SYMBOLIC COMPUTATION

Artificial Intelligence

Managing Editor: D. W. Loveland

Editors: S. Amarel

A. Biermann

L. Bolc

A. Bundy

H. Gallaire

P. Hayes

A. Joshi

D. Lenat

A. Mackworth

R. Reiter

E. Sandewall

J. Siekmann

W. Wahlster

R.S. Michalski, J.G. Carbonell, T.M. Mitchell (Eds.): Machine Learning. An Artificial Intelligence Approach. XI, 572 pages, 1984

A. Bundy (Ed.): Catalogue of Artificial Intelligence Tools. Second, revised edition. IV, 168 pages, 1986

C. Blume, W. Jakob: Programming Languages for Industrial Robots. XIII, 376 pages, 145 figs., 1986

J.W. Lloyd: Foundations of Logic Programming. Second, extended edition. XII, 212 pages, 1987

L. Bolc (Ed.): Computational Models of Learning. IX, 208 pages, 34 figs., 1987

L. Bolc (Ed.): Natural Language Parsing Systems. XVIII, 367 pages, 151 figs., 1987

N. Cercone, G. McCalla (Eds.): The Knowledge Frontier. Essays in the Representation of Knowledge. XXXV, 512 pages, 93 figs., 1987

G. Rayna: REDUCE. Software for Algebraic Computation. IX, 329 pages, 1987

D.D. McDonald, L. Bolc (Eds.): Natural Language Generation Systems. XI, 389 pages, 84 figs., 1988

L. Bolc, M.J. Coombs (Eds.): Expert System Applications. IX, 471 pages, 84 figs., 1988

C.-H. Tzeng: A Theory of Heuristic Information in Game-Tree Search. X, 107 pages, 22 figs., 1988

L. Kanal, V. Kumar (Eds.): Search in Artificial Intelligence. X, 482 pages, 67 figs., 1988

H. Coelho, J. Cotta: Prolog by Example. 304 pages, 62 figs., 1988

H. Abramson, V. Dahl: Logic Grammars. XV, 258 pages, 40 figs., 1989

R. Hausser: Computation of Language. 425 pages, 1989

B. D'Ambrosio: Qualitative Process Theory Using Linguistic Variables. 156 pages, 22 figs., 1989

Bruce D'Ambrosio

Qualitative Process Theory Using Linguistic Variables

With 22 Figures

Springer-Verlag
New York Berlin Heidelberg
London Paris Tokyo Hong Kong

Bruce D'Ambrosio
Department of Computer Science
Oregon State University
Corvallis, OR 97331-4602

Library of Congress Cataloging-in-Publication Data
D'Ambrosio, Bruce.

Qualitative process theory using linguistic variables.

(Symbolic computation. Artificial intelligence)

Includes bibliographical references.

1. Artificial intelligence. 2. Reasoning.

3. Linguistics. I. Title. II. Series.

Q335.D36 1989 006.3 89-21698

Printed on acid-free paper

© 1989 Springer-Verlag New York Inc.

Softcover reprint of the hardcover 1st edition 1989

All rights reserved. This work may not be translated or copied in whole or in part without the written permission of the publisher (Springer-Verlag New York, Inc., 175 Fifth Avenue, New York, NY 10010, USA), except for brief excerpts in connection with reviews or scholarly analysis. Use in connection with any form of information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed is forbidden. The use of general descriptive names, trade names, trademarks, etc., in this publication, even if the former are not especially identified, is not to be taken as a sign that such names, as understood by the Trade Marks and Merchandise Marks Act, may accordingly be used freely by anyone.

Camera-ready text prepared by the author using T_EX.

9 8 7 6 5 4 3 2 1

ISBN-13: 978-1-4613-9673-4

e-ISBN-13: 978-1-4613-9671-0

DOI: 10.1007/978-1-4613-9671-0

Contents

1	Overview	1
2	Fuzzy Logic Control	5
2.1	Classical Control Theory	5
2.2	A New Approach to Control of Complex Systems	6
2.3	Fuzzy Control	7
2.3.1	Fuzzification of Input	9
2.3.2	Rule Interpretation	9
2.3.3	Defuzzification	10
2.4	Extensions of the Fuzzy Control Paradigm	12
2.5	The Next Step: Fuzzy-Model-Based Control	13
3	Introduction to Qualitative Process Theory	16
3.1	Uses of QP Theory	18
3.2	Process versus Device-Centered Theories	19
3.3	Qualitative Process Theory - Definitions and Examples . . .	21
3.4	Reasoning in QP Theory	25
3.5	Historical Background	28
3.6	Summary	30
4	Application of QP Theory to Process Control - An Example	31
4.1	The Reaction Process	34
4.2	Countercurrent Heat Flow	35
4.3	Basic Deductions	35
5	Ambiguity in QP Theory	44
5.1	Ambiguity in QP Theory	44
5.2	Representation Alternatives	46
5.2.1	Representations for Uncertainty	46
5.2.2	Representations for Parameters of Physical Systems	48
5.2.3	Characterizations of Functional Relationships	50
5.3	Related Work	52

5.4	Linguistic Extensions to QP Descriptions	53
6	Linguistic Variables	56
6.1	Introduction to Linguistic Variables	56
6.2	Approximate Reasoning and the Compositional Rule of Inference.	58
6.3	Similarity of Linguistic Variables and Relations	60
6.4	Support-Pair Certainty	61
6.4.1	Support Logic Programming	63
6.4.2	Support-Pair Certainty and Fuzzy Sets	64
6.4.3	Relationship of SLP with Linguistic Variables and the Compositional Rule of Inference	66
6.5	Truth Maintenance with Numeric Certainty Estimates . . .	66
6.5.1	Review of Methods for Uncertainty Management in AI	69
6.5.2	Assumption-Based Truth Maintenance	69
6.5.3	SLP and Assumption-Based Truth Maintenance . .	73
6.5.4	Symbolic Computation of Belief Functions	75
6.5.5	Example	78
6.5.6	Discussion and Related Research	78
6.6	Summary	81
7	Linguistic Quantity Spaces	82
7.1	A Functional Overview	82
7.2	Computing the Consequences of a Linguistic Quantity Space	83
7.2.1	Representation of Parameter Values and Relations .	83
7.2.2	Quantity Space Deductions	84
7.2.3	Implementing the Quantity Space Deductions	90
7.3	Linguistic Measurement Interpretation	91
8	Characterization of Functional Relationships	96
8.1	Sources of Ambiguity in QP Theory Models	96
8.1.1	Ambiguity 1 - Offgas Exit Temperature	97
8.1.2	Ambiguity 2 - Product Temperature	100
8.1.3	Ambiguity 3 - Material-Flow Rates	102
8.1.4	Discussion	104
8.2	Fuzzy Relational Algorithms	105
8.2.1	Computing Individual Influence Effects	107
8.2.2	Adjusting for Description Applicability	108
8.2.3	Combining Influence Effects	109
8.3	Annotation Management	110
8.4	Examples	113
8.5	Summary	118

9	Qualitative Perturbation Analysis	120
9.1	Qualitative Perturbation Analysis	120
9.2	Extended Perturbation Analysis	123
9.3	Linguistic Perturbation Analysis	131
9.4	LPA Extended Example	134
9.4.1	Input Script	134
9.4.2	Output Trace	137
9.5	Summary	141
10	Evaluation and Conclusion	142
10.1	Review	142
10.2	Evaluation	143
10.3	Further Research	145
10.4	Conclusion	146
10.5	References	147

List of Figures

1.1	Boiling Example, after Forbus [For84].	2
2.1	Classical Model of Process Control	5
2.2	A Model of Fuzzy Logic Control	8
2.3	Possible Membership Functions for Fuzzy Control Actions .	11
2.4	Fuzzy-Model-Based Control	14
3.1	Contained-Liquid View	22
3.2	Heat-Flow Process	25
4.1	A Simplified Chemical Furnace	32
4.2	Chemical Furnace Initial Situation Description	33
4.3	The Reaction Process	36
4.4	Countercurrent Heat Flow	37
4.5	Definition of Contained Substances	38
4.6	Influence Dependency Graph	41
4.7	Results of QP Analysis of Furnace	42
5.1	Arithmetic for Qualitative Sign Abstractions	52
6.1	Semantic Rule for a Linguistic Variable	57
6.2	Syntactic Rule as a Production System	58
6.3	Containment	62
6.4	Combining Independent Bodies of Evidence	65
6.5	Support-Pair Containment Tests	67
6.6	Composition Rule of Inference as a Set of SLP Implications	68
6.7	Simple Label Propagation in an ATMS	71
6.8	Representing Mutual Exclusion in an ATMS	72
6.9	Assumptions for a Basic Mass Assignment	74
6.10	Representing an SLP Inference Rule in the ATMS	76
6.11	Symbolic Computation of Belief Functions	77
6.12	Example Problem Setup	79
6.13	ATMS Example Results	80
7.1	Defining an Ordering Relation Inference Matrix	84

7.2	Definition of <i>strictlylessthan</i> over {10 20 30 40 50}	85
7.3	Sample Quantity Space	86
7.4	Construction of Quantity Spaces	93
7.5	Interpretation of Linguistic Quantity Ordering Information	94
7.6	State Details for Linguistic Measurement Interpretation	95
8.1	Ambiguity Source 1 - The Conflict Triangle	98
8.2	The Conflict Triangle Annotated with Influence Sensitivities	100
8.3	Ambiguity 2 - Loop Pair Case 1	101
8.4	Loop Pair Type 1 - With Annotations	103
8.5	Ambiguity 3 - Loop Pair Type 2	104
8.6	Loop Pair Type 2 - With Annotations	105
8.7	Adjusting for Applicability	109
8.8	Combining Influences	111
8.9	Combining influences graphically	112
8.10	Extended Influence Resolution Algorithm	114
8.11	Influence Resolution without Annotations	115
8.12	Annotating the Influences	116
8.13	Influence Resolution with Annotations	117
8.14	Comparison of Results of Influence Resolution	119
9.1	Simple Qualitative Perturbation Analysis Algorithm	122
9.2	QP Sample Influence Graph	123
9.3	Revised Qualitative Perturbation Analysis Algorithm	124
9.4	Annotation of EPA for Heater Temp Increase	126
9.5	Results of EPA on Heater Temp Increase	127
9.6	Annotation for Reactant Temp Increase	128
9.7	Results of Extended QPA on Reactant Temp Increase	129
9.8	Extended QPA Example Summary	130
9.9	Linguistic Perturbation Analysis Example	135