REPORT ON VISIT TO ICOT

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I visited ICOT from 16th September to 5th October 1990. I gave two prepared talks: "Inductive Logic Programming" on 27th September to the Working Group on Algorithmic Learning Theory and "Efficient Induction of Logic Programs" on 28th September at ANNEX-A2. In addition I gave an impromptu talk on "Applications of Inductive Logic Programming to Prediction of Protein Secondary Structures" to Mr Maeda, Prof. Konagaya and other members of the Laboratory 7 group investigating applications in Bio-technology.

I had discussions on "Inventing Theoretical Predicates" with both Dr Furukawa and Mr Ishizaka. Mr Ishizaka has very impressive learnability results for predicate invention within the restrictions of learning grammars. My own work uses a more expressive language than MrIshizaka's. This makes

predicate invention harder. However, I explained that by limiting invention to the construction of "minimally adequate" new predicates it should be possible to efficiently explore finite spaces of new predicates. I will be focussing on this problem during the next year of my research.

I explained that I have shown the relationship between Inverse Resolution (an approach described by myself and Buntine) and Relative Least General Generalisation (Plotkin's framework). This is described in the paper "Inductive Logic Programming" which I will be giving at the Algorithmic Learning Theory Conference in Tokyo. Dr Furukawa agreed that whereas Plotkin's method can be seen as giving a model-theoretic description of Abduction and Induction, the inverse resolution approach provides a proof-theoretic equivalent. Thus whereas Relative Least General Generalisation is based on finding the clause with the minimal common model of two clauses C and D relative to a given set of axioms, Inverse Resolution can be used to inversely derive the most specific clause which can be used to derive both C and D. Furthermore, we agreed that Kowalski's Abduction is a special case of inverse resolution. According to the philosopher Pierce Abduction is the process of constructing hypotheses, whereas Induction involves both hypothesis formation and statistical confirmation.

I discussed the relationship between Inverse Resolution, partial evaluation and program transformation with Dr H Fujita and Dr Furukawa. We agreed that the method of 'folding', described initially by Burstall and Darlington, is a special case of inverse resolution. This surprised me since 'folding' was intended to be a truth-preserving operation, whereas Inverse Resolution is used to generalise clauses. Dr Furukawa pointed out that Tamaki and Sato

in 1984 proved the conditions under which folding is sound.

Like Inverse Resolution, Fujita and Furukawa's partial evaluation methods also allow for the construction of new predicates. Again this is constrained to the case in which the operation is sound. I discussed a partial ordering over all predicates, which I am presently investigating, with Fujita and Furukawa and found that it provides a useful framework for predicate construction in partial evaluation.

During discussions with Dr Hasegawa I discovered that the theorem proving techniques being developed at ICOT use the same kind of bottom-up deductive inference that I am using for induction. I also discovered that I am using the same range restrictions that are applied to axioms within the theorem proving methods being developed here.

One of the applications of the theorem proving efforts at ICOT is program synthesis. Mr M. Fujita showed me an automatic synthesis of quick-sort from a general specification and set of appropriate axioms and lemmas. This is of considerable interest to me since I have also managed to synthesise quick-sort using an inductive approach. Both inductive and deductive approaches to this problem have their advantages. The inductive approach allows partial specification of I/O behaviour. The inductive approach also makes it straightforward to discriminate between efficient solutions, such as quick-sort, and inefficient solutions such as insertion sort. The method of doing so relies only on a comparison of the summed lengths of proofs for all the examples derived from both solutions. Such an approach can not be taken within a purely deductive framework since there are no guiding examples. In fact derivation of time complexity of logic programs is incomputable due to

the halting problem. It is not possible to discriminate between terminating and non-terminating programs. However, logic programs constructed using inverse resolution are guaranteed to terminate on the examples from which they were constructed. The proof of this comes from simply reversing the inverse derivations of the hypothesised clauses. I pointed out to Mr M Fujita that quick-sort cannot be fully specified only in terms of its least model, since all sorting algorithms have the same least model. What is special about quick-sort is its time complexity. A more complete specification would involve not only a model definition but also a required time complexity.

The advantage of deductive approaches to program synthesis is that they guarantee soundness of derivation. However the major disadvantage of all deductive approaches, as first demonstrated by Godel's incompleteness result, is the utter dependency on the completeness and correctness of the axioms provided. Thus a program synthesised from axioms is correct only if the axioms from which it was derived are correct. Furthermore, it can only be discovered if the provided axioms are sufficient. Even in the case in which sufficient axioms are provided synthesis will only be effective given appropriate intermediate lemmas. Thus M. Fujita's synthesis of quick-sort depends on the use of a 'splitting lemma'. This is equivalent to telling the synthesiser that it must partition lists. This is a very large hint about how to construct quick-sort. Without this lemma the construction of quick-sort is infeasible. We might ask if there is some way to find such lemmas automatically. In principle they can be derived deductively, but this is infeasible in practice. If we could conjecture such a lemma automatically it is easy enough to prove. However, inductive methodologies now provide much more efficient meth-

ods for construction of such conjectures than deductive approaches. In the work on Inverse Resolution by myself and Dr Buntine we call such a process "predicate invention". I believe that new improved Inverse Resolution techniques will soon be able to construct sub-predicates such as partition. Thus there seems a great opportunity here for mixed systems which combine the advantages of both technologies.

In my discussions with Mr Maeda and Prof. Konagaya I found that there is a large overlap of interests in applications in Bio-technology. I was able to show recent preliminary results of applying Inductive Logic Programming techniques to the prediction of secondary protein structure. Similar investigations are in their early stages at ICOT.

On 28th September I visited ASTEM in Kyoto. I gave a talk there on Inductive Logic Programming and had some interesting discussions with Mr Sakama on the relationship between abduction and induction. I was also introduced to Dr Ohno, the head of ASTEM and told him that I am very impressed with ASTEM which is similar in size and constitution to the Turing Institute in Glasgow.

During my stay at ICOT I also met Prof. Nakamura of Tokyo Denki University and Dr Akama from Hokaido University. Both these researchers have interests in inductive reasoning which are very similar to my own.

I have been very well looked after during my stay in Japan. Dr Iwata ensured that all arrangements were well organised, and that every possible problem was circumvented. Miss Karakawa has been very helpful and friendly to both my wife and myself. Mr Ishizaka, Mr M. Fujita, Dr Hasegawa, Dr Hiroshige, Dr Furukawa and Dr Fuchi have all shown my wife and myself

great friendship and hospitality.

This is my first visit to ICOT. I have been very impressed by the range and depth of research being carried out here. I have learned a lot and found many relationships between my work on inductive inference and the field of Logic Programming. The time seems right for a great expansion of investigations linking Machine Learning and Logic Programming. Various European projects that I am involved with are presently aimed at exactly such a synthesis. These projects include the ESPRIT Basic ECOLES project, the British IED project on Temporal Databases and Learning, and a new British SERC project on Learning and Non-monotonic reasoning between the Turing Institute and Imperial College London. Moves are also afoot in Europe to start collaborative research on linking Inductive reasoning and Formal Systems techniques. Europe and Japan seem in a good position to develop such a combined technologies jointly. I look forward to continued and increasing collaboration between our countries.

Curriculum Vitae

Personal Details

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