Chapter 2 The Direction of Japan's Efforts towards Realizing a Super Smart Society (Society 5.0)

For Japan to be the first country in the world to achieve a super smart society, what efforts will be necessary under the 5th Science and Technology Basic Plan? In this chapter, towards realizing a super smart society, we consider the direction of future efforts to be taken by Japan from three perspectives: R&D, environmental improvement and human resource development.

Section 1 Promotion and Systemization of R&D that Supports a Super Smart Society

With the rapid development of ICT, cyberspace has been rapidly integrated with real space. This section describes the history and the current state of the technology that led to this situation, Japan's strengths and weakness, and efforts in R&D and its systematization. Then we will clarify the direction to be taken by Japan.

1 History and Current State of Core Technology for a Super Smart Society

What scientific and technological innovations have brought us to this point? Needless to say, there have been great numbers of scientific and technological innovations, each of which has developed in interaction with others to bring us to the current situation. Looking back at the history of such development will provide context for the current situation of technologies that have played important roles.

(1) History of the development of computer technology

(Focusing on hardware)

Computers, including those that are used for business and entertainment, have become indispensable to our lives. "Computer" means "calculator." The origins trace back to the board-like abacus of Ancient Greece. In other words, the history of computers is the history of the humans who worked with numbers. In the early 20th century, calculators evolved into mechanical or electrical-mechanical calculators with relay circuits.

From the late 1930s to the early 1940s, electronic calculators using vacuum tubes appeared. The vacuum tube calculators of that time are called first-generation computers. Such electronic calculators were used as digital computers and were manufactured by combining logic circuits. They handled numbers only in binary (i.e., 0's and 1's). With analog computers, it was necessary to change the circuits according to what was being calculated, and there was a limit to the accuracy of the results. With the sophistication of electronic calculators, analog computers gradually became obsolete.

With the invention of semiconductor devices such as diodes[1] and transistors[2], circuits were

1 An electronic device that allows current to flow in only one direction (rectification)
2 An electronic device that amplifies current

miniaturized and accelerated. Electronic computers with transistors, which were released in the late 1950s and early 1960s are called second-generation computers. Programming languages were actively developed.

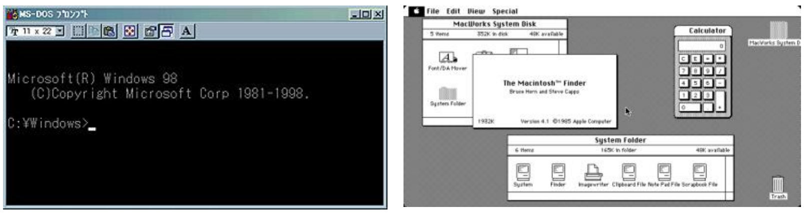
Furthermore, the integrated circuit (IC), in which wiring and circuit elements are applied to a semiconductor substrate, was put into practical use in 1961 in the United States. After that, the centralization, miniaturization and sophistication of circuits realized the large-scale integrated circuit (LSI) and the very-large-scale integrated circuit (VLSI). Computers with integrated circuits that appeared from the mid 1960s to the mid 1970s are called third-generation computers. The processing speed was increased[1].

The microprocessor-based computers used today are fourth-generation computers. Computers from the first generation to the fourth generation have employed the von Neumann architecture computers, in which the system uses a stored program. These machines store programs in a storage device and process the data while sequentially reading the program. This computer architecture has not changed in today's computers, smart phones and tablet terminals.

(Focusing on software and interaction)

Computers of the first and second generations were far from intuitive to operate. The human-computer interface was improved, and the mouse was developed in the 1960s in the United States.

With increases in computer processing speeds and the diversification of peripheral devices, the importance of the operating system (OS) has been growing. An OS is a basic program for operating a computer and the various devices connected to it. It realizes smooth information processing. The first operation system (OS) was developed by International Business Machines (IBM) Corp. in the U.S.A. in 1964, in the age of third-generation computers. In the 1970s, the IBM Corp. commissioned Microsoft Corp. of the U.S.A. to develop an OS that would be installed in IBM in-house microcomputers. MS-DOS[2], which had a command-line interface[3], was developed.



MS DOS interface (left) and Mac OS GUI (right)

Source: Created by MEXT based on the website of IPA

In 1972, Dr. Alan Kay, a computational scientist in the United States, presented the concept of the personal computer. In 1973, the Alto debuted. It had a GUI[4] and is the ancestor of the current personal computer. In 1984, the Macintosh, a personal computer equipped with an OS and a GUI was made available by Apple Computer, Inc. in the United States. With the advent of the GUI, a user-friendly environment that allowed the average person to use a computer was realized. As prices for devices came down, personal

1 The processing speeds of first-generation computers were measured in milliseconds (10^{-3}), those of second-generation computers in micro-seconds (10^{-6}), and those of third-generation computers in the nanoseconds (10^{-9}). This means that a 1,000-fold increase in speed was achieved with each successive generation. Today's computers are fourth-generation computers. Their processing speeds are measured in picoseconds.

2 Microsoft Disk Operating System

3 Also called a "character user interface." Input is done by keyboard, and the character output is shown on a display. No pointing devices, such as mouses, are used.

4 Graphical User Interface. A Graphical User Interface. This interface allows intuitive operation through the use of pointing devices such as mouses or touch pads.

computer use exploded.

The Nintendo Family Computer debuted in Japan in 1983, one year before the Macintosh appeared. It was regarded as having realized an interface far surpassing those of the personal computers of the day in terms of graphics sound effects. Interfaces were developed for video games. For example, a stylus was used to play games on the Nintendo DS (2004), a remote control unit equipped with an accelerometer was used to play games on the Wii (2006), and other such interfaces appeared. In addition, the iPhone from Apple Inc., which debuted in 2008, has an interface in which a touch panel is operated by finger. This interface has become pervasive everyday life.

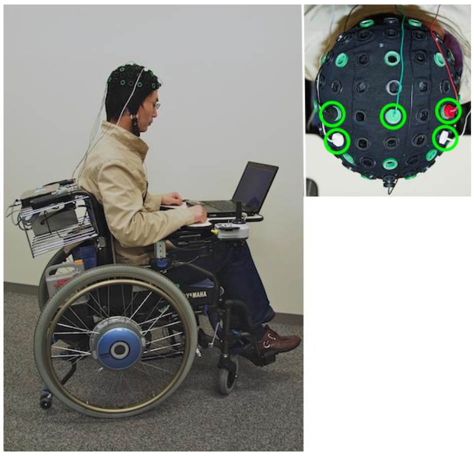
Moreover, the media that are handled by computers have increased, and forms of expression have expanded from numerals to text, then on to audio and still images, and finally to video. Computers have come to have various everyday uses, surpassing their initial limits of abacus-like "machines for calculating numerical values".

(Today's computers)

Today's computers have made progress in miniaturization and acceleration, but they have also changed in terms of style and use. It has become possible to use computers anywhere, any time in daily life. Furthermore, devices that have specific purposes, such as phones and audio players, have been consolidated in a smartphone or other single devices. Also, the performance of devices has been improved by giving them computer functions or by installing onboard computers in them.

The design concept of enhancing and improving device functions by adding and/or improving software without changing the components and hardware has become mainstream. So merely by adding and/or improving software, we can use devices with the latest functions and features that we once would have had to replace.

In addition, since many of these devices are equipped with communication capabilities, they provide new value and functions that cannot be provided by a conventional single device. For example, they provide information via data linkage and they enable the coordinated control of multiple devices (e.g., the control of a lighting fixture and an air conditioner and the operation of a web camera for watching a pet).



A BMI is used to control a wheelchair in real time

Source: RIKEN

Also, user interfaces have been made more sophisticated. For example, speech recognition technology that enables text to be input by voice into a computer or smartphone, and line-of-sight detection technology that enables what a user wants to see to be displayed onscreen by detecting the user's line of sight have been put into practical use. In addition, brain-machine interface (BMI) technologies that use computers to decode brain signals and that allow external devices to be operated by the mind have been studied, and the technologies are expected to be applied in medicine and social welfare. As seen above, a multi-modal approach in which combined signals, such as voice, line of sight, gestures, and brain waves generated by a person which are conveyed to the computer, has attracted attention.

In addition, media on computers have entered real space. The invention of 3D printers has made it possible to output three-dimensional objects. Such 3D output follows inventions that enabled text, sound and video output. In projection mapping, images are projected onto buildings and other 3D objects or onto other uneven surfaces and the appearance of the real object is synchronized with the images. In recent years, it has drawn attention as a new method of visual expression. It has been used at domestic and international events and at concerts. Furthermore, technologies such as those involving virtual reality (VR) and augmented reality (AR) have been developing, and new services and products are expected to be created.

Projection mapping on the wall of the Tokyo National Museum

Source: "KARAKURI" 3D projection mapping (Rakuchu-Rakugai-zu Byobu (Funaki version), registered as an Important Cultural Property and owned by the Tokyo National Museum ©NAKED Inc./NTV)

(2) History of the development of network technology

(The age of the telegraph and telephone, telecommunications liberalization and the spread of mobile phones)

In 1854 when Commodore Matthew Perry made his second visit, telegraphic instruments were first introduced to Japan. Furthermore, a telephone exchange opened in Japan in 1890, only 14 years after the 1876 invention of the telephone in the United States. The national government operated a telephone exchange until the end of World War II. After the war, telegraph and telephone services were operated by the Nippon Telegraph and Telephone Public Corp. under the supervision of the Ministry of Posts and Telecommunications.

The practical application of new technologies such as optical fiber and communication satellites required telecommunications liberalization, which was realized in 1985. According to an article on telecommunications liberalization that appeared in the 2015 White Paper on Information and Communications in Japan, in the 10 years since the introduction of competition due to liberalization, a number of businesses entered the telecommunications market, and cost reductions and diversification of services occurred as a result of competition among them.

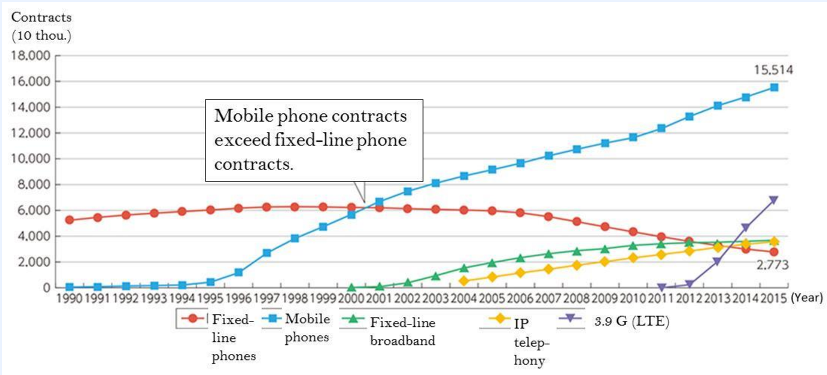
At present, mobile phones play a leading role in voice communication services, rather than land lines. Mobile phone subscribers have increased rapidly since 1995, when the personal handy-phone system (PHS) service started. Subscribers to mobile phone services exceeded subscribers to land line services from 2000 (Figure 1-2-1)[1]. In 1999, it became possible for mobile phones to connect to the Internet. Toward the end of 2005, the number of people who were using mobile phones and other mobile terminals to access the Internet exceeded the number of people who were using personal computers to access the Internet[2].

1 2015 White Paper on Information and Communications in Japan
2 2015 White Paper on Information and Communications in Japan

Furthermore, in 2000, mobile phones with a positioning function and onboard camera appeared. They began to play the role of more than just a phone.

In addition, in conjunction with the commercialization of smartphones and tablet devices, 3G networks, which started service in 2001 in Japan before any other country, and 3.9G (LTE [1]) networks, which started service in 2010, have spread.

■ Figure 1-2-1 / Changes in the number of subscribers to communications services



Source: Figure 1-1-2-4, Chapter 1, White Paper on Information and Communications 2015, MIC (P14)

(Emergence of the Internet)

In 1958, the Advanced Research Projects Agency (ARPA) was established under the supervision of the United States Department of Defense in order to carry out cutting-edge military research. At ARPA, research on the networking of computers scattered around the United States was also carried out. In 1968, a networking project called the ARPANET project was launched. The ARPANET interconnected the computers at the University of California at Los Angeles (UCLA), University of California at Santa Barbara (UCSB), Stanford University, and the University of Utah in addition to computers at the United States Department of Defense. The number of computers connected increased over the years, and the scale expanded.

In 1981, with the aim of interconnecting the ARPANET with computers at other universities, the operation of the CSNET [2] for academic research networking was initiated by the National Science Foundation (NSF). Then, the NSFNET was established in 1985 to interconnect supercomputers at five locations in the United States via high-speed lines. At that time, other networks had been built around the world. In Japan, the JUNET [3], for research networking, was built in 1984 by the University of Tokyo, the Tokyo Institute of Technology and the Keio University. The NSFNET had played a role as a network among networks (a backbone), one that connects these individual networks. As a result, a network covering the whole world was being developed.

The World Wide Web (WWW) was invented in 1990, thereby enabling web pages and multimedia data to be transmitted, received and browsed. This is the foundation of the current information society. In addition, in 1992, the Scientific and Advanced-Technology Act of 1992 and other acts passed by the US Congress allowed the NSFNET to be used for commercial use, which had previously been banned. As a

1 Long-Term Evolution: A communication standard that enables mobile telephone networks to transmit data as fast as broadband networks.
2 Computer Science NETwork
3 Japan University NETwork

result, Internet service providers (ISPs) emerged, and connection to the Internet by the public was promoted[1]. In this way, from the 1990s to the 2000s, a worldwide network was built, and it led to the Internet of today.

Initially, the average user in Japan accessed the Internet by dial-up connection using a telephone line. DSL[2] was introduced in 1999, and FTTH[3] service using optical fiber was introduced in 2001, a first in the world. The spread of these broadband services has made the Internet environment in Japan develop rapidly.

On the other hand, with the recent increases in devices that provide access to the Internet, the network ran out of IP addresses in February 2011[4]. To address the situation, a transition to IPv6[5] has been progressed.

(Expansion of the Internet, and big data generated by the IoT)

With the expansion of the range of Internet users, the concept of Web 2.0[6] began to emerge in the mid 2000s. It had two distinguishing features[7]: participatory media, such as blogs and SNS[8], and transparency of service providers who widely disclose their information. Since the emergence of Web2.0, even those who have no knowledge of HTML[9] or the like have been able to easily transmit information on the network. Thus, information, such as personal diaries, photos, voice data, video on blogs and SNS, and tweets on Twitter have been accumulated on the network. Further, due to the advent of the IoT, which is a network that connects all things via the Internet, data on networks are available in ever-greater amounts, and which makes them available as big data. Data generated on the network includes not only information such as e-mails and Web searches transmitted on the Internet from computers, smartphones, and mobile phones, but also location information recorded by the global positioning system (GPS) terminals, ride history recorded on IC boarding cards, purchase history recorded on membership cards, physical quantities such as temperature and pressure obtained from various sensors, and any events that are converted into data[10].

By using big data, it is possible to create different kinds of value and to acquire new knowledge. One example in Japan is the T Point member card system of Culture Convenience Club Co., Ltd. The company is affiliated with 131 businesses and about 450,000 stores, and provides four types of big data to them: the locations of members who use points, the repeat purchase rate and the purchase unit price, for 55.56 million card members. The big data has been used in the sales strategies of alliance partners. Another example is the Earthquake Disaster Big Data project of the Japan Broadcasting Corporation (NHK). The project analyzed the population and the movement of people in the inundated area during the 2011 Great East

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1 In Japan, the commercial use of the Internet started in 1993.
2 Digital Subscriber Line
3 Fiber To The Home
4 *Dealing with Exhaustion of Global IPv4 Address Inventories (press release issued in February 2011 by MIC)*
5 Internet IP addresses are currently issued under IPv4, which allows for 4,294,967,296 unique addresses. IPv6 will increase that number astronomically, raising it to the fourth power.
6 A concept propounded around 2005 by Tim O'Reilly, CEO of O'Reilly Media, a U.S.A. publisher of computer technology-related manuals and books
7 2006 White Paper on Information and Communications in Japan
8 Social Networking Service
9 Hyper Text Markup Language
10 In other words, events are converted into numerical values for aggregation and analysis.

Japan Earthquake based on location information from mobile phones, map data and time information. As a result, it became apparent that, after the earthquake, the people in the tsunami inundated area tended to return home to rescue their family "pick-up action," and other findings were obtained. These findings have been used in the planning and formulation of disaster prevention measures by municipalities.

Evacuation and rescue in Natori City and Iwanuma City, Miyagi Prefecture

Blue: Evacuees who left the inundated area. Green: People who entered the inundated area after the earthquake.
Red: People who stayed in the inundated area.

Source: NH

Factors contributing to the realization of the big data age are high-speed computers, large-capacity memory and sophisticated software. In addition, one of the key technologies can be said to be distributed computing (or grid computing)[1]. To process huge amounts of data as big data, enormous computational resources are required. Distributed computing enables the analysis of big data by utilizing countless general-purpose computers on the network as massive computational resources. Furthermore, with the sophistication of distributed computing, computing resources have been provided as external services. As a result, it is possible for users to obtain the required computational resources when necessary and as needed, without establishing a server environment by themselves (cloud computing).

(3) History of the development of robot technology

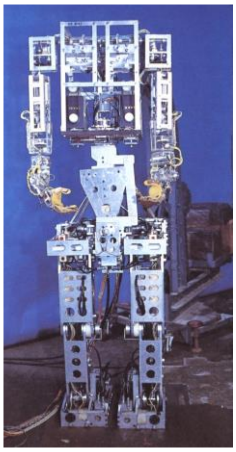
The history of robotics dates back to European automata, which were mainly made from the 18th century to the 19th century, and to the Japanese karakuri (mechanical) dolls that were actively made in the Edo era (1603-1868). After the 20 century, in 1954, a robot with the ability to pick up and put down objects was patented in the United States. The concept of the industrial robot was born. During the Second World War, control technology was developed, including feedback control[2], and this enabled more accurate movement.

In 1973, WABOT-1, the world's first humanoid robot, was developed at Waseda University. In 1969, Kawasaki Heavy Industries, Ltd. launched the Kawasaki-Unimate 2000, the first industrial robot in our county. Industrial robots gained popularity in the 1980s. In addition, along with the spread of industrial robots, the practical application of robots has progressed in daily life, in work at disaster sites that would be difficult for a human, and in substituting for lost physical functions (e.g., artificial legs and artificial hands).

1 Develop Big Data, September 2015, supervised by Masao Sakauchi, published by Kadokawa Gakugei Shuppan and The Shock of Big Data, July 2012, published by Toyo Keizai Inc.

2 A control method in which outputs are incorporated into calculations for successive outputs

In 1999, AIBO, a robot pet, was released by Sony Corporation. AIBO had a built-in program to mechanically learn things from its experiences and from training by users. AIBO comforted users, and users felt the "mind" of the robot. In 2000, ASIMO, a robot that achieved smooth bipedal motion, was released by Honda Motor Co., Ltd. ASIMO is equipped with intelligent real-time flexible walking technology that features a real-time center-of-gravity shift in anticipation of the next movement. It moves smoothly by controlling the zero moment point[1]. ASIMO became run enabled in 2004, and multiple ASIMOs became able to efficiently synchronize their movements over a network in 2007.



WABOT-1

Source: Humanoid Robotics Institute, Waseda University

In recent years, the need for nursing care has been growing in conjunction with rapid demographic aging. In light of this, a powered exoskeleton called Robot Suit HAL[2] (Hybrid Assistive Limb) developed by Professor Yoshiyuki Sankai at the University of Tsukuba has been put into use at medical and social welfare settings to improve, assist and extend the physical functioning of persons. In addition, it is nearly impossible for humans work at the accident site of the TEPCO Fukusihima Daiichi Nuclear Power Station, because of the high radiation level and rubble, so robots have recently been used to monitor the interior of the reactor building, remove rubble and the like.

ASIMO

Source: Honda Motor Co., Ltd.

In addition, with regard to industrial robots, collaborative robots that are capable of working with people have been put to practical use. For example, the CR-35iA, a collaborative robot produced by FANUC Corp. in 2015, and the Co-robot CORO, produced by Life Robotics Inc. in 2015, can work with people without a safety fence. In addition, NEXTAGE, produced by Kawada Robotics Corp. in 2011, has a structure that mimics the upper body of a human, and the robot can perform tasks that were previously done by human workers.

The humanoid robot NEXTAGE

Source: Glory Ltd.

Furthermore, the use of robots has become popular even in our daily life. For example, fully automatic washing machines, dishwashers, automatic ticket checkers and the Yurikamome fully automated transit

1 The point where the resultant force of gravity plus the inertial force of a bipedally moving robot acts on a road surface "Zero moment point" is abbreviated as ZMP.
2 The details are described in the White Paper on Science and Technology 2015.

system can be said to be robots in the broad sense. In 2010, iRobot Corporation of the United States released the Roomba, a vacuum cleaning robot, in Japan, too. Japanese manufacturers have released cleaning robots one after another. In addition, in 2015, Soft Bank Corp. launched Pepper, a personal robot that recognizes a person's emotions.

Research has been underway on the relationship between robots and humans. Professor Hiroshi Ishiguro at the Graduate School of Osaka University conducted research on overcoming the "uncanny valley" before a more lifelike robot is developed to interface with people. His androids are considered lifelike enough to be called human. However, it is difficult even now to reproduce subtle facial expressions, such as those of shyness and bitter smiles. These androids have come into use in media including TV programs and advertisements. New uses for them are being considered.

Professor Ishiguro with the his android Geminoid HI-4

Source: Osaka University

Conventional definitions of industrial robots, such as those seen in the Japanese Industrial Standards, describe them as machines with sensors, an intelligent control system and a drive system. However, according to the Japan's Robot Strategy compiled in February 2015, since there is the possibility that robots will evolve innovatively in the future, conventional definitions are unable to cover the current situation of robots.

(4) A history of the development of artificial intelligence technology

It is said that artificial intelligence technology had two boom times and two winters, and now it is in the third boom. In 2011, IBM's artificial intelligence platform Watson defeated the human champions of a TV quiz show. Artificial intelligence based programs have defeated professional champions of shogi in 2012 and that of igo in 2016, and demonstrating capabilities which overwhelmed people. For Japan, a project called "Can a Robot Get into the University of Tokyo?" has been led by the National Institute of Informatics (NII) since 2011. Under the industry-university-government collaboration, they study core technology, such as "summarizing the content," "deep language comprehension," and "robot-human collaboration" that can provide a breakthrough for the integrated artificial intelligence software aimed at the robot passing the entrance examination of the University of Tokyo in FY 2021.

The term "artificial intelligence" comes from the 1956 Dartmouth Conference. The period of the first artificial intelligence boom is considered to be 1956 to the 1960s. The artificial intelligence of those days consisted of ability to process natural languages through programs in which they could maintain a dialogue with patients and makes inferences and searches to prove mathematical theorems.

During the second artificial intelligence boom, in the 1980s, expert systems that used artificial intelligence with access to massive data were developed to offer appropriate solutions to real issues. In 1982, a project to develop a fifth-generation computer was launched in Japan, ahead of other countries. The project contributed to the strengthening of the foundation for artificial intelligence research in Japan.

The artificial intelligence worked properly within the scope of rules (programs) taught to a computer by humans; however, it was unable to respond to unexpected events that can occur in the real world. There were more issues with regard to artificial intelligence. For example, because it was hard for artificial intelligence to understand definitions (such as "An apple is a fruit") in the real world, humans had to always feed definitions to the computer.

Later, because vast amounts of big data have been created on networks with the development of the Internet and because the computing power of supercomputers has dramatically improved, the concept of using statistics and probability theory to find the most probable solution from a flood of data was introduced; thus, dramatic advances in artificial intelligence have been realized. It is the development of machine learning technology that has contributed greatly to the advancement of artificial intelligence.

Just as humans learn from experience, machine learning technology learns rules and knowledge by processing large amounts of data. For instance, when classifying e-mails as spam, artificial intelligence is given spam e-mail samples to educate the artificial intelligence in how to determine what spam is. It is also known that accuracy of machine learning in finding a correct answer is very high, but it reaches answers stochastically, so it cannot achieve 100% correctness in its answers.

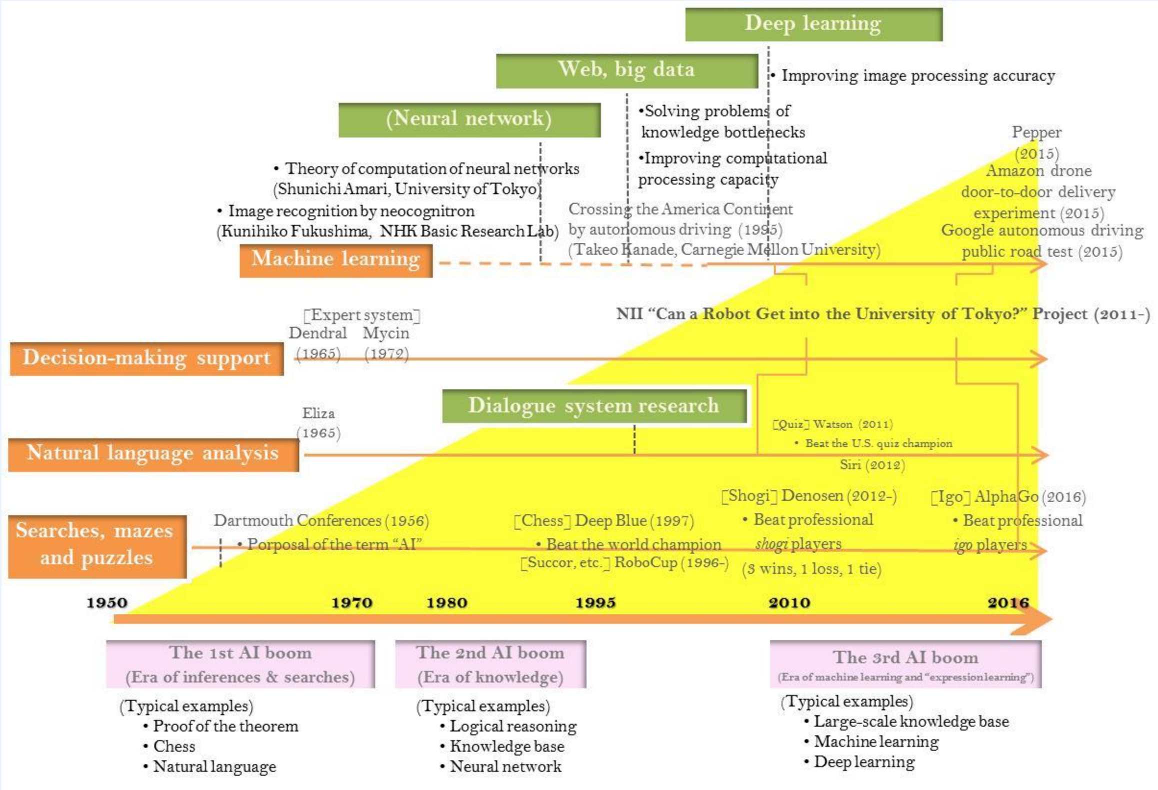
In 2012, deep learning appeared, dramatically improving the applicability of machine learning. Deep learning uses a large-scale artificial neural network that mimics the human brain. It learns by acquiring higher-order concepts every time information is processed at neurons[1]. For example, a computer that uses this technique to recognize the image of an object can acquire the concept of that object. In 2012, Google Inc. in the United States and Stanford University conducted an experiment in which they randomly loaded a large number of images from the Internet onto a computer. It was reported that the neural networks built in the computer acquired the concept of cat.

With the advent of deep learning, it has become possible to realize things that could only be conceptualized until now. Industrial robots have engaged in predetermined routine work under unchanging or minimally changing environments, such as those of factories. However, it is believed that deep learning will enable industrial robots to do various tasks involving the handling of natural objects that conventional artificial intelligence could not do. In addition, reinforcement learning effectively enables artificial intelligence to interact in real space. In such leaning, the artificial intelligence observes the surrounding environment and finds the best behaviors through repeated trial and error. In other words, success is rewarded and failure is penalized. In combination with deep learning, reinforcement learning has

The origin of the current deep learning is the stochastic gradient descent developed by the research group of Dr. Shun'ichi Amari[2] and the neural network developed by the research group of Dr. Kunihiko Fukushima[3]. In other words, Japanese researchers have been at the forefront in contributing to basic research on artificial intelligence (Figure 1-2-2).

1 A framework under which information processing modes are attempted to be built by modeling them on the human brain Human brains consist of large numbers of neurons and synapses for memorization and learning. This framework is an attempt to reproduce the complex mechanisms of the human brain on computers.
2 Special adviser to the RIKEN Brain Science Institute, Visiting Professor at Future University Hakodate, and Professor Emeritus, the University of Tokyo
3 Senior Research Scientist, Fuzzy Logic Systems Institute

■ Figure 1-2-2 / History of artificial intelligence technology



Source: Produced by MEXT from a document from Associate Professor Yutaka Matsuo at the University of Tokyo and a document from National Institute of Science and Technology (NISTEP)

Column 1-3

What is deep learning?

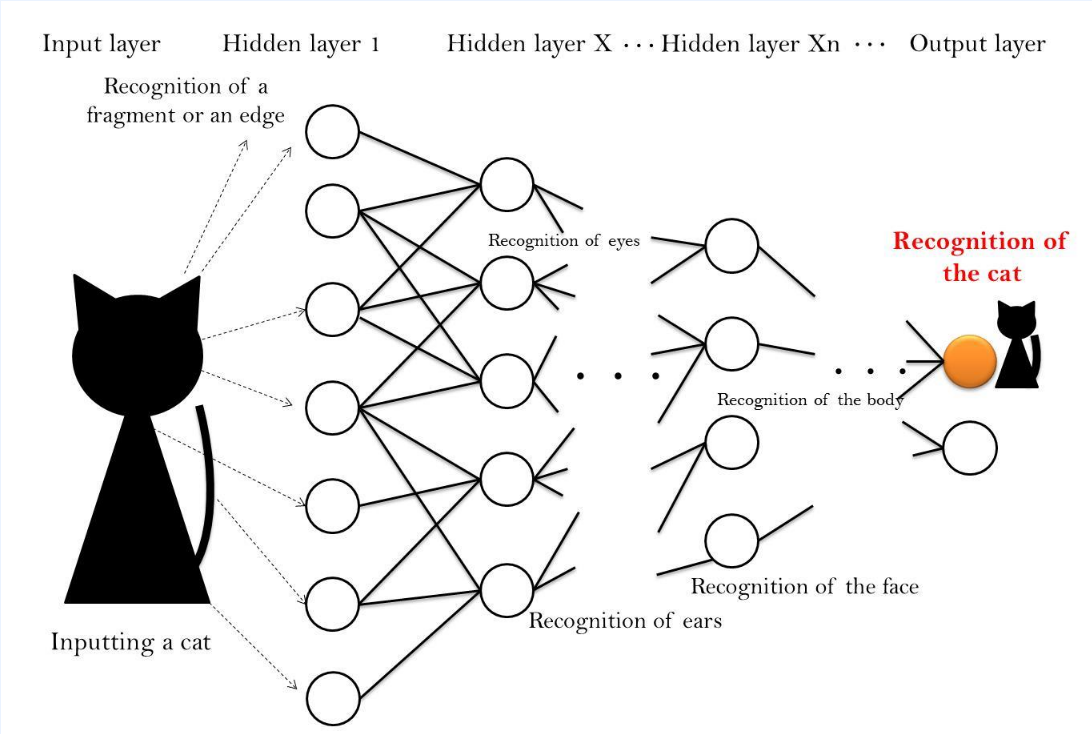
Has it become more common to hear the term "deep learning"? Deep learning is said to be the biggest breakthrough in artificial intelligence research in 50 years. It dramatically contributes to artificial intelligence's potential.

Deep learning is a technology that was created by applying the results of neuroscience research (neural networks) conducted by Professor Hinton and his colleagues at the University of Toronto (Canada) to artificial intelligence research. Deep learning was proposed by the professor in 2006. This was spotlighted at an international image recognition competition in 2012, because the University of Toronto team, which was participating for the first time, won first prize with an overwhelming performance that relied on deep learning technology. A neural network is a mathematical model that attempts to use a computer to simulate some of the characteristics of brain function.

A conventional neural network is formed in three layers: the input layer, the hidden layer and the output layer. The neural networks in deep learning have multiple hidden layers. Information on the object input to the input layer is abstracted, then, it goes to the hidden layers close to the input layer, and the layer recognizes the fragmentary information of the object. Fragmentary information in this context means a simple structure, such as a diagonal line and a curve. Thus, a recognized lower-order concept goes to the next layer, where it is combined with other concepts recognized in other hidden layers. Therefore, it is possible to recognize more advanced concepts. For instance, the lines and contours that make up a cat's ear are first recognized, and then the cat's ear is recognized by combining the recognized concepts. Similarly, the eyes, mouth and the like are recognized, and finally the cat's face is recognized, and so on.

Through repeated learning using a large number of data, deep learning extracts a certain amount of characteristics to perform image recognition, speech recognition, control and the like. It is a machine learning method that has achieved significant results--comparable to those achieved by humans in some areas.

■ Figure 1-2-3 / Schematic of image recognition in deep learning



Source: Adapted by MEXT from the book *Will Artificial Intelligence Surpass Humans? What Lies Ahead for Deep Learning*, by Yutaka Matsuo

2 The Strengths and Weaknesses of Japan

With the development of artificial intelligence, big data and the IoT, a major change has been brought about in our country's economy and society. We analyze the country's strengths and weaknesses, and then discuss the direction of future efforts.

① The strengths of Japan

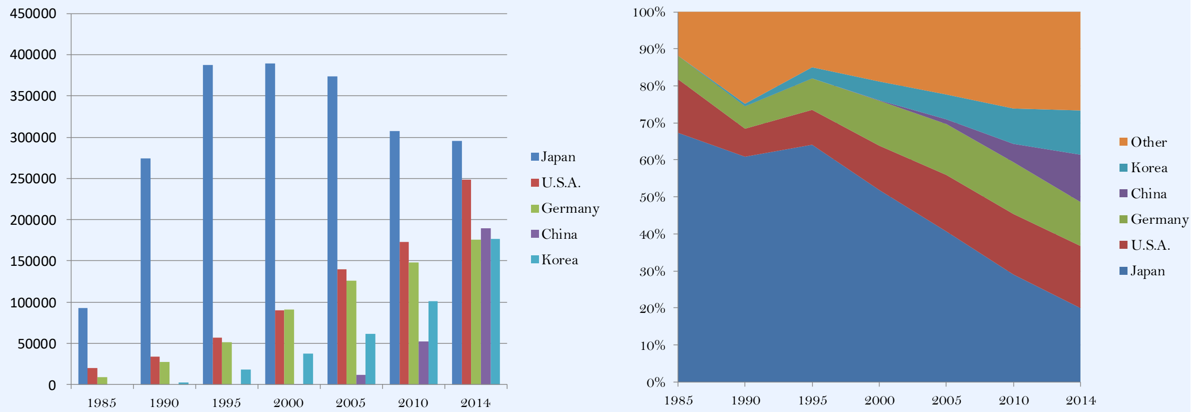
After the Second World War, Japan focused on catching up with industry in Western countries. Based on technologies owned by countries that were far more developed than Japan, our county enhanced its production efficiency, developed its manufacturing technology, and applied that technology to the production of sophisticated products. Then it achieved high economic growth. When one considers the history of postwar development, it can be said that Japan has a competitive edge in manufacturing.

(Robotics)

Shipments of Japanese industrial robots are valued at 340 billion yen, accounting for about 50% of the global market[1]. In addition, about 300,000 industrial robots were in operation as of the end of 2014, accounting for about 20% of the world market share. This ranks Japan first in the world. (Figure 1-2-4)

1 Japan's Robot Strategy (February 2015, Headquarters for Japan's Economic Revitalization)

■ Figure 1-2-4 / Number of industrial robots in operation and the market share of industrial robots for major countries

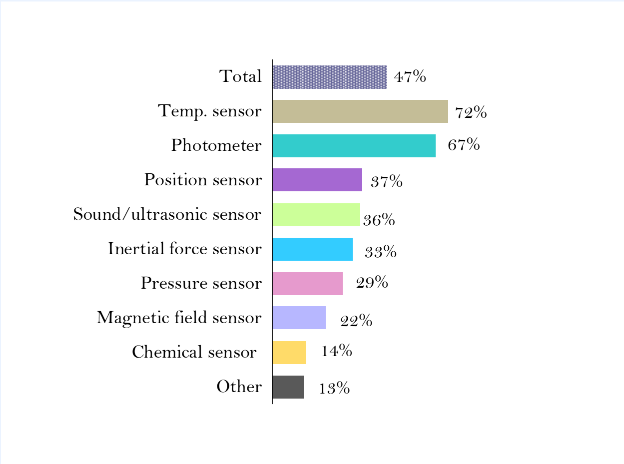


Source: Created by MEXT from data by the Japan Robot Association; original source: World Robotics 2015 Industrial Robots, International Federation of Robotics (IFR)

(Sensor devices)

With respect to the sales of sensor devices, Japan accounts for about half the world market. We are particularly strong in luminous intensity sensors and temperature sensors; Japanese companies account for about 70% of the world' sales (Figure 1-2-5).

■ Figure 1-2-5 / Global market share held by Japanese companies for each sensor type (2014, in value terms)



Reference: Social Transformation from a Trillion-Sensor Universe: *Trillion Sensors Summit 2015 Report*, Jan. 2016, Development Bank of Japan
Original source: adapted by the Development Bank of Japan from Production Forecasts for the Global Electronics and Information Technology Industries, Japan Electronics and Information Technology Industries Association, Dec. 2015)

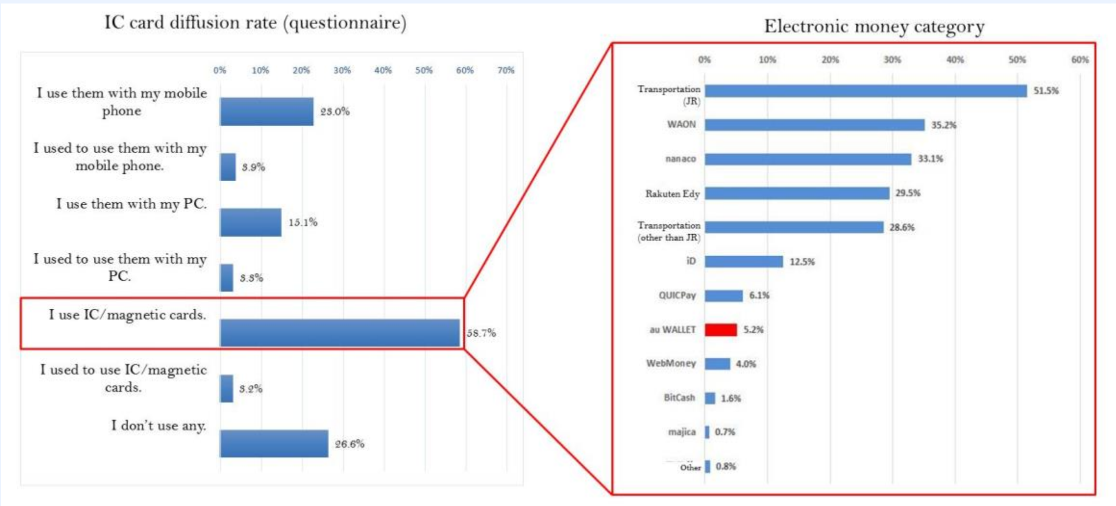
(Network infrastructure)

The penetration rate of broadband internet lines in Japan is the highest in the world. Additionally, Japan is a world leader in optical communications technology with regard to transmission capacity, manufacturing and core technologies of large-capacity multi-core fiber, and 100-Gbps digital signal processing circuits.[1,2]

(Real data)

Under these circumstances, the penetration rate of IC cards in our county has risen to 58.7%. The majority of these are transportation electronic money cards (i.e., Japan Railway). Thus, it is believed that great amounts of data have been accumulated from individual IC cards (Figure 1-2-6). In addition, it is likely that one-quarter of the world's sensors are used in Japan; thus, it can be said that the amount of big data (real data) owned by industry is one of Japan's strengths[3].

■ Figure 1-2-6 / Penetration rate of electronic money and the spread of electronic money for transportation



Source: Handout for the 3rd session (November 27, 2015) of the New Industrial Structure Committee, Industrial Structure Council
Reference: questionnaire survey by NTT Com.

(Computer development capabilities)

Japan is very capable of developing computers that are indispensable for big data analysis. The supercomputer "K computer," from Japan, is number one worldwide in computing power and computational efficiency. This is another of Japan's strengths[4].

② The weaknesses of Japan

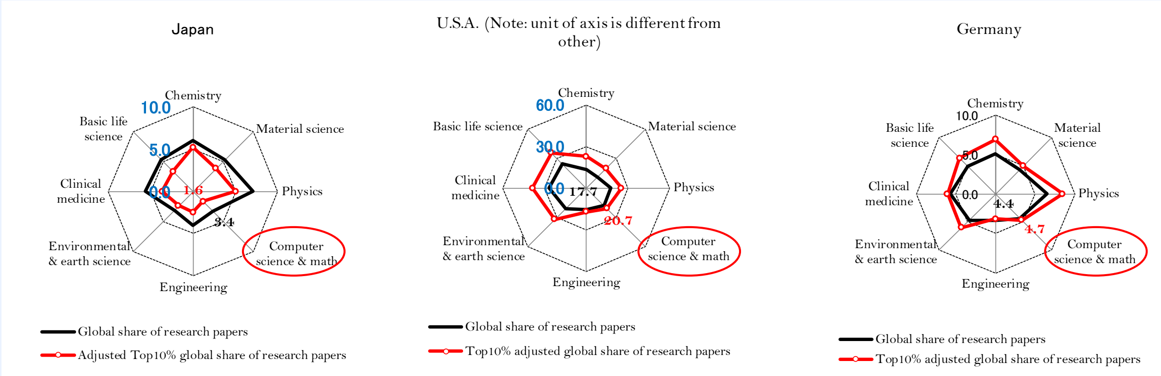
(Share of research papers and the scale of human resources in information science and technology)

With regard to Japan's information science and technology, Japan accounts for 3.4% of the world's research papers on computer science and mathematics, which is less than the shares of the United States

1 Based on a document for the 3rd session (November 27, 2015) of the New Industrial Structure Committee, Industrial Structure Council (Original source: *Current Situation of the Internet(first quarter edition, 2012)*, ITU Web and Akamai Technologies)
2 Intermediate Report on a New Ideal Information and Communications Strategy (July 28, 2015, Information and Communications Council)
3 Intermediate Report on a New Ideal Information and Communications Strategy (July 28, 2015, Information and Communications Council)
4 "The K supercomputer ranked first in the world at the Graph500 for two consecutive years. It also earned the highest evaluation for graph analysis, which is important in the processing of big data" (November 18, 2015, RIKEN) (Source: Graph500 (announced on November 18, Japan time)

(17.7%) and Germany (4.4%). In addition, with regard to "adjusted top 10% papers," which is an indicator of high-quality research papers, Japan accounts for only 1.6% of these, which is less than the shares of the United States (20.7%) and Germany (4.7%) (Figure 1-2-7).

■ Figure 1-2-7 / Major countries' global share of research papers, broken down by research field and "adjusted Top10% papers"



(Unit: %, 2011- 2013 (PY), fractional counting)

Note: Articles and reviews were analyzed by fractional counting. PY stands for publication year. The papers published in the period above were counted for the comparison. Citations are as of the end of 2014.

Physics: Physics and space science

Computers and math: computer science and mathematics

Environment and earth sciences: Environmental ecology and earth science

Clinical medicine: clinical medicine, psychiatry, psychology

Basic life science: agricultural science, biology, biochemistry, immunology, microbiology, molecular biology, molecular genetics, neuroscience, neuroethology, pharmacology, toxicology, botany, zoology

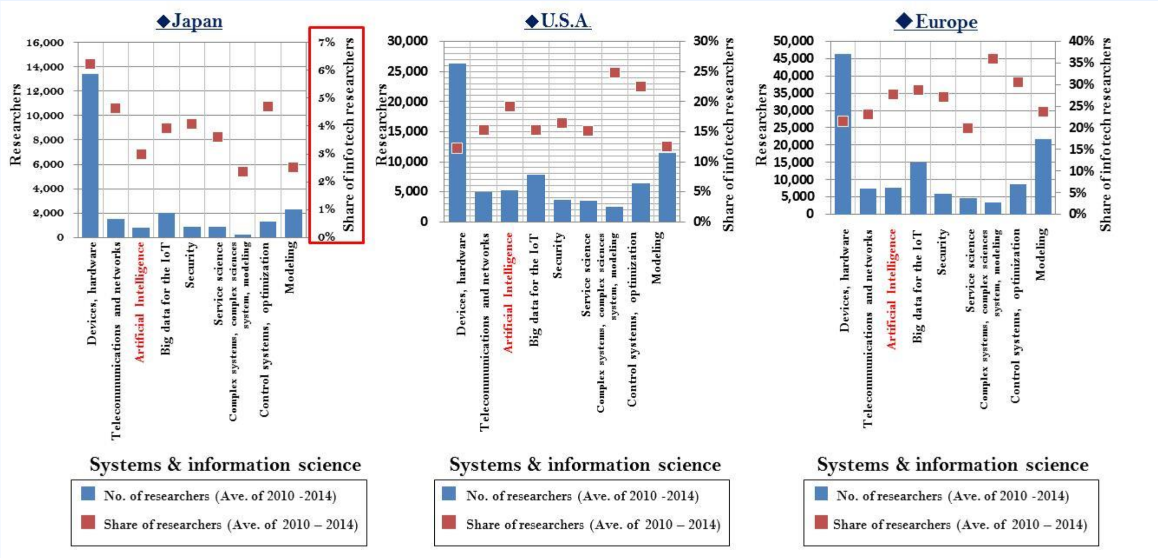
Original source: Adopted by NISTEP Policy (NISTEP) based on Thomson Reuters Web of Science XML (SCIE), Dec. 31, 2014.

Source: Survey material -238, Science and Technology Indicators 2015, NISTEP Policy (NISTEP), Aug, 2015

With regard to the number of researchers, Japan has 13,397 researchers in the hardware device field, the most in any field. However, this is still fewer than for the United States (26,350) and Europe (46,316)[1]. In particular, with regard to the number of researchers in service science relating to Internet business model patents, Japan has 233 researchers. In contrast, the United States has 5,216 researchers, and Europe has 7,575 researchers, showing that there are few Japanese researchers (Figure 1-2-8).

1 Note that with respect to individual countries in Europe, the number of researchers varies by research field. For example, German researchers in the hardware device field number 7,525, and those in the service science field number 471.

■ Figure 1-2-8 / International comparison of the number of researchers in information science and technology



Note 1: The number of researchers refers to the average number of research paper authors (who were given an author ID number) per year from 2010 - 2014.

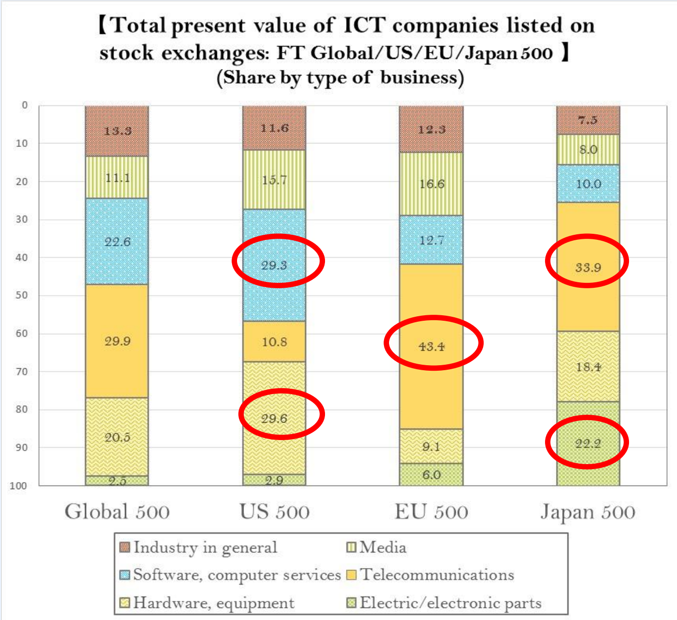
Note 2: "The share of infotech researchers" is the share of researchers in respective field of infotech in each country/region over the researchers of that field in the world.

Source: Created from Scopus by the CRDS (JST)

A movement to quickly commercialize the IoT, big data, and artificial intelligence has intensified around the world. The efforts of Western companies that were introduced in Chapter 1, Section 2 exemplify this movement. It can be said that ours is an age when the company that quickly builds a new business model dominates international competition.

In light of the current situation, let us break down the value of ICT companies by ICT sector for three regions and the world. In the United States, companies in the software and computer services sector and companies the hardware sector each account for about 30% of the value of ICT companies in that country. In Japan, companies in the communications service sector account for slightly more than 30% of the value of ICT companies in that country, and companies in the electrical/electronic parts sector account for slightly more 20% of the value of ICT companies in that country. Relative to companies in other countries, companies in the software and computer services sector account for a smaller share of the value of ICT companies in Japan. (Figure 1-2-9).

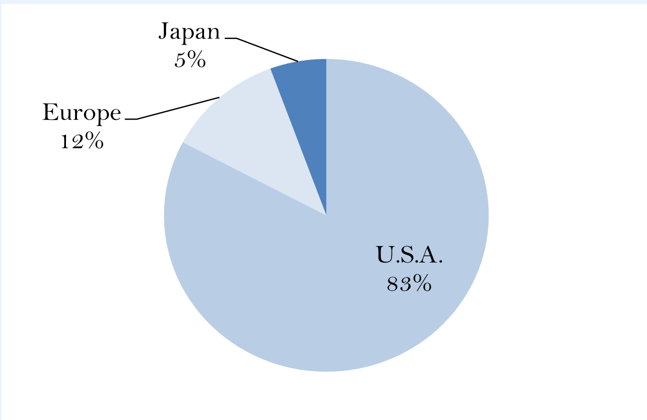
■ Figure 1-2-9 / Breakdown of ICT industry by country and region



Source: Figure 2-2-1-4, Chapter 2, *2014 White Paper on Information and Communications in Japan*, MIC

In addition, the West is overwhelmingly dominant in the development of business models and the creation of new digital content. We must note that Japan lags. For example, the United States accounts for 83%, Europe accounts for 12% and Japan accounts for 5% of patents for business intelligence and business analytics. The U.S.A. overwhelmingly dominates (Figure 1-2-10).

■ Figure 1-2-10 / The United States' share of the world's patents in business intelligence and business analytics



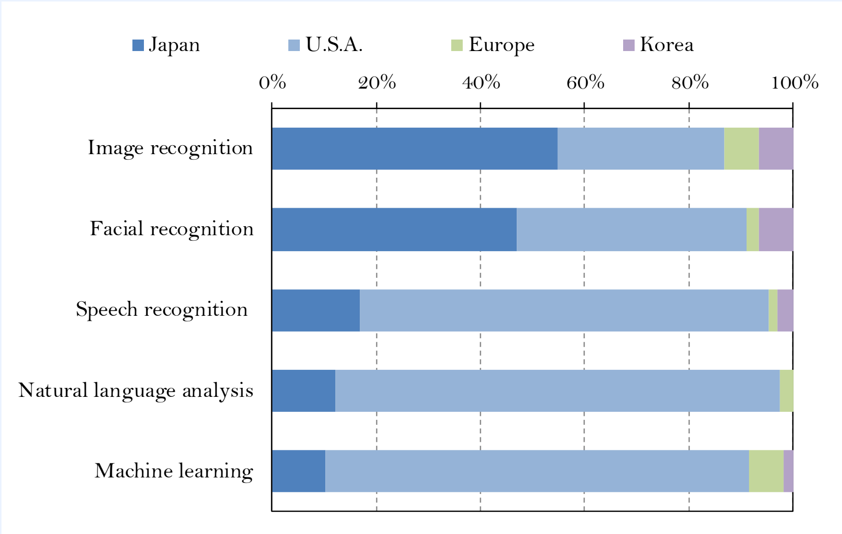
Note: Patents for business intelligence and business analytics include patents for the formulation of management strategies, and for performance analyses, management resource allocation, workflow analysis, risk management, market analysis, predictive analysis, data warehousing, online analytical processing, and extract-transform-load processing.

Reference: adapted by the Development Bank of Japan based on data provided by the Mitsubishi Research Institute, Inc. on the top 20 companies and their nations as of the end of Dec. 2012

Source: *Social transformation from a Trillion-Sensor Universe: Trillion Sensors Summit 2015 Report*, Jan. 2016, Development Bank of Japan

In addition, the United States accounts for an overwhelming share of patents for data analysis technologies, such as those for natural language analysis and machine learning, which form the core of artificial intelligence (Figure 1-2-11).

■ Figure 1-2-11 / Share of patents for data analysis technologies, broken down by nation



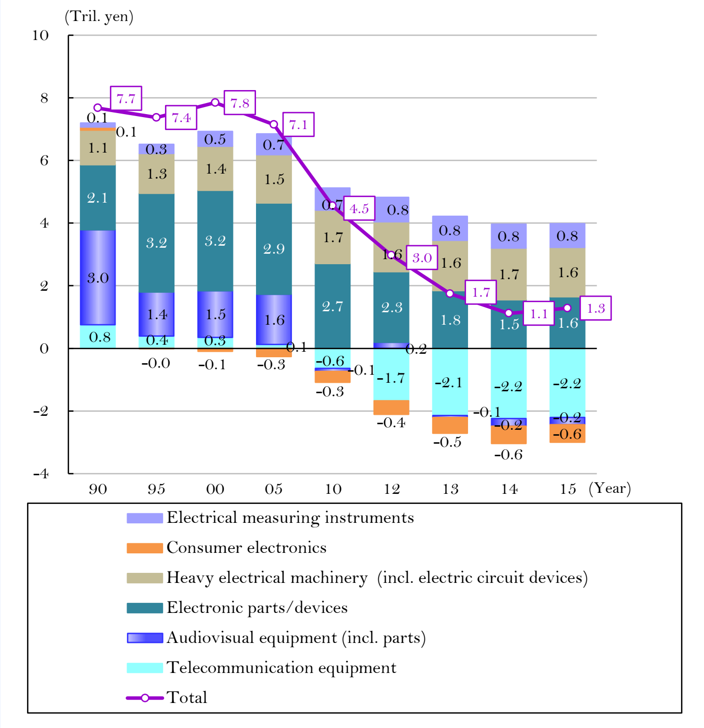
Reference: Adapted by the Development Bank of Japan based on data provided by the Mitsubishi Research Institute, Inc. as of the end of Dec. 2014)

Source: *Social Transformation from a Trillion-Sensor Universe: Trillion Sensors Summit 2015 Report*, Jan. 2016, Development Bank of Japan;

In addition, there are some concerns that Japan's strengths could become weaknesses. In the manufacturing sector, where commoditization has progressed, Asian countries other than Japan have become superior in manufacturing, and there is a fear that manufacturing will become a weakness for Japan.

According to an analysis by the Development Bank of Japan, exports of finished audio-visual equipment from Japan have decreased since the 1990s, and our county has shifted its focus to exports of electronic parts/devices and electrical circuits. From the mid-2000s, imports of flat-screen TVs and video recording equipment have increased, and the trade surplus in audio-visual equipment has become almost zero. In addition, from 2010 through 2012, the import of smartphones rose sharply, and trade in communications equipment has recorded significant deficits. Also, Japan's ability to achieve trade surpluses in electronic parts and devices has weakened (Figure 1-2-12).

■ Figure 1-2-12 / Trade balance for the main categories of electrical equipment

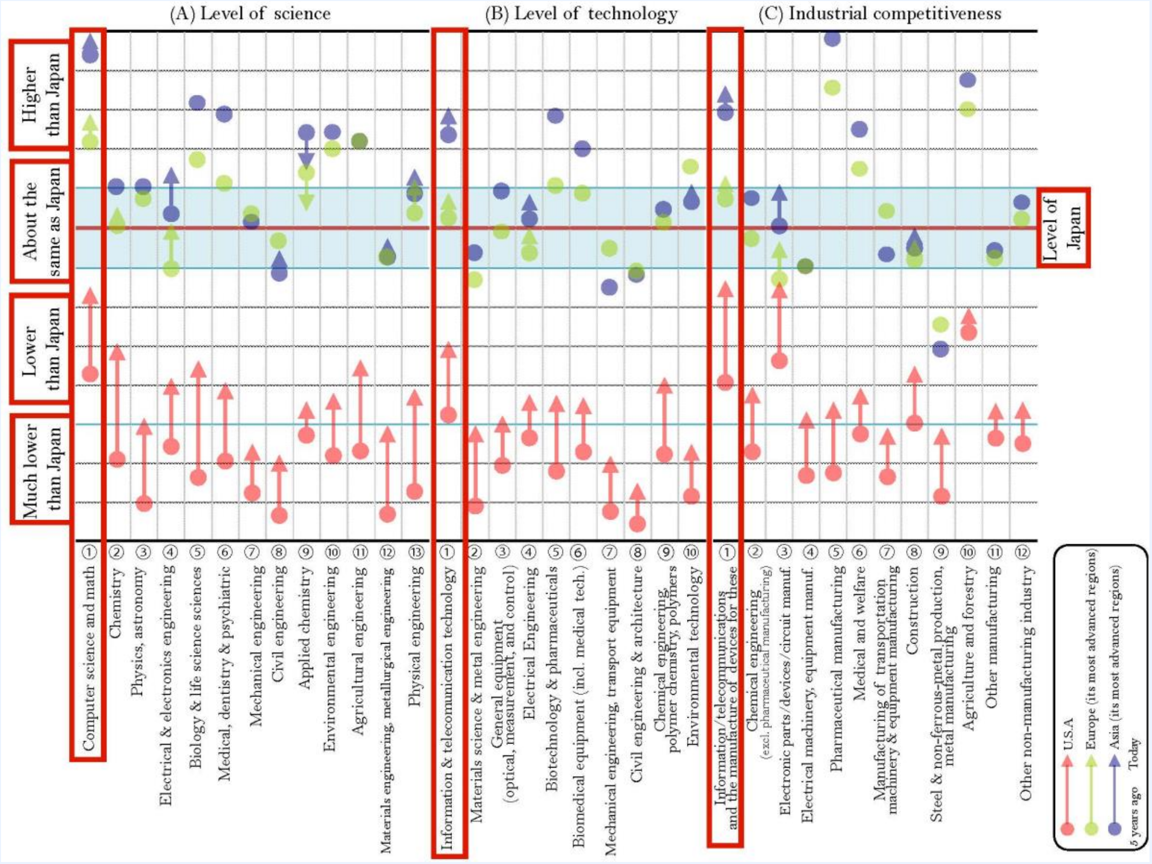


Original source: adapted by the Development Bank of Japan from *Trade Statistics of Japan*, Ministry of Finance
Source: *The Strengths of Japanese Electronic Parts Manufactures and Measures to Strengthen Their International Competitiveness* (Sept. 2014, Development Bank of Japan)

The above suggests that emerging countries, including those elsewhere in Asia, have caught up with Japan in terms of science, technology and industrial competitiveness in sectors in which Japan has traditionally had an advantage (Figure 1-2-13), and that the commoditization of equipment has evolved. In the electronic parts and device sector, which is the foundation for realizing a super smart society, Japan has a trade surplus. However, there is a concern that our ability to maintain this surplus will weaken in the future, with increases in imports from emerging economies and other countries.

In addition, as described in ③ below, Japanese companies, including those in the manufacturing sector, have not used the IoT to make progress in business systemization. In contrast, Western countries have made such efforts, and the decline in the competitiveness of Japan is inevitable.

■ Figure 1-2-13 / Level of science and technology, and industrial competitiveness



Source: Analytical Report for 2015 NISTEP Expert Survey on Japanese S&T and Innovation System (2015 NISTEP TEITEN survey), *NISTEP REPORT No.166*, (March 2014), NISTEP Policy (NISTEP)

③ Future direction of efforts

According to a survey (Industrial Internet Insights for 2015) of 250 business executives in the United States, the United Kingdom, Germany, France, India, South Africa and China, conducted by General Electric Co. in the U.S.A. and Accenture in the U.S.A., 66% of respondents who had an industrial Internet strategy reported "If we don't use big data, we'll lose our current market position in one to three years." In addition, 88% of respondents reported "Big data utilization is a top priority for our company."

Furthermore, many alliances have been established around the world, mainly among Western companies, including General Electric Corp. in the U.S.A., which leads the industrial Internet. Activities for standardization of the IoT have intensified, but Japanese companies cannot be said to have played a proactive role (Figure 1-2-14).

■ Figure 1-2-14 / Progress of IoT standardization around the world

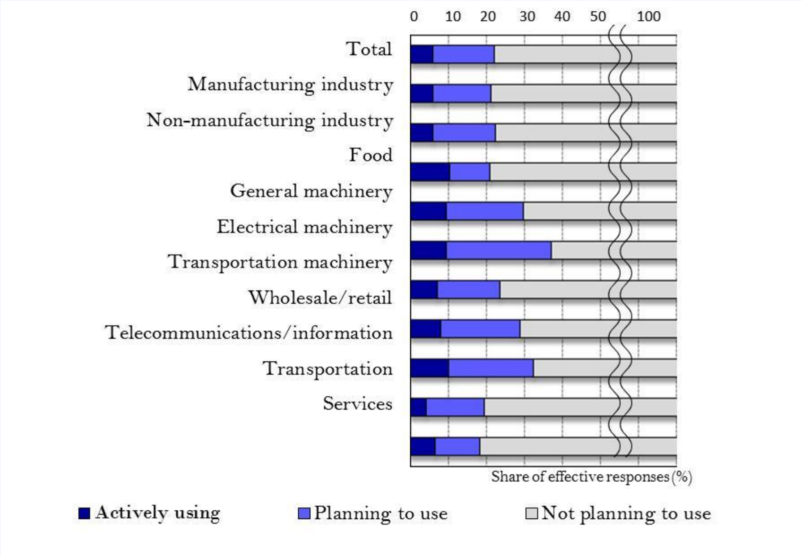
1	Industrial Internet Consortium	Allseen Alliance	Open Interconnect Consortium	IP500 Alliance	Thread Group
Outline of activities	Examination of inter-business standards for 5 fields: energy, medical, manufacturing, public services and transportation	Development and dissemination of "Alljoyn", an IoT framework	Development and dissemination of "IoTivity", an IoT framework	Promoting the dissemination of "IP500", a mesh network standard	Promoting the dissemination of "Thread", a mesh network standard
Year of establishment	Mar. 2014	Dec. 2013	July 2014	2007 (Feb. 3015: opened a center in Japan)	July 2014
Major members at the time of establishment	AT&T, Cisco Systems, GE, IBM, Intel	Haier, LG Electronics, Qualcomm, Silicon Image, TP-Link, Panasonic, Sharp	Atmel, Broadcom, Dell, Intel, Samsung, Wind River	Assa Abloy, Bosch, GEZE, Honeywell, Siemens	Samsung, ARM, Big Ass, Fans, Freescale, Silicon, Laboratories, Yale, Security, Nest
Major current members	Accenture, BlackBerry, Bosch, Dell, EMC, HP, Microsoft, Samsung, SAP, Symantec, Tata, TOYOTA Motor, Fujitsu Electric, Fuji Electric, Fuji Xerox, Mitsubishi Electric, NEC, Hitachi, etc.	Microsoft, Cisco, Lenovo, Symantec, Trend Micro, HTC, Bosch, Sony, etc.	Cisco, GE Software, MEDIATEK, HP, Siemens, ADT, Honeywell, Eyeball Networks, Acer, Lenovo, McAfee, Realtek, Wind River, etc.	ABI, Belimo, Data Linc, Dorma, Gisinger, Gunnebo, Hekatron, JBO, Link, Regent, Orange, SimonsVoss, STG-Beikirch, Tyco, UTC Fire&Security, Wago, Xtrails, Omron, Toyota Tsusho, etc.	Somfy, Tyco, Analog, Devices, Atmel, Philips, HTC, Huawei, Murata Manufacturing, Daikin, etc.

Original source: ITPro articles
Source: Document for the 3rd session (November 27, 2015) of the New Industrial Structure Committee, Industrial Structure Council

However, in a survey of Japanese companies, only about 20 to 30% of respondents in each industry sector responded "We've utilized artificial intelligence, big data, and/or the IoT" or "We're considering utilizing artificial intelligence, big data, and/or the IoT." This indicates that the introduction of artificial intelligence, big data and the IoT is sluggish (Figure 1-2-15).

In addition, to a question on the importance of investment in information systems, 75.3% of respondents at US companies answered "Extremely important." In contrast, only 15.7% of respondents at Japanese companies gave this answer, which is lower than the figure for US companies (Figure 1-2-16).

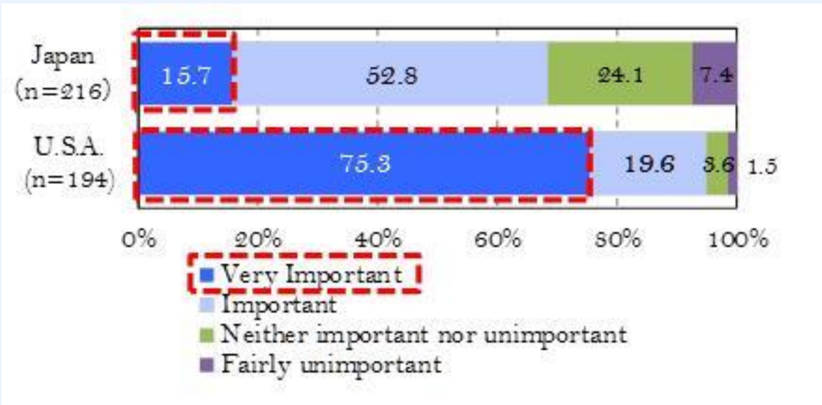
■ Figure 1-2-15 / Utilization of the IoT/big data



Note: Respondents were 520 businesses with paid-in capital of 1 bil. yen or more. Breakdown of businesses: manufacturing: 520, non-manufacturing: 688, food: 38, general machinery: 74, electrical machinery: 62, transportation machinery: 55, wholesale & retail: 135, telecommunications & broadcasting: 89, transportation: 144, services: 60.

Source: *Investment Trend of Electric machine: Investment for Growth to the Strong Fields*, Sept. 2015, Development Bank of Japan
Original source: *2015 Awareness Survey of Corporate Behavior*, Development Bank of Japan.

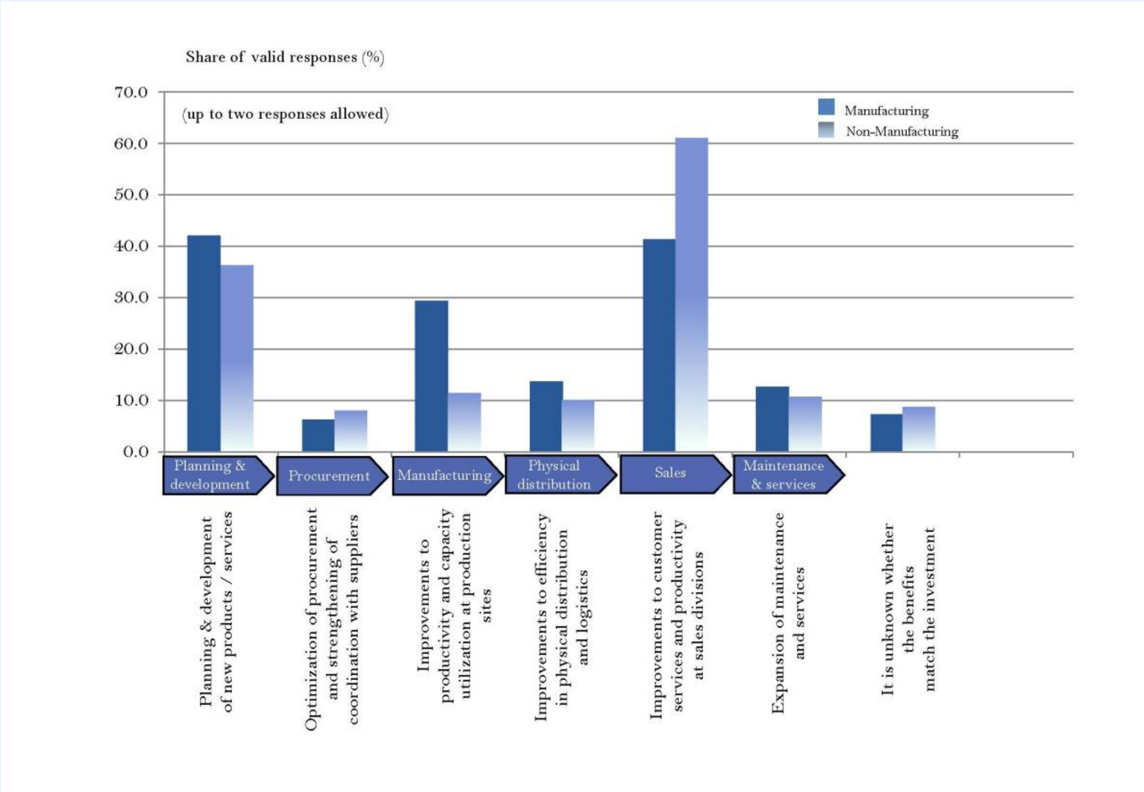
■ Figure 1-2-16 / Importance of investment to information systems



Note: The survey covered section managers or higher in non-IT departments (general affairs, sales, marketing, corporate planning) at private companies in Japan and the U.S.A.
Source: *Networking Equipment by the Internet of Things (IoT) toward Creating New Markets* (Feb. 2014, Development Bank of Japan); based on the *Differential Analysis between Japan and the U.S.A. in the Management of Businesses Making the Most of IT*, Oct. 2013. Adapted by the Development Bank of Japan based on data from the JEITA and the IDC Japan)

Furthermore, according to a survey conducted by the Development Bank of Japan on Japanese companies that have utilized the IoT/big data or that are considering utilizing the IoT/Big data, such companies recognize that the IoT/big data is useful for planning, development and sales. There is not much awareness about the use of the IoT/big data for operations that cannot be done without outsourcing, such as procurement and logistics (Figure 1-2-17). However, as described in the overseas trends in Chapter 1, Section 2, the transformation of the industrial structure using the IoT/big data in departments such as procurement and logistics has been taking place. Therefore, it is suggested that the issue for Japan is the systemization of value chains at every point, from upstream to downstream.

■ Figure 1-2-17 / Sectors in which the utilization of the IoT/big data is effective and/or expected to be effective in business



Original source: *2015 Awareness Survey of Corporate Behavior*, Development Bank of Japan. Respondents included 109 manufacturing companies and 149 non-manufacturing companies. Respondents are those already using IoT/big data or are planning to actively use them.

Source: *Transformation of manufacturing industry by IoT: Industrie 4.0 progressing in Germany* (Aug. 2015, Development Bank of Japan)

Japan's strengths and weaknesses described so far are summarized in (Figure 1-2-18). In summary, to solve the various issues of the real world, it is important to enhance Japan's manufacturing industry, analyze big data accumulated in a wide range of sectors, from health care to transportation, develop robot technology that connects artificial intelligence with the real space, and strengthen R&D and foster human resources in information science and technology.

In particular, to maintain international competitiveness in the future, it is important for Japan to lead the development of technologies related with interaction between the cyber space and the real space by adopting rapidly developing technologies from recent years and by leveraging the manufacturing industry that gives Japan a major advantage, and create new services that address various issues in the real world, especially issues related to manufacturing, agriculture, construction, health care and security.

In light of certain trends underway in companies of foreign countries, it is necessary to take measures now. Based on the 5th Science and Technology Basic Plan, the transformation of Japan's industrial structure should be promoted, toward the creation of new value and services through the active utilization of artificial intelligence, big data, and the IoT in various sectors and the systemization of value chains.

■ Figure 1-2-18 / Summary of Japan's strengths and weaknesses

Strengths	Weaknesses
○ Japan is No. 1 in terms of the shipment value and the share of industrial robots produced. Industrial robots in operation here number 300,000 in Japan. These account for 20% of the industrial robots in the world, which is the highest share for any country. (as of Dec. 31, 2014). ○ Japanese businesses (including domestic and overseas subsidiaries) account for about a half of all sensor devices in the world. For photo sensors and temperature sensors, the global share of each is 70%. ○ The Internet and broadband telecommunications have higher diffusion rates in Japan than elsewhere in the world. The level of optical communication technology is among the highest in the world. ○ Japan has real data obtained as the result of the widespread use of transportation IC card systems ○ Japan's K supercomputer is the fastest in the world and has the highest computing efficiency ratio. Japan excels in the development of such machines.	○ Japan's share of the world's research papers on telecommunications and human resources is smaller than those of the U.S.A and Europe. ○ The U.S.A and European countries are overwhelmingly stronger than Japan in the construction of business models and the creation of new content. ○ The U.S.A. is the strongest in terms of data analysis technology. ○ The fields of electronic parts and devices were once profitable for Japan, but their profitability has been eroded. ○ Emerging countries have been catching up to Japan in science, technology and industrial competitiveness. ○ Japan has a low awareness of the importance of actively using the IoT and big data. Awareness of the importance of systemization is also low.

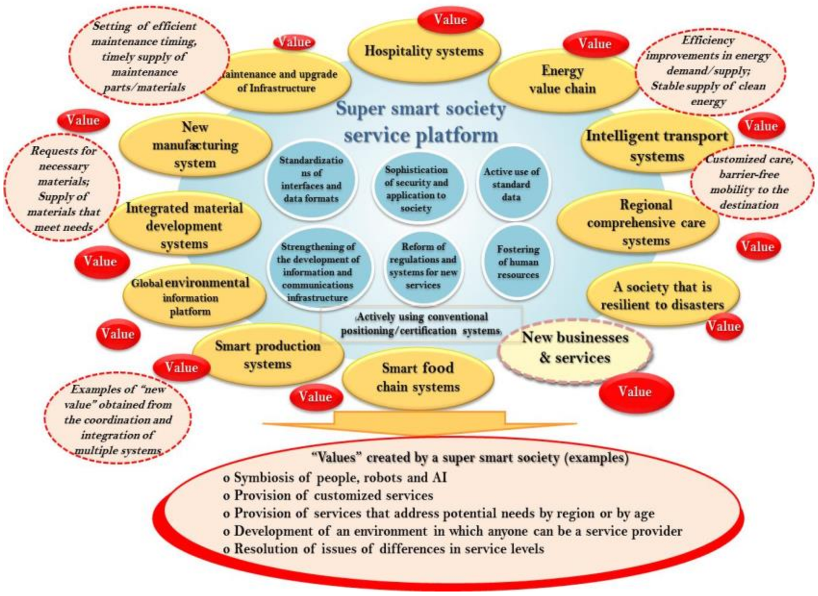
Source: MEXT

3 Efforts towards Realizing a Super Smart Society

This subsection describes the features and current status of core technologies and their systematization toward the realization of a super smart society, and then describes the direction of our future efforts based on Japan's strengths and weaknesses.

(1) Efforts to systematize core technologies

In the era of the IoT, everything is connected to networks, torrents of sensor data and log data from all things



Outline of service platform of a super smart society

Source: Cabinet Office

are generated on networks and everything can be linked. This makes it possible to link multiple systems, which enables the creation of new value and services. For the creation of new values, it is important that efforts for systemization coordinate individual, separately developed systems. In the 5th Science and Technology Basic Plan, we aim to build a common platform that effectively uses the IoT (Super smart Society Service Platform). The "National Energy and Environmental Strategy for Technological Innovation towards 2050," approved by the Cabinet Office in April 2016, calls for the networking of energy-related devices and equipment, and the optimization of networked systems in order to realize thoroughly effective utilization of energy and to minimize global energy consumption and CO2 emissions.

Data Integration and Analysis System (DIAS)

Source: The University of Tokyo

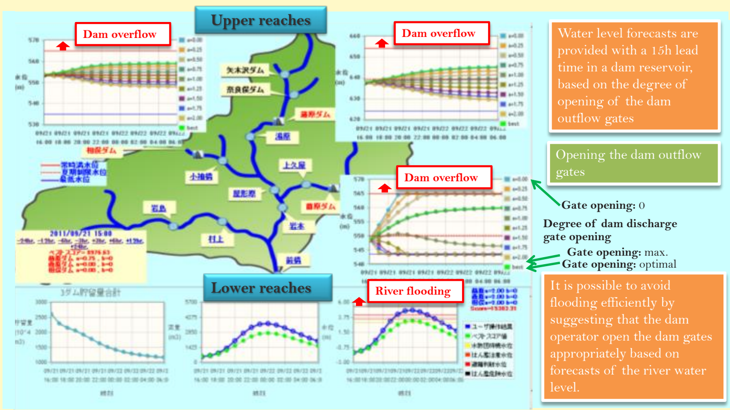
The full-scale utilization of the IoT requires that we develop interfaces and data formats that promote the use of data across multiple systems.

In addition, we will promote the development of a mechanism and technologies to ensure the broad sharing of information among systems. The information includes three-dimensional maps, positioning data and meteorological data provided by Japan's shared infrastructure systems, such as the Quasi-Zenith Satellite System, the Data Integration and Analysis System (DIAS) and public authentication infrastructure.

In addition, it is important to achieve the componentization of hardware and software, and the introduction of edge computing in order to accelerate and diversify real-time processing of end users' systems, which is required for the sophistication of the IoT.

Column 1-4 A pioneering system using big data of the global environment: Data Integration and Analysis System (DIAS)

DIAS, developed by Japan, is the first information infrastructure of its kind in the world. This pioneering system utilizes big data on the global environment. Its use is creating new, useful information by effectively and efficiently combining global meteorological data; climate change prediction data obtained from artificial satellites, marine research ships, and other observation facilities; and other data.



Example of a real-time river and dam management system

Source: MEXT, adapted from the materials from the University of Tokyo

DIAS has a subsystem for storing large amounts of data and rapidly analyzing aggregated data. It stores about 700 types of data obtained from satellites such as the Himawari-8 meteorological satellite, the Daichi advanced land observation satellite and the SHIZUKU water cycle observation satellite, and ocean observation data obtained from ships and Argo floats, rainfall data obtained from the X Band MP Radar Network (X-rain), highly accurate climate data reproducing the past climate, global climate change prediction data, and the like. The combination and analysis of these data, have contributed to various research results, including those of water circulation.

For example, we analyzed the flood frequency and the effect of future climate change on flood damage on the Medjerda River in Tunisia by using DIAS. In this way, we contributed to the Mejerda River Flood Control Project, a yen-loan-financed project of the Tunisian government. (The loan ceiling was about 10.4 billion yen.) Also, in Japan, a dam management demonstration experiment has been conducted in which such management is performed based on the dam water level and river flow rate for 15 hours ahead, as predicted by real-time integration analysis using weather observation data, dam management data, river flow data stored in DIAS and other data. Such analysis is expected to mitigate flood and drought damage through water pre-discharge and redistribution to reservoirs for optimal water capacity, and through optimal dam management in response to changes in river flow and precipitation due to future climate change. Furthermore, the automated operation of dams may be realized.

By connecting to the database of the Global Earth Observation System of Systems (GEOSS), which is the international framework that was proposed at the G8 Evian-les-Bains Summit in 2003, DIAS provides its global observation data. With this connection, global observation data from other countries are available to Japan through GEOSS.

In the future, DIAS will be used as a core system of the Global Environment Information Platform, one of 11 systems described in the 5th Science and Technology Basic Plan. As a result, the number of DIAS users who work for the private sector will be increased as will the number of researchers at public research institutions. DIAS is expected to be used to solve various social issues and to be used as a business tool, as well as for mitigating and adapting to climate change. (DIAS website: http://www.diasjp.net/)

(2) Strategic strengthening of infrastructure technology for the super smart society

(Cybersecurity technology)

In aiming to achieve a super smart society, ensuring cybersecurity is a major premise. Therefore, it is essential to promote super smart society projects based on the concept of security by design, which ensures security in the planning and design stages of an overall system. (The details are described in Section 2 of this chapter.)

(IoT system building technology)

To realize the componentization of hardware and software and the building and operation of large-scale systems, it is important to enhance the technologies that are needed IoT system development. MIC has made efforts to establish a shared base of technology to interconnect vast numbers of devices quickly and efficiently, and to connect or integrate wireless communication devices of different standards and multiple services with networks efficiently and safely. Also, MIC has strengthened efforts to make the technology an international standard. Additionally, MIC has created an environment (the IoT Testbed) that allows various businesses to develop and test optimal IoT systems and it has promoted the development and demonstration of advanced IoT services.

(Big data analysis technology)

It is important to improve big data analysis technology to derive knowledge and value from a wide variety of large-scale data, including unstructured data. With the understanding that data is an asset, it is necessary for us to actively utilize accumulated and available data in Japan, and to promote the further improvement and utilization of certain types of data that give Japan a competitive advantage.

(Artificial intelligence technologies)

Artificial intelligence technologies can support the use of the IoT, big data analysis and advanced communications.

Regarding artificial intelligence technology, the Universal Communication Research Institute of the National Institute of Information and Communications Technology, which was under the jurisdiction of MIC, has worked on R&D for multi-lingual speech translation using a natural language processing technology that is based on big data analysis and has worked on an information analysis system. In addition, the Center for Information and Neural Networks of the NICT has worked to elucidate human brain functions and has applied that knowledge to R&D on technologies such as for estimating a person's perceptions and impressions from their brain activities, and for creating an information network.

The Universal Communication Research Institute has carried out R&D and demonstrated the multi-lingual speech translation system for the further improvement of translation accuracy. The institute aims to increase the number of languages for which accurate translation is possible from four (Japanese, English, Chinese and Korean) to ten and aims to introduce translation technology to hospitals, commercial facilities, tourist destinations and the like no later than the Tokyo Olympic and Paralympic Games in 2020. In addition, with the aim of the early introduction and broad use of electric vehicles and electric wheelchairs that utilize artificial intelligence, MIC has carried out the development and demonstration of an autonomous mobility system (automated driving technology, automated control technology, and the like).

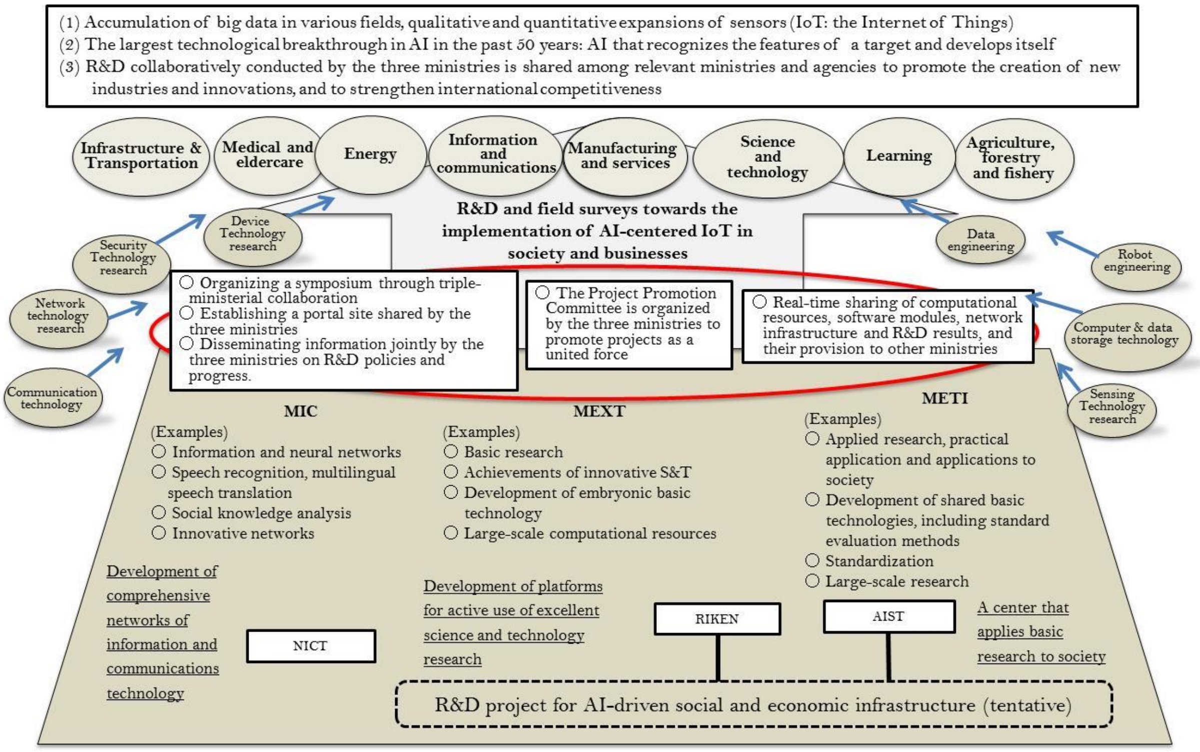
The Ministry of Economy, Trade and Industry (METI) established the Artificial Intelligence Research Center at the National Institute of Advanced Industrial Science and Technology in May 2015. As a hub for research by academia and industry, the center has brought together excellent researchers and technologies, and has worked to form an environment that produces an efficient cycle for commercializing the results of basic research. Specifically, the center has worked on advanced research on brain-like artificial intelligence and artificial intelligence integrating data with knowledge, the development of tools for artificial intelligence frameworks and advanced core modules that enable the early bridging of research results and the development of a standard technique for quantitatively evaluating the effectiveness and reliability of artificial intelligence technologies. In addition, the New Energy and Industrial Technology Development Organization launched the Next-generation Artificial Intelligence and Robot Core Technology Development Project. Under the project, the organization has carried out research and development on artificial intelligence technology, sensing devices such as a camera system that can recognize hard-to-identify objects, and actuator technology for artificial muscles.

Apart from R&D conducted jointly with industry, new basic R&D is required. For Japan to lead the world in 10 to 15 years, it is important to create a new base technology for artificial intelligence and big data analysis.

MEXT launched the Advanced Integrated Intelligence Platform Project (AIP) and set up an R&D center (AIP Center) at RIKEN to move the project forward. In this project, the center will integrally promote R&D on innovative artificial intelligence, the adaptation of artificial intelligence and big data to various scientific fields, the creation of new values using the IoT, and the fostering of human resources for cybersecurity.

The project aims to develop a base technology for a new innovative artificial intelligence that is far superior to deep learning. To achieve this goal, project members will apply results from brain science, cognitive science and mathematical science that have been accumulated in Japan, and will use knowledge of human intellectual activities. More specifically, the AIP Center will carry out R&D on the reproduction of human inspiration by combining various deep-learning technologies and theories, such as stochastic inference, "Automated Learning" technology that enables knowledge from the real world to be acquired by way of language processing and large-scale video and image analysis and entirely new artificial intelligence algorithms based on the calculation model of the brain's neural circuits.

In this way, R&D on artificial intelligence has been progressed with role-sharing between MIC, MEXT and METI. In addition, the three ministries have established the Artificial Intelligence Technology Strategy Council in order to promote projects in an integrated fashion, and the three ministries have offered the results of collaborative R&D to other ministries. Thus, the entire national government has made efforts to create new industries and foster innovation, and to enhance Japan's international competitiveness.



Collaboration framework of the three ministries for R&D on next-generation artificial intelligence technology

Source: MEXT, MIC and METI

Column 1-5 Entering the global market by using technologies from fields in which Japan is internationally competitive and by using deep learning

If asked "What are your Japan's internationally competitive fields?" you might think of the automotive industry first. In number of cars sold around the world in 2015, TOYOTA Motor Corp. was the top company, with 10.15 million cars. In addition, as described in Japan's Robot Strategy formulated in February 2015 by the Headquarters for Japan's Economic Revitalization, Japan has maintained its top position in the world for the number of industrial robots shipped and in operation. Japan retains its position as a Robotics Powerhouse. Furthermore, in regenerative medicine using iPS cells, which were the research subject of Professor Shinya Yamanaka, the awarded the Nobel Prize in 2012, a sheet of retinal cells that were produced from iPS cells was transplanted into the eye of a patient with eye disease in September 2014. This operation was the first of its kind in the world, and it attracted global attention.

This column introduces Preferred Network, Inc., a venture company founded by students at the University of Tokyo. The company has tried to enter the global market armed with its capability to apply artificial intelligence to business in three sectors where Japan has a certain international competitiveness. Artificial intelligence is described in the 5th Science and Technology Basic Plan as one of the new science technologies that have a significant impact on not only human life but also on "what it means to be human."

With the missions of "developing new computers of the IoT era" and "giving intelligence to everything so as to realize distributed intelligence," Preferred Network, Inc. has worked on applying artificial intelligence technology to automobiles, robots and biotechnology, in which Japan has a substantial advantage. The company's hallmark is distributed intelligence. With the development of ICT, data associated with things has increased rapidly; thus, when such vast amounts of data are uploaded to the cloud, quick processing is impossible. Therefore, Preferred Network, Inc. developed Chainer, a framework for deep learning that processes data cooperatively at the edge side rather than centralized processing data on a conventional manner in the cloud. The company has made an open-source version of Chainer.

Demonstration at CES

Source: TOYOTA Motor, Corp.

Jointly with TOYOTA Motor Corp. and Nippon Telegraph and Telephone Corp., the company ran a booth at the Consumer Electronics Show (CES) in January of this year. This trade show for consumer electronics is held in Las Vegas, U.S.A. The companies exhibited collision-free cars that rely on deep learning technology. In collaboration with TOYOTA Motor Corp., the company carried out R&D on cars that learn to avoid collisions. These cars run autonomously while using sensors to detect positional relationships with other traveling cars. At first, these cars collide with other cars, and penalty is given to them and reinforcement learning is performed. All learning is done on the simulator. Over time, these cars can run smoothly as a result of deep learning. Each car has the ability to learn and to share its learning. By utilizing the technology, it may become possible for each car to choose a way of driving that is optimal for each situation.

Regarding industrial robots, the company conducted joint research with Fanuc Corp. They aim to realize "non-stop factories" where one robot can take over the tasks of another robot in the event of a malfunction. Currently, a malfunctioning robot needs to be repaired by human hands, and the production line is stopped until that repair is completed. Thus, it causes a long delay in production. However, if the malfunction of a robot can be predicted through deep learning, it will be possible to avoid extended downtime for repairs by taking measures in advance. Further, deep learning enables the collaborative work of multiple robots to be automatically optimized, thereby shortening the work time.

Finally, we introduce the example of deep learning use in biotechnology. Preferred Network, Inc. has conducted joint research with the Center for iPS Cell Research and Application of Kyoto University to explore the highly precise design of drugs. By using deep learning to evaluate the pharmacological activity of compounds, it is possible to analyze data more effectively than with conventional techniques. Moreover, it was proved that the data analysis was able to judge whether iPS cell differentiation had been precisely induced. The company and the center have been examining whether such techniques can be used to determine pharmacological activity by administering hundreds of thousands of compounds to large numbers of disease-specific iPS cells. The 10th Science and Technology Foresight Future Perspectives on Science and Technology by Field published by the NISTEP Policy in September 2015 noted that high-throughput screening[1] techniques for verifying drug response using differentiated cells derived from stem cells such as iPS cells is a Japanese technology that is highly competitive in the international market. Further promotion is expected to strengthen the international competitiveness of Japanese biotechnology.

(Device technology)

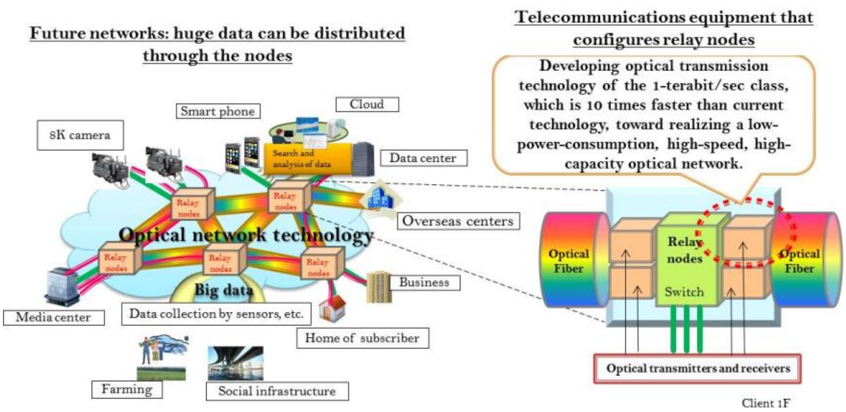
The development of device technology is realizing the high-speed, real-time processing of large-scale data with low power consumption. To realize ultra-low power consumption in devices, it is important to enhance materials technology, nanotechnology and light-quantum technology.

Furthermore, due to the increased demand for information transmission and the expanded use of radio waves, the transmission capacity in the currently used frequency bands is expected to reach capacity. Therefore, the development of new radio wave resources and the sophistication of the network have become urgent issues. MIC has been conducting R&D on a base technology for terahertz wave devices for the eight fiscal years from FY2011 to FY2018 toward opening the terahertz wave band (300GHz band), which is not currently used.

(Network technology)

To send large-scale data in great volumes at high speeds, the sophistication of network technology is also important.

For the mobile communications system of Japan, MIC aims at a thousand-fold increase in communication capacity and a hundred-fold increase in the number of connected devices. Collaborative R&D and activities for international standardization between industry, academia and government have been promoted towards the realization of the fifth-generation mobile communication system (5G) around 2020. In addition, to create various IoT-based services, the ministry has conducted R&D on network function virtualization technology that enables the construction of network infrastructure that quickly and flexibly meets various network connectivity needs. Furthermore, the ministry has promoted R&D on next-generation optical network technology that enables low power consumption, long-distance transmission, high speed and large capacity (1 terabit per second). This is ten times the optical transmission of 100 gigabit that is currently becoming popular. The target for realizing this technology is no later than 2020.



The promotion of R&D on next-generation optical network technology

Source: MIC

The ministry has promoted R&D on technologies for IoT systems, such as edge computing technology

1 High-Throughput Screening is a technique that uses robots to screen compounds with useful physiological activities from a compound library consisting of numerous compounds.

for automatically judging the allowable delay depending on the information type and urgency for various IoT devices and for performing optimum control of the network by turning back communications data at the optimum point in the network. In this way, the ministry aims to build a base technology that enables optimal communication processing throughout networks that interconnect various IoT devices.

In addition, the ministry has conducted R&D on accurate and reliable network technology to promote the early commercialization and dissemination of autonomous mobility systems (e.g., electric cars and electric wheelchairs etc.) that rely on automatic driving technology.

(Next-generation supercomputer)

MEXT has been implementing the FLAGSHIP 2020 Project, which aims at developing a successor to the K supercomputer (Post K supercomputer). The Post K supercomputer will enter service in 2020. The organizations involved in the project have designed and developed hardware and application software for the Post K supercomputer in a unified, cooperative manner, toward achieving research results earlier than those of next-generation supercomputers of other countries. The development goal for the Post K supercomputer is a maximum effective performance 100 times that of the K supercomputer and 30 - 40 MW of power consumption.

Using the Post K supercomputer, the FLAGSHIP 2020 Project will carry out ambitious, pioneering research with an eye to future society and academia over the next 10 to 20 years. As a result, it will achieve scientific breakthroughs, open the future of our industry and economy, and create innovative, world-leading achievements. By strategically addressing social and scientific challenges that can only be solved by computer systems in the 2020s, the project is expected to contribute to Japan's growth and to the realization of world-leading achievements. The system is characterized by 1) efficient power consumption, 2) high computing power, 3) user friendliness and 4) the potential for innovative results. The Post K supercomputer, to be completed in 2020 with the highest specifications in the world for these features, will surpass the computer systems of other countries in overall strength.

(Sensor technology)

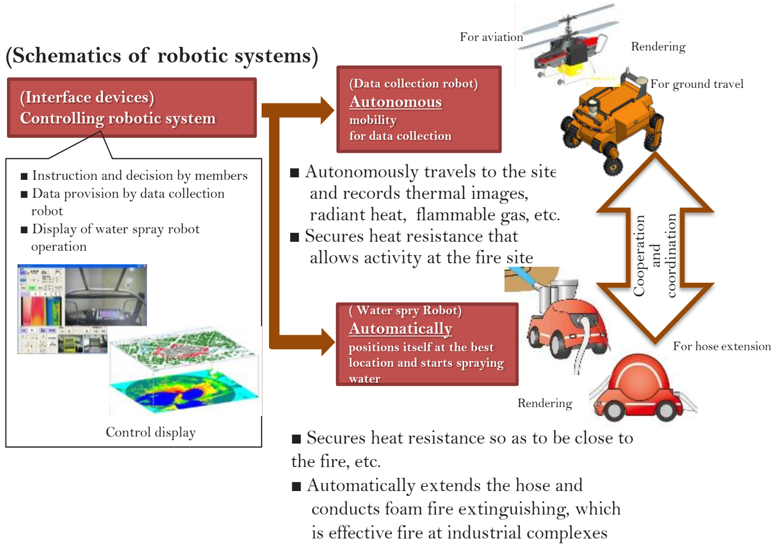
In the era of big data and the IoT, the utilization of dependable data becomes important. Thus, the sophistication of sensor technology to collect information from people and all things is also important. MIC has carried out R&D on a terahertz camera that allows see-through imaging on the shapes of materials. METI has carried out R&D on technologies for robot sensing (e.g., sight and hearing) that is not affected by changes in the environment.

(Technology for robots, actuators and human interfaces)

It is important to carry out R&D on actuator technology relating to machines' mechanisms, drive and control that enable machines to act in the real world by using processed and analyzed information in cyberspace. What is also important is robot technology that can expect to be utilized in various fields, such as communications, welfare, work support and manufacturing; and human interface technology that utilize augmented reality, Kansei engineering and brain science.

MIC has conducted R&D to establish technologies for smart networked robots since FY2015. These include a base technology that enables various robots to share information through the network and to operate automatically in real-time, and a communication technology that enables robots to communicate with humans based on an understanding of human feelings as determined through robot sight and hearing and from human brain information.

Since FY2014, the Fire and Disaster Management Agency of MIC has carried out R&D on a fire-fighting robot to address disasters at energy and industrial infrastructure. There is a great risk of a mega-quake along the Nankai Trough and of a quake whose hypocenter is under the Japanese capital, where major energy and industrial infrastructure are concentrated. In addition, the agency has carried out the development of a fire-fighting robot system that enables multiple robots to autonomously and cooperatively fight fires at all stages, from information collection to water discharge, because it is difficult for humans to approach sites of extraordinary disasters, such as at oil complexes. Under this project of the agency, there are five R&D themes, which address the following: an information collecting robot (aerial and land), a water discharging robot, a hose extension robot, and the interface for human firefighters. At the site of a fire, an information collecting robot autonomously collects site information by capturing heat images and measuring flammable gases and the like. Based on the information, a water discharging robot automatically determines the optimum location for water discharge, and then a hose extension robot extends a hose to a safe place, and the water discharging robot discharges water. The robot system will be deployed and improved after 2019.



Schematic of R&D on fire-fighting robots for disasters at energy and industrial infrastructure

Source: MIC

(Optical quantum technology)

Optical technologies that evolved as tools for observing atoms and molecules have also been used as interdisciplinary technologies for communications and clinical settings. In recent years, due to the advancement of optical technologies for precise control and high-sensitivity measurement, the use of the technologies has spread to social infrastructure. Toward further advances in optical technologies, MEXT has carried out the development and utilization of new artificially generated optical functional materials, as typified by meta-materials, and innovative optical communications technologies, and aims at the creation of new optical base technologies and systems born from the fusion of optical technologies and advanced mathematical science.

Quantum technologies have been utilized in various ways from semiconductors in familiar electronic devices to a quantum beam used in accelerators, and the technologies have dramatically developed the knowledge-based and technological society. We also aim to contribute to the realization of the super smart society by developing the next-generation quantum technologies earlier than other countries. Such technology will be a core technology for new industries and infrastructure.

Through the use and control of optical quantum technology, we are promoting efforts to build high-level social and industrial infrastructure that supports a wide range of sectors such as information, medical care, environment and energy, and that meet various social demands for devices/equipment with more accuracy, greater sensitivity, higher capacity and/or lower power consumption.

(Mathematical science)

Mathematical science is an interdisciplinary science that supports base technologies to realize the super smart society. Mathematical science contributes to the understanding of large amounts of complex data and the abstraction of things. However, there are some issues, such as the small number of experts in the field and the low recognition by experts in other fields of science and industry. Therefore, it is necessary to make efforts to provide opportunities for people to learn mathematical modeling and data science at universities and other educational facilities, to make exchanges with industry that prevent "compartmentalization," and to develop career paths. In addition, efforts to establish a "center for mathematics innovation" need to enable experts in mathematical science to collaborate with those in other sciences and industry.

Column 1-6 Understanding the human mind: What is cognitive science?

To realize a super smart society, the practical use of various technologies must be achieved, with the understanding of human cognition and thinking. As a scientific approach to this, innovations in artificial intelligence and big data are essential. In addition, we would like to suggest the importance of studies based on the results of cognitive science that addresses human thinking, learning, exploratory behavior, and other fields.

This column introduces a scientific field called cognitive science, which unravels the minds of humans and other animals with a brain.

Cognitive science addresses the structure, functions and generation of intelligence in humans, animals, machinery and societies through psychological experiments, brain activity measurement, computer simulations, statistical analyses and the like.

Cognitive science originated in the cognitive revolution that occurred in the United States in the late 1950s. Initially, it was a study that addressed artificial intelligence and twins. Then, cognitive science expanded to cover human cognition (e.g., perception, memory, language, thinking) and to study the foundation of human intelligence and the expression and utilization of human knowledge. Cognitive science expanded its research area to neural networks, cognitive neuroscience, evolutionary psychology and robotics. This science has had a major impact on computer vision; natural language processing, including translation; decision-making in economic activities; school education programs; and the analysis and improvement of user interfaces. Below, we pick four topics that have applicability in the real world, and we introduce notable research trends[1].

1. Emotional intelligence

Neuroscience and biometrics that allow the measurement of brain functions have been put into practical use; thus, emotional intelligence has become a subject of research in cognitive science. For example, the Okanoya Emotional Information Project, part of the JST Strategic Basic Research Program, uses physiological indexes to investigate emotional information conveyed in the form of shy behaviors in infants and the impact of apologies by adults on the attack impulse and discomfort of the other party.

2. The sociality of knowledge

In cooperation with researchers of child development, researchers of comparative cognitive science (addressing the perceptions of closely related species of humans) and researchers of evolutionary psychology, cognitive scientists have conducted research on the sociality of knowledge, under the view that the evolution of human intelligence and the human brain that supports it derive from human sociality. Our country is a leader in these fields of study, in particular, comparative cognitive science, since we have the world's leading research institutions, such as the Primate Research Institute at Kyoto University and the Center for Evolutionary Cognitive Sciences at the University of Tokyo.

3. The embodiment of knowledge

The body and its organs have been conventionally regarded as passively receiving commands from the brain and the central nervous system. Today, however, the brain and the central nervous system have come to be widely regarded not as commanding the body to move, but as coordinating the movements of different body parts. Based on that view, joint research by experts in biological psychology and robotics has been conducted. For example, research to explore the human development process has been carried out by giving robots a wide variety of experience.

4. The creation and emergence of knowledge

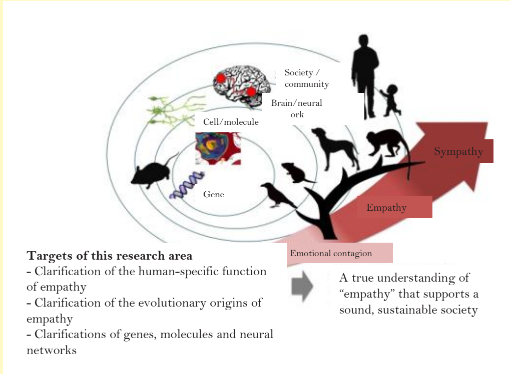
As seen in scientific discoveries, engineering inventions, art works, and sports, humans do more than just use stored knowledge. They also constantly generate new knowledge within the constraints of given circumstances. In light of the above fact, scientific approaches for elucidating tacit knowledge, such as seen in music, fine arts, and the "breaths" and "pauses" of traditional performing arts, have begun.

1 Bird's-eye Report of Research and Development on Information, Science and Technology (2015) (CRDS/JST)

Case study

The evolutionary origin and neural basis of the empathetic systems (Professor Toshikazu Hasegawa, Graduate School of Arts and Sciences, the University of Tokyo)

"Empathy" is important in terms of establishing cooperation, coordination and mutual understanding between myself and others. It is a mental function that becomes the foundation of collective actions, such as the maintenance of the social order, fairness, mutual assistance, rioting and demonstrations. Behaviors based on empathy are also found in human infants. As other primates and other animals, behaviors that are thought to be based on primitive empathy have been reported. These facts show that animals have primitive empathy, and empathy is regarded as an evolutionary adaptation.



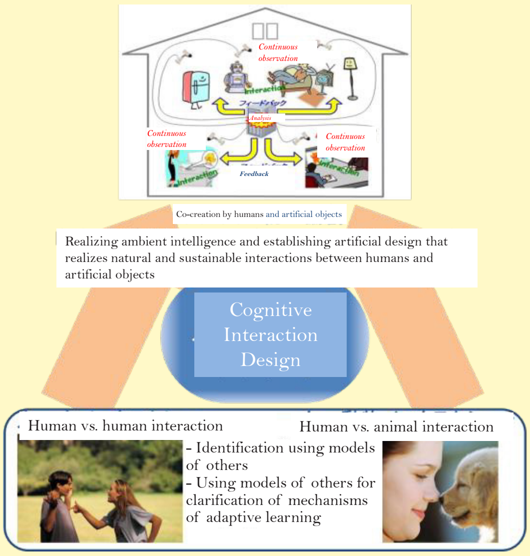
The evolutionary origin and neural basis of empathetic systems

Source: The University of Tokyo

To find the origins of empathy in animals and to clarify the evolutionary process whereby the high-order empathy unique to humans is generated, the study aims to 1) examine the social origins of empathy in humans, 2) elucidate the generation process of empathy phylogenetically and ontogenetically, and 3) elucidate empathy in neural circuits, neural networks and molecules, and at the genetic level.

Cognitive Interaction Design: A Model-Based Understanding of Communication and its Application to Artifact Design (Professor Kazuhiro Ueda, Graduate School of Arts and Sciences, the University of Tokyo)

When a person communicates with another person, a mental model (a "model of others") plays an important role in understanding and predicting the utterances and behaviors of other people, depending on the situation. In a conversation between strangers, there may be a pause, because they do not have each have a model of the other. This phenomenon is not unique to communication between people. It can also be seen in interactions between people and companion animals or between people and objects.



Cognitive interaction design

Source: The University of Tokyo

The study examines models of others, which change depending on the situation so that the behaviors of others can be understood and predicted, from the perspective of cognitive science. This study aims to establish the academic field of cognitive interaction design by applying models of others to the design and creation of objects. In addition, this study aims to elucidate the cognitive process that is common to the interactions of person-to-person, person-to-animal, and person-to-object, and elucidate models of the other at the algorithm level.

Such basic research of cognitive science is one of Japan's strengths. It is possible that knowledge of cognitive science accumulated so far will play an important role in the development of various fields, such as industry, medical care, nursing care, education, culture and the arts. To this end, coordination and cooperation with related academic fields is essential, rather than completing the study only within the scope of cognitive science.