Outline of Research and Development Plans for Fifth Generation Computer Systems

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1. Background and Introduction

As computerization advances, information technology with computers as its core has been applied to various areas of society, and become an indispensable tool in modern society.

To provide for the conditions and information demands of the society in the 1990s, more advanced and higher-level functions and performance will be required of information technology; these include utilization of more varied media, easy-to-use computers, higher software productivity and application of information technology to those areas in which existing information technology has not been applied.

In order to meet these needs, the design philosophy itself of the current computer technology should be studied and evaluated.

Conventional computers, following the von Neumann computer architecture, are now realized by the simplest hardware because the hardware was expensive and bulky when the first computers were invented. Most of the functions required are then realized by software in order to provide an efficient processing system. Therefore, the conventional computers have become numerical-processing oriented, stored-program sequential processing systems. High speed and large memory capacity have been pursued from the economic standpoint, producing the present enormously big computer systems.

However, the situation has evolved as follows.

(1) VLSIs have substantially reduced hardware costs, so computer systems can use as much hardware as required.

(2) A new architecture for parallel processing is now required because device speed has approached the limit for sequential processing.

(3) Parallel processing should be realized in order to utilize effective mass production of VLSIs.

(4) The current computer technology lacks the basic functions for non-numeric processing of speech, text, graphics and patterns, and for artificial intelligence field such as inference, association and learning.

From these reasons, the Fifth Generation Computer Systems (FGCS) should be developed, which provide knowledge information processing systems. FGCS should thus employ latest research results in VLSI technology, as well as technology of distributed processing, software engineering, knowledge engineering, artificial intelligence, and pattern information processing.

Thus we have concluded that it is meaningful to pursue research and development of the FGCS as innovative information technology. We hope not only to conduct creative research in this field, but also to contribute thereby to the benefit of all humankind.

2. Research and Development Themes

The Fifth Generation Computer Systems aim at knowledge information processing based on innovative inference functions and technologies that meet the needs anticipated in the 1990s, including intelligent interaction between man and machine and inference using knowledge bases.

The functions required of such a system can be broadly divided into four types:

(1) Problem solving and inference function

This function is intended to enable the system to find solutions to problems by carrying on logical reasoning using data and knowledge stored in the system as well as information given to it from outside. This capability covers deductive inference, inductive inference including guessing based on incomplete knowledge, and cooperative problem solving by mutual complementation of several bodies of knowledge.

(2) Knowledge base function

This function is aimed at providing systematic storage and retrieval of not only so-called data but also reasonable judgements and test results organized into a knowledge. Besides knowledge accumulation, it includes knowledge representation tailored to problem solving, knowledge acquisition and updating, and simultaneous utilization of distributed knowledge sources.

(3) Intelligent interface function

This function is intended to enable computers to handle speech, graphics and images so that computers can interact with humans flexibly and smoothly. It might be regarded as giving computers the equivalents of human eyes, mouth and ears, but its primary objective is to provide computers with a linguistic ability close to that of man.

(4) Intelligent programming function

This function is intended to enhance the intelligence of computers so that they can take over the burden of programming from humans. While its ultimate goal is to achieve an ability to automatically convert problems into efficient computer programs, it is aimed preliminarily at achieving a modular programming system and a program verification system and at establishing a specification description language.

To achieve these four functions requires the development of innovative technologies encompassing the diverse fields of architecture, hardware and software. The major research and development themes are listed below.

(1) Hardware architecture and software to achieve inference function. This will include:
   1 An inference mechanism based on a distributed control-based architecture which is oriented to parallel processing instead of sequential processing.
   2 Basic software to manage and execute parallel inference.

(2) Hardware architecture and software to achieve knowledge base function. This will include:
   1 A knowledge base mechanism based on structured memory instead of one-dimensional memory.
   2 Basic software to manage knowledge bases for high-speed retrieval and relational storage of knowledge data.

(3) Hardware architecture and software to achieve intelligent interface function. This will include:
   1 An intelligent interface mechanism composed of a voice or signal processor and other devices.
   2 Basic software for natural language processing and graphics and image understanding to ensure flexible man-machine interaction.

(4) Software to achieve intelligent programming. This will include:
   1 Basic software for automatic creation of optimum programs

New application fields

The knowledge information processing systems realized by the Fifth Generation Computers are expected to expand extensively the fields where computers are applied such as manufacturing, service, engineering, and office and business management.

VLSI CAD, machine translation and consultation systems are chosen to develop as the model systems to apply the basic Fifth Generation software to as well as to prove and assess the basic software system. The development of these application systems is planned in the intermediate and later stages.

3. Research and Development Plans

3.1 Overall Plans

The research and development goals of the Fifth Generation Computer Systems are such core functions for the knowledge information processing as problem-solving and inference systems and knowledge base systems, that cannot be handled within the framework of conventional computer systems.

We are obliged to move toward the target systems through a lengthy process of trial and error, producing many original ideas along the way.

In Japan, little effort has been made in research on the key technologies, particularly software and basic theories. The research in this field should be promoted because it has a great influence on development of hardware technology, including computer architectures and VLSIs.

Since this project aims at computer technology for the 1990s, plans encompass as wide an extension of basic technology as possible. And this project is planned to span about 10 years, divided, as shown in Fig. 1, into an initial, intermediate, and final stages.

The emphasis in the research and development of the initial stage is on accumulating the research achievements of the past in the field of knowledge information processing, and evaluating and restructuring them. In addition, candidates for each research subject have to be screened and basic technology is developed for the intermediate stage.

The research and development of the intermediate stage is focused on establishing computation models as the basis for software and hardware as well as algorithms and basic architecture based on the evaluations of the initial stage. Small- to medium-scale sub-systems are then built.

The final stage puts an emphasis on appropriate functions of both software and hardware systems, interfaces to maximize these functions, and the architecture for the total system.

Concerning the overall flow of research and development efforts, the initial stage is envisioned that software and hardware modules are built and also some experimental systems configured by integrating these modules. These systems include hardware and software simulators, prototypes for language processing, and experimental natural language processing systems.

The intermediate stage is mainly devoted to improving and extending the results of the initial stage, and integrating them into inference and knowledge-base subsystems.

In the early part of the final stage, the configurations of these software and hardware systems developed in the intermediate stage are reviewed and evaluated. The total system is developed, integrating the subsystems in order to define the ultimate goals clearly.

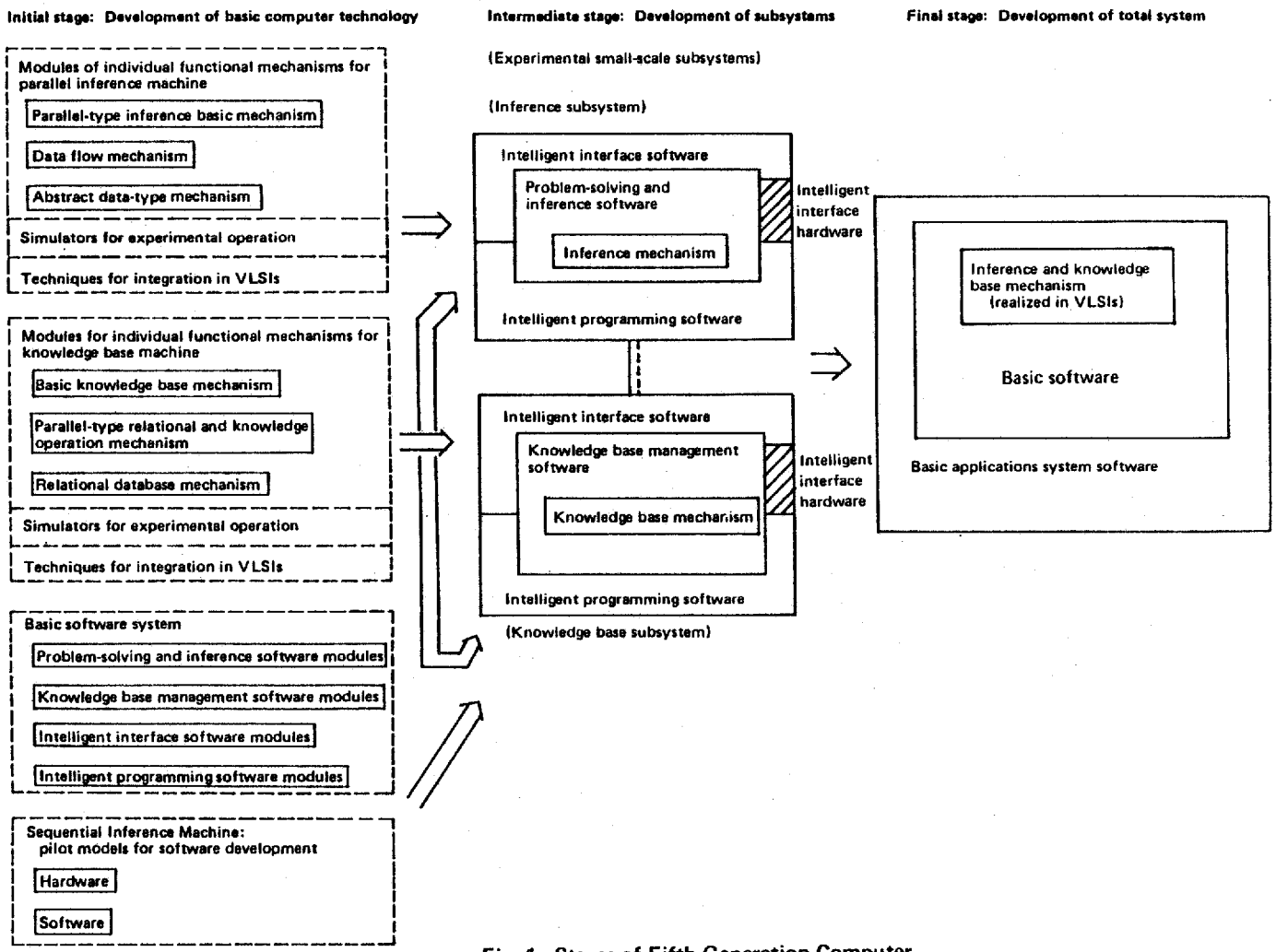

Fig. 1 Stages of Fifth Generation Computer research and development

3.2 Research and Development Plans in the Initial Stage

Table 1 describes each research item planned in the initial stage. Figure 2 is the overview of the research and development in the initial stage which shows the relationships among each research item.

Table 1 Research and development themes in the initial stage

Research & development theme	Details
Parallel Inference Machine (PIM)	The parallel inference machine, together with the knowledge base machine, forms the nucleus of the Fifth Generation Computer hardware. At the initial stage, an evaluation and study will be made on the basic inference module configuration composed of the following: (1) A parallel-type inference basic mechanism to manage the parallel execution of inference operations. (2) A data flow mechanism to execute inference operations and rapidly determine solutions. (3) An abstract data-type mechanism to consolidate detailed inference operations into several groups and control them by group.
Modules for individual functional mechanisms for PIM	The parallel-type inference basic mechanism, data flow mechanism, and abstract data-type mechanism individually consists of functional sub-modules. Initially, prototypes of these sub-modules will be constructed. Then these prototype sub-modules will be combined to construct a prototype module for each of the three functional mechanisms.
Simulators for experimental operation	Prototype simulators for experimental operation will be built to simulate module configurations, using different numbers and combination of sub-modules. They will also be used to determine the optimum configuration of the modules for three functional mechanisms and also of the inference basic module which these sub-modules will comprise.

Research & development theme		Details
	Techniques for integration in VLSIs	Prototype software will be developed for evaluation and examination of the VLSI convertibility of the circuit composition of each sub-module designed. It will be used to data gathering and evaluation for integration in VLSIs.
Knowledge Base Machine (KBM)		The knowledge base machine, together with the parallel inference machine, forms the nucleus of the Fifth Generation Computer hardware. At the initial stage, an evaluative study will be made on the configuration of the basic knowledge base module composed of the following: (1) A basic knowledge base mechanism to provide overall management of the execution of basic knowledge base operations. (2) A parallel-type relation and knowledge operation mechanism to provide speedy knowledge accumulation, retrieval and updating, data conversion, etc. (3) A relational data base mechanism to provide large-capacity knowledge accumulation, storage and management.
	Modules for individual functional mechanisms for KBM	The basic knowledge base mechanism, parallel-type relation and knowledge operation mechanism, and relational data base mechanism individually consist of functional sub-modules. Prototypes of these sub-modules will be constructed at the initial stage. These prototype sub-modules will be subsequently combined to produce a prototype module for each of the three functional mechanisms.
	Simulators for experimental operation	Prototype simulators for operation tests will be built to simulate module configuration using different numbers and combinations of sub-modules. They will also be used to determine the optimum configuration of the modules for three functional mechanisms and also of the basic knowledge base module which these sub-modules will comprise.
	Techniques for integration in VLSIs	Prototype software will be developed for evaluation and examination of the VLSI convertibility of the circuit composition of each sub-module designed. It will be used to data gathering and evaluation for integration in VLSIs.

Research & development theme	Details
Basic software system	The basic software system forms the nucleus of the Fifth Generation Computer software, and is composed of the following four software modules for knowledge information processing: 1. Problem solving and inference software module 2. Knowledge base management software module 3. Intelligent interface software module 4. Intelligent programming software module An extended Fifth Generation kernel language needed for the intermediate stage will be developed by organizing the knowledge obtained through designing and breadboarding the basic software system. Furthermore, a prototype software system will be produced to test the correctness of specifications and validate their accuracy.
Problem solving and inference software module	The problem solving and inference software module has the capabilities of deductive inference, inductive inference including conjecture proposing based on incomplete knowledge, and inference by mutual complementation of knowledge. The development of a prototype of basic software for parallel inference is planned for the initial stage for use in high-speed execution of deductive inference and basic software for problem solving to determine efficient solutions to problems.
Knowledge base management software module	The knowledge base management software module has the capabilities of knowledge accumulation, distributed-knowledge source utilization, and knowledge acquisition. The development of a prototype of a knowledge representation system is planned for the initial stage in order to define knowledge data representation methods. A large-scale relational data base management program is also planned to accumulate and manage a large volume of data represented as knowledge.

Research & development theme		Details
	Intelligent interface software module	The intelligent interface software module is for flexible interaction between human and computer. The development of a prototype of a high-level parsing program is planned for the initial stage, and is aimed at achieving high-speed parsing and simplified algorithms for natural language understanding, which is critical to the man-machine interaction. Basic technologies for semantic analysis and a pilot model of a support dictionary system will also be developed.
	Intelligent programming software module	The intelligent programming software module has the capability of automatic conversion of an input problem into an efficient computer program (a kernel language level). A program module management system with extraction capability of component modules, and verification facility of a program is planned to develop at the initial stage with the objectives to establish modular programming, which is basic to intelligent programming, extraction of the necessary program, and program verification prepared thereby.
Sequential Inference Machines (SIM) Pilot models for software development		A pilot model (a prototype sequential inference machine) for efficient development of software for the Fifth Generation Computer Systems will be developed. This model will be developed by improving a selected language suitable for inference and by partly modifying the existing von Neumann type architecture.

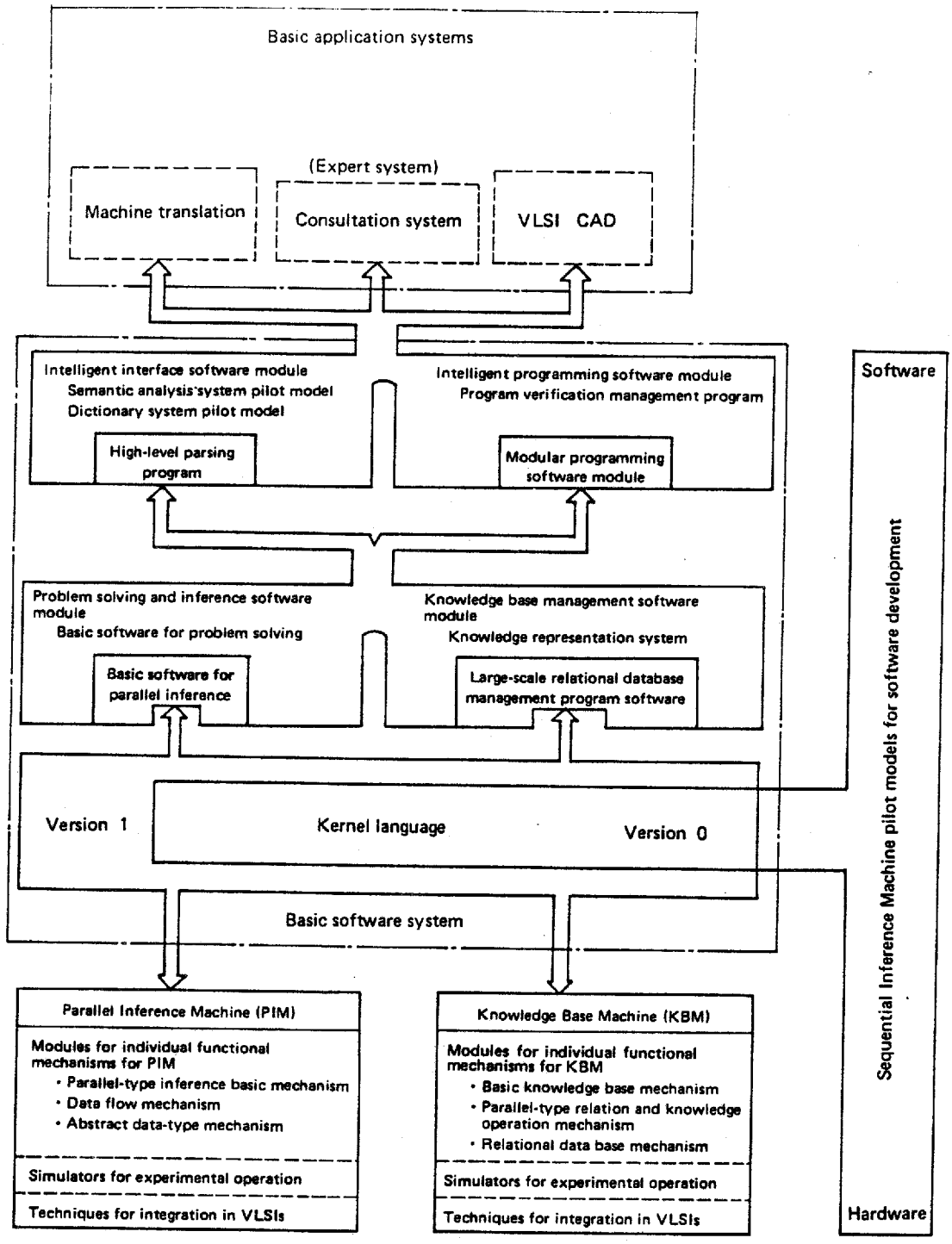

Fig. 2 Overview of research and development in the initial stage

Research in the initial stage of the Fifth Generation Computer Systems Project is based on the new programming language the Version 0 Kernel Language, which is extended on Prolog. The specification of the Version 0 Kernel Language was completed in 1982. The Version 0 serves as the machine language for Sequential Inference Machine, a pilot model for software development, as well as it is tentatively used for program description in software development. While the Version 0 was developed for sequential processing, the Version 1 Kernel Language is parallel processing oriented. The Version 1 is a logic programming language based on accumulation of experiences on the Version 0 with new functions added.

As shown in Fig. 2, the Parallel Inference Machine (PIM) is a high-level parallel processor to directly execute the Version 1 Kernel Language. The Knowledge Base Machine (KBM) is responsible for high-speed execution of knowledge operations derived from the study on knowledge representation and relational data base operations.

The Fifth Generation software comprises two software modules: a problem solving and inference software module for the purpose of problem processing and a knowledge base management software module for knowledge accumulation and management. The two software modules have two hierarchical levels. On the lower level are the description or execution supporting systems to provide various functions on the upper level. For the intelligent interface system whose main purpose is to realize natural language processing, and the intelligent programming system for realizing automatic programming though it remains in a preliminary form for the initial stage. These two software modules could be also regarded as having two levels, but rather complementary than hierarchical.

The elementary application systems in the top of the figure is half experimental, half practical systems which are planned to develop in the intermediate stage based on the research results of the basic software systems.

Among these, the consultation system has rather well established technology. So, it is purposely chosen to prove and assess the basic software system and its preliminary version called Experimental Knowledge-Based System is planned to develop in the initial stage. This development is understood as an additional subject to Table 1.