FIFTH GENERATION COMPUTER SYSTEMS 1988

Proceedings of the International Conference on Fifth Generation Computer Systems 1988

Edited by
Institute for New Generation Computer Technology (ICOT)

Volume 1

OHM Springer-Verlag

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British Library Cataloguing in Publication Data
International Conference on Fifth Generation Computers: 1988
International Conference on Fifth Generation Computer Systems (FGCS '88).
1, Computer systems
I. Title
004
ISBN 3-540-19558-0

Library of Congress Cataloging-in-Publication Data
International Conference on Fifth Generation Computer systems (1988: Tokyo, Japan)
Proceedings of the International Conference on Fifth Generation Computer Systems 1988:
Nov. 28– Dec. 2, 1988, Tokyo Prince Hotel, Tokyo Japan/
Institute for New Generation Computer Technology.
p. cm.
Bibliography: p.
Includes indexes,
ISBN 0-387-19558-0 (U.S.)
1. Fifth generation computers — Congresses. I. Shin Sedai Konpyūta Gijutsu Kaihatsu Kikō (Japan) II. Title.
QA76.85.I58, 1988
004 — dc20 89-11366
CIP

ISBN-3-540-19558-0 Springer-Verlag Berlin Heidelberg New York
ISBN 0-387-19558-0 Springer-Verlag New York Berlin Heidelberg
ISBN 4-274-19558-0 OHMSHA, LTD.

Printed in Japan

GREETINGS

Looking back on the history of fifth generation computer research, it was seven years ago, in October of 1981, that research themes and plans aiming at the realization of a fifth generation computer by Japanese scientists were first announced, and the International Conference on Fifth Generation Computer Systems 1981 was held.

In April of 1982, the ten-year Fifth Generation Computer Systems Project was initiated by MITI with the enthusiastic support and cooperation of numerous individuals and organizations in government, academia, and industry. It was this Institute which assumed responsibility for execution of the project.

In November 1984, the International Conference on Fifth Generation Computer Systems 1984 was held, for the purpose of reporting the results of basic research achieved in the initial three-year stage.

This conference is the third of its kind, and coincides with the fourth and last year of the intermediate stage of the project.

The central aim of the intermediate stage of research and development was to lay the foundations for full-fledged parallel processing systems, something never before attempted on a large scale. Another important goal of our work was the accumulation of software resources and expertise for the development of intelligent software programs based on inference mechanisms. For the parallel processing hardware, an experimental parallel inference machine has been completed, incorporating 64 processors, and a demonstration parallel operating system which will serve as the core of the parallel processing software resources has begun to run on this hardware system.

Work is now underway to trial-fabricate a parallel inference machine, consisting of 128 more powerful processors; and our initial goals have nearly been achieved.

Research on intelligent software has culminated in the development of a system for natural language understanding, various expert systems, and a system for theorem-proving and other mathematical operations.

The final stage of research, to begin next year, will aim at the development of a fifth generation computer prototype comprising approximately 1000 processors, a fully functional parallel operating system running on this hardware, and a knowledge programming system and other tools.

ICOT has performed research and development under commission by MITI with a budget of 8.2 billion yen for the initial three-year stage.

In the intermediate stage, ICOT has carried out R&D with a budget of 4.7 billion yen in 1985, 5.5 billion yen in 1986, 5.6 billion yen in 1987, and 5.7 billion yen in 1988, for a total of 21.5 billion in the four years of the intermediate stage.

Overseas as well, countries in Europe and America are vigorously promoting projects, under government direction, for the establishment of

fifth generation computer technology. ICOT also emphasizes international exchanges, and makes every effort to facilitate such intercourse, including admission for foreign researchers for extended periods.

At this international conference, we intend to introduce the results of research in the intermediate stage, including more than thirty separate demonstrations, as well as provide a forum both for presentations by researchers from Japan and abroad and for exchange of opinions.

It is my fervent hope that through the synergy and lively exchange of information between the many participants, this international conference will prove a fruitful exercise for all concerned, and will contribute greatly to further advances in information processing in other countries as well.

Katsushige Mita
President of ICOT

CHAIRMAN'S GREETINGS

On behalf of the Organizing Committee, it is my great pleasure to welcome you to this International Conference on Fifth Generation Computer Systems 1988.

This is the third international conference on Fifth Generation Computer Systems, following the first conference in October of 1981 and the second conference in November of 1984. At the 1981 conference, we introduced our country's plans for research and development of Fifth Generation Computer Systems, and called for cooperation from other countries in this endeavor. That conference appears to have had a considerable impact, and became the impetus for the initiation of similar projects in several other countries. The 1984 conference was primarily devoted to explanations of the Fifth Generation Computer Systems Project, and to presentations of research results for the initial stage of two and one-half years at the Institute for New Generation Computer Technology (ICOT), which is responsible for the actual research and development. At this conference, there were also reports of the latest research results, both from within Japan and from abroad. There is no doubt that this conference held great significance, both in confirming the importance of research on Fifth Generation Computers, and in indicating concrete directions for future research efforts.

Professor Tohru Moto-oka of the Department of Electrical Engineering at the University of Tokyo had supervised research at ICOT during the initial three-year stage, and had also overseen preparations for the last two international conferences; unfortunately, Professor Moto-oka passed away in November of 1985, with the work only half completed. Thereafter, I have strived in my humble way to fill the gap left by Professor Moto-oka, and have also done my best to keep alive at ICOT the same positive spirit in which research and development is carried out.

Reflecting on the experiences of '81 and '84, I have noticed that these FGCS conferences are quite unique in several ways. First, an extremely large numbers of outstanding papers have been submitted; second, highest-quality scientists and engineers from around the world cooperated to make the conferences successful, with many persons attending; third, participants from various fields were present, including government officials, journalists and managers involved in R&D projects; fourth, there were animated exchanges of opinion which transcended the perspectives of individuals; and fifth, the conferences ranked as international events commanding worldwide attention. These facts attest to the crucially important role in store for research on Fifth Generation Computer Systems, both for the field of information science, and as a means of resolving the problems faced by information-oriented societies.

At this conference, we would hope that the participants would evaluate the accumulated results of basic research at ICOT over the past six and

one-half years, and would also appreciate any comments or criticism of research plans for the final stage of the project. And, we hope for and expect that presentations of technical papers by researchers from Japan and abroad will lead to an understanding of advanced research on Fifth Generation Computer Systems, and will facilitate exchange of opinions. To this end, we have arranged for participants to view a demonstration indicating the major results of research at ICOT. Such a demonstration of advanced technology has not until now been attempted at an international conference; we are confident that it will aid understanding of the fruits of our work. Also, we have planned invited lectures and panel discussions by distinguished researchers active in the 'front lines' of the field, so that participants can better grasp the state of research on an international level, and to aid in estimations of themes for future research. Finally, we have scheduled a reception and banquet so that participants may mingle in an informal atmosphere.

As the late Professor Moto-oka once observed, this is the "age of competition and cooperation." Now is the time for us to pool our most important resource — human ingenuity — to prove what we can achieve, and to aim at a more plentiful society.

It is my fervent hope that this conference will serve as an occasion for vigorous debate and fruitful exchange of opinions and information.

Once more, in my capacity as Chairman of the Organizing Committee I wish to express my heartfelt gratitude to all participants. I would also like to extend warm thanks to those persons on the Program Committee who made great efforts to create such an attractive program of events for this conference, to the many persons from this country and others who agreed to review papers, to the Organizing Committee members for their selfless efforts to ensure that all conference events come off as planned, to the ICOT personnel who labored day and night to make a demonstration of their research results possible, and to the various individuals and institutions who lent their generous support to enable this conference.

Hideo Aiso
Conference Chairman

PREFACE

It has been seven years since the first International Conference on the Fifth Generation Computer Systems. A great deal of research effort has been made toward the goal of FGCS throughout the world and produced many excellent results. Evidence of this progress is that we received 355 papers of very high quality from 29 countries for the third International Conference on FGCS.

These proceedings consist of three volumes. The first volume includes the plenary session and portions of the technical sessions. It contains reports on the current status of the FGCS project research carried out over the past four years at ICOT, as well as future planning along this line. The other two volumes are collections of technical literature. Because the quality of papers we received was very high, we faced difficulty in making the final selections. However, limitation in length of the conference as well as size of this proceedings forced us to select only 95 submissions and four invited papers. Papers were selected according to their relevance, technical content, originality, and clarity by at least four referees: one from Program Committee, one from Japan, and two from other countries.

It is our sincere hope that the conference program itself will prove rewarding and enjoyable to all who are able to participate in FGCS'88 and that the Proceedings will serve as a valuable reference source for years to come.

As Program Chairman, it is my great pleasure to acknowledge the support of a number of people. First of all, I would like to single out the program committee members, who made great efforts to arrange an attractive conference program. They are the Program Vicechairman,Dr.Koichi Furukawa, and the four chairmen of subcommittees, Professors Setsuo Arikawa, Akinori Yonezawa, Makoto Amamiya and Hozumi Tanaka. I would also like to thank the 483 referees from 17 countries who worked hard to evaluate the submitted papers within so limited a schedule. A list of the referees is provided on pages ix to xii for our acknowledgment.

Finally, I would like to thank the many people at ICOT who provided excellent administrative services to the program committee.

Hidehiko Tanaka
Program Chairman

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Shapiro, E.	Israel
Sharma, M.	U.S.A.
Shepherdson, J.C.	U.K.
Shibayama, E.	Japan
Shibayama, K.	Japan
Shibayama, S.	Japan
Shimada, T.	Japan
Shinohara, T.	Japan
Shin, D.	U.S.A.

Shirai, H.	Japan
Shirai, K.	Japan
Shoham, Y.	U.S.A.
Shoji, I.	Japan
Shultz, J.	Australia
Singh, V.	U.S.A.
Sjoland, T.	Sweden
Sleep, R.	U.K.
Sonenberg, E.A.	Australia
Srini, V.P.	U.S.A.
Stalmarck, G.	Sweden
Steels, L.	Belgium
Sterling, L.	U.S.A.
Stickel, M.E.	U.S.A.
Stolfo, S.J.	U.S.A.
Su, S.	U.S.A.
Sugie, M.	Japan
Sugimoto, M.	Japan
Sugimura, R.	Japan
Sugino, E.	Japan
Suwa, M.	Japan
Syre, J.C.	F.R.G.
Takagi, S.	Japan
Takahashi, K.	Japan
Takahashi, N.	Japan
Takahashi, Y.	Japan
Takano, A.	Japan
Takayama, Y.	Japan
Takeda, M.	Japan
Takeuchi, A.	Japan
Taki, K.	Japan
Tamai, T.	Japan
Tamaki, H.	Japan
Tamura, H.	Japan
Tamura, K.	Japan
Tamura, N.	Japan
Tanaka, H.	Japan
Tanaka, J.	Japan
Tanaka, K.	Japan
Tanaka, Y.	Japan
Tanimoto, S.	U.S.A.
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Terada, H.	Japan
Terano, T.	Japan
Thrift, P.	U.S.A.
Tick, E.	Japan
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Tomita, M.	U.S.A.
Tomita, S.	Japan
Tomura, S.	Japan
Tonssen, B.	Sweden
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Touati, H.	U.S.A.
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Ueda, K.	Japan
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Unemi, T.	Japan
van Emden, M.H.	Canada
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Vieille, L.	F.R.G.
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Waltz, D.L.	U.S.A.
Waning, E.	Netherlands
Warren, D.H.D.	U.K.
Warren, D.S.	U.S.A.
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Watson, I.	U.K.
Watson, P.	U.K.
Webb, J.	U.S.A.
Wilcox, B.	U.S.A.
Wilk, P.F.	U.K.
Wilks, Y.	U.S.A.
Yamaguchi, J.	Japan
Yamaguchi, T.	Japan
Yamaguchi, Y.	Japan
Yamamoto, A.	Japan
Yamamoto, M.	Japan
Yamasaki, S.	Japan
Yamashita, M.	Japan
Yamauchi, N.	Japan
Yang, R.	U.K.
Yasukawa, H.	Japan
Yasumura, M.	Japan
Yasuura, H.	Japan
Yokomori, T.	Japan
Yokota, H.	Japan
Yokota, K.	Japan
Yokota, M.	Japan
Yokota, M.	Japan
Yokouchi, H.	Japan
Yokoyama, S.	Japan
Yonezawa, A.	Japan
Yoshida, H.	Japan
Yoshida, K.	Japan
Yoshida, N.	Japan
Yoshizumi, S.	Japan
You, J-H	Canada
Yuba, T.	Japan
Zeidler, H.Ch.	F.R.G.

KEYNOTE SPEECH

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE
ON FIFTH GENERATION COMPUTER SYSTEMS 1988,
edited by ICOT.

HOP, STEP, and JUMP

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One of the objectives of FGCS'88 is for us at ICOT to present the results of the middle stage of research being conducted in the fifth generation computer project.

Another objective of this conference is for researchers from all over the world to exchange the results of their research, aiming towards a new generation of computers.

Our fifth-generation project started in 1982. This year is its seventh year, and the end of the middle stage. The previous FGCS conference, FGCS'84, was held at the end of the project's third year, four years ago. The three stages of the project can be represented as three stages of movement : hop, step, and jump. We have already hopped and stepped, and now we are about to jump into the final stage of the project.

I would like to outline the FGCS project briefly. It is proceeding according to plan, along the lines that I envisaged at the beginning of the project, and research is yielding results at the pace expected at the beginning of the project.

It goes without saying that these results could never have been obtained without the concerted efforts of the researchers involved in this project, and without the support and cooperation of the many people around ICOT.

The efforts and cooperation of all these people are bound up with the results, but the excellent project set-up and basic policies have made it possible for everyone to do their best.

I am sure that I have said this many times before, but the key words that express the technological features of this project are parallel inference. I will go into these key words in more detail later, but, briefly, parallel inference was the objective of the project from the start. This objective was not changed in the initial or middle stages. This research has formed a base for the final three years of this project, and the last stage will see the establishment of a basic parallel inference technology, as envisaged whenthe project was set up.

The initial stage, or "hop" stage, was from 1982 to 1984. It can be thought of as the personal sequential inference machine, or PSI, stage. The research results can be seen in the technical reports and papers of this period, but it is easier to understand by looking at examples.

The PSI is a sequential computer that uses a logic language as the machine language. It was designed as a tool and workstation for software research in the middle and final stages.

In addition to the hardware, the sequential inference machine programming and operating system, or SIMPOS, was being developed as the operating system on the PSI. It was the first operating system and the first large-scale software built using a logic language.

The PSI and SIMPOS are representative results of the initial stage.

In the initial stage, research tools were developed, fundamental software problems were researched based on the concept of logic programming, and progress was made in research on natural languages. Other basic research was also conducted. The initial stage can be roughly thought of as such age.

The middle stage, from 1985 to this year, was the "step" stage. One of the features of research during this period was the start of research on parallelization. On the language side, Guarded Horn Clauses, or GHC, was proposed. It acted as a springboard for research on parallelization. GHC is a logic language with parallel operation added.

The problem of how to add parallel control to a logic language has been a major item in logic programming research worldwide over the last few years. ICOT has contributed greatly to this field by proposing GHC, which formed the base for fundamental research on parallel programming.

With GHC as the base, KL1 was decided on as

the kernel language in the first plans. The kernel language is the software base, and is also the starting point for machine architecture. Research on parallel architecture started, based on KL1.

One of the results of the middle stage was the Multi-PSI. The Multi-PSI uses an upgraded version of the PSI developed in the initial stage. Sixty-four PSIs form one Multi-PSI system. The purpose of developing it was to provide an environment for research on parallel software as quickly as possible. To achieve this purpose, a prototype of the PIMOS, the operating system for parallel inference machines, are being developed on the Multi-PSI.

In parallel with the Multi-PSI, a 100 processor element parallel inference machine, or PIM, system is being developed. This PIM is the middle stage version of the target parallel inference machine, and is expected to be completed during the first half of next year. It will be linked with research in the final stage.

Another feature of the middle stage is research on software based on the PSI and SIMPOS developed in the initial stage. The PSI and SIMPOS have been upgraded. There are now more than 300 PSIs, which are being used as workstations for software research in this project.

One of the main themes in this project is researching logic programming in depth. Parallel programming and constraint programming are major research themes all over the world. ICOT is also researching constraint programming, with the aim of integrating it with parallel programming.

In the framework of logic programming, the development of meta-programming, program transformation, and partial evaluation have been in progress since the initial stage. In the middle stage, parallelization has also been emphasized, based on GHC.

Research on natural language understanding is part of core research on artificial intelligence. It will be essential in future man-machine communication. It has been a major part of research at ICOT since the initial stage. Research on models based on situation semantics theory is also under way.

One result of natural language research in the middle stage is DUALS3, Discourse Understanding Aimed at Logic-based System, a language understanding system that has been upgraded from the system developed in the initial stage. The logic programming library developed through research during this period is the language tool box, or LTB, for language processing.

Another part of core research on artificial intelligence is knowledge processing. Testing expert systems in various areas is another feature of the middle stage. ICOT is researching knowledge processing not for immediate practical application, but in order to pioneer high-level techniques and to prepare for parallelization. This research will help us to work on knowledge acquisition, induction, learning, hypothetical reasoning, and non-monotonic reasoning.

Compared to the initial stage, research in the middle stage has been more active, and results have diversified. In a broad sense, this is a preparation for integrating and developing the basic concepts held from the beginning in the final stage.

Next year will see the beginning of the final stage, the "jump" stage. This will be the period for in-depth research on parallel inference software. Until now, parallel software has been researched by simulation, but now that a new and powerful research environment has appeared in the form of the Multi-PSI, we hope that research will move faster.

On the hardware side, the target is to build a 1000 processor element parallel inference machine, integrating a knowledge base machine architecture.

By using this machine to the full, the abstract and theoretical research that has been done until now, such as research on resource management, will give birth to specific problems.

The parallelization of knowledge processing, natural language processing, and application programs of a reasonable scale will be a major area of research in the final stage. This is an area on which almost no work has been done as yet.

To realize this research, systemization is necessary, along with research that returns to the basics. At the same time, it is essential to set up a parallel programming environment.

One of the software targets of the final stage is to group parallel programming techniques in the form of knowledge programming, using the environmental conditions provided up to the middle stage.

As I have shown, the project has been developing with parallel inference as the warp of its material, because we expect parallel inference to be the core of future information processing, and because we believe that it will lead to a new type of computer.