

Contents

- 1. The Agent Landscape** 1
 - 1.1 Introduction 1
 - 1.2 Agents 3
 - 1.2.1 Terminology 3
 - 1.2.2 Problems with Definition 5
 - 1.3 Multi-Agent Systems 6
 - 1.4 Desiderata for a Conceptual View of Agents 7
 - 1.5 A Formal Framework for Agent Definition and Development 8
 - 1.5.1 Formal Frameworks 8
 - 1.5.2 Notation 9
 - 1.5.3 Specification Structure Diagrams 10

- 2. The SMART Agent Framework** 15
 - 2.1 Introduction 15
 - 2.2 Initial Concepts 15
 - 2.3 Entities 19
 - 2.3.1 Entity State 20
 - 2.3.2 Entity Operations 21
 - 2.4 Objects 21
 - 2.4.1 Object Behaviour 22
 - 2.4.2 Object State 22
 - 2.4.3 Object Operations 23
 - 2.5 Agents 24
 - 2.5.1 Introduction 24
 - 2.5.2 Agent Specification 24
 - 2.5.3 Agent Perception 26
 - 2.5.4 Agent Action 27
 - 2.5.5 Agent State 27
 - 2.5.6 Agent Operations 28
 - 2.6 Autonomy 29
 - 2.6.1 Introduction 29
 - 2.6.2 Autonomous Agent Specification 30
 - 2.6.3 Autonomous Agent Perception 31
 - 2.6.4 Autonomous Agent Action 31

2.6.5	Autonomous Agent State	32
2.6.6	Autonomous Agent Operations	32
2.7	Applying SMART: Tropistic Agents	33
2.7.1	Tropistic Agents	33
2.7.2	Reformulating Perception	33
2.7.3	Reformulating Action	34
2.7.4	Discussion	35
2.8	Specification Structure of SMART	35
2.9	Related Work	38
2.10	Summary	39
3.	Agent Relationships	41
3.1	Introduction	41
3.2	Multi-Agent Systems	42
3.2.1	Multi-Agent System Definition	42
3.2.2	Server-Agents and Neutral-Objects	42
3.2.3	Multi-Agent System Specification	43
3.3	Goal Generation	44
3.3.1	Discussion	44
3.3.2	Goal Generation Specification	45
3.4	Goal Adoption	47
3.4.1	Goal Adoption by Neutral-Objects	48
3.4.2	Goal Adoption by Server-Agents	50
3.4.3	Autonomous Goal Adoption	51
3.4.4	Autonomous Goal Destruction	52
3.5	Engagement	53
3.5.1	Direct Engagement	53
3.5.2	Direct Engagements in a Multi-Agent System	55
3.5.3	Engagement Chains	55
3.5.4	Engagement Chains in a Multi-Agent System	57
3.6	Cooperation	58
3.6.1	Cooperations in a Multi-Agent System	59
3.6.2	Discussion and Example	60
3.7	The Agent Society	61
3.8	Agent Relationships Taxonomy	63
3.8.1	Direct Engagement Relation	63
3.8.2	Generic Engagement Relation	63
3.8.3	Indirect Engagement Relation	64
3.8.4	Generic Ownership Relation	65
3.8.5	Direct Ownership Relation	65
3.8.6	Unique Ownership Relation	66
3.8.7	Specific Ownership Relation	66
3.8.8	Generic Cooperation Relation	67
3.9	Summary	68

- 4. An Operational Analysis of Agent Relationships** 71
 - 4.1 Introduction 71
 - 4.2 Initial Concepts 72
 - 4.3 Making Engagements 74
 - 4.4 Breaking Engagements 79
 - 4.5 Joining Cooperations 81
 - 4.6 Leaving Cooperations 83
 - 4.7 An Illustrative Example 86
 - 4.8 Summary 91

- 5. Sociological Agents** 93
 - 5.1 Introduction 93
 - 5.2 Agent Store 94
 - 5.2.1 Applying SMART: Hysteretic Agents 98
 - 5.2.2 Applying SMART: Knowledge-Based Agents 99
 - 5.3 Agent Models 101
 - 5.3.1 Entity Models 101
 - 5.3.2 Sociological Agents 102
 - 5.3.3 Modelling the Motivations of Others 106
 - 5.3.4 Modelling the Models of Others 108
 - 5.4 Agent Plans 110
 - 5.4.1 Introduction 110
 - 5.4.2 Plan-Agents 110
 - 5.4.3 Multi-Agent Plans 112
 - 5.4.4 Multi-Agent Plan-Agents 116
 - 5.4.5 Sociological Plan-Agents 117
 - 5.4.6 An Illustrative Example 120
 - 5.4.7 Modelling the Plans of Others 124
 - 5.5 Summary 124

- 6. Autonomous Interaction** 127
 - 6.1 Introduction 127
 - 6.1.1 Speech Acts 127
 - 6.2 Problems with Autonomous Interaction 128
 - 6.2.1 Pre-determined Agenda 128
 - 6.2.2 Benevolence 129
 - 6.2.3 Guaranteed Effects 129
 - 6.2.4 Automatic Intention Recognition 129
 - 6.2.5 Multi-Agent Modelling 129
 - 6.2.6 Summary 130
 - 6.3 A Model of Autonomous Interaction 130
 - 6.3.1 Sociological Goal Generation 131
 - 6.3.2 Agent Interaction 131
 - 6.3.3 Prediction 133
 - 6.3.4 Experimentation 133

6.3.5	Observation and Evaluation	134
6.3.6	Revision	136
6.4	Summary	136
7.	The Contract Net as a Goal Directed System	139
7.1	Introduction	139
7.2	Contract Net Protocol	139
7.3	Contract Net Components	141
7.3.1	Nodes	141
7.3.2	Agents	141
7.3.3	Monitor Agents	142
7.3.4	Idle Nodes	142
7.3.5	Server-Agents	142
7.4	Contract Net Relationships	143
7.5	Contract Net State	146
7.5.1	Task Announcements	146
7.5.2	Bids	146
7.5.3	System State	147
7.6	Contract Net Protocol	147
7.6.1	Axiomatic Definitions	147
7.6.2	Making Task Announcements	148
7.6.3	Making Bids	149
7.6.4	Awarding Contracts	150
7.6.5	Terminating Contracts	151
7.7	Summary	152
8.	Computational Architecture for BDI Agents	155
8.1	Introduction	155
8.2	AgentSpeak(L)	155
8.3	Types	156
8.3.1	Beliefs	157
8.3.2	Events	157
8.3.3	Plans	158
8.3.4	Intentions	159
8.4	AgentSpeak(L) Agents	159
8.5	AgentSpeak(L) Agent Operation	160
8.6	Summary	165
9.	Evaluating Social Dependence Networks	167
9.1	Introduction	167
9.2	Social Dependence Networks	167
9.2.1	Action and Resource Autonomy	169
9.2.2	Dependence Relations	169
9.2.3	Dependence Situations	169
9.3	External Descriptions	169

9.3.1	Introduction	169
9.3.2	SDN in SMART	170
9.3.3	Formalising External Descriptions	172
9.4	Action and Resource Autonomy	173
9.5	Dependence Relations	175
9.6	Dependence Situations	178
9.7	Summary	180
10.	Normative Agents	183
10.1	Introduction	183
10.2	Norms	184
10.2.1	Obligations and Prohibitions	185
10.2.2	Social Commitments	186
10.2.3	Social Codes	186
10.3	Chains of Norms	187
10.3.1	Norm Instances	187
10.3.2	Interlocking Norms	188
10.4	Normative Agents	189
10.4.1	Normative Multi-Agent Systems	190
10.4.2	Normative Roles	191
10.5	Norm Dynamics	192
10.5.1	Changing Norms	192
10.5.2	Norm States	193
10.6	Norm Compliance	195
10.6.1	Enforcement Mechanisms	195
10.6.2	Normative Agent State	196
10.6.3	The Norm Compliance Process	197
10.7	Conclusions	198
11.	<i>act</i>SMART: Building a SMART System	201
11.1	Introduction	201
11.2	An Example	202
11.3	<i>act</i> SMART Agent Implementation	203
11.3.1	Design Principles	203
11.3.2	Java for Agent Systems	204
11.3.3	Jini	204
11.3.4	eXtensible Markup Language	205
11.4	Agent construction model for <i>act</i> SMART	206
11.5	Object and Agent Creation in <i>act</i> SMART	207
11.5.1	Neutral-Object	207
11.5.2	Autonomous Agents	208
11.5.3	Example architecture	209
11.5.4	Engaging Neutral-Objects	210
11.6	Conclusions	211

12. Conclusions	213
12.1 Summary	213
12.1.1 The SMART Framework	213
12.1.2 Agent Relationships	213
12.1.3 Agent Architectures	214
12.2 Evaluation	214
12.2.1 Generality	215
12.2.2 Application	215
12.3 Concluding Remarks	216
A. The Z Specification Language	219
A.1 Introduction to Z	219
A.2 Generic Z Definitions	222
A.2.1 Sets	222
A.2.2 Relations	223
A.2.3 Functions	224
A.2.4 Sequences	225
References	227
Index	237