

Cambridge University Press

0521781760 - The Description Logic Handbook: Theory, Implementation, and Applications

Edited by Franz Baader, Diego Calvanese, Deborah L. McGuinness, Daniele Nardi and Peter F. Patel-Schneider
Frontmatter

[More information](#)

THE DESCRIPTION LOGIC HANDBOOK

Cambridge University Press

0521781760 - The Description Logic Handbook: Theory, Implementation, and Applications

Edited by Franz Baader, Diego Calvanese, Deborah L. McGuinness, Daniele Nardi and Peter F. Patel-Schneider
Frontmatter

[More information](#)

THE DESCRIPTION LOGIC HANDBOOK

Theory, implementation, and applications

Edited by

FRANZ BAADER

DIEGO CALVANESE

DEBORAH L. MCGUINNESS

DANIELE NARDI

PETER F. PATEL-SCHNEIDER



CAMBRIDGE
UNIVERSITY PRESS

Cambridge University Press

0521781760 - The Description Logic Handbook: Theory, Implementation, and Applications

Edited by Franz Baader, Diego Calvanese, Deborah L. McGuinness, Daniele Nardi and Peter F. Patel-Schneider
Frontmatter[More information](#)PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge, United Kingdom

CAMBRIDGE UNIVERSITY PRESS

The Edinburgh Building, Cambridge CB2 2RU, UK
40 West 20th Street, New York, NY 10011-4211, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
Ruiz de Alarcón 13, 28014 Madrid, Spain
Dock House, The Waterfront, Cape Town 8001, South Africa<http://www.cambridge.org>

© Cambridge University Press 2003

This book is in copyright. Subject to statutory exception
and to the provisions of relevant collective licensing agreements,
no reproduction of any part may take place without
the written permission of Cambridge University Press.The publisher has used its best endeavours to ensure that the URLs for
external websites referred to in this book are correct and active at the
time of going to press. However, the publisher has no responsibility for the
websites and can make no guarantee that a site will remain live or that the
content is or will remain appropriate.First published 2003
Reprinted 2004

Printed in the United Kingdom at the University Press, Cambridge

Typeface Times 11/14 pt System L^AT_EX 2_ε [TB]*A catalogue record for this book is available from the British Library**Library of Congress Cataloguing in Publication data*The description logic handbook : theory, implementation, and applications / edited by
Franz Baader . . . [et al.].

p. cm.

Includes bibliographical references and index.

ISBN 0-521-78176-0

1. Description logics – Handbooks, manuals, etc. I. Baader, Franz.

Q387.3 .D47 2002

006.3'32 – dc21 2002023796

ISBN 0 521 78176 0 hardback

Cambridge University Press

0521781760 - The Description Logic Handbook: Theory, Implementation, and Applications

Edited by Franz Baader, Diego Calvanese, Deborah L. McGuinness, Daniele Nardi and Peter F. Patel-Schneider
Frontmatter[More information](#)

Contents

<i>List of contributors</i>	<i>page</i> ix
<i>Preface</i>	xiii
1 An Introduction to Description Logics <i>D. Nardi and R. J. Brachman</i>	1
1.1 Introduction	1
1.2 From networks to Description Logics	4
1.3 Knowledge representation in Description Logics	12
1.4 From theory to practice: Description Logic systems	16
1.5 Applications developed with Description Logic systems	20
1.6 Extensions of Description Logics	30
1.7 Relationship to other fields of Computer Science	36
1.8 Conclusion	39
Part I: Theory	41
2 Basic Description Logics <i>F. Baader and W. Nutt</i>	43
2.1 Introduction	43
2.2 Definition of the basic formalism	46
2.3 Reasoning algorithms	74
2.4 Language extensions	90
3 Complexity of Reasoning <i>F. M. Donini</i>	96
3.1 Introduction	96
3.2 OR-branching: finding a model	100
3.3 AND-branching: finding a clash	107
3.4 Combining sources of complexity	114
3.5 Reasoning in the presence of axioms	116
3.6 Undecidability	122
3.7 Reasoning about individuals in ABoxes	128
3.8 Discussion	132
3.9 A list of complexity results for subsumption and satisfiability	133

vi	<i>Contents</i>	
4	Relationships with other Formalisms <i>U. Sattler, D. Calvanese, and R. Molitor</i>	137
4.1	AI knowledge representation formalisms	137
4.2	Logical formalisms	149
4.3	Database models	161
5	Expressive Description Logics <i>D. Calvanese and G. De Giacomo</i>	178
5.1	Introduction	178
5.2	Correspondence between Description Logics and Propositional Dynamic Logics	179
5.3	Functional restrictions	186
5.4	Qualified number restrictions	193
5.5	Objects	197
5.6	Fixpoint constructs	201
5.7	Relations of arbitrary arity	204
5.8	Finite model reasoning	209
5.9	Undecidability results	215
6	Extensions to Description Logics <i>F. Baader, R. Küsters, and F. Wolter</i>	219
6.1	Introduction	219
6.2	Language extensions	220
6.3	Non-standard inference problems	250
	Part II: Implementation	263
7	From Description Logic Provers to Knowledge Representation Systems <i>D. L. McGuinness and P. F. Patel-Schneider</i>	265
7.1	Introduction	265
7.2	Basic access	267
7.3	Advanced application access	270
7.4	Advanced human access	274
7.5	Other technical concerns	280
7.6	Public relations concerns	280
7.7	Summary	281
8	Description Logic Systems <i>R. Möller and V. Haarslev</i>	282
8.1	New light through old windows?	282
8.2	The first generation	283
8.3	Second generation Description Logic systems	291
8.4	The next generation: FACT, DLP and RACER	301
8.5	Lessons learned	303
9	Implementation and Optimization Techniques <i>I. Horrocks</i>	306
9.1	Introduction	306
9.2	Preliminaries	308

Cambridge University Press

0521781760 - The Description Logic Handbook: Theory, Implementation, and Applications

Edited by Franz Baader, Diego Calvanese, Deborah L. McGuinness, Daniele Nardi and Peter F. Patel-Schneider
Frontmatter[More information](#)

<i>Contents</i>		vii
9.3	Subsumption-testing algorithms	313
9.4	Theory versus practice	317
9.5	Optimization techniques	322
9.6	Discussion	345
Part III: Applications		347
10	Conceptual Modeling with Description Logics <i>A. Borgida and R. J. Brachman</i>	349
10.1	Background	349
10.2	Elementary Description Logic modeling	351
10.3	Individuals in the world	353
10.4	Concepts	355
10.5	Subconcepts	358
10.6	Modeling relationships	361
10.7	Modeling ontological aspects of relationships	363
10.8	A conceptual modeling methodology	369
10.9	The ABox: modeling specific states of the world	370
10.10	Conclusions	371
11	Software Engineering <i>C. A. Welty</i>	373
11.1	Introduction	373
11.2	Background	373
11.3	LASSIE	374
11.4	CODEBASE	379
11.5	CSIS and CBMS	380
12	Configuration <i>D. L. McGuinness</i>	388
12.1	Introduction	388
12.2	Configuration description and requirements	390
12.3	The PROSE and QUESTAR family of configurators	403
12.4	Summary	404
13	Medical Informatics <i>A. Rector</i>	406
13.1	Background and history	407
13.2	Example applications	410
13.3	Technical issues in medical ontologies	416
13.4	Ontological issues in medical ontologies	422
13.5	Architectures: terminology servers, views, and change management	424
13.6	Discussion: key lessons from medical ontologies	426
14	Digital Libraries and Web-Based Information Systems <i>I. Horrocks, D. L. McGuinness, and A. C. Welty</i>	427
14.1	Background and history	427
14.2	Enabling the semantic web: DAML	432

Cambridge University Press

0521781760 - The Description Logic Handbook: Theory, Implementation, and Applications

Edited by Franz Baader, Diego Calvanese, Deborah L. McGuinness, Daniele Nardi and Peter F. Patel-Schneider
Frontmatter[More information](#)

viii	<i>Contents</i>	
14.3	OIL and DAML+OIL	434
14.4	Summary	448
15	Natural Language Processing <i>E. Franconi</i>	450
15.1	Introduction	450
15.2	Semantic interpretation	451
15.3	Reasoning with the logical form	454
15.4	Knowledge-based natural language generation	460
16	Description Logics for Databases <i>A. Borgida, M. Lenzerini, and R. Rosati</i>	462
16.1	Introduction	462
16.2	Data models and Description Logics	465
16.3	Description Logics and database querying	474
16.4	Data integration	478
16.5	Conclusions	483
Appendix	Description Logic Terminology <i>F. Baader</i>	485
A.1	Notational conventions	485
A.2	Syntax and semantics of common Description Logics	485
A.3	Additional constructors	491
A.4	A note on the naming scheme for Description Logics	494
	<i>Bibliography</i>	496
	<i>Index</i>	547

Cambridge University Press

0521781760 - The Description Logic Handbook: Theory, Implementation, and Applications

Edited by Franz Baader, Diego Calvanese, Deborah L. McGuinness, Daniele Nardi and Peter F. Patel-Schneider
Frontmatter

[More information](#)

Contributors

Franz Baader

Institut für Theoretische Informatik

Fakultät Informatik

TU Dresden

01062 Dresden, Germany

baader@tcs.inf.tu-dresden.de

<http://wwwtcs.inf.tu-dresden.de/~baader/>

Alex Borgida

Department of Computer Science

Rutgers University

Piscataway, NJ 08855, U.S.A.

borgida@cs.rutgers.edu

<http://www.cs.rutgers.edu/~borgida/>

Ronald J. Brachman

Corporation for National Research Initiatives, U.S.A.

rjb@brachman.org

<http://www.brachman.org/>

Diego Calvanese

Dipartimento di Informatica e Sistemistica

Università di Roma "La Sapienza"

Via Salaria 113, 00198 Roma, Italy

calvanese@dis.uniroma1.it

<http://www.dis.uniroma1.it/~calvanese/>

Giuseppe De Giacomo

Dipartimento di Informatica e Sistemistica

Università di Roma "La Sapienza"

Via Salaria 113, 00198 Roma, Italy

degiacomo@dis.uniroma1.it

<http://www.dis.uniroma1.it/~degiacomo/>

Cambridge University Press

0521781760 - The Description Logic Handbook: Theory, Implementation, and Applications

Edited by Franz Baader, Diego Calvanese, Deborah L. McGuinness, Daniele Nardi and Peter F. Patel-Schneider
Frontmatter[More information](#)

x

List of contributors

Francesco M. Donini

*Dipartimento di Elettrotecnica ed Elettronica**Politecnico di Bari**Via Re David 200, 70125 Bari, Italy*

donini@poliba.it

<http://dee.poliba.it/dee-web/doniniweb/donini.html>

Enrico Franconi

*Faculty of Computer Science**Free University of Bozen-Bolzano**Dominikanerplatz 3, I-39100 Bozen, Italy*

franconi@inf.unibz.it

<http://www.inf.unibz.it/~franconi/>

Volker Haarslev

*Computer Science Department**Concordia University**1455 de Maisonneuve Blvd. W., Montreal, Quebec H3G 1M8, Canada*

haarslev@cs.concordia.ca

<http://www.cs.concordia.ca/~faculty/haarslev/>

Ian Horrocks

*Information Management Group**Department of Computer Science**University of Manchester**Manchester M13 9PL, U.K.*

horrocks@cs.man.ac.uk

<http://www.cs.man.ac.uk/~horrocks/>

Ralf Küsters

*Institut für Informatik und Praktische Mathematik**Christian-Albrechts-Universität zu Kiel**Olshausenstraße 40, 24098 Kiel, Germany*

kuesters@ti.informatik.uni-kiel.de

<http://www.ti.informatik.uni-kiel.de/~kuesters/>

Maurizio Lenzerini

*Dipartimento di Informatica e Sistemistica**Università di Roma "La Sapienza"**Via Salaria 113, 00198 Roma, Italy*

lenzerini@dis.uniroma1.it

<http://www.dis.uniroma1.it/~lenzerini/>

Deborah L. McGuinness

*Knowledge Systems Laboratory**Gates Building 2A, Stanford University**Stanford, CA 94305-9020, U.S.A.*

dlm@ksl.stanford.edu

<http://ksl.stanford.edu/people/dlm/>

Cambridge University Press

0521781760 - The Description Logic Handbook: Theory, Implementation, and Applications

Edited by Franz Baader, Diego Calvanese, Deborah L. McGuinness, Daniele Nardi and Peter F. Patel-Schneider
Frontmatter[More information](#)*List of contributors*

xi

Ralf Molitor

*Swiss Life**IT Research and Development Group**General Guisan Quai 40, CH-8002 Zürich, Switzerland*

ralf.molitor@swisslife.ch

<http://research.swisslife.ch/~molitor/>

Ralf Möller

*Computer Science Department**University of Hamburg**Vogt-Kölln-Strasse 30, 22527 Hamburg, Germany*

moeller@informatik.uni-hamburg.de

<http://kogs-www.informatik.uni-hamburg.de/~moeller/>

Daniele Nardi

*Dipartimento di Informatica e Sistemistica**Università di Roma “La Sapienza”**Via Salaria 113, 00198 Roma, Italy*

nardi@dis.uniroma1.it

<http://www.dis.uniroma1.it/~nardi/>

Werner Nutt

*Department of Computing and Electrical Engineering**Heriot-Watt University**Edinburgh, EH14 4AS, U.K.*

nutt@cee.hw.ac.uk

<http://www.cee.hw.ac.uk/~nutt/>

Peter F. Patel-Schneider

*Bell Labs Research**600 Mountain Avenue**Murray Hill, NJ 07974, U.S.A.*

pfps@research.bell-labs.com

<http://www.bell-labs.com/user/pfps/>

Alan Rector

*Medical Informatics Group**Department of Computer Science**University of Manchester**Manchester M13 9PL, U.K.*

rector@cs.man.ac.uk

<http://www.cs.man.ac.uk/mig/>

Riccardo Rosati

*Dipartimento di Informatica e Sistemistica**Università di Roma “La Sapienza”**Via Salaria 113, 00198 Roma, Italy*

rosati@dis.uniroma1.it

<http://www.dis.uniroma1.it/~rosati/>

Cambridge University Press

0521781760 - The Description Logic Handbook: Theory, Implementation, and Applications

Edited by Franz Baader, Diego Calvanese, Deborah L. McGuinness, Daniele Nardi and Peter F. Patel-Schneider
Frontmatter

[More information](#)

xii

List of contributors

Ulrike Sattler

Institut für Theoretische Informatik

Fakultät Informatik

TU Dresden

01062 Dresden, Germany

sattler@tcs.inf.tu-dresden.de

<http://www.tcs.inf.tu-dresden.de/~uli/>

Christopher A. Welty

Knowledge Structures Group

IBM Watson Research Center

19 Skyline Dr., Hawthorne, NY 10532, U.S.A.

weltyc@us.ibm.com

Frank Wolter

Institut für Informatik

Universität Leipzig

Augustus-Platz 10–11, 04109 Leipzig, Germany

wolter@informatik.uni-leipzig.de

<http://www.informatik.uni-leipzig.de/~wolter/>

Preface

Knowledge Representation is the field of Artificial Intelligence that focuses on the design of formalisms that are both epistemologically and computationally adequate for expressing knowledge about a particular domain. One of the main lines of investigation has been concerned with the principle that knowledge should be represented by characterizing classes of objects and the relationships between them. The organization of the classes used to describe a domain of interest is based on a hierarchical structure, which not only provides an effective and compact representation of information, but also allows the relevant reasoning tasks to be performed in a computationally effective way.

The above principle drove the development of the first frame-based systems and semantic networks in the 1970s. However, these systems were in general not formally defined and the associated reasoning tools were strongly dependent on the implementation strategies. A fundamental step towards a logic-based characterization of required formalisms was accomplished through the work on the KL-ONE system, which collected many of the ideas stemming from earlier semantic networks and frame-based systems, and provided a logical basis for interpreting objects, classes (or concepts), and relationships (or links, roles) between them. The first goal of such a logical reconstruction was the precise characterization of the set of constructs used to build class and link expressions. The second goal was to provide reasoning procedures that are sound and complete with respect to the semantics. The article ‘The tractability of subsumption in Frame-Based Description Languages’ by Ron Brachman and Hector Levesque, presented at AAAI 1984, addressing the tradeoff between the expressiveness of KL-ONE like languages and the computational complexity of reasoning, is usually regarded as the origin of research on *Description Logics*.

Subsequent research came under the label *terminological systems* to emphasize the fact that classes and relationships were used to establish the basic terminology adopted in the modeled domain. Still later, the emphasis was on the set of concept

Cambridge University Press

0521781760 - The Description Logic Handbook: Theory, Implementation, and Applications

Edited by Franz Baader, Diego Calvanese, Deborah L. McGuinness, Daniele Nardi and Peter F. Patel-Schneider
Frontmatter[More information](#)

forming constructs admitted in the language, giving rise to the name *concept languages*. Recently, attention has moved closer to the properties of the underlying logical systems, and the term *Description Logics* has become popular.

Research on Description Logics has covered theoretical aspects, implementation of knowledge representation systems (modern frame-based systems) and the use of such systems to realize applications in several areas. This pattern of development is an example of one of the standard research methodologies, as is recognized by the Artificial Intelligence community. The key element has been the very close interaction between theory and practice. On the one hand, there are various implemented systems based on Description Logics, offering a palette of description formalisms with differing expressive power, and which are employed in various application domains (such as natural language processing, configuration of technical systems, databases). On the other hand, the formal and computational properties (like decidability, complexity) of various description formalisms have been studied in detail. These investigations are usually motivated by the use of certain constructors in systems or the need for these constructors in specific applications, and the results of such investigations have strongly influenced the design of new systems.

The Description Logics research community currently consists of at least 100 active researchers. In addition, other communities are now becoming interested in Description Logics, most notably the Databases community and, more recently, the Semantic Web one. After more than a decade of research on Description Logics there is a substantial body of work and well-established technical literature. However, there is no comprehensive presentation of the major achievements in the field, although survey papers have been published and workshop proceedings are available.

Now, since 1989 a workshop dedicated to Description Logics has been held, initially every two years but annually from 1994. At the 1997 workshop a Working Group was formed to develop a proposal for a book that would provide a systematic introduction to Description Logics, covering all aspects of the research in the field, namely: theory, implementation, and applications. Following the spirit that fostered this research, the *Description Logic Handbook* would provide a thorough introduction to Description Logics both for the more theoretically oriented reader interested in the formal study of Description Logics and for the more practically oriented reader aiming at a principled usage of knowledge representation systems based on Description Logics. Although some refinements have been made to the initial proposal to embody recent developments in the field, the final structure of the *Handbook* reflects the original intentions.

The *Handbook* is organized into three parts plus an initial chapter providing a general introduction to the field.

Part I addresses the theoretical work in Description Logics and includes five chapters. Chapter 2 introduces Description Logics as a formal language for representing knowledge and reasoning about it. Chapter 3 addresses the computational complexity of reasoning in several Description Logics. Chapter 4 explores the relationship with other representation formalisms, within and outside the field of Knowledge Representation. Chapter 5 covers extensions of the basic Description Logics introduced in Chapter 2 by very expressive constructs that require advanced reasoning techniques.

Chapter 6 considers extensions of Description Logics by representation features and non-standard inference problems not available in the basic framework.

Part II is concerned with the implementation of knowledge representation systems based on Description Logics. Chapter 7 describes the features that need to be provided, in addition to the inference engine for a particular Description Logic, to build a knowledge representation system. Chapter 8 reviews implemented knowledge representation systems based on Description Logics that have played or play an important role in the field. Chapter 9 describes the implementation of the reasoning services which form the core of Description Logic knowledge representation systems.

Part III addresses the deployment of Description Logics in the design and implementation of fielded applications. Chapter 10 discusses the issues involved in the development of an ontology for some universe of discourse, which is to become a conceptual model or knowledge base represented and reasoned with using Description Logics. Chapter 11 presents applications of Description Logics in the area of software engineering. Chapter 12 introduces the problem of configuration and the largest and longest lived family of Description Logic-based configurators. Chapter 13 is concerned with the use of Description logics in various kinds of applications in medical informatics—terminology, intelligent user interfaces, decision support and semantic indexing, language technology, and systems integration. Chapter 14 reviews the applications of Description Logics in web-based information systems, and the more recent developments related to languages for the Semantic Web. Chapter 15 analyzes the uses of Description Logics for natural language processing to encode syntactic, semantic, and pragmatic elements needed to drive semantic interpretation and natural language generation processes. Chapter 16 surveys the major classes of application of Description Logics and their reasoning facilities to the issues of data management, including the expression of the conceptual domain model/ontology of the data source, the integration of multiple data sources, and the formulation and evaluation of queries.

The syntax and semantics for Description Logics is summarized in an Appendix, which has been used as a reference to unify the notation throughout the book.

Cambridge University Press

0521781760 - The Description Logic Handbook: Theory, Implementation, and Applications

Edited by Franz Baader, Diego Calvanese, Deborah L. McGuinness, Daniele Nardi and Peter F. Patel-Schneider
Frontmatter[More information](#)

xvi

Preface

Finally, an extended, integrated bibliography is provided and, within each chapter, comprehensive guides through the relevant literature are given.

The chapters are written by some of the most prominent researchers in the field, introducing the basic technical material before taking the reader to the current state of the subject. The chapters have been reviewed in a two step process, which involved two or three reviewers for each chapter. We have relied on the work of several external reviewers, selected both within the Description Logic community, and outside the field, to increase the readability for non experts. In addition, each chapter has been read also by authors of other chapters, to improve the overall coherence.

As such, the book is conceived as a unique reference for the subject. Although not intended as a textbook, the *Handbook* can be used as a basis for specialized courses on Description Logics. In addition, some of the chapters can be used as teaching material in Knowledge Representation courses. The *Handbook* is also a comprehensive reference to the subject in more introductory courses in the field of Artificial Intelligence.

We want to acknowledge the contribution and help of several people. First of all, the authors, who have successfully accomplished the hardest task of writing the chapters, carefully addressing the reviewers' comments as well as the issues raised by the effort in making the presentation and notation uniform. Second, we thank the reviewers for their precious work, which led to significant improvements in the final outcome. The external reviewers were:

Premkumar T. Devanbu,
Peter L. Elkin,
Jerome Euzenat,
Erich Grädel,
Michael Gruninger,
Frank van Harmelen,
Jana Koehler,
Diane Litman,
Robert M. MacGregor,
Amedeo Napoli,
Hans-Jürgen Ohlbach,
Marie-Christine Rousset,
Nestor Rychtycky,
Renate Schmidt,
James G. Schmolze,
Roberto Sebastiani,
Michael Uschold,

Cambridge University Press

0521781760 - The Description Logic Handbook: Theory, Implementation, and Applications

Edited by Franz Baader, Diego Calvanese, Deborah L. McGuinness, Daniele Nardi and Peter F. Patel-Schneider
Frontmatter

[More information](#)

Preface

xvii

Moshe Y. Vardi,
Grant Weddell,
Robert A. Weida.

A special thank you goes also to Christopher A. Welty who, besides serving as a reviewer, also coordinated the reviewing process for some of the chapters. Third, we express our gratitude to the Description Logics community as a whole (see also the Description Logics homepage at <http://dl.kr.org/>) for the outstanding research achievements and for applying the pressure that enabled us to complete the *Handbook*. Finally, we are indebted to Cambridge University Press, and, in particular, to David Tranah, for giving us the opportunity to put the *Handbook* together and for the excellent support in the editing process.

The publisher has used its best endeavours to ensure that the URLs for external websites referred to in this book are correct and active at the time of going to press. However, the publisher has no responsibility for the websites and can make no guarantee that a site will remain live or that the content is or will remain appropriate.