Report on a Visit to ICOT

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1. Introduction

I was invited to visit ICOT, the Japanese Institute for New Generation Computer Technology, from November 25, 1985 to December 20, 1985. The main purpose of this visit is to discuss with the researchers in the Second Research Laboratory of ICOT on issues concerning term rewriting systems and automated reasoning in first order logic with equality. A second reason, which is no less important for me than the first one, is to learn first hand the work and progress in the Japanese Fifth Generation Computer Systems project.

2. Presentations of Research in ICOT

During the first week I spent most of the time receiving presentations of research activities in ICOT and preparing for my own talks. The presentations I received covered a wide spectrum, from the theoretical high end of logics for natural language understanding to the details in designing parallel machines; some of which I immediately understand and appreciate, some I only know vaguely. They are, of course, all related to realizing the ultimate goal of a fifth generation computer. It was a very exciting experience to see such an elite group of people working together toward the same goal. Their dedication and the willingness to modify their own research interests to achieve a common goal is commendable. It was also very interesting to see how some seemingly unrelated research areas influence and help each other. In the presentations there were many cross references of results obtained from other research labs of ICOT. Somehow everybody seems to know his function and role in this ambitious project and is working very hard to achieve it.

3. Lectures and Presentations

I was originally scheduled to give four talks, three in theorem proving and term rewriting systems, and one in deductive program generation. Since the last one is not directly related to the others and preparing for it would distract me from concentrating in the collaborative work with my hosts in automated reasoning, I decided to cancel the last lecture. I also suggested that the two lectures in term rewriting systems (one was scheduled in the third week) be combined into one and be given as early as possible. This way we can learn the research interests of each other early and speed up the collaboration. My hosts were very understanding and changed the schedule accordingly. Consequently, the following lectures were given:

(1) "On term Rewriting", presented to the TRS-WG (Term Rewriting System Working Group) of ICOT on 29 November. In this two and a half hour lecture I first gave a survey of the most important results in term rewriting system, then I presented my own work in using term rewriting to first order theorem proving.

(2) "A New Method for Establishing Refutational Completeness in Theorem Proving", presented to the CAP-WG (Computer Aided Proofs Working Group) of ICOT on 10 December. In this lecture I described my recent work on a new proof technique for establishing completeness of theorem proving methods, in particular those that involve equality.

In addition to these two lectures at ICOT, I also gave lectures at Tokyo University and ETL, on 3 December and 6 December respectively. Both talks are of the title "Rewrite Method for First Order Theorem Proving".

I also brought a few automated reasoning systems with me. Unfortunately they were all on the UNIX system, which is not compatible with the TOPS system used in ICOT. Professor Sato of Tokyo University was kind enough to allow me to install my systems on the VAX machine at Tokyo University. And on 10 December, after the meeting with the CAP-WG, I presented my software as well as the other systems I brought to the members of the working group.

4. Research Collaboration

I spent most of the time with the PPG group (Problem solving and Programming group), led by Ko Sakai, of the Second Research Lab. The main activities of their research include building proof checkers for several different mathematical theories and term rewriting systems. One of the objectives is to study automated reasoning methods concerning equality, which is one area that I have concentrated my research on for the past few years.

The basic goal of automated reasoning is to use computers as an aid to prove mathematical theorems either automatically or semi-automatically. Mathematical theorems, in a general sense, can be any specification of any activity in our daily life. In addition to being an actively pursued field in AI and theoretical computer science, automated reasoning has also made significant contribution to other areas of computer science. For example, the design of the language Prolog is, in some sense, based on ideas developed in theorem proving. And the existence an efficient automated reasoning system which is capable of solving simple to moderately difficult problems automatically in reasonable time plays an important role in the final success of an intelligent computer.

One of the most challenging areas of research in automated reasoning is to develop efficient method for theorem proving involving equalities. A major tool used in this area is the notion of term rewriting. The basic idea behind term rewriting is to treat equations as rewrite rules if possible, so that equational replacements need be done only in one direction. In addition to being a powerful theorem proving tool, the term rewriting method has also been applied to compiler constructions, programming transformations, abstract data types, parallel processing, and data base management. Recently there is also a surge of interest in applying term rewriting to programming languages, in particular for combining functional and logic programming languages.

After giving the talk on term rewriting to the TRS-WG, Dr. Sakai and I started to think about a specific project which we could work on during the rest of my stay. He took interest in a modification of the Knuth-Bendix procedure in term rewriting which I discovered very recently and described in my talk. The method lifts almost all restrictions in the original Knuth-Bendix procedure, notably so the termination requirement which has been a major source for the failure of the Knuth-Bendix method. I felt that the new method is effective but I did not have an implementation to support my claim. Dr. Sakai volunteered to implement the algorithm and did it in Prolog in only two days! During the first test run, his program generated a complete set of reduction rules for a set of equations which I thought could not be completed. (It was too complicated to simulate by hand.) I was amazed at the effectiveness of both the method and the Prolog language. During subsequent experiments, he improved the functionality of the program and we derived several other very interesting complete sets of rules.

Encouraged by the outcome of the first collaboration, we decided to work on something more challenging, namely, to incorporate a special inference rule for the cancellation law in automated reasoning. Although cancellation can be presented using simply one axiom, using this axiom for resolution will generate redundant resolvents which will in turn lead to more redundant clauses. By incorporating cancellation as an inference rule, much of the redundancy can be eliminated. This will alleviate somewhat the exponential growth of the search space caused by the cancellation axiom. I has always had a suspicion that cancellation can be eliminated by using special inference rules, but never had the opportunity to think about it in detail.

I first came up with a simple inference rule which I thought was complete. To prove the completeness of this inference rule, I suggested that we use a new proof technique which I presented in my talk for the CAP-WG. However, I encountered some difficulties while proving the completeness. Dr. Sakai observed that this inference rule alone is not sufficient. He then suggested adding another inference rule. The two simple inference rules combined were shown to be enough to replace the cancellation axiom. We also observed that the same inference rules can also be incorporated into the Knuth-Bendix procedure to increase its power. The functionality of the term rewriting method has been only substituting equality by equality. Even if some operator satisfies the cancellation law, cancellation cannot be used since the axiom cannot be represented in a purely equational way. Adding cancellation to the Knuth-Bendix procedure would increase the efficiency of the method and should reduce some cases of failure which were caused by the generation of infinitely many rules. In order to see if this is really true, we decided to implement it on top of the previous program. The new inference rules are so simple that it only took a few hours for Dr. Sakai to complete the implementation. Experiments showed that our speculation was correct. In a standard group theory example, the program produced a complete set of reduction rules after generating 14 rules. The previous program generated 16 rules. This is because the operator of group theory satisfies cancellation, and our special inference rules allow the program to generate useful rules earlier than without assuming cancellation. In addition to the gain of efficiency, our program has also found finite, complete sets of reductions rules for certain examples where the original Knuth-Bendix would run forever and never stop.

5. Future Collaboration

I feel that the results we obtained and reported above are significant. From the term rewriting point of view, we showed that inference mechanisms other than equational substitution can also be incorporated into the Knuth-Bendix procedure. This opens a new perspective for future research in term rewriting systems. From the general theorem proving side, we showed that special inference rules are effective in dealing with special relations. Although this is not a new insight in theorem proving, people usually find it quite difficult to prove the completeness of such inference rules. (In fact, the completeness of the majority of such inference rules were either unproven or partially proved.) We demonstrated that the new proof method which I proposed is very effective in producing such proofs. Using this proof method, not only did we prove the completeness of the cancellation inference rules, we could even locate the difficulty and refine our rules.

Dr. Sakai and I agreed to produce a joint paper reporting our results. We also feel that there is much more to be done in this general approach to theorem proving and we should pursue it further. Although it is not easy to collaborate across the Pacific, hopefully ICOT will soon be on the CSNet or the Usenet which will make communication much easier.

6. Concluding Remarks

Ever since I learned about the FGCS project and ICOT about three years ago, the question of "will they succeed?" has always been lingering on my mind. The same question came out even more often during my stay at ICOT. Since I am really not in a position to judge, I still cannot answer this question after staying here for one month. However, I do believe that if ICOT cannot do it, probably neither can anyone else.

Aside from the final outcome of the project, I think ICOT has already achieved something that is extremely important for the future development of computer science in Japan. The computer science community in Japan traditionally has been overlooked by the outside world. There were only a handful of internationally known Japanese computer scientists, and most of them do not work in Japan. There was a general feeling that Japanese don't do basic research in computer science but only concerned with building "gadgets". ICOT and the FGCS project opened the door of the Japanese computer research community to the outside world. I remember a few years back when FGCS first stirred a storm in the U.S.. There were a lot of discussions in the academia and the industrial community about the project, and people were not hesitant to put in their two cents worth. Although some speculations were out of good nature, some were also malicious. I think one of the reasons for some of the wild speculations was that people did not know much about the ability of computer scientists in Japan. ICOT's policy of inviting foreign researchers and not holding back its own research results has gained tremendous publicity and respect for the Japanese computer research community as a whole. One evidence is that now there are almost always papers from Japan presented in important international conferences. ICOT has put Japan on the map of computer science research. I feel that the importance of this effect alone is unmeasurable for Japan.

On personal side, I have learned much more from this trip than I had expected before I came. ICOT is a living example of how theory and practice can be combined into one and help each other. I am also happy that Dr. Sakai and I were able to come up with new research results in one month, which is relatively short in the time frame of research. This is mostly due to the dedication and enthusiasm of him and his colleagues. It is also nice to be away from teaching and administrative duties for a month and do (almost) nothing but research. For somebody like me who works in the academia, such an opportunity does not come by very often.

7. Acknowledgments

It is both an honor and a privilege to be invited to ICOT for a month, which has been most enjoyable and educational. I would like to thank Drs. K. Fuchi, T. Yokoi (Chief of the Second Research Laboratory), and Sakai for the invitation. I also thank Dr. K. Futatsugi for inviting me to visit ETL, which has been another intriguing experience.

Many people have gone out of their way to make my stay in Japan as pleasant as possible. Being a Chinese, it was perhaps not as difficult for me to learn about the Japanese way of life as the Western visitors. For example, I have almost no difficulty getting around Tokyo using the subway system since most signs are written in Kanji, a subset of Chinese words. However, there were still some difficulties, especially in restaurants where Kana seems to be the principle form of letters used. Dr. Sakai and his colleagues, Drs. A. Ohsuga, Y. Takayama, K. Yokota, and K. Mukai of the NKG group accompanied me to lunches and dinners whenever they could. They also took me on my first trip outside of Tokyo to Kamakura and Yokohama. Finally I would like to thank Mr. H. Kusama for being a splendid host, who anticipated all my needs down to the last detail such as making sure that I confirmed the reservation for my returning flight. His hospitality is unforgettable and deeply appreciated.

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Personal Data

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Birth: May 26, 1954, Taipei, China

Education:

1976	B.S., Mathematics, National Taiwan University
1978	M.A., Mathematics, SUNY at Buffalo
1982	Ph.D., Computer Science, University of Illinois at Urbana-Champaign Thesis: *Topics in Automated Theorem Proving and Program Generation*

Employment:

9/75-5/76	Teaching Assistant: Mathematics, National Taiwan University
9/76-8/78	Teaching Assistant: Mathematics, SUNY at Buffalo
9/78-5/79	Teaching Assistant: Mathematics, University of Illinois
6/79-8/82	Research Assistant: Computer Science, University of Illinois
9/82-	Assistant Professor: Computer Science, SUNY at Stony Brook

Research Interests

Term Rewriting Systems, Automated Theorem Proving, Program Transformation and Synthesis, Programming Language Semantics, Logic Programming, Mathematical Logic.

Member: ACM, MAA, EATCS, AAR

Honors:

University Awards Faculty Research Fellowship, 1983
CNRS Research Scientist (Maitre de recherche), Spring, 1985

Grants:

SUNY-RF	1983	"A Deductive Approach to Program Generation"
NSF	1984-1986	"Theory and Applications of Term Rewriting Systems"
CNRS	1985	Research Fellowship from the French government
NSF	1985	Acquisition of Lisp machines

Professional Activities

Referee for *Theoretical Computer Science*, *Journal of Symbolic Computation*, *Acta Informatica*, *Journal of Automated Reasoning*, and various conferences.

Current Research Projects

(1) *Developing a uniform view of automated theorem proving using the term rewriting method.*

We are studying the theoretical foundation of the term rewriting technique as an all-purpose theorem proving method, which includes the first order inductive theory and the first order predicate calculus with/without equality in various formalisms. An extensive implementation is also underway.

(2) *Developing a Prolog environment for reasoning about Prolog programs.*

The goal of this project is to develop a program environment for the specification, implementation, and verification of Prolog programs. The major theoretical contribution of this work is a Prolog based inductive theorem proving method which does not explicitly use any inductive inference rule. We are also studying transformation techniques which use 'cut's in a restricted way with a clearly defined semantics.

(3) *Deductive program generation*
In this project, we propose a deductive approach to program generation. The goal is to provide a effective way for constructing programs and ensuring their correctness. Our method is based on an enriched sequent calculus, with new inference rules introduced to manipulate more effectively programming constructs. Algorithms are specified as sequents, and the inference rules are used to complete a deduction tree (i.e. a proof) for the input/output relation from the given seqents. This proof can then be executed as a program.

(4) *Studies in proof techniques in theorem proving*
We are interested in general proof techniques for establishing the completeness of theorem proving strategies, in particular those which can deal with the equality relation. One method which we are studying is a refutational method which can handle transfinite semantic trees. Using this method, we have successfully proved the completeness of resolution and (oriented) paramodulation for first order predicate logic with equality (without the functional reflexive axioms), as well as strategies with verious restrictions on resolution and paramodulation. As a side effect, we have also proved the completeness of a Knuth-Bendix type procedure which does not require the noetherian property. By studying the general proof techniques instead of the strategies themselves, we have obtained a better understanding of the efficiency issues involved in general theorem proving methods. We feel that this leads us one step closer to reaching a solution to one of the most challenging problems in automated theorem proving today, namely, of developing a relatively efficient (and complete) method for theorem proving with the equality relation.