Monographs in Computer Science

Editors

David Gries
Fred B. Schneider

Springer
New York
Berlin
Heidelberg
Barcelona
Budapest
Hong Kong
London
Milan
Paris
Santa Clara
Singapore
Tokyo

Monographs in Computer Science

Abadi and Cardelli, **A Theory of Objects**

Brzozowski and Seger, **Asynchronous Circuits**

Selig, **Geometrical Methods in Robotics**

Nielson [editor], **ML with Concurrency**

Castillo, Gutiérrez, and Hadi, **Expert Systems and Probabilistic Network Models**

Enrique Castillo
José Manuel Gutiérrez
Ali S. Hadi

Expert Systems and Probabilistic Network Models

With 250 Figures

Springer

Enrique Castillo
Cantabria University
39005 Santander, Spain
E-mail: castie@ccaix3.unican.es

José Manuel Gutiérrez
Cantabria University
39005 Santander, Spain
E-mail: gutierjm@ccaix3.unican.es

Ali S. Hadi
Cornell University
358 Ives Hall
Ithaca, NY 14853-3901
USA

Library of Congress Catologing-in-Publication Data
Castillo, Enrique.
Expert systems and probabilistic network models / Enrique Castillo, José Manuel Gutiérrez, Ali S. Hadi.
p. cm. – (Monographs in computer science)
Includes bibliographical references and index.
ISBN-13:978-1-4612-7481-0 e-ISBN-13:978-1-4612-2270-5
DOI: 10.1007/978-1-4612-2270-5

1. Expert systems (Computer science) 2. Probabilities.
I. Gutiérrez, José Manuel. II. Hadi, Ali S. III. Title.
IV. Series.
QA76.76.E95C378 1997
006.3'3–dc20 96-33161

Printed on acid-free paper.

Production managed by Lesley Poliner; manufacturing supervised by Johanna Tschebull.
Photocomposed using the authors' LaTeX files.

9 8 7 6 5 4 3 2 1

ISBN-13:978-1-4612-7481-0 Springer-Verlag New York Berlin Heidelberg SPIN 10524048

To all the people of the former Yugoslavia with the hope that they will live together in peace and be friends, as are the authors, despite the differences in our religions, languages, and national origins.

Preface

The artificial intelligence area in general and the expert systems and probabilistic network models in particular have seen a great surge of research activity during the last decade. Because of the multidisciplinary nature of the field, the research has been scattered in professional journals in many fields such as computer science, engineering, mathematics, probability, and statistics. This book collects, organizes, and summarizes these research works in what we hope to be a clear presentation. Every effort has been made to keep the treatment of the subject as up-to-date as possible. Actually, some of the material presented in the book is yet to be published in the literature. See, for example, the material in Chapter 12 and some of the material in Chapters 7 and 11.

The book is intended for students and research workers from many fields such as computer science; engineering and manufacturing; medical and pharmaceutical sciences; mathematical, statistical, and decision sciences; business and management; economics and social sciences; etc. For this reason, we assumed no previous background in the subject matter of the book. The reader, however, is assumed to have some background in probability and statistics and to be familiar with some matrix notation (see, e.g., Hadi (1996)). In a few instances, we give some programs in *Mathematica* to perform the calculations. For a full understanding of these programs some knowledge of *Mathematica* is needed.

The book can be used as a reference or consulting book and as a textbook in upper-division undergraduate courses or in graduate-level courses. The book contains numerous illustrative examples and end-of-chapter exercises. We have also developed some computer programs to implement the various algorithms and methodologies presented in this book. The current version of these programs, together with a brief User's Guide, can be obtained from the World Wide Web site http://ccaix3.unican.es/~AIGroup. We have used these programs to do the examples and we encourage the reader to use them to solve some of the exercises. The computer programs can also help research workers and professionals apply the methodology to their own

fields of study. Actually, we have used these programs to analyze some real-life applications (case studies) in Chapter 12. We therefore encourage the reader to use and explore the capabilities of these programs. It is suggested that the reader repeat the computations in the examples and solve the exercises at the end of the chapters using these programs. We hope that making such programs available will facilitate the learning of the material presented in this book. Finally, the extensive bibliography included at the end of the book can also serve as a basis for additional research.

Although some theory is present in the book, the emphasis is on applications rather than on theory. For this reason, the proofs of many theorems are left out, numerous examples are used to illustrate the concepts and theory, and the mathematical level is kept to a minimum.

The book is organized as follows. Chapter 1 is an introductory chapter, which among other things, gives some motivating examples, describes the components and development of an expert system, and surveys other related areas of artificial intelligence. Chapters 2 and 3 describe the main two types of expert systems: rule-based and probabilistic expert systems. Although the two types of expert systems are introduced separately, rule-based expert system can be thought of as a special case of the more powerful probabilistic expert system.

It is argued in Chapters 1–3 that two of the most important and complex components of expert systems are the coherence control and the inference engine. These are perhaps the two weakest links in almost all current expert systems, the former because it has appeared relatively recently and many of the existing expert systems do not have it, and the latter because of its complexity. In Chapters 1–3 we show how these subsystems can be implemented in rule-based and probability-based expert systems and how the probability assignment must be done in order to avoid inconsistencies. For example, the automatic updating of knowledge and the automatic elimination of object values are important for maintaining the coherence of the system. Chapters 5–10 are mainly devoted to the details of such implementations.

The materials in Chapter 5 and beyond require some concepts of graph theory. Since we expect that some of the readers may not be familiar with these concepts, Chapter 4 presents these concepts. This chapter is an essential prerequisite for understanding the topics covered in the remaining chapters. Building probabilistic models, which are needed for the knowledge base of a probabilistic expert system, is presented in Chapters 5–7. In particular, the independence and conditional independence concepts, which are useful for defining the internal structure of probabilistic network models and for knowing whether or not some variables or sets of variables have information about other variables, are discussed in Chapter 5. As mentioned in Chapter 4, graphs are essential tools for building probabilistic and other models used in expert systems. Chapter 6 presents the Markov and Bayesian network models as two of the most widely used graphical

network models. Chapter 7 extends graphically specified models to more powerful models such as models specified by multiple graphs, models specified by input lists, multifactorized probabilistic models, and conditionally specified probabilistic models.

Chapters 8 and 9 present the most commonly used exact and approximate methods for the propagation of evidence, respectively. Chapter 10 introduces symbolic propagation, which is perhaps one of the most recent advances in evidence propagation. Chapter 11 deals with the problem of learning Bayesian network models from data. Finally, Chapter 12 includes several examples of applications (case studies).

Many of our colleagues and students have read earlier versions of this manuscript and have provided us with valuable comments and suggestions. Their contributions have given rise to the current substantially improved version. In particular, we acknowledge the help of the following (in alphabetical order): Noha Adly, Remco Bouckaert, Federico Ceballos, Jong Wang Chow, Javier Díez, Dan Geiger, Joseph Halpern, Judea Pearl, Julius Reiner, Milan Studený, and Jana Zvárová.

Enrique Castillo
Jose Manuel Gutiérrez
Ali S. Hadi

Contents