4

Research Trends in Computer Science and Challenges for Japan
— Findings from the International Science Awards —

AKIHIRO FUJII
Information and Communications Research Unit

1 Introduction

Securing top-quality research personnel is an essential for science and technology policy[1,2]. One possible measure for research promotion is to increase the number of winners of international awards and prizes[3-5]. This article focuses on trends in computer science research from the viewpoint of science awards in computer science, such as the Turing Award, and discusses how to facilitate academic development in this area.

Computer science emerged as an academic discipline in the mid 20th century and achieved rapid development. No matter how outstanding, commercial success has not necessarily been valued from the academic perspective. This means that it is a field in which academic structure and the boundaries between basic theory and application technology are subject to constant review.

In the field of computer science, which has undergone such a transformation, the Turing Award has been known for its consistent review and recognition of research results since 1966. To highlight certain aspects of research trends in computer science, this article traces the history of the Turing Award.

There are many other awards and prizes that honor achievement in computer science. The Gödel Prize is particularly intended for achievement in basic theory. The prize is given for outstanding papers in theoretical computer science. Since its institution in 1993, the prize has been presented to, among others, papers on the discovery of algorithms, proposals for computational models, and the elucidation of computational complexity. In Japan, too, awards have been established for computer science, such as the Japan Prize, the Kyoto Prize, and the Japan IBM Science Award.

By reviewing the history of these awards and prizes for the past ten years or so, this article discusses world-wide research trends in computer science. It also summarizes the current Japanese research environment surrounding computer science research through interviews with prominent Japanese researchers about the level of Japanese research and education as well as possible measures for promotion in the area.

2 What the awards and prizes indicate about recent computer science

2-1 The Turing Award

(1) Recent laureates and characteristics of the award

Essential research on the information was established in the mid 20th century, leading to the basic principles of the computer and communications. One of these fundamental principles is a concept known as the "Turing machine," which was introduced by Alan M. Turing. His research results, represented in his 1937 paper "Computable Numbers," later contributed to the birth of the computer and probably created a turning point in the entire world of science that furthered its advancement.

Alan J. Perlis, the first winner of the Turing Award, praised Turing's achievement in his commemorative lecture as having "completely captured the imagination of one generation of researchers and demanded all their thinking power"[12].

The Turing Award was established in honor of Turing's achievement, and has been recognizing outstanding research achievements since its first presentation in 1966. Currently, a prize of 100,000 U.S. dollars is provided by the Intel Corporation.

Table 1 shows the names of the Turing Award winners of the past 10 years, along with their achievements. Since the Turing Award honors "general technical achievement in the field of computer science," each of the listed research achievements has made a significant contribution to the computer science and the development of information and communications technology today.

For example, as early as in the 1960s, Douglas Engelbart, the 1997 winner, was seeking innovative ideas about the functions characteristic of the current models of information terminals, including those on the precursor to the mouse that is in widespread use today and a camera-based interface for the personal computer. He and his colleagues were already envisioning the computer of the future in the 1960s, when ideas like the mouse and the laptop computer were revolutionary in the world of computer systems. His winning of the Turing Award was recognition of his long-lasting contribution to both the computer system and human beings.

In 2001, Kristen Nygaard and Ole-Johan Dahl received the award for their research into object-oriented technology. This was another research effort that had a significant impact on computer science. During the development process of a programming language named "Simula I," they invented a scheme for building a layered control structure for computing, based on the notion called the "object." This "object-oriented" programming paradigm has triggered a fundamental change in how programs are designed and developed. Not only has the award-winning scheme been strongly inherited in today's programming languages, such as C++ and Java, which are widely used for system development, but it also exerts a considerable influence on software development processes and design concepts.

The 2002 recipients are Ronald L. Rivest, Adi Shamir and Leonard M. Adleman, the inventors of

Table 1 : Turing Award for the past 10 years

Year	Laureate Name	Achievement
2002	Ronald L. Rivest, Adi Shamir, Leonard M. Adleman	Contribution to the development of RSA cryptography and the subsequent advancement of cryptographic technology
2001	Kristen Nygaard, Ole-Johan Dahl	Establishment of the ideas fundamental to object-oriented programming through the design of the programming languages, including Simula I
2000	Andrew Chi-Chih Yao	Research in the theory of computation, especially computational complexity, cryptography, and communication complexity, based on the theory of pseudorandom number generation
1999	Frederick P. Brooks, Jr.	Contributions to computer architecture, operating systems, and software engineering
1998	James Gray	Contributions to database and transaction processing research and system implementation
1997	Douglas Engelbart	Presentation of a vision of the future of interactive computing between the human and the computer, and invention of key technologies to help realize this vision
1996	Amir Pnueli	Introduction of temporal logic into computing science and outstanding contributions to program and systems verification
1995	Manuel Blum	Contributions to the foundations of computational complexity theory and its application to cryptography and program checking
1994	Edward Feigenbaum Raj Reddy	Pioneering research on the design and construction of large-scale artificial intelligence systems, demonstrating the practical application of artificial intelligence technology
1993	Richard E. Stearns Juris Hartmanis	Establishment of the foundations of the field of computational complexity theory

Source: Compiled by the author based on Reference[7].

RSA public key cryptography. Their achievement, which is a technology providing basic principles for ensuring electronic information security, has had a significant impact on the computing world. As society becomes increasingly computerized, a framework for electronic security protection is expected to play an essential role in a variety of areas. Security capability for these purposes will be enabled based on public key cryptography.

An example of award-winning research achievement more inclined to basic theory is that of Andrew Chi-Chih Yao, who was honored with the Turing Award in 2000 for his contribution to quantum computing. He established a completely new computational paradigm based on the principles of quantum mechanics. He succeeded in proving the equivalence between quantum circuits in quantum mechanics and the Turing machine in computer science. This achievement indicates that algorithms used on regular computers can be realized at the quantum level. These findings have provided new possibilities for innovation such as the development of computer mechanisms based on new principles and ultra high-speed communications systems.

Award recipients in other theoretical fields include Robin Milner (1995) and Manuel Blum (1995), who have been described by a theoretical computer scientist as having “received the award they deserve.”

(2) Profiles of the laureates

We investigated at what age the Turing Award laureates get the idea that was later recognized. The main source of the survey was the website on which the content of the Turing Lectures is posted; this information is presented by the recipients after award acceptance, together with their achievements[7].

This investigation reveals that many of the researchers awarded have opened a new field at a relatively early age (between the ages of 30 and 40) and have made continuous contributions to research progress in that field.

From the perspective of nationality, many of the Turing Award laureates acquired U.S. citizenship later in their lives, although their original nationalities varied widely. This indicates the typical way in which U.S. research personnel have been supplied in the area of natural science, particularly over the past half-century.

One characteristic of computer science is that there are many researchers who used to work in the area of mathematics or applied physics. This can be attributed to the short history of computer science as well as to the academic position of computer science as a discipline that lies on the boundary between existing academic disciplines such as mathematics, communication engineering and electrical engineering.

Another characteristic is that, for achievements in such fields as cryptography, database theory and software engineering, laureates not only write theoretical papers, but also concurrently develop practical systems. In fact, the essential objectives of their projects have often been the design of practical systems.

As these findings indicate, for a scientist to receive the Turing Award, his or her achievement must involve the discovery or elucidation of a fundamental principle. In addition to this, practical application of this principle must be demonstrated, or alternatively, a concept established by the researcher must be inherited and evolved by another, which is also the case with many projects that have won the award.

2-2 The Gödel Prize

The Gödel Prize is, like the Turing Award, a prestigious award that recognizes achievement particularly in the field of theoretical computer science. The prize selection is jointly conducted by the Special Interest Group on Algorithms and Computing Theory of ACM (ACM-SIGACT) and the European Association for Theoretical Computer Science (EATCS), a European scientific society[8].

The prize was inaugurated in honor of Kurt Gödel, a mathematician renowned for achievements such as proving “Gödel’s Incompleteness Theorems.” In recognition of contributions to pure theory in mathematical science, the prize is granted to papers published in the last few years. The prize includes an award of 5,000 U.S. dollars. Please refer to [8] for a list of laureates and their prize-winning papers.

In the field of theoretical computer science, “computational complexity” is one of the core research areas. An important unanswered question about computational complexity is known as the “P versus NP” problem. The complexity of problems is classified as P or NP. Class P is a set consisting of problems that are relatively easy, such as asking the path of drawing a graph using a single stroke, and are solved in polynomial time. Class NP consists of problems whose positive solutions can be verified, provided that part of the solution is given, in polynomial time, such as a Hamiltonian path problem, which asks to find a path that visits each point in a given graph. While it is clear that P is a subset of NP, it remains unsolved whether there are any problems that belong to NP but not to P. The P versus NP problem asks whether such problems exist. A prize of 1,000,000 U.S. dollars is offered from the Clay Mathematics Institute for a solution to the P versus NP problem[6]. Gödel is one of the discoverers of this question.

One of the Gödel Prize recipients is Seinosuke Toda, a Japanese researcher who won the Gödel Prize in 1998, the sixth year since the prize was instituted. His research efforts contributed to the resolution of the P versus NP problem. He introduced to the NP problem the concept of the counting problem (PP problem) and proved that studying a PP problem can provide large amounts of information about an NP problem. The theorem, known as the “Toda’s polynomial equation,” is considered a key achievement in theoretical computer science.

In the area of computational models, Joseph Halpern and Yoram Morses received the Gödel Prize in 1997, the fifth year, for their research on distributed computing. It was a basic theory on the coordinated operation of distributed systems and was related to the implementation of parallel computing with greater granularity. Their research results are expected to serve as a theoretical proof in designing large-scale computational software based on grid computing, a technology that is currently attracting huge attention.

2-3 The Kyoto Prize

Next, let us consider the Japanese awards for world-class research. The Kyoto Prize is awarded as part of the activities of the Inamori Foundation, which was established through the initiative and benevolence of Dr. Kazuo Inamori. [10] states, “the Kyoto Prizes are international awards to honor those who have contributed significantly to the scientific, cultural, and spiritual development of mankind. The prizes are presented annually, one in each of the following three categories: Advanced Technology, Basic Sciences, and Arts and Philosophy (Creative Arts and Moral Sciences until the 1999 Prizes).” The prize money is 50 million yen.

Table 2 lists the Kyoto Prize laureates in the field of computer science and their research themes. The laureates are selected from researchers in the computer science category

Table 2 : The Kyoto Prize

No.	Year	Laureate Name	Field	Turing Award
16th	2000	Antony Hoare (UK)	Information Science	1980
12th	1996	Donald Ervin Knuth (US)	Information Science	1974
9th	1993	Jack St.Clair Kilby (US)	Electronics	—
8th	1992	Maurice Vincent Wilkes (UK)	Information Science	1967
5th	1989	Amos Edward Joel Jr. (US)	Electronics, Telecommunications, Lasers, and Control Engineering	—
4th	1988	John McCarthy (US)	Computer Science and Engineering, Artificial Intelligence	1971
4th	1988	Avram Noam Chomsky (US)	Cognitive Science (in its wider sense)	—
1st	1985	Rudolf Emil Kalman (US)	Electronics, Telecommunications Technology, Laser Technology, Control Engineering, Computer Sciences, Information Engineering and Artificial Intelligence	—
1st	1985	Claude Elwood Shannon (US)	Mathematical Sciences (including Pure Mathematics)	—

Source: Compiled by the author based on Reference[10].

Table 3 : The Japan Prize

No.	Year	Laureate Name	Field	Recognized Achievement
19th	2003	Benoit B. Mandelbrot	Science and Technology of Complexity	Creation of universal concepts in complex systems — Chaos and Fractals
18th	2002	Timothy John Berners-Lee	Computing and Computational Science and Engineering	Advancement of civilization through the invention, implementation and deployment of the World Wide Web
15th	1999	W. Wesley Peterson	Information Technologies	Establishment of coding theory for digital communication, broadcasting and storage
12th	1996	Charles K. Kao	Information, Computer and Communication Systems	For pioneering research on wide-band, low-loss optical fiber communications
6th	1990	Marvin Minsky	Category of Technology of Integration—Design, Production and Control Technologies	Establishment of the academic field of Artificial Intelligence and a proposal of fundamental theories in this field
1st	1985	John R. Pierce	Category of Information and Communications	Outstanding achievement in the field of electronics and communications technologies

Source: Compiled by the author based on Reference [11].

almost biannually. Many of these recipients are already widely recognized for their achievements in the field before being honored. They include some Turing Award winners. The laureates of the Kyoto Prize have often been selected from researchers whose achievements have already been widely recognized in the scientific community.

2-4 The Japan Prize

Another famous science award in Japan is the Japan Prize. The Japan Prize is awarded by the Science and Technology Foundation of Japan "to people whose original and outstanding achievements in science and technology are recognized as having advanced the frontiers of knowledge and served the cause of peace and prosperity for mankind," according to [11]. An award of 50 million yen is presented to the laureates.

Table 3 lists the Japan Prize laureates in the field of computer science and their research themes.

For instance, Tim Berners-Lee, one of the 2002 laureates, was awarded in recognition of his "invention and first-ever implementation of the World Wide Web (WWW), which is the most important element of the Internet technology in information communications networks" and also of his "significant contribution to the further development and proliferation of the WWW"[11].

Benoit Mandelbrot, awarded in 2003, is known for his discovery of the Mandelbrot set, which draws complex, beautiful figures using series of complex numbers. He was awarded for having "discovered that self-similarity is the universal property that underlies complexity, and coined the expression 'fractal' for this concept, and illustrated its properties." The prize-giving body also noted "the applicability of this concept has been extended even to the arts, economics and the social sciences."

2-5 The Japan IBM Science Award

The Japan IBM Science Award is aimed particularly at young Japanese researchers aged under 45 and who are based in Japan. The award was established in 1987 to mark the fiftieth anniversary of IBM Japan, Ltd., for "contributing to the promotion of academic research in Japan and the development of excellent talent, as part of the social action program."

The laureates in the computer science category include Seinosuke Toda, a then-professor at Nihon University, honored in 1998. He is also a recipient of the Gödel Prize mentioned earlier. See [9] for the list of the Japan IBM Science Award laureates and their recognized achievements.

2-6 Characteristics of the evaluation criteria of each award

An overview of the past recipients of each award helps to identify elements emphasized in the selection process. In addition to the above-mentioned Turing Award and the Gödel Prize, ACM recognizes excellence through many other awards based on its Policies and Guide to Establishing an ACM Award[7]. According to this guideline, ACM awards are given in honor of (i) contributions to a discipline, (ii) service to the award's sponsor and/or to a community, and (iii) the best papers published.

In the case of the Gödel Prize, which obviously adopts the third criterion for selection, it does not take long for a researcher to be recognized after he or she makes a deserving achievement. In contrast, the selection process of the Turing Award emphasizes point (ii), which suggests that an innovative concept must wait until it is evolved in the academic or industrial community before it can be appreciated and awarded. This means there are greater delays between achievement and award winning. For example, RSA cryptography, on which a paper was published in 1977, was an accomplishment that took as long as 25 years before it was honored in 2002.

In other words, when growth in the industry or development in the academic field derives from an idea obtained through research activities, the credit usually goes to the underlying research achievement in the field.

3 Current research activities in computer science and challenges to Japan

The following sections first discuss the characteristics of computer science as an academic discipline, in reference to the profiles of the awards and prizes described above. Suggestions are then made for the future promotion of computer science, based on the opinions of researchers working in this area.

3-1 What awards and prizes indicate about computer science research

One can criticize the Turing Award for not being balanced as an international award because it acknowledges contributions to a specific scientific society. However, there is no doubt that its list of laureates is filled with great names in computer science.

In particular, recent award-winning achievements such as public key cryptography and object-oriented technology are either concepts or basic principles/methods that enable the epoch-making application of information processing capabilities. The web is another accomplishment that is as highly regarded as these technologies in international science awards.

3-2 International recognition of research results

One important step in promoting computer science is to produce excellent research results originating in Japan that are recognized by the international scientific community. The level of international recognition can be measured by, for example, the number of publications in the Journal of the ACM, the most historic and prestigious journal in the field of computer science. The journal, which marked its fiftieth anniversary in 2003, has constantly been publishing 30 to 60 significant papers on an annual basis for the past few decades. The number of articles that have appeared in the journal totals over 2,300.

Of these papers, those submitted by Japanese researchers account only for 1.1%. In the last 10 years, the figure is even smaller, about 0.8%. Discussing the number of acceptances by Journal of the ACM alone is insufficient for making an adequate judgment, but it is undeniable that Japan should make more effort to raise international recognition of its research achievements.

For example, the Japanese language input system for Japanese word processors, which has had a significant impact on non-English language input systems, deserves wider international recognition and respect than it has had. Other world-class achievements in recent years include the development of an operating system for embedded systems and the acquisition of the best results in vector computing against the benchmarks.

3-3 International exchange between research communities

Today's computer science field covers a variety of research areas. It is therefore often the case that individual researchers are unable to find a domestic scientific community in which they can discuss the specific topics in which they specialize. Some call for research fund management in a manner that allows for more frequent hosting of international conferences.

Another direction for improvement can be learned from the U.S., where there is dynamism that attracts top-quality students and researchers from other counties. Many recipients of the Turing Award have been such people. While Japan also accepts many excellent students from overseas and grants a number of doctorates to foreign researchers annually, there are certain cultural aspects that make life in Japan difficult for foreigners. It is essential that Japan give further consideration to accepting foreign students as well as be more active in hiring foreign researchers.

3-4 Significance of interdisciplinary research activities

Researchers specializing in theory sometimes mention their laboratories' need for research personnel who have completed an undergraduate mathematics course. This provides an important point of view in developing course models and curricula for science and engineering departments. There have been a number of cases where advance in information processing technology has opened completely new research possibilities, as has recently happened in the area of life science. Thus, interdisciplinary research is becoming increasingly vital.

As important as interdisciplinarity in science and technology are the boundary areas between scientific and social activities. Public key cryptography has proven truly effective because of the widespread availability of electronic information. Close and continuous cooperation between industry and academia is essential for allowing scientists to achieve outstanding results. Essential elements in realizing this include an increase in the number of research projects entrusted to universities, improved mobility of research personnel, and efficient management of research organizations.

3-5 Recognizing the scientific significance of computer science

Here is a comment by a researcher that is worthwhile considering: "Japan's research and education communities related to information processing lack the intention to capture the essence of information and recognize computer science as a field of science. Engineering did not precede the invention of the computer."

There is a traditional perception that computer science serves as the basis of information processing technology. An important additional view is that, in the future, research on information will lead to new developments in a wide range of fields of science and technology. The ripple effect of information technology in other academic disciplines largely depends on breakthroughs in information processing capability. The possibility of new developments does not lie exclusively in computer science but in broader areas where computer science is the foundation. From this point of view, implementing research projects intended to explore the frontiers of interdisciplinary fields is essential.

4 Conclusion

Research in the area of computer science continues to be important because computer science is expected to have, in addition to its ripple effect on industry, a considerable influence on other science and technology fields in terms of application.

Japan has acquired a certain level of strength in computer science research specifically in the pure theory field. Moreover, the nation is affluent in industrial infrastructure as has been proven through the development of mainframe computers and the production of personal computers. More recently, Japan's strength has been shown in world leading-edge developments such as advanced mobile phone capabilities and intelligent home appliances. The right combination of these advantages promises an outcome with international impact. To achieve this, Japan should establish goals from a wide perspective in application fields and a long-term view of the direction of technological evolution.

References

[1] "Toward the Development and Securing of Research Personnel for Stronger

International Competitiveness", Second Proposal by the Committee on Human Resources, Council for Science and Technology, June 2003. (in Japansese)
[2] Akira Goto, "Innovation and Japanese Economy", Iwanami Shinsho, August 2000. (in Japanese)
[3] "The Estimation on the Number of World-class Researchers," National Institute of Science and Technology Policy, Research Material No. 87, July 2002. (in Japanese)
[4] "Research and Educational Environments and Effective Measures to Nurture World Class Scientists" National Institute of Science and Technology Policy, Research Material No. 102, July 2003. (in Japanese)
[5] Rensei Baba, "The Hundred Years of the Nobel Prize — A Science History Revealed by the Three Natural Science Awards—", Chuko Shinsho, March 2002. (in Japanese)
[6] "New Trends in Computer Science," Journal of IEICE, December 2003 issue. (in Japanese)
[7] Turing Award: http://www.acm.org/award/
[8] Gödel Prize: http://sigact.acm.org/
[9] Japan IBM Science Award: http://www.ibm.com/jp/
[10] Kyoto Prize: http://www.inamori-f.or.jp/
[11] Japan Prize: http://www.japanprize.jp/
[12] ACM Turing Award Lectures The First Twenty Years 1966 to 1985, Ashenhurst, R. (Edt), ACM Press, July 1987

(Original Japanese version: published in April 2004)