policy.

NISTEP has established the Science and Technology Foresight Center (STFC) with the aim to strengthen survey functions about trends of important science and technology field. The mission is to provide timely and detailed information about the latest science and technology trends both in Japan and overseas, comprehensive analysis of these trends, and reliable predictions of future science and technology directions to policy makers.

Beneath the Director are five units, each of which conducts surveys of trends in their respective science and technology fields. STFC conducts surveys and analyses from a broad range of perspectives, including the future outlook for society.

The research results will form a basic reference database for MEXT, CSTP, and other ministries. STFC makes them widely available to private companies, organizations outside the administrative departments, mass media, etc. on NISTEP website.

The following are major activities:

1. Collection and analysis of information on science and technology trends through expert network

— STFC builds an information network linking about 3000 experts of various science and technology fields in the industrial, academic and government sectors. They are in the front line or have advanced knowledge in their fields.

— Through the network, STFC collects information in various science and technology fields via the Internet, analyzes trends both in Japan and overseas, identifies important R&D activities, and prospects the future directions. STFC also collects information on its own terms from vast resources.

— Collected information is regularly reported to MEXT and CSTP. Furthermore, STFC compiles the chief points of this information as topics for “Science and Technology Trends” (monthly report).

2. Research into trends in major science and technology fields

— Targeting the vital subjects for science and technology progress, STFC analyzes its trends deeply, and helps administrative departments to set priority in policy formulating.

— STFC publishes the research results as feature articles for "Science Technology Trends" (monthly report).

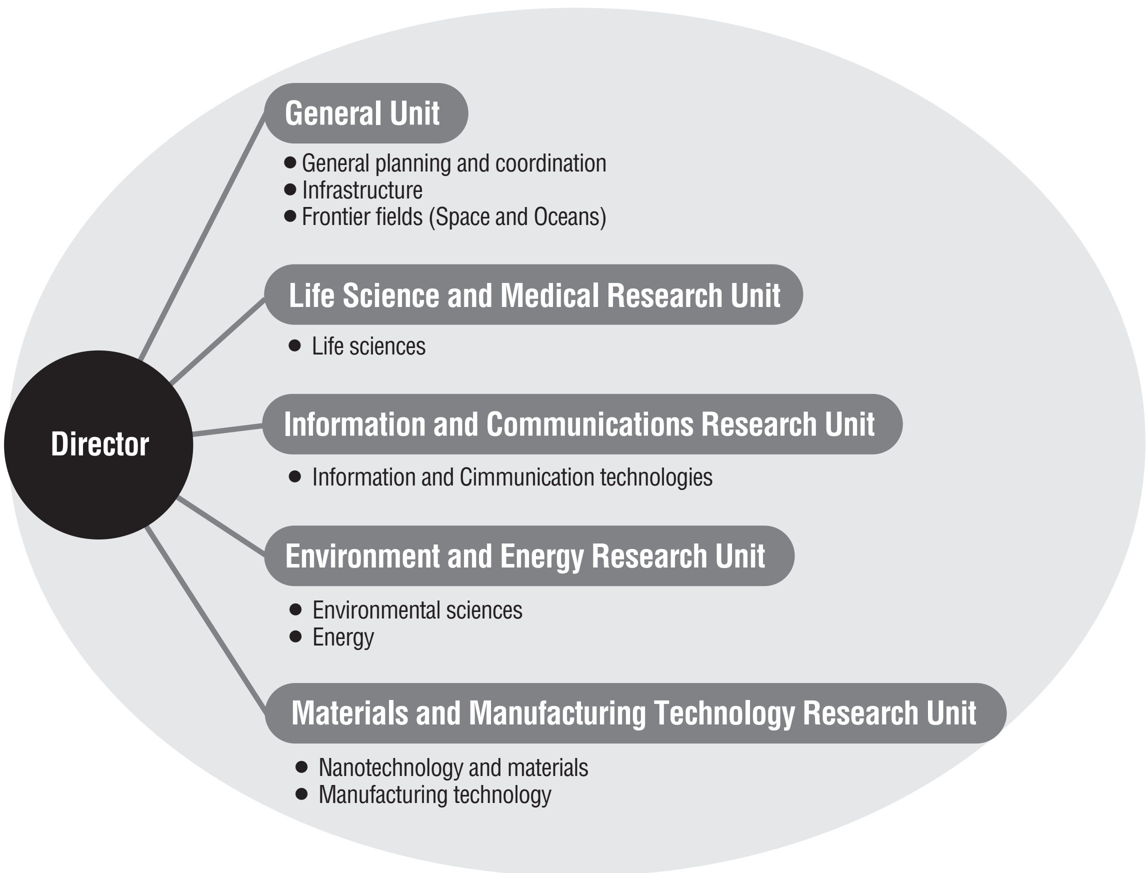
3. Technology foresight and S&T benchmarking survey

— STFC conducts technology foresight survey every five years to grasp the direction of technological development in coming 30 years with the cooperation of experts in various fields.

— STFC benchmarks Japan's current and future position in key technologies of various fields with those of the U.S and major European nations.

— The research results are published as NISTEP report.

Organization of the Science and Technology Foresight Center



＊Units comprise permanent staff and visiting reseachers (non-permanent staff)
＊The Center's organization and responsible are reviewed as required

- Life Sciences
- Information & Communication Technologies
- Environmental Sciences
- Nanotechnology & Materials
- Energy
- Manufacturing Technology
- Infrastructure
- Frontier
- Science & Technology Policy

Science and Technology Trends —Quarterly Review

No.14 January 2005

Science & Technology Foresight Center
National Institute of Science and Technology Policy (NISTEP)
Ministry of Education, Culture, Sports, Science and Technology, JAPAN