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Information processing and the management of uncertainty

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1 Overview

The First International Conference on Information Processing and the Management of Uncertainty (IPMU) was held in 1986 at a time of great debate about the necessity of modelling uncertainty in intelligent systems (which at that time largely meant rule-based expert systems) and the best way of doing so. Whereas the founders of the Conference on Uncertainty in Artificial Intelligence[3] (UAI) in the United States set out with the aim of promoting the use of probability, the organisers of IPMU chose a diametrically opposed course. Though there were a few papers on probability at IPMU '86, the main focus was on alternative methods, primarily those based upon fuzzy sets. Though subsequent conferences have seen greater mix of papers, IPMU remains largely non-probabilistic with the result that the bulk of the participants come from Europe rather than the United States (despite the large amount of work on uncertainty, and especially probability, that is carried out in the US) making IPMU something of a counterpoint to UAI. The difference in participation is exacerbated by the location—whilst the UAI remains in North America, IPMU alternates between Paris and other cities in Europe, including Urbino in 1988 and Palma in 1992.

The fifth IPMU event (IPMU '94) was held at the Cité Internationale Universitaire in Paris from 4–8 July. The participants came mainly from Europe (and especially from France, as one might expect given the location), though a fairly high number of people travelled from the Americas and the Far East. This year, for the first time, authors had to supply full papers rather than abstracts, with the result that the proceedings inflated from an 800 page A5 sized tome in 1992 to two massive A4 volumes totalling 1300 pages. The necessity to provide full papers does not appear to have reduced the number of papers submitted to any significant degree, since it was still possible to supply four parallel sessions for the four and a half full days of the conference. This, of course, means that it is impossible for anyone to see more than a quarter of all the papers, and so it is difficult to gain more than a flavour of the conference as a whole. Thus, what we have tried to do is to pick out those parts of the conference that seemed most interesting to us, and identify the common themes and issues within those parts. As a result we will present a very personal view of what was said, a view that is necessarily distorted by our own opinions of what is important.

2 Invited talks

There is a growing interest in the uncertainty management community for the modelling of the *structure* of knowledge—as opposed to the mere quantification of uncertainty. A sign of this can be spotted in the choice of the chemist and philosopher Ilya Prigogine, winner of the Nobel Prize for Chemistry in 1977, as one of the lecturers for the plenary sessions. Prigogine is an "outsider" to the

[3]Which began life in 1985 as the Workshop on Uncertainty in Artificial Intelligence in 1985 allowing the organizers of the initial IPMU to claim that theirs was the first *conference* to be specifically organized to focus on uncertainty.

uncertainty community, but has a lot to teach about the necessity to take structure into consideration. In his talk, he suggested that important insights could come from considering "resonances", manifestations of collective interaction phenomena, as primitive objects of study, and contrasted this attitude with the current use of atomic independent units (propositions) as basic elements, largely derived from classical logics. Unfortunately, Prigogine's lecture is not abstracted in the proceedings.

A second invited talk, given by Glenn Shafer, also went in the direction of a need for a deeper understanding of the (qualitative) structure of interaction. Shafer focused on the notions of causality and independence, and proposed a preliminary foundational attempt based on probability trees.

Two of the other invited talks were given by Lotfi Zadeh and Philippe Smets, the first the father of fuzzy sets and the second one of the major proponents of approaches to reasoning under uncertainty other than subjective probability. Zadeh spoke on one of his major themes—that precise subjective probability is a fallacy, and that the real way of handling beliefs is via fuzzy probabilities. According to his claim, the whole calculus of probability must be fuzzified to take account of natural imprecision in specifying probability distributions, and he sketched out some of the requirements of this fuzzification. Smets, on the other hand, rather than describing a new system, surveyed a number of existing systems of non-additive probability before introducing his own preferred version, known as the transferable belief model.

3 Numerical approaches

A major theme of the conference was, as one might expect, the use of numerical models of uncertainty. As ever, network models attracted a lot of attention, with probabilistic networks topping the bill, and most of the papers in this area concentrated on increasing expressiveness or efficiency, since the accepted point of view is that the basic techniques are now well developed. Notable contributions include those of Wong, who showed that it is possible to perform Bayesian inference by means of querying an extended relational database (thus permitting the tight integration of databases and probabilistic networks), van der Stadt, who showed how to increase efficiency by pruning unnecessary nodes from the graph, and Cano and Moral, who presented a number of heuristics for triangulating graphs in a more efficient manner. Also worth noting are the extension of the influence diagram formalism (Ezawa), the inclusion of the cost of obtaining information into the Hugin system (Jensen et al.), and the approximation of multiply-connected networks by polytrees (Acid and de Campos).

The other major network formalism that was discussed was that of Shenoy's valuation-based systems. This was extended both by Shenoy, who considered the question of asymmetric decision problems (that is problems in which not every outcome features every variable) and showed how valuation systems could be altered to cope with them, and Xu, who described a modification that makes it possible to compute the value of any set of variables, even if the required set is not a node in the underlying Markov tree. Both of these rather technical modifications help to considerably broaden the expressiveness of the formalism.

Work on methods that are not network-oriented was also reported. This included Snow's considerations on how to represent ignorance in a probabilistic framework, Wellman's classification of some of the varieties of qualitative probability, and de Campos et al.'s foundational work on the use of probabilistic intervals. There was a good deal of work on the foundations and use of Dempster–Shafer's theory of belief functions, including the work on decision making using belief functions by Mellouli, and the substantial foundational contribution by Kohlas and Brachinger. The latter is another demonstration of the emergent preoccupation for the structural aspects of uncertainty and evidence. Other foundational studies presented at the conference focused on fuzzy set theory. These include the work on similarity by Esteva et al. and Ruspini, the work on fuzzy inference by Valverde, and the interpretation of fuzzy sets in terms of *conceptual sets* proposed by Arigoni and Rossi to make contact with the practice adopted in artificial intelligence.

Finally, possibility theory was also well represented. Dubois et al. described work on possibilistic Markov chains, and Gebhardt and Kruse presented results on possibilistic approaches to abduction. Last, but not least, Sandri and Bittencourt described a combination of possibility theory and semantic networks as a means of expressing imprecise information about taxonomic structures.

4 Logical approaches

Recent years have witnessed an increase in the synergy between purely numerical and purely logical approaches to the management of uncertainty. A symptom of this phenomenon is the increasing amount of work on non-standard logics presented at IPMU, a conference initially dominated by numerical models. Several facets of this synergy were represented at the conference, and we briefly summarize some of them.

The problem of how to formalize non-monotonic reasoning has probably been the earliest bridge between people working on numerical models of uncertainty and people working with non-standard logics. Researchers initially addressed this problem by using logical methods, but they soon realized that some notion of order, or preference, had to be introduced in order to choose between different ways to revise an inconsistent belief set. Introducing an order, often a total order, brought the logical models of non-monotonic reasoning closer to the numerical models of uncertainty, and a number of links have quickly been found (in particular with possibility theory, which is ordinal in nature). Thus, Benferhat proposed a system for representing default rules and for performing default reasoning based on possibilistic logic. In Benferhat's system, possibility distributions induce a preferential total order among interpretations. Other solutions use different orders. Tsoukias based his proposal on a partial order induced by the algebraic structure of the logic. Hajek related possibility theory to interpretability logic and tense logic—the order here is given over time instants. And Bigham uses preferences for the more mundane task of controlling the search for solutions in a cost bounded ATMS.

A second result of the cross-fertilization between the logical and the numerical traditions is the emergence of logical studies of the notion of independence. Independence has been studied in the framework of probability, but it does not have a clear place in logic, though it seems that several problems found in non-monotonic reasoning (e.g. irrelevance, or inheritance blocking) can be tracked down to relations of independence between items of knowledge. Fariñas del Cerro and Herzig presented an initial study where they use the framework of possibility theory to capture three different notions of logical independence. Again, this work bears witness to the increased attention in the community for the structural properties of uncertain knowledge.

Finally, some authors have used ideas borrowed from numerical approaches to define logics with weaker properties. Gottwald explored the possibility of having rules of inference that are only partially sound, Virtanen presented a fuzzy unification algorithm that can be used in a fuzzy Prolog, Thiele proposed "soft" dynamic logics where programs and/or formulae are given a fuzzy interpretation, and Cardoso et al. discussed their work on fuzzy Petri nets using an approximate version of linear logic.

5 Applications

The continuing maturity of fuzzy systems was evident from the many papers on applications, a large number of which involved the use of fuzzy techniques, sometimes on their own, and sometimes in conjunction with more recent methods such as neural networks. The papers on fuzzy techniques on their own included, predictably enough, a number on fuzzy control (for instance, Ferreiro Garcia, or Glorennec & Ambrozy), including one (Glorennec et al.) on the control of an artificial pancreas based on a model of glycemia established from years of patient records (a pleasant change from the usual engineering applications of fuzzy control to car suspensions and the like). Other papers in the same category considered fuzzy methods for decision support (Eklund et al., Ribeiro & Baldwin)

(the latter including a happy digression on the subject of how to identify a hero), a formalism for fuzzy temporal reasoning (Barro et al.), fuzzy pattern matching (a kind of case-based reasoning by another name) to predict the outcome of forest fire (Olivas and Sobrino), and the development of a fuzzy expert system shell (Paduraru et al.).

Notable papers that fall into the category of involving fuzzy techniques and other methods include those describing a system that helps to make medical decisions based on vague medical data (Hudson et al.), which is particularly interesting because it combines a neural network which weighs evidence along with a symbolic manipulation layer that makes the decision, and a system that interprets visual data (Binaghi et al.). There were also several papers on more conventional techniques for handling image data (Anderson et al.; Jaulent & Yang; Smits et al.).

Finally, there were several papers which described fuzzy extensions to database systems, both to handle complex fuzzy queries (Bosc & Pivert) and to perform cooperative answering so that queries with many answers prompt suggestions on how to narrow the search, and those with no answers prompt suggestions on how to widen the search (Ozowa & Yamada).

6 Other notable things

There were a couple of other interesting mini-themes to the conference. The first was, encouragingly, the integration of different techniques. This was the theme of two papers (Bigham et al.; Ramparany et al.) which considered techniques for the combination of different methods of handling uncertainty along with temporal information based upon the use of valuation systems and constraint propagation. The same idea seems to underlie the work of Cano and colleagues who strive to make it possible to propagate any form of uncertainty in their graphical structures, and even extend into the work of such hardline probabilists as Lauritzen, who commented during his talk that the generality of the algorithm that he was describing (Dawid et al.) meant that it could be used to propagate different formalisms.

The second mini-theme was that of verifying and validating systems for reasoning under uncertainty. Completeness dictates that we briefly mention our paper which uses a qualitative analysis of the behaviour of a quantitative system to determine if it is behaving as required, before proceeding to discuss papers in the special session on the subject. Several of these (O'Leary; O'Leary & O'Keefe) dealt with the problem of combining probabilistic judgements from different experts, and proposed several solutions which are arguably more acceptable than simply averaging the estimates. The other notable paper in the session (Kinkielélé & Ayel) considered fuzzy rule-bases and the problems that arise in trying to validate them. Because of the fact that the rules are fuzzy, the normal notions of rule inconsistency and subsumption must be altered and the authors propose suitable fuzzy notions which take account of the many different types of fuzzy implication.

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[4]'Proc. IPMU' is an abbreviation for Proceedings of the Fifth International Conference on Information Processing and Management of Uncertainty in Knowledge-Based Systems, Paris, 4–8 July 1994, ISBN 2-905433-26-4. The Proceedings are available from Professor B. Bouchon-Meunier, LAFORIA, Université Paris VI, Boite 169, 4 Place Jussieu, F-75252 Paris Cedex 05, France, Price 490 FF.

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