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Artificial Intelligence as a Hope

AI for Taking on the Challenges of an Unpredictable Era

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From the Editor

The term artificial intelligence (AI) has started to become commonplace in Japanese print media and TV. However, since many people are still largely unfamiliar with what the term actually means, my office receives questions about AI and requests for presentations about it on a daily basis.

AI has certainly been covered in a large number of books and other media, however only certain aspects of it tend to be presented. As the term AI is currently trending, some of the coverage has started to exploit the trend by interpreting it in a broad sense, giving people the wrong impression.

Another problem is that the latest developments in AI are taking place at centers of corporate activity, so they are restricted by corporate confidentiality, making mass media exposure difficult. At the same time, only the technologies that can be shown to the general public, such as web-based image recognition, are being covered as examples of AI, creating a poor balance of coverage.

This feature issue attempts to go beyond the current coverage to present a total picture of the many different aspects of AI. The first half contains several views of AI presented by National Institute of Informatics professor, Noriko Arai, and Yahoo Japan Corporation Chief Strategy Officer, Kazuto Ataka. The second half looks at the breadth of AI applications and depth of the technology involved, along with the innovations that are making them possible using the same general-purpose AI. There is information on AI applications and technology that have expanded into industries such as finance, railway, distribution, water and manufacturing.

Many readers will doubtlessly view a collection of corporate articles like this one as a form of corporate PR. However, while this issue uses Hitachi examples to describe AI, it is designed as a special feature that will satisfy the interests of many readers who are eager to learn about the current state of AI. We have aimed to make this issue something that busy business people will be willing to pay to read. Whether we have succeeded in this aim will be up to our readers to determine.

This April, Hitachi strengthened its front-office organization, making a fresh start with a new organization for creating innovations in collaboration with customers. We are showcasing AI as the core technology for this new approach.

Japan is now at the turning point of a shift from a manufacturing-based economy to an economy based more on value generated from services. However, there is a need to survive this age of innovation as the effects of never-ending global economic changes and conflicts extend to each and every one of us. I think that AI provides hope for survival in this unpredictable age. I hope this issue will help readers take advantage of this new ray of hope.

Editorial Coordinator,
"Artificial Intelligence as a Hope:
AI for Taking on the Challenges of an
Unpredictable Era" Issue

Kazuo Yano, Dr. Eng.

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Artificial Intelligence as a Hope
AI for Taking on the Challenges of an Unpredictable Era

Contents

Artificial Intelligence as a Hope

AI for Taking on the Challenges of an Unpredictable Era

Artificial intelligence (AI) has started to move beyond the realm of computer science and find genuine practical uses.
What impact this will have on business and other parts of society is a matter of growing interest.
A general-purpose AI developed by Hitachi is being put to use in a wide range of industries where it is successfully using past data to generate knowledge for a better future and to devise accurate ways to deal with the problem of unknowns.
In doing so, it is giving a foretaste of new ways of confronting the unknown.
AI is beginning to demonstrate its great potential as a source of hope for us, living in unpredictable times of relentless change.

Expert Insights

Approximate Solutions and True Solutions

Noriko Arai, Ph.D.

Professor, National Institute of Informatics

Born in Tokyo. Hitotsubashi University Faculty of Law, graduated from University of Illinois, and completed her doctorate at the University of Illinois Graduate School of Mathematics. Ph.D. (Science).
Dr. Arai specializes in mathematical logic (proof theory) and artificial intelligence.
Following positions as Hiroshima City University assistant, and visiting researcher at Fields Institute for Research in Mathematical Sciences and the Princeton Institute for Advanced Study, she has been a professor at the National Institute of Informatics since 2006, and Director of the Research Center for Community Knowledge at the same institution since 2008. She was awarded a 2010 Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology. Project director of the Todai Robot Project "Can a Robot Get into the University of Tokyo?" since 2011.
Important works "Math is Language—Math Stories" (Tokyo Tosho Co., Ltd.), "How Computers Can Take Our Jobs" (Nikkei Publishing Inc.), "Can a Robot Get into the University of Tokyo?" (East Press), etc.

I don't like machines very much. I don't like riding in cars or on trains, and I chose a high school and university that I could commute to by bicycle.

However, of all the various types of machines around today, I think I most dislike appliances with artificial intelligence (AI) functions—'talking appliances' in particular. People are surprised to hear this coming from the leader of an artificial intelligence project, the Todai Robot Project. Naturally there is no microwave in my house. Microwave heating ruins tasty *sake* and makes *mochi* rice cakes lose their shape. It may be more work, but *sake* is better when warmed in hot water, and *mochi* is better when cooked on a grill.

I have friends who say microwaving is handy. Most dishes can be cooked just by following the directions of the appliance. Today's microwaves have dozens of pre-programmed recipe settings, letting you cook things like hamburgers and deep-fried shrimp just by doing as the appliance commands. Of course, microwaves can't actually deep-fry, so deep-fried foods are only simulacra of the genuine article, though reportedly very tasty nonetheless.

However, herein lies the issue. When an approximate solution to a problem is provided, many people at first notice how different it is from the true solution, feeling, for example, that *mochi* is better cooked with a grill. However, when they consider the labor required to achieve the true solution (cooking *mochi* with a grill), people often just get lazy and accept the approximate solution (microwaving the *mochi*). The thinking goes as follows: "I am clearly aware of the difference between the true solution and approximate solution, however on this occasion I have simply made a rational choice by considering the costs versus the benefits. Naturally, I will choose the true solution when I have to."

In his book, *Laws of Media*, the philosopher Marshall McLuhan makes the astute observation that this way of thinking is a flagrant misapprehension. Humans are shaped by the tools they produce, not the other way around. By using these tools, we inevitably become a new entity that complements them. Socrates also understood this. He refused to use the greatest invention in the history of mankind—writing. His choice was lamented by his student Plato, who wrote down Socrates' ideas. Plato's choice may have been rational, however we are unable to judge the value of what was lost by it since we are all the products of cultures from after Plato's time, so we have lost the ability to feel how different the world would be without writing. In the future, we will likely be shaped by microwaves, by smartphones, by Watson[*1], and by Siri[*2].

So, when I am asked in interviews about whether artificial intelligence will become able to feel emotions like humans do, I respond as follows: "When artificial intelligence becomes part of daily life, humans will lose the ability to feel emotions before artificial intelligence gains them, so we will likely no longer be very aware of the difference." Journalists must not understand this answer, because it has so far never appeared in any article.

*1 IBM and Watson are trademarks of International Business Machines Corporation, registered in many jurisdictions worldwide.

*2 Siri is a trademark of Apple Inc., registered in the U.S. and other countries.

Technotalk

Human-friendly AI that Learns from Life

Kazuto Ataka, Ph.D. Chief Strategy Officer, Yahoo Japan Corporation
Kazuo Yano, Dr. Eng. Corporate Chief Scientist, Research & Development Group, Hitachi, Ltd.

The use of artificial intelligence (AI) is growing, with applications that range from big data analytics to marketing and self-driving vehicles. It is anticipated that new possibilities for business will open up through the combination of AI with large quantities of data acquired from real life, including human behavior and operating conditions from a variety of equipment. Anticipating such developments, Hitachi was among the first to work on the development and deployment of general-purpose AI. Through this work, Hitachi is seeking to revolutionize business and society using AI solutions based on proprietary technology and concepts. Today, we invited Kazuto Ataka of Yahoo Japan Corporation, a leading evangelist for new AI, and engaged in a discussion with Kazuo Yano, who directs general-purpose AI research at Hitachi, concerning the shape of the future in which AI and people will co-exist.

A Number of Problems for AI

Yano: Currently, interest in AI is growing around the world. Having had much to say about AI and data analysis, drawing on a background of knowledge from neuroscience, how do you view recent developments in the field of AI?
Ataka: As I see it, there are three problems. The first is the misdirected hype surrounding the subject that, lacking an understanding of what AI actually is, has engulfed it in fear-mongering and exaggeration. Certain ways of thinking specific to Japanese people, inspired by robot anime and a fondness for science fiction, may play a part in this.

The second is a lack of understanding of the genuine changes brought about by the synergy of AI and data. It is almost certain that many different types of work based on the processing of information, including the assessment and classification of information, analysis and prediction, and manual work, will be automated at speeds tens of thousands of times faster than human beings are capable of. I wonder how many people genuinely appreciate the incredible power of this.

The third problem is that, perhaps influenced by these preconceptions and lack of understanding, and despite Japan having many AI-related technologies, I have a strong sense that we are lagging behind the advanced economies of Europe and America, who have a more realistic view of things and where the pace of development is accelerating.
Yano: Having discussed AI in many different places, I too, have become strongly aware of the preconceptions you are talking about. The greatest problem, which is not limited only to Japan, is the view that humans and AI are in conflict. This is the biggest mistake.
Ataka: That's right. And this is despite AI being for the benefit of humans.
Yano: The real conflict is not with machines but with other humans. It is a battle between the traditional approach of only learning from one's own experience or from those around oneself, and the new approach of utilizing computing power to learn systematically from all available data. This is because it typically makes no sense to compare the speed of a human to that of a car, or the extent of your knowledge to that of an Internet search engine.
Ataka: Because you can't win comparisons like that.
Yano: A search engine is in truth an agglomeration of AIs. In the same way, machines will always win out in certain areas. Nevertheless, there are also things that only we humans can do. I believe we need to increase the number of people who view AI in terms of this correct framework.
Ataka: I completely agree, and for this reason we are engaged in public education initiatives. On the other hand, when you consider the relationship with robotics, there is also a danger that we will build something that will be antagonistic to humans. What are your thoughts on this?
Yano: I believe that ethics will become more important. However, if you think about it, all tools are capable of both good and bad uses, and creating a technology that is absolutely incapable of being misused is an impossible objective. If you consider AI as a tool, then

it is no exception. That said, there will be a need to impose some form of restrictions.
Ataka: As with genetic engineering, there is a need for measures that govern the technology. The Boston-based Future of Life Institute, a research support organization, is involved in activities such as supporting research into AI that will contribute to the future of humanity and looking into the risks that AI poses. The Future of Humanity Institute at the University of Oxford headed by philosopher Nick Bostrom is studying the impact that AI will have on humanity and how to control it. I have also heard of similar institutions being established at The Massachusetts Institute of Technology (MIT) and the University of California, Berkeley. I believe we also need to be doing something similar in Japan.
Yano: What is needed are places where people from all walks of life can come together to debate the subject, including those with no involvement in AI research. More fundamentally, it may also be that we need to be thinking about mechanisms to prevent the misuse of technology or runaway research.

AI Should Mimic the Immune System

Ataka: While it is difficult to impose restrictions that do not impede progress, there is a concern that, unless debate gets underway and we start thinking about guidelines soon, it will be too late. For example, a more pressing problem than the misuse of robots may be the use of AI in cyber-attacks.
Yano: But by the same token, can't AI also be used as a defense? In practice, consultations along these lines are already in progress. Might it not be possible to build AIs that act as an immune system, protecting against unauthorized activities?
Ataka: Constantly retuning itself to provide protection. That is quite a good fit with how AI works.
Yano: So you agree that there is a great deal of similarity between an AI and an immune system?
Ataka: Very much so. They both learn from a complex environment.
Yano: The immune system deals with unknown threats yet is based on a finite number of genes. It works by partially accepting the unknown entity and acquiring the means of manufacturing antibodies from the invader itself so that it can be defeated the next time it is encountered. It operates autonomously on a completely different level than consciousness and the brain and is eminently systematic. While the brain is frequently used as a comparison in the discussion of AI, it seems to me that we should be trying to mimic the immune system.
Ataka: This extremely high capacity for learning is not the only thing that the immune system has in common with the central nervous system (CNS), which I originally studied. The proteins expressed on membranes are also similar. In fact, there are a number of proteins that are specifically expressed in the CNS and immune systems.
Yano: No doubt there is some significance to that. Along with the brain, I also see the immune system and evolution as examples of knowledge-based activity by living organisms. This makes me think that AI research should pay more attention to mechanisms from these two fields.
Ataka: That is a good idea. Although a life scientist myself, I have just learned something new about living organisms from a physicist, Dr. Yano (laughs).
Yano: I wouldn't think of trying to teach you that. Despite being a physicist, I have a fascination with life and the study of it, and accordingly I have paid a lot of attention to biology, especially the biology of the human body, in my AI research. The question of how we can get AI to understand human happiness and use it to enhance that happiness is one of my main research topics, and a key factor in assessing people's happiness is their bodily rhythms.

For the last 10 years we have been working on research in which we analyze people's activities by using wearable nametag sensors to record their movements in the form of three-dimensional acceleration data. In doing so, we have identified characteristic patterns of bodily movement that correlate strongly with people's happiness. Looking at fluctuations in the duration and frequency of activity, we find that in groups with high happiness these fluctuations have a natural distribution, by which we mean that there is diversity in people's movements. Through this analysis we have developed the ability to numerically calculate a happiness index from group activity data.

From various studies into variations among living organisms, it can be seen that there is a commonality in the rhythm of variation between people and mice, and even with flies. Furthermore, if mice or flies are genetically modified to exhibit characteristics of depression, the same disruptions to rhythm can be seen in them as in people with symptoms of depression. While we tend to think of happiness as something that belongs to the field of psychology, I believe it is linked to more fundamental aspects of biology.
Ataka: Behaviors (actions) you say? I believe our emotions and thinking follow from our behaviors (actions). From a neuroscience perspective, nerve

cells tend to die if they are not part of a network, which is to say, if not connected to inputs and outputs. Considering this, it may be that the body does not exist for the benefit of the nervous system, rather it is the body that is central.

Adult AIs, Child AIs, and Gut AIs

Yano: That's why we focus on acceleration. We want to look at the outputs. Naturally, the ease of making all-encompassing measurements is also a factor.
Ataka: If you look at the outputs, then the brain is not all that important. This is a very bold idea.
Yano: The brain is like a router. Not that routing isn't important.
Ataka: "The brain is a router" – that makes a quotable phrase.
Yano: What is important about routers is that different tasks are performed through the same paths. We talk about people as "having guts" or having a "gut feeling." In English, the meanings of the word "guts" include grit and determination. In this way, it seems to me that what an internal organ essential to our survival and a decision-making system have in common are a gut-like nervous system and a router.
Ataka: I agree. That's because the nervous system for the gut region is as well developed as the central nervous system. In other words, the gut is also a brain.
Yano: The gut, too, is a brain.
Ataka: It seems that pursuing the brain of the gut is one path open to AI research in Japan.
Yano: That's right. That's because we at least have a capacity for "belly talk" (in Japanese idiom, the ability to communicate through one's attitude rather than through words).
Ataka: That's right. In the Ministry of Economy, Trade and Industry (METI) council on which I sit, we are currently debating the possibilities and challenges of AI. A major topic in this discussion relates to what Dr. Yutaka Matsuo of the University of Tokyo calls "adult AIs" (information processing systems) and "child AIs" (motor systems). This is the view that Japan should leave adult AIs to major international players and instead take advantage of our position as a world leader in manufacturing to focus on child AIs that can be used in construction, factory, and other workplaces. As I see it, adult AIs correspond to the cerebral cortex and child AIs correspond to the cerebellum. If the ingenuity and manufacturing excellence of the Japanese people are equated to the cerebellum, then it is natural for us to direct our efforts toward the cerebellum AI. The idea of a gut AI has never arisen.
Yano: Whatever it is that determines our gut feelings, it is a decisive force. That people around the time of the Meiji Restoration who didn't know much English could engage with people from America and Europe on an equal footing and be respected was likely because of their gutsiness and the fact that this is a universal that goes beyond language. I believe that AIs that make decisions on a larger scale rather than competing on speed of detailed decision making may be an option that plays to Japan's strengths.
Ataka: The pitcher Hideo Nomo was playing major league baseball when I was a graduate student in the US, and I remember how a friend in my class commented on how dignified he appeared. Despite not being able to speak English, he conveyed an impression of having guts. Still, how do you go about developing a gutsy AI? Yano: Perhaps it is something we could work on together (laughs).
Ataka: It is certainly a very creative subject. It is completely different from the usual concept of AI.

Kazuto Ataka, Ph.D.

Chief Strategy Officer, Yahoo Japan Corporation

Joined McKinsey & Company after completing the Master's program at the University of Tokyo in Biophysics & Biochemistry. After working there for four and half years, he entered the Interdepartmental Neuroscience Program at Yale, where he earned a Ph.D. in Spring 2001. After postdoctoral studies, he came back to Japan to re-join McKinsey at the end of 2001. As a core member of its Marketing and Sales Practice for the Asia-Pacific region, he was involved with brand rebuilding and product and business development for a wide range of sectors. In September of 2008, he moved to Yahoo. Following positions as Director of COO office and Head of Data, Research and Strategy, he took up his current appointment in July of 2012. In addition to resolving business strategy issues and promoting large-scale partnership projects, he is in charge of the Marketing Insight and Intelligence Department, the Yahoo! Big Data Report, and company-wide strategy including data utilization. Director of the Japan DataScientist Society. Director of the Japanese Society of Applied Statistics. Among his literary works is "Issue Driven – A Simple Essence of Intellectual Works" (Eiji Press).

Being Issue Driven

Yano: While deep learning, for example, has huge potential, most real-world problems cannot be solved by the weight of data and computing power alone. What are needed are techniques that can deal with business and other parts of society from a different angle.
Ataka: In this respect, while it may sound odd coming from a director of The Japan DataScientist Society, there are also aspects of the data science boom itself that make me concerned. While data processing techniques are clearly powerful when seeking to solve problems in business, how to pose the problem is so much more crucial, rather than how to apply specific techniques or logic.
Yano: Which is the same idea you expressed in your book, "Issue Driven – A Simple Essence of Intellectual Works." Most of the time when we fail it is because we have misunderstood the issues.
Ataka: It is the same with me. The title of the book was directed at myself (laughs). The majority of business decisions do not require particularly advanced data science. In this data-driven era, without having a clear understanding of the issues, namely what questions we are seeking to answer, we will end up going in the wrong direction. In achieving this, it is vital to get the basics right, meaning collecting clean data and making appropriate comparisons in accordance with the issues. I am concerned that inflated expectations for data science are spreading through a failure to understand this point.
Yano: In that case, it is important to aim for AIs that are capable of general-purpose application in a variety of systems and that can respond proactively and autonomously to all sorts of threats and other changes, just like the immune system.
Ataka: I agree. Along with gutsy AI there is also immune system AI. I will suggest at the next council meeting that Japan should compete on the basis of the cerebellum, the gut, and the immune system (laughs). However, what is the current situation in Japan? Are we ready to join the international battle for AI development?
Yano: In the context of our earlier discussion of issues, I believe we Japanese need to hone, not only our skills for solving specific problems, but also those for formulating good problems and concepts. Rather than insights on their own, we need to strengthen our ability to draw on specific experiences and formulate concepts and problems, and I believe we can do so.

The formulation of good problems is in some ways related to AI. We spoke about the immune system, and I see AI as a tool for controlling an unknown world. Because we have no knowledge of unknown problems, there is nothing to be gained by repeating past practice. If you think about it in terms of a hierarchical structure where, in the past, a mechanism existed whereby a particular phenomenon occurred and that mechanism in turn was caused by a higher level mechanism, then you realize that structure exists in the unknown, that a way exists for finding a solution, and that each piece of information contains a hundred meanings. I believe that AIs capable of doing this in an extremely systematic manner will prove to be partners that will help people by building an as-yet-unknown future.
Ataka: But if AIs did this for us, would there be anything left for people to do?
Yano: You can also view it as a means for better utilizing the abilities we have. In relation to the happiness index we talked about earlier, what we found in a project at a call center was that the overall happiness of the group was influenced by the level of conversation during breaks, and that the order

Kazuo Yano, Dr. Eng.

Corporate Chief Scientist, Research & Development Group, Hitachi, Ltd.

Joined Hitachi, Ltd. in 1984. In 1993, he achieved the world's first successful operation of single-electron memory at room temperature. Since 2004, he has taken the lead in the collection and utilization of big data. His papers have been cited 2500 times, and he has 350 patent applications. The wearable sensor he developed has been described by the Harvard Business Review as a "historic wearable device." His literary work, "Invisible Hand of Data: The Rule for People, Organizations, and Society Uncovered by Wearable Sensors" (Soshisha Publishing), was elected one of BookVinegar's 2014 10 Best Business Books. Dr. Yano has a doctorate in engineering, he is an IEEE Fellow, a visiting professor at the Tokyo Institute of Technology, and a member of the Ministry of Education, Culture, Sports, Science and Technology's Information Science and Technology Committee. He has been awarded many international awards, including the 2007 MBE Erice Prize, and Best Paper at the 2012 International Conference on Social Informatics.

rate was 34% higher on days with above average happiness compared to below-average days. The ability of people to put their skills to use is influenced by small changes in their surroundings.

One thing that was deeply interesting was that there was no correlation at all between days with high order rates and days with a high proportion of staff with high order rate performance in the data from the previous half year. You cannot build a strong team from number four batters alone. The performance of a team is not the sum of the individual skills of its members. Rather, there are other factors that come into play. One example is that there are people who, despite their own results being poor, act to bring out the best in those around them. Although we naturally assume these subtle intra-group relationships must exist, thanks to data and AI, this is the first time we have been able to visualize them. If we think only about logic, all of these subtle effects tend to get swept away.

Ataka: And yet the truth was present in the data.

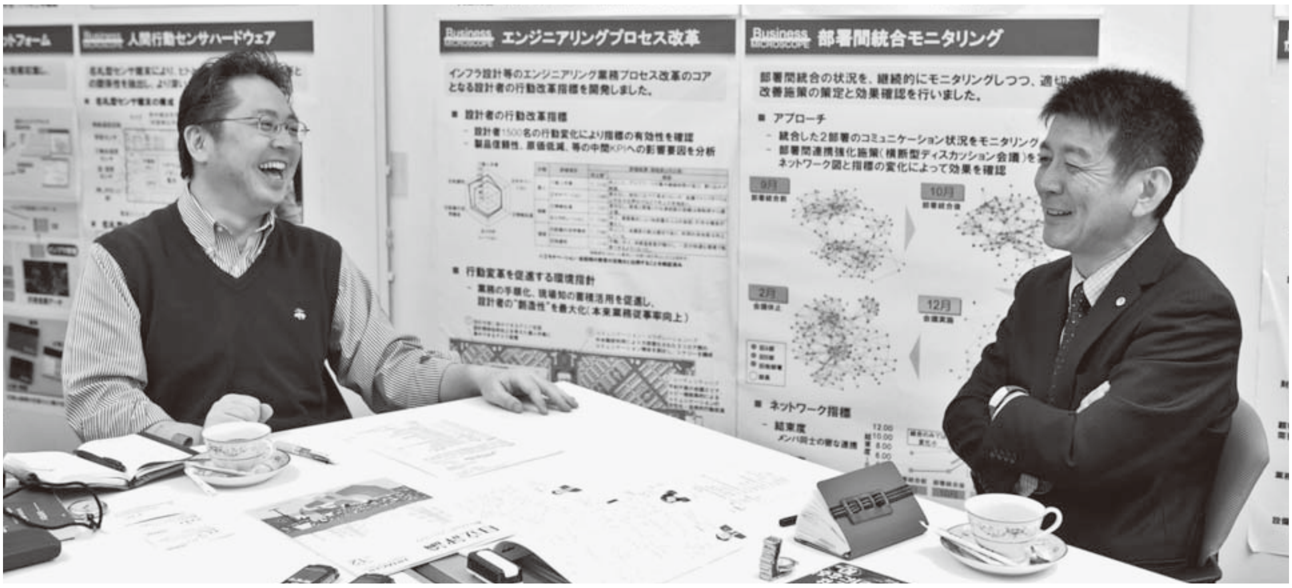
Evolving AI for Exploring an Unknown World

Yano: Hitachi underwent a corporate reorganization this April. Following the Research & Development Division, which had already moved to a new structure that focuses on collaborative creation with customers, this involved a major transformation in which the business units switched from the previous product-based company structure to a customer-oriented and service-based structure. Within this structure, instead of selling AIs as such, our philosophy is to supply services that utilize AIs to help overcome a wide variety of customer challenges. Finally, please tell me your views on this relationship between AIs and services.

Ataka: In the case of interpersonal services, for example, I see the greatest potential for data and AI analysis coming at the stage of learning about the background and latent needs of customers. In a healthcare context, this would be when conducting a diagnosis prior to writing a prescription. As for the subsequent marketing and actual service delivery (or prescription writing and treatment), because having people do this work generates more value, I see AI as serving a backup role, supporting people on the frontline.

Elsewhere, data analysis can provide support for work that in the past has been more of an art, such as optimizing logistics or the physical layout of equipment, etc. While these are back-end services, they should enable improvements on the front end through AI and people thinking together. While it is difficult to simulate models that involve the interaction of multiple systems, I see scope for AI in fields such as business dynamics.

Yano: I see change as being the essence of services. This includes both changes over time and changes due to people or circumstances. In this sense, you can describe AI as a tool for dramatically reducing the cost of adapting to these changes. It is the generation of wealth and elimination of inequalities in the world



through the resulting fundamental improvements in productivity that are the ultimate goal of AI research.

Ataka: Nevertheless, the view persists that this is something that only large corporations can achieve.

Yano: I don't believe this myself. Whereas the options for responding to change under past business logic have been limited, data and AI open up a much larger range of options. It can also be said that the process of earning a profit equates to finding a place for oneself in the network of economic transactions that is of benefit to everyone. It is my hope that the use of AI to look at things in ways that are different from those of the past will enable a greater number of companies to find such a place for themselves.

Ataka: Finding their own niche, in other words.

Yano: And isn't that just another way of saying evolution?

Ataka: That's right. In ecological models, the opening up of a new niche leads to the emergence of new species.

Yano: Evolutionary AI supports this process.

Ataka: Yes, I see the connection. I hope we can make ongoing progress on research into evolutionary AI that will open up unknown worlds.

Yano: Our aim is to create human-friendly AIs that work with us to create a happy future. Thank you for your time today.

Featured Articles

AI for Taking on the Challenges of an Unpredictable Era

Kazuo Yano, Dr. Eng.

RISING INTEREST IN AI

ARTIFICIAL intelligence (AI) is a topical subject. Large investments in the technology, which is a major factor in international competitiveness, have been announced by governments and other organizations.

Nobody as yet has an overall grasp of what impact AI will have on business and other parts of society. However, new developments that give a glimpse of the future have already begun to appear. These can be found in marketing, academic papers, investment decisions, and Internet chatter. And they already include examples of how things will play out in the future. The future is already happening.

However, very few people have the opportunity to deal with these in their entirety. Business people find it difficult to understand technology and its significance while, for AI technologists, the world of business is far away.

The author's own life reached a turning point some 13 years ago when Hitachi's exit from the semiconductor industry meant that he was forced to abandon the semiconductor research he had been engaged in for the previous 20 years. While the company's decision was very unfortunate for him personally, he regrouped and made a fresh start along with his colleagues. This was a turning point because it enabled him to embark on research into what is now called big data and the Internet of Things (IoT), along with AI, before these became popular topics. It wasn't that he had any particular vision, it was more a matter of someone who had nowhere else to turn finding unexpected strength. Looking back, there is nothing for which he is more grateful than this decision by Hitachi to shut down its semiconductor business.

Thanks to these changes, the author now gives more than 500 lectures and other presentations on AI each year, providing opportunities to meet many different people and to discuss how AI relates to companies, business, and people. These range from lectures given to audiences of 1,000 or more to the board meetings of listed companies. The people he meets come from a wide range of industries, including many executives from the manufacturing, finance, retail, logistics, and public sectors.

Through these discussions he has been able to identify developments that, while still in their early stages, are already up and running and will have a significant impact in the future. This article describes the developments he has found.

MISUNDERSTANDINGS ABOUT AI

Accompanying the recent rapid growth of interest in AI there have been increasing numbers of editorials and other commentaries coming out that the author finds disquieting. The following are statements that are commonly heard in relation to AI.

"Machines can now beat humans, even at the game of *go*."
"This will lead to competition between people and machines (AI)."

Both of these statements are misleading.

The science journal, *Nature*, carried an article about how the AlphaGo *go*-playing software developed in the UK defeated the European champion[1]. While computers have already beaten professional players of both chess and *shogi*, because the search space of *go* is orders of magnitude larger it was believed that victory would not come so easily. Nevertheless, computers have become triumphant in a much shorter time than expected. Because the software uses deep learning[a], a topical AI technique, it has been reported that AI has now surpassed human intelligence.

By contrast, the author sees this in terms of a battle between humans.

(a) Deep Learning
A machine learning technique that incorporates mechanisms from the neural circuits of the brain (deep neural networks). Like the brain, deep learning is designed to increase the weighting of circuits that produce correct answers and it can make judgments on unknown patterns, especially in images, by having the computer identify features on its own from input learning data.

On one side are those who adopt the traditional approach of improving their abilities through experience and learning. In other words, people who choose to compete using their own physical and mental strengths.

On the other side, there are those who choose to learn systematically from past records of games, using computers for this purpose, and then having these computers play against each other tens of millions of times to provide more data for learning. These people take a systematic approach to thinking about how best to take advantage of large amounts of past data and the overwhelming data processing and memory capabilities of computers, and apply their physical and mental strengths to this end.

In both cases, it is a human choice and the competition is one between humans.

As a result, those who have taken the latter approach have predominated. That is, success has been achieved by striving systematically to build computer-based techniques for tackling the problem of unknowns.

The reason for this is simple. It is because computer performance has improved and more data has become available to use for learning. This does not apply only to the game of *go*. The same thing is also happening in business.

An important factor for business in all of this is that the development team for the *go* program did not include anyone with professional-level skills in the game. The development of conventional business and management systems has required expertise in the relevant fields. By contrast, the systematic learning used by the computer described above did not require the people involved to have any special expertise. It is anticipated that, as greater use is made of systematic learning, the relative value of practical application-specific knowledge will diminish.

Instead, what is important is data. The value of business and other real-world data is growing rapidly. What is also becoming important is the ability to use computers to learn systematically from data.

To view this as a competition between humans and machines is to misunderstand what is happening. Despite the fact that new ways of solving problems through AI are driving rapid changes in what is required of people and in how they go about living their lives, there is a risk that they will adopt misguided ideas and actions by failing to recognize this.

Nobody would be surprised to hear that the track athlete, Usain Bolt, lost in a race against a motor vehicle. Likewise, the author has never heard anyone claim that their own knowledge is less than the results of a web search engine (which itself is a form of specialist AI). People are simply happy to make use of vehicles and search engines. And, by using the technology themselves, people will acquire an understanding and rid themselves of this unusual way of looking at the situation as a competition between humans and machines.

NECESSITY OF AI

Use of AI as a new methodology is growing rapidly in business. This is because of the significant positive impact it has on productivity.

20th Century and Standardization

Peter Drucker predicted that “The most important, and indeed the truly unique, contribution of management in the 20th century was the fifty-fold increase in the productivity of the manual worker in manufacturing. The most important contribution management needs to make in the 21st century is similarly to increase the productivity of knowledge work and the knowledge worker[(2)].” In other words, Drucker sees a fundamental difference in the nature of work in the 20th and 21st centuries.

The 20th century was one of dramatic improvement in the productivity of factory work. The driving force behind this was the scientific management theory of American engineer and management theorist Frederick Winslow Taylor. Taylor conducted rigorous studies of shoveling work at a steel mill. He broke the work down into separate processes that he then looked at individually to identify activities that were unnecessary or that could be done more quickly. Based on these studies the necessary processes were then standardized. This made it possible for work that had been believed to be possible only by experienced staff, to be done instead by inexperienced people while still maintaining a level of quality.

Taylor’s scientific management theory was adopted across a wide range of activities during the 20th century. This led to work associated with diverse tasks and services being broken down into processes and standardized to eliminate waste.

In the latter half of the 20th century, computers were introduced as a way to achieve this with even greater rigor. Once a computer program was written, it could be used to process and output large amounts of data. Initially used for accounting, computer applications have been expanded into all areas of corporate activity to monitor and automate such business processes as order entry, procurement, production, inventory, dispatch, and human resources. In accordance with Taylor's philosophy, business activities were broken down into individual processes and standardized, with computers being used to record and manage the status and progress of each standardized process. This achieved a fifty-fold increase in productivity and created the modern economies of developed nations.

Now, however, with services and other knowledge work accounting for more than 70% of all work in developed nations, Taylor's methods are no longer sufficient on their own. This is because of the extent to which changes have occurred in services and other knowledge work and the environment in which they are performed. Rigid and uniform practices are frequently unable to cope with people's preferences, greater individual diversity, and the characteristics of specific locations or regions, not to mention fluctuations in things like demand and prices. Rigid business processes based on the Taylor model are a poor match with reality, and even defining business processes is difficult. Similarly, the definition and measurement of business productivity are also frequently difficult.

Benefits of Introducing Computers

In parallel, this also means there is a limit to the productivity benefits that can be achieved by introducing computers as described above. Conventional computers do not learn and grow when circumstances change. For this reason, they are referred to as hard-coded systems, because the programs have to be written explicitly.

In accordance with Taylor's philosophy, people who improve their capabilities by sharing best practices are called Human 2.0, which is to say they are characterized as standardized workers. By contrast, people whose capabilities have been specialized through the division of labor are called Human 1.0, which is to say they are characterized as specialized workers (see Fig. 1).

Current corporate information systems have been developed to support the work of this second generation (Human 2.0). Unfortunately, this approach is reaching its limits in terms of cost-benefit. This is the background to the emergence of the third generation of machines and information systems described in this article.

The productivity of nurses or department store sales staff, for example, cannot be improved using manuals alone. In addition to their core role of caring for patients, nurses also need to produce documents and to consult and coordinate with other people. Likewise, in addition to their core role of recommending products to customers and encouraging their interest, sales staff also need to produce documents, check inventory, and keep track of deliveries. In a diverse and ever-changing environment, it is not possible for manuals to document things like how to prioritize this work and allocate time, meaning that the nurses and sales staff must make these decisions for themselves.

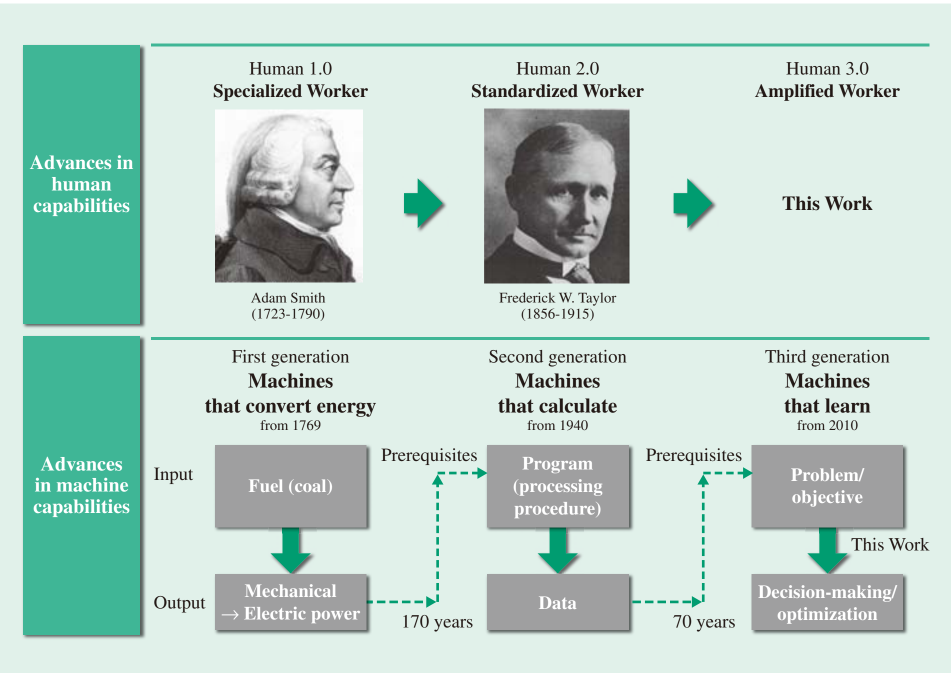


Fig. 1—Improving Productivity through Advances in Human and Machine Capabilities.
People who have built tools and have been specialized through the division of labor (first generation) amplify their capabilities by disseminating and learning from the know-how of experts (second generation), and by autonomously learning from real-world situations that transcend time and space (third generation).

What is important for services and other knowledge work is to set work objectives and other goals. In this article, these are referred to as outcomes. Given a clear objective, it is possible to make flexible and accurate decisions under widely varying circumstances. Past information systems have not been able to satisfy this need for flexibility. Instead, they have tended to result in more standardized practices.

New Image of Humans

What changes all of this is the advent of new methods based on the use of AI. Modern information systems are steadily building up huge quantities of data. The changes taking place in businesses and other parts of society are reflected in this data. By utilizing the data, it is becoming possible for computers to modify the logic by which they operate in accordance with changing circumstances. In other words, AIs have the ability to learn from data and make decisions.

Further underpinning this progress are developments in data collection methods. Ongoing advances in technology include sensors, wearable devices, robots, and drones. Combined with AIs that can learn from this data autonomously, this can create systems (AI-based systems) capable of adapting flexibly to change.

These new AI-based systems have the potential to provide powerful augmentation and amplification of human learning abilities, and can be expected to deliver productivity improvements. This represents the third generation, Human 3.0. A feature of this generation is the amplification of human capabilities. In other words, an amplified worker (see Fig. 1). Whereas enterprise resource planning (ERP) and other similar computer systems were used for standardization in Human 2.0, AI-based systems that learn will assist people in the third generation, Human 3.0, with ongoing learning from quantities of data that are too large for humans to consider on their own. This will enable decision-making with an accuracy that would be impossible when relying only on human experience. It will also allow flexibility in decision-making in ways that are not able to be documented in conventional procedure manuals such that systems will be able to adapt if business conditions change (such as distribution channels or supply and demand conditions). This contrasts with the tendency for people to persist with practices that have worked in the past, even when circumstances change.

Accepted wisdom in the past has been that business process standardization and procedure documentation represent best practices for improving business efficiency, and customers and staff have adapted to work with predefined procedure manuals and machines. In practice, however, the policy of standardizing business processes and implementing them on a computer has not been a success in many services that need to deal with change and a wide range of other conditions. In fact, the concern has been that they pose an obstacle. This in turn has impeded the growth of the traditional information system business.

In the third generation of work, it is the computers and other machines that adapt to humans rather than humans adapting to machines and processes. They support people who make autonomous decisions amid changing circumstances and who are accountable for the results.

AI AS A WAY TO SURVIVE AN UNPREDICTABLE FUTURE

The arrival of AI represents more than just the provision of a convenient tool. Rather, it changes how we go about solving problems and other aspects of our life. While the future is full of endless new possibilities, it also harbors threats to our existence.

In talking about the impossibility of predicting the future, Peter Drucker offered the following insight.

> We know only two things about the future:
> It cannot be known.
> It will be different from what exists now and from what we now expect.
> (...)
> The purpose of the work on making the future is not to decide what should be done tomorrow, but what should be done today to have a tomorrow.[3]

In other words, we are only able to act today. We have no direct means of changing the past or the future. We can only influence the future by how we act today.

However, the author believes there are two different ways of thinking about the present (the point where past and future meet).

The first is to see the present as resting on the knowledge and events of the past. Under this view, what is important is to study established knowledge (academic, scientific, and practical knowledge) and put it to use today. When confronted with things not covered by past knowledge, the only option is to deal with it as it presents itself.

The second is to view the present as the vanguard of an unpredictable future. In response, even if the future is impossible to predict, it should still be possible to establish ways of dealing systematically with a diverse range of changing circumstances. This view of the present is about striving to achieve this.

The 20th century was a time in which scientific discoveries were made in a wide range of fields, with widespread technological applications. Because knowledge was being created so rapidly that learning found it hard to keep up, it was a time in which the former approach to the present prevailed. It is an approach that is deeply engrained within people.

AI is a new way of doing things that represents a shift toward the latter approach to the present and also a turning point that combines both.

Which of the two approaches has been emphasized has changed over time. Historically, there have been times in the past when dealing systematically with a future that is impossible to predict was seen as more important than it is now.

The Edo Period was one such time. Kaishuu Katsu and Mutsu Munemitsu provide examples. Both of them changed history in the transition from the Tokugawa shogunate to the Meiji Era. They also had something else in common, the ship in which Kaishuu Katsu visited America was the Kanrin-maru. The main work of Mutsu Munemitsu was his *Kenkenroku* diplomatic memoirs. Each of these people chose the respective names from the hexagrams described in the oldest of oriental classics, the *I Ching*.

Written more than 2000 years ago, the *I Ching* states that there are ways of dealing systematically with the unknown based on the identification of the smallest of signs. The scope of the *I Ching*'s application extended from matters of state to personal decisions. The other English name given to the *I Ching* is *The Book of Changes*. It systematically classifies unknown changes into 64 hexagrams and explains how they are to be interpreted. Given its place as the foremost of the *Four Books and Five Classics* of Confucianism[(b)], the *I Ching* clearly placed ways of dealing with the unknown as central to learning. Over and above knowledge of practices and information that have already been established, it placed an emphasis on ways of dealing systematically with these unpredictable situations.

(b) *Four Books and Five Classics* of Confucianism
Nine books that are recognized for their particular importance in the teachings of Confucianism. The four books are the *Analects*, the *Great Learning*, the *Doctrine of the Mean*, and the *Mencius*. The five classics are the *I Ching*, the *Book of Documents*, the *Classic of Poetry*, the *Book of Rites*, and the *Spring and Autumn Annals*. Confucianism is the general term for the ideas and beliefs attributed to Confucius.

Specifically, *xian*, *lin*, and *jian*, the Chinese characters used in the above names, are three hexagrams from the full set of 64, something that was well known among learned people of that time.

The *xian* hexagram refers to conjoining with space and other aspects of the world in ways that go beyond words. The *I Ching* classifies changes using hexagrams that can be specified by a six-bit binary number, with changes being represented by a combination of two states, *yin* and *yang*. If a binary representation is adopted in which 0 is *yin* and 1 is *yang*, the code for *xian* is 001 110. The term *lin* (110 000) refers to acting forthrightly to unhesitatingly grasp opportunities that arise. Accordingly, *Kanrin* (the Japanese translation of *xian – lin*) can be interpreted as indicting a situation in which one should be conjoined with the world in ways that go beyond words, and by doing so, be ready to act forthrightly to seize opportunities that present themselves. In other words, by using the *I Ching*'s language of hexagrams to name his vessel, the name expressed the attitude of facing up to an era of new changes in the transition from the Edo to the Meiji Period.

Similarly, the *jian* hexagram (001 101) referenced by Mutsu means to progress one step at a time despite adversity by asking for help from others. The *Kenken* in the title of Mutsu's book is the Japanese translation of *jian-jian*, with the repetition serving to emphasize this meaning. That is, it means to progress one step at a time despite adversity by asking for help from others, such that even if this leads to more adversity one can continue to make steady progress by asking for help from others. In this way, a large number of changes (64×64 = 4,096) can be expressed by pairs of hexagrams.

For learned people of the Edo and Meiji periods, the pursuit of learning was all about becoming the sort of person who adopts the correct attitude to the unknown. The *I Ching* was the canonical and foremost text for this purpose.

Furthermore, this methodology of the *I Ching*, namely the use of data as a basis for selecting from a set of systematically predefined options, is the same as that used by modern AI. The author discusses this in more detail below.

It is completely different from the modern idea of learning as being an understanding gained from sources such as books or schools. The view that learning was about the acquisition of pre-existing information spread quickly, starting from around the generation that came after those educated during the Edo Period

TABLE 1. Five Requirements for Responding Systematically to Unpredictable Situations
There is a need for broad applicability to unpredictable problems in which the situation cannot be foreseen.

	Problem	What to decide
F0: Outcomes	What is the objective to be achieved?	Outcomes (KPIs)
F1: Scope	What is the scope that needs to be considered?	Input data (scope)
F2: Options	What potential actions are available?	Options
F3: Decision criteria	What are the criteria for selecting which action to take?	Evaluation function
F4: Decision and optimization	Which action should be taken (decision)	Actions
	F1 to F4 are revised based on the outcomes of the action taken.	

KPI: key performance indicator

described above and continuing to the era of catch-up and overtake in the Meiji and post-war periods.

Now, however, new AI methodologies are placing a fresh emphasis on responding systematically to unpredictable changes over and above the utilization of existing knowledge.

Furthermore, as the essence of management, as noted by Peter Drucker, lies in adopting the right approach to an unpredictable future, AI will transform corporate management.

NEED FOR AI TO HAVE BROAD APPLICATIONS

In practice, how is it possible to respond systematically to unpredictable situations? And how can the capabilities of computers help with this?

First, there is a clear need to use general-purpose methods. Countermeasures built on guesswork will be of no use in unanticipated situations.

The practice adopted in the past has been categorization. The idea was that, by grouping situations into categories and devising countermeasures to each one in advance, the correct response could be delivered when something happened. While this works well for simple problems, it fails when the situation is complex. The accurate categorization of situations requires a large number of categories. Furthermore, because it is in principle impossible to anticipate all possible situations, there is an ongoing need to update the categories and countermeasures. In many cases, this takes too much work to be practical.

By contrast, rather than relying on predefined categories, the new approach using AI involves loading large amounts of data from past and present and taking advantage of the overwhelming data processing capabilities of computers to infer the appropriate response from past examples.

These new techniques require broad applicability (i.e. they need to be general-purpose) in order to be able to deal with unpredictable situations. Put another way, the progress of AI depends on the extent to which it is capable of broad application.

PROGRESSIVE DEVELOPMENT OF AI

Along with the following five requirements associated with responding to unanticipated changes, how broadly AI can be applied depends on the extent to which these can be generalized.

The five requirements for responding systematically to unanticipated situations are as follows (see Table 1).

F0: Outcomes: Determining the objective to be achieved
F1: Scope: Determining the scope that needs to be considered
F2: Options: Devising a list of options (potential actions)
F3: Decision criteria: Devising an evaluation function that specifies the criteria for selecting which action to take
F4: Decision and optimization: Using the evaluation function as a basis for selecting which option (action) to take

F1, F2, F3, and F4 are then revised based on the outcomes of the action taken.

There is no great difficulty in developing a program for a particular problem that satisfies these five requirements. What is difficult is achieving the broad applicability needed to use the program on unpredictable problems in which the circumstances are not known in advance.

While achieving broad applicability is more difficult the higher the requirement is in the table

Table 2. AI Levels

AI is classified into levels 1 to 4 based on its scope of application. Level 0 applies to existing mechanistic systems that are not AI.

Level	Category		Features (outcomes are given)	Examples*
4	General-purpose AI	Scope	Decide by learning from data to determine scope and options	Corporate strategy, urban design, wellbeing policies
3		Options	Decide by learning from data in a given scope to determine options	Generation of programs for inventing drugs or materials
2		Judgment	Decide by learning from data for a given scope and options	Optimization of factories, warehouses, or sales
1	Special-purpose AI		Update specified parameters based on learning from data	Recommendations, answering questions
0	Non-AI		Fixed logic specified by hand	Existing business systems

AI: artificial intelligence

* Examples for levels 3 and 4 are the author's predictions

(F1), once achieved, the higher the requirement is in the table, the greater the possibility is of applying the AI program in a wider range of situations.

An outcome is an indicator of success (how good or bad a result is). In business these are also called key performance indicators (KPIs). Choosing these indicators is an important human decision. It is something that in principle must be decided by people.

There has been considerable discussion and research into artificial general intelligence (AGI) in recent times. While the definition of AGI remains unclear, it is frequently used to refer to artificial intelligence that has a similar broad scope to human intelligence. The idea that the achievement of AGI will bring about a singularity has been widely debated[(4) – (7)]. In the sense used above, the pursuit of broad applicability in itself is the right way forward for AI. However, the author's personal view is that arbitrary distinctions about whether or not AGI has been achieved are undesirable.

In other words, people should avoid making arbitrary distinctions and aim instead to progressively expand the applicability of AI. The five requirements above are useful for this. The author has devised his own classification for the progress of AI comprising four levels based on its scope of application (see Table 2).

Level 0 indicates traditional mechanistic systems that do not include learning from data. These are not AI. Level 0 programs are implemented as fixed logic and are written by hand. Most existing corporate information systems and infrastructure systems are at level 0.

Level 1 indicates systems that autonomously modify parameters based on data to achieve an objective, and in which these parameters have been specified by people. Most systems that use machine learning[(c)] are at level 1. The simplest example of this is multiple regression[(d)], a technique for determining the parameters of an approximate model (gradient and intercept) by fitting it to actual data (scatter diagram) using the least squares method. Other forms of machine learning include more complex forms of multiple regression, such as support vector machines (SVMs), decision trees[(e)], deep learning[(8)], and collaborative filtering[(f)]. In essence, however, these are just more complex models that achieve greater accuracy by increasing the number of multiple regression parameters. These machine learning algorithms are already well known and are available through open source libraries such as the R language.

These level 1 systems are special-purpose AIs that are necessarily designed for a particular purpose only. Well-known examples include the generation of customer recommendations in the retail sector and systems for performing facial recognition from photographs. A system for generating quiz answers[(9)] and a technique for identifying a person's face in web

(c) Machine Learning
An AI technique that performs recursive learning from past data and uses this to identify meaningful patterns. Predictions of the future can be made by applying the results to new data.

(d) Multiple regression
An analysis technique for predicting a particular variable (objective variable) using multiple variables (explanatory variables). In the case where the value of purchases by a customer at a store is the objective variable and the customer's annual income, age, gender, and family structure are the explanatory variables, to use annual income alone to predict the value of purchases would be single regression analysis, whereas using the customer's annual income, age, gender, and family structure to make the prediction is multiple regression analysis.

(e) Decision tree
A technique for assisting with decision making by using a model with a tree structure to analyze the factors involved in achieving an objective. In the machine learning field, decision trees are used as predictive models in which the objective variable and explanatory variables are represented by a tree structure. The technique is commonly used in data mining.

(f) Collaborative filtering
A method for inferring the preferences of a particular user from their history of activity that hypothesizes that user preferences will be similar to those with a similar past history of activity and creates a database of the relationships between the history of activity and preferences of a large number of users.

images[10] have been reported in the media, and both of these are special-purpose level 1 AIs.

In the case of level 1 systems, however, the choice of data (feature values) to input to the algorithm is determined based on hypotheses made by humans, requiring the development of a program, and problem-specific program development is also required in association with the algorithm. Accordingly, each problem to which the system is applied involves accompanying analysis and development costs. Furthermore, because the systems lack general-purpose capabilities (are unable to go beyond hypotheses that involve feature values anticipated by people), they are unlikely to produce results that go beyond human ideas.

By contrast, level 2 AIs have the broad applicability to overcome these limitations. Level 2 systems generate decision criteria automatically from large amounts of data and select the best option from among those offered by people. In this case, the scope (range of data to be considered) and outcomes are given by people (see Fig. 2).

A major difference from level 1 is that both the form of the evaluation function used for decision making and its parameters are determined automatically from the data. This means that, in level 2 systems, people do not need to predefine the hypotheses about the subject matter, and therefore they can generate solutions that people had never considered.

Another difference is that there is clear independence between level 2 AI and non-AI systems (IT and other equipment) (see Fig. 2).

It is the broader applicability of level 2 AIs that makes this independence possible. This leads to significant savings on the cost of implementation. Because level 1 learning algorithms are permanently embedded in the system, there is no clear distinction about where the AI starts and ends. Accordingly, there is a large cost associated with program development and maintenance for each problem, and only in rare instances do the benefits (outcomes) outweigh the costs.

The Hitachi AI Technology/H (hereafter referred to as H) announced by Hitachi in 2015 is a general-purpose level-2 AI. As far as the author is aware, it is the first such level-2 AI to enter practical use. H automatically generates more than a million hypotheses, identifies which factors are important, and determines in a quantitative manner the conditions under which better outcomes will be achieved. This technique is called leap learning. A general-purpose AI can be added on to an existing system to transform it into a system that learns and grows by specifying the outcomes and the inputs and outputs.

The daily operation of a warehouse was improved by connecting a general-purpose AI to its warehouse management system (WMS). The outcome in this case was the minimization of total working time. To achieve this, H received the latest data from the WMS each night and used it to determine an equation (evaluation function) expressing how to minimize the total working time. When the dispatch orders (numbering in the thousands) were ready in the morning, H then performed automatic scheduling to prioritize which orders to execute first and output the results as a picking list. While the warehouse staff would then perform the work in accordance with these instructions, in practice they would make various trial and error initiatives during their work. The consequence of this was that work time would decrease on some days and increase on others. As this in turn became input data for the AI, the schedule produced for the next day would take it into account. In this way, integrating a general-purpose AI into an existing system succeeded in creating a learning arrangement whereby the AI and staff cooperated on a daily basis. The warehouse achieved an 8% improvement in productivity.

Other projects achieved a 15% increase in sales at a retail store and a 27% increase in orders at a call center. As described in this issue of *Hitachi Review*, the technology is being deployed in applications such as finance, railways, factories, and water treatment plants, with a total of 24 projects having commenced, covering seven different industries (see Fig. 3).

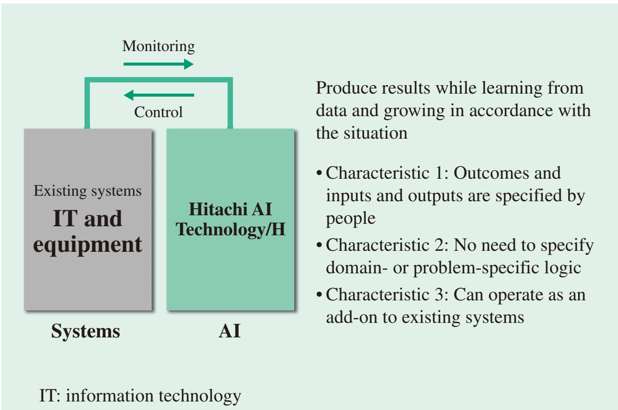


Fig. 2—Features of General-purpose AI (Level 2 and Higher).
People specify the outcomes and the inputs and outputs (based on factors such as the problem scope) and the AI operates based on the data to find or control the conditions that improve the outcomes. There is no need to specify problem-specific logic. In general-purpose AI, the AI and non-AI systems are separate.

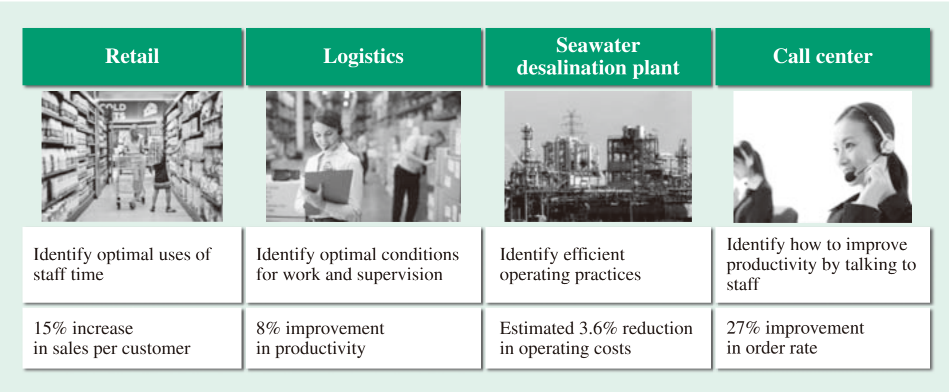


Fig. 3—Applications of H General-purpose AI.
H has been used in 24 projects across seven industries, including finance, retail, logistics, plant, transportation, and manufacturing, where it has generated actions and improvements in a general-purpose manner using the same AI software.

The important point is that the same general-purpose AI software (H) is being used without its being customized for the specific industry or problem. This has resulted in a sudden expansion in the scope of application of AI.

While the system is a level-2 AI with a wider range of application, it is still only capable of choosing the best alternative from a range of options provided by people. In practice, this is enough to implement fairly complex control functions. In the warehouse, for example, the AI prioritizes which of the thousands of dispatch orders to perform first. The total number of combinations for executing 1,000 dispatch orders is nearly infinite (approximately 1,000 factorial). This can be determined accurately.

However, producing more creative answers requires the even greater degree of generality provided by a level 3 AI. For level 3, the AI uses data to determine the options for what action to perform next. An AI with this capability would, for example, be able to produce new drugs or other materials or write software automatically based only on examples. What makes this intrinsically more difficult than level 2 is the need to determine the procedures or sequences for generating these. Here, the term "procedure" means a complex combination of things like conditional branches and loops based on intermediate results, elements that are not present in level 2. The inclusion of these causes a dramatic increase in the size of the search space, making it difficult to learn from example data.

Up to level 3 it is people who determine the scope and decide which data to input. In level 4, the AI also determines what data to input (the scope). With this capability, the ability of AIs to choose their own inputs enables a higher degree of generality to be to achieved by combining AIs in complex ways.

If level 4 AIs can be achieved, it should be possible to devise sustainable national and corporate growth strategies even amid unpredictable changes in circumstances resulting from globalization, and to generate the actions needed to guide people toward their own wellbeing.

IMPACT OF GENERAL-PURPOSE AI

For the purposes of this article, AIs at level 2 or higher are referred to as general-purpose AIs and those at level 1 as special-purpose AIs. Level 2 AIs can already be used on a wider range of problems than could be covered by any individual person. The quantity of data that can be loaded and knowledge that can be extracted from it is much greater than can be processed by one person. However, as noted above, this should be thought of not as machines outstripping humans, but as a measure of how far human capabilities have been enhanced.

To demonstrate the power of these general-purpose AIs, Hitachi used LEGO*1 blocks to build a robot capable of swinging on a playground-style swing and connected it to the H general-purpose AI. The outcome (objective) was specified as maximizing the amplitude of the swing. The system was set up so that movement data was input into the AI via the controller and so that the AI could control the movement of the robot's knees. The robot was successfully able to use the swing after only about five minutes of system operation, without the use of any predefined knowledge.

In this way, an existing system was transformed into one capable of learning, applying what it has learned, and growing simply by integrating it with a general-purpose AI and providing the desired outcome and data with the potential to influence that outcome.

Such systems based on general-purpose AI can operate 24 hours a day, 365 days a year. Nevertheless,

*1: LEGO is a trademark of the LEGO Group.

they are able to learn quickly. It was astonishing that it took only five minutes to learn how to use a swing. This also demonstrates its ability to adapt to changes in supply and demand, prices, people, places, or time. Unlike people, it can continue doggedly to adapt without requiring instructions. Moreover, the H general-purpose AI also indicates the reasons for its decisions.

Past special-purpose (level 1) AIs required new programs to be written for each problem. The provision of product recommendations at a retail store, for example, required dedicated software to be developed. With a general-purpose AI, by contrast, product recommendations and optimal product ordering or product ranges can be achieved simply by changing the configuration of the H software, without new program development.

The emergence of general-purpose AI is expected to have as great an impact as the initial development of computers some 80 years ago.

The current interest in AI began about two years ago. Nevertheless, behind the scenes, AIs have been playing a part in people's lives for the last 15 years or so. When someone does a web search in response to a product recommendation from an e-commerce site they are using AI technology without their knowing it. This is because AI technology is used behind the scenes in both cases. However, these are both special-purpose AIs designed specifically for the application. The recommendation engine cannot be used for web searches and vice versa.

Meanwhile, this general-purpose technology[11] (the term used by US economist Erik Brynjolfsson) will come to be more broadly applied after initially proving itself in specialist applications. This is a very important turning point because this broader applicability will greatly expand potential applications while also driving down costs.

Mobile phones provide an example of this. The first mobile phones were vehicle-mounted and enabled people to call each other whenever they wanted. Subsequently, the widespread adoption of smartphones transformed the mobile phone into a truly general-purpose device, thereby greatly increasing its value. The size of the resulting market was much larger than it had been prior to this wider scope of use.

Likewise, given that an evolution from special-purpose to general-purpose AI can be anticipated, Hitachi chose to start development of general-purpose AI earlier than the rest of the world. This work is now beginning to bear fruit (see Fig. 4).

AI MEANS SEARCHING A LARGE INFORMATION SPACE

Essence of AI Technology

What is the nature of the technology that makes this AI possible? The answer has already been given in *Computing Machinery and Intelligence*[12], published in 1950 by Alan Turing, the mathematician who provided the theoretical underpinnings for computers. Turing

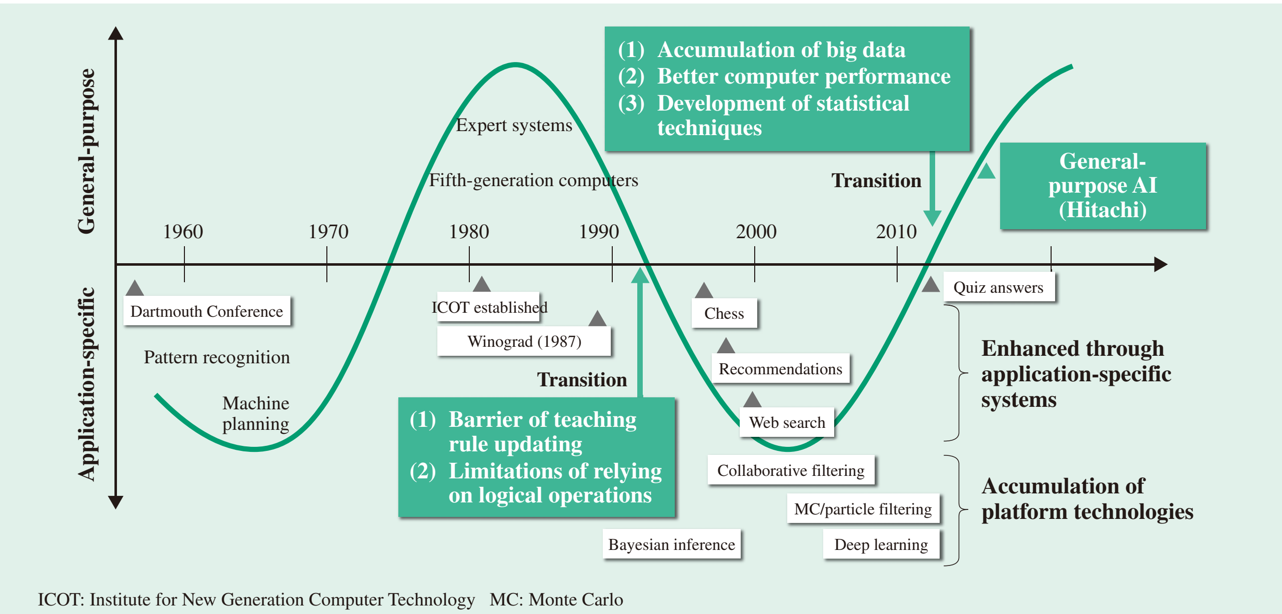


Fig. 4—Transition for Special-purpose to General-purpose AI.
AI techniques developed for specific applications are being redeployed for general application.

proposed that the objectives of learning machines can only be achieved by trial and error. It is through this trial and error that computers derive their intelligence. The following explains in more detail.

All AIs, regardless of their level, build models for improving outcomes from large amounts of actual data. What this actually involves is finding, by trial and error, the conditions in this large information space under which the outcome is maximized.

While this may not seem like much, the availability of large amounts of data and improvements in the speed of computers mean that, in practice, the difficulties of AI have become concentrated around the problem of how to search an information space.

However, the larger the search space, the more the search process comes to resemble prospecting for gold. The higher the AI level (as defined above), the greater the dimensionality and the more difficult the search. Accordingly, the key to AI lies in how to search such a large space of unknowns both efficiently and systematically.

Traditionally there have been two ways to go about such a gold prospecting search. The first is to perform a random search. This is equivalent to saying that, when dealing with the unknown, you may as well search blindly.

The other method is to search in the vicinity of places where previous searches have found good results (have obtained a high value for the outcome). This is based on the assumption of continuity in the information space, such that there must be a reason why good results are obtained in a particular location, and therefore it can be anticipated that a "seam of gold" must be present somewhere near places that have delivered good results in the past.

While algorithms based on this principle go under a wide variety of names that are prone to confuse non-specialists, they are fundamentally quite simple. They consist of the Monte Carlo method[g] (which is based on random numbers) and its derivatives, with techniques used in AI including the Markov-Chain Monte Carlo (MCMC) method, Hamiltonian Monte Carlo method, particle filtering, Boltzmann machines, simulated annealing, genetic algorithms, and quantum annealing. Deep learning neural networks, a topical subject in recent times, use these techniques internally.

(g) Monte Carlo method
A calculation technique for obtaining an approximate solution by repeating a simulation many times using random numbers (random digits like those obtained by throwing dice).

Learning from the Universe and Evolution

It is anticipated, however, that searching large information spaces, as required in level 3 and level 4 AIs, will need more than the two simplistic methods described above.

In fact, ways of achieving this are already becoming apparent. These methods derive from the idea that information spaces are not uniform. In other words, space is not an empty vessel and the outcomes being sought are in fact very unevenly distributed. This means there is no need to perform evenly spread random searches of large areas.

The reason this statement can be made is due to a deep physical principle, namely that information is something that derives from the universe, and that the universe itself is a form of information[(13) – (15)]. Approximately 14 billion years ago, immediately after the Big Bang, the universe contained only hydrogen and helium. Describing this state required much less information than would be needed to describe the present-day universe. In other words, the information content of the universe at that time was smaller. This was followed by numerous generations of stars forming during which planets were also created in orbit around these stars, including our own beautiful Earth. On Earth, many different types of complex life arose over a period of about four billion years, leading ultimately to human beings. Humans in turn invented writing, media, and other tools, subsequently giving rise to systems, organizations, and psychology. The space that encompasses all of these outcomes represents a huge information space. The universe itself contains all of the information that represents these things.

The principles that underpin the creation and progression of this space are already known. In physics, they are referred to as the first and second laws of thermodynamics, namely the conservation of energy and the rule that entropy always increases. While these laws were initially used to explain thermal processes such as engines and turbines, they also govern the creation and progression of all things.

A simple way of putting it is to say that, while resources are constant, neither increasing nor decreasing, information is continually increasing through new combinations of resources and therefore the universe has come to contain a greater diversity of information. This combines the law of conservation of resources with that of increasing diversity of information.

The important factor in this is that conservation of resources and diversity of information are not independent of each other, rather, they make up two halves of the same law. The principle by which the universe is created and expands is that of a continual increase in entropy (diversity of information) under the constraint of a conservation of energy (resources). The diversity of information serves as the universe's objective function and the limitation on resources serves as the constraint.

Even with finite resources, information can increase indefinitely through combination. Here, it is helpful to recall the formulas taught at school about permutations and combinations. Use of factorials can quickly result in extremely large numbers. This means that the number of potential resource combinations is nearly infinite.

This indicates the desire expressed above relating to searching large spaces. If information becomes increasingly diverse without constraints, it is necessary to search this large space uniformly. In this case, performing needle-in-a-haystack searches becomes increasingly difficult as the number of dimensions of the space increases. If, on the other hand, information becomes increasingly diverse under the constraint of finite resources, it can be shown that the desired outcomes will be very unevenly distributed(16). This means there is the potential to significantly narrow down the space to be searched.

The H general-purpose level 2 AI already makes use of this principle in some of its operations. It is anticipated that achieving levels 3 and 4 will require more systematic use of the principle.

As to whether it is really possible to build level 3 or level 4 AIs, there is no doubt about this because their existence has already been proven by the evolution of life.

Evolution was frequently assumed in the past to be a random search in the form of natural selection, with survival as the objective. However, the mathematician Gregory Chaitin has asserted the need for a new principle, stating that the complexity of modern lifeforms could not have been achieved in four billion years by a random search(17). Rather, it seems likely that evolution is already putting the above principle to good use.

Discussion of AI often calls on comparisons with the brain, however, the secret key to effectively navigating large information spaces can be found in the mechanism of evolution, which gave rise to even the brain among other things. This could provide a mathematical principle for explaining how the universe has come to be the way it is. We still need to learn from nature.

RELATIONSHIP BETWEEN PEOPLE AND AI

Does Technology Make People Happy?

In recent times, the subject of the relationship between AI and people has arisen frequently in books and other media.

There is no doubt that technology has made people's lives easier up to now. However, the question of whether technology makes people happy is not such an easy one to answer.

Whether AI will make people happy is becoming an important question.

Speaking personally, even since the author was a university student, he has had a strong interest in the questions of what constitutes happiness and what can be done to bring it about. Back then, he was particularly fond of the book, *Happiness: Essays on the Meaning of Life* by the Swiss philosopher Carl Hilty(18). After starting at Hitachi, however, his focus shifted to things like technology and money, and it did not occur to him to consider happiness in his work.

As explained earlier, the author had to start all over again 20 years after joining Hitachi when he and his colleagues had their careers reset. Having had their escape routes cut off, their thoughts about what future direction they should now take related to the importance of data. That is, they discussed the idea that data, including data about people, would be more important in the future. The author believes that, somewhere in the background of all this, he was influenced by his interest in people's happiness during his time as a student.

As a result, a decision was made to develop devices for measuring large amounts of data about people, leading to the development in early 2006 of prototype wearable sensors in the form of wristbands and nametags, the latter being worn on the chest. Confident of the small size and low power consumption of the devices, they could be used to collect a steady stream of data on people powered only by a small battery.

Accelerometers were of particular interest(19), (20). A wearable sensor with a built-in accelerometer can collect data on bodily movements 24 hours a day. The idea was that it would be possible to determine a variety of information about people's behavior from their movements (see Fig. 5).

In the author's role as the leader of this project, he was its first experimental subject. Since March 16, 2006, the wristband wearable sensor has remained on his left wrist throughout the 10 years that have passed. This means that all of the movements of his

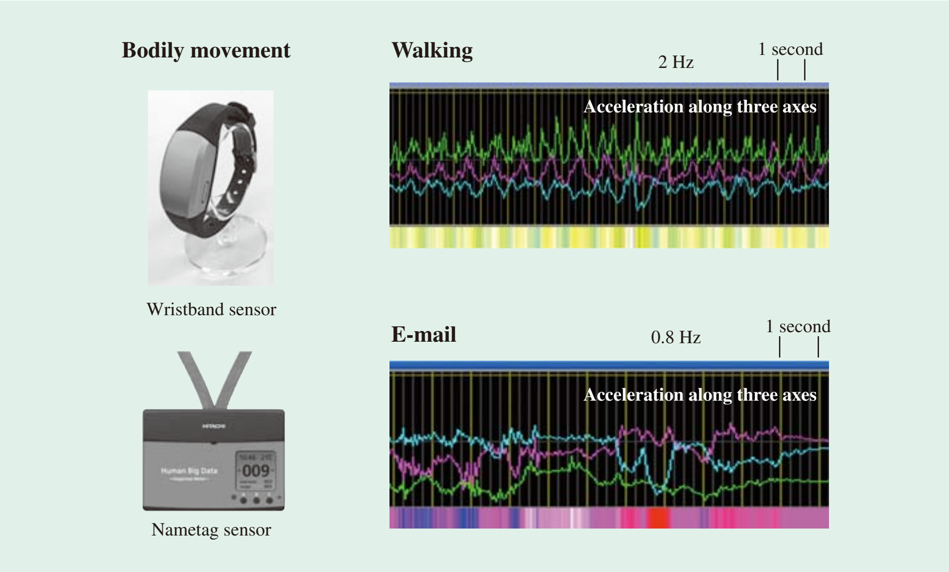


Fig. 5—Wearable Wristband and Nametag Sensors and Acceleration Waveforms (x, y, and z Axes).
Walking gives a waveform with a frequency of approximately 2 Hz and writing an e-mail gives an intermittent waveform with an average frequency of about 0.8 Hz.

left wrist over the last 10 years have been recorded on a computer(16).

The visualization technique adopted to present this data is a graph called a life tapestry. Fig. 6 shows a trace of the data over the last seven years. Sleeping and waking, commuting, lunch breaks, and everything else from going on overseas business trips to working in the office is reflected in the data on wrist movements and is visible at a glance.

The data was collected and presented for a large number of users and an analysis was performed of the correlations with the results of questionnaires about personal activities. The results contained an interesting discovery. Individual data values only represent wrist movements, and this data on its own is of no value. However, it was also found that more meaningful conclusions could be drawn when the data was consolidated and patterns were observed.

Something occurred to the author as he looked at and analyzed the data on a daily basis: could it be that the data contains patterns indicative of the person's happiness?

Subsequently, more than a million days' worth of data was collected on people with millisecond resolution. The data covered a wide range of work in different industries. An analysis of the data, which

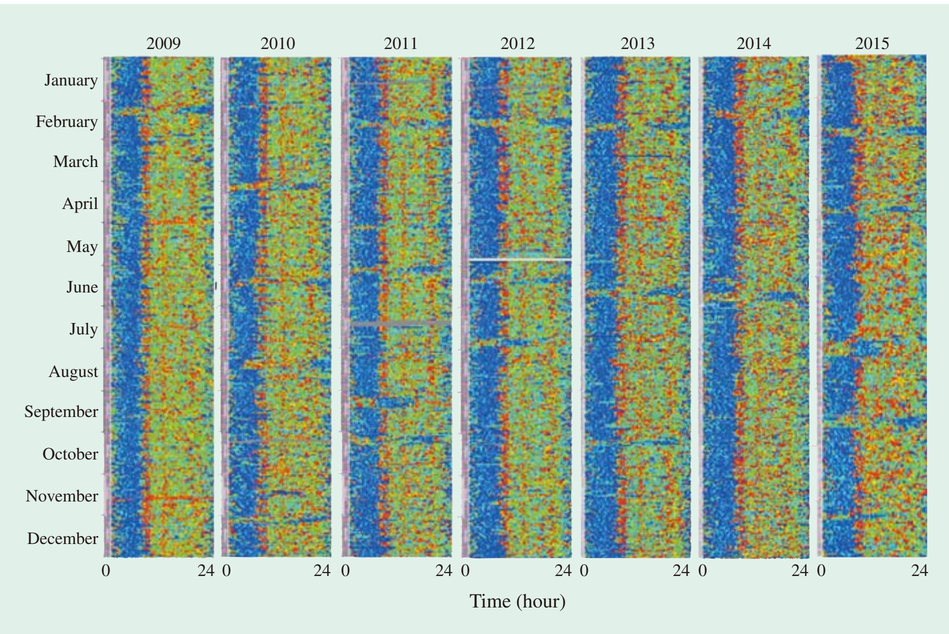


Fig. 6—Bodily Movement of Author over Past Seven Years (at 50-ms Intervals).
The data is called a life tapestry. Red indicates active movement, blue indicates being stationary, and intermediate colors indicate intermediate states. Things like shifts in time zones due to overseas travel and variations in sleeping time can be seen at a glance. The reason for the increase in the variegated pattern of red during 2015 was due to a rapid increase in the number of lectures and other presentations on AI given by the author.

included the use of an AI, succeeded in identifying patterns of people's happiness[(21), (22)]. This result was announced to the press in February 2015, and the author wrote an article that appeared in the Japanese edition of the *Harvard Business Review*.

Measuring Happiness

How is it possible to measure happiness? Hitachi conducted a 20-question survey of 468 people across 10 organizations. How many days were you happy this week? How many days were you feeling good, lonely, or sad? The subjects were asked to respond to these questions on happiness with a ranking between zero and three. When the results were collated for each organization, it provided a quantitative measure of whether the organization was happy on average. Organizations with a high level of wellbeing and activity scored highly and those with low levels scored poorly.

The bodily movement patterns of the subjects were also measured by wearable nametag sensors worn on the chest. The results showed a very strong correlation between particular figures on bodily movement patterns and the results of the above happiness survey (see Fig. 7). The high correlation coefficient of 0.94 indicates that the happiness of an organization can be measured using wearable sensors alone, without performing a survey or similar study.

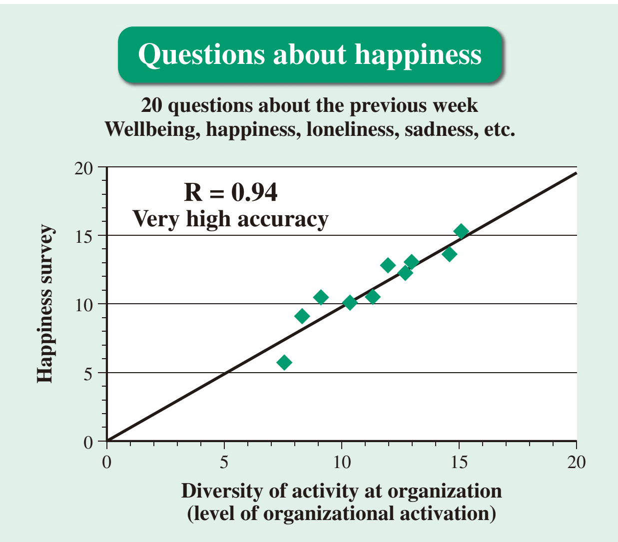


Fig. 7—Identification of Bodily Movement Patterns that Correlate with Group Happiness.
The diversity of activity at an organization is strongly correlated with the results of surveys (questionnaires) of happiness at the organization (with a correlation coefficient of 0.94). The total sample size was 5 billion data points, with 5,000 person-days of data collected from 468 people across 10 organizations (statistically significant at less than 1%).

The bodily movement patterns referred to here quantify the diversity of movement in a group. First, bodily movements were classified based on whether or not they were static. This totally unconscious pattern was then used to represent people's movements as a pattern of 1s and 0s, as in a bar code. There were cases where people appeared to have moved but stopped again within one minute, and cases when they continued to move for 20 minutes or more. The results indicated that, in practice, once people start moving, they often continue moving for about 10 minutes on average.

When this pattern of movement continuity was looked at for active organizations with a high level of happiness, what was found was a mix that included movement of both short and long duration. This was interpreted as a projection onto the time axis of a wide range of actions taking place at the organization.

In organizations with a low level of happiness and activity, on the other hand, this diversity of movement was low. In an extreme case, this might involve frequent instances in which people continued to move en masse for 10 minutes or so once they started moving, and then stopped again. There were no drivers to sustain the movement.

The term organizational activation was used to indicate this numeric representation of diversity in the duration of sustained movement. It represents bodily movement, which has a strong correlation with the happiness of the organization.

By using this technique, it is possible to measure organizational happiness as if it were weight or height.

Rules of Happiness in Organizations

Once it became possible to measure happiness, something believed in the past to be impossible to measure, a series of previously unnoticed regularities were identified in organizations and work. These were collated in the form of three rules about happiness and are described below using the example of a call center.

The first rule is that organizations with a high level of happiness also have a high level of productivity. Many people will associate terms like happiness or wellbeing with the suspicion that the staff are taking things easy. The data clearly refutes this.

It was found at an outbound call center that, compared to below-average days, order rates were 34% higher on days with a high level of organizational activation, meaning a high level of happiness in the organization (see Fig. 8). Likewise, sales at a retail store were 15% higher on days with a high level of organizational activation. Similar results were

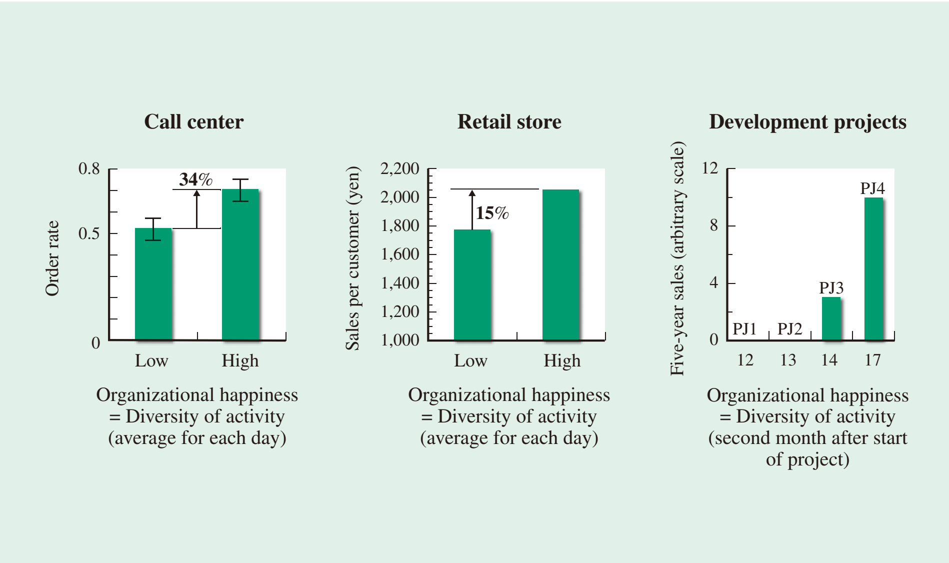


Fig. 8—Relationship (Level of Organizational Activation) between Happiness and Productivity.
Examples are shown for a call center, retail store, and projects. The call center and store both achieved good results on days with a high level of movement diversity (level of organizational activation). The level of organizational activation in four development projects in the second month after starting was correlated with the contribution to sales of the development outcomes (statistically significant at less than 5%).

obtained from development projects. Measurements were taken in four projects and it was found that the subsequent sales contribution from the deliverables developed was higher in those projects with a high level of organizational activation in the second month after the project started. Projects with a high level of happiness delivered better financial results. Put another way, bodily movement predicted the success or otherwise of a project long before the financial results became apparent. Using this knowledge, action can be taken on a project earlier than is currently the case.

The second rule is that both happiness and financial performance are group phenomena. There is a tendency to think of happiness as something that exists in the minds of individuals. The data clearly refutes this.

The following words were spoken by Kimiyasu Kudo of the Fukuoka Softbank Hawks professional baseball team after a victory.

> When we are losing and I ask the team what's happened to their voices, people like Kawashima and Fukuda (motivators) yell for us to go for it. When everyone shouts it together we really do go for it. Creating the right sort of atmosphere on the bench is also important.
> (Sports Nippon, September 18, 2015)
> (Author's translation)

This quote is saying that the atmosphere on the bench is very important for winning, to which the bench players Kawashima and Fukuda made a major contribution. While this may look at first glance like a belated expression of gratitude to the bench players after a win, I believe it was just as Kimiyasu Kudo said. This is because the exact same situation occurred at the call center and it was possible to capture quantitative figures on this in big data.

At the outbound call center, staff members call potential customers to sell them products. Performance is measured by the product order rate. A look at the data on order rates over the previous half-year shows that the staff includes both people with high performance (like the fourth batter in a baseball team) and others who do not perform as well. The make up of the staff varies from day to day, with a large number of high-performing staff members on some days and a low number on others. Naturally, it can be predicted that the overall order rate for the center will be high on days with a large number of high-performing staff members. In practice, however, no such correlation was found.

Bringing together a large number of high performers such as number-four batters does not create a strong team. A degree of group effect is present even in an individual activity like making calls and taking orders as instructed by a manual. The effect is likely to be greater still in work that requires team players.

Together with this, performance was 34% higher on days when there were a large number of people with a high level of diversity in their bodily movements and people who increase the diversity of bodily movements of those around them. It seems likely that these are people who improve the workplace mood. At a workplace where great effort is made to improve the order rate by even 1%, a 34% improvement is very large indeed.

What is interesting when looking at the performance of those people who contribute to the mood of the workplace is that there is no correlation with order rate.

These people improve the results of those around them by creating a better atmosphere around them. Don't all workplaces have people like Kawashima and Fukuda? But it is likely that people like this are not necessarily recognized by existing human resource practices.

The data also clearly shows that communication has a large influence on generating such a workplace mood. It was found that both happiness and order rates at the call center were high on days when there was vibrant conversation during work breaks. It was also found that both happiness and order rates were strongly influenced by who the supervisor spoke to on that day[23].

The third rule is that happiness is represented by a single measure regardless of the work or people involved. Many people will imagine that the definition of happiness will itself vary depending on things like the company, type of work, and region. However, the high 0.94 correlation coefficient does not allow for this interpretation. It means that a single measure can be used to represent happiness.

It follows that AIs can be used to improve happiness, and thereby to also improve productivity.

Specifically, Hitachi has developed a system that inputs staff activity data captured by wearable sensors into the H general-purpose AI and provides feedback on the communications and uses of time needed to improve the happiness of those individuals and those around them[24] (see Fig. 9). This has enabled the AI to understand people's happiness.

Fig. 9—Photo of the Happiness Improvement Support Service Utilizing Wearable Sensors and AI.
By having staff wear wearable nametag sensors, the service is able to provide feedback on the communications and uses of time that will enhance the level of organizational activation (which is correlated with productivity and happiness). Feedback provided using AI is customized automatically to the circumstances in the user organization.

For example, happiness dashboard software was developed for the call center that outputs instructions to the supervisor as to who they should focus on talking to on that day[25]. The software was used for more than one year and improved the order rate by 27%.

Happiness is Infectious

This work has been publicized since the spring of 2015 and has generated a considerable response, including the publication of news releases describing work at a bank and an airline[26], [27].

Of course concepts like happiness and wellbeing are not things that were invented or proposed by the author. In fact, there has also been growing interest in happiness in academia over the last 15 or so years. It has been reported that people with a high level of happiness are more likely to enjoy good health, a long life, and successful marriage, with better income and career performance, 37% higher sales productivity, and 300% higher creativity, and that companies with a large number of happy people have 18% higher earnings per share than companies with few such people. Papers like this are appearing on a monthly basis[28].

However, happiness in the past has been measured by questionnaires, and given the inability to take realtime measurements, there has been little clarity as to what actions serve to improve happiness. Along with the divide between academia and practical business, this has led to little use being made of these findings in business. This situation has been transformed by the use of wearable sensors for measurement and feedback using general-purpose AI. The prerequisites for utilizing this knowledge in business are at last in place.

In practice, small things can influence happiness. Hitachi conducted experiments jointly with Professor Sonja Lyubomirsky and Dr. Joseph Chancellor of the University of California, Riverside[29]. A group was divided randomly and the experimental subjects were asked to write down three good things that had happened to them during the past week. Similarly, the control subjects were asked to write down three things that had happened to them during the past week. The only difference was the inclusion of the word "good." This was repeated for five weeks and the results were reviewed for differences two months later. Clear differences were evident in the results. The experimental subjects had higher happiness, a greater sense of belonging to their organization, and a higher level of bodily activity from the morning.

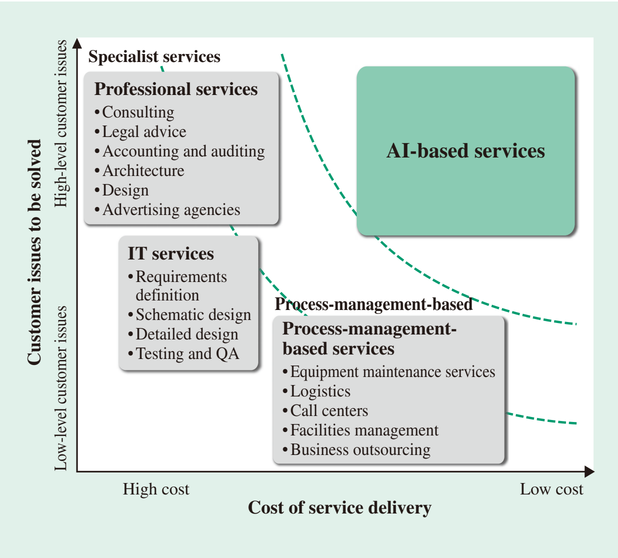


Fig. 10—Tradeoff Between Customer Value and Cost in Services.
The use of AI enables high-level issues that derive from customer outcomes to be supplied at low cost.

We were surprised that this action, which took only about five minutes each week to perform, could produce such a difference. It demonstrated how the subjective phenomenon of happiness could be altered significantly by small changes. There is still room for improvement in people.

HOW AI WILL CHANGE SERVICES

AI has the disruptive power to change services.

In advanced economies such as Japan, the heart of the economy is shifting from manufacturing to services. Whether its previously strong manufacturers can become service-oriented is a major issue for Japan.

There are common challenges faced by anyone seeking to improve profits from services. The value of services is enhanced by solving the problems of customers. However, individual customers have different issues. Value is enhanced when solutions can be offered that are tailored to these individual issues. On the other hand, there is a cost associated with trying to supply individually tailored solutions. There is a tradeoff between these costs and the value delivered to customers, a situation in which profits are difficult to achieve.

Accordingly, many service industries have low profitability on average. Industry-average profit margins in areas such as distribution, retail, advertising, hospitality, and accommodation are below 5%.

In the past, services have adopted two approaches to this problem (see Fig. 10). One approach is professional services, which include a wide range of services such as consulting, law, and accounting. These services are provided in the form of work, making them labor-intensive. While some individuals may be capable of high performance, the larger the organization, the less variation there tends to be between companies on average. To achieve profits, such services often use star players to front their business but have the actual work done by young staff on lower wages.

The other approach involves process-management-based services. These are services in which processes can be standardized, such as distribution warehouses, call centers, and equipment maintenance. Costs are cut and profits achieved by using manuals and training. Services such as IT lie midway between these two approaches.

AI overcomes this tradeoff between individual optimization and cost to enable scalable services. Advertising services that are linked to Google*2 or other searches already earn margins that are an order of magnitude greater than traditional advertising services. These search-linked advertising services use a particular type of special-purpose AI to deliver advertising services that are customized to specific customers. Moreover, they improve customer value without incurring costs thanks to fully automatic customization. This enables businesses that transcend the above tradeoff.

It is anticipated that this model can be applied to a wide range of services by using general-purpose AI. Services that use AI are increasingly automating customization for specific customers.

Another important point is that the use of AI makes services more outcome-oriented. In the past, suppliers were only able to offer their own products and associated services. A supplier of production machinery, for example, would also have supplied repair and other maintenance services. However, customer issues have a hierarchical structure. This hierarchy extends from top-level issues that directly influence the outcome of customer profits to more indirect low-level issues(30). Wireless communication operators, for example, face the issues of operating their network successfully and attracting customers that influence profit directly, and also low-level issues such as the appropriate construction of the physical layer. While higher profits can be achieved if solutions can be provided to top-level issues that influence outcomes directly, the delivery of higher level solutions is difficult

*2: Google is a trademark of Google Inc.

when limited only to the company's own products.

This is a situation where the benefits of a general-purpose AI can be utilized. If a general-purpose AI can be connected to existing systems to obtain input data, outputs with value to the customer can be obtained from customer outcomes. To achieve this, a company must not be bound by its own products during system implementation. There is greater potential for winning large orders through the orchestration of a wide range of products, including those from other suppliers.

CORPORATE ORGANIZATION IN THE ERA OF AI

AI enables services that generate ongoing innovation, with businesses that use AI being outcome-oriented. Accordingly, they require viewpoints and actions different to those of traditional product or service organizations. Organizations will need to undertake the following three reforms.

Reform of Frontline Organizations

The first is the reform of frontline organizations. There is a need for frontline staff members and organizations that can engage with and market to customers in ways that derive from outcomes.

The concepts associated with this are significantly different from those of traditional product-based negotiation and marketing capabilities. Two externally evident differences are the need to ask customers about the outcomes they want and what outcomes to use to evaluate the success of the solutions to these challenges. There is also a need to discuss the value of suggested outcomes and how this value relates to their associated investment and other costs. This will require consultative abilities to avoid outcomes that are not likely to provide a cost-benefit and choosing outcomes that are likely to be beneficial.

Furthermore, existing sales staff members and system engineers will initially have no appreciation for the flexibility of general-purpose AI. Accordingly, even after they have succeeded in identifying new requirements from customers, they will tend to be hesitant about adopting unproven methods. This is because they are used to the rigid view of products and marketing practices of the past.

The revolutionary feature of general-purpose AI is that it can be used for many different functions simply by changing the input configuration. The value of this will be wasted if the technology is limited only to proven applications. Conversely, even in what appears to be proven applications, if different data is used, the results will be completely different. Customers also need to be made to understand this possibility.

There is a need to reform staffs and organizations to provide opportunities for training and practice so that these things can be utilized in practical marketing.

Reform of Integration Organizations

The second is the reform of integration organizations. There is a need for flexibility that goes beyond the past practice of system integration (SI) driven by customer specifications.

General-purpose AI can transform the mechanistic IT and other equipment of the past into IT and other equipment that can learn and grow. Infinite possibilities are made available by combining this general-purpose AI with conventional IT and other equipment, and it has the power to generate significant value for customers. These IT and other equipment systems do not distinguish either between in-house and outsourced products, or between existing and new installations. Value can be generated through diverse combinations of AI with these in-house, outsourced, existing, and new installations.

To begin with, the combination of AI with existing IT and other equipment opens up opportunities for new services. In the past, maintenance services for IT and other equipment have been an important business. An ongoing and reliable source of income can be created by augmenting an equipment business with maintenance services. General-purpose AI takes this a step further. It is possible to achieve ongoing increases in asset value by integrating a general-purpose AI with existing equipment and IT. This is because it enables a steady progression of new management and business challenges to be dealt with in an ongoing manner by changing the configuration.

In the distribution warehouse example mentioned above, scheduling functions able to adapt flexibly to fluctuations in supply and demand or variations between staff were added to an existing WMS by connecting it to a general-purpose AI. New functions that in the past would have needed to be added to the WMS were instead achieved by adding a general-purpose AI. Furthermore, daily changes in circumstances are identified automatically from data and control logic that are updated automatically. Once the connection is in place, the optimal allocation of a wide range of people, goods, and money related to WMS data can be achieved simply by changing the AI configuration. Ongoing improvements to system functions can be made in accordance with operational and managerial requirements.

Here, the connection of a general-purpose AI is of great significance for the business regardless of whether it is an in-house or outsourced product. This is because it expands opportunities for working with customers by using IT and other equipment from other suppliers.

Consider also the significant expansion in the scope of products that can be offered when marketing new IT and other equipment. It is possible to offer new systems that learn about and react to changes in circumstances by combining a general-purpose AI with in-house and outsourced IT and other equipment products. Achieving this requires the establishment of an ecosystem or other network that includes products from other suppliers as well as in-house products.

For the new solutions using general-purpose AI described above, both staff members and organizations need the flexibility to combine a wide range of products and AI. Supporting this requires an ecosystem for a diverse range of companies capable of supplying an extensive range of products and services to exchange information and facilitate orchestration across products.

Reform of Platform Organizations

The third is the reform of platform organizations. There is also a need to reform platform organizations in order to enable the first and second activities described above.

The first requirement is to raise the level of technical hierarchies handled by platforms. The platforms for the ongoing improvement and operation of general-purpose AIs and their configurations will handle management outcomes at a much higher level than the servers, storage, databases, operating systems (OSs), and operational middleware platforms used in the past. There is a need to change the mindset of people who have performed past hardware, software, and other development in accordance with specifications. Moreover, this means that customer outcomes will become easier to understand, including for the people responsible for platforms. They will serve in roles where they deal more directly with customers. It also means being able to contact people with greater decision-making authority. In both cases, it will put them in situations that are more rewarding. One obstacle to this is anxiety and fear of change. This will likely need to be dealt with in an organizational manner.

Dealing with higher level matters means greater exposure to change. It requires an organization in which 100 new AI applications each month commence operation using new configurations and that is able to incorporate the subsequent new requirements into the platform. This will require the establishment of practices that are capable of high rotation in a more agile and DevOps[h] manner than past low-level platforms[31].

The aim of the above three reforms is simple. It is to transform organizations into ones that generate innovation. According to Peter Drucker, the purpose of companies is to create customers. Innovation is the act of generating new demand for this purpose.

Example of Organizational Reform: Reform of Hitachi

The new business structure adopted by Hitachi in April 2016 provides an example of the form taken by organizations for services that use AI[32] (see Fig. 11). In place of the previous product-oriented company structure, it is made up of customer-driven frontline organizations together with horizontal service and platform organizations and product organizations. For the frontline organizations, the aim is to create a business structure that generates innovation alongside customers by setting up 12 business units (BUs) to improve frontline functions such as sales, engineering, and consulting in four markets: (1) Power/Energy, (2) Manufacturing/Water, (3) Urban Development, and (4) Finance/Public/Healthcare. Hitachi also set up service and platform BUs that consolidate and integrate the technologies essential to providing advanced services, including AI, analytics, and control technology, to create a business structure that supplies open common platforms to the frontline BUs and other partners. The product-focused businesses supply components, materials, and other products to the frontline BUs and other customers.

In this way, moves to reform organizational structures can be expected to become more widespread in the future along with the emergence of the innovative technology of AI.

CONCLUSIONS

This article has presented an overview of AI, which has a potential that goes beyond just advances in computing. As a new methodology for humankind, AI dramatically enhances the ability of companies and people to respond amid the unpredictable changes in

(h) DevOps
A term coined from the combination of development and operations. It is a method for developing systems that adapt more quickly and flexibly to business challenges through cooperation and collaboration between the people responsible for development and operations.

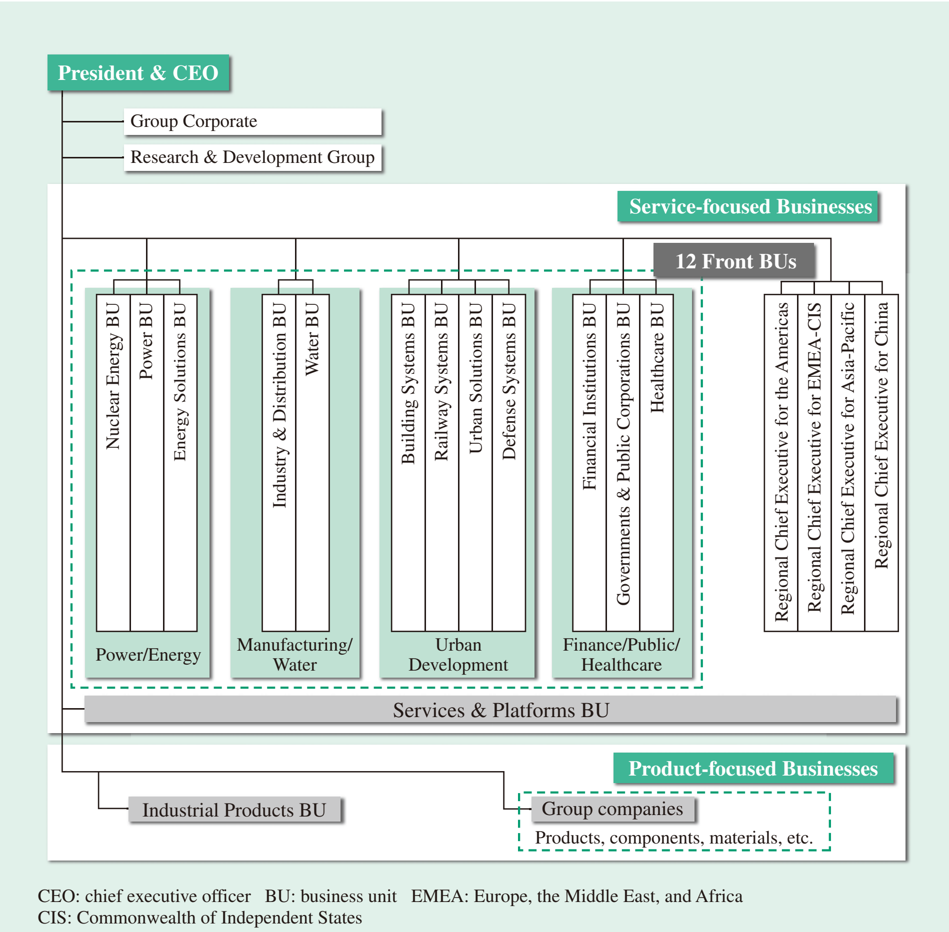


Fig. 11—Example Organization that Uses AI (Reorganization of Hitachi).
AI plays an important role in Hitachi's new structure made up of customer-driven frontline organizations together with horizontal service and platform organizations and product organizations. The reorganization took place in April 2016.

the environment that are occurring globally. The power of this new way of doing things will grow rapidly over time compared to previous practices that relied on the capabilities of individuals. This trend will extend across all industries and types of work. The author refers to this as the general adoption of AI.

Nevertheless, AI is a methodology for humankind. Its purpose is to increase the ability of people to solve problems and it is the task of people to decide which problems to solve, a process that calls heavily on experience and intuition. This will enable people to take on challenges they could never have imagined in an unpredictable world. The creation of the unknown future is something we can start today.

After being paralyzed on her left side by a stroke at the age of 77, the sociologist Kazuko Tsurumi wrote a poem about encountering a world she had been unaware of when healthy.

Small universe, named I, resonates in the large universe
The sound it makes is new every day[33]
(Author's translation)

The poem expresses, with a grand sense of scale, the feeling of contemplating the unknown world prompted by the trials of a disability.

In acquiring AI as a new way of confronting the unknown, can people investigate new things every day? People want to progress by routinely making new investigations into the unknowns faced in corporate strategy, business operations, national policy making, and the lives of individuals. This approach by people is likely to be always creative in facing the possibilities of the unknown while also being incomplete. The author would like to be like this.

Completion consists of being forever incomplete
(Kenji Miyazawa 1926[34]) (Author's translation)

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Featured Articles

AI Technology

Achieving General-Purpose AI that Can Learn and Make Decisions for Itself

Norihiko Moriwaki, Ph.D.
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Fumiya Kudo
Ryuji Mine
Toshio Moriya, Ph.D.
Kazuo Yano, Dr. Eng.

OVERVIEW: There are increasing trends toward utilizing the big data collected at companies and the data acquired through the IoT to generate new management value. Of these trends, AI technology is attracting attention as a means of intelligently utilizing large amounts of data by making full use of computer processing capacity. Hitachi is developing Hitachi AI Technology/H, which optimizes and automates decision-making in various ways through the utilization of large amounts of data, thereby contributing to improvements in outcomes for corporations. This article first describes the trends in and types of AI technologies, and then explains the concepts and basic principles of Hitachi AI Technology/H Hitachi has developed. Furthermore, it touches on the technology's potential as a general-purpose AI solution that can shed light on complicated problems through possible applications in a wide range of different industries and fields.

INTRODUCTION

MOVEMENTS are picking up steam in every industry towards the utilization of the large amounts of big data being collected by companies and the new data being gathered through the Internet of Things (IoT) to enable management reforms such as internal operational reforms and the creation of new customer-oriented services. As data volumes increase, however, the requirements of traditional methods based on having humans test hypotheses exceed the limitations of human cognition, making it difficult to utilize data effectively. This makes it necessary to use artificial intelligence (AI) that can automate the extraction of value from large quantities of data by applying intellectual algorithms that can replace humans(1). Expectations are also high for AI that can learn by itself in order to acquire knowledge.

This article describes the concepts and basic principles of Hitachi AI Technology/H(2) promoted by Hitachi (hereafter referred to as H), and the possibilities for application in a diverse range of industries and fields.

AI: A NEW WAY TO UTILIZE COMPUTERS

Toward Computers that Can Learn from Data

The general roles played by traditional computers and business applications were to execute predefined functions and automate business processes. In other words, the flow of development traditionally entails designers (humans) envisioning and designing functions in advance, after which programmers code the logic. As the performance of computers continues to increase and prices continue to fall, this is expected to enable more intellectual processes in the future as opposed to the traditional fixed processes. Specifically, the availability of a wide variety of different types of data, including the IoT and other types of sensing, technological advances such as the expansion of feedback targets including wearable devices and humanoid robots, and other factors are working together to help facilitate flexible responses from computers to changes in data, thereby enabling learning from experience (see Fig. 1). When it comes to intellectual computer processing, although intense research efforts have been focused on the field of AI since the 1980s, the type of AI for which humans build in cause and effect rules in advance has not been able to understand the diverse range of user contexts, and thus has not reached the level of practical application. In recent years, however, the availability of inexpensive high-performance computers and high-capacity data storage is triggering a technological upheaval, and expectations are running high for machine-learning AI that can learn from data.

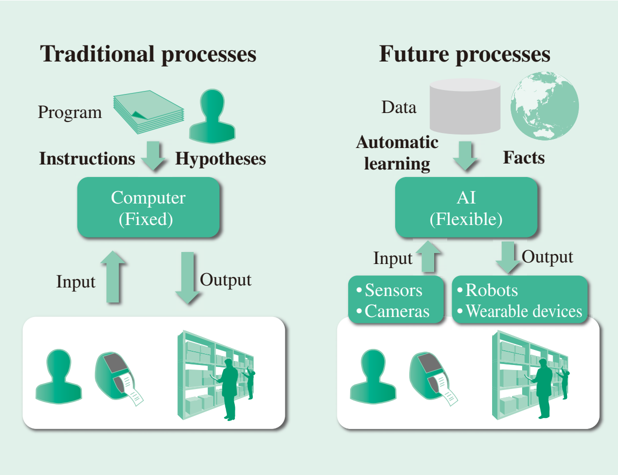

Fig. 1—Computers Transitioning to AI that Learns from Data.
Instead of fixed processing that must be designed in advance, this AI enables processing that is more intellectual and flexible.

New AI for Optimization and Decision-making

Table 1 shows the H technology Hitachi is developing and promoting along with other representative types of AI (and intelligent systems), categorized by type. Based on the role it plays, AI can be categorized as either the searching type, which supports humans as an intelligent machine with expert systems and other functions at its core, or as the recognition type, which emulates the ability of humans to recognize images or voice input through seeing and understanding or hearing and understanding.

International Business Machines Corporation's (IBM's) Watson[*1] and other AI systems of the searching type take newspapers, technical papers, and other documents and text data as input and use natural language processing technology to search for information and provide responses. As for the recognition type, deep learning and other technologies have been starting to advance at a rapid rate in recent years, toward the achievement of recognition functions based on the effective extraction of patterns from massive amounts of image and voice data. Hitachi's H goes beyond those two categories, however, by achieving automation of optimization and decision-making. More specifically, H is characterized by the ability to automatically generate models for improving specified outcomes based on a wide range of mixed numerical data types.

*1 IBM and Watson are trademarks of International Business Machines Corporation, registered in many jurisdictions worldwide.

Table 1. Positioning of H
The strength of Hitachi's H technology lies in its ability to convert a wide range of mixed numerical input to corporate profit.

Type	Search	Recognition	Optimization and decision-making
Representative example	IBM Watson	Google* Deep Learning	Hitachi H
Data	Documents/ Research papers (Text)	Images/voice (Signal waveforms)	Corporate information/ sensors (Heterogeneous mixed numerical values)
Utilization situations	• Information searching • Physician assist	• Security • Wearable user interfaces	• Creating profit
Destructive technology	Page ranks (1998, L. Page)	Deep learning (2006, G. Hinton)	Leap learning (2014, Hitachi)

IBM: International Business Machines Corporation
* Google is a trademark of Google Inc.

CONCEPTS AND BASIC PRINCIPLES OF H

Automating the Generation of Hypotheses

In addition to technical challenges such as the achievement of raw computing power and storage capacity, the effective utilization of large amounts of data is also accompanied by a redefinition of the roles of both humans and computers. In other words, with the traditional approach of having humans first come up with hypotheses, gather the data that is required, and then attempt to validate the hypotheses, it is difficult to fully utilize the large amounts of frequently updated data. Also, the problems that must be solved for society or for companies are themselves growing more complicated, to the extent that even for experts in the relevant fields, the capacity of humans to recognize methods for constructing sophisticated predictive models is being exceeded. In the future, an effective approach will be to fully utilize data and computers by having humans set the problems to be solved (the outcomes to improve) so that the computers can automatically generate a large number of hypotheses and discover solutions by following the data.

Principles of H

H is an analytical engine that recursively derives from large amounts of data the correct measures and how they should be implemented in order to improve the target indicators that represent value for customers [key performance indicators (KPI), etc.]. Rather than collecting models of detailed work processes, H focuses on modeling outcomes in a data-driven system.

The principles of H are shown in Fig. 2. H uses a numerical table format to input data that might influence outcomes such as management effects to

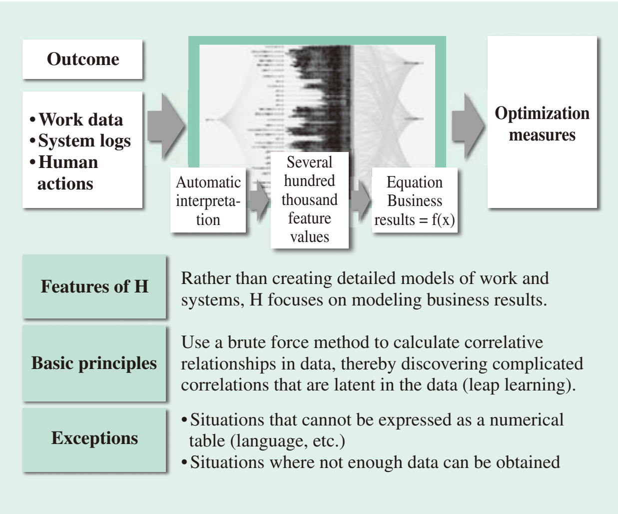

Fig. 2—Principles of H.
Hitachi's proprietary leap learning technology derives the factors required for improving business outcomes from the data.

be increased or decreased (sales, productivity, design bugs, service disengagement, and so on).

H internally generates an exhaustive number of combinations of the input data, generates huge amounts of feature quantities for each combination, and then uses a brute force method to calculate the relationships between these feature quantities and the outcome in order to discover any complicated correlations that are latent in the data through statistical processing. The output of H is an equation that describes the correlation between the outcome and the feature values of the combinations. By taking this equation as an optimization function, and incorporating it into work and control systems in combination with outcome improvement prototype designs and means of providing execution, it is possible to continuously improve outcomes while tracking data even if the environment or orders change.

Also, since it is easy to envision combinatorial explosions occurring if huge numbers of data parameters are input, a variety of different measures are taken to inhibit this problem. One of the techniques that was developed is spatial deformable clustering (SDC), which is an advanced version of grid-based clustering that enables the automatic discovery of regions of data combinations that might strongly affect the outcome (see Fig. 3)(3). By increasing or decreasing phenomena with respect to the regions identified by this technique, it is possible to effectively control the outcome.

AUTOMATION OF SYSTEM OPTIMIZATION AND DECISION-MAKING

Online AI

H is not only utilized for data analysis, but it can also be connected to existing systems and utilized for optimization and decision-making as well (see Fig. 4).

In other words, it regenerates models by adapting to daily changes in the environment and orders, and can maximize management effects by contributing to productivity and reducing costs. Specifically, H enables the implementation of adaptive and self-improving systems by using equations related to the output of outcomes as optimization functions and narrowing down a variety of different complicated work and control systems into mathematical optimization problems. For example, H can be used to automatically track changing on-site conditions in order to improve outcomes in various environments including manufacturing lines, warehouses, and stores.

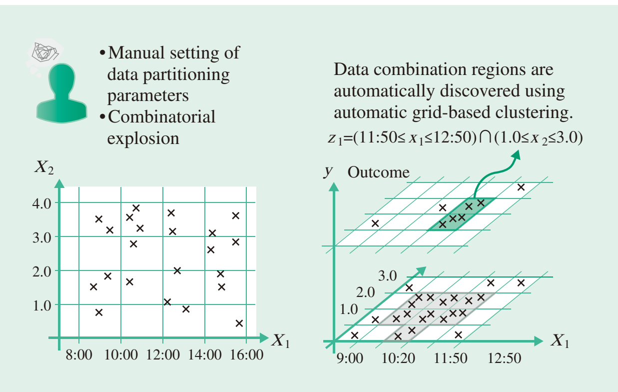

Fig. 3—Spatial Deformable Clustering (SDC).
The grid-based clustering technique is utilized in order to automatically discover data combination regions that might strongly affect the outcome.

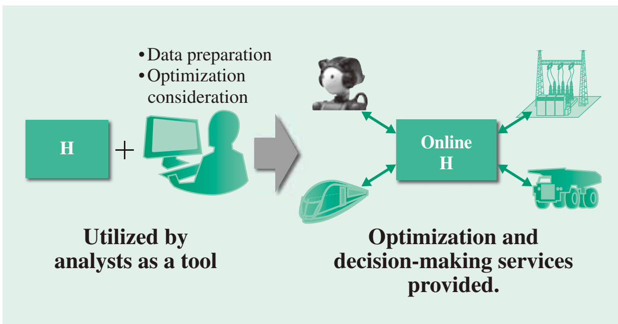

Fig. 4—Online AI Providing Optimization and Decision-Making Services.
H is connected to the system in order to automate optimization and decision-making.

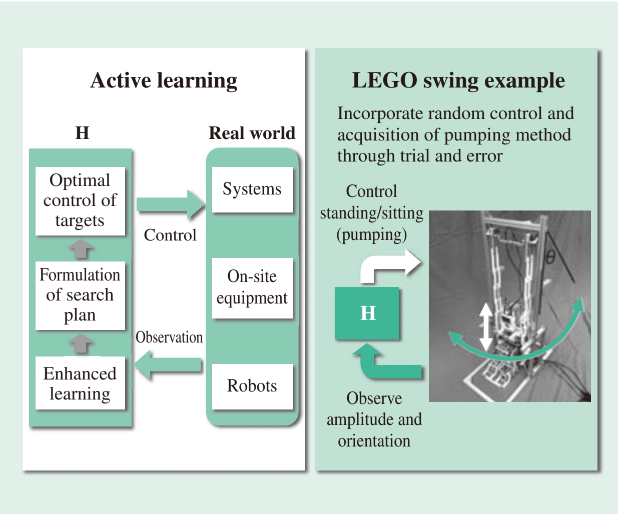

Fig. 5—Active Learning.
H incorporates enhanced learning capabilities in order to enable the automatic learning of optimization parameters.

AI that Learns from Experience

Furthermore, H can not only be applied to past data, it also attempts to actively search for methods that can more optimally achieve objectives by acquiring new data by itself. The example shown in Fig. 5 is a prototype of an experimental system connecting H to a swing robot that was created using the educational LEGO[*2] Mindstorms[*2] product. This experiment was designed to see whether or not the robot could learn how to swing on a swing without being given a model beforehand.

With the target indicator corresponding to the outcome set as increments in the swing's deflection angle, and with the deflection angle, pumping state, and pumping operation acquired from the system set as explanatory variables, the AI gradually generates a model by maximizing the outcome with random pumping patterns, thereby enabling the robot to successfully swing on the swing after an average of approximately five minutes. Furthermore, the robot was able to increase the outcome (the swing's deflection angle) by using the unexpected method of pumping at both ends of the swing.

Although it is necessary to fully consider possibilities such as a system running amok when implementing enhanced learning AI of this type, it can be used to greatly contribute in areas such as optimizing the parameter control of complicated control systems, or implementing robust systems that handle changing environments.

*2 LEGO and Mindstorms are trademarks of the LEGO Group.

TABLE 2. Fields where H is Utilized
H is highly versatile because its level of dependence on modeling and tuning based on field-specific domain knowledge is low.

Industry or field	Targets of optimization and decision-making
Production	Control manufacturing equipment parameters
Traffic	Fuel-efficient driving control, maintenance optimization
Distribution	Optimize product placement, warehouses, and task sequences
Marketing	Customer analysis, proposal of recommended products
Office work	Automate approvals, improve happiness

POSSIBILITIES AS A GENERAL-PURPOSE TECHNOLOGY

The effectiveness of H has been confirmed via application in 24 case studies covering seven fields. The core algorithms of H are characterized by independence from modeling or tuning based on domain knowledge in each field. In other words, unlike previous types of AI that had to be specialized for each field, H is versatile enough to automate the optimization and decision-making of a wide range of different systems, so all that is necessary is to specify the outcome to be maximized and to input data that might be associated with changes in that outcome. By taking advantage of this characteristic, H can be applied to a diverse range of problems in society as well as different industries, fields, and sectors. Table 2 shows the fields Hitachi is currently envisioning for the application of H.

CONCLUSIONS

This article discussed the concepts and basic principles of the H optimization and decision-making AI system championed by Hitachi, as well as the possibilities of adding intelligence to existing systems.

Whereas the type of AI that specializes in a specific field by utilizing domain knowledge has traditionally been in the mainstream, H's key characteristic is its high level of versatility. All that is necessary to use H is to specify the outcome to be increased and to input the data that might affect changes in that outcome in order to automate system optimization and decision-making. H can contribute to the solution of a large number of complicated problems in order to improve corporate outcomes, including the control of parameters for manufacturing equipment, the optimization of operation control, the proposal of optimal products to customers, and so on.

In order to strengthen intelligence technology even further, Hitachi will continue working to make it even easier to connect to existing systems, develop new feature quantities, apply predictive diagnostics, construct a service framework to enable application to even more industries, horizontally deploy usage and application logic with the assistance of the open development community, and engage in other efforts to further expand H.

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Featured Articles

AI Services and Platforms
A Practical Approach to Increasing Business Sophistication

Yasuharu Namba, Dr. Eng.
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Takuya Haraguchi

OVERVIEW: Companies have begun working on business improvement initiatives inspired by insights acquired from events occurring around the world. To provide efficient support for these initiatives, Hitachi is working on projects to help solve wide scale problems and assist business growth. Collectively referred to as Hitachi AI Technology, these projects consist of cutting-edge AI technology and solutions driven by AI technology. The Hitachi AI Technology/Business Improvement Service was developed as the first of these projects. The service is designed to help solve management problems in areas such as improving corporate sales and cutting costs. This article describes an overview of this practical AI-driven service designed to increase business sophistication, and looks at the platforms that help make this service possible.

INTRODUCTION

TODAY'S more demanding worldwide market competition is making it difficult just to maintain the same prices for existing standard products and services. This environment is shifting the source of corporate competition toward innovation, that is, the creation of new value. Generally, value creation most often starts from a rediscovery or insight, but people tend to cling to fixed ideas formed from experience. They are often unable to free themselves from a limited range of ideas, and this tendency becomes more pronounced with longer experience. However, at the same time, the difficulty of defining goals (outcomes), recognizing the significance of business data, spotting exceptions, and applying value discoveries to business processes makes value creation difficult for anyone other than highly experienced insiders who are thoroughly familiar with the business. In response to these challenges, Hitachi decided to draw on the strengths of the latest artificial intelligence (AI) technology to boost human understanding and abilities, while creating new value to help solve wide scale problems and assist business growth through human-AI cooperation.

The recent rapid growth and spread of technologies such as cloud computing, mobile terminals, social media, and sensor technology is increasing the amount of data being generated worldwide. Companies have started to draw on these technologies to gain an understanding of various events through data, to learn new insights from this data, and to apply them to policies leading to innovative business improvements. AI is an increasingly promising technology for efficiently assisting these efforts. For example, among sites that have nearly reached the limit of possible improvement with current business methods, there is a lot of demand for AI that can check whether human-created hypotheses are correct or not, or for AI that can devise hypotheses beyond human capabilities. Table 1 shows examples of demands for the use of AI to increase business sophistication in the area of marketing.

Table 1. Examples of Demand for Use of AI to Increase Marketing Business Sophistication

There is increasing demand to identify trends that have been difficult for humans to notice previously, to provide services efficiently, and to innovate business.

Industry/ innovation demands	• Provide services tailored to the interests and preferences of individuals • Improve product stock forecasting precision • Optimize overall expenses such as labor costs and capital investment costs
Expectations for AI	• Identify elements that transform customer purchasing behavior • Identify differences between customers of brick-and-mortar stores and online stores • Identify characteristics of efficient sales activities

AI: artificial intelligence

To meet these expectations, Hitachi is working on projects to help solve wide scale problems and assist business growth. Collectively referred to as Hitachi AI Technology, these projects consist of cutting-edge AI technology and solutions driven by AI technology. The Hitachi AI Technology/Business Improvement Service[(1)] was developed as the first of these projects. The service is designed to help solve management problems in areas such as improving corporate sales and cutting costs. The following sections of this article describe an overview of the service, an example of its application to the creation of marketing solutions, and the Pentaho software used as the platform that helps make this service possible.

BUSINESS IMPROVEMENT SERVICE OVERVIEW

Using an AI technology developed by Hitachi called Hitachi AI Technology/H (hereafter referred to as H)[(2), (3)], the Hitachi AI Technology/Business Improvement Service creates business improvement proposals to help solve business problems. H is an AI technology that uses a large volume of complex business-related data to efficiently derive elements with strong correlations to organizational outcomes [key performance indicators (KPI)] and hypotheses for policies to improve them. The service uses H to propose improvement processes for problems facing various industries.

Expectations for AI

Up until recently, experts who manage areas such as quality, sales, and stock have been studying policies for improving KPIs. However, with policy studies done by humans, there have been difficulties making objective evaluations because of assumptions based on preconceptions, stereotypical thinking, and personal hunches and experience. H is expected to overcome these shortcomings by eliminating preconceptions, discovering quantitatively important elements from data previously unused in analyses or proposed hypotheses, and proposing innovative improvement policies that do not rely on the thinking of human experts. But H is simply a tool, and the results obtained from it will vary greatly depending on which business processes its findings are applied to, and how they are used. So the best results are obtained by combining H with additional support services provided by technicians with the expertise to make thorough use of analytical methods and H.

TABLE 2. Challenges when Applying AI to Business

Below are some examples of commonly encountered challenges when applying AI to business.

Application phase	Challenges when applying
Utilizing for business	Even if new suggestions can be acquired by Hitachi AI Technology/H, it is unclear how to use them in business.
AI usage frequency	It is unclear whether AI should be used once, or used repeatedly such as on a daily or monthly basis.
Selecting data parameters	New correlations may be found by increasing the number of data types or volume. But it is unclear how much more data is needed.
Preprocessing of data analysis	Before using AI, outliers must be removed from the data (data cleansing). If data contains many outliers, the analysis results can often be affected.

Issues When Applying H to Business

The measures proposed by H can be appealing, often containing unprecedented suggestions. However, when applying them to actual business, the same sorts of issues faced by every company often have to be overcome (see Table 2).

APPLICATION OF AI TO BUSINESS IMPROVEMENT SERVICE

Marketing Solutions

Hitachi's Business Improvement Service uses AI to propose business improvements for areas such as retail sales, equipment maintenance, finance, and manufacturing. This section provides an example of how the service has provided marketing solutions for areas such as retail sales.

Conventional services analyze data collected from marketing systems [such as customer relationship management (CRM) systems and sales force automation (SFA) systems] to present suggestions to marketing staff with expert knowledge of marketing. However, conventional services are unable to incorporate marketing expertise and business site restrictions into the analysis.

Hitachi's marketing solutions enable input and analysis of a variety of data such as business data sets, marketing staff expertise, site restrictions, and external environmental factors. Expertise that had previously only been tacitly understood as well as new insights can be turned into formalized knowledge and shared to increase the efficiency of the business improvement cycle (see Fig. 1).

In Hitachi's marketing solutions, processes ranging from identifying current issues to measuring the benefits of marketing policies, making evaluations,

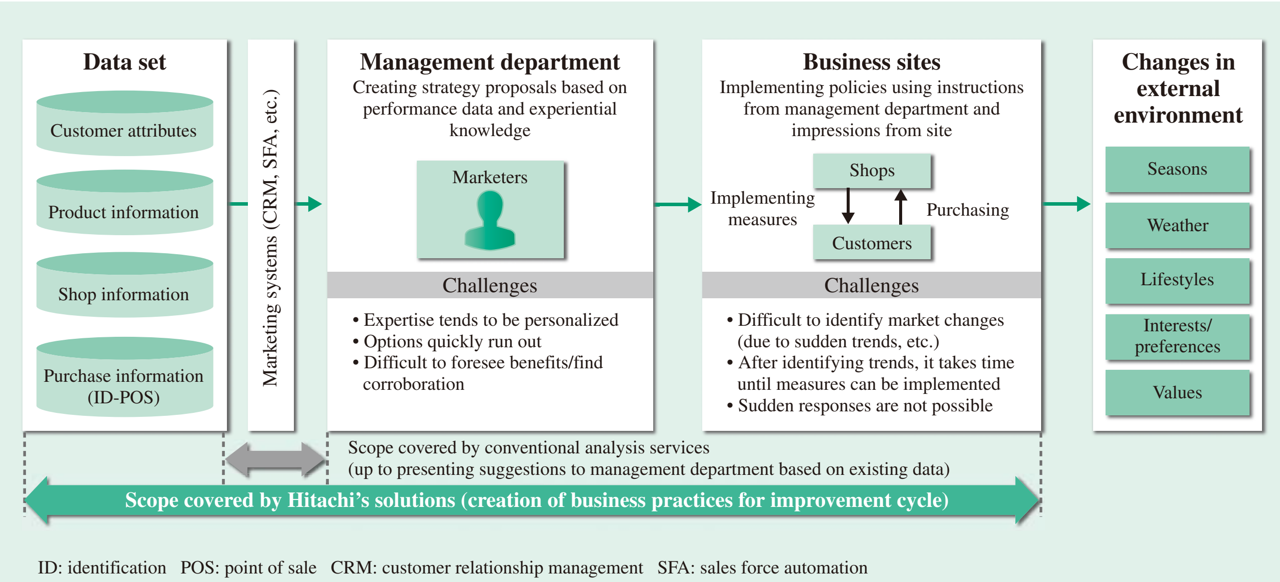

Fig. 1—Scope of Marketing Solution Services.
Marketing solution services provide business improvement cycles including business practices done before/after marketing systems.

and proposing subsequent policies [the plan, do, check, act (PDCA) cycle] are categorized into 10 tasks. These tasks are combined in accordance with the client's business conditions (see Fig. 2). Using H for Task 2 (Proposing improvement measures) enables comprehensive analysis that eliminates fixed ideas, leading to discoveries of new performance indicators for improving business issues (outcomes).

Using H to Formulate Improvement Measure Proposals

This section looks at the example of using of H for retail sales marketing, with sales volume as the outcome. When conventional methods are used, the marketer decides on measures to improve sales using performance indicators derived from previous experience.

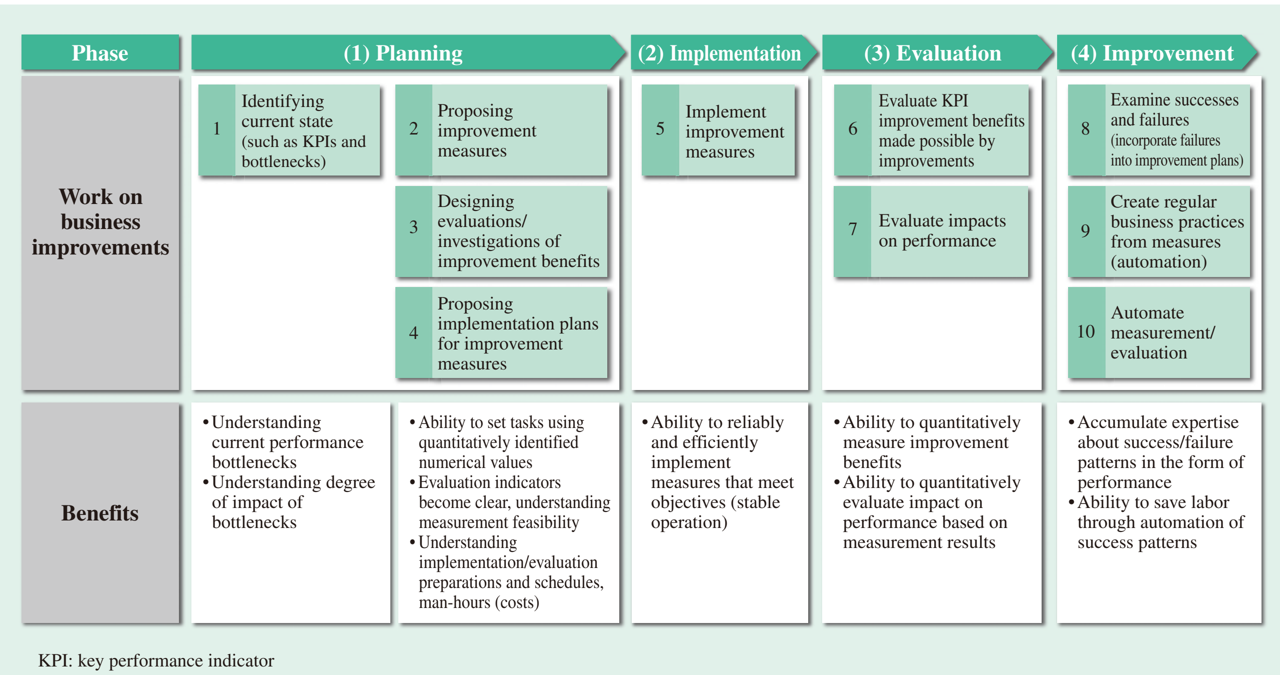

Fig. 2—Tasks for Providing Marketing Solutions.
These tasks provide comprehensive support for planning business innovation, implementing measures, evaluating benefits, and making improvements.

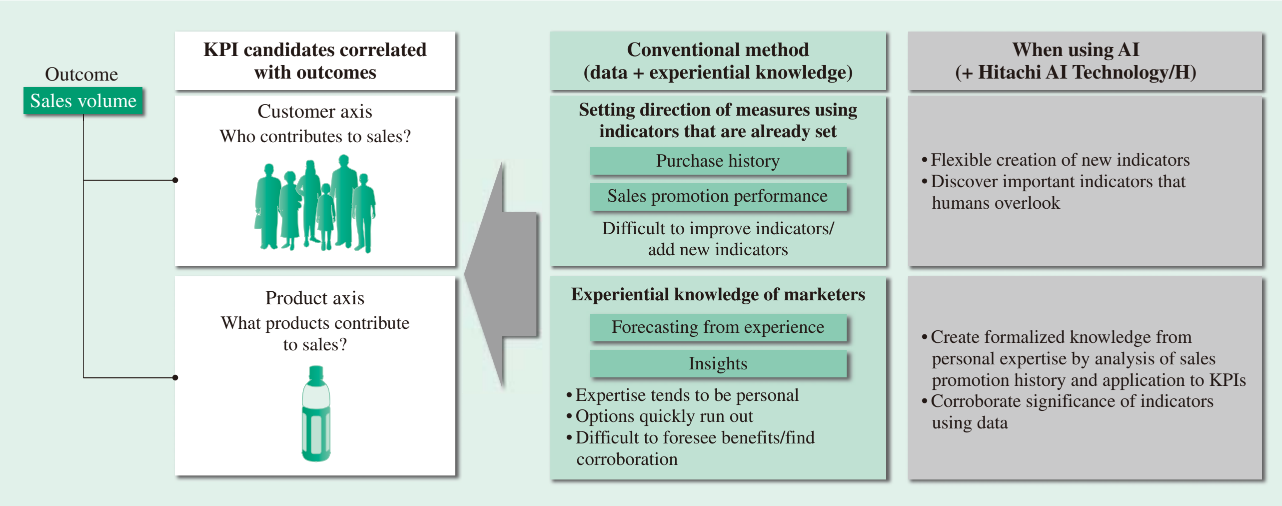

Fig. 3—Application of AI to Proposal of Improvement Measures and Expected Benefits.
The use of AI to discover new indicators enables efficient proposal of innovative policies.

However, analysis using H involves a comprehensive search for measures that improve outcomes, enabling the discovery of previously overlooked effective indicators and important indicators that tend to be missed. Expertise previously considered to be the tacit knowledge of the marketer is turned into formalized knowledge from data, enabling the derivation of new performance indicators. These indicators would previously have been considered to be the marketer's hunches, but since they can now be corroborated by data, they are expected to provide backing for new initiatives (see Fig. 3).

PLATFORM SUPPORTING BUSINESS IMPROVEMENT SERVICE: PENTAHO SOFTWARE

Pentaho Software

Pentaho software[(4)] is a data integration and analysis platform used to integrate a wide variety of data created from sources such as business systems, sensors, and social media, and to analyze it from various perspectives. Two platforms provide the environment needed for all operations ranging from data collection to analysis/usage. Pentaho Data Integration (PDI) collects, processes, and outputs data, while Pentaho Business Analytics (PBA) analyzes the collected data and provides visual representations of it.

Pentaho software offers benefits that are not available in competitors' products. For example, it enables data integration and analysis to be done on a single platform, shortening the data usage cycle. It also provides an abundant array of connected parts. And since it is an open source software (OSS) product, it can be quickly adapted to big data technology.

Using Pentaho Software in the Business Improvement Service

Pentaho software is positioned as a data usage platform, where data integration is performed by PDI, the data is then analyzed by H, and finally PBA provides visual representations of the results (see Fig. 4).

Data integration consists of creating visual representations of the data provided by the client to identify the data distribution and attributes (profiling), remove heterogenous data from the original data (cleansing), and join the remaining data to create a data set. These processes are the preprocessing done to enable analysis, and account for over half of the entire analytical work. This preprocessing must be done carefully since it can affect the analysis results if

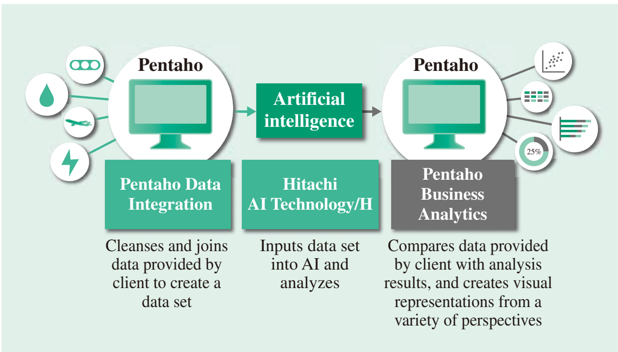

Fig. 4—Link Between H and Pentaho Software.
Data is integrated by Pentaho Data Integration, analyzed by H, and then visually represented by Pentaho Business Analytics.

done inadequately. The profiling process is done using tools such as the R programming language.

The development environment provided by PDI is provided by means of a graphical user interface (GUI), and most operations can be done without programming. PDI jobs (a job is a series of operations that are grouped together) used in past projects can be modularized, enabling them to be used immediately in new projects just by making changes in the applicable locations. Modularization also increases productivity. Even users with no programming experience can combine and define jobs using the GUI, enabling data processing to be done easily. Java* coding will be needed if the required data integration processes cannot be achieved using only the standard connection and processing parts provided by PDI. However, an abundant array of Java methods specialized for data processing are provided, enabling flexible and efficient processing.

Performance data shows that one project involving Java data processing required 16.2 man-days for cleansing and data integration, but only 7.5 man-days for the same processes to be done using PDI, a labor reduction of about 54%. When modularized templates were applied to the same project, the time was further reduced to 3.0 man-days, a labor reduction of about 81% relative to the original Java data processing.

PBA is used to load and create visual representations of the H analysis results and data provided by the client, evaluating it from a variety of perspectives. The benefits of increases in the data volume on performance are relatively small.

In the future, using the Pentaho software as the data processing platform of the Hitachi AI Technology/Business Improvement Service, Hitachi will create templates on it for a wide variety of use cases, aiming to further increase the efficiency of the data integration, analysis, visual representation, and evaluation processes to shorten the process cycle time.

CONCLUSIONS

This article has described a marketing solution that is one of the solutions provided by Hitachi's Business Improvement Service, and the Pentaho software, which is the platform technology that supports it.

The Hitachi Group is studying various types of AI-driven business initiatives, through Group-wide collective efforts. While making use of the successes it has achieved to date, Hitachi will continue working on collaborative innovation activities with clients and partners, promoting projects that help solve societal issues and aid business growth by applying AI in a wide range of areas.

*Java is a registered trademark of Oracle and/or its affiliates.

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Featured Articles

Utilization of AI in the Financial Sector

Case Study and Outlook for FinTech Era

Kiyoshi Kumagai
Satomi Tsuji
Hisanaga Omori

OVERVIEW: A succession of new user-oriented services combining finance and IT have been appearing recently. Known as FinTech, these services influence competitive advantage for their ability to create innovation beyond the framework of conventional financial services. Acting as an enabler for creating innovation, Hitachi is taking a close look at AI, and working on its utilization in the financial sector. This article looks at phenomena such as FinTech and the IoT as precursors of changes in the financial industry. It discusses how AI is being used in the financial industry through activities designed to raise management KPIs by quantitatively evaluating organizational activity levels from action data acquired from wearable terminals. The article also describes the future outlook for AI use by examining concepts such as the development of business applications that use embedded AI.

INTRODUCTION

FINANCIAL services have developed along with advances in information technology (IT). The use of IT among financial institutions extends to every aspect of their business, and IT has become an indispensable part of finance. However, until recently, IT has mainly been used to improve the efficiency of operations performed by humans.

New services called FinTech, due to their combination of finance and IT, have recently been gaining attention, and financial services offering users a high level of convenience have appeared one after another(1). These services go beyond the framework of existing financial services, creating new value for clients. The financial industry is on the verge of a new era of innovation that will radically transform business models through IT.

Acting as an enabler for creating innovation, Hitachi is taking a close look at artificial intelligence (AI) and working on introducing it to the financial sector. In particular, anticipating the arrival of the Internet of Things (IoT) era, Hitachi is taking on the challenge of new services that support business optimization that use AI to analyze sensor data from wearable terminals, etc. that was unobtainable by financial businesses in the past.

This article looks at how FinTech and the IoT are changing the financial business environment, and describes how AI is being used in the financial sector through activities designed to improve the management key performance indicators (KPIs) of financial institutions by using AI to analyze action data obtained from wearable terminals. The article also describes the outlook for the use of AI in the financial sector by looking at concepts such as the development of business applications that use embedded AI.

CHANGES IN THE FINANCIAL BUSINESS ENVIRONMENT

Appearance of FinTech

FinTech is a portmanteau word coined from Finance and Technology. It is characterized by the creation of innovative financial services that offer users a high level of convenience by combining finance and IT. The succession of FinTech services that have appeared include user-to-user fund transfer services the use Internet peer-to-peer (P2P) communication technology, and cloud funding services that enable direct procurement of funds from multiple individuals through social media. These services have gained a large amount of user support for their low cost and procedural simplicity.

New FinTech services are being provided by IT industry startup companies, etc., which were previously not major names in the financial industry. As a result, the ability to create innovation that can drastically transform financial business models using technology is influencing competitive advantage.

AI has gained attention as the core technology of FinTech. Financial services driven by AI include new credit services and investment support services that improve credit/risk management precision by using AI to analyze Internet-based activity data and transaction data. The use of AI is expected to produce more advanced credit and risk management models through discovery of new factors that were previously undiscoverable.

Arrival of the IoT Era

The IoT is creating a network of objects that are connected to the Internet, and its growth is driving the innovation of services that use object operation data and human activity data acquired from sensors. IoT-driven innovation has become influential in fields such as production management and product maintenance in the manufacturing industry. Its use should continue to advance in finance and many other areas in the future.

Several new IoT-driven insurance services are appearing and growing in popularity. Examples include telematics insurance in which driving data acquired from vehicle onboard sensors is used to evaluate accident risks to adjust insurance premiums, and new medical insurance that evaluates the risk of illnesses from health data acquired from wearable terminals.

Creation of Innovations in Finance

In the IoT era, it will become possible to use sensors attached to objects and people for realtime acquisition of various types of data used in various applications. The IoT era will see many innovative services appear one after another. They will be made possible by finding new connections by merging external data acquired from sources such as the IoT, with internal data gathered from financial operations.

Joseph Schumpeter, the father of innovation research, said that innovation is created from new combinations of existing things. For financial institutions to constantly create innovation, it is important for them actively gather external data from sources such as the IoT, and to discover new connections by combining this external data with their own internal data.

But discovering new connections from large volumes of external data that change daily is not easy. Hitachi is looking closely at AI as a technology that exceeds human abilities to discover new connections, and is working on developing analytical methods for finding new correlations among massive volumes of variables. The next chapter describes how AI is being used in the financial sector through activities designed to improve management KPIs by using AI to analyze human behavior data obtained from wearable terminals.

AI USE IN FINANCIAL SECTOR

Background and Aims

To respond to the changing financial business environment, Hitachi is working on financial service applications of the IoT and AI. One of these efforts was a study on how to use technology for measuring and analyzing human behavior(2) to improve the quality of financial institution services and to help innovate work styles. It included a trial conducted with The Bank of Tokyo-Mitsubishi UFJ, Ltd. The trial studied 40 office workers from the planning department of the bank's headquarters. Differences in action characteristics on days of high and low levels of organizational activity(3) were extracted as proxies for productivity indicator values, and it was found that specific knowledge on productivity improvement could be extracted.

Management Support Driven by Human Action Measurement and AI

Hitachi has developed technology for ID card-type wearable sensors used to measure the actions of people in groups. By connecting this technology to AI, it is studying the creation of management support systems that present quantitative advice on working styles that increase productivity (see Fig. 1).

In a previous study, Hitachi acquired action data about communication and deskwork from several hundred subjects in one-second increments. However, quantitatively expressing the actions and subjects that contributed the most to the organizational activity level was a costly and time-consuming task requiring careful analysis by experts. The aim of the recent study was to enter a large volume of sensor data in the Hitachi AI Technology/H artificial intelligence system (hereafter referred to as H) to speed up comprehensive searches and the refinement of objectives, and to enable analysts to focus on presenting advice tailored to the client's industry/job type characteristics.

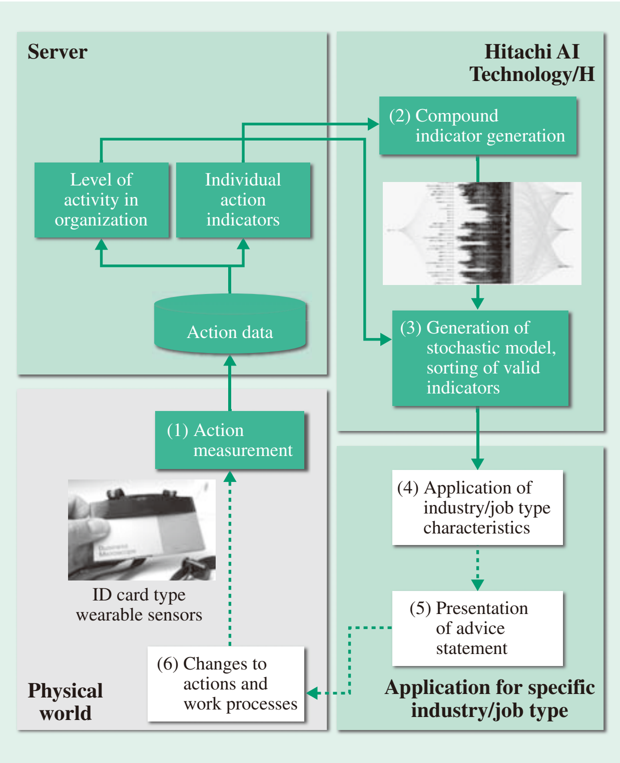


Fig. 1—Conceptual Diagram of a Management Support System.
AI is used to analyze collected human behavior data, to provide advice on work methods designed to increase productivity.

Trial Procedure and Analytical Results

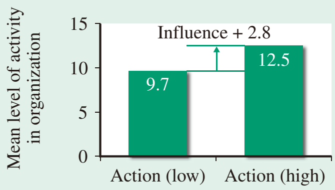
Action data was collected for three weeks at The Bank of Tokyo-Mitsubishi UFJ, Ltd. and, using the procedure shown by items (1) to (3) in Fig. 1, a search was conducted for correlated action indicators, with organization activity level as the target variable. Items (4) to (6) were done by analysts, since work characteristics needed to be taken into account.

To quantify typical office worker work patterns, groups of indicators related to deskwork and communication were used as action indicators. The indicators that were collected daily were entered into H (see Table 1). H generated compound indicators combining attributes and actions, refined them into effective indicators that could describe organizational activity levels, and generated stochastic models.

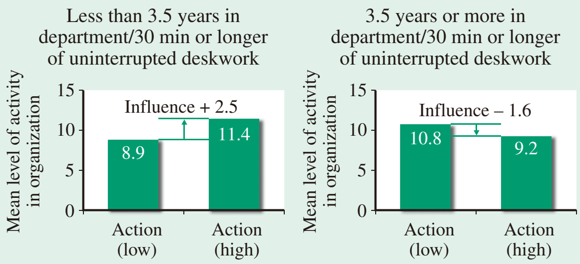
Fig. 2 shows some of the results. The first finding was that days on which subjects in their 30s had short, frequent conversations had higher overall organizational activity than other days. A difference in action indicators between new and experienced department members was also found. The activity level was better when new department members (with less than 3.5 years in the department) did prolonged deskwork (at least 30 minutes). However, for more experienced department members (with at least 3.5 years in the department), the activity level increased more when deskwork was divided into sessions of less than 30 minutes due to interruptions for reasons such as answering questions. This finding shows that although the personal productivity of more experienced workers may decline, they improve the productivity of the overall organization. This corroborates the notion that more experienced workers contribute to raising team synergy. Quantitatively expressing this contribution to the entire organization

TABLE 1. List of Action Indicators for Office Workers
Hitachi has defined indicators for interactive communication and deskwork.

Category	Indicator	Definition
Duration of interaction (min)	Total time	Time during which interaction with at least one other person is detected
	Two-way	Time during which two-way conversation is in progress
	Pitcher	Time during which subject is speaking
	Catcher	Time during which subject is listening
Number of interactions: Number of instances of each category of interaction duration	(a) Continuing for < 5 min	Number of short conversations (greetings or passing on a message)
	(b) Continuing for 5 < 15 min	
	(c) Continuing for 15 < 30 min	Number of long conversations (such as meetings)
	(d) Continuing for ≥ 30 min	
Duration of deskwork (min)	Total duration of deskwork	Time during which subject does not interact with others and has minimal physical movement
	Maximum duration of continuous deskwork	Longest period of uninterrupted deskwork during the day
Number of instances of deskwork: Number of instances of each duration category	(a) Continuing for < 5 min	Number of times deskwork is interrupted (by being spoken to, going for a walk, etc.)
	(b) Continuing for 5 < 15 min	
	(c) Continuing for 15 < 30 min	Number of times deskwork continues for a long period with few interruptions
	(d) Continuing for ≥ 30 min	
Length of time sensor is worn (min)	Length of time sensor is worn	Time measured by ID card type sensor (in the case of office work, this is the office's working hours)



(a) Relationship between number of short conversations by people in their 30s and level of activity in organization



(b) Different action guidelines depending on how long employee has been in the department

Fig. 2—Example of Action Characteristics Analysis for Different Attributes.*
(a) The level of activity in the organization is higher by 2.8 on days on which people in their 30s had frequent short conversations such as greetings or passing on a message.
(b) Opposite guidelines were obtained for uninterrupted deskwork time depending on how long the employee has been in the department.

may help experienced workers understand the value of their support to others, and be effective for overall optimization of service and work methods.

Validity and Remaining Challenges

The case study described in the previous section confirmed the validity of the following:

(1) It was possible to extract knowledge for improving service and work methods in a financial institution through quantitative analysis of data from wearable terminals.

(2) It was possible to use AI to comprehensively scrutinize which employees to focus on, and which actions of those employees to focus on.

(3) It was possible to use AI to extract individual indicators for overall optimization.

Achieving ongoing operation by automating the presentation of advice is a remaining challenge for achieving a management support system. The analysis of the results output by H are currently being interpreted and compiled by analysts, and client work characteristics are being considered when presenting advice. To increase the efficiency of these processes, it may be necessary to embed functions such as work applications into H to automate the analysis, and to create a method of visualizing and sharing results on a daily basis.

*The experimental data shown in this article (see Fig. 2) is a mock up for presentation purposes. However, the knowledge obtained is the same as that achieved in practice.

FUTURE OUTLOOK

This section describes the future outlook for the use of AI in the financial sector, looking at the projects that are currently underway.

Creation of Social Innovation in the Financial Sector

Hitachi is focusing on it Social Innovation Business, which solve problems in public systems by combining infrastructure technology and IT. By using IT to link public infrastructure projects in areas such as finance and railroads with related peripheral projects, it aims to produce innovative services by creating new connections that exceed the framework of existing projects.

Expectations for innovation are increasing in the financial sector, and AI has gained attention as an enabler for the discovery of new connections. For example, new FinTech services are being created by linking finance and electronic commerce (eCommerce), with functions such as calculation of credit scores of eCommerce providers by using AI to analyze the data of transactions on eCommerce sites.

Hitachi is working on optimization problem searches in financial operations, an area in which AI is effective. It seeks to speed up the creation of Social Innovation in financial operations by using AI to develop optimization models.

Combining Financial Operation Data and IoT Data

The arrival of the IoT era will greatly increase the scope of data that financial institutions can use. Acquiring position information and operation data from sensors attached to objects such as vehicles and residential facilities is already possible, and it is becoming possible to acquire activity data and health data in real time from wearable terminals worn by people.

The use of this data holds the potential to radically transform the business models of financial institutions. Specifically, the insurance industry is expected to evolve from calculating risks using traditional statistics to calculating risks for each policy individually using the IoT.

Creating analysis environments and methods by accurately combining in-house data acquired using existing financial operations with new external data acquired from the IoT will be an indispensable requirement for achieving these new business models.

To meet this requirement, Hitachi is creating AI analysis models that combine financial operation data and IoT data, and developing and applying methods of creating new financial services from the connections discovered by these models.

Development of Embedded AI Business Applications

To maximize the benefits of AI-driven analysis, AI should ideally be embedded in routine operations, and new models for financial operations should be constructed that coordinate humans and AI.

To achieve these aims, there is a need for embedded AI business applications that provide support for routine decision-making using financial business applications with embedded AI. For example, an embedded AI application that proposes policy plans could be developed for the insurance industry that would enable optimum plan proposals to be derived by coordinating the efforts of AI and humans. By using AI to perform analysis that combines existing policyholder data with IoT-based action data and health data, this application could be expected to propose appropriate policy plans that capture the risks and preferences of individuals in real time.

In the future, Hitachi would like to develop embedded AI business applications that draw on the strengths of AI to bring new innovations to financial operations.

CONCLUSIONS

This article has discussed the expanding use of AI in the financial sector by looking at trends in the creation of innovations in finance in light of the changing financial business environment resulting from FinTech and the IoT. Also described were a study undertaken by Hitachi as the first step toward achieving these innovations in which organizational activity levels were measured using ID card type wearable sensors and AI, and the future outlook for AI.

In the future, the growth of the IoT should create an era in which the degree of skill in the use of external data will affect the competitive advantage of financial businesses. To prepare for this coming era, Hitachi wants to help create financial sector innovations by creating analytical methods that combine internal data from financial operations with external data, and working on developing embedded AI business applications.

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Featured Articles

Utilization of AI in the Railway Sector

Case Study of Energy Efficiency in Railway Operations

Ryo Furutani
Fumiya Kudo
Norihiko Moriwaki, Ph.D.

OVERVIEW: Leveraging its past track record in rolling stock maintenance of high-speed Class 395 rolling stock for the UK's High Speed 1 project, for which it received orders in 2005, Hitachi is advancing the expansion of its services business in the railway sector, for example, through the UK's Intercity Express Programme (IEP) and by providing rolling stock maintenance for Abellio, a railway operator. Condition monitoring systems that remotely monitor the condition of rolling stock will be the key to expanding and developing the services business. Hitachi is working on utilizing AI technology that it has developed to provide further added value using rolling stock information that is collected on a daily basis. This article covers power consumption while operating railway rolling stock, and presents an analytical case study of where feature values for reducing power consumption are identified using AI.

INTRODUCTION

INCREASED energy efficiency of railway systems, both inside and outside Japan, is being sought for the purpose of reducing CO_2 emissions as a measure against global warming(1). Sixty to eighty percent of the energy consumed by railway systems is the energy used when operating rolling stock, and increasing the energy efficiency is effective in reducing CO_2 emissions. For this reason, Hitachi developed the A-train concept featuring a lightweight aluminum structure and main converters that apply silicon carbide (SiC) hybrid modules to achieve increased energy efficiency in the overall traction power supply system(2).

The utilization of data obtained by measuring operating rolling stock is pointed out as one means of verifying the energy savings from applying these technologies. With information and communication technology (ICT) progressing rapidly in recent years, there has been accelerated movement toward utilizing the diverse sensor information that is collected by railway systems in operation and maintenance (O&M) services. Hitachi, too, is expanding its rolling stock maintenance services through remote condition monitoring.

The use and application of artificial intelligence (AI) such as deep learning is being vigorously promoted as a technique for high speed and efficient processing of the vast amounts of information collected by these technologies.

This article describes a case study of the application of Hitachi AI Technology/H (hereafter referred to as H) to the analysis of energy saving performance in terms of rolling stock energy, and the future outlook for railway systems where AI is put to use.

UTILIZATION OF AI IN THE ANALYSIS OF ENERGY SAVING PERFORMANCE IN TRACTION POWER CONSUMPTION

Applications

In this case, some rolling stock operating data collected by remotely monitoring the condition of rolling stock was used to automatically extract the most effective feature values for reducing traction power consumption (i.e. the energy consumed by the traction power supply system when driving rolling stock motors) with H (see Fig. 1).

The technology on which H is based is a statistical technique in which the objective variables and explanatory variables must be assigned in advance. For this reason, the traction power consumption of the entire train per travel between stations at which the train stops as the objective variable for one sample, and the time-history data from the rolling stock operating

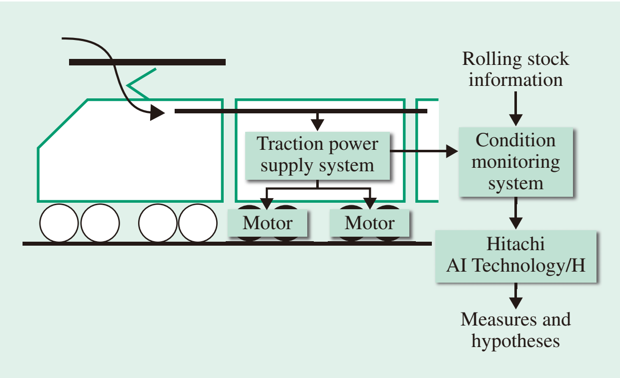

Fig. 1—Example of Utilizing H for Rolling Stock Operating Information.
Diverse sensor information during rolling stock operation is input into H, and parameters for reducing traction power consumption are automatically extracted.

data at that time was directly assigned as explanatory variables (see Table 1).

Then, a distinctive technology of H, leap learning, was used to automatically and comprehensively generate the objective variables, correlations, and feature values having a large influence based on explanatory variables, including nine parameters of rolling stock operating data, such as the rolling stock travel speed (carriage speed), and three parameters of track infrastructure data, such as the track gradient information.

Furthermore, one year's (2013) worth of data that was collected when a specific train passes through four stations was used as the input data for H.

Application Results

Approximately 4,000 feature values were automatically generated by H based on the input data of the objective variable and explanatory variables shown in Table 1 (see Fig. 2).

TABLE 1. List of Data Input into H
Traction power consumption was provided as the objective variable, and rolling stock operating information and track infrastructure information were provided as explanatory variables.

No	Item	Item		Type	Unit
1	Objective variable	Traction power consumption		Number	kWh
2	Explanatory variables	Rolling stock operating information	Rolling stock travel speed	Number	km/h
3			Train mass	Number	kg
4			Individual carriage mass	Number	kg
5			External air temperature	Number	°C
6			Acceleration/deceleration	Number	m/s^2
7			Coupling information	Character	-
8			Operating information (notch)	Character	-
9			Up/down	Character	-
10			Operating date/time	Character	-
11		Track infrastructure information	Gradient	Character	-
12			Line feature value	Character	-
13			Curve information	Character	-

The following shows one example of the feature values that were automatically generated:
(1) Carriage speed is 0 to 57 km/h
(2) Gradient is down gradient
(3) Operating time is 18:00 to 24:00 and Mass of carriage A is 45,000 to 48,000 kg

These features can be broadly divided into three categories: "feature values (1)" that are directly generated from numerical data, "feature values (2)" that are directly generated from character codes, and "feature values (3)" that are combinations of individual

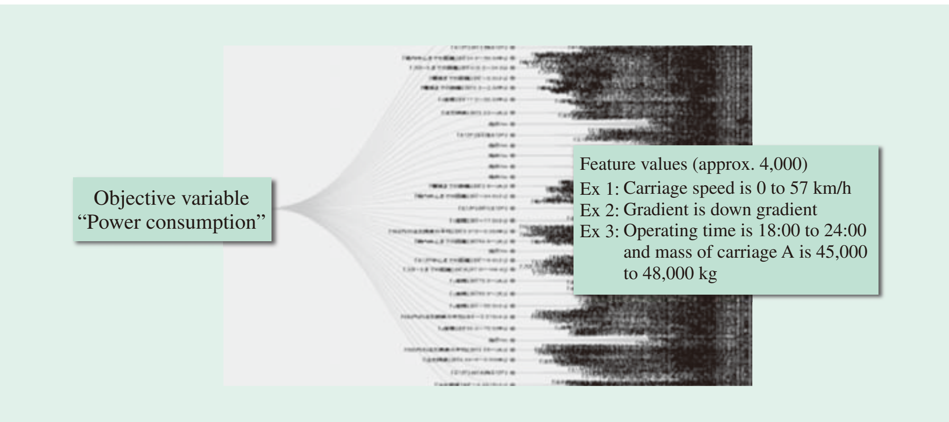

Fig. 2—Feature Values Generated by H.
For H, approximately 4,000 feature values were automatically generated from the 12 explanatory variables.

feature values. By analyzing the correlations between the objective variables and these automatically and comprehensively generated feature values, it is possible to gain knowledge and hypotheses that humans cannot process and that humans are not capable of noticing.

The following explains the effective feature values that were extracted from the approximately 4,000 automatically generated feature values. The following feature value, which has the highest negative correlation (correlation coefficient: –0.81) with traction power consumption, was extracted in August 2013:

Feature value: Operating information (notch) is Notch-off

The operating information feature value, notch, expresses a step in acceleration force for accelerating/decelerating rolling stock. For the railway rolling stock discussed in this article, among the notch positions, when the notch-off operating time is longer, traction power consumption shows a downward trend (see Fig. 3).

On the other hand, the extracted feature value with the most positive correlation with traction power consumption was the notch called “maximum notch (correlation coefficient: 0.73).” This means the maximum notch operating time should be lengthened. The fact that these feature values, notch-off and maximum notch, were extracted as effective feature values indicates that both are largely affected by driver operation. Also, in each of the other months of 2013, it was confirmed that there was a high correlation between each of the respective feature values and the objective variable.

Moreover, the traction power consumption on the vertical axis and feature value on the horizontal axis in Fig. 3 have been normalized by the travel distance of each of the four representative sections and by the travel time of each sample, respectively.

Next, Fig. 4 shows the carriage speed information and notch information for each of the following operations, Operation 1 and Operation 2, in the sample for representative Section A in Fig. 3.

Operation 1: Traction power consumption is large, and notch-off operating time is short (August 26, 2013).

Operation 2: Traction power consumption is small, and notch-off operating time is long (August 6, 2013).

According to Fig. 4, for the travel in Operation 1, travel under notch-off operation was conducted frequently for short distances, and there were long sections of travel under maximum notch operation.

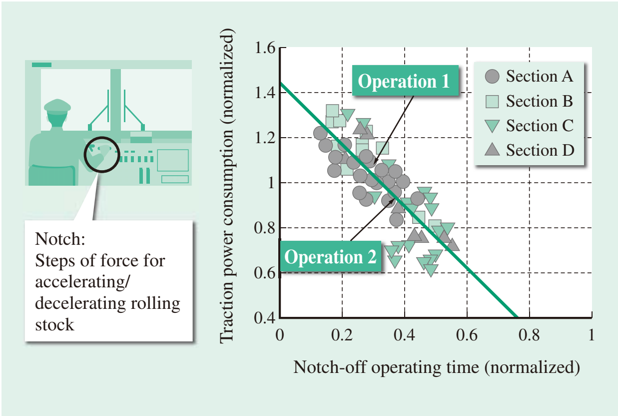

Fig. 3—Relationship between Traction Power Consumption and Notch-off Operating Time.
There is an extremely high negative correlation (correlation coefficient: −0.81) between the notch-off operating time and traction power consumption of the four representative sections on August, 2013.

Whereas, for the travel in Operation 2, travel under notch-off operation was conducted infrequently and over relatively long distances, and, in the latter half of this section, it can be confirmed that the rolling stock traveled in such a way that the section travelled under notch-off operation was longer. From this fact, it can be confirmed based on the data obtained by measuring actual rolling stock operation, that there are differences in driving skills even in the same section of travel.

Estimating the Effect of Energy Consumption Reduction

Fig. 5 shows the correlation between traction power consumption and notch operating times (notch-off, maximum notch) in Section B for the period of one year, 2013. According to the figure, the longer the maximum notch operating time is, and the shorter the notch-off operating time is, traction power consumption increases. Alternatively, it can be seen that a relationship exists where traction power consumption decreases when the maximum notch operating time is shorter and the notch-off operating time is longer. Furthermore, it can be seen that there is large variation in each of the samples and there is room for improving traction power consumption.

In this respect, if we assume that operation has improved in the 20% superset that has small traction power consumption along the regression line in Fig. 5, then a yearly decrease in traction power consumption of approximately 20% can be anticipated. Furthermore, the relationship between traction power consumption

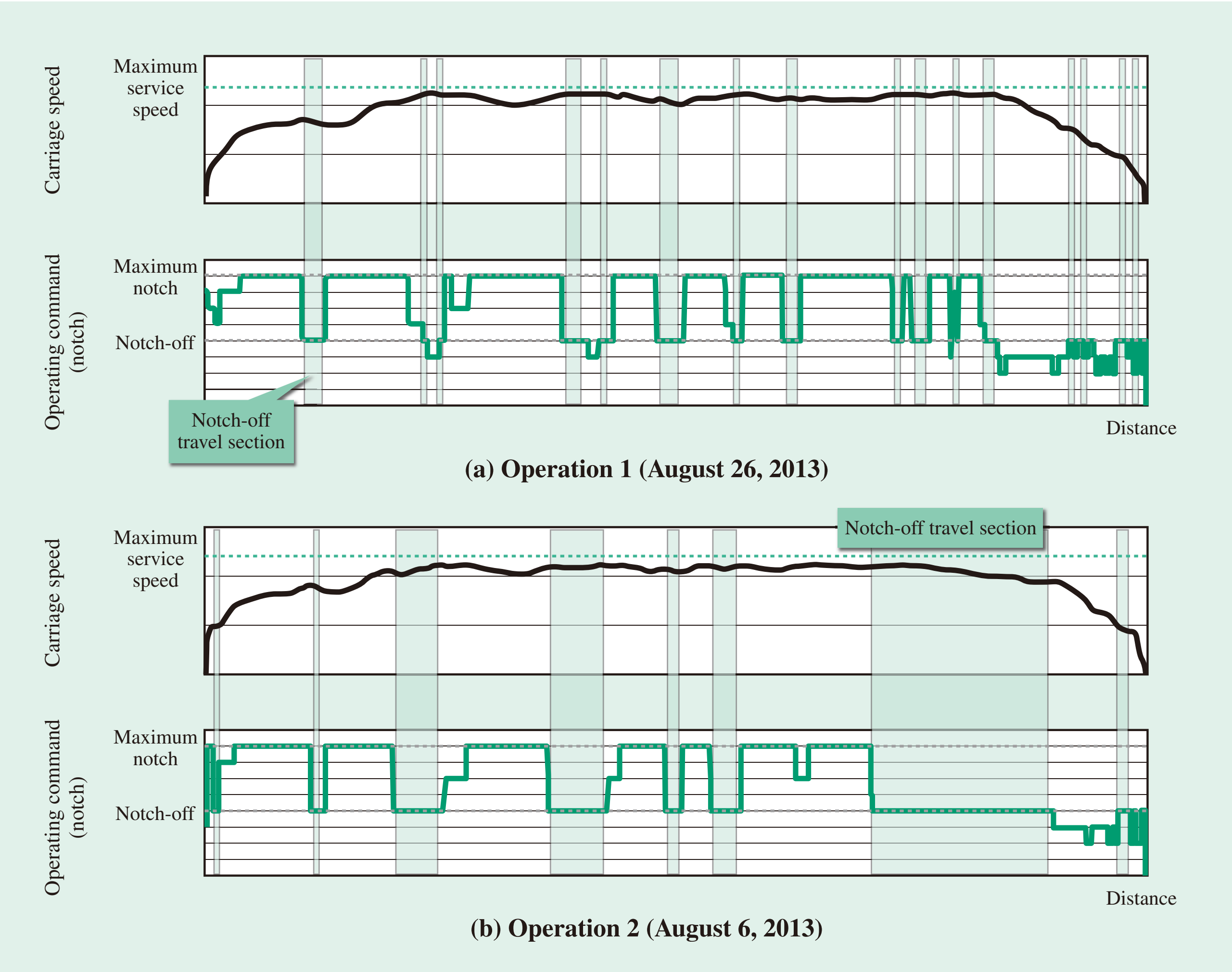

Fig. 4—Comparison of Carriage Speed Information and Operating Command Information in Section A.
With travel under Operation 2 where the traction power consumption is small, travel was conducted under relatively long notch-off operations.

and notch operating time shown in Fig. 5 shows the same tendency in the other three representative sections. And, when the four representative sections are taken as a whole, it can be confirmed that a yearly power consumption reducing effect of approximately 14% can be anticipated. Rolling stock operation information in which rolling stock ran punctually according to operating travel times was used for this analysis.

This case study introduced a study where H was applied with data limited to a representative train and four representative sections, however, Hitachi is currently proceeding with analysis of expanded travel distances using multiple trains. It is also proceeding with analysis using an expanded amount of information for explanatory variables such as the operation status of the traction power supply system which was not targeted as an explanatory variable in this article.

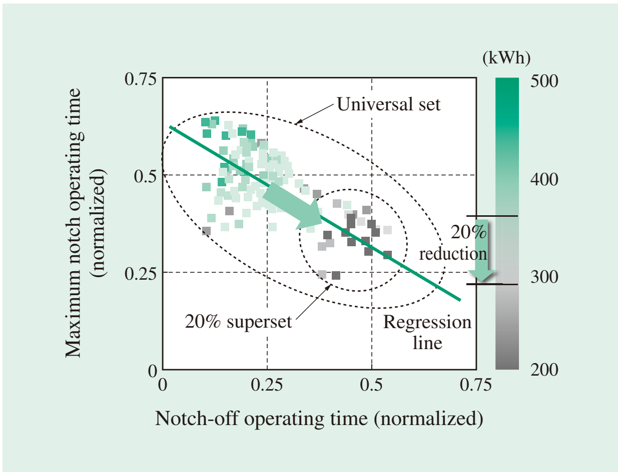

Fig. 5—Visualization of Relationship between Notch Operating Time and Traction Power Consumption.
For the year 2013, the variation in notch operating times was large, and when operation improvements were assumed, it was found that a power consumption reduction effect of about 20% could be anticipated for the year in representative Section B.

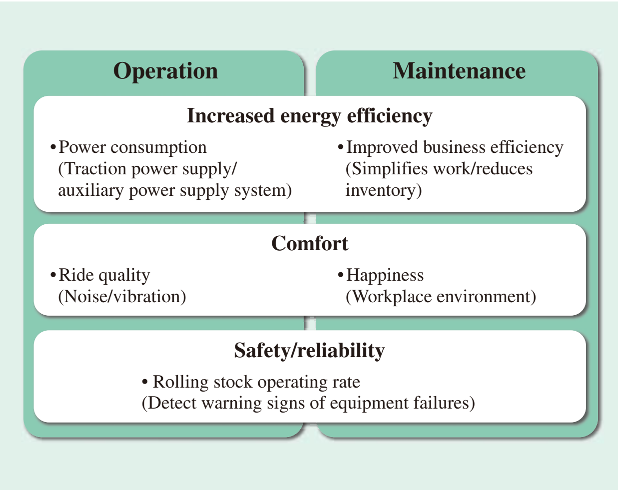

Fig. 6—Example of Applicable Targets on Railway O&M Services. This figure shows some applicable targets for H with respect to increased energy efficiency, comfort, and safety/reliability.

FUTURE OUTLOOK OF RAILWAY SYSTEMS THAT UTILIZE AI

In the future, it is anticipated that H will be applied in various situations on diverse big data that is collected by railway systems. In particular, the applied deployment of H in railway O&M services that is being promoted by Hitachi is described below (see Fig. 6).

In railway operations, comfort, etc. is one representative key performance indicator (KPI) in addition to the increased energy efficiency introduced in the applied case study mentioned above. For increased energy efficiency, it is conceivable that the power consumption of the auxiliary power supply system used, for example, for operating air conditioning or opening/closing doors, will be targeted in addition to the power consumption of the traction power supply system. The extraction of new knowledge can be anticipated since power consumption is affected more substantially by the behavior of people in the carriages. And since there are also two ways of operating, by electric rolling stock and by rolling stock with diesel engines, depending on carriage composition, the identification of increased energy efficiency measures in operation management can also be anticipated. With regard to comfort, comfort parameters relating to ride quality, such as vibration and noise can be targeted and design guidelines for operating rolling stock comfortably and safely may conceivably be gained.

Next, indices relating to the work efficiency of maintenance workers and the rolling stock utilization rate resulting from rolling stock malfunctions can be pointed out as representative KPIs in railway maintenance. If wearable sensors are made use of in maintenance services, measures for improving and enhancing work efficiency can conceivably be identified based on maintenance workers' daily activities. Moreover, maintenance workers' level of well-being (happiness) also could be applied as a measure for improving work efficiency. By improving the rolling stock utilization rate, it is anticipated that the relationship between the time-related deterioration of rolling stock and the operating conditions of rolling stock will be discovered from H, and that this can be applied to the detection of the warning signs of equipment failure.

CONCLUSIONS

This article introduced a case study where H was applied to automatically extracting feature values to reduce the power consumed in driving rolling stock, and described the future outlook for applications of H in railway O&M services.

Hitachi intends to accelerate the full-scale application of AI to the railway sector, and to promote further initiatives for increasing energy efficiency in railway operations and for improving efficiency in rolling stock maintenance.

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Featured Articles

Use of AI in the Logistics Sector

Case Study of Improving Productivity in Warehouse Work

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Fumiya Kudo
Atsushi Miyamoto, Ph.D.
Ryuji Mine

OVERVIEW: Attempts are being made to increase the efficiency of work improvements through more widespread application of IT to work systems. However, as each new improvement is added or improvements are made with respect to environmental changes, it requires manual changes to the system, leading to increases in work improvement costs. Hitachi has developed an AI system that uses big data such as work performance information, to understand worksite improvements and environmental changes and issue appropriate work instructions. It has conducted a demonstration test, which confirmed the effectiveness of this system for improving distribution warehouse work. In the future, Hitachi will continue to work on expanding the AI system to a wide range of Social Innovation Business in areas such as manufacturing and distribution.

INTRODUCTION

AS information technology (IT) has advanced in recent years, IT systems have been introduced in a variety of work to improve efficiency. In the future it will be important to make further improvements to work efficiency that take site improvement activities and site environmental changes into consideration. However, conventional work systems are controlled by pre-designed programs, and system engineers have had to redesign the systems whenever new improvement activities needed to be applied to work systems. Moreover, work procedures and settings have had to be changed whenever changes in the work environment necessitated operations that were different from the current conditions. Such frequent system changes have been expensive and have made it difficult to issue efficient work instructions rapidly to respond to new improvement activities or environmental changes.

This article describes the development of an artificial intelligence (AI)-driven work system that uses big data from work performance information gathered on a daily basis by the work system, to issue appropriate work instructions by understanding worksite improvements or environmental changes. The AI-driven work system was subjected to demonstration testing at a distribution warehouse to determine its effectiveness, and these test results are also described.

AI-DRIVEN WORK SYSTEM USING HITACHI AI TECHNOLOGY/H

Hitachi AI Technology/H (hereafter referred to as H) is an original AI system that the Research & Development Group at Hitachi, Ltd. developed as a means of achieving an AI-driven work system. This chapter describes the features of the AI-driven work system developed based on this technology.

Deriving Work Improvement Proposals Originating from Data

H is an AI system used for data analysis to automatically calculate relationships between key performance indicators (KPIs) and the explanatory variables related to them. Specifically, it generates hundreds of thousands of feature values by comprehensively combining explanatory variables on an exploratory basis, and describes the relationships between the KPIs and these feature values in the form of equations. For example, taking site work efficiency as the KPI and work behaviors (people, locations, things, quantities, etc.) as the explanatory variables, it can generate

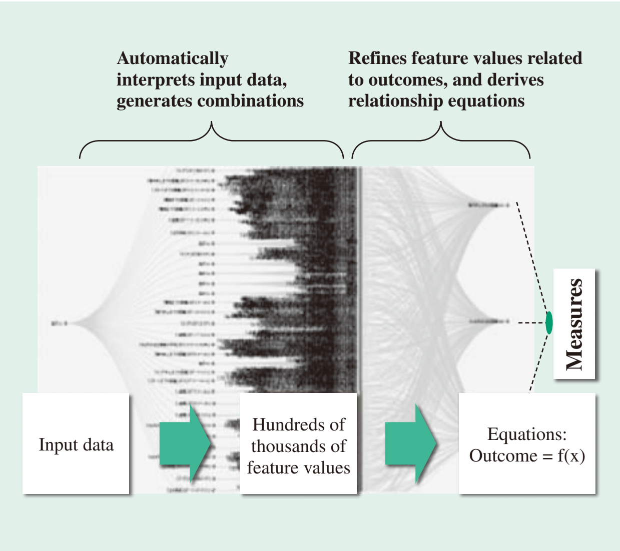

Fig. 1—Overview of H.
H generates feature values from input data (explanatory variables) comprehensively combined on an exploratory basis and describes their relationships to the outcomes (KPIs) in the form of equations.

numerical models of behavioral characteristics related to work efficiency. These models can be used to derive proposed measures for work improvements that originate from the data (see Fig. 1).

Understanding Human Ingenuity and Reflecting It in Work Instructions

Fig. 2 shows the configuration of the AI-driven work system. Site workers perform work according to the work instructions output by the work system, and the results of the work done by the workers are collected daily by the work system. The AI-driven work system uses the work results collected by H to derive work improvement proposals, and reflects them in the work instructions.

The site workers work according to the work instructions output by the work system, however, to work efficiently, they often add their own ingenuity or improvements to the work based on their own experience. H recaptures and analyzes the results created from worker ingenuity and improvements, to select the results that generate higher efficiency and reflects them in subsequent work instructions. By understanding site workers' ingenuity and improvements and repeatedly reflecting them in work instructions on a daily basis, H makes it possible to continually improving work efficiency through mutual cooperation between humans and AI.

Rapidly Incorporating Various Types of Big Data

The big data collected by work systems consists of several different types of data such as numerical quantities, times, and product codes, along with text and symbols. So, for all this data to be entered into an analytical system, it must be tagged in advance by experts with knowledge of the industry and business operations, requiring work whenever data is added or changed. H has a function that rapidly enters new additional data without requiring human intervention. The function works by analyzing the statistical distribution of the data and automatically identifying data formats such as quantities, times and product codes in advance. This enables daily worker ingenuity and fluctuation in demand to be automatically entered into the system and reflected in the work instructions in a timely manner (see Fig. 3).

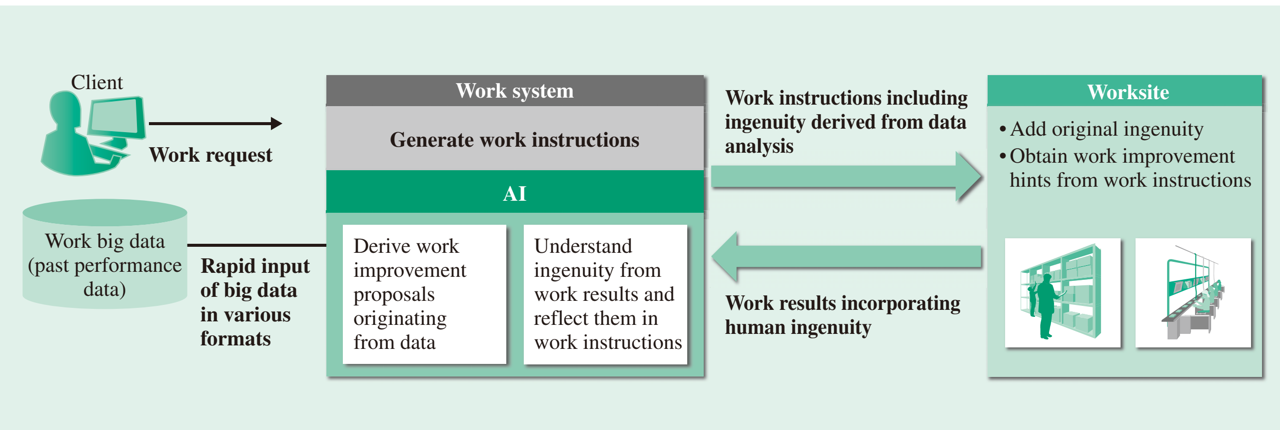

Fig. 2—AI-driven Work System Configuration.
The system enables continual improvement of work efficiency through human-AI cooperation by issuing AI-derived work instructions and a cycle of collecting work results incorporating human ingenuity.

DEMONSTRATION TEST FOR DISTRIBUTION WAREHOUSE WORK

Challenges of Distribution Warehouse Work

As the importance of logistics in the distribution industry increases, improving distribution warehouse work is becoming indispensable for maintaining competitiveness. Specifically, shorter work times are needed for work processes such as receiving and shipping. Receiving consists of receiving products from shippers and storing them at the designated locations in the warehouse. Shipping consists of receiving orders from stores or individuals and picking (collecting) products stored in the designated locations. The aim of this demonstration test was to reduce the work time spent on picking work, which has the highest work cost.

Test Overview

Picking work consists of collecting a specified product from the warehouse in response to a product order from a client. The picking work instructions specify the product to collect and the product's storage location. The worker follows these instructions to travel through the warehouse and collect the specified product. The warehouse management system (WMS) issues the picking work instructions and collects the work results.

Fig. 4 shows the configuration of the AI-driven work system used in the demonstration test. The data flow in the standard work system (WMS) is illustrated by (3) → (4), while the data flow in the AI-driven work system is illustrated by (1) → (2) → (3) → (4).

(1) H reads past work results, and generates mathematical models of the KPIs and work behaviors.

(2) The generated models are used to generate improvement proposals for that day's work instructions. The work instruction improvement proposals are fed back to the WMS.

(3) Work instructions are issued from the WMS.

(4) The work is done as specified in the work instructions, and the work results are collected in the WMS.

In other words, the difference between the standard work system and the AI-driven work system in this test was whether standard work instructions are issued in Step (3), or whether the work instructions devised by H are issued.

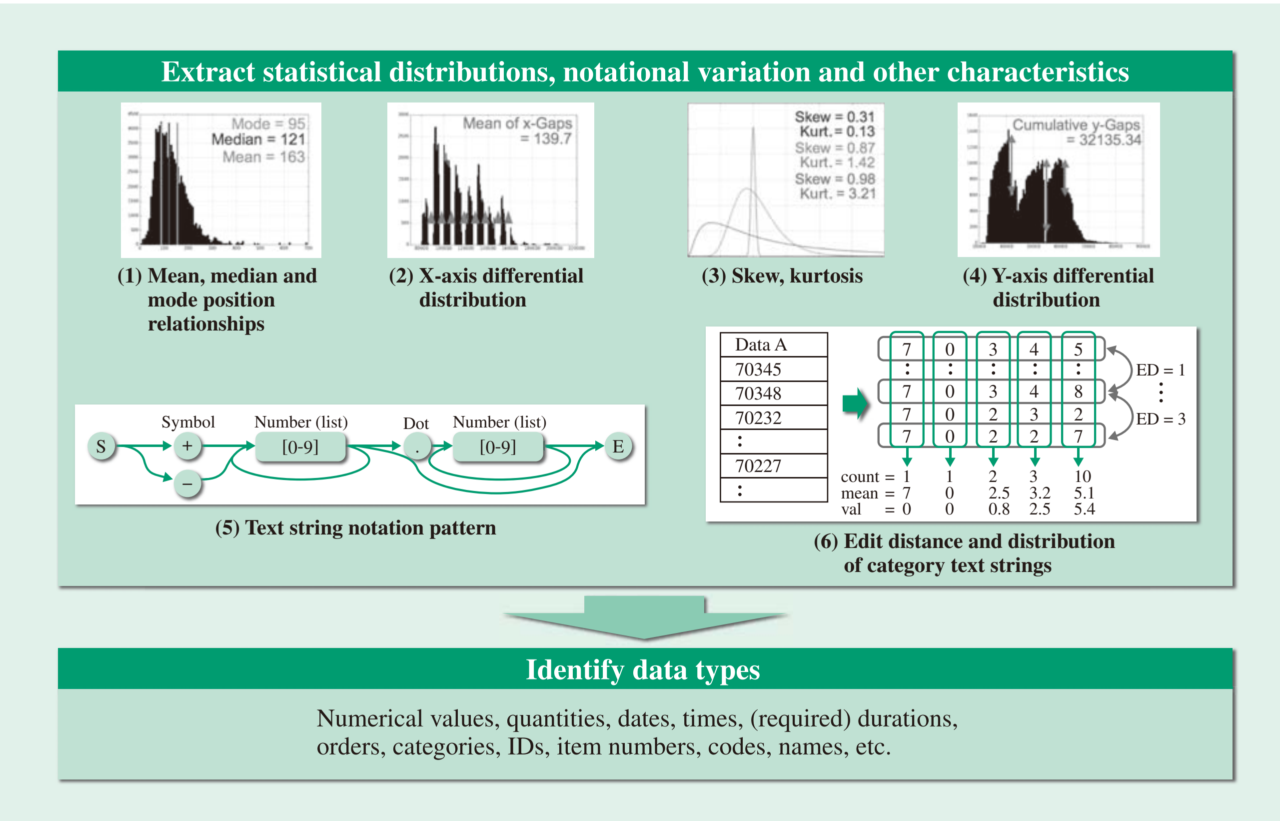

Fig. 3—Example of Automatic Identification of Data Types by H.
H combines statistical distributions of data and notational knowledge to automatically identify data types.

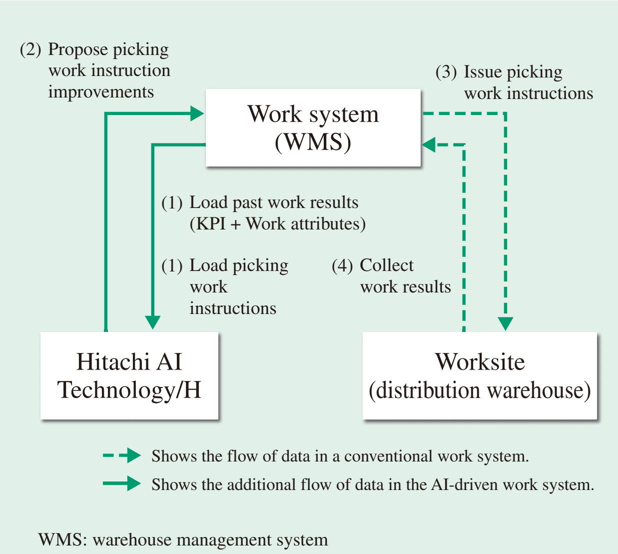

Fig. 4—Configuration of AI-driven Work System Used in Test.
The data flow of the conventional system is shown by (3) → (4). The AI-driven work system adds the new data flow shown by (1) → (2).

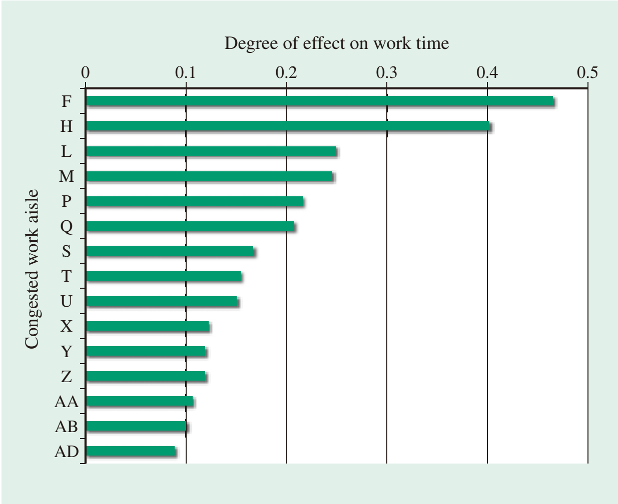

Fig. 5—Congestion and Its Effect on Work Time for Individual Work Aisles.
This histogram shows that the congestion of specific work aisles has a large effect on work time. (The work aisle names are sorted in order from greatest to least effect on work time.)

Analysis Results

The mathematical model results [the results of Step (1) in the previous section] generated by H are described below. The picking work times were set as the KPI, and the work attributes of picking work (what work was done, how much was done, and by whom, when and where) were set as the work behaviors.

Worker congestion at specific times and locations (aisles) in the warehouse was obtained as a behavioral characteristic that had a large effect on picking work time. Fig. 5 is a graph showing the degree to which each aisle's work time was affected. As it shows, the higher the value for an aisle, the more the work time tended to increase when that aisle was crowded.

Using the mathematical models, H created the day's work instructions in a way designed to reduce worker congestion at particular times and locations [Step (2) in the previous section].

Fig. 6—Histogram of Work Operations by Picking Work Time.
An overall reduction in work time was demonstrated for the trial period relative to the control period.

Demonstration Test Results

Hitachi conducted a trial of the AI-driven work system over a period of about two months in an actual distribution warehouse, and compared the work efficiency to the work efficiency during a control period. The trial was not explained to the site workers, and they worked as usual according to the picking work instructions.

Fig. 6 is a histogram of the picking work times. The horizontal axis shows the work time, and the vertical axis shows the number of work operations. The histogram bars representing work operations done during the trial period are shifted to the left relative to the bars for the operations done during the control period, indicating an overall reduction in work time. Work time was reduced an average of 8%.

CONCLUSIONS

This article has described an AI-driven work system that uses big data from work performance information to issue appropriate work instructions with an understanding of the worksite improvements and environmental changes. A demonstration test of picking work improvement was conducted in a distribution warehouse, and a work reduction of 8% was obtained as the result. In the future, Hitachi will work on further generalization of this technology, and on expanding its application into other fields such as manufacturing and distribution.

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Featured Articles

Utilization of AI in the Water Sector

Case Study of Converting Operating History Data to Values

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OVERVIEW: Global demand for water has been increasing as urban economic activity expands. A significant amount of energy is required to obtain clear water, and the reduction of this energy requirement is a major concern for water utilities. Since the qualities of raw water vary greatly in water processing systems, such systems are constructed out of combinations of multiple unit processes designed to handle each of these qualities. For this reason, there are many cases where explicit models based on physical and chemical phenomena are not sufficient for implementing appropriate operation and control, and so expectations have grown for the utilization of implicit knowledge that is inherent in the operating history data. Hitachi is deploying its Hitachi AI Technology/H technology to social infrastructure, and will continue contributing to water supplies that are both safe and reliable by proactively applying the system to water treatment systems.

INTRODUCTION

THE global water environment market shows promise and is poised to grow from 36.2 trillion yen in 2007 to 86.5 trillion yen in 2025[1]. Of this, just under 90% is comprised of water supply and sewage systems, between 40% and 50% of which is management and operation. The over 10% remaining is taken up by seawater desalination, industry, and recycling segments which are expected to grow tremendously.

Hitachi is promoting its Social Innovation Business in a bid to reform social infrastructure by fully utilizing information and communication technologies (ICT), and its provision of solutions for the water industry is playing a key role in these efforts. Specifically, by supplying products, systems, and services, Hitachi is working to provide solutions for customers' issues in areas such as water conservation, flood control, water supply and sewage systems, securing water resources (desalination and water recycling), and wastewater treatment, etc.

The biggest concern of water utilities introducing solutions such as these is how to minimize business costs while maintaining the regulated level of water quality. Most of all, along with streamlining and the reduction of manpower requirements related to the operation of water processing systems, Hitachi is giving priority to energy-saving solutions as a major focus of its research and development, since expectations for them are high.

The technology of artificial intelligence (AI) has seen new progress in recent years, and is expected to be effectively applicable to water treatment systems as well. This article introduces these efforts.

ATTEMPTS AT UTILIZING AI IN THE WATER SECTOR

Water supply and sewer systems, seawater desalination systems, and other water treatment systems differ greatly from other typical industrial systems in that fluctuations cannot be avoided in the qualities of the raw water that they process (river water, sewage, seawater, etc.). In order to deal with these changing raw water qualities, water treatment systems are comprised of multiple unit processes including sedimentation, biological treatment, membrane filtration, and others. The physicochemical phenomena that occur within these unit processes are systematized and formulated based on previous knowledge, and although this is controlled automatically to a great extent, it depends on the know-how and skill level of operators. Sometimes flexible responses are required, and it is important to provide solutions that can deal with these types of cases.

The history of attempts to apply AI is relatively long in the water sector, and even Hitachi experimented with applying the know-how of operators involved with water treatment systems and the causal relationships inherent in operating history data to operation and control in the 1990s. For instance, Hitachi applied fuzzy logic-based expert systems, which can be considered to be one type of AI in the broader sense, along with neural networks to coagulant chemical injection operations at water treatment plants, and demonstrated at the actual plant level that these technologies can be used to handle operation during both normal and abnormal situations, including high-turbidity raw water[(2), (3)].

Due to advancements in AI technology and improvements in machine power that have been occurring in recent years, the environment is in place for utilizing more massive amounts of operating history data than before. The next chapter describes in detail how Hitachi is considering the application of AI technology with a focus on the seawater desalination sector.

CASE STUDY EXAMINING DESALINATION SYSTEM OPERATION AND CONTROL

Target System: Water Desalination & Reclamation System

Fig. 1 shows an example of a representative process flow using the "water desalination & reclamation system" integrated seawater desalination and sewage treatment system. This system recycles treated sewage and other types of water while at the same time utilizing the concentrated water (brine) generated in the final filtration process as dilution water for its seawater desalination system, thereby achieving low-cost desalination that saves energy while reducing the burden placed on the environment. The system can be broadly divided into a sewage and industrial drainage recycling system and a seawater desalination system. The sewage and industrial drainage recycling system biologically treats the sewage in a membrane bioreactor (MBR), and then filters the output through a sewer system reverse osmosis (RO) membrane device to get water for reuse. With this water, it is possible to achieve water quality that is at the level of drinking water or industrial water.

The seawater desalination system filters seawater through ultrafiltration (UF) and then mixes the resulting water with the concentrated water in the sewer system RO membrane device, and then filters the output through a seawater RO membrane device to get purer water, after which the seawater RO membrane device's concentrated water is released into the ocean as drainage water. When compared with general seawater desalination systems, this system offers the following four advantages:

(1) It can effectively utilize the sewer system RO membrane device's concentrated water output from the sewage recycling system, thereby reducing the amount of drainage water.

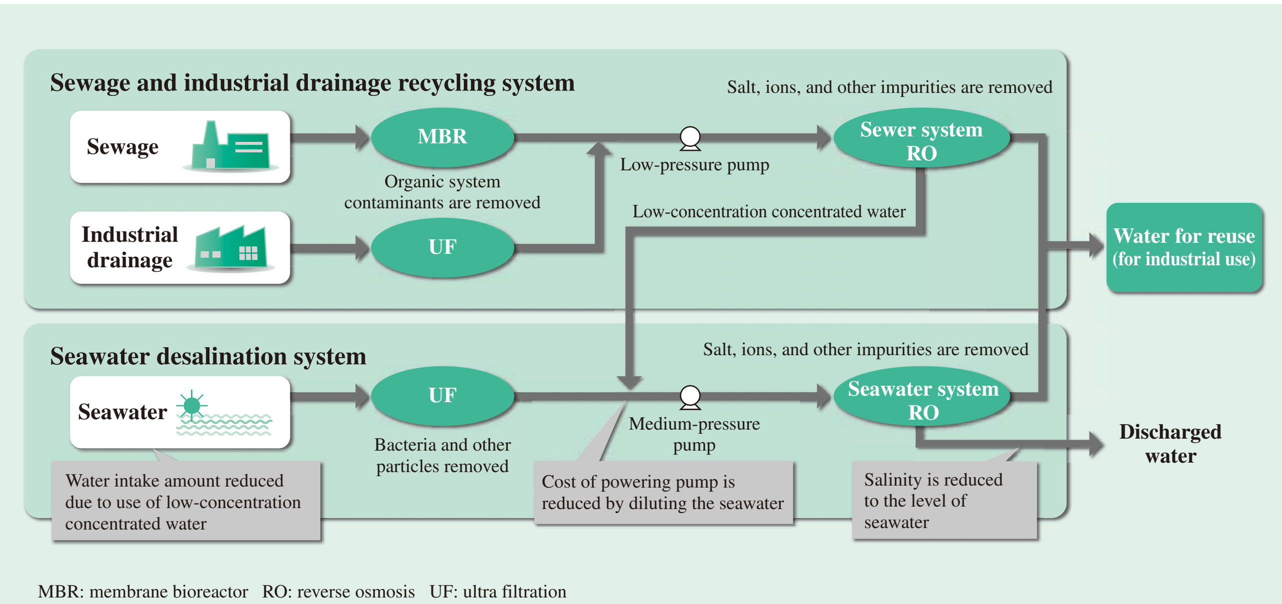

Fig. 1—Water Desalination & Reclamation System Process Flow Example.
The figure shows a representative configuration example integrating seawater desalination and the recycling of sewage and other input.

(2) It can reduce the quantity of seawater intake required to produce a given amount of production water (fresh water), thereby reducing the size of water intake facilities while at the same time lowering the cost of power required for water intake.
(3) By mixing seawater with the concentrated water from the sewer system's RO membrane device, it reduces the osmotic pressure of the treated water in the seawater system's RO membrane device, thereby lowering the cost of powering the filtration pumps necessary for desalination.
(4) The salinity of the concentrated water of the seawater system's RO membrane device is reduced to roughly the level of seawater.

On the other hand, a seawater desalination system based on RO membrane devices does suffer from the same problem of fouling, which is widely known to increase the cost of power to run the filter and to decrease equipment utilization. Although there is established knowledge regarding the mechanisms that cause fouling(4), at present, effective suppression methods still rely in part on trial and error. It is for this reason that Hitachi attempted to acquire knowledge regarding operation and control methods that can suppress fouling by applying AI technology to operating history data from the past.

Applied AI Technology: Hitachi AI Technology/H

In order to acquire new knowledge regarding the suppression of fouling, Hitachi is applying AI technology it has developed called Hitachi AI Technology/H (hereafter referred to as H). This technology offers functions that exhaustively derive and visually represent correlations from large amounts of numerical data (indices) generated by combining huge amounts of data(5). In this way, the system can extract from among the many different types of indices those that have useful correlations with objective variables, and use this information to create specific measures that are highly effective with respect to the objective variables.

By inputting and analyzing operating history data from the water desalination & reclamation system, Hitachi is attempting to come up with control methods based on new causal relationships that have been overlooked in the past. This includes, for example, the expected ability to extract candidate process parameters that correlate meaningfully with the seawater system RO membrane device's inlet pressure, which increases when fouling occurs.

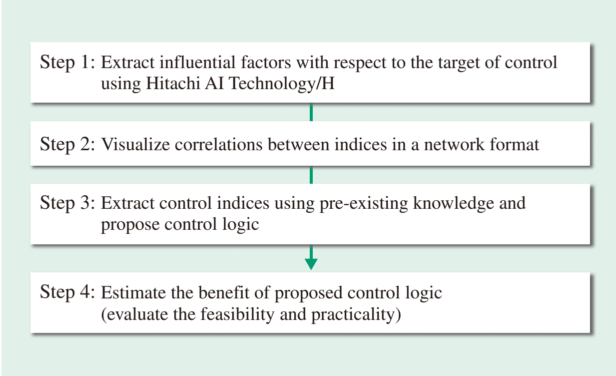

Fig. 2—Analysis Flow for Consideration of Control Logic.
H was applied in a four-step analysis.

Used Data and Analytical Methods

This analysis used operating history data acquired through "Water Plaza Kitakyushu," which was contracted to the Global Water Recycling and Reuse Solution Technology Research Association (GWSTA) as a project for the New Energy and Industrial Technology Development Organization (NEDO). Hitachi used the acquired data by selecting data at one-hour intervals without irregular operations in order to create an analytical data set comprised of one objective variable and 43 explanatory variables.

The analytical method was implemented based on the four-step process shown in Fig. 2, with the goal of extracting the influencing factors affecting inlet pressure at the seawater system RO membranes that could indicate the degree of fouling, and which could be used as a basis to consider methods of fouling suppression control. For this reason, the analysis was conducted using the seawater system RO membrane inlet pressure as the objective variable.

First, Hitachi extracted influencing factors from this data set using H, and then extracted explanatory variables (influencing factors) based on these results that had meaningful correlations with the objective variable. The relationships between the extracted influential factors and the objective variable were then visualized using a network format. Phenomenological pre-existing knowledge regarding fouling was then used to extract control indices and devise control logic. Finally, the devised control logic was used to estimate the expected fouling suppression benefit, and both feasibility and practicality were evaluated.

Analysis Results and Consideration of Control Methods

The results of the analysis using H with seawater system RO membrane inlet pressure selected as the

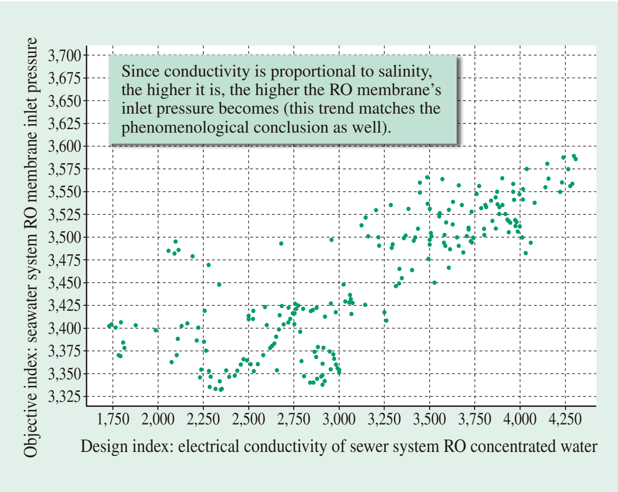

Fig. 3—Correlation Chart between Water Quality Parameters Extracted by H and Objective Variables.
The results imply a trend where the higher conductivity is, the higher RO membrane inlet pressure becomes.

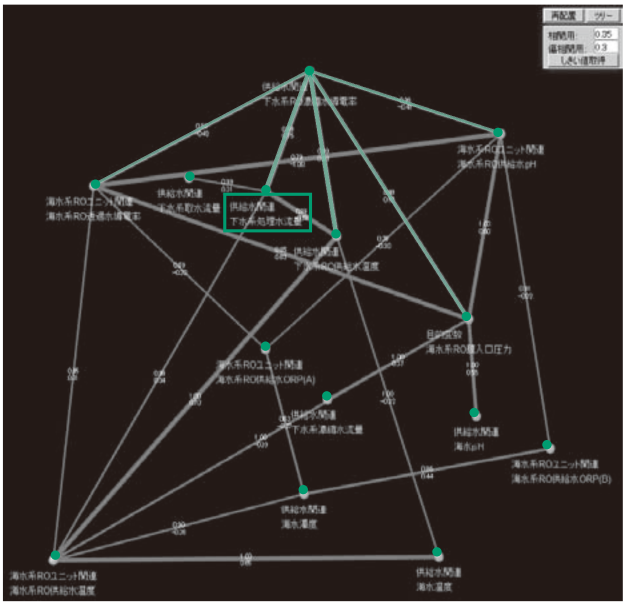

Fig. 4—Example of Visualization in Network Format of Correlation between Indices Related to Sewer System RO Membrane Concentration Water Electrical Conductivity Based on Results of H Analysis.
The controllable factors can be extracted by visualizing correlative relationships.

objective variable produced correlation coefficients with 43 explanatory variables. Of these variables, Hitachi focused on one related to the quality of the sewer system RO membrane's concentrated water, which accounted for approximately half of the water supplied to the seawater system's RO membranes. As shown in the scatter plot in Fig. 3, a direct correlation existed with respect to the objective variable. Increasing electrical conductivity is thought to be associated with increases in salinity and other factors, and the connection with the increasing inlet pressure of the seawater system's RO membranes agrees with the phenomenological analysis as well.

Furthermore, Fig. 4 shows the results of visualizing the relationships of other variables with the conductivity of the concentrated water from the sewer system's RO membranes, based on the network analysis function applied between indices. When viewed from the perspective of changing conductivity and then verifying results, the flow rate of water through the sewer system process was derived as a variable factor. The related operating history data also showed that specific increases in conductivity were triggered by changes in the flow rate of water through the process.

Of the knowledge attained from the analysis described above, the knowledge of what was seen as an effective method for suppressing increases in the inlet pressure of the seawater system's RO membranes, which was the objective variable (causal relationships between variables), can be summed up with the following inferred causal relationship: suppressing the electrical conductivity of the concentrated water from the sewer system's RO membranes will suppress the electrical conductivity of the mixture of the concentrated water from the sewer system's RO membranes with seawater, which will then suppress the osmotic pressure of the mixed water, thereby suppressing the inlet pressure (absolute value) of the seawater system's RO membranes and/or the inlet pressure's increase over time. A conceivable control plan based on this is, (1) controlling the mixed water electrical conductivity. Conceivable subordinate control plans include, (2) controlling the electrical conductivity of the sewer system RO membrane's concentrated water, (3) controlling the blend ratio, and (4) controlling the seawater intake. The specific control methods derived are shown in Fig. 5.

Hitachi estimated the suppression benefit with respect to increases in inlet pressure at the seawater system's RO membranes based on these control methods (details such as the method of estimation are omitted here). Estimates showed that operation and control that restrained the flow rate of the sewer system process for the approximately ten days of the evaluation period resulted in a total pressure increase (integrated value) of approximately 6% of the 1.47 MPa that would occur without this control, producing a figure of only 0.09 MPa. Analysis of a breakdown of this benefit showed a direct benefit

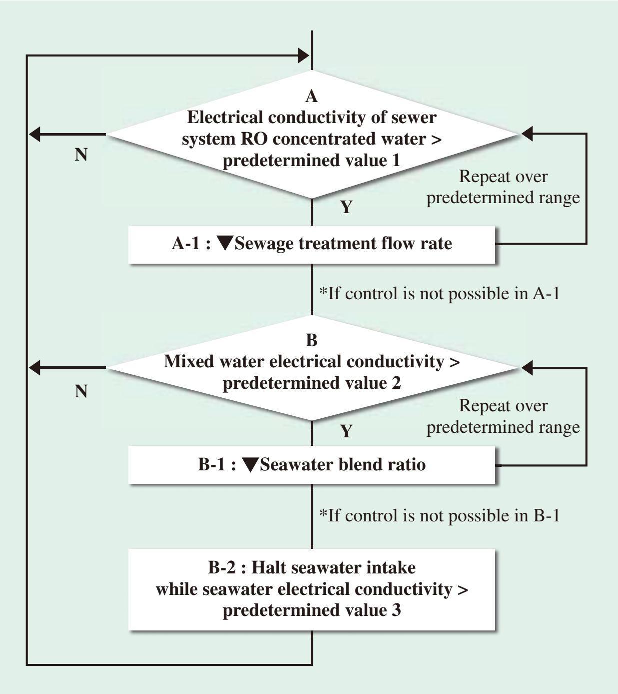

Fig. 5—Control Method Flow for Suppressing Fouling.
This control method was derived based on knowledge extracted using H.

of approximately 3% due to a reduction in osmotic pressure through lowered conductivity. The benefit of suppressing the increase in irreversibility of filtration pressure (that is, fouling suppression) was also shown to be approximately 3%.

Since the cost of powering a high-pressure pump can be considered to be proportional to the filtration pressure, this means that the cost of power is expected to be reduced by approximately 6%. At present, when it comes to the operation of seawater desalination plants, a variety of different on-site efforts have incrementally reduced operating costs a steady rate of several tenths of a percent. The proposed control methods are judged as providing a significant benefit in terms of reducing running expenses without generating additional costs or requiring new equipment or chemicals.

CONCLUSIONS

The water desalination & reclamation system is a process that integrates both sewage recycling and seawater desalination, and Hitachi is aiming to expand its adoption both domestically and internationally. By applying Hitachi AI Technology/H to the fouling problem shared by all water treatment systems that use filtration membranes, it was possible to extract the knowledge necessary for considering control methods.

In addition to seawater desalination plants, this technology can be applied to any other plant as long as past operating history data is available. Hitachi will continue working to expand the application of this technology to other plants, including water supply and sewer systems as well as other water treatment plants.

The authors would like to thank GWSTA for its permission and cooperation in providing the operating history data used for the evaluation tasks described above.

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Featured Articles

Utilization of AI in the Manufacturing Sector

Case Studies and Outlook for Linked Factories

Naohiko Irie, Dr. Eng.
Hiroto Nagayoshi
Hikaru Koyama

OVERVIEW: Utilization of the IoT is steadily advancing in the manufacturing sector. In response to this trend, Hitachi is working to provide new industry solutions based on the symbiotic autonomous decentralization concept for achieving overall optimization of activities and for creating new business by linking various systems and stakeholders together. To make new industry solutions a reality, it will be necessary to have on-site sensing, to provide an infrastructure for collecting and archiving big data, to analyze and plan countermeasures, and to give feedback to sites. This article describes advanced on-site sensing, integrated analysis of a variety of on-site data for analyzing and planning countermeasures, and the utilization of AI technology for them.

INTRODUCTION

IN recent years, utilization of the Internet of Things (IoT) has resulted in increasingly active trend towards a new evolution of the manufacturing industry. The Industrial Internet Consortium (IIC), which includes General Electric Company (GE) as one of its founders, and the government-led Industrie 4.0 were established in the USA and Germany, respectively. Both of these organizations are engaged in the formation and standardization of a new ecosystem that involves the manufacturing industry and information technology (IT) industry.

Hitachi has a track record for building large-scale control systems in diverse fields, such as energy, transportation, and water supply and sewerage, in addition to production management systems and control systems designed for various manufacturing industries including steelmaking, automobiles, and medicine. Hitachi is leveraging its knowledge of systems such as these to link diverse systems. It is advocating the "symbiotic autonomous decentralization" concept(1) to provide value gained from this to the manufacturing industry and the social infrastructure sector, and to promote new growth.

Symbiotic autonomous decentralization allows sensing of a site's various statuses (Sensing), analysis of issues and planning of countermeasures based on various collected and archived information (Thinking), and feed back of the results obtained to the site (Acting), thus enabling the optimization of value chains inside and outside of the factory.

This article describes new industry solutions that will be achieved by such symbiotic autonomous decentralization, and the machine learning technology and artificial intelligence (AI) that form the core of these systems.

LINKED FACTORIES AND NEW INDUSTRY SOLUTIONS ACHIEVED BY SYMBIOTIC AUTONOMOUS DECENTRALIZATION

Conventional optimization at production sites is limited to analysis at the individual system level and improvement of each site based on this, and the effectiveness of such improvements is becoming saturated. This is why symbiotic autonomous decentralization is being applied to achieve linked factories with a view toward optimizing activities across multiple systems and the creation of new value chains. To make this a reality, Hitachi is collecting and archiving information from other related systems in addition to the information gained from manufacturing systems, and is also further analyzing the information of other factories that are being expanded globally, planning countermeasures, and giving feedback to sites with the aim of optimizing activities overall (see Fig. 1).

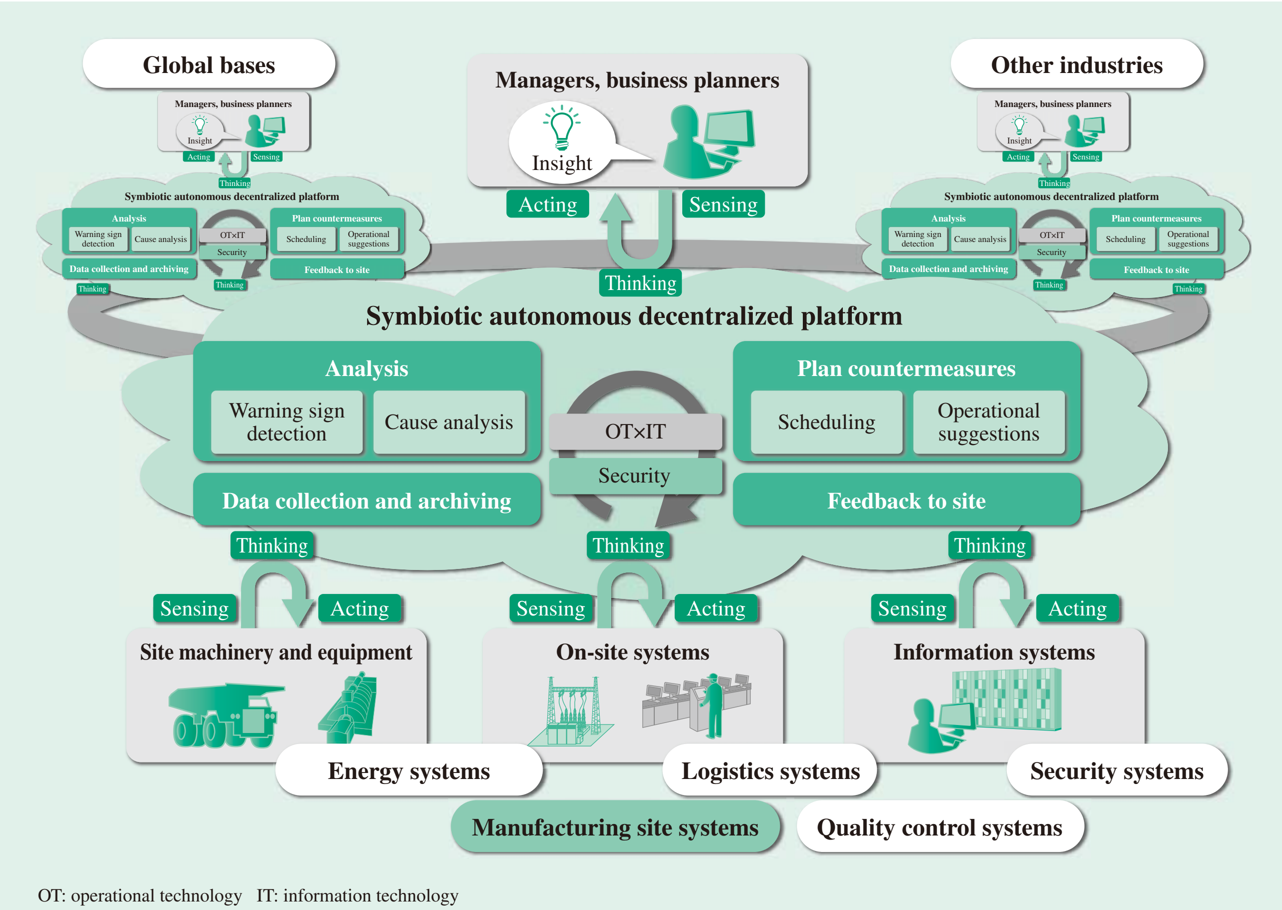

Fig. 1—Symbiotic Autonomous Decentralization Concept.
Activities can be optimized in terms of management considerations and new value chains created by collecting and archiving data from a variety of on-site systems, analyzing it and planning countermeasures, and providing information back to the site as feedback.

Depending on the information to be combined, the following types of solutions are possible.

(1) Improved energy productivity

It is predicted that energy costs will fluctuate considerably as a result of the liberalization of electric power, violent fluctuation of the crude oil price, utilization of renewable energy, and other factors, and improvements in productivity to correspond with this fluctuation will be required. For this reason, Hitachi is collecting data on the status of energy consumption in addition to detailed production site information from sources such as manufacturing execution systems (MESs) and points of production (POPs), is conducting analysis regarding the relation between energy and productivity, and is formulating energy procurement plans and production plans that will lead to the reduction of overall energy costs and peak shaving. Formulated plans are fed back to an MES and the optimum production plan is executed so that renewable energy in the factory is used effectively and energy costs are reduced.

(2) Supply Chain Management (SCM) coordination

To achieve optimum operation of factories that are expanding globally, site information from MESs and inventory control systems is analyzed, and high-precision management indicators are evaluated by a business value simulation tool that factors in the logistical status of each region. These indicators are then used to determine the optimum production plan for each site, distribution routes, stock quantities, etc., and the production plan is then executed based on these parameters. Also, since on-site information is analyzed in real time, production capacity and inventory is adjusted to accommodate unforeseen circumstances.

(3) Global quality management/improvement

Ensuring consistent quality at a high level between factories that are expanding globally not only results in cost reductions but also reduces the risk of product recalls. To accommodate this, worker actions are sensed by video analysis as well as detailed manufacturing information from MES and POP. The information that is gained is archived and analyzed so that factors that degrade quality can be extracted and countermeasures can be planned. Hitachi will introduce new analytical methods such as AI since the factors that affect quality are complex and are predicted to be wide-ranging. Obtained countermeasures will be fed back to workers using augmented reality (AR) as well as MESs and other control systems.

(4) Business Continuity Plan (BCP) support

In recent years, cyber-attacks have increased the risk of factory operations being shut down. As a result, the impact on business when an incident occurs must be minimized. Monitoring information, detected illegal access to control systems, and detected viruses, as well as detailed information collected from manufacturing systems, is collected from each base. When an incident such as a virus infection is reported by the security monitoring center, the impact of the virus itself, the scope of impact from the viewpoint of control system configuration, and the impact on business operations from the viewpoint of production status are judged as a whole, and plans, for example, for setting the system offline, eradicating the virus, or adjusting production capacity are formulated.

UTILIZING AI TO ACHIEVE NEW INDUSTRY SOLUTIONS

Technology for (1) conducting advanced sensing of site information and (2) analyzing a variety of data to plan countermeasures will be the keys to achieving the solutions described above. With regard to advanced sensing, video analysis technology is gradually being put to use in obtaining birds-eye-view like information such as people's movements, and learning functions, AI, or the like for comprehending the meaning of captured video are anticipated.

For the analysis and planning of countermeasures, it is strongly desirable to utilize AI from the viewpoint of analyzing diverse data in an inter-disciplinary manner to obtain new knowledge.

The following describes actual case studies where AI was utilized.

Application of Machine Learning to the Recognition of Work Activities

Hitachi is developing a sensing technology for recognizing the movements of factory workers and for detecting worker movements that deviate from a predetermined standard range (i.e. abnormal operation) for the purpose of improving product quality. The following describes the machine learning that forms the core of this sensing technology.

First, a motion camera is used to recognize worker movements. This allows joint position information (e.g. wrists, elbows, shoulders) to be obtained from a worker's 3D shape. Machine learning is then used based on the obtained joint position information to recognize the worker's movements.

Fig. 2 shows an overview of the abnormal operation detection algorithm. In the preprocessor, noise in the joint information is removed by smoothing, and information that is not directly related to work, such as arm length or leg length, is canceled out through normalization. The feature value extractor extracts feature values, which are pieces of information that represent movements. In the classifier, combinations of feature values are selected according to the kind of work in which abnormal operation is to be detected.

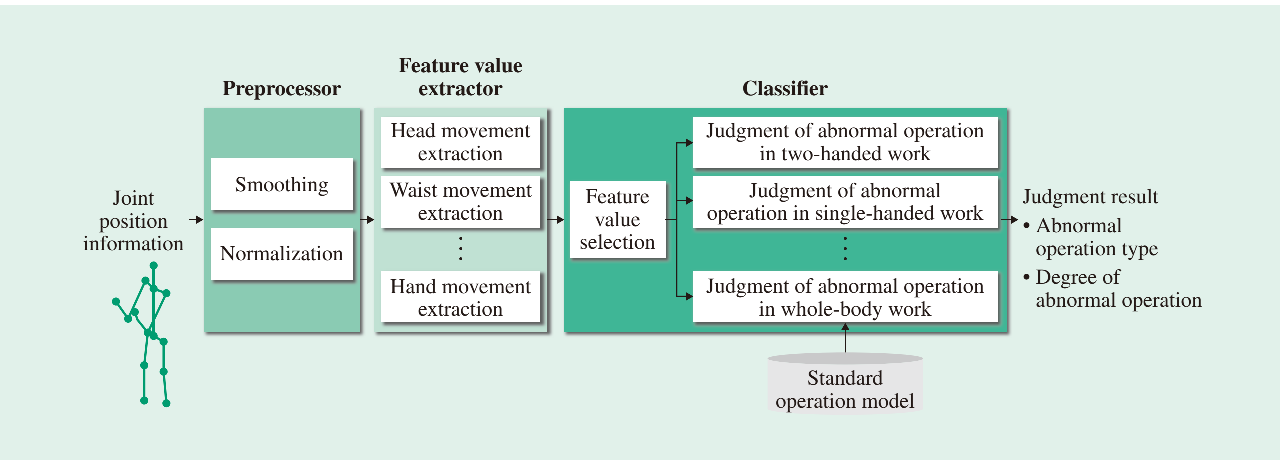

Fig. 2—Overview of the Abnormal Operation Detection Algorithm.
Machine learning is applied in each of the abnormal operation judgment processes in the classifier.

And, the presence of each abnormal operation is judged (abnormal operation judgment) by making a statistical comparison with a standard operation model.

Machine learning can be put to effective use by the feature value extractor and classifier. In particular, when there is a large amount of data, both can be optimized using a technology called “deep learning,” in other words, automatic design is now becoming possible. However, when a large amount of data cannot be obtained, prior human knowledge is used to execute optimization up to the feature value extractor and to design the combinations of feature values. With the proposed techniques, work movements were decomposed down to their motion elements based on the observation and investigation of on-site work, and those elements were taken as prior knowledge in the design of the feature value extractor and combinations. Up to this point, the process is qualitative design, which can be understood by humans.

On the other hand, with abnormal operation classification, the question is: what kind of judgments are to be made about the feature values, namely, quantitative design is required. Machine learning is generally excellent for quantitative design.

There are two types of machine learning, supervised and unsupervised. With supervised machine learning, two types of training samples are used, normal operation samples and abnormal operation samples. When a training sample is input, the abnormal operation classifier is optimized so that the correct judgment is made. However, collecting abnormal operation samples is difficult, for two reasons: there are few abnormal operations and there are countless variations.

For this reason, unsupervised training, which uses only normal operation samples to perform learning, is used. As a result, the standard operation model can be estimated as a probability distribution.

Fig. 3 shows a conceptual diagram of a probability distribution. Judgment results are expressed by single points within this distribution, and the further the judgment is from the center of the distribution, the stronger the degree of abnormal operation is going to be. For example, the center is the operation that is taken as the model, and the peripheral area around the center is a normal operation. If we move further away from the center, operations that require caution or abnormal operations can be demarcated as caution or abnormal, respectively. It has been demonstrated that operations that different from the norm can be actually extracted by using the standard operation model that has been learned.

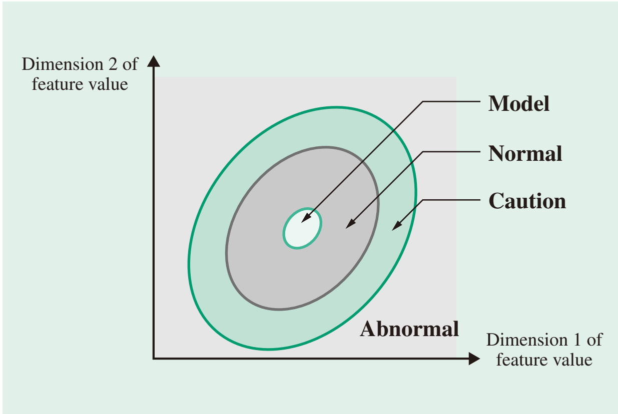

Fig. 3—Conceptual Diagram of Probability Distribution Showing a Standard Operation Model.
A standard operation model is estimated as a probability distribution. Judgment results are expressed by single points within this distribution, and the further the judgment is from the center of the distribution, the stronger the degree of deviation will be.

Utilizing AI for Analyzing Site Data

Generally, distributed control systems (DCSs), which are in charge of the direct control of facilities, and MESs, which are in charge of production and quality management, are installed at productions sites. These systems collect enormous volumes of data relating to manufacturing facilities, production processes, and product quality every day. This data is mainly archived as numerical values and have been analyzed and utilized by statistical quality control techniques up to now. However, the rapid increase in the volume of archived data has made it humanly difficult to search for relationships between that data and key performance indicators (KPIs), such as quality and non-defective product ratio at production sites, and identify causes.

For this reason, Hitachi has been implementing analysis using Hitachi AI Technology/H (hereafter referred to as H), its own proprietary artificial intelligence technology[2]. When a KPI and data potentially related to the KPI (explanatory parameters) are input, H automatically generates feature values from the explanatory parameters, comprehensively calculates the correlation with KPI, and outputs statistically significant feature values (see Fig. 4). The characteristic of H here is that it generates combinations of explanatory parameters as feature values.

For example, with product manufacturing in a discrete system, assume manufacturing equipment X and Y, for which the processing values fall roughly within the ranges 1.0 to 4.0 and 5.0 to 10.0, respectively.

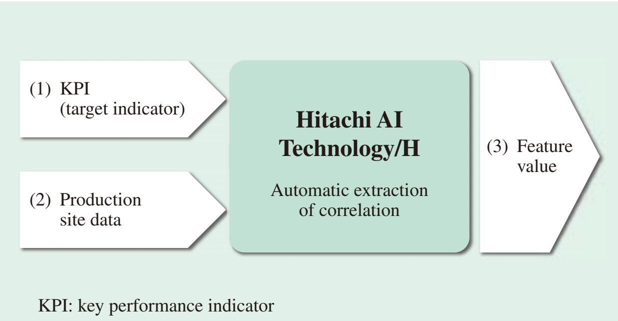

Fig. 4—Diagram Illustrating Input/Output of H.
When (1) KPI and (2) KPI-related production site data are input, then (3) multiple correlated feature values are output.

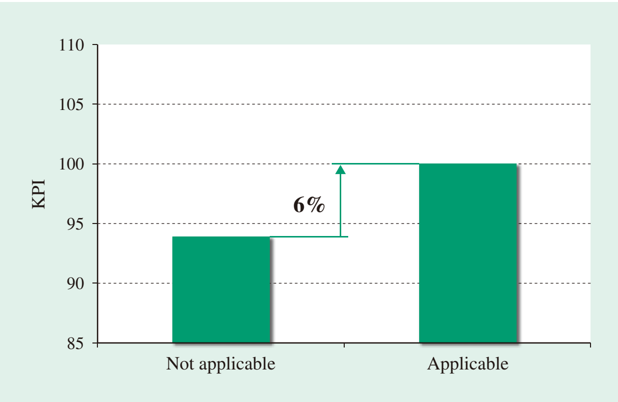

Fig. 5—Example of Results Discovered by H (Relative Values taking Applicable to be 100).
"Applicable" indicates a group that satisfies the discovered feature values, and "Not applicable" shows a group that does not.

When the data from manufacturing equipment X and Y and the KPI (here: production volume) are input to H, an enormous volume of feature values is generated, the correlation with KPI is comprehensively analyzed, and statistically significant feature values are extracted.

Fig. 5 shows an example of the analysis. The product group that satisfies the feature value (X: 1.0 to 1.5 and Y: 9.5 to 10.0) discovered by H is shown as Applicable, and the average value of that KPI (production volume) was 100 (relative value). Whereas, the product group that does not satisfy the feature value (where either X: 1.0 to 1.5 or Y: 9.5 to 10.0 deviate outside this range) is shown as "Not applicable," and the average value of that KPI (production volume) is 94. It can be seen that there is a difference of 6% in production volume between when product manufacturing satisfies the feature value and when it does not. In other words, an improvement in production volume of 6% can be anticipated by controlling manufacturing equipment X and Y so that the feature value is satisfied.

With production in a continuous system, each piece of equipment and each process generally has designed control values, and as long as these control values fall within the control ranges at each step of production there is no problem. However, production processes fluctuate on a daily basis, and appropriate operating conditions for the production processes keep changing because of the wearing and degradation of parts, and before and after facility maintenance. Furthermore, operating conditions and control conditions must be reviewed when production is switched over to new products. H is effective for discovering the appropriate operating conditions for responding to changes such as these and for gaining new awareness based on large amounts of data. For example, in processes that are comprised of a total of ten steps, combinations of data across processing in the first and third steps can be analyzed. The ability to analyze a wide breadth of data across steps and processes in this way is an advantage of H, and this can be used as an opportunity to make workers and managers at production sites, who tend to focus on the management of facilities and processes, more aware.

CONCLUSIONS

This article described linked factories and new industry solutions based on the symbiotic autonomous decentralization concept, as well as the utilization of AI that will be key in achieving this.

Although the article dealt mainly with utilization of AI geared towards improving quality, in the future, Hitachi intends to increase the number of case studies where AI is utilized in other solutions, and to apply AI technology to production and engineering sites while advancing the verification of its effectiveness with a view to supporting manufacturing innovation.

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Featured Articles

Advanced Research into AI

Debating Artificial Intelligence

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Misa Sato
Toshihiko Yanase, Ph.D.
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OVERVIEW: This article describes a debating AI that can debate decision-making matters with humans. Given a discussion issue, the system outputs short argument scripts based on multiple viewpoints. The argument scripts are summarized information with a length of about 10 sentences, which is composed of evidence, analytics, and opinions obtained from large amounts of document data. They can be thought of as a consolidated essence for decision-making. The debating AI can automatically investigate business opportunities and risks on a regular basis from multiple points of view. With the aim of creating an enterprise IT system that drives innovation in organizations, Hitachi is accelerating the development of the debating AI through open collaborative creation.

INTRODUCTION

HITACHI has been working on developing a debating artificial intelligence (AI) that can debate decision-making matters with humans. Given a discussion issue and a stance, the system provides useful information for making decisions, such as grounds and counterexamples. For the issue "Should we use electric vehicles as office cars?" for example, it answers "Electric vehicles are environmentally conscious" when asked for a positive stance, or "Electric vehicles are expensive" when asked for a negative stance. Next, it provides evidential information extracted from news articles, white papers, research reports, and other material.

Fig. 1 shows an overview of the debating AI. On the present computing platform, it composes three opinions within 80 seconds. Each generated opinion includes a different viewpoint and is based on the analysis of about 10 million English news articles. The purpose of using the AI system is to explore discussion issues by "debating" with humans, and to induce evidence-based decisions.

The rest of this section explains the background of the development. Hitachi assumes that data analytics technologies will evolve through the three phases illustrated in Fig. 2. While the second phase, optimization using big data, has been well-studied, the focus here is on the third phase. In today's fast-moving world, companies need to continuously produce innovative services and value. R. G. McGrath, a professor at Columbia Business School, argues that competitive advantage is becoming harder to maintain. In an era of transient competitive advantage, companies need to build and manage multiple innovations to keep exploiting transient advantages(1). She also makes the case that the process of developing innovations should not be experimental, but central to corporate strategy. In such an environment, strategic planning should take on a greater importance within enterprises. Therefore, there is value in being able automatically to find business opportunities and risks on a regular basis from multiple points of view through integrating various information resources, such as news articles, company databases, user reviews, white papers, and research reports.

Hitachi has been developing the debating AI with the aim of creating an enterprise IT system that automatically investigates business opportunities and risks. Believing it important to provide counterexamples that represent the risks associated with decisions, the focus is on techniques for composing counterarguments.

The following section describes the value provided by the debating AI. Subsequent sections describe an evidence recognition technique and social implementation through open collaborative creation.

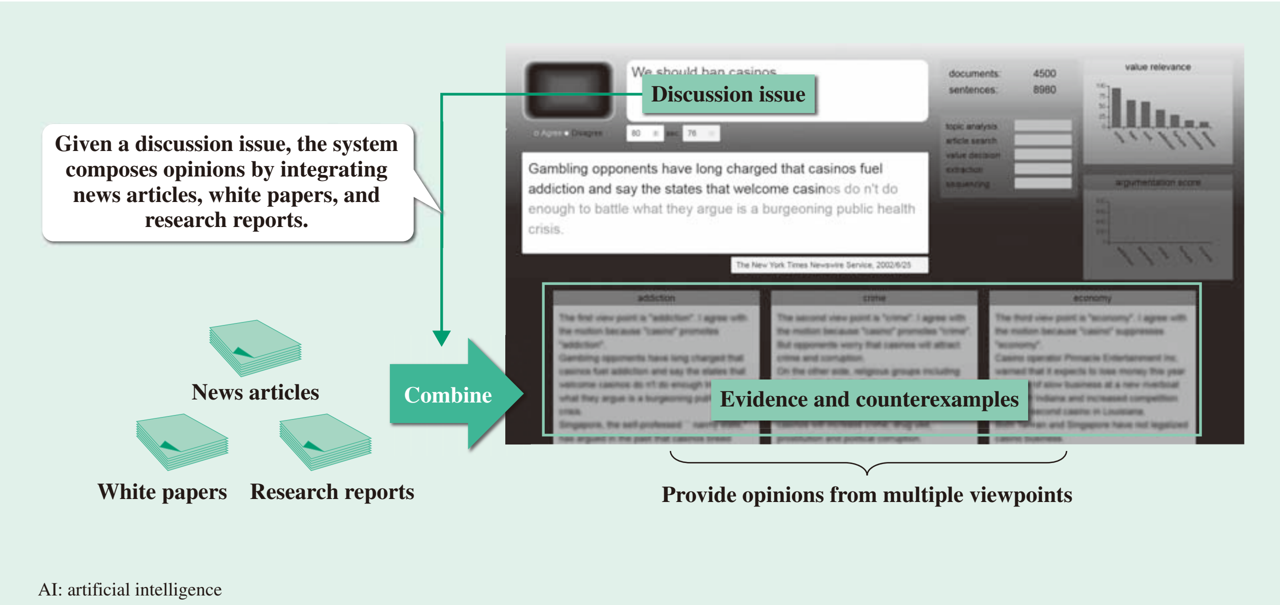

Fig. 1—Overview of Debating AI.
The screenshot is from the interface of the debating AI. When a discussion issue "We should ban casinos" is given, it composes opinions by integrating various information resources. The above example illustrates that the system provides opinions based on three viewpoints: addiction, crime, and economy.

VALUE PROVIDED BY DEBATING AI

As shown in Fig. 1, the debating AI generates short scripts that describe opinions for a given discussion issue. The generated short scripts are called "arguments." The definition is as follows.

Argument: A summarized text, consisting of about 10 sentences, which is composed of evidence, analytics, and opinions from large amounts of document data.

The authors estimate that reading a generated argument is roughly equivalent to reading 400 sentences obtained by querying the discussion topic using a traditional text search technique. The intention is that the arguments will provide a consolidated summary of the material for decision-making.

The arguments are likely to be of most use when people need to read large amounts of document data to investigate a decision. Typical cases are as follows.

(1) Analysis of facilities and policies

Consider the case of investigating past examples prior to building a new casino. It would be desirable to gather information from various accessible resources

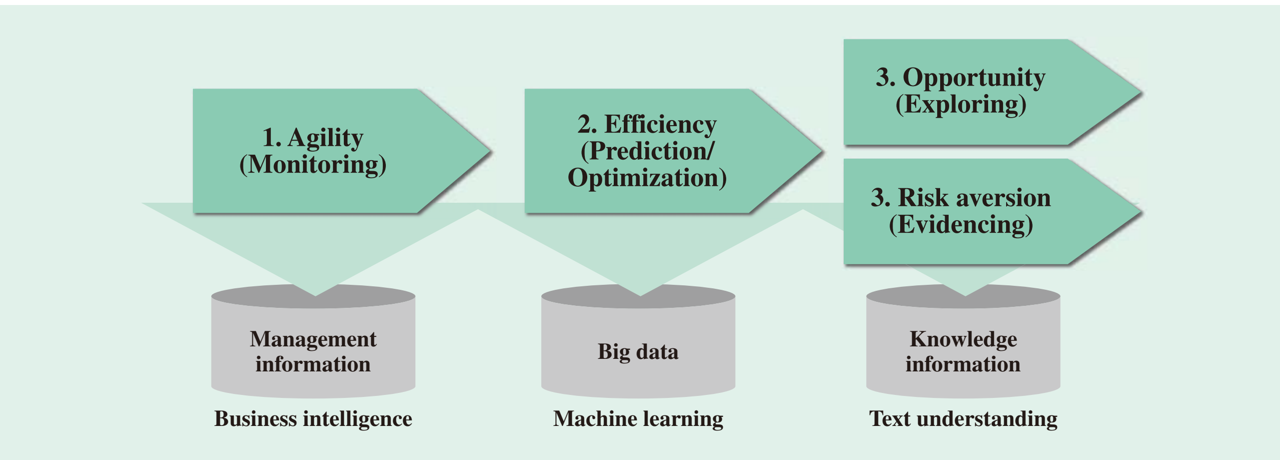

Fig. 2—Values of Data Analytics.
While past studies have dealt with the second phase of optimization using big data, it will also be important to automatically investigate business opportunities and risks on a regular basis.

that describe similar cases from the past about matters such as how much employment was actually created, how the crime rate changed, whether the economy improved or worsened, and the response of residents in the years following the opening of a new casino. Such information would be available in white papers and news articles. In general, investigations of this nature are required whenever companies introduce new facilities or policies.

(2) Analysis of companies or organizations

It can be useful for investigating information about customers or business partners, such as what kind of products a company has launched in the past, the public response to the product, what kinds of problems the company is facing, and whether the company is engaged in any leading-edge programs with foreign governments. In general, numerical data such as profit margins, growth rates, and stock prices are the most important. However, when people have to make important decisions, they also tend to refer to textual information of the sort described above. In some cases, a decision may be changed based on negative evidence despite numerical data supporting the decision. Requirements of this nature tend to occur when making investment decisions or selecting a business partner.

(3) Analysis of locations or markets

When a company plans to expand its business in a new location, it needs to find out about any local security risks in the area, economic trends, the state of social infrastructure, and information about social problems. It also needs up-to-date information about residential interests and important local government plans. While numerical data is available on things like population changes and industrial structure, this can be complemented by textual information.

CORE TECHNICAL COMPONENTS OF DEBATING AI

The debating AI consists of the following technical components[(2), (3)].

(1) Understanding user issues

(2) Investigating issues using large amounts of text documents

(a) Identifying relevant factors (such as environment or cost), here referred to as “aspects”

(b) Retrieving grounds or counterexamples

(3) Providing argument scripts in a persuasive manner

The key to the debating AI is the quality of grounds and counterexamples retrieved from large amounts of text data. This section describes the evidence recognition technique used to retrieve this information (2-b).

In this step, the AI recognizes whether a retrieved sentence represents evidence for a predefined claim or not. The claim consists of an argument topic and an argument aspect. For example, that “electric cars” are good for “the environment” is a claim. Evidence comes in two types. Positive evidence is referred to as “grounds” and negative evidence as “counterexamples.” While grounds support the claim, counterexamples argue against it.

In trying to find counterexamples, it is important to accurately recognize whether a sentence is a ground or a counterexample. When composing arguments about electric cars, for example, a traditional text search would find a lot of positive evidence such as their producing zero emissions, which makes them good for the environment. On the other hand, a small amount of negative evidence, such as a manufacturing process imposing a large burden on the environment, is likely to be overlooked. However, these counterexamples are important because they can have a significant influence on decision-making. In order to find this important but infrequent evidence, it is necessary to recognize whether a sentence contains positive or negative evidence.

The recognition technique used for this purpose is as follows. In practical situations, many sentences have a more complicated syntax structure than, say, “electric cars are good for the environment.” Therefore, the authors constructed a technique to interpret sentences by folding partial linguistic structures into two hierarchical feature structures. The recognition steps are as follows.

(1) Extract partial relations between contextual words as the first feature of the sentence

(2) Combine them into relations of relations as the second feature of the sentence

(3) Calculate a score for the sentence using machine learning

In the example shown in Fig. 3, step (1) extracts five partial linguistic structures, such as whether a subject of a causal verb refers to the topic or the aspect, or whether a specific word is present that reverses the meaning (positive or negative) of the text. In step (3), machine learning can achieve more accurate classification in a broader range of cases than manually created rules.

The debating AI achieved 77-point accuracy in evidence recognition. Future work will include

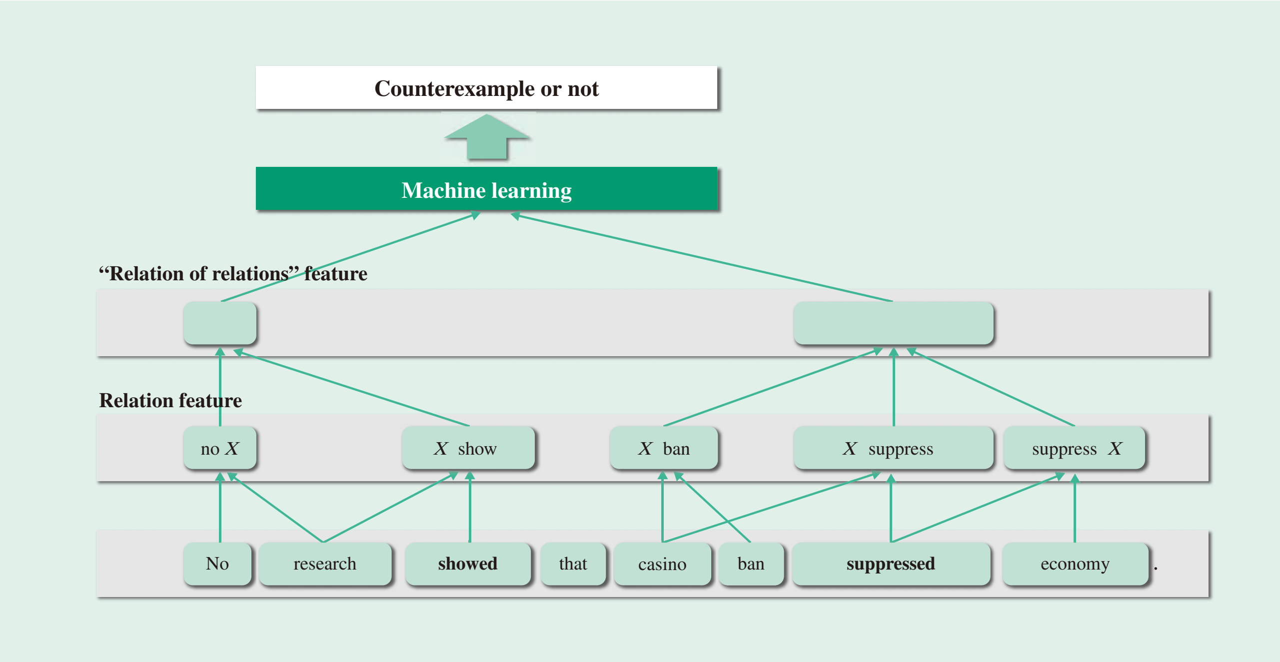

Fig. 3—Evidence Recognition Technique.
The technique extracts linguistic features from a given text. The technique recognizes whether a sentence is evidence or not by extracting information about causal effects, positive and negative factors, and sources, and then calculates a score using a machine learning technique.

improving the accuracy by using more complicated models of machine learning.

SOCIAL IMPLEMENTATION THROUGH OPEN COLLABORATIVE CREATION

The goal of the debating AI is to automatically investigate business opportunities and risks on a regular basis by integrating various information resources. To implement the vision, it is necessary to combine theories of corporate strategy, managers' experiences, and a novel style of providing textual content. For example, it is possible that the form of news articles might change in the future. While news articles currently assume humans readers, in the future AIs may read news articles to support enterprise decision-making. Hitachi plans to start open collaborative creation in which various experts collaborate with one another.

CONCLUSIONS

This article has described an overview of the debating AI. Society has high expectations for AI technology. However, the actual level of the technology has yet to reach these expectations. To implement the vision, Hitachi will continue to improve the accuracy of the arguments that the debating AI provides. Hitachi will also work to build open collaborative creation relationships.

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Featured Articles

Advanced Research into AI

Ising Computer

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OVERVIEW: A major challenge facing AI is the enormous computational load it imposes, of which combinational optimization makes up a large part. Hitachi has devised a computing technology based on a new paradigm that is capable of solving combinatorial optimization problems efficiently using an Ising model, and has built a prototype 20k-spin Ising computer chip using a 65-nm process. An Ising chip represents a combinatorial optimization problem by mapping it onto an Ising model based on the spin of magnetic materials, and solves the problem by taking advantage of the system's natural tendency to converge. This convergence is implemented using a CMOS circuit. In addition to demonstrating its ability to solve combinatorial optimization problems and operate at 100 MHz, the prototype chip has been demonstrated to consume approximately 1,800 times less power to obtain the solution than would be required by a conventional computer with a von Neumann architecture.

INTRODUCTION

A major challenge facing artificial intelligence (AI) is the enormous computational load it imposes. This is because, in contrast to the conventional practice of mechanical execution of an algorithm defined by hand in the form of a program, AI learns automatically from data and uses this as the basis for realtime decision-making. Combinational optimization forms a large part of the heavy processing load associated with both the learning and decision-making steps. When an AI learns from data, for example, it needs to optimize the model parameters in order to minimize error. Similarly, when subsequently using the model for decision-making, the AI needs to optimize the decision parameters in order to maximize a performance function. In both cases, this combinational optimization requires finding the parameters that best satisfy the conditions out of a large number of possibilities, a problem that is difficult to solve efficiently using conventional computing practices.

Accordingly, Hitachi has developed a new concept in computing that can efficiently solve combinatorial optimization problems by using an Ising model, a statistical mechanics model that mimics the behavior of a magnetic material. Tests conducted on a prototype demonstrated that combinational optimization problems could be solved with an efficiency three orders of magnitude or greater compared to conventional computing practices. This article describes this Ising computer.

COMBINATIONAL OPTIMIZATION PROBLEMS

A combinatorial optimization problem involves finding a solution that maximizes (or minimizes) a performance index under given conditions. A characteristic of combinatorial optimization problems is that the number of candidate solutions increases explosively the greater the number of parameters that define the problem. As the number of parameters in AI computation is increasing, the number of candidate solutions to combinational optimization problems is expected to increase dramatically in the future.

The solution of combinatorial optimization problems using existing computing techniques involves calculating the performance index for all parameter combinations and then selecting the combination that results in the minimum performance index [see Fig. 1 (a)]. Because the number of combinations for a problem with n parameters is 2^n, a 1,000 parameter problem requires the performance indices to be calculated for 2^{1000} parameter combinations (roughly

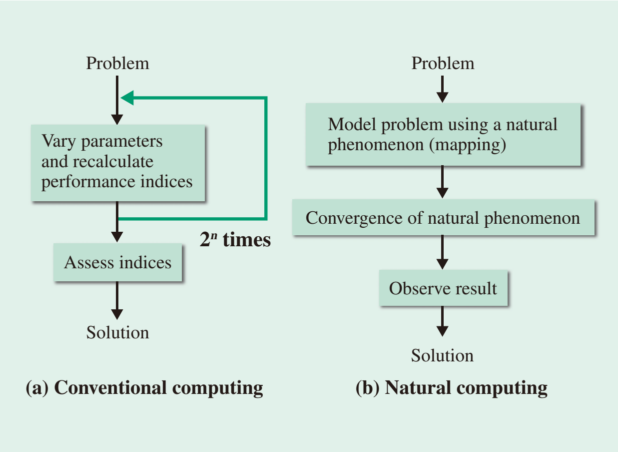


Fig. 1—Procedure for Solving Optimization Problems.
Conventional practice has been to repeatedly calculate all performance indices and assess the values obtained. Natural computing, in contrast, reduces the number of calculation iterations by taking advantage of the tendency for a natural system to converge.

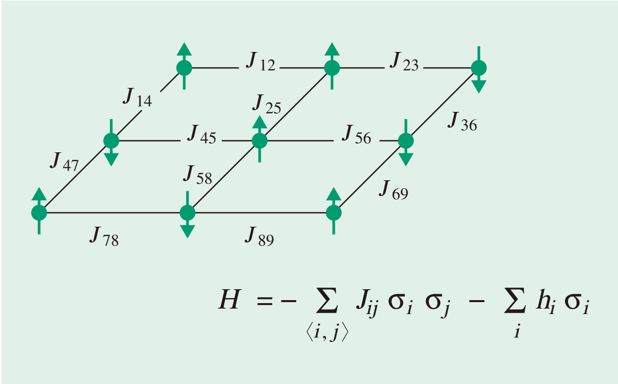


Fig. 2—Ising Model.
An Ising model represents the properties of ferromagnetic materials in terms of statistical mechanics. It consists of a lattice of points (spins), each of which can occupy one of two orientation states, and reaches stability when the energy H is at a minimum, taking account of interactions between adjacent points in the lattice.

10^{300}). Calculating performance indices for such a huge number of combinations is impossible in practice.

What is actually done in situations like this is that, rather than calculating the performance indices for all combinations, an approximation algorithm is used to obtain a roughly optimal combination of parameters. Unfortunately, as the number of parameters increases, finding even an approximate solution becomes difficult. Furthermore, semiconductor scaling has enabled the computational methods used in the past to deal with larger problems by improving the performance of the central processing units (CPUs) used for the calculations. However, progress on semiconductor scaling appears to have plateaued in recent years, and in practice there have been no further improvements in CPU clock speeds since the late 2000s. In other words, optimizing the larger and more complex systems of the future will require new computing techniques that do not rely on the practices of the past.

NEW COMPUTING CONCEPT

Conventional computers break problems down into a collection of programs (procedures) and solve the problems by executing these programs sequentially. As noted above, however, the difficulty with solving combinatorial optimization problems is the explosive growth in the number of procedures required for program execution. Accordingly, Hitachi has proposed adopting a different computing concept, namely natural computing.

Fig. 1 (b) shows the calculation procedure using natural computing. Natural computing works by using a natural phenomenon to model the problem to be solved (mapping) and taking advantage of the convergence inherent in this natural phenomenon to converge on the solution to the problem. The problem can then be solved by observing this converged result.

An Ising model, meanwhile, represents the behavior of magnetic spin in a magnetic material in terms of statistical mechanics and has been proposed as a suitable technique for solving combinatorial optimization problems. Fig. 2 shows an Ising model. The properties of a magnetic material are determined by magnetic spins, which can be oriented up or down. An Ising model is expressed in terms of the individual spin states (σ_i), the interaction coefficients (J_{ij}) that represent the strength of the interactions between different pairs of spin states, and the external magnetic coefficients (h_i) that represent the strength of the external magnetic field. The figure also includes the equation for the energy (H) of the Ising model. One property of an Ising model is that the spins shift to the states that minimize this energy, ultimately leaving the model in this minimum state. If a combinatorial optimization problem is mapped onto an Ising model in such a way that its performance index corresponds to the model's energy, the Ising model is allowed to converge so that the spin states adopt the minimum-energy configuration. This is equivalent to obtaining the combination of parameters that minimizes the performance index of the original optimization problem.

CMOS ISING COMPUTING

While computing methods that use superconductors to replicate an Ising model have been proposed in the past, Hitachi has proposed using a complementary metal oxide semiconductor (CMOS) circuit for this purpose. The benefits of using a CMOS circuit are simpler manufacturing, greater scalability, and ease of use.

The updating of actual spin values is performed in accordance with the following rule:

New spin value = +1 (if $a > b$)
−1 (if $a < b$)
+/−1 (if $a = b$)

Here, a is the number of cases in which (adjacent spin value, interaction coefficient) is (+1, +1) or (−1, −1) and b is the number of cases in which it is (+1, −1) or (−1, +1). These interactions cause the energy of the Ising model to fall, following the energy contours (landscape) like that shown in Fig. 3. However, because the energy profile includes peaks and valleys (as shown in the figure), this interaction process operating on its own has the potential to leave the model trapped in a local minimum in a region that is not the overall minimum for the system.

To escape such local minima, the spin states are randomly perturbed. This causes the system to randomly switch to an unrelated state, as indicated by the dotted line in Fig. 3. Collectively, these two processes are called CMOS annealing. By using them, it is possible to identify the state with the lowest energy that can be found.

In practice, this use of random numbers means that the solution obtained is not necessarily the optimal one. However, when the computing technique is used for parameter optimization, it is likely that it will not matter if the results obtained are not always optimal. In situations where this computing technique might be deployed, it is possible to anticipate applications where providing a theoretical guarantee that it will produce solutions with 99% or better accuracy, 90% or more of the time, for example, will mean that these solutions can be relied on to not cause any problems for the system.

PROTOTYPE COMPUTER

A prototype Ising chip was manufactured using a 65-nm CMOS process to test the proposed Ising computing technique. An Ising node was then built with this Ising chip and its ability to solve optimization problems was demonstrated. This section describes the prototype and the results of its use to solve optimization problems.

CMOS Ising Chip

The prototype Ising chip was fabricated using a 65-nm semiconductor CMOS process. Fig. 4 shows a photograph of the chip. The 3-mm × 4-mm chip can hold 20,000 spin circuits, each occupying an area of 11.27 µm × 23.94 µm ≈ 270 µm^2. The interface circuit used for reading and writing the spin states and interaction coefficients operates at 100 MHz, as does the interaction process for updating spin values.

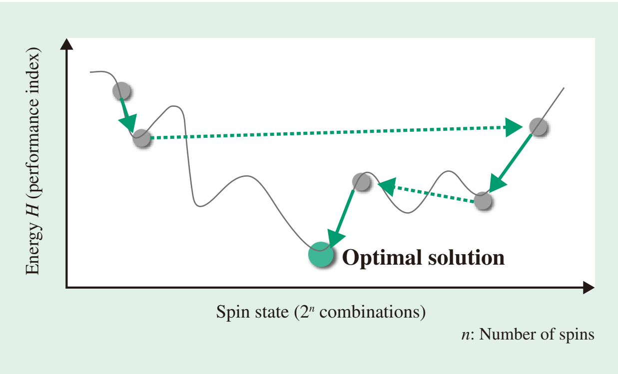


Fig. 3—Ising Model Energy Landscape and CMOS Annealing.
In Ising computing, although the energy falls in accordance with the energy contours (landscape) due to the interactions between spins (solid arrows), there is a potential for it to get trapped at a local minimum. This can be prevented by inputting random numbers to deliberately invert spin values (dotted arrows). Called CMOS annealing, this operation obtains a solution with low energy.

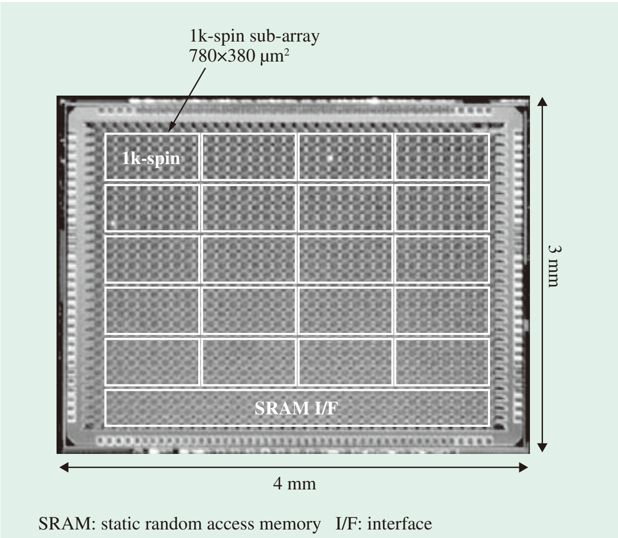
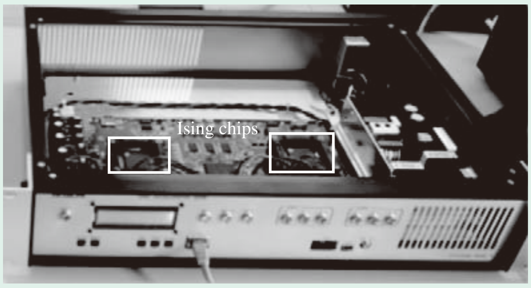


Fig. 4—Ising Chip Photograph.
The chip has 20,000 spin circuits in a 3-mm × 4-mm = 12-mm^2 area.



PC: personal computer LAN: local area network

Fig. 5—Ising Node.
The photograph shows an Ising node with two Ising chips. The Ising node is connected to a server or PC via a LAN cable and can be used to solve combinatorial optimization problems.

The Ising chip implements a three-dimensional Ising model on a two-dimensional memory lattice. Semiconductor chips achieve a high level of integration by using a two-dimensional layout, and the prototype Ising chip also takes advantage of this to achieve a high level of integration, meaning that it can implement a large number of spin circuits.

Ising Computer

Fig. 5 shows a prototype Ising node fitted with two Ising chips.

The Ising node can be accessed from a personal computer (PC) or server via a local area network (LAN) to input optimization problems and obtain the solutions.

Fig. 6 shows a comparison of the energies required to solve a randomly generated maximum cut problem using the Ising node and using conventional computing. The horizontal axis represents the number of spins in the Ising model. The conventional computing technique used for comparison consisted of executing the SG3 approximation algorithm (which has been optimized for solving maximum cut problems) on a general-purpose CPU. The same problems were solved using both techniques and a comparison was made of the energies consumed in obtaining a solution to an equivalent level of accuracy in each case. Because the SG3 approximation algorithm used for the comparison had been optimized for maximum cut problems that use Ising models, there was no significant difference between the times taken by the two techniques for a problem with 20,000 spins. The amount of energy consumed in solving a 20,000-spin problem, however, was approximately 1,800 times less using the new technique.

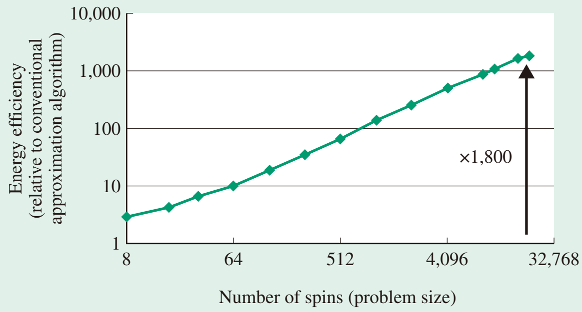


Fig. 6—Energy Efficiency of Solving Randomly Generated Maximum Cut Problem.
The graph shows the relative energy efficiency of the calculation compared to an approximation algorithm executing on a general-purpose CPU. The energy efficiency improves as the size (number of spins) of the problem increases, with the new technique being approximately 1,800 times more efficient for a 20,000-spin problem.

CONCLUSIONS

Table 1 shows a comparison with previous Ising computers. Use of a CMOS semiconductor circuit means the computer can operate at room temperature. This means low power consumption for cooling is achieved. While the prototype computer has approximately 20,000 spin circuits, it will be possible to replicate even larger Ising models by using higher levels of semiconductor process scaling.

Furthermore, because the current system uses digital values to calculate spin interactions, it is easy to link a number of chips together and expand the size by using multiple chips.

Although it is anticipated that this use of digital circuits will result in lower solution accuracy

TABLE 1. Comparison with Existing Ising Computers
The new technique is significant in engineering terms because of its suitability for real-world applications, being superior to an existing Ising computer that uses superconductors in terms of things like ease-of-use and scalability.

	New technique	Existing technique
Approach	Ising computing	
	Semiconductor (CMOS)	Superconductor
Operating temperature	Room temperature	20 mK
Power consumption	0.05 W	15,000 W (including cooling)
Scalability (number of spins)	20,000 (65 nm) Can be scaled up by using higher level of scaling	512
Computation time	Milliseconds	Milliseconds (fast in principle)

than can be achieved by previous systems based on superconductors, it is adequate for use in the optimization of actual social systems because it is able to solve problems in practice. Moreover, the approach described here of using a semiconductor is significant in engineering terms for reasons that include ease-of-use and scalability.

This article has described how the prototype Ising computer successfully solved a maximum cut problem, which is a form of combinatorial optimization problem. As it is known that this problem can be translated mathematically into other combinatorial optimization problems, this indicates that the technique has potential for use in actual system optimization. Furthermore, energy measurements demonstrated that the technique can reduce consumption by three or more orders of magnitude compared to conventional computing techniques.

In the future, Hitachi sees the Ising computer as a highly efficient technology for solving combinational optimization problems in AI applications, which are expected to impose increasing processing loads in the future.

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