APPROXIMATE REASONING IN EXPERT SYSTEMS

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Foreword by:

Lotfi A. ZADEH

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FOREWORD

L.A. Zadeh

The publication of this volume reflects a pressing need for a better understanding of how to deal with uncertainty in expert systems – a problem which has its genesis in the fact that much of the information which is stored in the knowledge base of an expert system is imprecise, incomplete or not totally reliable.

In the pioneering work of Shortliffe, Buchanan, Duda, Hart, Nilsson, Reboh, Konolige and others on MYCIN and PROSPECTOR, uncertainty in the knowledge base was dealt with through the introduction of the concept of a certainty factor and the development of techniques for propagating such factors through an inference network.

A significant shortcoming of the probability-based techniques for inference under uncertainty in rule-based systems is that the employment of such techniques necessitates a pervasive use of various types of assumptions regarding the independence of antecedents and consequents. In practice, it is hard to check on the validity of such assumptions, with the result that the validity of the final conclusion is left in doubt.

In essence, the need for independence assumptions is forced by the desideratum of compositionality. Thus, we expect that from the knowledge of the certainty factors of propositions p and q, we should be able to deduce the certainty factor of a proposition, r, which is a specified combination of p and q. Without some assumptions about p and q, the certainty factor of r will be expressible not as a real-valued function of the certainty factors of p and q, but as an interval-valued function.

Another complicating problem in dealing with uncertainty in rule-based systems is that of partial matching. More specifically, if an observed state of knowledge does not match exactly the antecedent of any rule, but matches partially the antecedents of two or more rules which may be partially inconsistent, then how should the partially matched rules be executed? It is likely that a satisfactory answer to this question cannot be found within the framework of traditional predicate-logic and probability-based methods.

A unifying theme of the papers presented in this volume is that of approximate reasoning. In its broad sense, approximate reasoning as simply a collection of techniques for dealing with inference under uncertainty in which the underlying logic is approximate or probabilistic rather than exact or deterministic. In its narrower sense, which is the sense in which it is employed in those papers in this volume which utilize the theory of fuzzy sets, approximate reasoning is a branch of fuzzy logic. In a way, fuzzy logic may be viewed as a unification as well as a generalization of both predicate logic and probability theory which allows the use of fuzzy predicates, fuzzy truth values and fuzzy quantifiers or probabilities.

In this way, fuzzy logic provides a more expressive language for the representation of uncertain knowledge and a less *ad hoc* basis for the development of rules of combination of uncertain evidence.

The collection of papers in this volume provides a comprehensive and up-to-date exposition of both points of view. The contributors are well known in their respective fields and what they have to say sheds considerable light on the complex problem of how to represent – and infer from – uncertain knowledge. The editors deserve to be complimented for producing a volume which should be on the desk of everyone who wants to develop a better understanding of some of the basic issues which arise in the conception, design and implementation of expert systems in the presence of uncertainty.

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Lotfi A. Zadeh
Berkeley, June 1985

PREFACE

This volume deals with the newly emerging field of 'Approximate Reasoning and Expert Systems' and their application to such important fields as engineering, medicine, physical sciences and management.

The past decade has seen rapid growth in the field of expert systems and their applications. Some of these applications are in the fields of medical diagnosis, engineering design, electronic trouble shooting, risk and damage assessment, reliability engineering, pattern classification, scene analysis, speech recognition, feedback control systems, robotics control, intelligent control systems, computer aided design, VLSI design, defence systems, surveillance systems, judicial and judiciary systems, management science, text classification, and many other fields of applications to the engineering and non-engineering disciplines.

The first generation of expert systems (IEEE Spectrum, August 1983, pp. 39-45) such as MYCIN, PROSPECTORS, CASNET, and INTERNIST/CADS VCEUS etc. were designed using conventional probabilistic tools and two valued logic. Expert systems then emerged as one of the most important applications of artificial intelligence, but they had limited capabilities. They could make inferences only on a low level, but they broke down abruptly in situations outside the domain of such conventional tools as probabilistic methods and two-valued logic.

These expert systems have serious deficiencies such as the reliability of conclusions of prime importance in areas such as medical diagnosis and surveillance systems. They lacked both learning and adaptive capabilities in their basic design philosophy.

The introduction of the fifth generation computers and the new methodology based on approximate reasoning has introduced new innovations in the design philosophy of expert systems, and has brought the 'second generation of expert systems'. This design methodology makes extensive use of the expert's knowledge base. The subject of knowledge engineering and information technology are playing an increasing role in the new design philosophy. This new design methodology and the new generation of computing power have increased the design capabilities as well as the field of applications.

Much of the information used in the knowledge-based expert systems arises from human thought and the cognition process, and as such it is uncertain, vague, imprecise and fuzzy. This information does not necessarily have the same characteristics as uncertainty in random signals encountered in the communication systems. Our interest in the use of information arising from human thought processes is in a much larger context than usually found in the design of telecommunication systems. It lies in making use of this information in the design of knowledge-based expert systems. The theory of approximate reasoning in the characterization and the management of uncertainty for the design of expert systems has played intrinsically an important role. This theory is based on the theory of fuzzy sets, which deals with the set of events that do not have a crisply defined membership as in ordinary set theory. It allows objects to have a grade of membership between 0 and 1. The elasticity of fuzzy sets avoids the rigidity of conventional mathematical reasoning and computer programming. Human reasoning is inherently elastic, and computer operation is rigid. The tools of fuzzy sets and approximate reasoning provide an interface between these elastic and rigid domains. In the elastic domain we use linguistic variables – such as 'small', 'large', 'rich', etc., while in the rigid domain (of conventional mathematics) we tend to use numbers. In fuzzy sets, unlike ordinary sets, we assign gradual transitions from membership to non-membership. We use modifiers or intensifiers such as 'not', 'very' ..... 'slightly' and so forth to modify or intensify the meaning of the fuzzy variables.

This present volume was conceived almost a year ago and was inspired by Lotif A. Zadeh's paper 'The Role of Fuzzy Logic in the Management of Uncertainty in Expert Systems', Fuzzy Sets and Systems, 1983, pp. 199-227, and by many other papers and books in the rapidly growing fields of artificial intelligence, and knowledge-based engineering systems. The mandate of this book was to present some of the new methodologies in the field of approximate reasoning which deals with the processing of information arising from human thought processes and expert's knowledge, rather than the processing of data which usually arise from physical systems. For example, in conventional satellite control systems use is made of the signals available to the system, while a new intelligent satellite control system can be designed using knowledge-based expert systems which will have the capabilities of navigation based on 'reasoning'. Such systems will have better capabilities to fulfil their missions. Most of the information needed for correct signal interpretation is really in the knowledge surrounding the situation such as espionage reports and knowledge of other vital information which usually falls in the domain of an expert. Precisely a similar situation exists in the development of expert systems for medical diagnosis.

This volume is divided into three parts:

Part I:	The Theory of Approximate Reasoning,
Part II:	Theoretical Developments in Expert Systems, and
Part III:	Applications of Expert Systems,

In this volume fifty articles authored by eighty six researchers representing all the important research institutions in seventeen different countries are included. Authorship of these articles from the different countries is as follows:

Belgium (4), Brazil (1), Canada (6), Czchoslovakia (1), Federal Republic of Germany (1), France (5), GDR (1), India (7), Israel (1), Italy (7), Japan (7), Norway (1), People's Republic of China (8), Poland (5), Spain (6), United Kingdom (3), and the United States of America (28).

Part I contains seventeen contributions. These articles give an overview of the theory of approximate reasoning with possible applications to expert systems. These articles also describe the basic theory of approximate reasoning, knowledge representation, decision functions, measure of fuzzy information, and properties of fuzzy set-valued mapping. This part of the volume will help the reader in acquiring a basic theoretical knowledge of approximate reasoning.

Part II contains twenty selected articles which describe the theoretical developments in the area of expert systems. These articles deal with such topics as the foundations for reasoning in expert systems, properties of expert control systems, forms of reasoning, AI knowledge representation, applications of multivalued logic and fuzzy logics in expert systems, knowledge representation in inferential activities and uncertainty in expert systems, etc. The theoretical developments, as reported here, will be useful in the planning and design of future generations of expert systems.

Part III contains thirteen contributions which deal with some expert systems which have been developed theoretically, and others that are working models. These articles deal with soft data based expert systems, fuzzy logic controllers, robotic control, scene analysis, expert system for facial restoration, clinical diagnosis, medical expert systems, expert systems for chest pain analysis, ship steering, expert system in damage assessment, approximate reasoning based inference engine, and fuzzy logic operators. In the works reported here, some interesting features are included which are not necessarily available in the first generation of the expert systems. They make use of the tools of approximate reasoning which appear to be performing very well.

In designing the present volume, the goal of the editors was to present a pedagogically reprint volume containing some of the theoretical developments and some working models of the new generation of expert systems. Additionally, this collection should have a conceptual and theoretical information, and an overall view of some expert systems which have emerged recently. The editors, to some extent, have achieved what they initially planned to do. Hopefully, this volume along with a long list of cited bibliographical material will stimulate research in this field and give a comprehensive view of it to practising engineers, academics and students.

It is our hope that this volume will provide the reader not only with valuable conceptual and technical information but also with a comprehensive view of the general field of approximate reasoning and expert systems, its problems, accomplishments, and future potentials.

March, 1985

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PROLOGUE

Fuzzy set theory originated two decades ago in the work of Lotfi A. Zadeh. At that time it was just another mathematical tool for characterizing the uncertainty and vagueness which arises from the human thought process. Over the last decade, however, the theory has been applied to many situations, and, more recently, has helped in the management of uncertainty in the knowledge base. This, in turn, has shown new promises in the design of the next generation of expert systems. This volume describes some recent theoretical work in the area of approximate reasoning and developments of expert systems based upon this theory.

This volume was conceived almost a year ago, the goal was to assemble and produce a comprehensive set of the most recently unpublished work in a single volume in this growing, but scattered field of approximate reasoning and expert systems. Several colleagues from the 'fuzzy' and 'expert systems' community have provided us with useful feedback at various phases of this project. Contributing authors of this volume have co-operated by providing their excellent work for this volume, and by observing our relatively tight schedule in the production of this book.

It is our hope that this volume will provide a basic impetus in the development of the next generation of expert systems based upon human knowledge and will create new scientific methodology.

March, 1985

Madan M. Gupta
Abraham Kandel
Wyllis Bandler
Jerzy B. Kiszka

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THE ROLE OF FUZZY LOGIC IN THE MANAGEMENT OF UNCERTAINTY IN EXPERT SYSTEMS

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To Professor Elie Sanchez

Received July 1983

Management of uncertainty is an intrinsically important issue in the design of expert systems because much of the information in the knowledge base of a typical expert system is imprecise, incomplete or not totally reliable.

In the existing expert systems, uncertainty is dealt with through a combination of predicate logic and probability-based methods. A serious shortcoming of these methods is that they are not capable of coming to grips with the pervasive fuzziness of information in the knowledge base, and, as a result, are mostly ad hoc in nature. An alternative approach to the management of uncertainty which is suggested in this paper is based on the use of fuzzy logic, which is the logic underlying approximate or, equivalently, fuzzy reasoning. A feature of fuzzy logic which is of particular importance to the management of uncertainty in expert systems is that it provides a systematic framework for dealing with fuzzy quantifiers, e.g., *most, many, few, not very many, almost all, infrequently, about 0.8*, etc. In this way, fuzzy logic subsumes both predicate logic and probability theory, and makes it possible to deal with different types of uncertainty within a single conceptual framework.

In fuzzy logic, the deduction of a conclusion from a set of premises is reduced, in general, to the solution of a nonlinear program through the application of projection and extension principles. This approach to deduction leads to various basic syllogisms which may be used as rules of combination of evidence in expert systems. Among syllogisms of this type which are discussed in this paper are the intersection/product syllogism, the generalized modus ponens, the consequent conjunction syllogism, and the major-premise reversibility rule.

Keywords: Expert systems, Knowledge representation, Fuzzy logic, Fuzzy sets.

1. Introduction

An expert system, as its name implies, is an information system which provides the user with a facility for posing and obtaining answers to questions relating to the information stored in its knowledge base. Typically, such systems possess a nontrivial inferential capability and, in particular, have the capability to infer from premises which are imprecise, incomplete or not totally reliable.

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Since the knowledge base of an expert system is a repository of human knowledge, and since much of human knowledge is imprecise in nature, it is usually the case that the knowledge base of an expert system is a collection of rules and facts which, for the most part, are neither totally certain nor totally consistent. Now, as a general principle, the uncertainty of information in the knowledge base of any question-answering system induces some uncertainty in the validity of its conclusions. Hence, to serve a useful purpose, the answer to a question must be associated – explicitly or, at least, implicitly – with an assessment of its reliability. For this reason, a basic issue in the design of expert systems is how to equip them with a computational capability to analyze the transmission of uncertainty from the premises to the conclusion and associate the conclusion with what is commonly called a *certainty factor.*

In the existing expert systems, the computation of certainty factors is carried out through a combination of methods which are based on, or, at least, not far removed from, two-valued logic and probability theory. However, it is widely recognized at this juncture that such methods have serious shortcomings and, for the most part, are hard to rationalize. In particular, what is open to question is the universally made assumption that if each premise is associated with a numerical certainty factor then the certainty factor of the conclusion is a number which may be expressed as a function of the certainty factors of the premises. As will be seen in the sequel, this assumption is, in general, invalid. It regains its validity, however, if the certainty factors are represented as fuzzy rather than crisp numbers.

More generally, a point of view which is articulated in the present paper is that the conventional approaches to the management of uncertainty in expert systems are intrinsically inadequate because they fail to come to grips with the fact that much of the uncertainty in such systems is possibilistic rather than probabilistic in nature. As an alternative, it is suggested that a fuzzy-logic-based computational framework be employed to deal with both possibilistic and probabilistic uncertainty within a single conceptual system. In this system, test-score semantics – which is the meaning-representational component of fuzzy logic – forms the basis for the representation of knowledge, while the inferential component of fuzzy logic is employed to deduce answers to questions and, when necessary, associate each answer with a probability which is represented as a fuzzy quantifier.

The employment of fuzzy logic as a framework for the management of uncertainty in expert systems makes it possible to consider a number of issues which cannot be dealth with effectively or correctly by conventional techniques. The more important of these issues are the following.

(1) The fuzziness of antecedents and/or consequents in rules of the form

(a) If X is A then Y is B,

(b) If X is A then Y is B with $\text{CF}=\alpha$,

where the antecedent, X is A, and the consequent, X is B, are fuzzy propositions, and α is a numerical value of the certainty factor, CF. For example,

$$\textit{If } \mathbf{X} \textit{ is small then } \mathbf{Y} \textit{ is large with } \text{CF}=0.8,$$