A framework for technology transfer within the Artificial Intelligence Applications Institute

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1 Introduction

The University of Edinburgh established the Artificial Institute (AIAI) in 1984 with the objective of transferring the technologies of artificial intelligence from the academic research environment to the practical worlds of commerce, government and industry.

The Artificial Intelligence Applications Institute collaborates closely with Edinburgh University's Department of Artificial Intelligence (DAI), however, unlike an academic department, it emphasises applied research, channelling its efforts into activities which are directly useful to industry.

Technology transfer within AIAI can be viewed diagramatically as shown in Figure 1. This shows that technology transfer is a two-way exchange of ideas and that research and development, industry and market forces all influence the type and rate of that exchange.

This paper details three of the mechanisms that have been adopted in AIAI to achieve technology transfer. Each mechanism is covered in a separate section of this paper:

Section 1. KRSTL—trials, evaluations and tribulations;
Section 2. A model for artificial intelligence technology transfer;
Section 3. An experience with technology transfer: ICL and AIAI.

In the first section we have shown the importance of trial projects as a means of demonstrating the feasiblity of introducing AI technology into a particular application area within a company. Two case histories are discussed which highlight the typical pitfalls and successes that can be expected when a company embarks on such an undertaking. In the second section we describe a model for

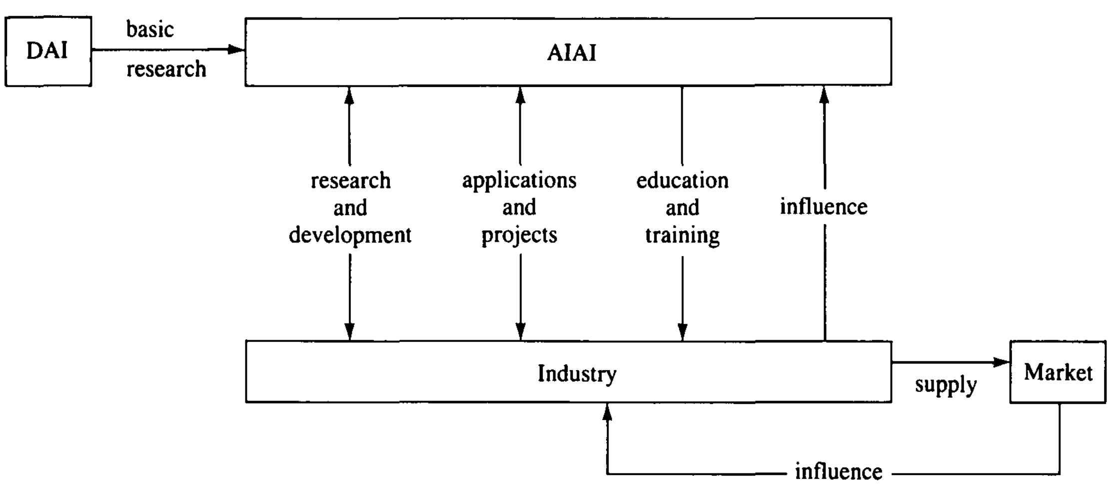

Figure 1 Technology transfer within the Artificial Intelligence Applications Institute

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education and training in AI technology. We emphasize the need to use senior technical staff in the training stage and describe a mechanism for maximizing the impact of the time they can spend on training. The last section is co-authored by AIAI and ICL. Here we describe a study programme in knowledge based planning which is offered at AIAI and which has been attended by the ICL authors.

2 KRSTL—trials, evaluations and tribulations

2.a What is KRSTL?

The Knowledge Representation Systems Trials Laboratory (KRSTL—pronounced "crystal") is a unique European facility established to make knowledge representation languages and environments available to industry and academia on a trial basis. The KRSTL facility is supported by the UK Alvey Programme, the Science and Engineering Research Council (SERC), the Department of Trade and Industry, AIAI's Affiliate Programme and several vendors of AI systems (including Carnegie (UK), Ferranti, Hewlett Packard, IntelliCorp, Rank Xerox and Systems Designers).

The facilities comprise a range of UNIX based systems including SUN and Hewlett Packard workstations and Lisp based machines including Symbolics and Xerox systems. The AI software systems available on these workstations include: Common Lisp; Edinburgh Prolog; OPS5; the POPLOG development environment; and the knowledge representation systems: Inference ART; KEE; Knowledge Craft; and LOOPS.

The objective of setting up such a laboratory within a university environment was to encourage the important two-way exchange of information between AI academic researchers on the one hand and industrial application innovators on the other. It was hoped that by making available both AI systems and AI expertise a wider cross section of European industry would experiment and achieve success in introducing AI technology.

The KRSTL facility has now been open for more than 12 months and it seems an appropriate time to review its activities noting its successes and its failures. It has indeed attracted considerable interest from industry and commerce. Up to the end of August 1987 there have been approximately 70 enquiries about using the facility from various sectors of industry.

Companies ranging from the engineering industry to financial institutions have logged onto the systems to work on projects in their specific application domains. To-date, the average length of project has been 8 weeks. At the end of that time visitors have managed to produce trials systems that demonstrated the usefulness of introducing various aspects of AI technology into pre-specified parts of their organizations' work practices, while at the same time fully appreciating the knowledge representation decisions taken in order to implement the system. The next section describes two such case histories which lie at opposite ends of the application spectrum.

2.b KRSTL case histories

These two case histories are typical of organizations that have used the KRSTL facility. In each case history, the progress of AI technology transfer is highlighted under four headings.

- Initial difficulties

    In some cases there appeared to be none until the project was underway—these were the most disconcerting kind.
- The technology transfer process

    The stages in undertaking a trials project from initial discussion with management to implementing the system are documented.
- Results

    These are both in terms of a tangible working demonstrator and also the intangible, less easy to quantify, technology transfer to the company.

- Future direction

  This is usually shown as a commitment by the company on whether to proceed and how to proceed—perhaps in some respects this can be viewed as a measure of the intangible results above.

2.b.1 Case history-1

This case history is taken as typical of that set of organizations working in very intense scientific environments. The personnel comprise primarily engineers, none were experienced in AI. The company is involved with engineering design applications, is based in England and has approximately 2000 staff. The particular trials project was concerned with system diagnostics and health monitoring.

This company had already taken the positive decision on the necessity of introducing AI technology and selected an in-house core team to carry out the task. A long-term strategy was required and this had to be justified to senior management.

Initial difficulties

1 The company had already considered where AI could be introduced beneficially. However, their initial project would have been a many-man-year project. Also the particular aspect of AI they required for their chosen task was in some respects still a research issue and the one thing this company could not afford to do was risk introducing unproved research ideas.
2 On the personnel side, there was concern that the core team initially comprised one person with no computer experience.

The technology transfer process

1 A visit to the company and lengthy discussions on various aspects of the company's work practices enabled a small well-contained project to be defined. This type of project meant that it could be expanded or shrunk depending on how the visitor progressed.
2 The visitor came to AIAI for 10 weeks. Two things were initially done to overcome his lack of experience; first, he spent his first 2 weeks acclimatizing to the environment by being taught, on an informal basis, the rule-based programming language OPS5. This proved a simple but useful way to introduce basic AI concepts such as rules and inferencing. Second, he attended the expert systems lectures of the MSc Course in Knowledge Based Systems run by the Department of Artificial Intelligence at Edinburgh.
3 After 2 weeks a detailed project specification was drawn up and the visitor received an introduction to one of the AI toolkits. Work began on his project in week 3 of his 10-week stay. Naturally, to begin with the level of supervision was high but this was lowered as he gradually gained sufficient confidence to work on his own and only resort to his supervisor if there was a problem.
4 Fortnightly progress meetings between the visitor and the KRSTL staff involved in the project formed an important part of the two-way exchange of information. At these meetings difficulties were discussed and the next 2-week work plan drawn up.
5 During week 7 the visitor returned to the company to discuss his project with the application expert. On the expert's advice the system was modified and extended.
6 Towards the end of the trials period senior management from the company visited AIAI to see a demonstration of the system. They also had the opportunity to discuss other AI technology transfer issues relevant to the company with senior members of the KRSTL team.

Results

1 The results were very promising. To begin with a simple demonstrator was built in one of the major AI toolkits. This was demonstrated to management and the results shown to the expert. The system has since been extended on the expert's advice.
2 The most striking success of this case history was the transformation of an inexperienced person to one able to use AI techniques and also (after about 1 year and continued interaction with AIAI) be in a position to produce confidently a long term strategy for AI technology transfer for the company.
3 To point to success on the intangible side, the company has expanded the core team and committed funds for further projects.

Future direction

AI software and hardware has been selected and will be purchased in the near future and the core team is expected to grow from one (when work began with AIAI) to five (after 18 months). Further demonstrator projects using AIAI resources are planned.

2.b.2 Case history-2

This case history represents the experiences of a traditional service-sector company in carrying out a trials project as a means of introducing AI technology. The computer personnel are involved in the data processing with no AI experience. The particular service-sector company has a long and established history in its specific service area, its main offices are based in Scotland. The trials project involved implementing an advisor system to assist the company's consultants.

Although the company took the decision to invest in AI, it had no clear idea as to which application areas would benefit from it most. The whole process was viewed by some within the company with scepticism.

Initial difficulties

1 The individual chosen to take on the AI technology transfer role, and hence become the AIAI visitor, was a relatively new recruit to the company and therefore not fully aware of the company's work practices.
2 Before a project could be defined a general application area within the company had to be chosen. The visitor found it difficult to specify this area because of his newness to the company, and senior management were understandably always very busy.
3 Previous to this KRSTL trials project, the visitor had implemented a small system in a PC-based shell. This system was not accepted by the company as other work practices were introduced that proved more efficient. Therefore, misunderstandings about AI, inadvertantly caused by this small shell system, had to be overcome.

The technology transfer process

1 The visitor was a very competent and determined person who soon made himself aware of his company's work practices once he understood the necessity for a well-defined trials project.
2 In order to appreciate the basics of AI programming and to help use the major toolkits, the visitor attended a 5-day Common Lisp course given by AIAI.
3 A major part of the trials project involved knowledge elicitation. The visitor spent 2 weeks back with the company during this phase returning to AIAI for progress meetings with the KRSTL team.
4 The project was such that one particular stage could be first implemented and then further stages

added incrementally. Although each stage required further knowledge elicitation the system could be easily extended.

5 One of the KRSTL team worked closely alongside the visitor while he implemented the first stage. A second member of the KRSTL team acted as co-ordinator for the project.
6 In order to involve the company more closely and further the technology transfer process, the visitor was encouraged to give a presentation on his trials project to senior management.

Results

1 A good and complete system was implemented and the results were such that the initial PC shell problems were overcome.
2 The system acted as a demonstrator on the possibilities of introducing AI, but any long term systems would have to be incorporated with the existing large databases on mainframes. The trials project was viewed as the first stage in a long term AI technology transfer process.

Future direction

Having gained experience in building a knowledge representation system the next stage is to evaluate systems and decide on appropriate development and delivery vehicles for the company.

2.c KRSTL conclusions

The above case histories have given an insight into:

- first-time expectations
- two-way exchange of information in order to select the initial project
- trials projects for technology transfer.

Each of these is discussed in turn.

Not surprisingly, first-time users expect a lot more than can actually be accomplished in an 8–12 weeks trials project. Unfortunately, but importantly, it has been our responsibility to lower that expectation level while at the same time build up a feasible project specification. It should be added here that at the end of the trials period expectations of what AI techniques can immediately deliver to the organization have lowered, but conversely, this has been replaced by a definite idea on how a long term AI technology can benefit the organization and can be incorporated in a realistic manner.

Second, it has also been possible to extract realistic expectations from those initial thoughts. However, both the AI expert and the industry expert have to appreciate that this takes time and that both parties have to start to understand the complexities involved in both the AI and application areas. The initial trials project must be of such a size that the visitor can implement a working system in approximately 10 weeks. However, it must be of such a complexity that management can appreciate its usefulness. Typically, a small subset of a larger problem is chosen.

Third, although one of the objectives is to produce a trials project useful to the company, the primary objective must be to ensure that the visitors understand the underlying processes so that they can return to their company and continue to implement other systems. Therefore, the AI programming systems used to create trials projects are less relevant than the visitors gaining overall appreciation of knowledge representation systems and knowing how to choose the correct knowledge representation to suit a particular problem. The visitors we have had working in AIAI, alongside our KRSTL team, have achieved success with their projects and gained confidence in the AI area. This has enabled them to return to their company and start to plan a long term co-ordinated introduction of AI technology.

In conclusion, KRSTL, as an AI technology transfer mechanism, can be considered a success but this success is heavily dependent on a commitment from the AI expert and an even greater commitment from the company to invest sufficient staff resources to achieve a worthwhile trials project.

3 A model for AI technology transfer

3.a Objective

Advanced AI techniques have been developed within academic research groups that are unable to devote the considerable resources needed to ensure that the results of their work are available to industry and other groups. A mechanism is needed to lighten the burden on these groups while still ensuring that the most advanced techniques are promoted to industry and the very best (hence busiest) research workers are made available as consultants. This section outlines a mechanism that has been adopted in AIAI to achieve this aim. The result is a study programme in AI applications.

3.b Outline of the study programme

There are four stages to the programme preceded by a preparatory stage. The four stages are repeated as necessary depending on the number of people involved in a potential user group and the resources available to aid them within AIAI or the associated Department of Artificial Intelligence at Edinburgh.

- Preparation. The "experts" (within the group with the techniques) prepare the modules, course materials and software aids needed to carry out the study programme. The staff responsible for teaching at AIAI assist with samples from previous study programmes.
- Stage 1. An introductory course is given to make the students to be involved aware of the issues, terminology, background reading matter, etc.
- Stage 2. A project (normally taking 8–12 weeks) is carried out at AIAI using the visitor resources (space, computers, supervision, seminars, library, etc.). This normally involves use of a software base provided for the students to get them up to speed quickly. Design as well as implementation should be involved. It is often more effective for a pair of students to carry out one project together and for there to be at least two pairs doing the same study programme at the same time. In parallel with the project, the students may be offered a more general AI or expert systems course spread over the visit period.
- Stage 3. A wind-up session and tutorial on more advanced aspects is held making use of the experience gained by the students in stage 2. Proposals for future independent work to gain further experience are made.
- Stage 4. Follow-up consultancy is provided after the students return to their companies or organizations and seek to exploit their newly gained skills.

To be effective, the programme needs to be repeated as necessary for groups needing the relevant skills. It probably involves too great an effort in preparation to be considered if it is only to be used once. However, the "expert" resource is scarce and use of it needs to be optimized.

3.c Resources

The first time that a specific study programme is carried out, the "experts" are involved in preparation and giving the course in stage 1. They are also involved in the supervision of stage 2 for the first visitors. One or two people from AIAI are trained at the same time by taking the course and doing a project.

The second time that a specific technology transfer programme is carried out, the stage 2 project is supervised by the AIAI staff under the *direction* of the "experts". The third time, the AIAI staff are responsible for supervision but can call on the "experts" for help as necessary.

The "experts" continue to be involved for stage 3 (project wind-up and advanced issues) and are available for stage 4 follow-up consultancy. However, AIAI staff may take some part in stages 3 and 4 as they gain experience.

3.d Certificate

The Artificial Intelligence Applications Institute may provide a certificate of attendance for projects and training carried out at the Institute. A certificate in AI applications, suited to the particular technology transfer programme, could be an outcome if certain constraints are met.

4 An experience with technology transfer: ICL and AIAI

(co-authored by AIAI and Dave Barlow and Mark Greenwood, ICL)

4.a Introduction

The Artificial Intelligence Applications Institute and International Computers Limited have been involved in a technology transfer exercise. This brief section provides some background for the two organizations, and gives an account of the sort of technology transfer that has been going on.

AIAI overview

The objective of AIAI as a technology transfer organization has been described earlier in the paper. To meet this objective AIAI has established an Affiliate Scheme whereby interested companies can become *affiliates* of the Institute. Once affiliated they have access to a wide range of services, from consulting through to the possibility of joint research and development projects.

The AIAI is divided up into a number of different *groups*. One of these is called the *knowledge-based planning* group. Members of this group do research, consulting, and prototype development in the area of automatic plan construction and analysis. Planning work at Edinburgh has quite a distinguished history, dating back to the early 1970s. The focus of planning research and development in Edinburgh is now housed within the Institute.

It is not easy to get into the AI planning literature. Papers are eclectic and scattered; terms vary; notation is non-standard. There is no all-encompassing textbook which pulls the material together. To make the corpus of ideas, techniques and tools of AI planning more accessible to industry (where they might be most effectively used) we designed and implemented the AIAI Planning Study Programme.

ICL overview

ICL, a member of the STC group, has traditionally been known for creating and exploiting information technology products and systems. In an attempt to meet the market's demands more effectively, ICL has focussed on supplying integrated solutions to five particular "vertical markets". These are public administration, retail, manufacturing, finance and defence.

To meet both the short-term and long-term needs of these markets, new developments in hardware and software systems are required. A major source of these developments in ICL's fifth generation programme. Within this programme ICL is involved in developing parallel machine architectures and their software, declarative languages, and applications based upon AI techniques. It is in respect of this latter activity that ICL has sought to acquire expertise in AI tasks, techniques and tools in the belief that these will become mandatory within the industry, and further, will form the basis of new products demanded by information technology customers in the 1990s.

In-house manufacturing remains a significant part of the business in which the problems of inventory, production lead times, product mix and lifetime, and rapidly changing technology all conspire to create a complex problem for those employed in the supply of physical products to customers. Aspects of the fifth generation programming and AI in particular, such as knowledge-based system development and advanced planning techniques, are seen as vital tools to underpin the strategies being used to meet the needs of this rapidly changing environment. These strategies include: advanced inventory management & control, computer integrated manufacturing, dynamic quality control, and flexible manufacturing systems.

To obtain the AI skills required, a group has been set up within manufacturing to learn, test and evaluate these skills. Through the use of internal manufacturing projects, there is an ever increasing exposure to company staff of the AI techniques and tools they need to take us into the next decade and beyond. In this context, the technology transfer course being provided by AIAI for selected ICL staff can be seen as just part of a much wider programme to equip ICL manufacturing staff with the tools for the future.

4.b The general idea of the study programme

People learn AI concepts best by making systems which use them. Each AIAI study programme is based on this principle. The courses are oriented around the construction of a prototype system, generally written in an AI language such as Lisp or toolkit such as KEE. There are four main threads to a course:

1 lectures;
2 reading;
3 tutorials;
4 programming.

The *lectures* are designed to present abstract ideas. The *reading* is designed to reinforce the ideas by going into the material in more detail. The *tutorials* are there to make sure that the ideas gained by reading are correct. The *programming* is designed to reinforce the ideas even further by making the student implement them. The theory is that if a student can make an idea work in a program, then he or she probably understands it quite well.

Each study programme lasts 6–10 weeks. The ideal number of attendees is around four, but up to six can be accommodated if required. Programming teams are formed for carrying out the implementation effort. Generally one team is best; if there are too many people however, an organization of two teams which interact closely has also been found to work.

The first week of the course is unique, but the rest follow a template. From week 2 onwards, Monday is given over to lectures. Primarily this means a morning lecture, with an afternoon to follow if required. Tuesday afternoon is a tutorial session, intended to cover lecture topics in terms of the implementation effort. On Wednesday afternoon each group gives an informal presentation, often based on the week's reading. Friday afternoon is a review and opportunity for discussion of the entire week's material.

The programming exercise for each week is expected to be completed by the Friday. Ordinarily, each programming task must be handed in on the Friday with a single A4 sheet describing what has been implemented.

4.c Specifics of the planning study programme

In the following paragraphs we give a typical course syllabus. This syllabus has been structured around a course which is 6 weeks long.

Week 1. The students begin to understand what will be taught in the course. The first two days are spent in overview lectures that deal with introductory concepts involved with planning and search. Machine user registration is carried out. The week includes a Lisp familiarization exercise. The programming exercise is to implement one of the example problems covered in the overview lectures.

Week 2. Basic issues of plan structure are covered. Data structures for the representation of actions and plans are explained. The difference and relationship between internal and external forms is examined. Hierarchical plans are introduced, as is abstration in its various forms. STRIPS operators are introduced, and more modern work which builds on them, such as NonLin's *Task Formalism* (Tate, 1977).

Week 3. This week looks at the need for *question answering* (QA) at points in a plan. We consider what QA does, and why it is necessary. There is an introduction to the idea of plan modification operations; specifically, action expansion and goal achievement. We pause for a moment to consider the nature of the search space explored by older systems, such as STRIPS (Fikes et al., 1972). A motivation for means-ends analysis is presented. Search heuristics are looked at in some detail; in particular, we examine the so-called *linearity assumption*, and show how STRIPS suffered from it. The interaction of sub-goals is covered in very rudimentary fashion. There is an initial investigation of how to detect interactions, including the notion of sub-goal protection.

Week 4. Here we begin to cover the real hows and whys of QA. The difficult issue of QA with variables is discussed. The basic idea of what must be done to fix undesirable interactions is introduced. Not all interactions are harmful, so we also cover the notion of helpful interactions. We look into all the options for making a plan achieve a goal, and consider how this can be done in a computer program. We return to the issue of search, and consider how the plan modification operations define a search space of partial plans. We introduce the important concept of a plan state and fault annotations to characterize a complete plan. In line with this topic, context layering mechanisms are introduced; we cover both theoretical and efficiency issues.

Week 5. This week looks at some engineering issues; in particular, we consider how the space of partial plans can be pruned. The *modal truth criterion* is examined, and sensitivity analysis suggested as a way of limiting its application. The use of metric time and resource information to prune partial plans is considered, as is the use of typed preconditions. We return to methods of search, and look at *one-then-best* search, as implemented in NonLin. We also consider constraint handling mechanisms, both representation and processing.

Week 6. A plan is not a solution, but it does specify one possible solution. This means that a plan must be executed, and plan execution brings a host of problems. This week looks at these problems, and discusses approaches to their solution. In particular, we examine the role of *goal structure* in catching execution failures, and the use of blackboard and agenda-based scheduling techniques. We also discuss the scheduling problem very generally, and look at AI planning and net theory approaches. There is also a general postmortem of the students' programming efforts.

4.d Summary of experience

4.d.1 From the perspective of the Artificial Intelligence Applications Institute.

Our experience with the Planning Study Programme has been very good. Three versions of the programme have been given. The first had four attendees and lasted 8 weeks; the second and third had three and four attendees respectively, and lasted 6 weeks. The planner produced by the first group had some problems. This was almost inevitable, as the course had never been given before. The second and third time round the groups managed to produce a planner (in Common Lisp) which solved all the benchmark problems presented to it.

We are now using the study programme as a springboard for consultancy work. The people in ICL who have been on the programme understand AI planning notions and notation. This makes it much easier to communicate directly about the problems of interest to ICL. Both sides involved in discussions can use a common language, and this makes solving an actual problem much easier. This phase of the relationship is just beginning, but we expect it to work well.

We feel that the idea of an AI study programme is a good one. With such a programme it is possible to learn rather abstract AI concepts in a short time by implementing a system which makes use of them. Our experience with the programme itself has been positive; we are now entering into a consultancy relationship, based on the foundations the programme has laid.

4.d.2 From the perspective of ICL

For ICL, the programme has also proved extremely beneficial. In particular, the following points can be noted.

- There is now a common understanding of the concepts and terminology involved in planning amonst the course attendees. In the field of AI planning, many of the terms involved are used with different meanings. It is therefore very useful to have a common internal understanding.
- There is a recognition that although many of the AI based projects we are engaged in are not strictly "planning projects", they nevertheless embody many of the techniques covered in the programme.
- Having a high level of expertise in the planning area within the group means that we have a firm confident base, from which we can start to evaluate other areas in AI.
- We now have a greater awareness that these new computer-based techniques can partially automate tasks performed within manufacturing which currently require a lot of human activity.
- AI based planning techniques are able to provide sub-optimal solutions to complex planning problems. In line with the Quality programme in ICL, it is now recognized that sub-optimal solutions to problems are acceptable if they meet the requirements specified.

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