PRELIMINARY REPORT ON STUDY AND RESEARCH ON FIFTH-GENERATION COMPUTERS 1979-1980

FALL 1981

JIPDEC

JAPAN INFORMATION PROCESSING DEVELOPMENT CENTER

Japan Information Processing Development Center (JIPDEC)
was established in 1967 with the support of the Government and related industrial circles.
JIPDEC is a non-profit organization aimed at the promotion, research and
development of information processing and information processing industries in Japan.

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CONTENTS

Preface

1. Summary 5

   1.1 Background and significance 5
   1.2 Functional requirements 7
   1.3 Objective and image 9
   1.4 Themes in research and development 12

2. Background and significance of the development program for fifth generation computers 16

   2.1 Social requirements of computers in the 1990's 16
   2.2 Problems with today's computer systems 18
   2.3 The maturing technological foundation and expected new technologies 19
   2.4 Objective and significance of the fifth generation computer project 22

3. Impacts and effects 26

   3.1 Possible impacts of fifth generation computers on society 26
   3.2 Impacts and effects in various applied fields 27

4. Contents of research and development 29

   4.1 Targets of research and development 29
   4.2 The image of the fifth generation computer system 29
   4.3 Research and development themes 38
   4.4 Research and development procedure 67
   4.5 Research and development schedule 77
   4.6 Project organization and execution 85

Preface

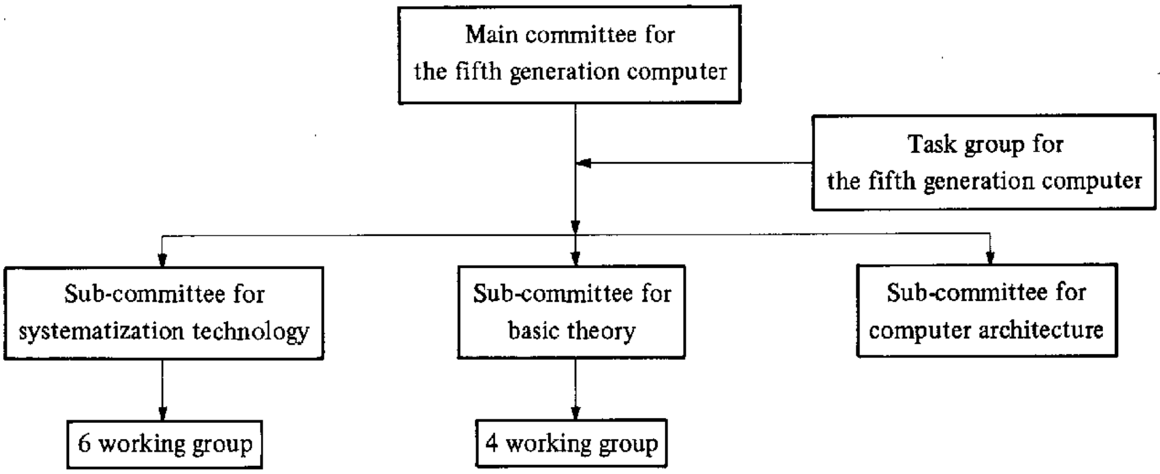
The Japanese economy is caught in the stream of international change and uncertainty, particularly as these are represented by the problems of energy and raw materials. At the same time, the nation is in the process of forming an information-oriented society wherein great importance is coming to be attached to the appropriate processing and utilization of information.

The computer has become an indispensable tool in our use of information. Still, over the next ten years, we are certain to find the need for even more highly sophisticated technology in overcoming the many problems we will come to face, and the realization of computer systems based on new theoretical foundations and technology will be much desired.

It was for these reasons that this Association established a Committee for Study and Research on Fifth-Generation Computers (chairman, Tohru Moto-oka) which, beginning in 1979, set out on a two-year investigation into the most desirable types of computer systems for application in the 1990's (fifth-generation computers) and how the development projects aimed at the realization of these systems should be carried forward.

Presented here is an preliminary report on the findings of the Committee. We sincerely hope that its contents will be of interest to the various circles concerned.

Organization of the Fifth Generation Computer Committee (1980)



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1. SUMMARY

1.1 Background and significance

(1) Social requirements expected of computers in the 1990's

In the 1990's when it is expected that fifth generation computers systems will be in wide use, information processing systems will be central tools in all areas of social activity to include economics, industry, art and science, administration, international relations, education, culture and daily life and so forth. Such information processing systems will be required to meet those new needs generated by environmental changes and will not only be expected to play active roles in the resolving of anticipated social bottlenecks but also to advance society along a more desirable path through the effective utilization of their advanced capabilities.

Information processing systems in the 1990's will be expected to play the following roles:

1) To increase productivity in low-productivity areas.

Although product quality and productivity in the secondary industries have been greatly improved through the adoption of computer controlled manufacturing processes and assembly lines, productivity in the primary industries such as agriculture and fishing and also in the tertiary industries such as goods distribution and public services, has remained little changed. This fact has been the cause of serious social imbalances. Cost reductions via increased efficiency as represented by industrialization and office automation can be expected in these fields as well, as a result of the effective employment of advanced computer systems.

2) To meet international competition and contribute toward international cooperation.

Suffering from a shortage of land and natural resources, it is impossible for Japan to be fully self-sufficient in food, and her ability to supply her own energy and oil needs is the lowest among the developed countries. On the other hand, we do have one precious asset, that is, a highly educated, diligent and top quality labor force, our human resources. It is desirable to utilize this advantage to cultivate information itself as a new resource comparable to food and energy, and information – related knowledge – intensive industries should strongly be promoted to make possible the processing and management of information at will.

Such an effect would not only serve to help our country meet international competition, but would also enable us to make international contributions through knowledge-intensive technology.

3) To assist in saving energy and resources.

One of the most important tasks facing mankind in this century is how to use our worlds finite resources effectively. Paralleling the realization of minimization and optimization of energy consumption, improvement of energy conversion effficiency and simulators for use in developing new sources of energy through the use of computer technology, even the industrial system itself could be expected to change into a knowledge-intensive type information industry which would be typically non-energy consuming.

4) To cope with an aged society.

Our society is aging at an unprecedented rate. Rapid increases in medical expenses and welfare costs together with the relative reduction in the labor force resulting from this aged society could lead to big social problems. Accordingly, utilization of fifth generation computers to prevent the occurrence of or to cope with such problems by way of developing streamlined medical and related information systems, health management systems and lifetime education systems for the aged etc. will be necessary.

(2) Technological background

Computer technology has, from its birth on, consistently and emphatically been aimed at high-speed operation and large capacity, and has been developed mainly for processing numerical calculations. As a result, computers have had significantly limited functions in terms of input and output processing that restricted their applications, and this has caused considerable inconvenience. As applications for computers have become widespread, from the initial scientific and technical computations to the more recent business data processing, there has arisen a strong need for freer input/output capabilities such as by speech or voice, images, graphics and the like, all of which are natural forms of information transmission for man.

The high cost of hardware up to now has not only minimized the number of functions capable of being carried out by it, but has also gradually increased dependence upon software, the proliferation of which has led to a situation called the "software crisis". This problem has had an undesirable side effect in that computer architecture has become stiff and inflexible due to the continued reliance on existing software and is believed to be unable to meet new applications as long as it continues to rely on existing technologies.

From the standpoint of seeds for the development of new technology, a technological basis permiting new architectures and new functions such as improved computer intelligence has matured. This includes VLSI technology which has rapidly advanced in the past few years, the realization of larger capacity memories, increased possibility for developing high-speed elements, promotion of research into artificial intelligence and pattern recognition technology and the technological fusion of communication and information processing among others.

Judging from the relationship between needs and seeds, it is quite natural to hope that information processing systems based on new conceptions and architectures which would prove to be a quantum leap in the computer technology of the past thirty years will appear in about ten years.

(3) Significance of the project

Japan has come to be considered an "economic power" by the other countries of the world. Thus, if we consider the direction in which our industries should proceed, it becomes clear that we no longer need chase the more developed countries, but instead should begin to set goals of leadership and creativity in research and development and to pioneer the promotion of such a project throughout the world.

The significance and effect of the research and development project for fifth generation computers is summarized as follows:

1) By promoting this project, Japan is playing a leading role worldwide in the field of computer technology development. This effort will not only help our computer industry foster more creative technology, but will also provide our country with a means of bargaining power. We can also fulfill our duty as an economic power expected to assume international responsibility by investing in the development of this leading field.

2) In addition to making our society a better, richer one by the 1990's, this project will also prove influential in other areas.

The fifth generation computer is expected to be beneficial in the solution of social bottlenecks such as the energy problem and problems related to an aging society etc. It is also expected to serve as a prime mover in the field of industry by helping those industires experiencing difficulty to improve their efficiency and thus their productivity. Further, society as a whole will become more affluent as computers are applied to increasingly new fields and areas.

3) Developments in heretofore unexplored fields will actively contribute to the progress of all humanity.

Through the promotion of research into artificial intelligence, a better understanding should be gained of the mechanisms of life which future research and development will then concentrate on. The realization of automatic translation into multiple languages will help promote mutual understanding between and among peoples of different tongues and thus aid in reducing trouble due to misunderstandings and ignorance.

With the construction of a knowledge base made possible, the knowledge which man has accumulated over the ages can be stored and effectively utilized, and new kinds of insights and perceptions can be more easily obtained by man with the aid of computers.

4) Experiments for advanced research and development organizations.

It is of great importance to conduct national tests of research and development organizations which have been in existence for a long period of time. The majority of national projects from now on will be required to be carried out by organizations for advanced research and development such as these. Thus tests of these organizations at the national level could be considered a kind of experimental project for future projects. Promotion of this kind of testing project will create an environment which will produce original research based around it.

1.2 Functional requirements

Fifth generation computer systems will be required to have an extremely wide variety of sophisticated functions to solve the numerous problems which todays computers have and to meet the social needs of the 1990's during which decade computerization is expected to find many more applications than nowadays.

As a whole, functions required of fifth generation computer systems will be as follows:

(1) Increased intelligence and ease of use so that they will be better able to assist man.

1) Functions which enable inputting and outputting of information via speech or voice, graphics, images and documents.

Enhancement of input/output functions which serve as the interface between man and computer is of prime importance in making computers easier to use.

In particular, since current computers are quite limited in their input/output functions, the ability to input and output information in a wide variety of forms such as speech or voice, graphics, images, documents and the like man's daily means of transmitting information will be of utmost necessity.

2) The ability to process information conversationally using everyday langauge.

As computers penetrate further and further into every field of our society, there will be more opportunities for laymen to operate them and thus gain direct access to needed information. Therefore, the ability to communicate conversationally with a computer using everyday language will prove most beneficial.

3) The ability to put stored knowledge to practical use.

The ability to handle information in speech, graph or natural language form does not end with the input function, but rather such a computer can only fulfill its purpose if backed up with the knowledge to comprehended that input information.

In order to be able to utilize computers more effectively as tools for solving various problems, they will have to be equipped with specialized knowledge i.e. knowledge bases, related to the fields in which they are employed. Then by putting these knowledge bases to practical use computers will be better able to lessen the burden on their human operators as well as serve a role as consultant systems for all mankind.

4) The functions of learning, associating and infering.

So that computers have knowledge and can sufficiently use it for a desired purpose, they should be given in one form or another abilities of learning, associating and infering just like ours. With such abilities, computers would be able to clarify even vague requests given by man and using their vast ability to store information achieve new judgement facilities of their own which will help expand the capabilities of we humans as well.

(2) Lessening the burden of software generation.

1) Automated processing based on the input description of requirement specifications.

The cost of the development of software is now greater than that of hardware, and there will be increasing needs for software in the future. In such a situation, it is necessary to raise the proportion of automated programming in software development.

For example, an ideal process is one where a computer processing procedure is synthesized directly from requirement specifications described in a natural language, generated and performed.

2) Realization of a language capable of program verification and a suitable architecture.

A programming language is a direct interface between man and machine in the development of a program. The ease with which the programming language can be used and language specifications functions greatly influence the degree of difficulty of software development. Moreover, it is desired that in future ultra high-level languages with a high degree of verifiability to enhance reliability of software appear, and a machine be realized which has architectures suitable for processing such languages.

3) Improvement of environments for programming and realization of intelligent interfaces.

To improve programming productivity, not only language would be improved, but also programming environments should greatly be improved to provide intelligent interfaces between users and systems. Such requirements are common in every form of computer access such as data base access for retrieving desired information out of a great amount of information, or a knowledge base access for gaining a new perception to cope with an unknown problem.

4) Utilization of existing software assets.

As computer functions and performance are improved, new applications will increase to the point where conventional computers will not be able to deal with them. However, it will be desirable to utilize software developed to date as much as possible. To this end, systems will be preferred which are flexible enough to run software based on conventional architectures.

(3) Improved overall functions and performance to meet social needs.

1) Improved cost/performance.

It is a common principle to all industrial products that technological progress improve the cost/performance of products. In the 1990's, the cost/performance of hardware and software combined should be improved significantly.

2) Light, compact computers.

Computers are expected to be lighter and smaller as the technology of integration of devices progresses. The 1990's should find portable, high-function computers, multilingual translating machines, and industrial products equipped with high-performance computers.

3) High-speed, large-capacity computers to meet new applications.

It can be said that demands on speed of processing and memory capacity as basic computer abilities are and will be limitless. Many problems that are considered unprocessable by conventional machines will appear as new applications as processing speed and memory capacity increase. Realization of the intelligent system, described above, is dependent on great improvements in these basic performances. With these improvements, unknown situations can be simulated with high precision to assist in widening our ability to solve problems.

4) Increased diversification and adaptability.

Up to now general-purpose computers with fixed hardware have been in the mainstream, but computer systems in the 1990's will be required to have much wider diversification and purpose-oriented adaptability and flexibility. Hardware and software both should have their basic components modularized for free system adaptability and rearrangeability to suit various purposes.

5) Highly reliable functions.

As computers find their way into more and more field area of our society, they are likely to cause much more damage when they get malfunction. Therefore, constructing highly-reliable systems is an absolute requisite for future society. Computer systems should not only be equipped with functions to automatically detect and repair their own malfunctions, but should also be capable of preventing the danger of a runaway computer by means of malfunction prevention devices and the aforementioned improved machine intelligence.

6) Sophisticated function for the protection of secrets.

Social computer systems will be largely expected to serve as social utilities and thus will have to be equipped with sophisticated functions for the protection of secrets. These systems will also be required to have built-in mechanisms for preventing computer crimes and unauthorized use of computers.

1.3 Objective and image

The Fifth Generation Computer Systems will be knowledge information processing systems based on innovative theories and technologies that can offer the advanced functions expected to be required in the 1990's, overcoming the technical limitations inherent in conventional computers.

1.3.1 Basic concept

The Fifth Generation Computer Systems will be knowledge information processing systems having problem-solving functions of a very high level. In these systems, intelligence will be greatly imporved to approach that of a human being, and, when compared with conventional systems, man-machine interface will become closer to the human system. Figure 1-1 shows a conceptual diagram of the Fifth Generation Computer Systems. As shown in the figure, a powerful problem-solving mechanism based on problem understanding and inference functions, knowledge bases, etc. are found between the human system and the conventional machine functions. In addition to that models will be realized principally through software, and the machine principally through hardware, and the Fifth Generation Computer Systems will perform the following functions as integrated capacities:

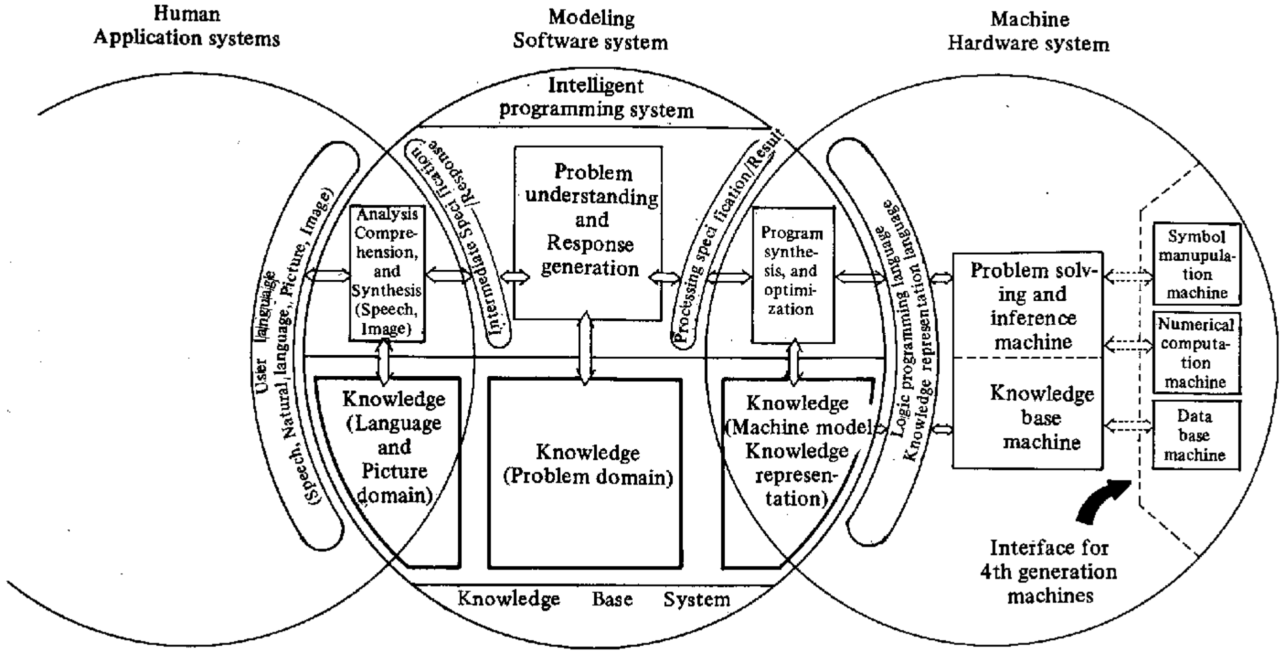

Fig. 1-1 Conceptual diagram of the fifth generation computer systems

1) Understanding of problem description and requirement specifications
2) Synthesizing processing procedures
3) Optimization between machine system and processing procedures
4) Synthesizing response based on outputs from machine system
5) Intelligent interface functions capable of understanding speech, image and natural language, etc.

The knowledge bases that support the above functions will contain knowledge of the following types:

1) Knowledge of the languages to be used for man machine communication
2) Knowledge on the problem areas to be solved
3) Knowledge on the machine systems

1.3.2 Constituent elements of software system

Figure 1-2 shows the system configuration image.

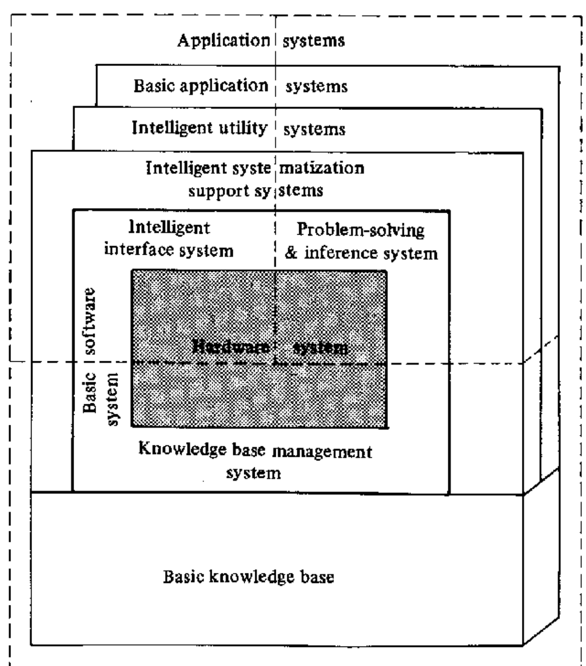

Fig. 1-2 Configuration of the fifth generation computer software system

These constituent elements perform the following functions:

(1) Basic software system

The basic software system forms the core of the software system, and consists of the three subsystems of Problem-solving and inference, Knowledge base management and Intelligent interface which are the basic functions of the Fifth Generation Computer Systems.

(2) Intelligent systematization support system

The system provides the human designer intelligent functions to strongly support systematization work based on the knowledge base contents and it consists of three subsystems of Intelligent programming, Knowledge base designing and Intelligent VLSI designing.

(3) Intelligent utility system

This system has such functions as to enable the user easy use of the entire computer system and make the system highly reliable.

These include programs to support the portability of software and database from other machines, user guidance functions, and automatic inspection and repair functions for the prevention and detection of failures.

(4) Basic knowledge base

The basic knowledge base supports the operation of the system itself in addition to containing the accumulated valid and universal knowledge necessary to the user. Generally, there are three types; the general knowledge base that mainly relates to the understanding of natural languages, the system knowledge base related to the system itself and the applied knowledge base containing specialized knowledge for various applications.

(5) Basic application system

The following types of basic application systems can be cited:

. Machine translation system
. Question-answering system
. Applied speech understanding system
. Applied picture and image understanding system
. Applied problem solving system

(6) Application systems

The following systems can be thought of as examples of knowledge information processing application systems:

. Intelligent CAE/CAD system(Note 1)
. Intelligent CAI system
. Intelligent OA system
. Intelligent Robot

1.3.3 Configuration image of the hardware system

The Fifth Generation Computer Systems should consist of all levels, from small to large scale machines, in order to process diversified applications. The machines of all performance levels must have common languages as well as the following three basic functions. The remarks in parentheses indicate the correspondence with conventional computer systems.

1) Problem-solving and inference machine (Central processing unit)
2) Knowledge base machine (Main memory with virtual memory facilities and file system)
3) Intelligent interface machine (Input/output channels and Input/output devices)

There will be machines of several performance levels in each of these small to large computer systems, to permit system configurations which emphasize any of the several

(Note 1)

CAE: Computer Aided Engineering
CAD: Computer Aided Design
CAI: Computer Assisted Instruction
OA: Office Automation

functions by application or purpose of use.

Figure 1-3 shows a configuration image of the Fifth Generation Computer Systems. The machines are to be structured according to function on various new architectures, including a data flow machine, which are based on VLSI architecture and each system is to be a combination of machines suitable for various individual applications or needs.

Furthermore, from a macro configuration point of view, having the system shown in the figure below as one of the principal elements, a multiple system form of usage where this would be connected to a local or global network and the whole network then be utilized as a large-scale distributed processing system, is also being envisioned.

1.4 Themes in research and development

Themes in research and development of the fifth generation computer systems are shown in Table 1-1, which contain seven groups and twenty six themes. The research and development are classified into four divisions as shown in Figure 1-4. The program will be affected at early, intermediate and final stages during which times achievements will be continuously re-evaluated with new trends in technology in view. It is planned to complete proto-types of the fifth generation computer system in the target year of 1990.

For the smooth accomplishment of this research and development program, it is indispensable also to develop and complete as soon as possible powerful support systems such as software-developing tools, high-function personal computers, VLSI-CAD, computer network systems, and the like.

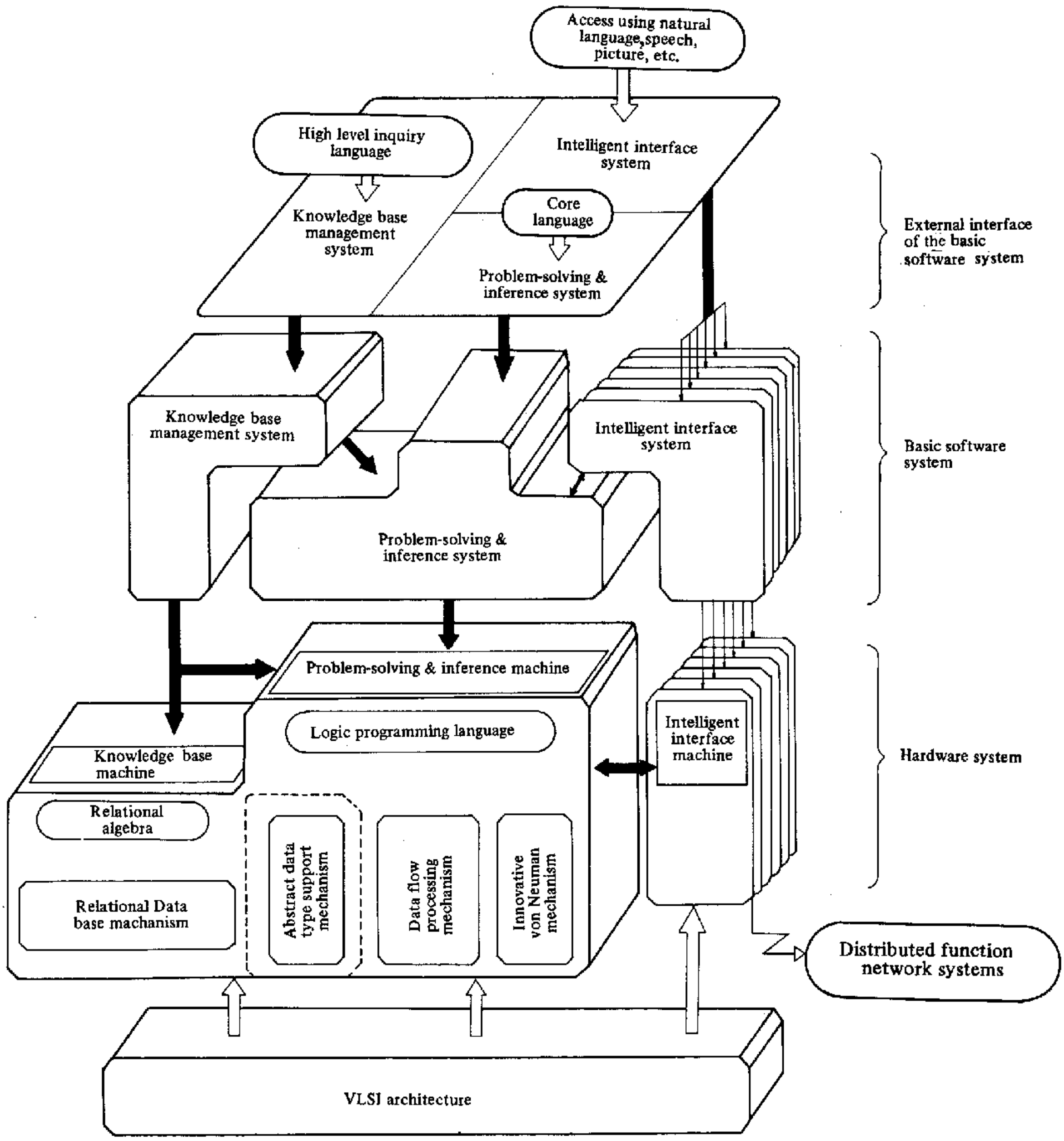

Fig. 1-3 Basic configuration image of the fifth generation computer systems

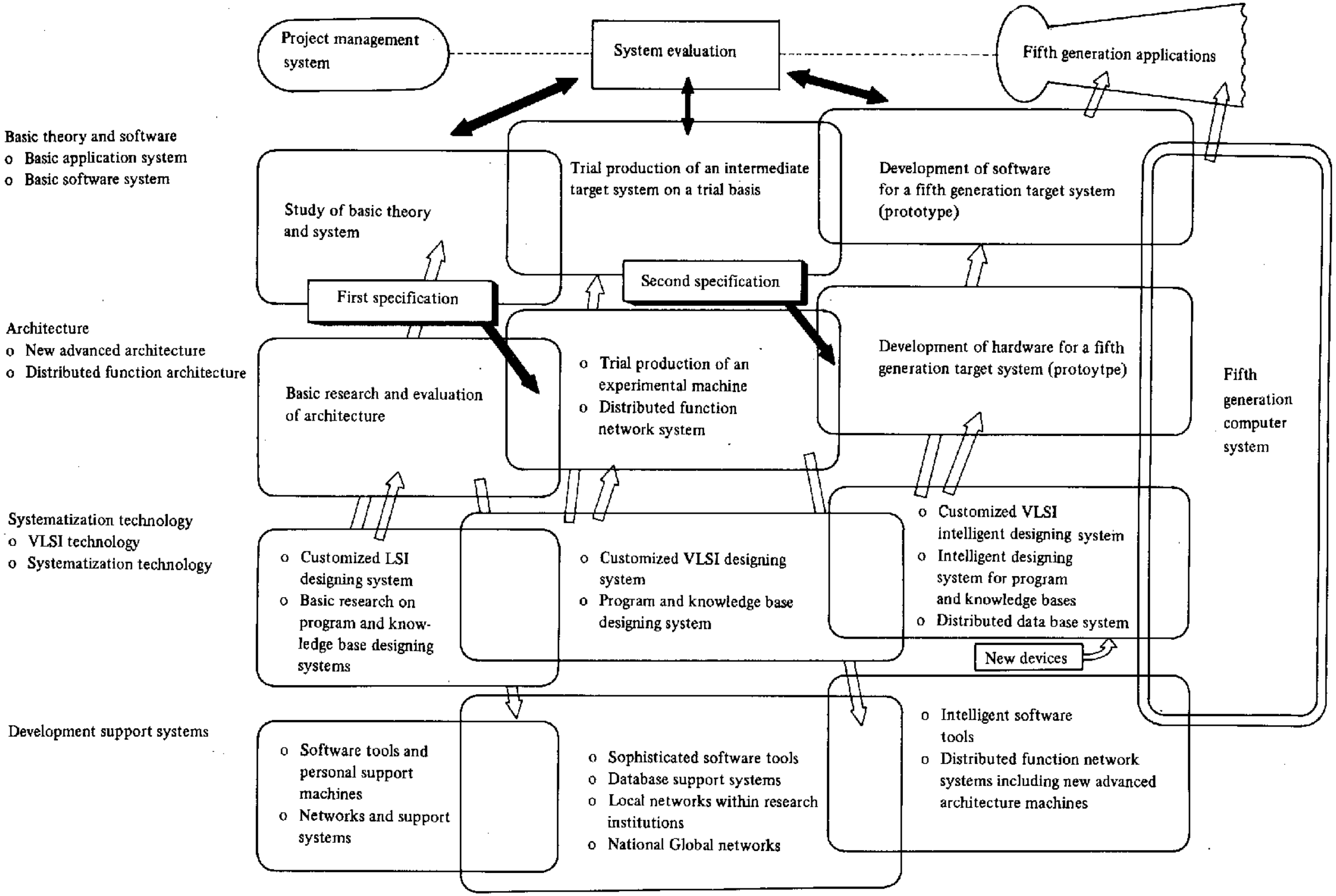

Fig. 1-4 Concept diagram showing how research and dvelopment are to progress

Table 1-1 Themes in research and development of the fifth generation computer system

Basic application systems	1–1) 1–2) 1–3) 1–4) 1–5)	Machine translation system Question answering system Applied speech understanding system Applied picture and image understanding system Applied problem solving system
Basic software systems	2–1) 2–2) 2–3)	Knowledge base management system Problem solving and inference system Intelligent interface system
New advanced architecture	3–1) 3–2) 3–3) 3–4) 3–5) 3–6)	Logic programming machine Functional machine Relational algebra machine Abstract data type support machine Data flow machine Innovative von Neumann machine
Distributed function architecture	4–1) 4–2) 4–3) 4–4) 4–5)	Distributed function architecture Network architecture Data base machine High-speed numerical computation machine High-level man-machine communication system
VLSI technology	5–1) 5–2)	VLSI architecture Intelligent VLSI CAD system
Systematization technology	6–1) 6–2) 6–3) 6–4)	Intelligent programming system Knowledge base design system Systematization technology for computer architecture Data base and distributed data base system
Development supporting technology	7–1)	Development support system

2. BACKGROUND AND SIGNIFICANCE OF THE DEVELOPMENT PROGRAM FOR FIFTH GENERATION COMPUTERS

2.1 Social requirements of computers in the 1990's

Our society is about to enter a transition period in various meanings of the term. It is an age of changes in internal and external environmental conditions such as the energy situation, and together with building a wealthy, liberal society, and overcoming the constrains of resources and energy, we must at the same time make international contributions as an economic power.

In making our way through this new age, informationization and the information industry which centers around computers are expected to play a big role. In 1990's when fifth generation computers will be widely used, information processing systems will be a central tool in all areas of social activity to include economics, industry, science and art, administration, interantional relations, education, culture, daily life and the like, and will be required to meet those new needs generated by environmental changes. Information processing systems will be expected to play an active role in the resolving of anticipated social bottlenecks and the advancing of society along a more desirable path through the effective utilization of their capabilities.

If we try to form an image of how society ought to be in the 1990's, information processing systems will be expected to play the following roles to achieve such a society:

(1) To increase productivity in low-productivity areas

Although product quality and productivity in the secondary industries have been improved through the adoption of computer controlled manufacturing processes and assembly lines, and a further improvement of productivity in the secondary industries can be expected with the use of industrial robots, productivity in the primary industries such as agriculture and fishing and the tertiary industries such as goods distribution and public services have remained almost the same. Examples of low-productivity areas are documents processing, office management, and decision making in management, and the ultimate purpose of office automation can be said to be increasing productivity in such areas.

Future images of office automation are:

1) Japanized office automation capable of processing the Japanese languages in a natural way;
2) Irregular or non-fixed job processing systems capable of freely handling non-numerical data such as documents, graphics, images, speech and voice, etc.;
3) Consultation and expert systems having inference and learning mechanisms of their own and capable of storing knowledge and providing adequate information as desired; and
4) Various data bases for providing high-level information necessary for decision making, and man-machine interfaces supported by artificial intelligence technology for making and supporting decisions.

(2) To meet international competition and contribute toward international cooperation

Japan, which has shortage of land and a population density about 40 times that of the United States cannot attain self-sufficiency in food, and her rate of self-sufficiency in energy is about 15% and that of oil about 0.3%. On the other hand, we have one precious asset, that is, our human resources, Japan's plentiful labor force is characterized by high degree of education, diligence, and high quality. It is desirable to utilize this advantage to cultivate information itself as a new resource comparable to food and energy, and to emphasize the development of information-related knowledge-intensive industries which make possible the processing and managing of information at will.

Such an effort would not only serve to help our country meet international competition, but would also enables us to make international contributions through knowledge-intensive technology.

We have to be internationally competitive and at the same time cooperative in the following subjects:

1) Construction and maintenance of various data bases;
2) Smoothing international exchanges through the development of translation-assisting and interpreting systems;
3) Improvement of productivity with the aid of intelligent robots; and
4) Accelerating research and development by using intelligent CAD systems.

Although we have mainly followed the head of other countries in computer technology up to now, it's time for us to break with this outmaded tradition, and center our efforts on the development of new computer technology based on our own conceptions, so that we can provide the world with new technology with a view to promoting international cooperation.

(3) To assist in saving energy and resources

One of the most important tasks facing mankind in this century is the effective use of finite resources. The information industry should cope with such problems by way of:

1) Minimization and optimization of energy consumption;
2) Improvement of energy conversion efficiency;
3) Simulators for use in developing new sources of energy;
4) Reduction of energy consumption in production through CAD/CAM*;
5) Extension of product service life through damage detection and automatic recovery; and
6) Reduction of movement of people through propagation of distributed systems.

Needless to say, the information industry itself is a typical knowledge-intensive non-consumptive industry.

(4) To cope with an aged society

People 65 years of age or older will make up 12% of the entire population of our country in 1990. Our society is aging of an unprecedented rate. Accordingly, a great increase in medical expenses and welfare costs together with a relative reduction in the labor force could become big social problems. Active contributions should be made to prepare for such problems by way of:

1) Improvement and streamlining of medical and realted information processing systems and helath management systems;
2) Development of systems for helping the physically handicapped get active;
3) Development of CAI system for the lifetime education of the aged; and
4) Development of distributed processing systems for enabling people to work at home.

As the society becomes more and more information-centered, computers and society will be related to each other in more complicated and diversified ways. Computers must be tools that can coexist with human beings. It is important to develop the information industry with meticulous care so as not to allow the rulers of countries to use computers as a tool for governing people and also not to let computers turn against mankind. Fifth generation computers should therefore be developed with a view to making them both usable and likable.

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* CAM: Computer Aided Manufacturing

2.2 Problems with today's computer systems

Computer technology-has, from its birth on, almost consistently been aimed at high-speed operation and large capacity, and has features enumerated below:

(1) Computers are designed mainly for carrying out numerical calculations irrespective of whether they are of scientific use or business use, and have a minimized function to process character or image data and the like.

(2) Since the cost of hardware has been high as can be seen from sequential control of stored program systems, the basic design idea is that the functions are minimized and put to use at a high rate of efficiency.

(3) To improve cost performance ratio has been to centralize processing and make systems more huge, because high-speed operation and large capacity are indispensable.

(4) In order to operate a huge system and use it efficiently, the proportion of the cost of developing software has gradually been increased, resulting in unification of architectures.

From the standpoint of recent technological advancements surrounding computers and changes in user demands, distinguishing characteristics associated with conventional technology can be described as follows:

(1) Today's computers are not equipped with the necessary functions and voice to process non-numerical data such as sentences, symbols, speech and voice, graphics, and images, etc. However computers are expected to be developed which will be capable of associative and inference processing such as pattern matching functions which deserve the name of artificial intelligence. Computers such as these will be required to widen the areas in which information processing can be applied, diversify the forms of processing, and realize information systems that have a high level of intelligence. Compueters with new architectures are also hoped for which not only have increased processing capabilities, but also can put to practical use information management such as data bases and knowledge bases. Computers with new processing functions are desired to improve man-machine interface by developing easy-to-use computers capable of being good assistants for man and to effectively extend the range of the human senses.

(2) The performance of conventional computers has been increased largely through improvements made to their separate elements, and efforts to improve the system itself have thus far proven fruitless. However, since the high-speed operation of elements themselves has a limitation imposed by the speed of light, combined efforts from the standpoint of both elements and systems should be made from now on to improve the performance of computers of effort made thus far in terms of systems is parallel processing. This is not only essential for large-scale numerical calculation such as partial differential equations and for simulators for various systems, but is also needed for speeding up inference and associative processings. Various parallel control systems should be put to practical use which include proposed data flow control that is basically different from conventional sequential control.

(3) Due to the diversification of fields of application and advancements in LSI technology, the merits of distributed processing have come to be looked at in a new light. Distribution of processing can roughly be grouped into two categories. One is a regional distribution form in which processing functions and data bases are located near persons in charge so that various resources such as hardware, software, database and the like can be shared by many through communications lines. The other system comprises distributed functions wherein processors of different kinds designed for dedicated uses are con-

nected to each other via high-speed buses and the like, thus replacing a system having a relatively small number of processors of one kind connected to a common main memory. The former should serve as a means for realizing a huge information system designed from the standpoint of users, and the latter should be put to practical use as a means for realizing systems which meet diversified demands.

(4) The cost of software development is ever increasing, but many difficulties have been encountered in improving the productivity of said. While architectures have been proposed which can accept high-level languages with ease, and attempts have gradually been made to change OS into firmware, emphasis is still placed on the utilization of software heretofore accumulated, and old and inconvenient architectures are followed. Efforts are required to prepare environments in which architectures suited for the new age centering around new applied fields or areas can be introduced. When software can be programmed with increased productivity as a consequence, diversified architectures will also be made possible thus opening up prospects for future computer science and engineering.

2.3 The maturing technological foundation and expected new technologies

Technologies surrounding computers, including LSI, have achieved epoch-making advancements during the past ten years in various fields, and can, moreover, be expected to attain even greater technical advancements during the next ten years.

Principal seed technologies to be introduced for the development of computers in the 1990's are set forth below:

(1) VLSI technology

To achieve a quantum leap in the computer technology of the future, it is essential to introduce LSIs and VLSIs fully into computer technology. Although these devices have been smoothly introduced into memories, evolution of storage systems in which a logic and memory are combined, such as an associative, will be of great importance.

Microprocessors were the first step toward the introduction of logic devices and it will be possible within a few years for a current large-size processor with about one hundred thousand gates to be produced on a single chip by way of VLSI technology. Such a possibility will undermine conventional computer technology which has advanced via the effective utilization of simple logic (circuits) serving as a central standard for evaluation. Stated otherwise, a technological foundation is in the process of being matured which will allow computers totally different from those existing today, something similar to artificial brains, to appear.

On one hand, individuals will be able to have personal computers which are comparable in function and performance with present day large-size computers and, on the other hand by reevaluating package systems of various functions which have thus far been considered impractical new computers having advanced functions and performance will make possible the opening of new fields of application.

VLSIs are not omnipotent, but rather have the following limitations:

1) Integration on a small area is required;
2) Wiring areas needed for connection are almost as important as the device area; and
3) Although repetive patterns can be designed with ease, many difficulties arise in designing error-free completely random patterns for large-scale systems.

To get the most out of VLSI technology, it is necessary to back to algorithms for a logic arrangement suitable for the two-dimensional structure of VLSIs, and to realize an integrated VLSI.CAD system including an evaluating simulator and a test data preparation system for a design free of errors. One ideal is to construct an intelligent CAD system centered around a knowledge base that will enable the smooth reutilization of data used in past designing and provide the designer with a supplementary source of knowledge.

(2) High-speed device technology

It is an important task to introduce into computer technology devices such as Josephson junctions or GaAs devices which can operate faster than silicon devices by more than one figure in unit time. Although the development of devices themselves is not the subject of the present program, (this task has been assigned to another project), this does not mean that we deny the importance of the development of devices. In order for these devices to be introduced into computers, VLSI technology utilizing such devices will have to be established. Since the establishment of such technology takes many years to achieve it appears impossible to consider fifth generation computer architectures premised on the technology of these devices because of the time factors involved, and hence these new devices themselves are excluded from the present program. However, the progress of the development of these devices should be watched so that they can be incorporated into the project at some intermediate stage of the fifth generation computer's development should these new devices prove sufficiently practical and capable of superior performance.

High-speed operation rendered possible by such devices tends to result directly in improved computer performance, and the construction of device-oriented systems is not nearly as difficult as for that of parallel systems. In addition to their high-speed operation, Josephson junctions are advantageous in that they require substantially no energy in storing information. Therefore, development of devices such as these should be carefully watched.

Optical technology should find a wide variety of applications in such areas as input and output devices and data transmission, and is also expected to prove useful in the area of peripheral memory technology, especially as a means for storing a knowledge base which requires no rewriting. Optical communication technology is suitable for high-speed data transmission, and can be utilized right now for high-performance local networks within a single building or premise. This technology will be a prime mover in the development of distributed environments described later on.

(3) Fusion with communication technology

The VLSI technology is oriented toward mass production, and calls for the extensive use of a single VLSI chip. If we consider VLSI's from the standpoint of architecture and systematization technologies, one possibility is load and function distribution due to miniaturization capabilities, and another is parallel processing which will be described below.

For the promotion of distributed processing technology, communication technology and computer technology will have to be more closely united.

It is necessary to establish a technoology which can connect a local network associated closely with a computer to a global network used for communication, and then to establish a system for allowing jobs and data bases to be distributed readily. Attempts have steadily been made to provide a foundation for realization of the foregoing technology and system, the technology of optical communication being an example. A wide variety of efforts ranging from technological research and development to standardization should further be made by those concerned.

One ideal to be realized toward and in the 1990's is either a nationwide or worldwide information system which utilizes a communication network for making correct and precise information readily available anywhere.

(4) Parallel processing technology

High-speed operation resulting from advanced devices is limited by the speed of light, and the paralleling of computers by means of pipe-line and SIMD* systems has been progressing. The fields in which high-speed operation has been most required are the area of large-scale numerical calculations such as solving partial differential equations and the field of simulators for large-scale systems. With the advance of LSIs, parallel computers have found a variety of applications and are expected to progress further, but control systems for these are limited by the fact that they can be commonly used for a wide variety of applications. Control systems based on data flow are now being widely accepted as systems capable of utilizing in its natural form, the parallelism possessed by algorithms. These systems are also considered capable of incorporating LSIs. Since such things as inference mechanisms, which will be described later on, are recognized as having an essentially large number of parallelisms, data flow machines are expected to become an an effective means of eliminating the many bottlenecks experienced with today's computers.

(5) Software technology

It has been pointed out for a long time that software is an impediment in the construction of information systems, and that its development and maintenance involve a lot of expense means of solving these problems have been researched as a part of software engineering, and many proposals have been made for the improvement of software productivity, some of which have been incorporated into high-level programming languages. Some examples of these are modularization, data abstraction, functional languages, non-procedural languages, and single assignment languages. Not only is reflecting the special features possessed by these languages in computer architectures necessary to efficiency process jobs described by these high-level language, but also, many functions are difficult to package without the aid of hardware.

The development of basic theories for programming and associated proposals for new computation models cannot be utilized without architectures and languages which have these as their premise. Thus, fixed architectures pose the danger of blocking the sound development of information technology as a whole.

On the other hand program verification and automatic synthesis technologies have steadily progressed. Although fully automated program rewriting to accompany architectural changes are impossible for the time being, it seems possible to construct systems for helping rewrite programs and greatly reducing the interposition of human hands. Such systems could be used to prepare new programs and effect program rewriting resulting from changes in specifications. In this way, the software crisis might also be avoided.

The realization of a highly intelligent support system for software generation is one of the ideals that fifth generation computers are aiming at.

(6) Artificial intellignece and pattern recognition technologies

Research into systems or highly intelligent robots which can understand the everyday conversation of human beings, know what it means, seek solutions and give answers together with machine translation and theorem proving as new computer applications, has been in progress from a relatively early stage. The study of some subjects, such as machine translation, though once considered readily realizable, has declined do to

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* SIMD: Single Instruction Multi-Data stream

their proving to difficult to accomplish.

Languages and knowledge have been steadily studied as subjects of artificial intelligence, to produce many fruitful results. We have now reached the stage where the understanding of natural languages and the structuralization of knowledge data are nearing our grasp. However, this research still hasn't advanced beyond the basic level, being limited to the world of small vocabularies and narrow subjects. Problems which will be encountered when the foregoing technologies become practical have yet to be studied. The reasons for this are as follows:

1) Researchers of basic studies tend to be satisfied with solving problems in principle, and to have less interest in putting their subjects to practical use;
2) Computers at present have architectures designed mainly for numerical calculation, and as such have almost no functions, such as inference mechanisms, required for artificial intelligence. Therefore, processing takes a long time, and they are impractical for large-scale experiments; and
3) A lot of manpower is needed to prepare and input data and programs necessary for experiments.

Since the most detrimental of these reasons is the insufficiency of computer performance, it is important to smoothly promote the present program so that a computer system geared for artificial intelligence can be developed at an early stage of the project thus making its resources available to researchers of artificial intelligence.

The same can be said about the technology of recognition and understanding of patterns such as graphics, images, speech, voice and characters, etc. Computers with architectures suitable for pattern processing are necessary if we are to utilize computers to promote our research, realize a natural man-machine interface and further expand the realm of our senses. Since this will also be important as a facility for promoting basic research in stages prior to that, such a computer should be developed as a research-support system at an early stage of this project.

2.4 Objectives and significance of the fifth generation computer project

Fifth generation computers should be equipped with functions that will serve to eliminate social bottlenecks expected to appear in the 1990's, functions which today's computers lack. These can be summarized as the following four tasks:

(1) To increase the level of computer intelligence as well as their affinity for cooperation with man.

The five human senses can fulfil their functions only when backed up by the knowledge necessary to understand the information obtained through them. In order to raise the level of computer intelligence and increase their affinity for cooperation with man, it is absolutely essential to provide these computers one way or another with knowledge related to their respective fields of application and the means for putting these to practical use. It will also be nécessary to develop a computer equipped with associative inference, and learning functions to process that knowledges more effectively.

Such requirements can be met by improving man-machine interface, and further researching understanding patterns such as speech, voice, graphics, images and objects, the comprehension of daily language, and knowledge bases.

(2) To process the ability to act on behalf of human beings as well as the ability to assist man in the development of unknown fields.

So that man and computers will be better able to share the burden of work related to environmental changes in our society, such as energy conservation and problems related to the aged etc., the intelligence level of computers will have to be increased to the extent where they can comprehend the environment. So as to expand the capabilities of our sensory organs with the aid of computers, development of sensor technology, and functions such as pattern collating abilities where a computer is connected to these sensors to extract the distinctive features of what is sensed, as well as a parallel processing ability for real time processing is necessary.

(3) To enable various forms of information to be made readily and easily available when necessary.

The information available through present information processing systems is highly limited with respect to the kinds, amounts and forms of information we come in contact with in our society. It is necessary to reduce the gap and facilitate instant access to a greater amount and wider variety of information. It is also important to develop a means of access which enables the easy and accurate retrieval of information needed at that time. Also important is a support system for clarifying the many vague requests made in the real world an essential technology for enabling computers to be applied to non-standardized jobs such as CAD and decision making support systems.

Computer networks which are capable of accessing dstributed data based, and knowledge bases capable of understanding the meaning of questions and giving answers are also important.

(4) Acquisition of new perceptions by simulating unknown situations.

It is expected that we will be able to acquire knowledge of unknown situations by means of large scale simulations in a variety of fields such as science and technology, management, administration, and society. Through realization of ultra-high-speed computers using high-speed devices and parallel processing, precise simulation will be made possible in fields where simulation had been impossible to date.

From the standpoint of the user, fifth generation computers should functions like the five which are enumerated below:

(1) Easy to use functions capable of being utilized even without professional knowledge.

Systems of this kind should be equipped with

1) functions for the inputting and outputting of information by way of sentences, speech and voice, graphics, images and the like,
2) functions for the processing of information in a conversational manner by means of daily language and graphs, and
3) functions for storing common knowledge as well as ones capable of utilizing the specialized knowledge for each field of application.

(2) Human substitute functions capable of judgement and decision making.

Ideally, judgements involving logic should be left up to the computer while the data necessary for important decision makings, is provided for man.

The following abilities should be developed:

1) functions which enable automatic retrieval of related information out of vast amounts of stored data in response to inquires,
2) functions which enable conclusions to be drawn from inferences based on stored data when an unknown problem is given, and
3) functions capable of learning and storing for subsequent use solutions to new problems.

(3) Functions capable of flexible configurations applicable to a wide range of jobs.

In order to be able to freely select efficient system configuratons responsibe to various non-standardized jobs in a wide variety of applied fields, the following are required:

1) functions capable of constructing system optimum for needs in question,
2) functions capable of handling large-scale computation processing and management of a large quantity of data as desired, and
3) functions that can easily be upgraded on a building block system to meet increased jobs.

(4) Functions for facilitating programming

Effective utilization of accumulated software and improvement of software productivity require:

1) functions enabling a computer to write and modify its own programs,
2) functions enabling a computer to judge and process matters of common sense without instructions from man, and
3) function able to cope easily with different types of computers as well as additions to existing equipment.

(5) System functions which are reliable and can be used expediently.

From the standpoint of system configurations, the following are necessary:

1) compact system functions having higher cost performance ratios,
2) system functions capable of sophisticated distributed processing between distant points,
3) highly reliable functions such as, functions able to recover automatically and minimize the adverse effects of malfunctions, as well as functions to facilitate verification, and system functions of high maintainability, and
4) sophisticated functions to protect secrets.

Japan has come to be called an "economic power" thanks to the remarkable growth of our various industries. But when we considered the future course of these industries, it is important to stop playing "catch-up" with the more advanced countries and to set goals of leadership and creativity in research and development, and to search for a research and development system suitable for such an aim. Promoting a national project such as this in the computer industry which has a strong effect on various leading technologies, will probably greatly influences the way in which research and development systems will be made in other industrial fields.

The role and effects of the research and development project for fifth generation computers is summarized as follows:

(1) By promoting this project, our country will play a world leading role in the field of computer technology development. Our efforts will not only foster creative technology for our own computer industry, but will also provide our country with bargaining power. We also fulfil our duty as an economic power by investing in the development of such leading fields.

(2) This project will enrich the society of the 1990's and produce other effects.

This project is expected be beneficial in the solution of social bottlenecks such as the energy problem, the ageing of society and the like, and to serve as an active prime mover in all industrial fields by helping increase efficiency in those areas were increasing productivity has proven difficult, with the aid of CAD and management decision-making support systems. An increase in the intelligence level of industrial robots will result in improved product quality and energy saving. As industrial robots are applied to the primary industries, productivity in these fields will also increase, and workers no longer suffer from poor working environments should have less accidents.

Elimination of the software crisis will not only allow us to challenge the construction of more sophisticated systems, but will also serve to remove the negative aspects brought about by computerization, such as computer crimes.

(3) Development in unexplored fields can contribute actively to the progress of human society.

By promoting the study of artificial intelligence and realizing intelligent robots, a better understanding of the mechanisms of life will become possible. The approaching realization of automatic interpretation and translation will serve to help people of different tongues understand each other, to reduce troubles due to misunderstanding and ignorance, and to lead to further growth based on mutual understanding of cultures. With the construction of a knowledge base made possible, the knowledge which mankind has accumulated can be stored and effectively utilized, so that the development of culture as a whole can be rapidly promoted. Mankind will more easily be able to acquire insights and perceptions with the aid of computers.

(4) Experiments for leading research and development organizations.

It is extremely important to test at the national level the leading organizations for research and development which have been in operation for a long time. Almost all national projects from now on will be required to be carried out by leading research and development organizations such as this, and the present program can be looked upon as a kind of experimental project for future projects. Promotion of such a project creates an environment conducive to producing original studies based around it.

3. IMPACTS AND EFFECTS

3.1 Possible impacts of fifth generation computers on society

It is necessary for us to try to foresee every possible impact that fifth generation computers will have on functions and systems of our society.

(1) Elimination of social distortions resulting from differences between low-productivity and high-productivity fields

Increases in the cost of goods such as products, services and others is in inverse proportion to increases in productivity. Industrial fields in which no increased productivity can be expected, are producing goods at ever increasing costs which will reach an unbearable point. The result is that such industrial fields will either decline in or disappear altogether from society.

Fifth generation computers are expected to function extremely effectively in all fields of society. First they will take the place of man in the area of physical labor, and through the intellectualization of these advanced computers totally new applied fields will be developed, social productivity will be increased, and distortions in values will be eliminated. As an example, there are indications that the agriculture and fishery industries might be changed into food industries which would function effectively enough to give Japan full self-sufficiency in food.

Fifth generation computers are also expected to greatly improve the low levels of productivity being experienced in the fields of medical treatment and education, and to play a big role in the distribution of information.

(2) Expansion of man's abilities

Heretofore, increasing productivity has been accomplished only through improvements in the efficiency of man's labor. In the future, we should let machines do what they can do for increased productivity, and should concentrate our efforts on those things that only human beings can do. Fifth generation computers can play an important role in anplifying an intelligent ability which only mankind can have. Representative for performing this task are DSS*, CAE/CAD.

(3) Impacts on individuals

Today's informationalized society appears to be flooded with a great amount of information. Considerable efforts are necessary for people to obtain only that information they desire and to form unbiased judgments on it. Thus, there is no general guarantee that their conclusions will be reasonable ones. Such a situation is sure to lead people to doubt the merits of the utilization of information.

This tendency is quite disadvantageous to the progress of information technology. One of the expectations for fifth generation computers concerns the great progress which is likely to be made in the relationship between individuals and information. This will stem from the fact that anyone will be able to converse with computers even without a professional knowledge of them, even if everyday natural language is used, the computers will be able to understand our thoughts, and give us suitable answers. Although we have heretofore had to adapt ourselves to machines in order to get results, in the future machines will become much more 'human' in their ability to handle our requests.

(4) New Society

It is difficult to foresee exactly what form the forthcoming new society will take. In the 1990's, by means of the realization of fifth generation computers we would like to expect that the numerous tasks outlined by the Subcommittee for Research into Social Environmental Conditions will be capable of being

* DSS: Decision Support System

solved. But perhaps even more than this, it is felt certain that fifth generation computers will trigger the realization of developments and phenomena heretofore undreamed of.

3.2 Impact and effects in various applied fields

The following are some effects that fifth generation computers can be expected to have on main fields which will be rapidly systematized up to the 1990's and in which computer systems will produce great advantages.

(1) Effects of OA

By means of office automation systems (OA), the various functions of EDP and other departments will be structurally connected to allow managers at various levels to make handy use of data bases and results of various simulations via personal computers and terminals, thus permitting jobs to be done on a company-wide scale.

Planning, research, design engineering and other departments will be able to use, in addition to conventional characters and numbers, a data base system capable of handling a wide variety of forms such as images, graphs, speech and other mediums for giving flexible creativity a greater chance to blossom from a general point of view.

Systems utilizing less paper will be realized to enable electronic storage and exchange of information together with the utilization of multiple-function terminals, and the support of office jobs with automatic translation and various knowledge processings.

As a result, productivity by white-collar workers will be increased, the quality of management improved, and creative environment achieved, thereby realizing offices which are labor and energy savers as well as more internationally oriented. Offices will be required to have the right men in the right places, to be organized structurally and flexibly, to cope with an ageing society, to have an increased ability to develop technology, and to have better international exchange, and to be more open internationally.

In the 1990's, with the technology to achieve these objectives, Japanese who are capable of adapting themselves flexibly to new environments will be able to realize sophisticated office automation systems for processing information through various mediums including images, graphs, speech and the like, and become a world pioneer of OA.

(2) Effects of DSS

DSS provides high-level information and support thinking processes to decision making individuals and groups for increasing the validity and reducing the time required for making decisions, as well as reducing the costs involved in decision making.

With DSS, due to the fact that consistency in decision making processes is imporved, and group decision making is rendered more efficient and adaptable, more sophisticated decision making becomes possible, thus enabling industries to increase productivity rationally and smoothly, separate technologies to be integrated, and general knowledge industries to be developed to allow for more stable and sophisticated judgment and decisions to be formed in politics, administration, and industry. DSS is being promoted at the home and personal level where it can be used in a sophisticated way for planning family finances, designing lifestyles, and scheduling activities.

With these achievements, activities in all facets of society will be affected and within a margin of safety, more advanced, humane behavior will be possible, thus allowing for a more balanced society.

(3) Effects of CAE

There are complicated steps involved in all manufacturing processes, from the basic design up to completion of the product. By incorporating a CAE system into such processes, a multi-form database, advanced image processing system, a high-speed calculation system for design use, a system for automatically translating and preparing documents and a project management system will become the principal construction elements necessary for supporting the process until product completion.

These systems are indispensable for putting a company's know-how to practical use especially where vast numbers of blueprints and basic data are concerned, for effecting high-speed, flexible designing operation, for making bids overseas, for preparing a large quantity of documents such as contracts and instruction manuals, and for optimum construction of large buildings and plants. Of course, performing these jobs requires a man-machine interface, safety, and improved cost performance.

With completion of the fifth generation computer and the above-mentioned subsystems production processes in the building and manufacturing fields will be greatly rationalized for saving labor, energy and time, and safety which has been dealt with empirically up to now can be greatly strengthened. Also better designs and new technologies can be introduced. Furthermore, our country can establish a foothold in the world by performing its role in the international division of labor, furthering qualitative improvements in economics, applying new technologies to other fields, and cultivating new frontier industries.

Such accomplishments will make possible the evaluation of plans even for huge developments based on sufficient data and simulation evaluation of component blocks, avoiding risks associated with big, long-term investments.

The products of our country will be rendered unique and specialized in their respective fields due to their performance, design and knowledge-intensive qualities. These achievements will further serve as a foundation for promoting the true knowledge intensiveness of our industries.

(4) Effects of intelligent robots

It is believed that the 1990's will find robots possessing senses and high intelligence approaching those of human beings based on sophisticated back-end computing power.

Such robots will be able to handle more sophisticated requests from mankind by means of their high-level intelligent processing capabilities, increased responsiveness to humans, and facilitated operation due to their compact size and high power.

These robots will extend our spheres of activity to outer space, the ocean depths and mines deep within the earth to acquire resources, develop natural sciences, and carry out various investigations. They will also liberate man from such adverse working environments as those where he would be exposed to radioactivity and high temperatures. These robots will also find themselves working in fields such as agriculture, fishing, forestry, transportation, and nursing, releasing man from labor in a wide sense of the word. Production activities that will require less care on the part of man will extend from the primary to tertiary industries, and will allow us to engage in more sophisticated activities in those fields. This will lead to automated production in the secondary industries, which means that the rate of productivity per worker will be greatly increased.

It is also expected that general-purpose robots will become popular for automated production in small-scale manufacturing industires, causing their productivity to approach that of big companies.

The impact of intelligent robots will be especially great from the standpoint that the small, rugged systems for inputting and outputting speech, understanding graphics, and controlling systems, plus the inference machine modules in the fifth generation computer systems which will be utilized and completed by these can be used as parts for general machines to make the latter more sophisticated in operation.

4. CONTENTS OF RESEARCH AND DEVELOPMENT

4.1 Targets of research and development

Fifth generation computer systems will be designed to overcome technical limitations which conventional computers have had, and will be oriented toward processing knowledge intensive information based on innovative theories and techniques proposed to meet the sophisticated functions which are considered to be required in the 1990's.

Such fifth generation computer systems will have the following basic functions:

1) Problem solving and inference functions;
2) Knowledge base management function; and
3) Intelligent interface function.

These functions will be realized by software and hardware systems respectively, and will be aimed at maximum scales and performances such as those which follow:

The problem solving and inference function will be aimed at a maximum performance of 100 M – 1 G LIPS*.

The knowledge base management function will be aimed at a performance capable of effecting retrieval of a knowledge base required for inference within several seconds, with a core data base machine having a maximum capacity of 100 – 1,000 GB.

The intelligent interface system will be aimed at making conversation with a computer through the medium of speech, graphics, and natural languages etc., a possibility as well as enabling the exchange of information in a form which is natural for man.

These functions will be combined together into a single general-purpose machine having a system configuration which can meet various performances required in a variety of applied fields.

These functions may be arranged so as to serve as machines in which any one of the functions is reinforced, and as machines they will have a common programming language.

The fifth generation computer system will be aimed at sufficient general-purpose functions and performances required to realize systems for machine translation, question answering and utilization of speech, picture and images, systems which will be basic and common for a wide variety of applications in the 1990's.

The target performances of the basic application systems perceived here are shown in Table 4-1.

4.2 The image of the fifth generation computer system

The fifth generation computer system will be considered here from two different points of view in order to get as general an image as possible.

The first point of view is a conceptual view of a hierarchical structure including a human system, a modeling system and a machine system, and is centered on how the level of the man-machine interface will increase with respect to its present level.

The second point of view deals with the fifth generation computer system more specifically, and shows how components are combined into the system as software or hardware. Since it would be difficult to describe the system in its overall configuration, it will be divided into an application system, software

Note: * 1 LIPS (logical Inferences per Second) means one inference operation of syllogism per second. One inference operation on a present computer is considered to require 100 – 1,000 steps, and hence 1 LIPS is equivalent to 100 – 1,000 IPS (Instruction per sec). Machines of the present generation are of approximately $10^4 - 10^5$ LIPS.

Table 4-1 Themes and targets of basic application systems

Machine translation system o Multi-lingual translation o Word capacity: 100,000 words o Translations should be 90% accurate, with the remaining 10% processed (edited) by humans. o Should be an integrated system capable of taking part in each of the processes from compilation of the text to the printing of the translated documents. o The entire cost of translation should be 30% or less than those made by humans.
Question answering system o Should be a system prototype for answering questions in a variety of professional fields. o Word capacity: 5,000 words or more o The number of inference rules: 10,000 or more
Applied speech understanding system o Phonetic (voice inputting) typewriter: Should handle 10,000 words, possess a meaning analyzing function, be capable of correcting errors in speech by itself, and output sentences easy to understand. o Speech-responding system: Should handle 10,000 words, be able to grasp the meaning of responses and thus be capable of natural conversation. o Speaker identification system: Should be able to handle a few hundred people or more and identify speakers within a practical interval of time.
Applied picture and image understanding system o This system should structurally store about 100,000 pieces of information in picture and image form so as to be usable for knowledge information processing.

system, and a hardware system to provide an image of the configurations for each system.

The application system corresponds to part of the human system in the hierarchical structure described above, the software system corredponds mainly to the modeling system, and the hardware system corresponds primarily to the machine system.

The image of the fifth generation computer system can be grasped more clearly by combining the foregoing two points of view.

4.2.1 A conceptual image of a fifth generation computer system

The fifth generation computer system will be oriented forward processing knowledge information and will have quite a high logic capability. Its greatest feature will be that interface between man and computer will greatly approach the human level.

Conventionally, man-machine interface has been via procedural programming languages. To solve a problem with the help of a computer, man has first had to describe, model and program the problem. Humans and computers have been able to understand each other only through programs thus prepared.

With fifth generation computer systems, however, the description and modeling of a problem will take place at interface. In other words, computers will be able to understand problem descriptions and from that express a model, and synthesize a program based on such modeling. Man will be able to communicate with computers by using speech, natural languages, picture or images with a certain extent of freedom.

To realize such sophisticated capabilities, both software and hardware should be functionally improved. Figure 4-1 shows a conceptual image of such a system in which the machine system indicates future hardware. It can be understood from this Figure that the machine system has functions much higher in level than those of conventional machines. If we compare the old with the new in terms

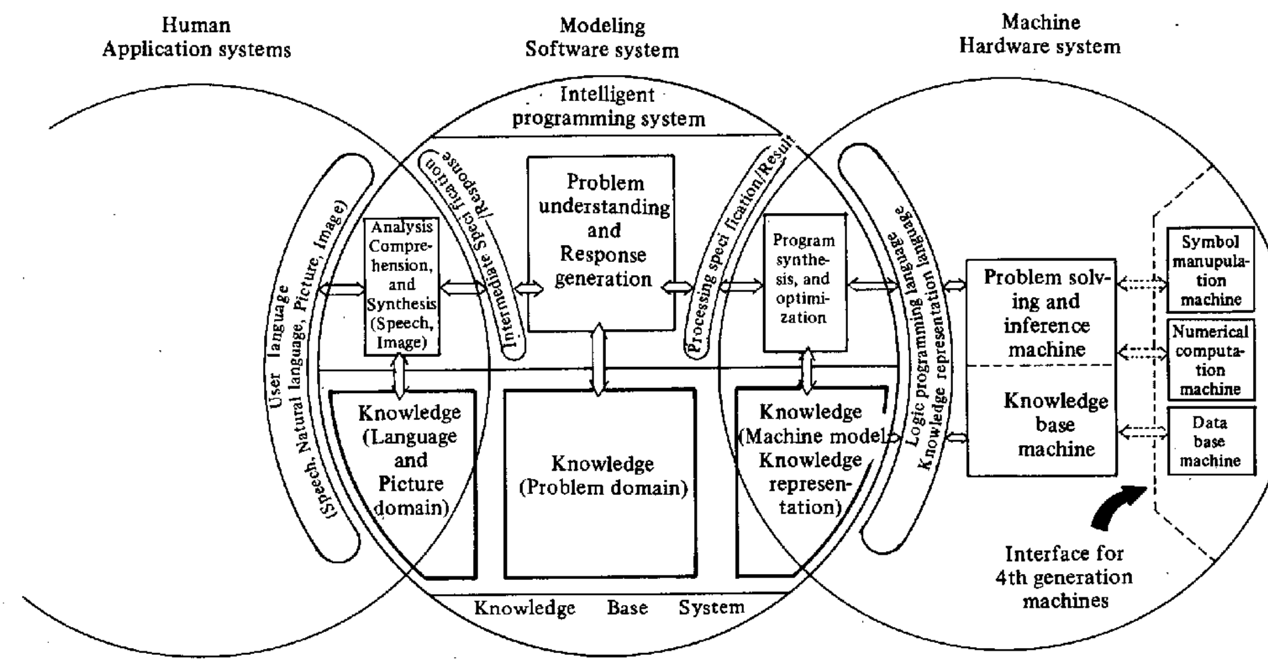

Fig. 4-1 Conceptual diagram of a fifth generation computer system as viewed from the standpoint of programming

of programming languages, while conventional machines use procedural languages on the basis of sequential execution, the new machine system will use logic programming languages or problem solving languages for trial-and-error logical inferences.

The modeling (software) system illustrated above will be highly effective software for such hardware and will serve mainly to perform meta-inference functions for problem solving such as understanding problems and synthesizing programs. Since the level of logic programming languages is quite high, the modeling system can be a man-machine interface during the period of transition before the final object is accomplished. However, input processing in the form of everyday language, picture, or images etc. In order to minimize the incompleteness and vagueness of inputs is indispensable if we wish to allow the next stage of development. Conversely, a function will be necessary to add some of vagueness and incompleteness to fully original responses for obtaining summarized outputs.

The modeling system includes an intelligent communication system capable of understanding speech, natural languages, pictures, and images at that point when it interfaces with the human system.

The intelligent communication system itself will be realized as a sophisticated knowledge information processing system having modeling and machines systems such as described above.

The fifth generation computer system will always utilize knowledges required in series processing, beginning with inputs such as speech, natural languages, picture or images from the human system, and extending to understanding these inputs, synthesizing and executing programs around them, and generating responses. These knowledges include a knowledge of languages, a knowledge about images, a knowledge about problem domains, and a knowledge about the mechanisms and data expression of the machine system, all stored in a knowledge base.

With the functions of the machine system being sophisticated and amplified by the modeling system in this way, our ability to process information will be greatly improved.

4.2.2 An image of the configuration of an application system

Structures common to various systems such as intelligent CAD, intelligent OA, intelligent CAI, and intelligent robots which will also be realized in the fifth generation computer system are shown in Figure 4-2.

Interactive system	Processing system
Management system	

Fig. 4-2 System structure

All application systems are composed of three subsystems, namely, interactive, processing and management systems. These three subsystems will be proportionally different from application system to application system. These subsystems are illustrated in Figure 4-3. (see next page.)

Showing their mutual relationship and internal operation to clarify the various functions they perform. Speech, natural languages, picture, images or their combinations are used to put a question to the system. The interactive system utilizes the knowledge inherent in languages or picture to analyze a structure (construction) and convert it into an internal (intermediate) expression such as an anatomical tree. Then, an analysis is made of that meaning in context and a description of the problem is extracted from that. This, however, is incomplete due to omissions and the like. A knowledge used here about context and background knowledge, which is one of the knowledges used at this time, is information related to the background and flow of the conversation taking place. The processing

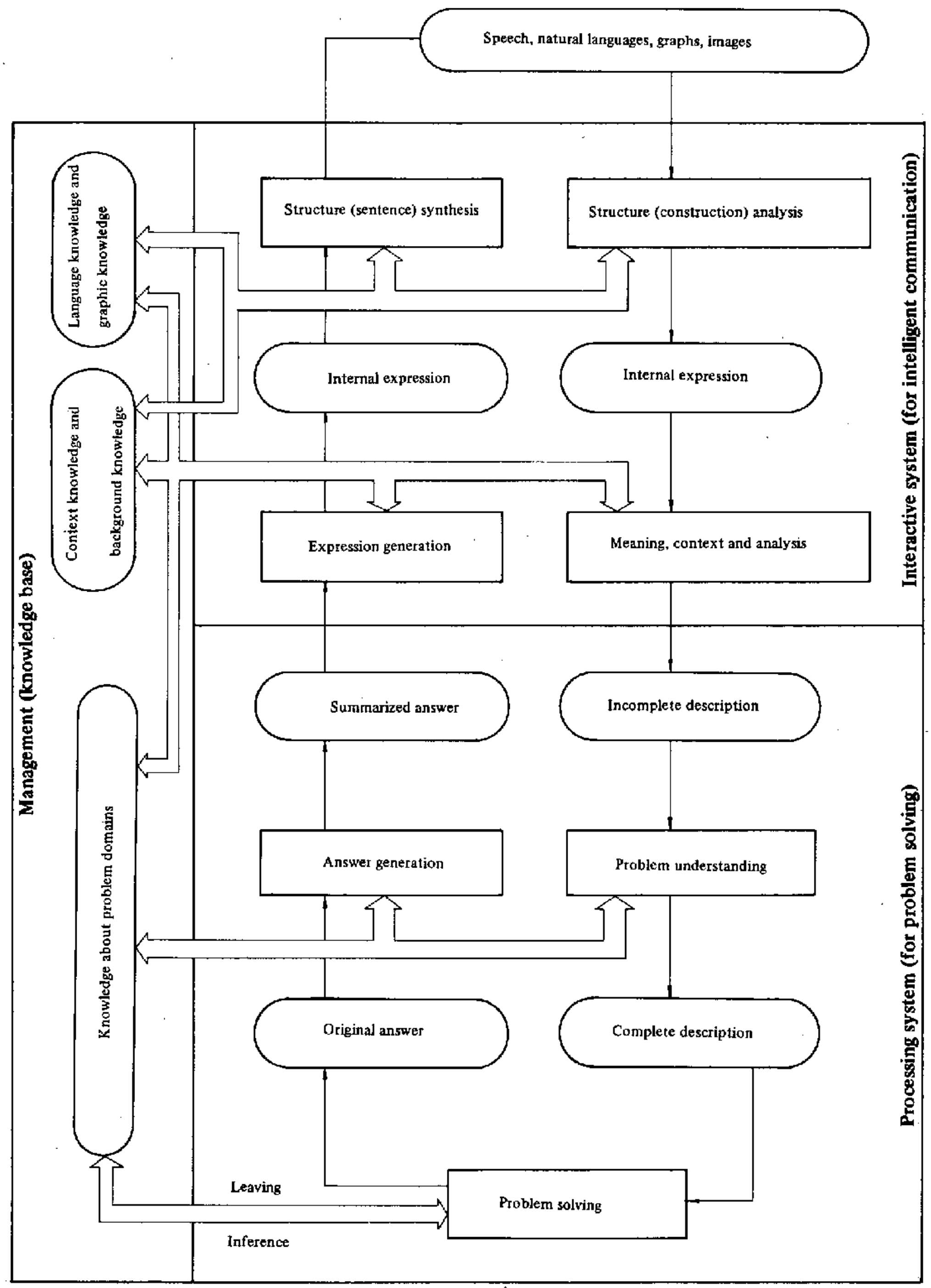

Fig. 4-3 Mutual relationship and internal operations of the three subsystems in an application system

system converts the incomplete description into a complete description using its knowledge about problem domains, and generates and answer to the description. At this time, opeations such as effective utilization (inference) of the knowledge about problem domains and storage (learning) or new knowledge are effected. The generated answer is then converted into a summarized answer by getting rid of unnecessary self-evident information. Thereafter, this summarized answer is converted by the interactive system into an internal expression, which in turn is converted into an external expression understandable to man. In this way, one conversational cycle is completed. During this cycle, the management system oversees a variety of knowledges for effecting common operations of inference and learning.

4.2.3 An image of the composition of a software system

An image of the composition of a software system for realizing various application systems is shown in Figure 4-4, the software system directly reflecting the structure of application systems.

(1) Basic software systems

These will be the core of all systems and consist of a problem solving and inference system, a knowledge base management system, and an intelligent interface system. These systems correspond respectively to the problem solving and inference machine, the knowledge base management machine, and the intelligent interface machine, and may be defined as those which cannot be constituted as hardware in realizing functions.

(2) Intelligent systematization support systems

These will be a group of systems which, in designing and producing (systematization) optimum information processing systems for various applications, will have knowledge about what is to be produced, production processes, and the like for greatly reducing the amount of work which man will do in systematization. These systems include subsystems which lead from a strict specification description language and a described specification to what is to be produced, or a subsystem for verifying correctness, and a subsystem for simulating operations, and the like. It also comprises three support systems, that is, an intelligent programming system for handling programs, a knowledge base design system for handling a knowledge base, and an intelligent VLSI design system for handling VLSI chips and computer architectures.

(3) Intelligent utility systems

These will be a group of systems which will provide sophisticated functions to facilitate utilization of the system itself. These will be comprised of a system for maintaining transferability to transfer stored programs and data bases from existing commercial machines to a target machine, a system-explanation and

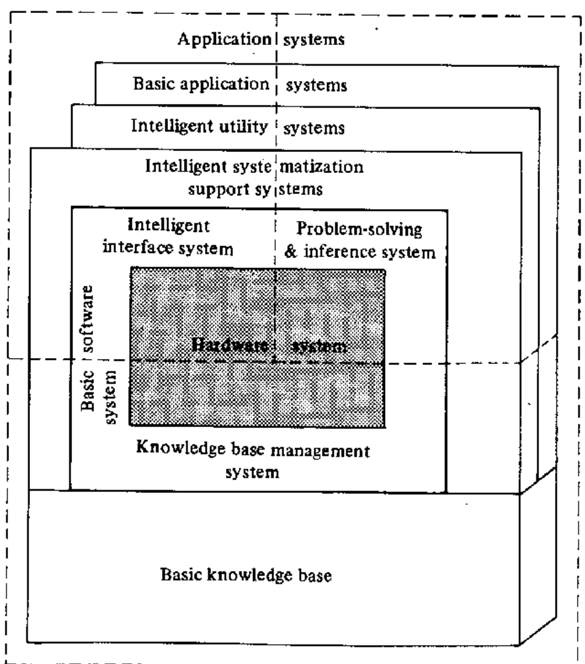

Fig. 4-4 Conceptual diagram of the composition of a fifth generation computer software system

education system for explaining the functions and use of the overall system and subsystems and for responding to user's consultation, an intelligent trouble diagnosis and maintenance system for automatic inspection and recovery and for guidance and consultation about inspection and repair of complicated troubles, and other systems.

(4) Basic knowledge bases

Universal knowledge used by the system itself and users will be arranged as basic knowledge bases which are components of the foregoing systems and are emplyable in application systems which users will make. There are largely three knowledge bases: a general knowledge base similar to common sense; a systems knowledge base which will gather knowledge related to systems; and an applied fields knowledge base which will gather together knowledge about certain applied fields. The general knowledge base includes bases of basic words of everyday use, basic sentence patterns and basic scripts, a base of dictionaries of various languages and sentence construction rules, and other bases related to natural languages. The systems knowledge base includes bases containing specifications for the system itself, such as a processor specification description base and an operating system specification description base, a language manual base, a program module base containing programs which are highly usable and other bases. The application knowledge base includes a VLSI design technology base, a computer architecture base, a basic program base, and other bases.

(5) Basic application systems

This group of systems which will be developed as basic application systems and ,have respective final target performances. These systems will be highly worth utilization and be a source of knowledge bases and sophisticated-function modules commonly usable by various application systems. The systems are largely classified as follows:

. Machine translation system
. Question answering system
. Applied speech understanding system
. Applied picture and image understanding system
. Applied problem solving system

4.2.4 Future of hardware system structure

(1) A profile of the fifth generation computer systems

Fifth generation computer systems, covering all sizes from the small ones for personal use to the large-scale computers, will find application in various fields. These will include machines for exclusive use as well, incorporating particular strengthened functions like the existing data base machines grouped into a community by a local network.

The computers in this community may be classified according to their abilities, but in so far as they will share a common programming language, they may be looked upon as members of a new computer family.

From the standpoint of their basic software interface, these computers shall have three functional components. These are listed below side by side with the corresponding components (in parentheses) of the existing computer systems.

1) Problem solving and inference machines (CPU)
2) Knowledge base management machines (Memory and filing system with virtual memory)
3) Intelligent interface machines (I/O channels and devices)

These three components will form part of each and every computer system. A general-purpose fifth generation computer system will be equipped with each of these machines in substantially the same proportion, whereas a small system with the same structure will form a general-purpose fifth generation personal computer.

A computer system with enhanced problem solving and inference function will be referred to as a problem solving and inference computer. This will find application in fields like consultation requiring professional knowledge, calling for strong ability to infer. Systems with reinforced knowledge base management function will be called a knowledge base computers. Like the existing data base machines, they will be applied in fields requiring storage of 'Knowledge' in large masses.

Computers incorporating an enhanced intelligent interface function will be provided with an interface with various interactive media, speech, picture and image as well as those based on natural languages. It will be possible to use these machines independently or in combination.

Figure 4-5 projects a conceptual image of the general fifth generation computer configuration.

Computer functions will be available at various levels and their combinations will create a wide range of machines covering both the small personal computers and large-scale machines incorporating each function to its maximum extent.

(2) Profile of the structures of machines serving different functions

Hardware architectures shaping the functional components will be based on a combination of six machines. These are the six machines that are being studied as the likely candidates to establish the new architecture. The machines will be so combined by adopting the distributed function architecture, namely by applying the modularization, adoptation, and microprogramming techniques.

For the smaller computers of moderate performance, a firmware base architecture built up on innovative von Neumann technique will be adopted. Language interfaces will center on new languages of both the predicate logic and abstract data types. Thus, the results of study on both the logic programming machines and abstract-data type support machines will be made programming use of.

For the powerful large-scale computers, data flow machines including functional machines will serve as the core technology. For the problem solving and inference computers, the execution part in the logic programming machine will use a large-scale data flow mechanism for its execution, and the knowledge base will be processed by a small-scale high-speed relational algebra machine. The relational algebra machine will use a suitable data flow mechanism for its execution.

A large-scale knowledge base computer will use as its core a large-scale relational data base machine including a relational algebra machine. Results of studies on the abstract data type support machines will also be used.

The supporting hardware in the intelligent interface system will include a VLSI processor for exclusive use in speech and a signal processors. Data flow machines techniques, including functional machine techniques will be used frequently in high-speed operations.

The data flow machine will constitute the basic execution mechanism for high-speed processing, and hence should be taken up as one of the main subjects for research and development.

A number of customized VLSIs are indispensable for the machines, and, therefore, development of VLSI-CAD to produce such VLSIs in a short period is to be treated as the most important theme from the standpoint of packaging.

(3) Macro image of the fifth generation computer structure

Fifth generation computers will be linked to communication systems to form a global network suitable for various social organizations. Potentially, each node in such a global network, that is, each computer site, will

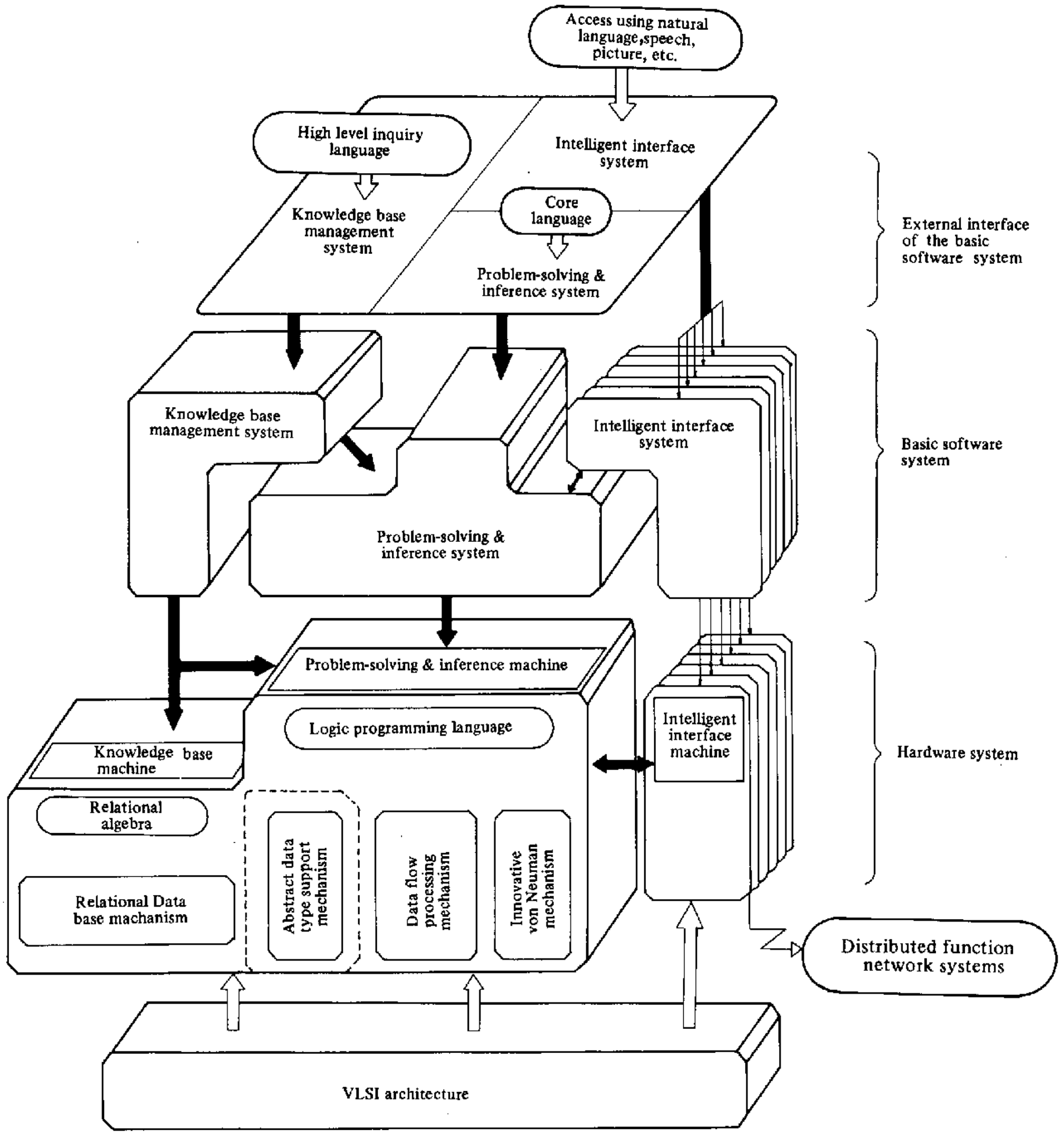

Fig. 4-5 Basic configuration image of the fifth generation computer systems

constitute a system connected by a local network to two or more computers. The local network, capable of high-speed data transfer, will connect together computers of different functions, including the smaller personnel computers, thus making up a single as a whole general-purpose group (community).

As the macro image suggests, a fifth generation computer system will be a collection of computers serving different functions: a small, general-purpose personal computer, a knowledge base computer, and a problem solving and inference computer, all connected by a local network.

In principle, the component computers will have a common programming language. These computers, therefore, will form a computer family linked by a common language even though they may be intended to serve exclusive purposes with one or the other of the functions enhanced.

A structure of this nature will help build up a flexible computer system suitable for the intended applications. As the above suggests, hardware and software research and development for fifth generation computer systems should be so carried out as to allow them to be connected by local and global networks.

4.3 Research and development themes

There are in all 26 themes on which research must be carried out to develop the fifth generation computers. These are grouped into seven in Table 4-2. These research and development themes are summarized in Table 4-3.

Table 4-2 Items in research and development of the fifth generation computer systems

Basic application systems	1–1)	Machine translation system
	1–2)	Question answering system
	1–3)	Applied speech understanding system
	1–4)	Applied picture and image understanding system
	1–5)	Applied problem solving system
Basic software systems	2–1)	Knowledge base management system
	2–2)	Problem solving and inference system
	2–3)	Intelligent interface system
New advanced architecture	3–1)	Logic programming machine
	3–2)	Functional machine
	3–3)	Relational algebra machine
	3–4)	Abstract data type support machine
	3–5)	Data flow machine
	3–6)	Innovative von Neumann machine
Distributed function architecture	4–1)	Distributed function architecture
	4–2)	Network architecture
	4–3)	Data base machine
	4–4)	High-speed numerical computation machine
	4–5)	High-level man-machine communication system
VLSI technology	5–1)	VLSI architecture
	5–2)	Intelligent VLSI CAD system
Systematization technology	6–1)	Intelligent programming system
	6–2)	Knowledge base design system
	6–3)	Systematization technology for computer architecture
	6–4)	Data base and distributed data base system
Development supporting technology	7–1)	Development support system

Table 4-3 Contents of research and development themes

Item group

- **Basic application system**

A basic application system representing functions like hearing, speaking, seeing, drawing, thinking, and problem solving will be studied and developed.

R & D themes

- Machine translation system

Results of researches in documentation techniques and artificial intelligence for knowledge utilization will be combined together to research and develop an integrated multi-lingual translation system.

R & D details

- Designing a machine translation system and its core
- Development of the grammars for the languages
- Development of sentence generating grammars
- Development of an integrated machine translation system with room for operator intervention
- Development of a specialized terminology data base (knowledge base)
- Development of a machine for the specialized terminology data base
- Development of high-level word processing techniques

Targets and specifications

- Number of words to be handled: 100,000 words
- Machine must assure 90% accuracy, and the remaining 10% is to be processed by the translators
- The system must serve general purposes computerizing all the jobs including text compilation to printing of translated documents
- Translation cost must be 30% or less than that by translators

Item group
• **Basic application system**
Themes in R & D
• Question answering system Research and development of a question answering system for various specialized fields including the intelligent CAE/CAD system, DSS, and intelligent robots.
R & D details
• Conversation analysis technique • Graphic data I/O units • Specialized data generating • Input error processing technique • Natural language subset designing and development of grammars and dictionaries • Synthesis technique
Targets and specifications

• An interim target to be achieved in 5 years is to develop a trial question answering system for limited use in particular specialized fields.
  • Number of words: 2,000 words (Japanese)
  • The user must provide supplementary information to eliminate ambiguity.
  • Number of inference rules: 1,000
 	
• The interim experimental question answering system will be evaluated, and prototype question answering systems will be developed for various specialized fields.
  • Number of words: 5,000 or more
  • Number of inference rules: 10,000 or more

Remarks
• Will be used for the development of an intelligent utility system.

Item group

- **Basic application system**

Themes in R & D

- Applied speech understanding system

Research and development of a speaker identification system as part of a general-purpose speech responding system for input and output in machine translation, a phonetic typewriter, and a telephonic inquiry system.

R & D details

- Development of a phonetic typewriter
- Development of a speech responding system
- Development of a speaker identification system

Targets and specifications

- Phonetic typewriter
  - (1) Interim target: A system with of simple sentence construction data to handle several hundreds to several thousand words.
  - (2) Final target: To handle about 10,000 words with simultaneous meaning analysis, automatic error correction during speech recognition, and generating as a whole comprehensible sentences.

- Speech responding system
  - (1) Interim target: Handling several thousands words mainly through analysis and synthesis system.
  - (2) Final target: Cap handling about 10,000 words, comprehending the meaning of questions to be answered, and developing a sophisticated structure to enable natural conversation.

- Speaker identification system
  - (1) Interim target: Identifying fifty to sixty speakers.
  - (2) Final target: Identifying several hundreds of speakers within a practicable interval.

Item group

- **Basic application system**

Themes in R & D

- Applied picture and image understanding system

  Development of a system for structural storage of picture and image data and effective retrieval of such information to process intelligence.

R & D details

- Research on a picture and image data storage and retrieval system image information
- Development of a language system to retrieve picture and image data
- Development of a picture and image data base machine
- Development of a system to store and retrieve picture and image data

Targets and specifications

- A picture and image data base must contain about 100,000 retrievable picture and image data items.
- The system must store picture and image data including abstract delineations within a few seconds.
- Picture and image data must be retrievable within 100 m sec. on the average.
- Interim target in the stage: about 10,000 picture and image data items to be handled and processed at about half the speed aimed in the final target.

Item group

- **Basic application system**

Themes in R & D

- Applied problem solving system

Development of a formula understanding system outputting an "answer" to the "problem" input, thereby solving general advanced problems. Also development of a system playing the Go-game.

R & D details

- Research on a basic formula understanding system for mathematical expressions
- Development of formula understanding system
- Research as a basic system to play the Go-game
- Development of a system to play the Go-game

Targets and specifications

- Formula understanding system
  (1) Interim target: System with a knowledge base combining the performances of the existing MACSYMA with inequalities and simple equations processing function.
  (2) Final target: A knowledge representation and problem solving system related to formula combining sophisticated formula manipulating algorithm.

- Go-game playing system
  (1) Interim target: A system having a playing standard equivalent more or less to amateur subgrade 10.
  (2) Final target: A system having a playing standard equivalent more or less to amateur grade 1.

Item group

- **Basic software system**

This will constitute out core of the fifth generation computer systems. A group of modules corresponding to basic information processing functions (management, processing, interaction) will be research and developed.

Themes in R & D

- Knowledge base management system

Research and development of intelligent system management techniques to format and store human knowledge in a computer to utilize it and support the user in solving problems.

R & D details

- Research on knowledge representation and utilization techniques
- Knowledge acquisition and learning
- Research on a large-scale knowledge base system
- Development of a knowledge base management system
- Development of a knowledge base machine

Targets and specifications

- Knowledge base management system
  - (1) Interim target: Simultaneous management of rules and data, to data base access optimization mechanism, a mechanism for eliminate inconsistencies, and interface with an inference machine.
  - (2) Final target: A multiple-world knowledge base, a distributed-knowledge base, learning based on inductive inference, fusion with an inference machine

- Knowledge base machine
  - (1) Interim target: Storage and retrieval of 2,000 rules and 1,000,000 data items (10^3 B per one item)
  - (2) Final target: Storage and retrieval of 20,000 rules and 100,000,000 data items (100 GB)

Item group

- **Basic software system**

Themes in R & D

- Problem solving and inference system

This will constitute the core of the processing functions in the fifth generation computers. Basic techniques will be research to develop a problem solving systems by establishing a processing model of the problem solving and inference systems, and to explain its processing ability theoretically.

R & D details

- Research on problem-solving and inference algorithm
- Development of a coding language to solve problems
- Development of an inference machine

Targets and specifications

- Inference machine
  (1) Final target: Performance of about $10^2 - 10^3$ Mega LIPS

- Coding language to solve problems must support functional and logic programming as well as object-oriented modular programming. Program modules generated will form a knowledge based software component for effective use in intelligent programming.

Remarks

- Logical Inference per Second

1 LIPS (Logical Inference Per Second) means one syllogistic inference per second.
One inference operation in the currency used computers is considered to require 100 – 1,000 steps, and hence 1 LIPS is equivalent to 100 – 1,000 IPS (Instructions Per Sec.)
Machines of the present generation feature approximately $10^4 - 10^5$ LIPS.

Item group

- **Basic software system**

Themes in R & D

- Intelligent interface system

Research and development of a technique for flexible conversational functions and elimination of the language (including natural languages, speech and image) gap between the user and his computer.

R & D details

Natural language and speech system

- Parsing (syntactic analysis)
- Semantic analysis
- Discourse analysis
- Sentence construction
- Construction of a language data base
- Natural langauge processor
- Multiple-language basic grammar generation
- Research on phoneme identification system
- Research on sentence understanding system
- Research on speech synthesys system
- Research on system to recognize the differences between individual speakers
- Development of a speech understanding system

Targets and specifications

- A man-machine communication technique based on natural language or speech data, providing an intelligent man-machine interface.

- The natural language and speech system with fulfil the following target:
  (1) Vocabulary to be handled with cover computer and one branch of scientific and technological terminology, will include specialized as well as frequently used terms.
  (2) The system must adapt itself to speakers and communicate with unspecified speakers.
  (3) The system must be capable of speech output in Japanese and English.
  (4) The system must identify speech signals on almost real-time basis.

Item group

- **Basic software system**

Themes in R & D

- Intelligent interface system

R & D details

Picture and image system

- Research on picture and image construction technique
- Research on picture and image generating algorithm
- Development of systematization technology
- Development of picture and image processors
- Research to interrelate natural languages, picture and image

Targets and specifications

(1) Development of soft- and hard-ware to enable smooth user interaction with the computer through picture and image media.

(2) Picture and image to be handled will be an complex as, respectively, medium small scale machine drawings, and photographs for medical use.

(3) High-speed information processing to allow smooth man-machine interaction.

(4) The interim target is to handle 70% as complex picture and image as are aimed in the final target. For the interim target emphasis will be laid on the method of processing rather than the processing speed.

Item group

- **New advanced architectures**

  Research will be made to enabled the fifth generation computer architecture to satisfy the knowledge data processing system requirements.

Themes in R & D

- Logic programming machine

  Study and development of the necessary architectures to support inferences and a computational model based on predicate logic with a power of expression approximating natural languages.

R & D details

- Development of and incorporating the predicate logic
  - PROLOG system
  - New language system

- Development of the basic technology
  - Research on parallel systems
  - Development of special-purpose mechanisms

- Logic programming machine
  - (1) Firmware base machine .... 0.1 Mega LIPS
  - (2) Personal logic programming machine ...... 0.1 – 1 Mega LIPS
  - (3) Parallel logic programming machine .... 50 – 60 Mega to 1 Giga LIPS

Remarks

- Development of languages and a processing systems
  - Extended PROLOG language
  - New logic programming language

Item group

- **New advanced architecture**

Themes in R & D

- Functional machine

Development of architectures to support a functional model and programming language suitable for symbol manipulation, both based on theory

R & D details

- Development of a function language (including LISP)
- Method of coding for parallel processing
- Parallel computation model (data flow model)
- Firmware based LISP machine
- UHM for symbol manipulation and its VLSI
- Method of interconnecting the processors
- Associative processor and associative memory

Targets and specifications

(1) Personal LISP machine
To be two or three times a general-purpose computer (4 MIPS) in list processing capacity

(2) Parallel reduction machine
To be ten times on a general-purpose computer in list processing capacity

(3) Data flow function machine
To be several hundreds to several thousands times a general-purpose computer in capacity list processing

Item group

- **New advanced architectures**

Themes in R & D

- Relational algebra machine

Research to develop a machine architectures to handle, say, set operations, using relational algebra (constituting the core of future data base systems) as the interface language.

R & D details

- Development of an interface language and a processing system (relational logic, relational algebra, basic machine operations)
- Development of a data base management system
- Development of the algorithm for basic machine operations
- Development of machine architectures.
- Development of processor elements and connective hardware
- Building up a memory hierarchy system and development of memory devices

Targets and specifications

- Number of processor elements in the parallel processors
  (1) Interim target: Not more than hundred
  (2) Final target: At least five to six hundred

- Storage capacity
  (1) Small capacity for high speed operations: 10 – 100 MB
  (2) Medium capacity for medium and high speed operations: 100 M – 10 GB
  (3) Large capacity for low and medium speed operations: 10 – 1,000 GB

Remarks

- To be closely related to data base machines and support the relational data base systems.

Item group

- **New advanced architecutres**

Themes in R & D

- Abstract data type support machine

Research and development of a memory structure and processor functions in the future computers to provide system architecture support to modularize the vast and complex software.

R & D details

- Arrangement and systematization of an abstract data type model, and research and development of a language system
- Mapping from the space handled to the physical resources
- Garbage collection
- Structured memory
- Abstract data type processors and architectures
- Parallel processing
- Others (I/O, relationship with the conventional languages, OS, DB, distributed processing)

Targers and specifications

(1) Development of about 100 parallel von Neumann abstract data type support machine

(2) Development of about 1,000 parallel non-von Neumann abstract data type support machine

Remarks

- Must be closely related to logic programming machines and functional machines.

Item group

- **New advanced architectures**

Themes in R & D

- Data flow machine

Research on an architecture based on a data flow model oriented to parallel processing thereby achieving sophisticated parallel processing.

R & D details

- Design of a machine instruction set
- Design of a high-level language for data flow
- Determination of the overall structure of the meachines
- Configuration of the network connected
- Development of a structured memory
- Establishment of an activity control system
- Method of developing OS functions
- Countermeasures against troubles and protection plans
- Structure allowing combination with a conventional machines
- Development of a prototype data flow machine
- Development of a personal data flow machine
- Combination with the data base management functions

Targets and specifications

(1) Initial target: 16 processors with a memory of 8 MB (basic operating level.)

(2) Interim target: 100 processors with a memory of 100 MB and achieving 50 MIPS (practicable use).

- Processor networks: Structured to accommodate LSIs
  Consist of $10^3 - 10^4$ processors

(3) Final target: An extra high-speed data flow machine, $10^3 - 10^4$ processors with a memory of 1 – 10 GB and 1 – 10 BIPS.

- Personal data flow machines
  32 processors with a memory of 10 MB and achieving 10 MIPS.

Remarks

- Closely related to parallel logic programming machines, parallel functional machines etc.

Item group
• **New advanced architecture**

Themes in R & D
• Innovative von Neumann machine Development of architecture with innovative von Neumann machines retaining their original advantages and with sophisticated VLSI.

R & D details
• Innovative VLSI von Neumann architecture with respectively one million and ten million transistors per chip • Research of an architecture data base • Development of micro 90 (object-oriented architecture)

Targets and specifications
(1) Interim target: A processor with one million transistors per chip for the innovative von Neumann machines (2) Final target: A processor with ten million transistors per chip for the innovative von Neumann machines

Item group

- **Distributed function architecture**

  Development of an architecture to combine the VLSI architectures with the new, advanced ones, using VLSI with importance attached to progressive architectures.

Themes in R & D

- Distributed function architecutre

  Development of a distributed function architecture consistently assuring high efficiency, high reliability, simple use and construction, easy adaptability to future technological improvements and the different machine/system levels, and sophisticated functions.

R & D details

(1) Development of a basic distributed function system
- Establishment of a logic model
- Establishment of various architecture system
- Dynamic architectures
- Implementation
- Special purpose machine development techniques

(2) Development of an experimental distributed function system
- Personal computer
- High-level language machine groups
- Local networks

(3) Development of an integrated system

Item group

- **Distributed function architecture**

Themes in R & D

- Network architecture

This architecture will be meant to loosely couple computer systems spaced apart. Development of the techniques to combine systems with a global network and build up a distributed information system based on the high-speed local network to be available to the fifth generation computer.

R & D details

- Standardization of network architectures
- Protocol coding, generating, and verifying technique
- Network OS development technique
- Multimedia processing technique
- Data security mechanism
- VLSI technology
- Optical fiber communication technology
- Satellite communication technology
- Local networks

Item group

- **Distributed function architecture**

Themes in R & D

- Data base machine

Development of special-purpose machine with an architecture suitable to process data bases and capable of high-speed accessing large-capacity data bases.

R & D details

- Research on new advanced architecture to process data bases (non-numeric)
- Research on data base machine with sophisticated functions
- Research on a man-machine interfaces
- Research on distributed data bases
- Research on techniques for conversion from or emulation of existing data bases
- Research on effective use new devices to be based on VLSI
- Collection and analysis of basic data to design data base machines
- Development of experimental machines
- Development of practically feasible machines

Targets and specifications

(1) Experimental machines
- Capacity: Up to 100 GB
- Processing ability: 10^3 transaction/sec
- Data model: Relational

(2) Practicable machines
- Capacity: Up to 1,000 GB
- Processing ability: 10^4 transactions/sec
- Data model: Relational

(To support conversion from and emulation of the data base of another model)

Item group

- **Distributed function architecture**

Themes in R & D

- High-speed numerical computation machine

Development of special-purpose machine for high-speed scientific and technical computation for, say, numeric simulation to replace experiments.

R & D details

- High-speed logic devices
- High-density implementation technology
- Cooling technique.
- Architectures (logical specifications)
- High-speed numerical computation technique
- Special-purpose operating systems
- High-level language compilers

Targets and specifications

- Development of processor elements (40 – 100 MFLOPS), using new high-speed devices

- Processor elements of about 4 MFLOPS will be developed. Also, a parallel processing system will be developed to simultaneously operate 1,000 such processor elements to develop an overall performance of about 1 BFLOPS.

- Head per track disk of some fifty to sixty GB.

Item group

- **Distributed function architecture**

Themes in R & D

- High-level man-machine communication system

Development of a system to input and output characters, speech, picture and image and interact (intelligence) with the user

R & D details

- Devices to input and output characters (including Chinese characters)
- Device to input and output picture and image
- Device to input and output speech
- Development of an integrated system to input and output characters, speech, picture and image

Targets and specifications

- Character (including Chinese characters) in- and out-put system
  (1) Interim target: A display unit with an input functon for 3,000 – 4,000 characters in four to five different typefaces.
  (2) Final target: Additional functions allowing input of Chinese characters together with speech, replacement of *kana* (the Japanese syllabary) by the Chinese characters and vice versa, and meaning comprehension.

- Picture and image in- and out-put system
  (1) Interim target: A tablet coordinates input device with 5,000 x 5,000 – 10,000 x 10,000 dots.
  (2) Final target: More advanced intelligent functions based on specifications laid down in the research theme for applied picture and image understanding system.

- Speech in- and out-put system
  (1) Interim target: Ability to identify 500 – 1,000 words.
  (2) Final target: More advanced intelligent specifications as laid down in the research theme for applied speech understanding system, including a meaning comprehension ability and capability to party handle natural languages.

- Integrated terminal with a multimedia input and output functions
  All the above functions will be combined on VLSI basis to develop integrated personal computer terminals.

Item group

- **VLSI technology**

Development of architectures making full utilization of VLSI and processing from the component devices to fifth generation computers.

Themes in R & D

- VLSI architecture

Development of architectures to make full utilization of VLSIs characterized by about ten million transistors per chip (as are expected to be available around 1990).

R & D details

- Techniques for constructing new advanced architectures (basic study)
  - VLSI device rule book
  - Design QA system
  - Architecture data base
  - CAD for VLSI architectures

- VLSI architectures
  - Complete 1-chip architectures
  - (one million transistors/chip, ten million transistors/chip)
  - Function parts architectures

- VLSI system
  - Function division and connection techniques

Targets and specifications

(1) Interim target: Complete one-chip architectures for one million transistor/chip.

(2) Final target: Complete one-chip architectures for ten million transistors/chip.

Item group

- **VLSI technology**

Themes in R & D

- Intelligent VLSI-CAD system

  Development of an integrated VLSI-CAD system capable of storing design know-how for effective utilization

R & D details

- Architecture data base
- Know-how data base
- Inquiry system for VLSI-CAD design
- Development of a technology for heuristic design

Targets and specifications

- An application designer should be able to design a masking pattern for a VLSI custom chip with one million transistors/chip within one month (a desired chip must be available within three months).

Item group

- **Systematization technology**

  Consistent systematization, of devices, architectures, and basic as well as applied software, and development of techniques relating to the cycle comprising system design, development, maintenance, and management.

Themes in R & D

- Intelligent programming system

  Development of a system fetching programs from an algorithm bank (knowledge base) by user requirements, and synthesizing a program which meets requirement specifications by inference. Furthermore, the system must verify, by a process of inference, whether the program generated to meets the requirements optimally.

R & D details

- Modular programming and a verification theory
- A theory to specification description and program synthesize
- A system for program verification and synthesis and a program base
- A system to maintain, imporve, and manage programs
- A consultant system for program designing

Targets and specifications

- System for program verification and synthesis, and program base
  (1) Interim target: Improvement through synthesis and converison of programs for particular fields, minimizing data base retrieval.
  Development of a small-scale program base.
  Generation of a system to verify functional, logic, and data-abstraction programs.
  (2) Final target: Synthesis of large-scale programs for data base management systems, language processors, etc.
  Development of a large-scale program base.
- System to maintain, improve, and manage programs
  (1) Interim target: Generation of a system to comprehend functional and logic programs.
  Equivalence transformation experiment.
  (2) Final target: A system to evaluate program performance, and a system improved through equivalence transformation.
  A system for correcting programs.
- Consultant system for program design
  (1) Interim target: Basic design
  (2) Final target: Question answering in natural languages.
  A system capable of offering consultation in data base management system design, data base application systems, etc.

Item group

- **Systematization technology**

Themes in R & D

- Knowledge base design system

A system with an organically contained basic knowledge base. The base must store the technical data and knowledge necessary to design, develop, and operate a knowledge information processing system, and to support creation of knowledge base systems from the basic knowledge base.

R & D details

- A system to express and use metaknowledge.
- Development of a system to support design and development of a knowledge base.
- Development of a system to support widening a knowledge base.

Targets and specifications

(1) Simple creation of a knowledge base system to offer consultaition to the specialists about problems requiring sophisticated, specialized knowledge.

(2) The knowledge base system must be designed to comprise knowledge in the form of about 20,000 rules.

(3) Partial system verification at the level of metaknowledge. A large-scale knowledge base system must allow. Simple debugging.

(4) The interim target will be to achieve 30% of the final knowledge base system target.

Item group

- **Systematization technology**

Themes in R & D

- Systematization technology for computer architecture

  Architecture-related systematization technique to complete a systematized fifth generation computer.

  Development of techniques to build up virtual systems and real systems, optimization for system configuration and load balance, designing and developing a large-scale system, and techniques for high reliability.

R & D details

- Techniques to build up virtual system and system configuration
- Optimization techniques for system configuration and load balance
- Design and development techniques for large-scale systems
- Technique for ultra high reliability
- Development of a local network as architecture developing tool

Item group

- **Systematization technology**

Themes in R & D

- Data bases and distributed data base systems

Development of a data base system for the fifth generation computers, technique of integrating and utilizing two or more data base systems, and integration of knowledge base systems.

R & D details

- Research of data semantics and data models
- Development of a flexible structured data base system
- Development of a system to support scheme designs
- Development of a system to support data storage
- Development of a QA system using natural languages
- Development of a distributed data base system
- Development of a metacharacter data base system
- Development of a data base machine

Item group

- **Development supporting technology**

  Various systems will be research and developed to support the development of hardware and software, as well as the system as a whole.

Themes in R & D

- Development support system

  Construction, at an early stage of the project, of VLSI-CAD, personal computers, computer networks, and systems to support development of software/knowledge base.

R & D details

- Computer network
- Support system for software development
- Support system for knowledge base development
- Use of VLSI-CAD as a supporting tool
- Use of personal computers in research and development

4.4 Research and development procedure

4.4.1 Relationship between the different item groups

The items calling for research and development are classified into seven groups (see 4.3). Research and development activities concerning the project as a whole must organically link the respective items.

The project will be divided into initial, intermediate, and final stages as shown in Figure 4-6. The respective research items will be interrelated and mutually adjusted at the beginning of the intermediate, and final stages.

The following deliveate the principles on which the research items will be interrelated and adjusted:

(1) Development of techniques supporting development will have priority over all other themes.

(2) Basic research will be taken up independently, and positive efforts will be made to use their results in subsequent research and development activities in other related field.

(3) Research on basic software systems will constitute the nucleus of the present project. Its results will be used in two ways, namely:

1) In practice they must contribute to the development of application systems (including a basic application system), and
2) Resulting language specifications must serve for architecture development (primary and secondary).

(4) Research and development of the new architectures will be carried out after selecting some practicable approaches before the final language specifications are completed, and they will be combined together when the results of the studies on the basic software system are obtained (primary and secondary).

(5) Research and development of the basic application system will be based on the results of research on the basic software system, and the results of such research will in turn be used to help imporve the basic software system.

(6) Distributed function architecture and systematization technology will be research in parallel with the other activities. From time to time their results will be incorporated in the supporting systems to reinforce them. Thus, results of research and development will be fully and constantly utilized.

(7) First version of the VLSI technique will be used to design the intermediate machines, and the second version to design the final machines.

Figure 4-6 provides the flow chart for the development of basic software, new advanced architectures, basic application system, and the systematization and supporting technologies.

4.4.2 Procedure for research and development of themes related to basic software and architecture

Research and development themes related to basic software are closely related to research and development themes related to architectures. Particularly, the research of problem solving and inference system will also determine the specifications underlying the core language forming the basis of the research and development specifications for the new advanced architectures. Research of a knowledge base management system will help lay down the specifications for the relational algebra machine to support a knowledge base. Likewise, study of an intelligent interface system will indicate specifications of a hardware system to support the system.

Thus, overall research and development will be achieved through interchange of research results between software and hardware.

Research and development themes relating to basic software and advanced architectures and their interrelation will be discussed with reference to Figure 4-7.

Basic theories and systems will be studied in advance for the themes related to basic software. These studies will mainly involve system of expressions including a knowledge representation language, a core language for problem solving based on predicate logic, phoneme identification and a sophisticated speech synthesizing system, a system for parsing and semantic analysis, and systems to abstract the characteristics of picture and image, and to generate and display them. The studies will be carried out by repeating a cycle in which various trial systems will be developed with the help of the support systems and then evaluated. In this way, new perceptions will emerge, leading to the development of commonly usable software based on support systems. Primary specifications for the systems to be developed line with the respective themes will be laid down by the end of the early stages of development. In particular, specifications will be laid down for the core language to precede the first stage language for the development support machine during the research on problem solving and inference systems.

During the intermediate stage, small-scale prototypes will be developed respectively for the problem solving and inference system, the knowledge base management system, and the intelligent interface system. These prototypes will help review the specifications determined in the early stages, delineate the problems, and thereby determine the specifications for the prototype systems to be developed in the final stage.

Results of the research will be utilized during the research on architectures. Also, the support software will serve as an effective aid in the research on the basic application system. At the same time, the theory underlying the fifth generation computer systems, with the core language and the knowledge representation system will be given a concrete shape.

By the end of the interim stage, specifications will be finalized for the basic software systems to support the architecture and the hardware.

During the final stage, simulators will be developed for the target machines on the basis of the support system and the prototype machines developed during the interim stage. The purpose of these simulators will be to develop the software system satisfying the final specifications. During this stage, problems will be brought to light and the target specifications will be reviewed and streamlined.

Another objective will be to establish a systematic basic theory for the fifth generation computer systems.

Finally, the basic softwares will be combined to serve as the core for the fifth generation operating system.

As for the architecture-related themes, a machine based on the initial core language specifications will be developed along with the logic programming and functional machines. The machines to be so developed will serve as a model for the supporting machine to aid research and development on soft- and hard-ware.

A part from machines based on use of the new language, systems will be built up early enough to support development. Such systems will be easy to handle and will include the existing general-purpose machines for use in, say simulation.

To deal with the themes related to the new advanced architectures, important fifth generation computer functions will be research separately. During the initial stage, research will be undertaken on machines serving different functions to build accurate computational models and construct the hardware. In addition, the relation between the programming language and the system architecture will be elucidated. To this end, both the software and the hardware will be used to develop a simulator and collect the basic data required to lay down the primary specifications.

Interrelation between the respective themes will become clear with the progress in their study during the intermediate and final stages. By the time the language specifications are combined, it will be desirable to streamline the relations between the machines and integrate them under a new theme. Such integration may be effected between functional and data flow machines, or between functional and abstract data type support machines. This, however, will presuppose a corresponding combination between the core language and its computation model.

Some of the themes concerning the architecture are described below in greater detail.

Since the data flow machine is to constitute the core of the sophisticated parallel execution mechanism, it will be better to incorporate if as an essential component of the logic programming and the relational algebra machine architectures. However, till date the theoretical basis for the integration to allow this remains incomplete. Thus precise targets must be finalized on the basis of the research results up to the interim stage. Depending on these results, it may be possible first to develop the data flow machine as a functional language machine, and then to examine how it can be connected to the logic programming machine.

An innovative von Neumann machine will recombine tag and dynamic architectures and the associative memories, improving the conventional von Neumann machines for the purpose of VLSI, and constructing new machines. The innovative von Neumann machine will be used in the initial stage as the basis on which to construct the support machines.

Machines related to new advanced architectures will be developed according to specifications laid down in the course of the studies carried out on the corresponding basic software themes. At the beginning of the interim stage, an experimental machine will be developed on the basis of the primary specifications related to the initial basic software themes. Part of the machine will serve as a basic software development tool.

During the early stage of development of the distributed function architectures, a group of supporting machines will be constructed, conducting basic research on distributed function systems like local networks. During the interim stage, a distributed function network will be constructed to include a data base system. Techniques will be developed for distributed OS, network, firmware, and UHM* leading to machines featuring new advanced architectures and groups of soft- and hard-ware modules constituting the foundation for the basic software.

Final targets for themes related to the new advanced architectures will be set up by considering the secondary specifications laid down during basic software researches and development of the respective machines.

Targets should preferably be precised first at the beginning of the interim stage and secondly at the beginning of the final stage.

Items related to the new advanced architectures in the final stages should preferably be split into two: one for the logic programming machine supporting a problem solving and inference machine, and the other for a data base machine having in its core a relational algebra mainly supporting a knowledge base management system.

In addition, results of the study on the individual machines forming part of the new advanced architecture will be used in developing the hardware required to support the intelligent interface system.

In addition, other useful machines may come up also and the possibility of such development should be evaluated at periods when precise targets and laid out (indicated

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* UHM: Universal Host Machine

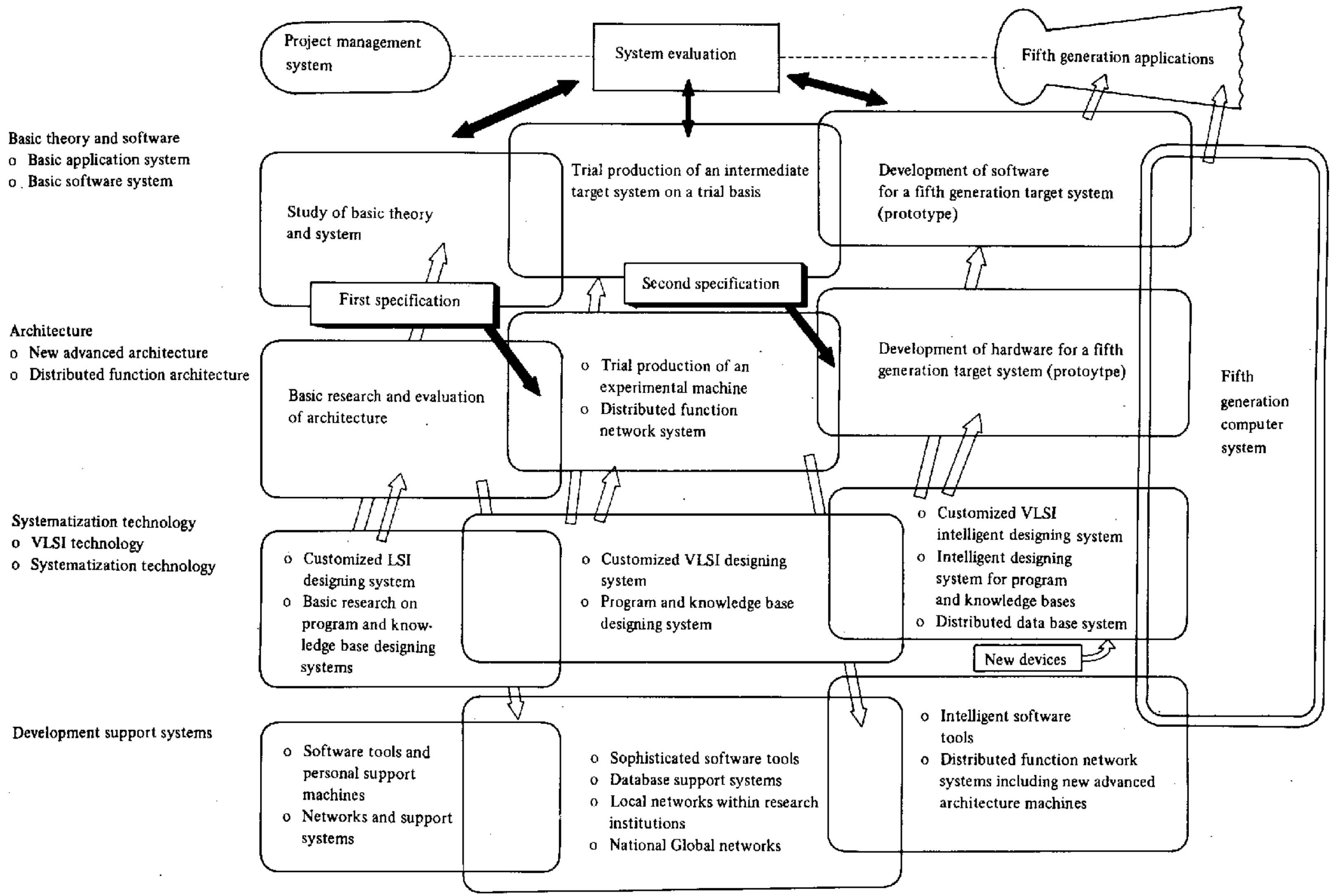

Fig. 4-6 Concept diagram showing how research and development are to progress

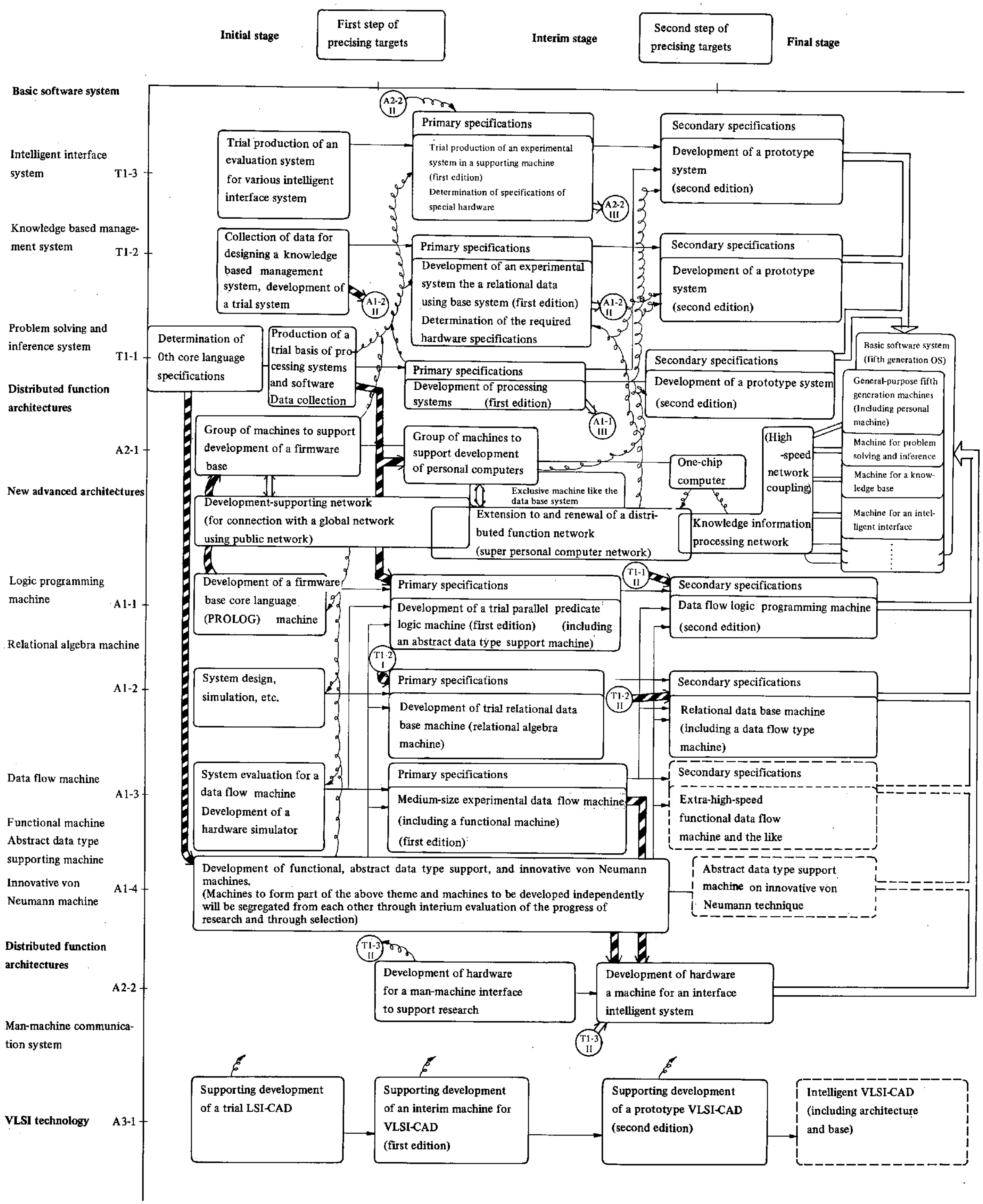

Fig. 4-7 Steps in research and development of themes related to basic software and architectures

: Related as a tool supporting development

: Related as a component determining specification

: Possible target (as a result of greater precision)

by dotted frames in Figure 4-7).

At the end of the final stage, themes rleated to, respectively, basic software and architecture will be combined to build up problem solving and inference functions, knowledge based management function, intelligent interface function, etc.

The hardware systems to be developed will comprise all ranges of machines, covering the general-purpose computers which have these functions, including their smaller versions, namely, the personal computers, and computers incorporating particular enhanced functions.

These fifth generation computers will be linked to a distributed function network system to be developed under the themes related to distributed function architectures. This will lead to the development of an overall knowledge information processing. Detailed specifications of software and hardware for the computers must be finalized by fixing precise targets at the beginning of the final stage.

Practical application of VLSI technologies will be indispensable in developing machines in conformity with the foregoing architecture. Finally, the themes related to VLSI will be taken up.

The first object concerned with VLSI technology is to fabricate customized VLSI chips in a short time. To this end, VLSI architectures and a VLSI-CAD system must be researched to support development of an experimented machine and a proto-type system. First, a trial VLSI necessary for the experimented machine must be built up during the interim stage, to be followed by, say, a CAD system to support the development of a prototype fifth generation computer.

The success with which this theme is pursued is of pivotal importance to the fifth generation computer systems. Research and development on this theme must, therefore, be carried out on priority basis with provision for adequate facilities. A simple interface to be connected to the supporting network must be available for the research on architectures, speech processing etc.

Research on this item will finally aim at development of an intelligent CAD system including the related architecture and data bases in the final target aimed at in this study.

4.4.3 Procedure for research and development of themes related to basic application systems

Roughly speaking, five items may be associated with the basic application systems, each deserving extensive research. For the best results, they should be taken up both as an interdependent scheme allowing mutual exchange of findings, and independently to give reins to creativity.

Progress of research and development on the respective themes related to basic application systems will be discussed with reference to Figure 4-8.

In the initial stage, a start will be made by studying the themes independently to delineate the basic systems, systematize basic data, and construct experimental systems. The following three conditions must be satisfied for this:

(1) Data must be accumulated by using an experimental research and development supporting system. Standardizing the programming language and a basic data accumulation format.

(2) Study results must be exchanged in view of the common information underlying machine translation, question answering, and speech applications.

(3) Innovations in basic software must be utilized progressively. Also, research on basic software must be closely followed up by a feedback system. With the support of the preparatory basic software system (serving as the foundation for the first specifications), data accuring will be fed back from time to

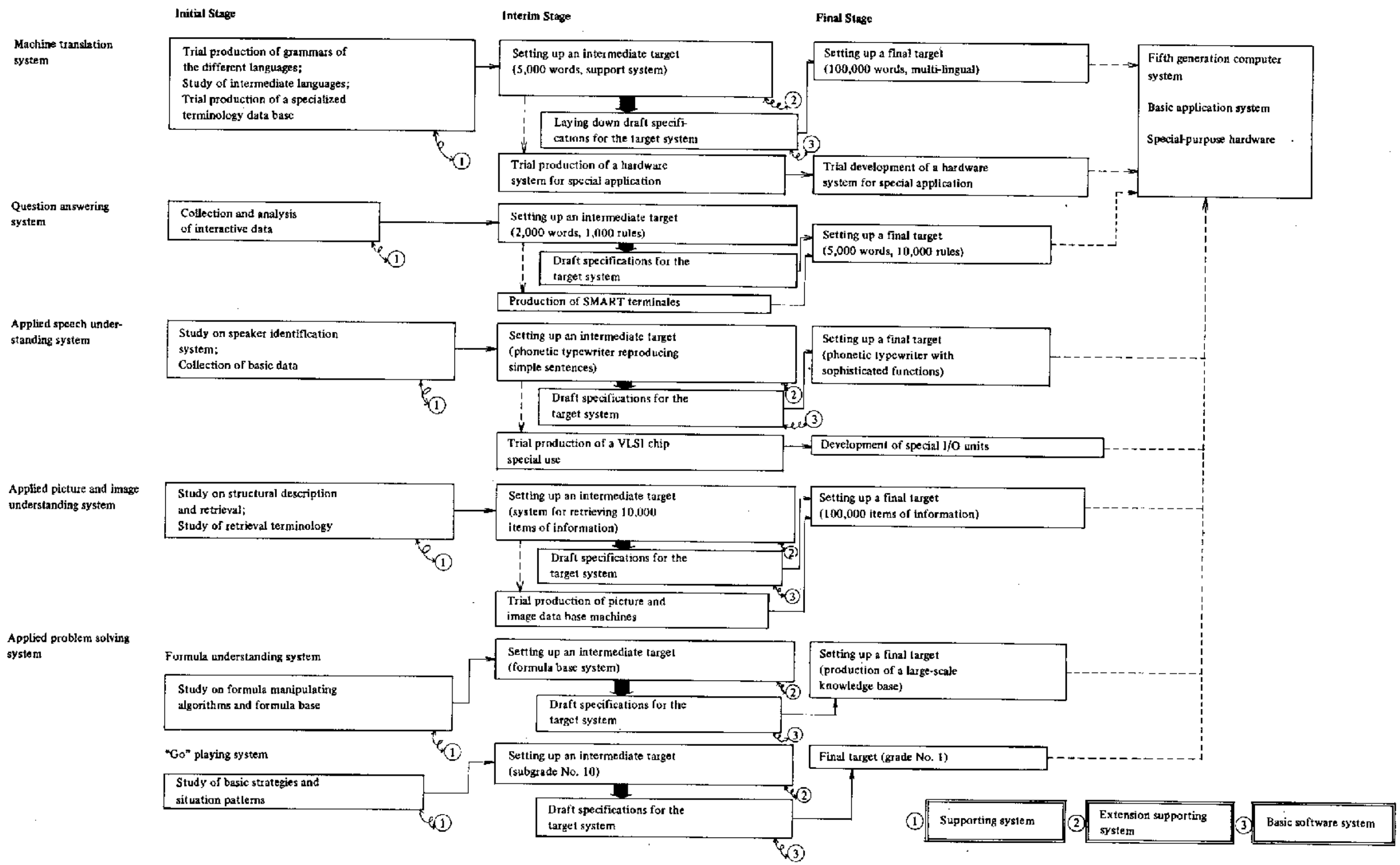

Fig. 4-8 Steps underlaying research on basic application systems related themes

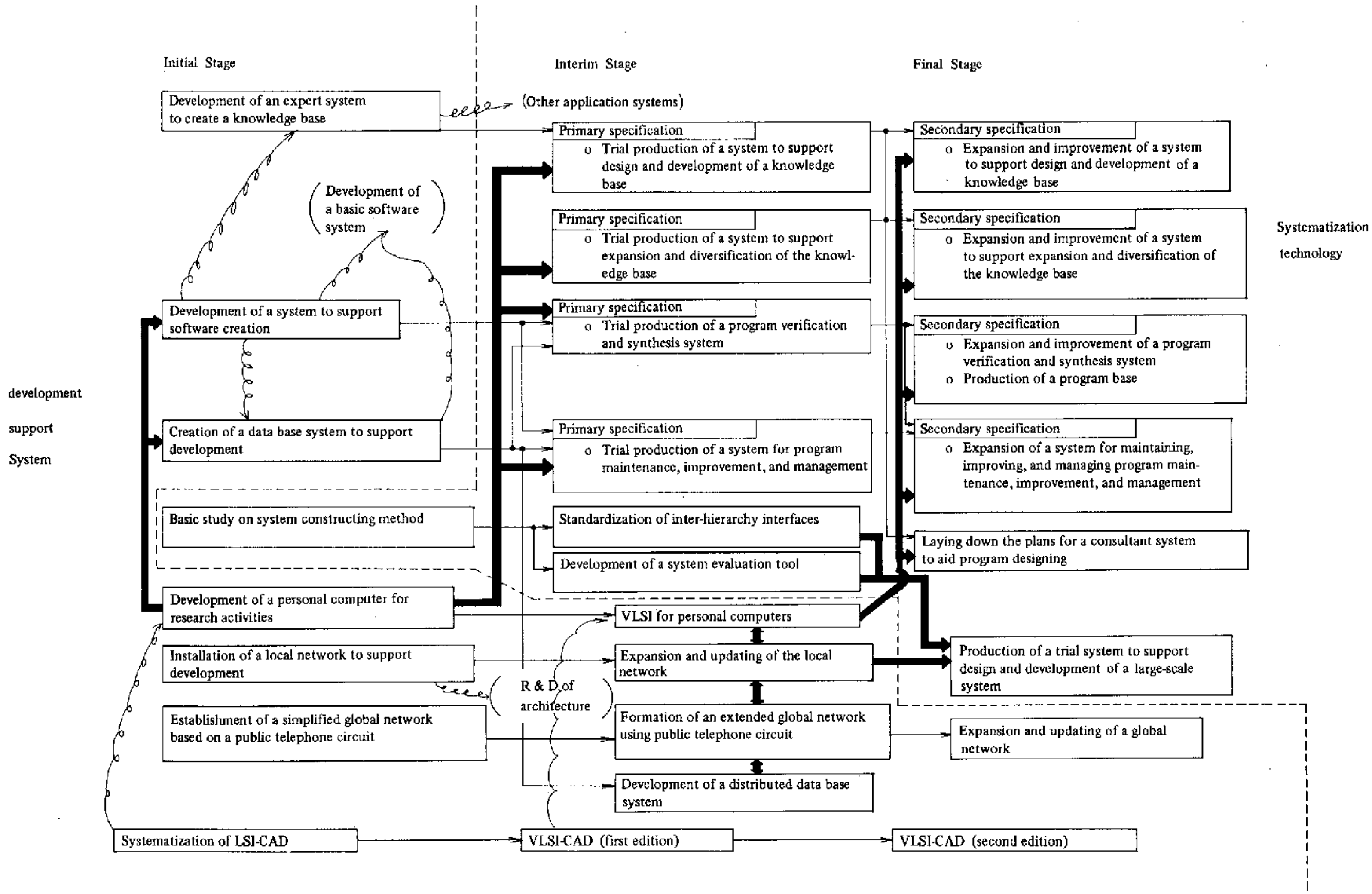

Fig. 4-9 Steps underlying systematization and creation of system to support development

time to ascertain the requirements that were not considered earlier.

Precise targets in the interim stage must be worked out on the basis of earlier results. Further progress must be based on a supporting system, which by this time will have been considerably expanded by making use of the advancements made in the basic software system. The intermediate target systems will not only fulfil the respective target specifications, but will, to a certain extent work hand in hand, forming a distributed function systems via a supporting network. For example, systems responding to speech, picture image or questions may be combined to built up an question answering system using speech and figures. Based on the experiences accruing as the intermediate target systems are constructed, final specifications for the basic software systems must laid down and adjusted to ascertain the final target system specifications in detail. Along with this, the special-purpose VLSI chips in the respective systems and hardware comprising, say, the input and output devices must be developed on a trial basis in harmony with research and development activities related to architectures.

Target systems will be developed in the final stage incorporating, as best as possible, the merits of the basic software system. Obviously, the basic software features need not all form part of the target machines. Where adjudged desirable systems will be built up independently.

4.4.4 Procedure for research and development of themes related to systematization technology and development support system

Figure 4-9 illustrates the steps underlying research on systematization technology and development support system.

Apart from the basic studies, research on systematization during the early stages will aim mainly at creation of development support system. Thus, research on systematization technology will center on the development support system. Final target in the process of development must be oriented to seeking newer avenues for systematization technology with the fifth generation computer system. Components found usable as tools in the course of development must be incorporated from time to time into systems to support the creation of the fifth generation computers.

Systematization technology includes device, architecture, basic software, and application system techniques, but over here the discussion will center on software. Systematization technology at the level of architecture in taken up under the discussion on distributed function architectures.

Research items related to software are oriented mainly to develop knowledge bases and the systems supporting the entire life cycle of programs. As shown in Figure 4-9, these items comprise:

1) A system to support design and development of a knowledge base;
2) A system to support diversification and expansion of the knowledge base;
3) Consultant system for designing programs;
4) A program verification and synthesis system; and
5) A system for maintain, improve and manage programs.

One of the research items concerning software and hardware systematization includes basic studies on system constructing method, standardization of inter-hierarchy interfaces, development of a system evaluation tool, and development of a system to support design and development of a large-scale system.

Development supporting technologies must be ready at the early project period to aid research on personal computers intended mainly for software studies, a local network to support the software and hardware for the personal computer, and LSI/VLSI-CAD. Preferably, a global network should be built up with the aid of NTT (Nippon Telegraph and Telephone Public Corporation)'s switched network.

The required number of personal computers for research and development must be mass-produced by referring to the results of the initial studies on logic programming machines (forming part of the research theme related to new architectures). The machines must be produced on VLSI basis by the middle of the intermediate stage. VLSI-CAD also must be developed by that time.

4.5 Research and development schedule

4.5.1 Research and development schedule

Table 4-4 furnishes the research and development schedule (see also 4.4). Section 4.5.2 below details the procedure envisaged for the respective items in research and development activities.

4.5.2 Research and devleopment procedure

(1) Initial stage

T1) Basic software system

1) For the knowledge base management system, studies will cover an expression system including a knowledge representation language, and methods of acquisition and application of knowledge, as well as control of distributed knowledge. These studies will emphasize on systematization of the basic theory, and collection of basic data through trial production of basic functions. Primary specifications must be laid down for the knowledge representation language.

2) For the problem solving and inference systems, specifications of the primitive core language must be based on predicate logic, which in its turn will center on PROLOG. This will serve as the language specifications for the logic programming machine forming part of system firmware and supporting research. Basic studies on must be carried out on the problem solving and inference system, combining the coding elements into a programming language and laying down the primary specifications for a core language. High-level problem solving modules must be developed tentatively and studied for use in the knowledge base management system and intelligent interface system. Results of modification and expansion of the core language specifications must be transferred immediately to a supporting personal computer to assist in developing other systems, and at the same time to collect data and analyze whether the specifications are acceptable or not.

3) For the intelligent interface system the approach will be to study of the methods as well as the basic theory encompassing natural languages, speech, picture and image systems. This will include a phoneme identification system an speech synthesiser, a parsing component, a sematic analyser, a picture and image analyzer, and picture and image displaying system. Basic studies must be carried out on knowledge representation and problem solving. To evaluate and improve these systems, the supporting system must be supplemented by tentatively developed systems. In this way the primary specifications will be laid down.

T2) Basic application systems

1) The machine translation system will be based on trial generation of grammars of the different languages, study of interim languages, laying down the guidelines for a basic system for trial production of a sentence and terminology data base, and basic data collection. These jobs will be performed with the help of a supporting system, creating, at the same time, a number of trial systems. This will be accompanied by study and design of suitable system hardware including sophisticated word processing techniques and a terminology data base machine.

2) For the question answering system,

Table 4-4 Research and development schedule

	Initial stage	Interim stage	Final stage
Basic application system	(1) Preparing the basic systems (grammars, recognition systems, description systems) (2) Collection and systematization of basic data (conversation data, terminology data base, formula base) (3) Trial production of an experimental system	(1) Setting up interim targets (a system to support translation involving 5,000 words: a specialized question answering system involving 2,000 words and 1,000 rules: speech understanding system handling simple sentences: a system retrieving 10,000 picture and image data items: a algebraic formula manipulation system using formula base: Go-playing system of subgrade 10 level.) (2) Draft specifications for the final target (3) Trial production of hardware for specialized use	(1) Development of final targets (a multi-lingual translation system involving 100,000 words: a question answering system involving 5,000 words and 10,000 rules: a sophisticated phonetic typewriter: a system retrieving 100,000 graphic and picture data items: a formula understanding system with a knowledge base: Go-game playing system at the grade level.) (2) Development of hardware fo for specialized use
Basic software system	(1) Determination (initial stage) of specifications for a core language (such as PROLOG) prior to primary specifications (2) Basic study on the respective software items and laying down the primary specifications (3) Trial production of some of the systems and collection of data	(1) Improvement and extension of the core language laying down the final specifications oriented to machine software (secondary specifications) (2) Trial production of a knowledge base management system on a relational data base machine (3) Development a prototype intelligent interface on a development-supporting machine Hardware specifications for specialized use (4) Drafting the new theoretical system	(1) Intermediate target machine simulator (2) Target system specifications (3) Development of a target system (4) Improved processing of the core language through addition of say, knowledge base enquiry function (5) Development of a final system, integrating it with the fifth generation machines (6) Establishment of a new theoretical system
New advanced architectures	(1) Evaluation of the proposed machines through simulation, and collection of basic data (2) Trial production of some of the experimental machines (3) Development of the firmware-based PROLOG and LISP machine to support development	(1) Incorporating the results of initial evaluation into machines proposed (2) Trial production of a medium-scale experimental machine (using VLSI of the first edition) Support to trial production of software (3) Extending the scope of machine to support development of a firmware base and application of VLSI for personal use	(1) Finalization of the proposed machines and their specifications (2) Development of a prototype and its combination with the software. Fifth generation prototype machine (use of second edition VLSI)

	Initial stage	Interim stage	Final stage
Distributed function architecture	(1) Establishment of a method of designing distributed function architecture design method (2) Basic study on distributed OS and local network techniques (3) Expansion of local network for development supporting	(1) Development of a distributed function network (super-personal computer network) including development-supporting machines (2) Development of distributed OS and related software, and hardware like data base machines (3) Trial production of UHM, supporting its use in personal computers	(1) Expansion to a distributed function network with the fifth generation prototype machine as its core (2) Development of intelligent interface hardware
VLSI technology	(1) Support to the new advanced architectures with customized LSI (2) Study and trial production of software for VLSI-CAD and organizing CAD (3) Basic study on architecture for VLSI	(1) Support to the study of new advanced architectures with customized VLSI (2) Development of a VLSI-CAD system and making it available for use (3) Development of an architecture data base for VLSI	(1) Supporting development of a prototype with customized VLSI (2) Expansion to intelligent VLSI-CAD (3) Conversion of VLSI architecture into a knowledge base
Systematization technology	(1) Basic studies on the method of system construction (modularization hierarchic organization) (2) Basic studies on knowledge base design (3) Basic studies on life cycle management technique	(1) Studies on expansion and diversification of systems (2) Standardization of interfaces between the hierarchic levels (3) Design and development of a system to support systematization (vertification and synthesis of programs, supporting design and development of knowledge base) (4) Development of a system evaluation tools	(1) Enlargement of a system to support systematization (support to expansion and diversification, design consultant system) (2) Development of a design supporting systems and development for a large system (3) Development of maintenance, improvement and management systems
Development supporting technology	(1) Installation of local network to support development and connecting the development-supporting machines (2) Establishment of a simple global network using public telephone line and connecting the development-supporting machines (3) Expansion of PROLOG, LISP machines as development supporting tools (4) Organizing LSI-CAD (5) Development of software development support system (language processing, editor, data base) (6) Development of an expert system to build up a knowledge base	(1) Installation of a local network applying the distributed function architecture (expansion and updating of the local network) (2) Expansion of the global network using public telephone lines and installation of a data base station (3) Supporting development with a superpersonal computer using a core language (first edition) (4) Development and utilization of a distributed data base	(1) Supporting systematization by expanding the distributed function system and local network (2) Expansion of the global network

conversation data must be collected and analyzed, basic specialized data such as specialist's knowledge must be collected, and a system must be built up to handle and use such data. To proceed with this job, use will be made of the supporting system, accompanied by creation of experimental systems. Input and output devices suitable for the systems, such as the SMART terminals, must be designed and fabricated on a trial basis.

3) For the applied speech understanding system, a basic system for, say, speaker identification must be created besides collecting basic data. The supporting system will be used and various experimental systems will be developed. Also, the hardware for specialised use, and input and output devices must be studied and their basic design laid down.

4) For the applied picture and image understanding system a structural programming system, a retrieval system, and a basic system for fundamental research on retrieval language will be taken up. Various experimental systems will be built up and studied with the help of the supporting system. Specialized hardware for, say, picture and image data base machine must be studied and designed.

5) Under the applied problem solving system, the processing algorithm and the methods for knowledge base formation must be studied to build up a mathematical expression understanding system and basic systems like one capable of taking cognizance of fundamental strategies and situation patterns must be developed for Go-game. Various experimental systems will be built up with the help of the supporting system, and basic studies on the input and output devices for specialized application.

A1) New advanced architectures

1) Most of the basic design data must be collected during this period for the machines considered prospective candidate, to constitute the new advanced architecture. This will be done through simulation and trial production of the hardware (hardware simulation). For this purpose, an existing large-size machine must be used.

2) A machine must be developed to aid in basic studies on the software to process intelligence. This machine will be built up using innovative von Neumann technique to support PROLOG and LISP and constitutte the firmware base.

A2) Distributed function architecture

1) Experimental models will be used side by side with simulation to evaluate the methods considered in distributed function system design.

2) Using the local network to aid development, prototype distributed OS and communication control systems will be built up. These will help carrying out basic studies on the distributed function network.

3) A personal computer system will be developed with high resolution display and a picture input functions. Specifications must be laid down for the other components of the distributed function network.

A3) VLSI architectures and CAD

1) Enviornment must be set up for the proudction of customized LSI in the way of aiding, in the way of aiding, development of experimental machines of conforming to the new advanced architecture as well as the development-supporting machines.

2) Simultaneously, software and hardware must be built up to fabricate customized chips and data must be collected besides accumulating the software to develop VLSI-CAD.

3) Basic research must be carried out to develop the architectures for VLSI.

S1) Systematization technology

1) For the intelligent programming system, basic study must be carried out to delineate the guideline for laying down the

specifications, and to build up system for verification, synthesis etc. An experimental system must be established at the same time. Side by side with this, a sophisticated conversational programming system must be developed with the support of the personal computer to provide the methodology for research and development activities. At the same time, a systematic approach must be evolved to collect data for systems to be studied and developed. Primary specifications must be decied in conformity with the basic software system specifications.

2) For the knowledge base design, a basic metaknowledge representation, inferences and verification system must be studied, producing an experimental system for deeper insight into the problems. At the same time, trial systems must be produced with the support of the personal computer for single functions. They will help research and development, and as data is collected side by side. Primary specifications must be laid down in conformity with the basic software system specifications.

S2) Development supporting technology

1) A local network must be laid by using existing technique to support development activities. To this should be connected the PROLOG/LISP machines to support development activities as well as existing machines.

2) A global network must be built up on the public network to connect several research sites.

3) LSI-CAD must be connected to the local network to aid the researchers. By this time, local networks similar to the ETHER and CHAOS network of, respectively, Xerox corporation and MIT will be laid.

For LSI, something like CIF, the standardized pattern describing language of U.S. will be specified.

(2) Interim stage

T1) Basic software system

1) For the knowledge base management system, a prototype will be developed by using the tentatively constructed data base machine utilizing the data collected during the initial stage. This will be used in research on other systems and evaluation data will be collected to prepare a draft for the final specifications. During this period an attempt will be made this with other basic software systems. The framework of a new theoretical system (such as a knowledge theory, a knowledge representation theory, etc.) should be given.

2) For the problem solving and inference system, experience with the supporting system will be utilized to extend the scope of the core language. At the same time, greater precision must be achieved in the link between this system and the meaning and specification coding systems. A trial processing system must be produced from the trial inference machine, and used tentatively to collect evaluation data and prepare the draft final specifications. During this period integration of merits of other basic software systems must be incorporated this system. The framework must be established for a new system of theories.

3) For the intelligent interface system, a prototype must be built up, with the help of the supporting system and the trial machine to assist in research on the basic application system. The final specifications must be drafted by using the experience gained in their use. During this period, attempt may be made to combine this system with other basic software systems. Framework must be built up for a new system of theories (such as a recognition theory, an comprehension theory, or an representation theory). Furthermore, specifications must be laid down for hardware comprizing VLSI chips and input and output devices with enhanced functions.

T2) Basic application system

1) Using the support system, a small-scale translation aid system handling 5,000 words must be produced as part of the interim target. By developing and evaluating such a system, data will be prepared to help study specifications of the basic software system and the supports to the intelligent system, and draft the specifications for the target system. Data base containing the dictionary and the collection of terminologies must be expanded, leading to the formation of an intelligence base. Specialized hardware will be built up tentatively.

2) With the help of the support system, an interim system will be built up to accommodate a limited collection of vocabulary (2000) aux rules (1000) for specialized work. Development and evaluation this system will yield the data needed to decide the specifications for the basic software system and the supports to systematize intelligence. The system must be harmonized with other basic application systems, and detailed specifications must be drafted for the target system. The respective specialized knowledge bases must be expanded, incorporating greater sophistication. These will include system and components related to the fifth generation computer system itself. Specialized hardware including, say, the SMART terminals must be constructed on a trial basis.

3) For the applied speech understanding system, the support system will be used to develop an interim phonetic typewriter handling simple sentences. In the course of development and evaluation of such systems, data will be available for the study of specifications for the basic software system and the supports to systematization of intelligence. Detailed specifications must be drafted for the target system special-purpose hardware must be developed.

4) For the applied picture and image understanding system, an interim target system will be developed with the aid of the supporting system to handle about 10,000 picture and images. Development and evaluation of the system will yield the data needed to work out the specifications for the basic software system and the support to systematization of intelligence. Detailed specifications must be laid down for the target system taking into consideration the problem of harmonizing it with other system. Special-purpose hardware, such as a picture and image data base machines must be constructed on a trial basis.

5) As for the applied problem solving system, the interim target will be to built up a rule-based mathematical expression understanding system, using the support an aid. The interim target will also include productions of a Go-game playing system of about subgrade No. 10 standard. During the development and evaluation of such systems, data will be available for the specifications of the basic software system and the support to intelligence systematization. Also, detailed specifications must be drafted for the target system. Rule bases etc. must be made more sophisticated, and special-purpose hardware must be developed.

A1) New advanced architectures

1) An interim experimental machine must be constructed to comform to the new architecture. It must be based on language specifications laid down during basic software study. For such development, the first version of customized VLSI must be used.

2) During this period, results of studies on machines conforming to the new architectures must be combined, and the number of candidated for the fifth generation computers must be reduced from 6 to 3 machines.

3) The PROLOG/LISP machines developed during the initial stage must be produced on VLSI basis to build up a small-szie personal computer and improve its performance.

4) Part of the machines forming part of the new advanced architectures must be taken

up for the software study.

A2) Distributed function architecture

1) Based on the results of initial studies, a distributed function network will be developed. This will expand and update the supporting local network. In addition, the base of the software, namely the distributed OS, must form part of the architecture.

2) The supproting personal computer, data base machine, etc. must be interconnected to form a superpersonal computer network. The global network must be expanded packet switching network, etc.).

3) Continuous research must be carried out on the software for the distributed function network and machine components like the universal host machines.

A3) VLSI architectures and CAD

1) A CAD system for custumized VLSI must be developed to support research on the new and distributed function architectures.

· 2) Based on the study of VLSI architectures, function modules, circuits, programming languages including mask patterns, and processing systems must be developed. The coded items must be accumulated and systematized to develop the architecture data base for intelligent VLSI-CAD.

S1) Systematization technology

1) For the intelligent programming system, the interim target will be to develop a system for simple verification and synthesis, a small-scale program base, and a basic system for understanding programs. These systems will be combined to expanding the scope of the supporting system functions. Based on their merits, these must be combined with the basic software system to design on integrated basic system and to draft the specifications for the target system. Specifications, verifications and synthesis must be backed up theoretically.

2) For the knowledge base design system, the interim target will be build up a system with a small metaknowledge representation system, an inference and verification system, etc. Through trial and experiments, basic integrated system will be built up in conformity with the basic software system. Metaknowledge representation must be backed up theoretically. At the same time, scope of the must be expanded in the supporting system. Furthermore, experiments must be to collect a large volume of knowledge conducted.

S2) Development supporting technology

1) To exchange results of research on soft- and hard-ware, methods of modularization and must be standardized together with their interfaces.

Also, a data base system must be created to store the results obtained, and management must be systematized.

2) The distributed function and global networks must be used as tools to support development. Peripherals must be organized for the personal computers (PROLOG/LISP machine).

(3) Final stage

T1) Basic software system

1) A simulator must be developed for the target machine, using the interim trial machine or the software support to the knowledge base management system. At the same time, specifications must be improved and made more accurate. The system developed must be incorporated in the target machine to built up the basic application system. Based on the data collected in the process, more sophisticated learning functions must be supplemented for research on an extended system. A new theory must be established.

2) For the target problem solving and inference system, a simulator must be built up, using the interim trial machine or the support to the processing system underlying the target machine. The processing

system must be integrated with the intelligent programming system and incorporated the target machine to develop other systems. Using the data collected, more sophisticated functions will be supplemented for problem solving. At the same time, research must be carried out to improve the performance of the machine. Attempts must be made to establish a new theory.

3) A simulator must be built up to develop the target intelligent interface system. This will include construction of the hardware for special purposes. This must be integrated with the knowledge base management system as well as the problem solving and inference systems so as to constitute part of the target system. Based on the data collected, research must be carried out to provide additional sophisticated functions aiding comprehension. Attempt will be make to found new theories.

T2) Basic application system

1) The target machine translation system will be based on the final machine to handle 100,000 words and several languages. For this efforts will be made to combine this system with the basic software, organizing various sophisticated knowledge bases, special-purpose hardware must be developed and improved.

2) The final question answering system will be built up with the target machine as the base. This will deal with various specialized fields using 5,000 or more words and at least 10,000 rules. The developement must be matched with the basic software system as well as other basic application systems. Knowledge bases must be organized and made more sophisticated besides being increased in number. The target system includes an intelligent utility system.

3) The final speech understanding system will include, say, a phonetic typewriter understanding speech, developed as a sophisticated I/O device for the target machine. The system must be matched to the intelligent interface system.

4) For the applied picture and image understanding system, the final target will be to develop picture and image data base handing 100,000 items of information. An integrated retrieval system must be developed at the same time. These systems must be matched with the intelligent interface system as well as other basic application systems.

5) The applied problem solving system in its final shape will comprise a large-scale formula processing system in the target machine with a knowledge base storing rules and formulas, and Go-game playing system of, say, grade 1 performance.

A1) New advanced architectures

1) Prototype machines constituting the new advanced architectures must be developed according to the new language specifications (final) decided in the course of studies on the basic software. During this period the number of candidate machines for the architecture must be reduced to one or two by referring to the results achieved by the intermediate stage. The machines are to be classified according to their respective scales of performance. Some machines must be developed to conform to the applied software.

2) The second edition of VLSI must be used in the development of such prototype machines.

3) The architecture must be evaluated and at the same time, improved as application systems through combination with the software of the final specifications.

A2) Distributed function architectures

1) The distributed function network developed in the intermediate stage must be expanded. Also a knowledge information processing network must be constructed with the core machines constituting the new advanced architectures.

2) Special-purpose VSLI chips and proces-

sors must be developed to process speech, picture image, and natural languages. The development must accord to the specifications determined during studies on the basic application system.

3) Packaged software groups must be incorporated in the distributed function network to process knowledge information. Also, these must be evaluated and improved.

A3) VLSI architectures and CAD

1) VSLI-CAD must be used to create the second edition of VLSI required for the development of prototypes of new advanced architectures.

2) Development of chips for exclusive use in speech, picture and natural language processing must be supported in the same way.

3) The VLSI architecture data base must be expanded and linked to the CAD system. A prototype must be built up for the intelligent VLSI-CAD system on the basis of the study resulty on knowledge bases. At the same time, algorithm design, a circuit design, pattern design etc. must be integrated.

S1) Systematization technology

1) For the intelligent programming system, a consultant system must be developed by using the target machine to design programs on the basis of questions and answers in a natural language. The system must include say, a large program base and an improved systems with their defects removed. The development must be effected in a sequence that will allow it to be utilized for the development of the basic application systems. Theoretical basis must be secured for specifications, verification, and synthesis.

2) For the knowledge base designing system the target machine must be used to develop an integrated knowledge base design support system. This will include, among others a system to support expansion and diversification, and a system to support program execution. The development will be carried out in a sequence that will help its utilization during the successive stages of basic application system development. The system must be linked with the intelligent programming system to integrate the two as a support to supporting systematization. Attempts must be made to secure the theoretical base underlying metaknowledge verification, etc.

S2) Development supporting technology

1) For better flexibility, the interface specifications must be standardized at different levels to include the modules and I/O channels across the prototype machines.

2) Results achieved during the process of development must be organized and systematized to form a data base.

3) Methods and tools must be developed and made available for system evaluation.

4.6 Project organization and execution

4.6.1 Basic principles to be followed in research and development activities

Features characterising the project will be set forth before the procedural details are discussed. Also, organizational details underlying the research activities and the procedure envisaged to execute the project will be discussed on the assumption that the essence of the project will not be sacrificed to facilitate its execution.

From the standpoint of organization and execution, the project features may be enumerated as follows:

(1) The project must play a pioneering role besides being creative in its approach

The purpose of the project does not lie in following or imitating the techniques developed by the other advanced countries. Instead, its aim is to achieve a target that will at once realize the social and technological ideals laid down for the future. One of the distinctive features of the project will be its emphasis on research and experimentation to set up this target.

(2) The project must look far ahead into the future

For the present, the project expects to achieve its target in ten years. At the same time, however, it contemplates a number of intermediate steps leading ultimately to knowledge information processing of a standard comparable to human brain. Corresponding to each to these steps, the project provides room for an interim target. On the other hand, the project looks forward to acting as a link with the future, and, therefore, attaches great importance to securely founded research activities. When contemplating the project, therefore, it is imperative to consider other projects also that may evlve out of it.

(3) The scope of the project must be wide enough to encompass the entire computer industry with all its ramifications, which, by the 1990s, will hopefully emerge as the mainstay of all industrial activities

In view of the natural limitations to human and material resources, the project will be content with a relatively modest but clearly described target during the initial stage of research and development. This, however, will be intended as a means to aid the progress of the project which will be implemented with a view to bearing upon the computers and the industry as a whole. Thus, it will be linked with, say, the studies under way on high-speed numerical computation systems for scientific and technical jobs relating to large-scale industrial research (large-scale projects) or current research to serve the techniques on which the next generation of industries will be established. In short, a wholesome development will be aimed at.

(4) The project must be an internationally oriented one

As mentioned earlier, this project is expected to play a pioneering role. This implies that the project will have a very important influence not only on Japan's own domestic industries but on other countries as well. If successful, the creative aspects of the project will make an important contribution to the international community besides, as it is hoped, elevating Japan's position in the world. As these suggest, the project must be oriented in an international perspective.

A project so distinctive in nature cannot be carried through without taking the following into consideration:

(1) It has already been noted that one of the most important topics for the research activities related to this project will be to set up the right target for it. The target must be an ambitious one in order to stimulate originality in research. At the same time, however, care must be taken not to overdo things by losing sight of the question of economic feasibility. Thus, the target must be finalized by striking a balance between demand and economics.

(2) Even if it is at the cost of ahving to cross numerous hardles, considering the long-term implecations of the project, a target may be set up if it is considered indispensable for the future. However, to lead the project along a sound course, it will be necessary to proceed to this target in bits by achieving more realistic interim targets established securely on economic and demand considerations. The interim targets so set up will include both conservative and ambitious ones, thought being given to the possibility of achieving them in parallel. In particular, during the initial stage of the project, attemps may be made to carry out parallel research on some topics not too far removed from the basic ones. On the other hand, subjects of research should be reorganized or integrated on the basis of strict yearly evaluation.

(3) Procedural aspects of research and the results thereof must be considered apart when

evaluating them. It must be understood that early detection of steps leading to a negative result is no less important than a successful end. Furthermore, evaluation emphasizing on originality is apt to lead to creative results capable of initiating further developments.

(4) The thinking behind the project must not lose its consistency during the long period of execution. To assure this, both the basic project targets and the ideas underlying it must be delineated in clear terms. In addition, strict guiding principles must maintained all throughout as the project is carried through.

(5) Success of a project of this nature depends much on the ability of the researchers. The more a research reflects originality, the greater is the likelihood of its having depended substantially on the researcher's own merits. Thus, it is important to appoint the researches from all walks of life, be it government offices, industries, or the academic world.

(6) Besides maintaining rigid guiding principles throughout the project, opinion of the individuals involved in the project will be honored, and attempts will be made to embody such opinion in planning. In addition, consensus of the researchers participating in the project will be obtained in each step, respecting their individuality and creating an atmosphere where they can exercise their originality. These steps are considered important for smooth running of the project. A feedback system must be established, creating a route for exchange of views through both top-down and bottom-up approaches. The guiding principles on which the execution of the project will rest must conform to the conditions prevailing in Japan.

(7) The fifth generation computers to be developed during this project will ultimately form the core computers in the 1990s. This will necessitate a transition from the machines of the preceding generations. All care must be taken to make this transition smooth and natural.

4.6.2 Desirable Research and Execution Principles

Further to the basic principles laid down earlier, all research and development activities in this project should, as far as possible, adopt the following norms:

(1) Consistent guiding principles

This is a project that ventures into untrodden grounds. It also is a project that will take a long time to execute. Accordingly, it must be based on consistent ideas with clearly delineated policies and targets.

The basic ideas underlying the project represent the point whence all the planning for its execution will start. These ideas should be set forth clearly in writing and no change must be made to them unless one clearly detects an error. This measure will prove effective not only if a project leader is replaced, but avoid possible deviations from the original stand as time passes even where the activities are led by one and the same person.

(2) Setting up targets

It is difficult to set up a rigid target for long-term research. On the other hand, as far as possible, the final target should be in full view throughout the project after it has been fixed through a strict selective process. In addition, interim, short-term targets must be set up clearly on concrete grounds, so that they may be referred to as the criteria to evaluate the project by. The final target must be fixed by embodying in it the latest developments in the related fields and amending it, if necessary, during the intermediate stages. A systematic approach is necessary for this, taking cognizance of the changes around and the maintaining up-to-date information on the latest technological developments abroad.

On principle, research will be scheduled by setting up and evaluating targets at three to four years' interval.

(3) Project systematization

This project covers an extensive area as reflected by the diverseness and number of topics taken up for related research as well as by the long period that intercepts its near-basic research stage and the actual development activities. In order to carry the project through, therefore, one must elucidate the relation of the individual research topics or developments to the project as a whole. Positive efforts must be made to modularize the approach and present the entire system clearly to the view.

During the initial stage a number of alternative techniques must be studied in parallel, selecting some and rejecting the others through a process of strict evaluation as progress is made towards the next stage. Each of these must be clearly related to the developments, the system being capable of applying the results attained in a particular stage during the course of the succeeding stage.

(4) Human resources

During its long execution period the project must provide opportunities for effective participation of researchers around the country. During the initial stages cooperation of the university researchers should be sought. For this a network must be established to connect the researchers around the country, equipping it with high-performance personal computers.

An organizational mechanism must be set up at the center to establish mutual contact between the participating researchers so that they cooperate with each other. This will necessitate appointment of really competent persons. For example, only persons with ability to lead must be selected as project leaders, playing a pivotal role in assuring uninterrupted progress of the project along the guidelines laid down.

(5) Role of organizational nucleus

To avoid interruptions to management and control as the project is carried through, the necleus of project organization should be constituted by an impartial body that will represent the government, industries, and the academic circles alike, without bias to any of these. Apart from drawing up plans and supervising the project, this nucleus will be responsible for fundamental technical research and investigations needed for project execution. It will pilot the project and will evaluate and select the techniques to be applied. In addition, it will lay down accurate specifications for research on each individual topic after thorough investigation and analysis. It will entrust actual execution of research to the makers, laboratories, and universities, but will, at the same time, undertake to supervise and evaluate the progress of such research and even offer advice as one of its essential functions.

Some of the activities expected of the organizational nucleus will include the management of components shared during the progress of the project, such as the different data bases, the CAD system, or the hard- and soft-ware tools that will eventually open fresh avenues for further advancement. At the same time, it will offer services in the related fields, and make it possible for the researchers in the different fields to exchange their views.

If required, the organizational nucleus will include not only a control center, but centers for, say, studies and investigations and services as well.

Besides the staff members appointed exclusively for it, the nucleus should include persons on loan from the government, industrial, and academic circles. This is expected to strengthen the bond between the different circles and ensure smooth running of the project as a whole. The group central to the project may comprise a small number of persons, but they should remain with the project along its entire course.

(6) International cooperation

Basically, international cooperation implies mutual effort by the different countries of the world to promote further advancements in information collecting and processing techniques. To this end, the project will, among others, encourage active participation in international conferences, make positve endeavours to attain standardization and sponsor periodic symposiums.

Emphasis must be placed on the importance of PR activities to avert misconceptions about this project in countries abroad and, instead, to stimulate enthusiasm in the different countries about its progress.

For a number of reasons it is difficult to make this an international project. Instead, it is desirable to execute it as a national project with Japan having the liberty to decide its course. It must be noted, however, that the project includes research on mechanical translation, mechanical interpretation etc. which must be carried out hand in hand with the other countries. In these fields, therefore, it will be found expedient to link the projects with similar projects abroad or arrange for joint studies where both the project researchers and researchers foreign enterprises will participate alike.

Specific policies must adopted to allow a constant flow of researchers to different countries, for this will pave the way for participation by outstanding researchers from the other countries during the extended periods of research organized under this project. This will not only orient the project in an international perspective, but will be effective in setting up a progressive and creative research atmosphere. The researchers must invited not only from the advanced countries but from all countries of the world alike, emphasis being placed on talent.

One way to encourage foreign researchers to participate in this project is to entrust research institutions abroad with studies on research subjects themselves. Before such a step is taken, however, the results it may be expected to yield must be considered carefully.