Struggle against Difficulties in Artificial Intelligence

Masami Yamasaki, Dr. Sc.

OVERVIEW: The latter part of the 20th century saw various types of computer-based automation technology being applied in industrial processes and incorporated into the products and services supplied to society, bringing numerous benefits such as lower costs and greater added value. However, what also became apparent along with these advances was the inherent difficulty of achieving the level of flexibility that can easily be reached by human beings, such as accommodating changes in the desires of the user or the circumstances under which these products and services are used. With the aim of clarifying and overcoming this difference between humans and automated machines, the research and development departments of Hitachi conduct research into artificial intelligence that can simulate human intelligence and are following various different approaches to this topic.

INTRODUCTION

FROM the dawn of artificial intelligence research until the present day, the subject has gone through repeated cycles of great expectations followed by disillusionment during which time an understanding has built up about what it can and cannot achieve.

In reviewing this history, this article will catalog the numerous common difficulties faced by researchers and will use research into natural language processing and into behavior and spatial recognition as examples of practical approaches for dealing with these difficulties. After going back

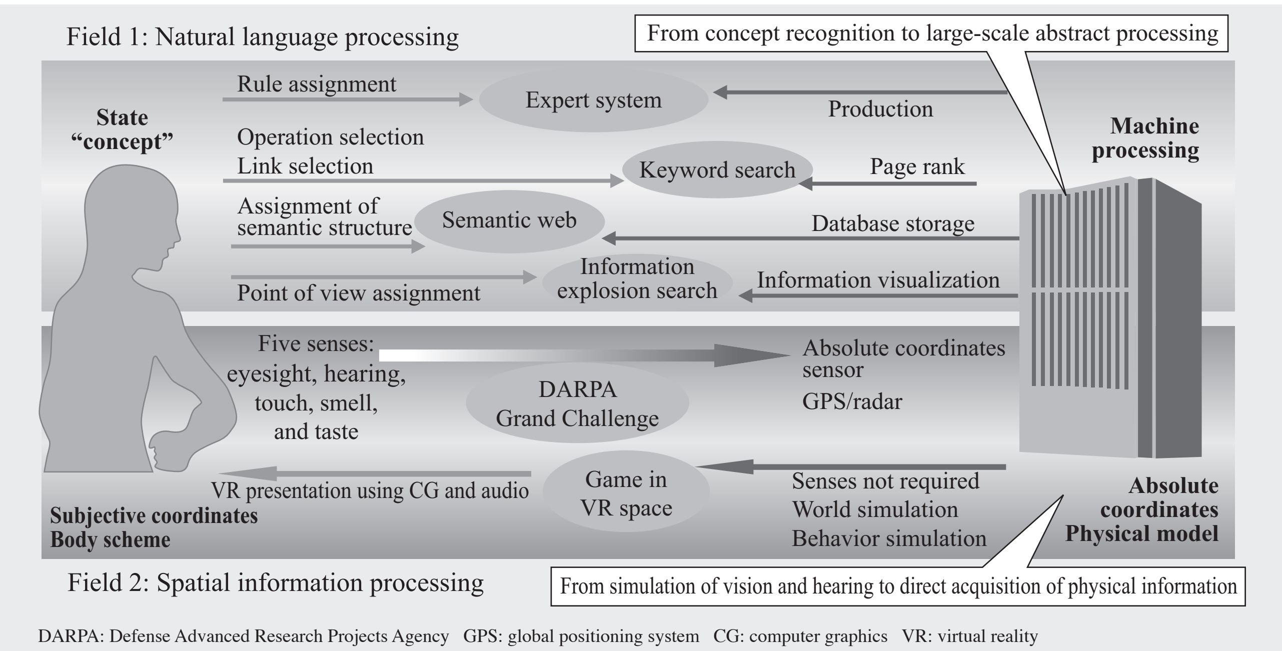

Fig. 1—Progress in Information Processing Techniques Aimed at Simulating Intelligence.
Research into artificial intelligence that seeks to completely replicate human intelligence has exposed the difficulties of achieving this in practice. Fields such as natural language processing and spatial information processing have made progress with pragmatic approaches that overcome these obstacles.

to think again about what sort of intelligence it is that we want to implement on a computer, the article describes the potential ways forward for the technologies for simulating intelligence in the 21st century from the various different perspectives that need to be considered.

PATH OF ARTIFICIAL INTELLIGENCE RESEARCH

Birth and Progress of Artificial Intelligence Research

The question of what human intelligence is is one that emerges naturally from our desire to gain a deeper understanding of ourselves and since ancient times has largely been inquired into by means of philosophy. However, the hope that it may be possible to simulate human intelligence has been around since the development of the von Neumann computer architecture. This hope was given the name "artificial intelligence" at the Dartmouth Conference held in 1956[(1)] where the field gained wide acceptance as topic for research.

Within the scope of the very limited computing power available at the time, progress in the period up until the 1960s was achieved in research topics such as techniques for finding a solution within a set of rules, such as in a board game, and in modeling various problems in a form able to be handled by a computer. Without delving deeply into philosophical questions about the definition of human intelligence, engineers got on with developing technology for simulating abilities such as the use of senses to recognize objects, speech recognition and the ability to understand natural language, use of symbolic logic for representing knowledge, and inference.

From the 1970s, "expert systems" were constructed that represented the knowledge of an expert in a particular problem domain in the form of computer data which could then be combined to derive new knowledge. These systems achieved notable results in fields such as medical diagnosis[(2)]. It was hoped that, by riding the trend of dramatic increases in computing performance, this approach could be put to practical use in numerous areas where human intervention was needed. In the 1980s, the Japanese fifth generation computer systems project's objective of achieving extensive inference processing capacity focused particular attention on the widespread practical application of artificial intelligence resulting in an "artificial intelligence boom" that became a social phenomenon and saw large-scale projects being undertaken around the world.

When knowledge is converted into a particular symbolic representation, the nature of the format itself limits the scope of the knowledge being manipulated and the scope of application of the inference system. This led to research into new ways of representing information that can cope with information that cannot be represented by symbols, and new ways of processing this information, resulting in the creation of a new paradigm where information is represented in terms of probabilities and distributions. As a result, the field of automation and control successfully introduced the concept of inference mechanisms to the numerically-based control techniques used in the past.

Pioneering Research at Hitachi

Hitachi has undertaken numerous pioneering research projects aimed at the application of artificial intelligence research in industry. The following is a list of some representative examples.

(1) An image recognition technique that simulates vision was used to develop functions that had proved problematic in the automation of precision assembly work on industrial assembly lines, namely position recognition for items to be assembled, shape recognition for selection, and defect recognition for inspection[(3)].

(2) In the field of expert systems, Hitachi has researched applications such as large-scale project management systems, although this work was viewed in the context of the fifth generation computer systems project and was used as an opportunity by the USA to take countermeasures[(4)].

(3) Hitachi developed operation guidance systems for use in nuclear power stations with functions that included diagnosis of abnormal situations and operational guidance[(5)]. The system combines a knowledge base expressed in the form of IF-THEN rules with mathematical models able to infer changes in process variables that are difficult to represent as rules. The system can predict potential causes of accidents in the ever-changing plant environment and provide appropriate operational guidance to plant operators.

(4) Hitachi embarked on research into large-scale document filing underpinned by text recognition technology and natural language processing technology in the early 1980s at a time when the huge volume of machine-readable documents now

available on the Web couldn't even be imagined. An interactive inference system was developed that represented concepts corresponding to the content of the documents as a semantic network (a knowledge engineering technique) which could be searched by meaning from the higher level concepts.

OBSTACLES TO PROGRESS

The early objective of artificial intelligence research was to replicate human intelligence. That is, to create an intelligence able to utilize the vast knowledge including common sense to respond flexibly to different situations and make judgments. It was hoped that such an artificial intelligence would be capable of the intuitive imagination to bypass multiple steps of logical inference with a single insight, or of interpreting visual image patterns and auditory signal patterns to extract the parts of these patterns that contain meaning.

However, what was actually able to be created were systems that represented a finite quantity of knowledge established in an ad hoc way as statements of symbolic logic, and that treated the set of logical statements that could be derived by an inference mechanism based on symbolic logic as the sum total of its knowledge. The broad base of knowledge that underlies this knowledge set needs to be carefully designed and built by human beings, but this is an expensive task that requires a high level of skill. This is called the "knowledge acquisition bottleneck." It also became apparent that, because of the difficulty of predicting how the overall system will behave in response to additions and changes to the knowledge, the creation and improvement of basic knowledge is itself an extremely difficult problem.

Further, in trying to solve the problems of how to judge situations appropriately and make decisions about actions through the use of knowledge representation and its manipulation by symbolic logic, the volume of computation required to enumerate the potential phenomena that can occur in the real world becomes huge and appropriate decision making becomes impossible due to the finite number of inference steps available. This is what is known as the "frame problem" and a solution has yet to be established.

POTENTIAL WAYS OF SURMOUNTING OBSTACLES

Two fields of research of a quite different nature exist within the pursuit of simulated intelligence. One is the "conceptual world" constructed from language and the other is the "physical world" which is subject to physical laws and which is where the human body itself exists. The following sections describe recent approaches taken to realizing intelligent functions in each of these fields (see Fig. 1).

Natural Language Processing

Rather than as a means for providing machines with an infrastructure of conceptual knowledge, the processing of intellectual information relating to concepts has made more progress as a way of assisting intellectual activity by people. One major change in the situation since the artificial intelligence boom in the 1980s has been the growth of the Internet and Web technology.

A huge quantity of information is available on the Internet in the form of documents and the volume of machine-readable text has grown explosively. Many people are looking for ways to make accurate use of this huge volume of information in intellectual activities.

One of these is research into constructing knowledge bases in accordance with an ontology framework so that knowledge bases covering a range of different specialist fields can be established in a way that allows interoperation. There is also the idea of the Semantic Web whereby semantic descriptions in a format consistent with a knowledge base are embedded in documents to make the documents searchable by meaning. However, these forms of information have yet to be widely adopted.

Rather than having machines that can understand and extract meaning from natural language, it is anticipated that what will actually be practical will be technologies that allow humans readily to infer the perspectives, concepts, and other elements expressed by a document through processing that extracts groups of words that correspond to the perspectives, concepts, and other elements that represent the content of the document, or that resolves synonyms and integrates them as representative concept keywords(6). This approach is effective for applications such as understanding the overall meaning of large volumes of text, searching for a particular document by concept, and the identification of valuable information in documents. Hitachi has developed search techniques based on the concept of duality in searching that considers the relationship between sets of documents and sets of words, and functions to assist the process by which people understand the meaning of text(7).

Simulating Intelligence in the Physical World

The other field for simulating intelligence is the physical world where the frame problem remains an ever-present obstacle. Against this background, artificial intelligence technology has been successful in the two areas described below.

One approach restricts modeling of the physical world in computers to only those areas relevant to the intended activity and integrates sensors that relate directly to the information used to construct the model. The key aspect of this approach is that it constructs a model of the physical world without trying to simulate human vision, hearing, or other types of perception.

One example of this approach comes from the Grand Challenge and Urban Challenge run by Defense Advanced Research Projects Agency (DARPA) in the USA. The Grand Challenge has unmanned self-guided vehicles competing to travel over approximately 230 km of road in the desert between California and Nevada(8) whereas the Urban Challenge requires them to travel over about 100 km of mocked up urban roadway while correctly obeying the traffic rules. While all vehicles in the inaugural Grand Challenge retired before reaching the finish, an indication of how hard it is to drive a vehicle based on an estimation of surroundings obtained under natural outdoor conditions, the second event held the following year saw five vehicles completing the full distance. In the Urban Challenge held two years later, six of the 11 teams in the final completed the course.

Although this result could be quoted as showing that machines can simulate human beings in the task of driving a vehicle, it was accomplished in a way that is quite different to the simulation of human beings to which early artificial intelligence aspired. This is because the methods used involved direct input of the information required to achieve the objective of driving the vehicle, including using GPS (global positioning system) to determine the vehicle's location on the earth's surface and laser range finder sensors to identify the three-dimensional coordinates of the driving surface and obstacles that determine where the vehicle could be driven. This avoids the problems associated with using senses like vision, hearing, and touch to determine the situation in the external world in the way that humans do. While techniques for processing visual information are still used, these no longer play a central role. Hitachi is working on research into behavioral intelligence in the physical domain based on the concept of "physical world crawling" which involves the autonomous collection of information that resides in the physical domain.

The second approach is paradoxical in that rather than dealing with the physical world directly, it attempts to construct a virtual world into which people's actions can be incorporated and where even human intellectual activities can be undertaken entirely within the virtual world.

In recent years, computer games have become able to reproduce worlds with a high degree of realism thanks to advances in simulation techniques underpinned by computer graphics technology and computing power. The entertainment value of a game is what determines its worth and the gaming industry has adopted numerous techniques that have emerged from past artificial intelligence research to improve this aspect of their products. Characters controlled by the computer plan what action they should take next and continuously produce autonomous reactions appropriate to their ever-changing environment so as to fulfill their behavioral objective which is to play out their role in the story. Games also use adaptive control that incorporates machine learning techniques to make the story more interesting by predicting what will happen next from a history of the past moves made by the game participants and adjusting the unfolding of the story or modifying the behavioral patterns of the characters(9).

Unlike when dealing with the physical world, computers have complete information about the situations in virtual worlds. This side-steps the frame problem and eliminates the problem of how to acquire information about the world. Whether game participants view the computer-controlled characters as having human levels of intelligence can only be judged through the actions of those characters and does not depend on how these functions are implemented. In this respect, we have now reached the point where we cannot help but recognize that intelligence is present in these virtual worlds.

VARIOUS PERSPECTIVES ON INTELLIGENCE

As described above, there are many cases where current intelligent systems have succeeded by avoiding the need to simulate human intelligence fully. If we consider that our ultimate goal is the perfect implementation of "intelligence," the biggest problem is that the intelligence we aim to simulate itself is not clearly defined. Rather, we could say that we have set out to simulate intelligence in order to obtain a functional and structural definition of intelligence itself.

Finally, this article will list some opposing viewpoints about how intelligence should be considered in the hope of providing some thought-starters about how we define intelligence.

Relationship between Language and Concept

When considering the relationship between natural language and concepts, one viewpoint is to consider that meanings are contained in words prior to our interpretation of this meaning. The ontology described above is a system for structuring knowledge that assumes that words and concepts have a strict one-to-one relationship and can be seen as representative of this viewpoint.

An alternative viewpoint is that the concepts (meanings) represented by words are different depending on who interprets them. There is no direct method of ascertaining whether the concept that one person associates with a particular word is the same as that of some other person. From this viewpoint, the words shared by a society with a common culture are merely markers of an agreement to take a common view of particular "mental images." If this uncertain relationship between words and concepts is accepted, then a knowledge base of common sense constructed using the ontology runs the risk of only having precise meanings for people from a single culture or only for the individual who constructed the knowledge base.

Unlike language expressions based on mathematics, it is considered that the source of the ambiguities of meaning in natural languages lies in the fact that the concepts expressed by particular words are intrinsically mapped to different mental images in each person and that this difference results in the meanings of words invoking varying different impressions when they come to be used.

Perception of External World

The physical world is another field where intelligence manifests itself and here we cannot claim that our spatial awareness, which is based on the information from sense organs such as vision and hearing, is understood in terms of a mathematical space as it is in a machine. The viewpoint called "affordance" holds that people remember space in terms of coordinates relative to our bodies and understand space in relation to our actions.

Logic does not allow us to infer the commonality of spatial understanding from the commonality and similarity of actions alone. Despite this, it may be that we have just such a rough understanding in our daily life experiences. In terms of the confirmation of concept-sharing described above, this is the same as the idea that when someone speaks a particular word, we assume that they share the same concept of what it means as is invoked in our own minds.

Viewpoint of Relationalism and Viewpoint of Realism

There is a viewpoint whereby, as a way of confirming the commonality of our understanding, we should use the "actions" obtained from each field as a proxy for judging whether something constitutes intelligence, as described above. With this viewpoint, the existence or otherwise of intelligence is based on the relationship between the entity making the judgement and the entity being judged. The well-known Turing Test is a standard for testing for the presence of intelligence that is based on this viewpoint of relationalism.

An alterative is the viewpoint of realism whereby the establishment of whether functions are intelligent depends on what those functions are, regardless of the actions or judgments of the person making the assessment. According to this viewpoint, a machine can only be considered as having the same intelligence as a human if it has the same functions as a brain or equivalent information processing mechanisms. The view current in recent years that neuroscience is important for understanding human intelligence or emotions is an aspect of this viewpoint of realism. The idea that the solution to the "mind and body problem," which asks how consciousness (intelligence) can reside in a physical object like a brain, can be resolved and understood through the functions of the brain itself can also be thought of as being close to this viewpoint.

CONCLUSIONS

In addition to giving a summary of the history of artificial intelligence research mixed in with information about Hitachi's pioneering efforts, this article has cataloged the many common difficulties faced by researchers and described new approaches that point to potential ways to overcome these difficulties. Various opposing viewpoints have been shown so that they may provide an opportunity to reconsider how to deal with "intelligence" which is the underlying objective of artificial intelligence research.

With information services penetrating into various different areas of our society, progress on techniques for simulating intelligence will be essential to further improvement of human-centric values and, to this end, the author has high expectations for progress in obtaining a fundamental elucidation of intelligence itself.

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ABOUT THE AUTHOR

Masami Yamasaki, Dr. Sc.

Joined Hitachi, Ltd. in 1987, and now works at the Systems Development Laboratory. He is currently engaged in the development of autostereoscopic display systems. Dr. Yamasaki is a member of the IEEE, The Institute of Electronics, Information and Communication Engineers, and The Physical Society of Japan.