Research Interests

Cognitive modelling and problem solving methods in the context of expertise for the development of intelligent systems

Dr Laurence Alpay
ACACIA Project
Institut National de Recherche en Informatique et en Automatique (INRIA)
2004 Route des Lucioles B.P. 93
06902 Sophia-Antipolis, France
Email: lalpay@sophia.inria.fr
Tel: +33 (93) 65 78 73 Fax: +33 (93) 65 77 83

Key words: artificial intelligence, cognitive science, expertise, knowledge modelling, diagnostic, problem solving, intelligent tutoring systems

Introduction

The aim of this document is to describe my research interests, and the context of my current research work through my contributions and participation within different projects and working groups. My research interests include *problem solving methods and reasoning, cognitive modelling and knowledge representation,* within the context of *decision support systems, knowledge base systems and intelligent tutoring systems.*

This document is structured as follows: Section 1 discusses my central research interest, namely cognitive modelling for problem solving methods, in particular related to the medical diagnostic process. The subsequent sections present two other research themes linked to the main one. Section 2 addresses the problem of expertise from two view points - knowledge acquisition and development of expertise from novice to expert. This section also stresses the importance of the domain and of the context of expertise. Research in the field of human expertise is important for understanding problem solving methods, as in the case of diagnostic problem solving. Secion 3 discusses formalisms to represent the expertise, for example with production rules or more recently with conceptual graphs which are based on semantic network. This section also presents aspects linked to the multi-representation. References are given at the end of the report.

1. Cognitive Modelling

1.1 Modelling Medical Reasoning

Educational context of intelligent tutoring systems

The focus of my Ph.D research (Alpay 91) has been on the modelling of medical diagnosis in the context of intelligent tutoring systems. I have investigated the application of the development of medical expertise for user modelling and I have applied AI planning techniques to model this developmental process. Specifically, my Ph.D thesis has investigated the development of medical reasoning processes and how student modelling of such processes can be achieved in intelligent tutoring systems. In collaboration with the medical doctor who supervised the medical aspect of my research, I chose the domain of orthopaedics. My literature review has shown that medical reasoning has been modelled mainly from an expert point of view. The research problem addressed in my thesis was to model explicitly various levels of medical expertise in terms of reasoning strategies. In other words, I succeeded in describing explicitly cognitive models of the evolution novice/expert using these reasoning strategies for the medical diagnostic process. I implemented a system called DEMEREST (DEvelopment of MEdical REasoning STrategies), a developmental user model component which describes successive stages of medical reasoning and which could ultimately be part of a medical tutor. The system diagnoses physicians' reasoning strategies, determines the level of expertise and produces a plan corresponding to the application of these strategies. As a basis of doing so, I identified in the medical problem solving literature a set of seven reasoning strategies, and I refined them. These strategies are generic and based on generalisation, specialisation, confirmation, elimination, problem refinement and hypothesis generation. Another strategy is directly linked to the domain and is based on the anatomy.

I carried out an empirical study to examine the development of these strategies. I collected and analysed protocols of ten physicians at various levels of expertise. Using half of these protocols, I identified a number of interactions of strategies at different levels of expertise and this information was used to construct a model of changes of strategies over time. I used planning in artificial intelligence as a means of decomposing medical problem solving into a set of goals; the goals being associated with the reasoning strategies. By taking this approach, medical reasoning is viewed as a planning process. I used the remaining protocols from the empirical study to evaluate DEMEREST. The system was tested for its ability to determine a level of expertise for each protocol, model the reasoning strategies applied and their interactions, and generate a plan for each protocol. The assessment of the overall performance of the system showed that it was successful. This assessment also helped to identify conceptual as well as implementation constraints of the prototype system. The main result of the research undertaken in the thesis was that the design of the system DEMEREST demonstrates the feasibility of modelling the development of medical reasoning strategies and its usefulness for student modelling. The system was developed in LPA Prolog on a Macintosh.

1.2 Modelling Reasoning in Accidentology

I have joined the ACACIA project (Acquisition des Connaissances pour l'Assistance à la Conception par Interaction entre Agents) conducted at the INRIA research centre in Sophia-Antipolis (France). This project focuses on the transfer of expertise and the knowledge acquisition from multiple experts for the development of knowledge based systems (ACACIA 93). One of the domains of applications is the accidentology (road accident analysis). In this domain, the experts of INRETS (Institut National de REcherche sur les Transports et leur Sécurité) come from various disciplines. They are psychologists, specialists in driver behaviour, vehicle engineers, road infrastructure engineers. This domain is interesting as it takes into account several experts of the same domain of expertise but who use different problem solving methods as well as several specialists coming from different domains of expertise.

The phase of knowledge acquisition of expertise from these experts in accidentology has been carried out by members of ACACIA-INRIA and of Universiy Paris V. These knowledge acquisition sessions included 2 psychologists, 2 vehicle engineers and 3 infrastructure engineers (Amergé et al 93). During the analysis of a road accident, each specialist has a different goal in mind to explain the accident. For example, the psychologist will be interested in understanding the errors of the driver, the vehicle engineer will be concerned with a possible disfunctionning of the car while the road infrastructure engineers will be interested in diagnosing the dangers due to the road infrastructures.

Modelling models of expertise in accidentology from these sessions started a few months ago. In the context of my post-doctoral research work at the INRIA research centre (Alpay 95a), one of the research actions is concerned with the analysis and modelling of reasoning strategies used by the experts from different specialties, and the comparison of expertise in terms of these strategies. The diagnostic task in accidentology consists of diagnosing the disfunctioning between driver/vehicule/infrastructure. Within different phases of the road accident analysis, I am particularly interested in the search for clues/ signs, which is interwined with the generation of hypotheses to explain the accident. In order to model aspects of the reasoning in accidentology, I use the same reasoning strategies (which I have studied for medical diagnostic problem solving in my Ph.D thesis) as well as some of the models of expertise proposed in KADS (Breuker & Van de Velde 94).

2. Problem of Expertise

Research in the area of expertise has been studied in terms of three directions: expert behaviour, novice behaviour and the differences between experts and novices, in various domains such as physics (e.g. Larkin et al 1980) and programming (e.g. Jeffries 1982), medical diagnosis (e.g. Lesgold 84). The research on expertise makes it clear that experts and novices differ in fundamental ways. These differences extend to a variety of behavioural responses such as problem solving performances, perception, preferences and social attitudes (Leventhal and Instone 1982).

In this section, three aspects related to human expertise are discussed: 1) knowledge acquisition, 2) development of expertise, from novice to expert, and 3) the importance of the domain and of the context of expertise.

2.1 Knowledge Acquisition

Knowledge acquisition is the process of knowledge elicitation from human experts and its formalisation in order to be used by knowledge based systems. In other words, knowledge acquisition is the transfer and transformation of knowledge from the forms in which it is available in the world into forms that can be used by a knowledge system. It is not only a process of knowledge elicitation but also a process of knowledge construction (Gruber 89).

Context of Intelligent Tutoring Systems in Medicine

In the literature review on the development of expertise which I carried out during my Ph.D study, I have reviewed the area of the acquisition of expertise (see Alpay 91 for a detailed analysis). In particular, I have studied generic models (e.g. the genetic graphs of Goldstein, the ACT* of Anderson) or models dependant of the domain (e.g. expertise in physics of White and Frederiksen).

Context of computer assisted medical diagnosis

The MELANIE project (Burke et al 92) is concerned with the production of two-dimensional gel electrophoresis (protein maps), the interpretation and analysis of these protein maps and computer assisted medical diagnosis. Diagnosing from a protein map consists of visually recognising proteins or groups of proteins which are disease markers or significant patterns. There are very few clinicians in the world who know how to interpret protein maps. In the context of the MELANIE project, I studied the diagnostic processes of the expert in our research group, a clinician who has been analysing protein maps for a number of years. I susbequently developed a prototype system for obtaining diagnosis from protein maps based on the clinician's knowledge using KEE™ and Lisp on a Sun SPARCStation^{TM} , and evaluating the performance of the system (Alpay et al 92). The cognitive aspects of the work provided a direct complement to the advanced techniques of protein recognition and detection already integrated in the MELANIE project.

Context of multi-expertise and interaction between agents in the domain of accidentology
This context is being studied within the ACACIA project at the INRIA research centre in Sophia-Antipolis. As mentioned in the previous section, this project is concerned with the tranfer of expertise and knowledge acquisition from multiples experts, for the development of knowledge base systems (ACACIA 93). One of the domains of applications is the accidentology i.e. road accident analysis. A key point of this research is how to solve the problem of knowledge acquisition from multiple experts/specialists. Thus, one of the goals is to build a system which can incorporate and integrate different representations corresponding to various experts (Dieng et al 94a, Amergé et al 93). My research interest in the area of knowledge acquisition focused on the aspect of reasoning strategies.

2.2 Development of Expertise
As Leventhal and Instone point out the rich body of literature in expertise has tended to focus on the characteristics of experts and novices and relatively little work has emphasised the process of becoming an expert. In the context of medical diagnosis, the aspect of the development of expertise - how one becomes expert, and the processes of this development have been studied for example by Lesgold (1984) and more recently in the context of student model of intelligent tutoring systems (see section 1.1, Alpay 91).

2.3 Domains and Contexts of Expertise
The importance of the context and of the domain of expertise was put forward during a workshop on “Expertise in Context” (Hoffman & Dietrich 94). Results from this workshop include the following:
a) The understanding of the nature of human expertise requires to study several domains of expertise, such as physics problem solving, athletic coaching, chess, medical diagnosis or accidentology. I have studied the domain of medical diagnosis during my Ph.D work, and I am currently working on the accidentology.
b) The study of the nature of human expertise must more and more take into consideration the cultural ans social aspects of the expertise. Indeed, expertise is not just a characteristic of individuals. It is also a matter of social selection and attribution (rites of passage; professional, economic, political, or cultural constraints on beliefs and practices, and so on). Hence, expertise is always contextually relative. This is a research theme in which several aspects - on how cognitive factors interact with contextual and social factors - are to be explored.

3. Knowledge Representation
Knowledge representation constitutes an important aspect in the building of knowledge base systems. Among the various formalisms used in AI, one can briefly mention 1) production rules (which were used for the first expert system MYCIN (Shortliffe 76), frames (Minsky 75), scripts (Schank 77)and semanic networks (Quillian 68).

3.1 Utilisation of Conceptual Graphs
More recently, the theory of conceptual graphs (CG) which has its foundations in linguistics and psychology has been developed by J. Sowa (1984). This theory was developed with the aim of being of general model of knowledge representation, based on existential graphs of C.S. Pierce (Pierce 1906) ans semantics network. A CG is an oriented

graph with two types of nodes: concepts which represent entities, and relations which represent conceptual relations between concepts. Concepts describe actions, states, events whereas relations show how the concepts are interconnected. At the present, this formalism may be considered as a complete model of knowledge representation, since it has unifed and formalised in a more rigorous way ideas in the research on semantic networks, frames and scripts.

Conceptual graphs are presently used in several domains. In particular, one can mention the projects in which I have contributed and currently participate.
a) In the context of European projects HELIOS and GALEN of the AIM programme (Advanced Informatics in Medicine of the Directorat XIII of the European Union), work on natural language processing for medical texts (Rassinoux et al 94, Rassinoux et al 93, Wagner et al 94), and work on knowledge representation for which I have directly contributed (Alpay et al 93).
b) In the context of the ACACIA project at the INRIA research centre, work on algorithmes of comparison of conceptual graphs which have been developed (Dieng et al 94b), and more recently my current post-doctoral work which is concerned with the formalisation of multiple reasoning strategies for the road accident analysis (Alpay 95a). Hence, tasks for this work include the construction of a typology of concepts containing concepts such as road accident information/clues and accident hypotheses, and a typology of conceptual relations for this specific domain. Tools which have been developed within the ACACIA project are to be used within the context of this post-doctoral work (Martin 95).

3.2 Representation and Modelling of Medical Terminology

I have actively participated in the Galen project (Generalized Architecture for Language Encyclopaedia and Nomenclatures in Medicine) of the AIM programme (Advanced Informatics in Medicine) which is concerned with the modelling of medical terminology. A server providing terminological services (such as multilingual or conceptual) to applications within a client-server has been developed. The Galen formalism (referred to as Galen Master Notation or GRAILfor Galen Representation And Integration Language) which allows to represent and modelise medical terminologies is based on a semantic network representation. One of my activities in Galen has been to become acquainted with the tasks of conceptual modelling and to construct models of medical terminologies using tools developed for this purpose.

In the development phase of demonstrators and experiments of Galen, the end-user aspect has been given an important place. One can mention for example the clinical application that I have developed in cooperation with two partners of the consortium: the Structured Clinical User Interface (SCUI). The clinical context of the SCUI is centred around requests made to the microbiology laboratory by the intensive care unit, and we have specified nosocomial infections within the infection diseases specialty as the domain of application. The SCUI is a test bed for the Galen technologies; and as such it is aimed to provide input (to the requirements) for the bottom up development of the Master Notation and the models, and to evaluate the effectiveness of this notation within a clinical setting and a multilingual environment (Alpay et al 95b, Alpay et al 95c).

3.3 Multiples Representations

Multi-representation is an important aspect in the context of knowledge acquisition as well as of learning. Multiple representations take into account different representations which exist within a human being or within a system. Problem-solving and learning imply the use of knowledge acquired in different forms and various representations.

Multi-representation linked to learning has been approached in the working group called ”Multiobjective learning with multiple representations" of the programme "Learning in Humans and Machines" (LHM) of the European Science Foundation (ESF). The theme of this research group in which I participate (Alpay 94) is concerned with learning processes based on multiple representations in the context of one or more tasks/ objectives. One of the sub-group where I belong is interested in particular on “Transformation versus coordination of representations". This sub-working group is concerned with the fact that humans and machines can learn from different sources, resulting in multiple representations. Initially these representationsma be independent, resulting in suboptimal performance. The question this sub-task force deals with is whether optimization of performance of a system is the result of coordination of these multiple representations or whether transformation of these representations has to occur.

Multi-representation linked to knowledge acquisition is a key research theme of the ACACIA project which is concerned with the development of tools for knowledge acquisition from multiple experts (for example in accidentology). In this context of multiple expertise, I am interested in particular in the comparison between experts from the same specialist or from different specialities (e.g. vehicule engineer, psychologist) at the level of their inferences in terms of their reasoning strategies. This work is carried out from analyses done on the protocols and with the support of models of expertise such as KADS or models of (medical) diagnostic problem solving (which I developed during my Ph.D thesis). This work which I carry out within the ACACIA project provides a basis for discussion within the working group of the LHM-ESF programme.

Conclusions

This document has described my past and current activities of research and development. In summary, the themes in **Artificial Intelligence / Sciences Cognitives** which interest me include the following:

- Cognitive modelling, in particular linked to a diagnostic problem;
- Knowledge representation. This includes recent formalisms such as conceptual graphss (proposed by Sowa) and Grail (of the Galen project) for which it would be interesting to further research their usability and applicability;
- Multi-expertise, in particular in terms of multiple reasoning strategies;
- The applicability of these research themes to intelligent tutoring systems or computer decision support systems.

A few research perspectives to keep in mind are:

Expertise from novice to expert: After having studied, during my Ph.D work, the development of expertise for the diagnostic problem in terms of reasoning strategies, it would be interesting in investigating this development for another domain. The other domain should specify a diagnostic problem solving, like in the case of the accidentology in the ACACIA project. My current work on the investigation of reasoning strategies applied in the phase of searching for clues/signs, which is interwined with the generation of hypotheses to explain the accident (see section 1.2), is a first step towards this future research perspective.

Knowledge representation across different domains: Another perspective to investigate would be to use the modelling tools developed in the Galen project in order to represent and modelise terminology of another domain (other than medical) as for example the domain of accidentology. This would enable, in particular, to highlight the independence of the formalism from its domain of application.

Contexts linked to the expertise: In studying the area of expertise, the cultural and social aspects linked to the expertise must not be forgotten. For example, the model of agents in the context of the multi-expertise, proposed in the ACACIA project, has started to take in account social elements of experts in accidentology (Dieng et al 94c). Thus, it seems important to be able to further research these elements of human expertise.

Finally, **the domains of application** which I have up to now favoured have been medicine and more recently accidentology. In relation to these domains, the interesting aspect for me is the application to a diagnostic problem (e.g. medical diagnostic, diagnostic in the reconstruction of the accident). Other domains which also involve a diagnostic problem constitute for me an additional source for further research.

References

ACACIA. 1993. *Acquisition des Connaissances pour l'Assistance à la Conception par Interaction entre Agents.* Activities Report 1993 of the ACACIA project - programme 3 (INRIA research centre, Sophia-Antipolis, France).

Alpay L. 1995a. *L'utilisation des graphes conceptuels pour la formalisation de multiples stratégies de raisonnement en analyse des accidents de la route.* Post-doctoral research proposal, ACACIA project (INRIA research centre, Sophia-Antipolis, France), 1995.

Alpay L, Lovis C, Nowlan A, Solomon D, Rush T, Baud R, Juge C, Scherrer J-R. 1995b. *Constructing Clinical Applications: The Galen Approach.* Accepted for MEDINFO1995 (8th World Congress on Medical Informatics), 23-27 July 1995, Vancouver, Canada.

Alpay L, Nowlan A, Solomon D, Lovis C, T Rush, Baud R, Scherrer J-R. 1995c. *A model-based application: The Galen Structured Clinical User Interface.* Accepted for AIME 95 (5th Conference on Artificial Intelligence in Medicine Europe), 25-28 June, Pavia, Italy.

Alpay L. 1994. *A two part paper: Part 1: Development of reasoning strategies from novices to experts for medical problem solving; Part 2: Multiple representations in artificial systems.* Workshop of the European Science Foundation (ESF) Learning in Humans and Machines Research Programme, Task Force #2: Multiobjective learning with multiple representations, Sitges, Spain, 9-13 November 1994.

Alpay L, Baud R, Rassinoux A-M, Wagner J, Lovis C, Scherrer J-R. 1993. *Interfacing conceptual graphs and the Galen Master Notation(MN) for medical knowledge representation and modelling.* Proceedings of AIME 93, editors S. Andreassen et al, IOS Press, 3-6 October 1993, Munich, pp337-347. Also published in AI in Medicine, Studies in Health Technology and Informatics, Vol. 10, ISO Press.

Alpay L, Appel RD, Hochstrasser DF. 1992. *Building an expert system for obtaining diagnoses from proteins maps.* Proceedings of MEDINFO92 (7th World Congress on Medical Informatics), editors Lun KC et al, Elsevier North Holland, 6-10 September 1992, Geneva, Switzerland, pp649-652.

Alpay L. 1991. *Modelling Medical Diagnostic Processes.* Ph.D thesis in Cognitive Science, Institute of Educational Technology, The Open University, Milton Keynes, United Kingdom.

Amergé C, Corby O, Dieng R, Fleury D, Giboin A, Labidi S, Lapalut S. December 1993. *Acquisition et modélisation des connaissances dans le cadre d'une coopération entre plusieurs experts: Application à un système d'aide à l'analyse de l'accident de la route.* ACACIA Project, INRIA Sophia-Antipolis, Intermediate report of the contract MRE no. 92 C 0757.

Anderson J.R. and Kosslyn S.M. (Eds). 1984. *Tutorials in Learning and Memory.* New York: W.H. Freeman.

J. Breuker and W. Van de Velde (Eds). 1994. *Reusable Problem Solving Components: the CommonKADS Library for Expertise Modelling,* IOS Press, 1994.

Burke P, Appel R, Vargas R, Alpay L, Pellegrini, Scherrer J-R. 1992. *Computer assisted analysis of two dimensional polycrylamide gel electrophoresis.* Proceedings of MEDINFO 92, editors Lun K C & al, Elsevier North Holland, 6-10 September 1992, pp312-317.

Dieng R, Corby O, Labidi S. 1994a. *Expertise Conflicts in Knowledge Acquisition.* Proceedings of 8th BANFF Knowledge Acquisition for Knowledge Based Systems Workshop, Canada.

Dieng R, Labidi S, Lapalut S, Martin P. 1994b. *Comparaison de graphes conceptuels dans le cadre de l'acquisition des connaissances à partir de multiples experts.* Proceedings of "Journées Graphes Conceptuels", Montpellier 25 March 1994, pp172-184.

Dieng R., Corby O., and Labidi S. 1994c. *Agent-based knowledge acquisition.* In G. Schreiber L. Steels and W. Van de Velde, editors, A Future for Knowledge Acquisition: Proceedings of the 8th European Knowledge Acquisition Workshop, EKAW94, Hoegaarden, Belgium. Springer-Verlag, Lecture Notes in AI n. 867, pp 63--82.

Gruber T.R. 1989. *The Acquisition of Strategic Knowledge.* Academic Press Inc.

Hoffman R & Dietrich E. *Expertise in Context: Report on the third international workshop on Human and machine cognition.* AI Magazine, volume 15, no. 4, pp67-68.

Jeffries R. 1982. *A Comparison of the Debugging Behavior of Expert and Novice Programmers.* Paper presented at the AERA Annual Meeting.

Lesgold A.M. 1984. *Acquiring Expertise.* In Anderson, J.R. and Kosslyn, S.M. pp31-60.

Larkin J, McDermott J, Simon DP and Simon H.A. 1980. *Expert and Novices Performance in Solving Physics Problems.* Science, 208, pp1335-1342.

Leventhal LM & Instone K. 1988. *Becoming an Expert?: The process of acquiring expertise among highly novice computer scientists (Pilot and Proposal).* Research Report. Department of Computer Science, Bowling Green University, U.S.A.

Martin Ph. 1995. *Knowledge acquisition using documents, conceptual graphs and a semantically structured dictionary.* Proceedings of the 9th International Workshop on Acquisition Knowledge for Knowledge-Based Systems Banff, Canada, February - March 1995.

Minsky M. 1975. *A framework for representing knowledge.* Dans Winston, PH (ed).The psychology of computer vision. New York: McGraw-Hill, pp221-277.

Pierce CS. Manuscripts on existential graphs: 1897-1906. Some are reprints in Burks AW (ed): Collected Papers of Charles Sanders Pierce, vol. 4 pp320-410. Cambridge, MA: Harvard University Press.

Quillian MR. 1968. *Semantic Memory. In Minksy M (ed). Semantic information processing.* Cambridge, MA:MIT Press, pp227-270.

Rassinoux A-M 1994. *Extraction et Représentation de la Connaissance Tirée des Textes Médicaux.* Doctorat thesis, University of Geneva, Switzerland.

Rassinoux A-M, Alpay L, Baud RH & Scherrer J-R. 1993. *Analyse Multilingue et Représentation du Contenu Informationnel des Textes Médicaux.*. In la Traductique, editors Bouillon P & Clas A, Montréal: PUM/AUPELF/UREF.

Schank RC, Abelson RP. 1977. *Scripts, plans, goals and understanding.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Shortliffe, EH. 1976. Computer Based Medical Consultations: MYCIN. New York: American Elsevier.

Sowa J. 1984. *Conceptual Structures: Information Processing in Mind and Machines.* Reading, MA: Addison-Wesley Publishing.

Wagner J, Rassinoux A-M, Baud R, Scherrer J-R. 1994. *Generating nouns phrases from medical knowledge representation.* Proceedings of MIE 94, Lisbon, Portugal.