# ARTIFICIAL INTELLIGENCE

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## 1. Overview (Past and Present)

Research on artificial intelligence (AI) originated from mankind's simple desire of creating a machine which can mimic human intelligent activity such as a thought process. Although such dreams have existed since antiquity, specific attempts at realization had to await the invention of computers.

Unlike their machine predecessors which mainly carried out physical laybor for humans, computers are a new breed of machines for manipulating symbols. Since symbol manipulation is closely related to human thinking, the advent of computers has allowed scientists to truly tackle the implementation of intelligent machines, or artificial intelligence systems.

Various technological constraints inherent in computers, however, retarded the start of AI research by about 10 years after the birth of the computer. It is generally considered that AI research actually began in 1956 when McCarthy, Minsky, Simon, Newell, Samuel, and other researchers had a meeting at Dartmouth College to discuss the present status and future prospects of artificial intelligence. The history of AI research over nearly a quarter of century since is classified by major research subjects by Kazuhiro Fuchi, director of the Research Center at the Institute for New Generation Computer Technology (ICOT), as follows:

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| First stage | : | Era of games and puzzles |
| Second stage | : | Era of intelligent robots |
| Third stage | : | Era of language and knowledge |
| Fourth stage | : | Era of knowledge engineering and congnitive science |

Thus far artificial intelligence has been studied with two different approaches. The first approach aims to achieve intelligent machines to enhance capabilities of computers and make them more familiar to humans.

Undoubtedly they excel humans in the abilities of rapidly performing numeric operations and precisely storing and retreiving large amounts of information. The current machines, however, have severe limitations in other, more intelligent activities, such as understanding queries in natural languages and responding to them accordingly, perceiving the external world with sight and hearing to perform appropriate problem solving, and discovering new rules from experience. Some of these capabilities have been partially realized by recent AI studies; compared to the human abilities, however, they are still rudimentary.

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ARTIFICIAL INTELLIGENCE

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Yet the AI research to date has proved the possibility of endowing computers with a considerable degree of problem-solving power, given an extremely narrowed object world. For example, some machines can partly exceed physicists in the ability of formula manipulations which appear in problems of physics. Practical formula-manipulating systems had emerged.

It is important to note that the problem-solving techniques obtained in the development of these systems cannot be easily upgraded to human level, i.e. flexible, general problem-solving able to handle wide range of problems. The present natural language understanding systems, for example, can only understand narrowly defined discourse, such as consultation of travel plans and queries to a database. Researchers thus far have considered that AI research limiting the target field was necessary to delve into difficult problems, such as semantic and context analyses in natural language understanding. This idea has permitted the development of AI systems with a fairly high degree of problem solving. The restricted target field, however, is causing a marked increase in the number of systems which employ heuristics only applicable to a particular domain. It is therefore natural that the establishment of more general AI theories is demanded.

The first AI research approach mainly targeting the implementation of intelligent machines is sometimes called knowledge engineering. Knowledge engineering initially aimed at developing expert systems, computers able to perform problem-solving using various pieces of expert knowledge stored in a knowledge base. More recently the attention of researchers are shifting to problems concerning knowledge, particularly basic problems, such as the ways of representing, using, and acquiring knowledge.

The second approach aims to explain the mechanism of human intelligence. Recently, this led to the birth of an interdisciplinary study, cognitive science, which encompasses psychology, linguistics, and philosophy.

Psychologists and linguists expect congitive science to provide them a tool, computers, to elucidate the internal mechanism of human intelligence. AI researchers, on the other hand, hope that, once cognitive science successfully clarifies the human intelligence mechanism, they will be able to make use of the results to implement smarter machines. The new science can be said to satisfy the expectations from both groups.

The knowledge-related problems are also becoming important in the AI research based on congnitive science. In this sense, the first and the second approach are related to each other via knowledge.

Human intelligence has been considered an exclusive blessing from God. It has allowed mankind to build a brilliant culture on the earth. Discussions have been conducted from various perspectives that machines equipped with human intellgience would have a tremendous social impact. This impact is expected to far exceed the influence conventional classic machines, which carry out physical labor for humans, produced on the history of mankind in the past. Some signs have already appeared.

The Fifth Generation Computer System (FGCS) project proposed by Japan aims to seriously tackle the implementation of intelligent computers and to provide, through advance investigations, countermeasures against the social impacts expected to be produced by these machines. The FGCS project has created a global sensation, because it came up with a clear image of future computers about which researchers in various countries had only fuzzy ideas before.

The project specifically aims at significantly advancing the current technology of artificial intelligence. To achieve this, it intends to establish the basic technologies of supporting hardware and software by the end of the first half of the 1990s.

The FGCS project has a target-searching rather than a target-oriented characteristic. This means that the project was planned on the assumptions that AI research is a formidable task. The words "target-searching" would also imply that AI research requires several additional breakthroughs which will be brought about by future fundamental research efforts. The research from this perspective seems to be especially necessary for artificial intelligence. Studies of practical systems will have to be carried out in parallel with this research.

## 1.1 Intelligent Man-Machine Interface

### (1) Natural Language Understanding

Until the mid 1960s, natural language research was carried out as machine translation. During this period machine translation was never taken up by projects as an application of artificial intelligence, although language translation is a sophisticated intelligent activity of humans.

Machine translation researchers in those days believed that a considerable degree of machine translation would be feasible by using Chomsky's linguistic theory which had taken a firm hold as a new paradigm of linguistics. AI researches, on the other hand, regard Chomsky's syntax-based theory as inadequate to realize a machine translation system able to cover a relatively wide range of linguistic events. Giving a higher priority to semantic processing than syntactic processing, they profoundly pursued semantic processing by limiting the range of discourse understanding to narrowly defined worlds, such as a block world.

The efforts by AI researchers led to the birth of the SHRDLU system developed by Winograd in the late 1960s to the 1970s. This system proved the possiblity of implementing a fairly sophisticated semantic understanding system, and language understanding system, with the object world narrowly defined. SHRDLU made a significant contribution in that it demonetrated that language understanding can be performed efficiently by combinging syntactic and semantic processing. By contrast, the syntax-based research on machine translation systems reached a deadlock in the mid 1960s, thereby causing research activities to considerably slacken globally.

The success of the SHRDLU system has since permitted natural language understanding to be studied as a major research theme of artificial intelligence. The subsequent research of natural language understanding was carried out in two directions to break the limit of SHRDLU. One aimed to develop a practical system capable of querying databases in ordinary languages; the other tried to expand the object world.

The former demonstrated the importance of the ability to appropriately recognize the intention of a question issued from a person and respond to it accordingly. This function is related to discourse understanding involving more than one sentence. The latter explained the significance of the problem of knowledge; various techniques were since proposed to solve the problem.

Natural language understanding systems must have huge volumes of knowledge to understand a wide range of natural language in the same manner as humans do. Discourse understanding, particularly which handles a sequence of sentences, often requires common-sense inference based on vast stores of knowledge to solve problems, such as determining the word pointed out by a demonstrative pronoun, finding elliptical words, extracting the discourse theme, and shifting focus and attention. A variety of research was conducted on how to formulate and use such knowledge. In this sense, the 1970s can be said to have seen fruitful basic studies of natural language understanding.

In the 1980s, researchers reviewed the AI research in the previous decade and remarked that the natural language understanding studies had relied upon makeshift solutions, and that semantic and discourse understanding should have been worked from an interdisciplinary standpoint.

The former problem seems to derive from the narrowly defined object world handled by natural language understanding systems. It shows that future studies of natural language understanding will have to cover a greater number of linguistic phenomena. For the latter, researchers are getting ready for investigating it as a study of cognitive science from different perspectives.

Recently the relation between logic programming and natural language processing is attracting attention. This will be discussed in 1.3 (4).

(2) Speech Understanding

Evidently speech understanding is related to natural language understanding. Speech understanding can be considered as a subset of natural language understanding. A problem inherent in speech understanding is to manipulate physical speech waveforms generated by humans. This problem belongs to the signal processing field rather than the AI domain.

Speech understanding projects carried out in the United States in the 1970s seemed to be based on the idea that even if signal processing were inadequate, it could be compensated by the subsequent processing at the language understanding level. In other words, this approach assumed that there was no appropriate signal processing technique capable of handling all parameters involved in speech waveform processing, such as pseaker dependence/independence, male/female/childrens' voice, noise level, power, continuous speech/isolated-word speech, conversation speed, stress, and intonation. The speech understanding project in the U.S. can be said to have achieved their objectives by introducing ad hoc heuristics closely dependent on the excessively narrow object world, such as movement of chessmen.

These U.S. projects demonstrated that the technology for processing physical voice waveforms plays a vital part in implementing more general speech understanding systems. The 1970s saw the emergence of new techniques, surpassing the conventional voice waveform processing based on the Fast Fourier Transform (FFT) method, such as the Linear Predictive Coding (LPC) scheme and the dynamic programming (DP) method to normalize conversation speed.

Many researchers believe that more general speech understanding systems cannot be achieved without processing speech waveforms and converting them into a time series of phonemes. It is difficult to physically define phonemes themselves; even if they could be defined, a series of phonemes extracted from speech waveforms would inevitably contain erros, such as dropouts, transpositions and contractions.

Another tough issue is how to extract a series of words from speech waveforms. Particularly continuous speech recognition poses a challenging problem called automatic segmentation; how to locate the position at which a certain word ends and the next word begins. Solving this problem is expected to need vast amounts of knowledge of speech. This also requires dynamic models for the human vocal tract and jaw to be considered; research on these aspects, however, are not being adequately carried out. Another well known problem related to continuous speech understanding is that the extracted partial speech is recognized as various phonemes by him because it is affected by the surrounding speech. This problem is being studied as auditory psychology. The establishment of models for continuous speech recognition able to handle these problems would be a major research theme in the future.

To sidestep these difficulties, some commercial speech understanding systems force the operator to speak each word separately and understand a limited vocabulary (currently around 300 words). For such systems, however, it is difficult to significantly expand the vocabulary. Furthermore, their speaker dependence characteristic makes it hard to upgrade them to speaker-independent, continuous speech understanding systems.

(3) Image Understanding

Studies of image understanding started as part of the research on intelligent robots. An early intelligent robot called a hand-eye system manipulated building blocks with its eyes and arms. The world of building blocks can be represented with simple figures consisting of circles and straight lines. The hand-eye system obtained an image of the building block world using a TV camera as its sight, recognized individual blocks on the basis of the image, and manipulated its arms to respond to the instruction from a person.

Such smart robots in the 1960s, which recognized the outside world by processing image data obtained through their eyes and performed certain problem solving, had an image understanding capability which was a long way from being used in practical applications. Researchers continued to study image understanding as an independent subject. They worked on not only the image understanding of the work space of a robot, but also the understanding of medical images, such as X-ray photographs of stomach and chest, micrographs, the comprehension of aerial photographs, and the recognition of characters, diagrams, and fingerprint. These were major research themes of the AI in the 1970s, resulting in some practical technologies.

Generally, image understanding must process large amounts of raw data; special processors for handling raw data thus have been developed. Solid cameras used as input devices permit image understanding systems to obtain even information which human sight fails to perceive, such as infrared or ultra-violet ray images in remote sensing. Some systems currently under development can easily acquire distance information whch is required to comprehend three-demensional images. Technical problems involved in input devices for a wide variety of image information have been solved to date to a considerable level. Present obstacles to image understanding would be rather the establishment of versatile algorithms and models for image understanding. Some recent efforts aim to apply knowledge obtained from research on nerve cells to image processing.

Image understanding work in the past led to practical image understanding systems equipped with a dedicated algorithm for a fixed object. They, however, have yet to succeed in establishing models for image understanding as flexible and general as human vision.

Researchers are beginning to realize that, as with natural language understanding and speech recognition, image understanding also requires knowledge. The frame theory proposed as a framework for representing knowledge by Minsky in the mid 1970s was originally devised as a framework for pattern recongition. It would be natural to consider that both images and natural languages can be eventually reduced to the same understanding process. The frame theory can be evaluated as the first stride toward this direction.

The image understanding scheme called the bottom-up method processes raw-data images obtained from a solid camera, and uses the processing results to perform higher-level processing. By contrast, the so-called top-down approach uses the built-in knowledge of the target world to understand images. A full-fledged image understanding model may combine both methods. But research on how to formalize image-related knowledge has only recently started.

Some researchers have an idea of constructing image databases and performing faster edition and retrieval of images to support applications, such as VLSI CAD and medical diagnosis. Still others regard image understanding as an interactive process between humans and machines, and are trying to build practical systems by breaking the technological bottlenecks involved in the present image understanding systems.

## 1.2 Applications

Artificial intelligence has a wide variety of applications. This subsection describes three typical applications--intelligent robots, expert systems, and machine translation. Up to now, machine translation has not been a major research subject of artificial intelligence. But I dare to take up this research theme as a separate issue, because, considering the future in 10 or 20 years, machine translation seems important as a test bed for integrating various results from AI studies or as a research theme to help natural language understanding systems evolve out of laboratories.

### (1) Intelligent Robots

Intelligent robots may feature the capabilities of understanding information from the outside world, making intelligent decisions, and performing actions accordingly. The intelligent robot research ultimately targets machines able to make judgements and behave in the same way as humans do. These robots are also expected to have the ability to work in severe environments where humans cannot exist.

The 1960s saw the creation of the hand-eye system with eyes and arms. Its arms were actually mechanical manipulators; therefore the system was a research theme in mechanical engineering rather than artificial intelligence. As described earlier in 1.1 (3), the hand-eye system's vision has already been studied as a major subject of artificial intelligence.

Another characteristic of the hand-eye system was that it had to perform problem solving (planning), when converting the image understanding results into arm movements, to avoid obstacles or produce an appropriate procedures for a sequence of actions. Instructions issued by humans to intelligent robots are usually general and do not show the details. Therefore, smart robots must be able to breakdown a given instruction into a set of detailed subcommands, and sometimes perform reasoning to relate seemingly separate individual instructions. This may require deep knowledge of the object world.

Some intelligent robots able to move about were experimentally developed from the late 1960s to the 1970s. In contrast to the hand-eye system whose eyes are fixed at a certain spatial position, mobile robots have eyes which change their body moves. Therefore, the vision system for these robots must be able to perceive motion images.

In recent years intelligent robot development projects are progressing in various contries to further enhance the functions of industrial robots. A key to the success of these endeavors may be the image understanding technology described in 1.1 (3). To perform positioning and locate obstacles, intelligent robots require the ability of comprehend three-demensional images.

(2) Expert Systems

So-called expert systems have large pools of knowledge of experts, such as doctors, lawyers, and teachers, and can respond to various questions as "clones" of human specialists. Some commercial expert systems have emerged in recent years, causing the "AI business" to be born.

The AI research in the 1960s gave rise to an early successful expert system for formula manipulation. Called MACSYMA, the system found its way, in the 1970s, into practical applications, and has since been widely used among physicists. With the capability of solving complicated formulae in physics at a reasonable speed, MACSYMA is beginnig to take a firm hold as a powerful tool for physicists. REDUCE, another formula-manipulating system has also been in practical use. Recently these systems are running on personal Lisp machines rather than mainframe computers.

Expert systems possibly started attracting general concern, when a medical diagnostic system was developed at Stanford University for diagnosing particular infectious diseases and providing subscriptions for antibiotic dosing. Named MYCIN, the system has a diagnostic capability matching human expert doctors. Its reasoning mechanism is based on "backward chaining" that runs the production system backward.

Researchers at Stanford University had already developed an expert system to estimate the chemical structure from a molecular formula and finally gotten MYCIN, whose partial success stimulated the development of various expert systems. Several expert system projects also started at laboratories of private companies to develop systems for diagnosing nuclear reactors or locating mineral deposits and oil wells, leading to the creation of lucrative expert systems.

Expert systems contain textbook-like specialized knowledge, plus empirical rules, or heuristics, which individual experts acquired through on-the-job experience. In addition, if it is a medical diagnostic system, the system includes certainty facotrs which show the reliability of diagnostic results. Experts often acquire heuristics and certainty factors unconsciously through their experience; therefore it is difficult to formulate such knowledge.

Challenging issues encountered by the recent research on expert systems include in what form (knowledge representation) expert knowledge should be give to systems (knwoledge acqusition), how that knowledge should be used to perform problem solving (inference). The detabase which holds acquired knowledge is call a knowledge base. Researchers are beginning to realize the necessity of meta-knowledge, or knowledge about the knowledge base, and a meta-inference mechanism to supervise the entire reasoning process and perform efficient inference. These research subjects need a relatively longer period to complete than other topics of expert systems.

Considering that various expert systems developed in the past have the nucleus program in common, some researchers are trying to extract basic elemen of the expert system. The so-called knowledge engineering was born to encompas all the knowledge-related studies mentioned above. Knowledge engineering has become the forefront of the applied AI domain. Forecasting the future of such expert system, Simon once remarked that experts who are out peddling their sophisticated special knowledge might soon lose their jobs.

Most expert systems described above were implemented in Lisp. Lisp is a typical symbol processing language used to develop most of the AI programs to date. Lately a new programming language called Prolog is beginning to attract attention.

Prolog has built-in mechanisms for pattern matching, list processing, and nondeterministic problem solving necessary for expert systems. This new languag is expected to offer a powerful tool in constructing expert systems. Efforts currently made in the U.K. aim to develop Prolog-based expert systems. More detailed discussions on Lisp and Prolog will be given in 1.5(4).

(3) Machine Translation

As described earlier, machine translation systems have not always been studied as a research subject of artificial intelligence. In the 1970s an English-to French translation system developed by Wilks was the only system at that time making use of AI research results. More recently the translation system built by Schank and other co-workers tried to incorporate the AI research results. While being small-scale experimental systems, both systems are worthy of attention in that they aimed to implement machine translation systems based on semantic analysis. To achieve this, these systems, narrowly defined the range of target sentences as described in 1.1 (1).

Machine translation research rapidly lost general interest in the mid 1960s after the ALPAC report concluded that there was no reason in terms of both market demand and technology for hastening to develop practical machine translation systems. Since the early of the 1980s, however, machine translation research is beginning to come to life again independently of AI research. For examples, the EC started the EUROTRA plan and Japan's Science and Technology Agency also has its own plan. Recently, Japanese computer manufacturers marketed English-to-Japanese and Japanese-to-English translation systems. Machine translation systems currently in practical use are essentially based on syntactic processing. Therefore they undoubtedly have technical constraints. Higher level machine translation definitely needs semantic understanding of natural languages.

Semantic understanding of natural languages once was a typical AI research theme. Since AI researchers in the past considerably limited the range of sentences to be handled, some researcher working on machine translation systems remarked that natural language understanding studies by AI researchers could not provide techniques directly applicable to machine translation able to handle linguistic phenomena extending over a fairly wide range. This remark may be correct from a short-term standpoint. From the standpoint of admitting that machine translation requires long-term research efforts, however, many results obtained from AI research to date, especially studies of natural language understanding systems, can be considered useful for implementing machine translation systems. I believe that this approach helps natural language understanding research evolve out of laboratories.

### 1.3 Fundamental Research

AI research essentially requires long-term efforts. Fundamental research subjects, such as knowledge-related research, inference mechanisms and supporting software and hardware for AI research, need to be tackled from a long-term perspective. These studies cannot be discussed separately, because they are interrelated at a deep level.

#### (1) Knowledge Representation

Thus far in this report I have repeatedly pointed out the importance of knowledge representation. The semantic network proposed by Quillian in the 1960s as a knowledge representation formalism is still in use. It is a network to represent the relationship among concepts, and consists of nodes which indicate concepts and links which connect nodes to indicate their relations. The semantic network offered an intuitive model to explain human memory organizations, such as association. It was examined in psychological validity. Future research themes of semantic networks include defining the meaning of links and finding ways to separate denotative knowledge from connotative knowledge. Some endeavors aimed to incorporate the scope of negatives and quantifiers into semantic networks, but failed to obtain natural solutions.

In the mid 1970s Minsky proposed a knowledge representation form called frames that has had a significant influence on subsequent AI researches. This technique puts knowledge related to an object into a structure (so called frame) so that the knowledge can be accessed in a chunk. It was considered to have psychological realities. Individual frames are networked with various links to represent organized knowledge.

The concept of frames integrates the knowledge framework used by Schank and co-workers for discourse understanding as well as the idea of case frames in case grammar. The frame mechanism is worthy of mention in that frames contain default knowledge and can inherit knowledge from other higher-level frames. This idea of a so-called "inheritance of knowledge" was not only implemented in the knowledge representatin language called KRL, but also recently introduced to a new type of languages, object oriented languages. The frame mechanism, however has no established formal base, and is involved in problems similar to those of semantic networks. The language called KLONE is an effort to solve these problems.

Some scientists suggest that representation formalism with a clear mathematical basis must be chosen as knowledge frameworks; for example, knowledge representation based on predicate logic. This knowledge representation excels other schemes in that it can naturally handle the scope of negatives and quantifiers and use theorem-proving techniques when performing reasoning for problem solving. Other researchers tried to represent the frame formalism with predicate logic. Still others proposed a knowledge representation scheme which combines semantic-network-based representation and predicate-logic-based representation.

The knowledge representation studies based on predicte logic in the 1970s provided two noteworthy results; the defined relationship between predicate logic and programming and the birth of a predicate logic programming language, Prolog. Prolog has already demonstrated the ability to easily implement knowledge inheritance with unification. It is expected that the relationship between predicat logic programming and knowledge representation will be gradually clarified.

The monotonic property of the predicate logic system enables new facts to b added to the system independently of other facts. Newly added facts, however, sometimes contradict with seemingly valid old facts. To handle such situations, ar idea called nonmonotonic logic was proposed recently. Its research results in the future will be worthy of notice.

(2) Knowledge Acquisition

As described in 1.2 (2), expert system research has a major problem in how t acquire expert knowledge. Knowledge acquisition research aims to automate the knowledge acquisition process currently performed manually, and hence knowledge acquisition ultimately boils down to the problem of learning. Expert systems used in rapidly advancing fields, such as medical science, must be constantly expanded by obtaining newly discovered facts. Knowledge acquisition, however, entails difficult problem, such as matching between the existing and new knowledge. Powerful algorithms to obtain knowledge yet to be developed.

It is generally admitted that AI research must handle learning, or knowledge acquisition involving structural changes. Learning includes the process of abstracting observed facts by several levels. The way to automate such abstraction processes will be an important research subject. The learning mechanism of human is the most fundamental human intellectual activity, and hence difficult to be elucidated. Therefore, if even a part of the human learning process could be mimicked by machines, the conventional image of artificial intelligence would radically change. For the present, the AI researcher may have to carry out studies by concentrating on methods of acquiring the simple expertise of specialists.

(3) Theorem Proving

The first theorem-proving system was developed by Newell and Simon for proving propositional logic. The system was revealed at the historic meeting which was held at Dartmouth College in 1956 to initiate the AI research era. Nine years later, Robinson developed a complete automatic algorithm for theorem proving, called a resolution principle, in the first-order predicate logic system. AI researchers applied this algorithm to question-answering systems. Since these systems had poor efficiency, however, some scientists concluded that theorem proving was not worth being studied as a major AI research subject. Axioms used in theorem proving are called declarative knowledge. Researchers taking a negative stance on the theorem-proving technique emphasized the need of procedural-knowledge-based problem solving.

Various heuristics were since proposed to improve the efficiency of resolution-principle-based theorem proving; but heuristics effectively applicable to all problems have yet to be discovered. Generally, a proving process starts with the premise and advances toward the conclusion. A theorem-proving system called natural deduction developed in the late 1970s maintained this directional property of proving. The theorem-proving process based on natural deduction can be easily understood by humans, hence leading to the creation of systems which performed theorem proving with the collaboration of humans.

Theorem proving based on the resolution principle can provide an excellent efficiency, should the predicate logic system be restricted to Horn clauses. Using this idea Kowalski introduced in 1974 a logic programming concept which regarded theorem proving on Horn clauses as program execution. At the same time, Colmerauer developed the programming language Prolog which is based on a similar concept. Prolog has begun to attract, as an AI-oriented language, ever since it was adopted as the kernel language for Japan's FGCS project. The language is discussed in 1.3 (4). The advent of Prolog caused theorem proving to play a vital role as a basis of problem solving in artificial intelligence.

(4) Progamming Languages

The programming language Lisp, designed by McCarthy, is a symbol processing language wth the widest use in developing the AI programs to date. Lisp is a functinal language based on the lambda calculus and demonstrates its powerful faculty in list processing. Most U.S. AI reearch still uses this language. The study of Lisp machines starting in the early 1970s led the way in 1980 into commercial products. Lisp has large pools of support software. Its rich programming environment seems to further accelerate the proliferation of Lisp.

By contrast, the new symbol processing language Prolog developed by Colmerauer is based on first-order predicate logic. It is younger than Lisp by more than 10 years, and therefore its programming environment is still in its infancy and nowhere near that of Lisp systems. Since Japan's FGCS project has successfully developed a Prolog prototype machine and is making efforts to establish a sophisticated programming environment for that machine, Prolog is expected to soon have a programming environment comparable to that of Lisp.

The features of Prolog can be summarized as follows: (i) nondeterministic programming language, and (ii) built-in powerful pattern matching mechanism based on unifiction. Its pattern matching function allows Prolog to completely incorporate Lisp's list processing capabilty. These functions undoubtedly offer indispensable tools in problem solving in artificial intelligence.

According to a method suggested by Colmerauer, Prolog also permits parsing of natural languages in an extremely straight-forward manner. This approach performs parsing by directly executing augmented context-free rules as Prolog programs. It eliminates the necessity of building a parser, resulting in superb efficiency. Colmerauer's method was hitherto proved to match augmented transition network grammar (ATNG) in capabilities; in addition a technique to combine syntactic and semantic processing in an extremely natural manner was developed for the method.

Predicates are actually a type of relation; this leads to the defined relationship between Prolog and relational databases. It was demonstrated that QBE (query by example), a database querying language developed by IBM, could have been implemented more easily with Prolog programs.

Recent experiences of the author suggest that knowledge representation in the frame form can also be natually implemented using Prolog's Horn clauses rather than the list form, and that knowledge inheritance can be easily achieved with unifcation.

As a language with a short history, Prolog inevitably exposes itself to criticisms, such as "its control structure recklessly relies on backtrack" or "it is n flexible and, except for the cut operation, no controls are worthy of their name." For the former criticism, it was once discussed that backtrack-based languages ar surpassed in efficiency by other languages. I believe that this problem will be abl to be solved by future efforts to equip backtrack-based languages with a mechanism to efficiently control the flow of execution. This can be also affirmec from the stand-point of parallel processing whose future is assured by VLSI technology. For this reason, the author think, it is not a correct approach to criticize the present drawbacks of Prolog and totally reject outstanding concepts proposed by Prolog.

(5) Hardware

Thus far AI research has been at the forefront of computer science. It has exhausted computing power more than any other research, hence causing McCartl to devise in the early 1960s the time sharing system in which a single large computer system is shared among many researchers. The subsequent drops in the hardware cost made it possible to develop personal computers for exclusive use b individual researchers. The fringe of AI research has created currently popular techniques, such as the mouse, a pointing device, and the window system which displays several partially overlapped pages on a screen and permits the user to freely manipulate them. The base of these techniques were established in the ear 1970s.

In 1973 Greenblatt and others launched a project at MIT to implement a Lis machine. Commercial Lisp machines started to appear from the beginning of the 1980s, and are currently used at various universities and corporations' laboratorie as a major tool for AI research. By contrast, a Prolog machine was completed in 1983 by ICOT. Researchers at ICOT are trying to enhance the programming environment for the Prolog machine to the level of Lisp machines.

Such powerful hardware supports are expected to further facilitate AI research. Also the successive drops in hardware costs have seemed to draw many researchers into the AI field. There is also the possibility that computers based on a revolutionary architecture will emerge from the fringes of AI research.

## 2. Future

Generally it is difficult to talk about the future. We can find, however, a number of encouraging factors for talking about the future of AI research. Compared with the AI community twenty years ago, the range of AI research activities, the number and quality of researchers, and the social interest in AI research have all been astonishingly improved. Backed by advances in hardware technology, such as VLSI, this trend is expected to be further accelerated in the years to come.

As overviewed in the previous section, AI research has already come up with some commercially successful systems with results unable to be expected from the technological level of artificial intelligence twenty years ago. Yet the harbingers of these systems already existed about a decade ago. AI research in the next decade will include the refinement of these systems. It should be noted, however, that the expert systems currently in practical use are beginning to encounter their technical bounds.

AI research involves a number of inherently difficult problems. The description in Section 1 showed that one of these problems concerns knowledge. "How should knowledge be handled? What theories are requried to handle knowledge?" These must be the keys to AI research in the future. Also, recent advances in VLSI technology is about to eliminate hardware-technology-related obstacles to parallel processing, thereby making it feasible to build artificial intelligence with a performance unable to be expected in the past.

Successive improvements will be made to individual artificial intelligence systems. Considering the future more than ten years away, we are now at the stage which needs to devise new approaches and theories for artificial intelligence.

### 2.1 Intelligent Man-Machine Interface

Understanding of natural language, speech, and images involves problems concerning the essence of human intelligence. These problems seem to take a long term to solve. They, however, can be bypassed for the present with a collaboration approach between man and machine in which machines solve difficult problems by interacting with humans. A combination of existing technology and this man-machine interactive approach is expected to permit the development and commercialization of many intelligent interfaces in the next decade which will enable humans to communicate with machines through ordinary language, speech, and images. Individual interface systems, however, will probably be able to understand only a limited range of natural language, speech and images.

Section 1 discussed the point that narrowly defined target ranges of natural languages, speech, and images have caused systems to tend to rely on ad hoc solutions and therefore emphasis should be placed on research on more general solutions. For natural language understanding, discourse understanding, or understanding of a stream of conversation, must be studied more intensively. Although this theme involves important problems, such as finding elliptical words and understanding metaphors, very limitted numbers of AI researchers are currently engaged in them seriously. Considering research in this domain pragmatic, linguists have also made small number of efforts to theoretically formalize discourse understanding. Intellectual conversation cannot be realized long as the discourse understanding problem is neglected. Solving this problem form a universal standpoint will require general theories conveying the knowledg we use to understand languages and the way we use it. This discussion also holds true for the recognition of speech and images.

Strategies to cope with this tough issue is critical, because they are closely associated with the functions of future intelligent interfaces. Research based or cognitive science will probably be necessary.

Let me point out a problem which is likely to be overlooked in the studies c intelligent interfaces. It is the importance of database systems which store a wi range of linguistic, speech, and image data necessary for conducting research an permits researchers to promptly retrieve specific examples for particular data which they want to analyze. The creation of these systems should be started as early as possible, because they must hold huge volumes of data. Such databases will be the base for new technologies and theories as well as facilitate cognitive science and other interdisciplinary research.

## 2.2 Applications

Expert systems also able to fullfill the roles of specialists in specific fields are likely to make their way into society and be widely used by the end of the ne decade. Expert system research yielded knowledge engineering. To implement t next generation of expert systems capable of flexibly responding to a wide varie of questions, revolutionary theories are now required for knowledge representati reasoning, and knowledge acquisition. Thus far relatively simple inference mechanisms have been considered adequate for expert systems. This discussion, however, will probably lose ground, as the amount of knowledge to be handled increases. Knowledge will be classified into hierarchical classes ranging from global to detailed level and stored in a knowledge base. Combining global and lc knowledge and performing efficient inference needs inference mechanisms base on new ideas. These mechanisms will incorporate parallel processing functions.

Important studies of expert systems not described in 1.2 (2) include the research on a function which explains the inference base made by an expert system. Expert systems must be able to trace backward a chain of reasoning to give an explanation and sometimes summarize the reasoning process to provide ground for an inference from a global standpoint. On some occasions they may l required to explain why the possibility of other inferences was discarded withou simply using certainty factors. This will be a challenging research theme in the future.

Conventinal industrial robots with limited capabilities will be gradually replaced with more vesatile intelligent successors. Algorithms for image understanding seem the key technology for successful intelligent robots.

Machine translation systems, although still relying on humans for preediting and postediting, will rapidly find their way into commercial applications. Future translation systems will call for immense volumes of terminology banks, which will probably not be achieved without international collaboration efforts. The implementation of high-qulaity machine translation systems will require various technologies for natural language understanding. In addition, as a byproduct of machine translation system research, pocket-sized electronic dictionaries may be seen to find wide acceptance.

2.3 Fundamental Research/Research Conduct

As repetitively described in this report, artificial intelligence essentially requires long-term research efforts. AI research contains important facts concerning knowledge which AI researchers have yet to recognize. Discovering these missing theories will call for research from a long-term perspective, particularly research on knowledge. This research will allow us to understand more intensively the true nature of knowledge and its manipulation.

As we handle larger volumes of knowledge, we will have to more seriously tackles the problem of learning. The true mechanisms of learning are hardly expected to be explained by the end of the next decade. There is, however, a possibility of discovering some clues to the mechanisms. Learning and knowledge are interrelated. Therefore the explained learning mechanism is likely to bear a new generation of AI systems to radically change the idea humans have regarding artificial intelligence. AI systems twenty years from now will probably have a learning mechanism with a limited capabiltiy.

Concerning the hardware system, AI systems thus far have been based on the simple von Neumann architecture. The simplicity of the architecture can be considered a driving force for the proliferation of the current computers. This simple architecture seems to have successfully survived to date due to technological constraints, such as limited computing power and the expensive price of computers. The simple architecture, on the other hand, has forced software to carry excessive burden, a problem so called "software crisis." Most AI systems today consist of huge volumes of software; therefore even the systems designers who built the system sometimes fail to understand it later. To solve the software crisis already in existence, we have to refine hardware and relieve software of the excessive burden. This approach is consistent with the direction of Lisp and Prolog machines, because these machines have further improved the machine language level.The recent advances in VLSI technology indicate the likelihood of enhancing hardware capability.. The enhanced hardware, in turn, will make it possible to implement highly parallel machine architectures.

Japan's FGCS project proposed a predicate-logic-based architecture to break the von Neumann bottleneck. To take full advantage of VLSI and ULSI (ultra-large scale integration) technologies in the future, it will be necessary to upgrade the capabilities of machine architectures to decrease the software burden, as well as to develop new architectures capable of ultra-parallel processing. Machines with such architectures will permit the design of programming languages far exceeding the present languages in performance. For example, future programming languages will be integrated into knowledge representation languages. Some signs can already be found in Bobsow's LOOPS and other programming languages.

Finally I would like to mention research conduct. AI research to date has been supported by long-term basic studies carried out mainly by U.S. research institutions, represented by MIT, Stanford, Carnegie Mellon Universities as well a SRI. Any AI research project in the future must be planned on the assumption tha AI research essentially must be viewed over the long run.

Lately an organization called the Center for Study of Language and Information (CSLI) was established at Stanford University. The organization mainly aims to review the natural language understanding research thus far conducted in the AI community and to establish theories of more general languag understanding from the standpoint of elucidating the true nature of language understanding. To achieve these targets, CSLI intends to offer abundant computi power and opportunities of interdisciplinary research to AI researchers, linguists, psychologists and philosophers. Such long-term research efforts will certainly be necessary for the healthy development of AI research, as the proverb says "The farthest way about is the nearest way home."

## 2.4 Social Impact

Artificial intelligence will have an incomparable tremendous and profound influence on society, much more so than the conventional machines which carry c physical labor for humans. Education, economy, medicine, and any other fields related to human intelligence will experience drastic innovation.

AI research is a current of history we cannot stop. AI systems stemming from this domain will cause significant social changes within the next twenty years, and ultimately take a firm hold everywhere in society. In the transient stage prior to the prevalence of AI systems, unnecessary worries are expected to cause confusion. We have to make efforts to position artificial intelligence as ou friend and good partner. We believe we can. To avoid any needless confusion, we have the obligation to intensively consider the value of artificial intelligence and disseminate the results among ordinary people.

## 3.3 Conclusion

AI research entails tough problems concerning the true nature of human intellignece. We have yet to elucidate the true nature of human intelligence; we are currently in the stage where we have just found some clues to these problems The AI research to date has narrowed the target domain to overcome these problems and developed commercial AI systems. The domain-specific systems, however, will soon reach technolgical bounds. What is requried now are research subjects and organizations planned from a long-term perspective. Particularly research themes concerning knowledge, learning and parallel processing seem to the keys to advances in future AI research.

AI research is likely to produce a radical impact on society. To avoid unnecessary confusion expected in the future, we have to actively examine the essential characteristics of artificial intelligence and enlighten our society. Artificial intelligence is the property of all mankind. Therefore AI research and development will have to be carried out through international cooperation and working relationship.

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