

# Contents

<b>1</b>	<b>Introduction</b> .....	1
1.1	Motivation .....	1
1.2	Methodology and Related Work .....	3
1.3	Structure of the Book .....	7
<b>2</b>	<b>Logic and Knowledge Representation</b> .....	9
2.1	Preliminaries .....	10
2.2	Classical Logic .....	11
2.2.1	Propositional Logic .....	11
2.2.2	First-Order Logic .....	12
2.3	Nonclassical Logics .....	14
2.4	Nonmonotonic Reasoning .....	16
2.5	Logic Programming .....	17
2.5.1	Stable-Model and Answer Set Semantics .....	19
2.6	Discussion .....	20
<b>3</b>	<b>Artificial Neural Networks</b> .....	23
3.1	Architectures of Neural Networks .....	23
3.2	Learning Strategy .....	26
3.3	Recurrent Networks .....	29
3.4	Evaluation of Learning Models .....	31
3.5	Discussion .....	33
<b>4</b>	<b>Neural-Symbolic Learning Systems</b> .....	35
4.1	The CILP System .....	35
4.2	Massively Parallel Deduction in CILP .....	43
4.3	Inductive Learning in CILP .....	44
4.4	Adding Classical Negation .....	45
4.5	Adding Metalevel Priorities .....	49
4.6	Applications of CILP .....	52
4.7	Discussion .....	53

<b>5</b>	<b>Connectionist Modal Logic</b> .....	55
5.1	Modal Logic and Extended Modal Programs .....	56
5.1.1	Semantics for Extended Modal Logic Programs .....	58
5.2	Connectionist Modal Logic .....	60
5.2.1	Computing Modalities in Neural Networks .....	61
5.2.2	Soundness of Modal Computation .....	66
5.2.3	Termination of Modal Computation .....	67
5.3	Case Study: The Muddy Children Puzzle .....	68
5.3.1	Distributed Knowledge Representation in CML .....	69
5.3.2	Learning in CML .....	71
5.4	Discussion .....	73
<b>6</b>	<b>Connectionist Temporal Reasoning</b> .....	75
6.1	Connectionist Temporal Logic of Knowledge .....	76
6.1.1	The Language of CTLK .....	77
6.1.2	The CTLK Algorithm .....	79
6.2	The Muddy Children Puzzle (Full Solution) .....	81
6.2.1	Temporal Knowledge Representation .....	81
6.2.2	Learning in CTLK .....	83
6.3	Discussion .....	84
<b>7</b>	<b>Connectionist Intuitionistic Reasoning</b> .....	87
7.1	Intuitionistic Logic and Programs .....	88
7.2	Connectionist Intuitionistic Reasoning .....	90
7.2.1	Creating the Networks .....	92
7.2.2	Connecting the Networks .....	93
7.3	Connectionist Intuitionistic Modal Reasoning .....	95
7.4	Discussion .....	100
<b>8</b>	<b>Applications of Connectionist Nonclassical Reasoning</b> .....	101
8.1	A Simple Card Game .....	101
8.2	The Wise Men Puzzle .....	102
8.2.1	A Formalisation of the Wise Men Puzzle .....	103
8.2.2	Representing the Wise Men Puzzle Using CML .....	104
8.3	Applications of Connectionist Intuitionism .....	108
8.3.1	Representing the Wise Men Puzzle Using CIL .....	109
8.4	Discussion .....	112
<b>9</b>	<b>Fibring Neural Networks</b> .....	115
9.1	The Idea of Fibring .....	115
9.2	Fibring Neural Networks .....	117
9.3	Examples of the Fibring of Networks .....	119
9.4	Definition of Fibred Networks .....	121
9.5	Dynamics of Fibred Networks .....	123
9.6	Expressiveness of Fibred Networks .....	124
9.7	Discussion .....	125

<b>10</b>	<b>Relational Learning in Neural Networks</b> .....	127
10.1	An Example .....	128
10.2	Variable Representation .....	130
10.3	Relation Representation .....	131
10.4	Relational Learning .....	132
10.5	Relational Reasoning .....	134
10.6	Experimental Results .....	135
10.7	Discussion .....	140
<b>11</b>	<b>Argumentation Frameworks as Neural Networks</b> .....	143
11.1	Value-Based Argumentation Frameworks .....	144
11.2	Argumentation Neural Networks .....	145
11.3	Argument Computation and Learning .....	149
11.3.1	Circular Argumentation .....	150
11.3.2	Argument Learning .....	154
11.3.3	Cumulative (Accrual) Argumentation .....	155
11.4	Fibring Applied to Argumentation .....	157
11.5	Discussion .....	159
<b>12</b>	<b>Reasoning about Probabilities in Neural Networks</b> .....	161
12.1	Representing Uncertainty .....	161
12.2	An Algorithm for Reasoning about Uncertainty .....	164
12.3	The Monty Hall Puzzle .....	166
12.4	Discussion .....	167
<b>13</b>	<b>Conclusions</b> .....	169
13.1	Neural-Symbolic Learning Systems .....	170
13.2	Connectionist Nonclassical Reasoning .....	172
13.2.1	Connectionist Modal Reasoning .....	173
13.2.2	Connectionist Temporal Reasoning .....	175
13.3	Fibring Neural Networks .....	176
13.4	Concluding Remarks .....	178
	<b>References</b> .....	181
	<b>Index</b> .....	193