

Contents

List of Figures	viii
List of Tables	ix
1 Introduction	1
1.1 Configuration of Metaheuristics	1
1.1.1 Methods for configuring metaheuristics	2
1.2 Why agents? Preliminary comments	3
1.3 Scope and Goals of the Thesis	5
1.4 Contributions of the Thesis	8
1.5 Outline of the Thesis	8
I Background	11
2 Metaheuristics at a Glance	13
2.1 Introduction	13
2.2 Overview and general aspects	14
2.3 Classification of Metaheuristics	15
2.4 Summary	18
3 Artificial Intelligence at a Glance	19
3.1 Introduction	19
3.2 Distributed Artificial Intelligence	20
3.2.1 Agents	21
3.2.2 Multiagent systems	23
3.2.3 Distributed Problem Solving	24
3.3 Summary	26
4 Related Work	27
4.1 Introduction	27
4.2 Setting up parameters in metaheuristics	27
4.3 Approaches that configure metaheuristics	30
4.3.1 Meta-evolution as configurator	30

4.3.2	Parallel approaches	32
4.3.3	More general configurators	32
4.4	Testing and developing metaheuristics	37
4.5	Metaheuristics and agent-based techniques	38
4.5.1	Related examples	40
4.6	Summary	42
II Multiagent System for Configuring Algorithms in Real Problem Solving		43
5	Formal Concepts Related to Metaheuristics and their Configuration	45
5.1	Introduction	45
5.2	Parameters and configurations	45
5.2.1	Design of experiments and evaluation	47
5.2.2	Performance indexes	49
5.3	Worth of a metaheuristic	50
5.3.1	Stop criteria	50
5.3.2	Definition of the worth	53
5.4	The metaheuristic configuration problem	56
5.4.1	Pareto-optimal configurations	56
5.4.2	Configuration problem	58
5.5	Summary	59
6	Agent-based Configuration of Metaheuristics. +CARPS's Design	61
6.1	Introduction	61
6.1.1	Decomposition of the configuration problem	61
6.1.2	<i>Why agents?</i> revisited	62
6.2	Agent architecture: +CARPS	64
6.2.1	User Mediator (UM agent)	66
6.2.2	Starting Configuration Builders (SCB agents)	67
6.2.3	Instantiation Strategy Manager (ISM agent)	71
6.2.4	Algorithm Solvers (AS agents)	74
6.2.5	Algorithm Configurators (AC agents)	75
6.2.6	Solution Manager (SM agent)	81
6.3	Interaction protocols in +CARPS	82
6.3.1	The Helper-Booker Interaction Protocol	82
6.3.2	The Engagement Interaction Protocol	84
6.3.3	The AC-AS Request Interaction Protocol	85
6.4	Basic essentials of agents creation and communication in +CARPS	87
6.5	Summary	88

7 Implementation of +CARPS	89
7.1 Introduction	89
7.2 Making +CARPS agents talk and reason	90
7.2.1 +CARPS vocabularies and ontologies	91
7.3 +CARPS agents' communications	97
7.3.1 User Mediator (UM agent)	97
7.3.2 Starting Configuration Builders (SCB agents)	106
7.3.3 Instantiation Strategy Manager (ISM agent)	108
7.3.4 Algorithm Solvers (AS agents)	111
7.3.5 Algorithm Configurators (AC agents)	115
7.3.6 Solution Manager (SM agent)	122
7.4 Interaction Protocols	123
7.4.1 The Helper-Booker Interaction Protocol	123
7.4.2 The Engagement Interaction Protocol	128
7.4.3 The AC-AS Request Interaction Protocol	132
7.5 Some design and technical information	134
7.6 Summary	135
8 Case Studies	137
8.1 Introduction	137
8.2 Basic essentials of evolutionary algorithms	138
8.2.1 Genetic Algorithms	139
8.2.2 Evolution Strategies	141
8.3 GA in Chemical Kinetics	141
8.3.1 Inverse problems	141
8.3.2 Applying GA	146
8.4 Summary	154
III Results, Discussion, and Conclusions of the Thesis	155
9 Testing +CARPS. Discussion	157
9.1 Introduction	157
9.2 Experimental part	159
9.2.1 General assumptions	161
9.2.2 Test problems for the GA	162
9.2.3 Test problem for the ES	163
9.3 Results	163
9.3.1 Presenting general aspects from the +CARPS fine-tuning	164
9.3.2 Varying the equations to calculate the worth	170
9.3.3 Varying the weight vectors	174
9.3.4 Varying the number of neighbors	176
9.3.5 Considering experimental repetitions	181

9.3.6	Varying the proportion of AC agents	182
9.3.7	Considering more search trials	187
9.4	Summary	193
10	Conclusions and Outlook	195
10.1	Conclusions and summary of the main contributions	195
10.2	Open questions	197
10.2.1	Comments on possible extensions	197
10.3	+CARPS applications	199
10.4	Final conclusions	200
A	JADE	201
A.1	What is JADE?	201
A.2	Where to find it?	201
A.3	General aspects about the platform	201
A.4	Related materials and tutorials	201
B	Format of the Input Files to the Metaheuristics from the Test Cases	203
B.1	Introduction	203
B.2	Format of the input files for the GA	203
B.2.1	Format of the input data file containing metaheuristic's parameters	204
B.2.2	Format of the input data file containing real problem information	205
B.3	Format of the input file for the ES	206
B.3.1	Format of the input data file containing metaheuristic's parameters	206
	Bibliography	207
	Index	229

List of Figures

1.1	Optimization and simulation processes in the agent-based configuration of metaheuristics.	4
1.2	System architecture and user interfaces: general view.	5
4.1	Tree Growing and Pruning Method for configuring metaheuristic algorithms.	33
4.2	Factorial Experimental Design and Local Search-based Method for configuring heuristic algorithms.	34
4.3	F-Race algorithm for configuring metaheuristics.	35
4.4	Fractional Experimental Design and Local Search-based Method for configuring metaheuristic algorithms.	36
4.5	Relationships between both metaheuristics and agent-based techniques.	40
5.1	Example of fixed and free parameters in the configuration of a metaheuristic.	47
6.1	Agent-Based Configuration of (Metaheuristic) Algorithms.	63
6.2	Layered view of +CARPS.	64
6.3	+CARPS architecture: Main interactions among the agents.	65
6.4	UM agent and its interactions.	67
6.5	SCB agents and their interactions.	68
6.6	Example of SCB agent. Four different starting configurations are constructed, p_1 , p_2 , p_3 , and p_4 , depending on the instantiation strategies that are available.	70
6.7	ISM agent and its interactions.	71
6.8	AS agents and their interactions.	74
6.9	Input and output data files.	75
6.10	AC agents and their interactions.	75
6.11	Agent-Based Random-Restart Hill-Climbing: Search procedure to improve configurations.	78
6.12	SM agent and its interactions.	81
6.13	Sequence diagram for the Helper-Booker Interaction Protocol.	83

6.14 Sequence diagram for the Engagement Interaction Protocol	85
6.15 FIPA Request Interaction Protocol	86
7.1 Classes diagram for both the +CARPS <i>Configuration</i> vocabulary and its ontology	92
7.2 Classes diagram for both the +CARPS <i>User Problem</i> vocabulary and its ontology	95
7.3 Classes diagram for both the +CARPS <i>Instantiation Strategy</i> vocabulary and its ontology	95
7.4 Classes diagram for both the +CARPS <i>Agent's List</i> vocabulary and its ontology	96
7.5 Behaviors of the UM agent	97
7.6 Graphical User Interface of +CARPS	99
7.7 Parameter Frame from +CARPS	99
7.8 Agents and Configuration Algorithms Frame from +CARPS	100
7.9 Tuning Frame from +CARPS	101
7.10 User Problem Frame from +CARPS	101
7.11 Behaviors of the SCB agents	107
7.12 Behaviors of the ISM agent	108
7.13 Behaviors of the AS agents	112
7.14 Finite State Machine from AS agents for running algorithms	114
7.15 Behaviors of the AC agents	116
7.16 Finite State Machine for the ABRRHC algorithm	118
7.17 Behaviors of the SM agent	122
7.18 Helper-Booker Initiator Finite State Machine	124
7.19 Helper-Booker Responder Finite State Machine	126
7.20 Engagement Initiator Finite State Machine	129
7.21 Engagement Responder Finite State Machine	130
7.22 Request Initiator Finite State Machine	132
8.1 Pseudo-code of a Genetic Algorithm	140
8.2 GA classes hierarchy	147
8.3 Functioning of the starting method	148
8.4 Main GA cycle	150
8.5 Random generation of individuals in a population	152
8.6 Recombination in a population of individuals	153
8.7 Functioning of the simple one-point crossover operator	153
9.1 Examples of agents, containers, and platforms	159
9.2 Sniffer agent from JADE	160
9.3 Singular and Pareto-optimal meta-solutions found by AC1 (left) and AC2 (right) agents for the system Q9-VP according to different criteria	166

9.4	Partial and Pareto-optimal meta-solutions found by AC1 (left) and AC2 (right) agents for the system Q9-VP according to different criteria.	167
9.5	All singular meta-solutions found by both AC1 and AC2 agents for the system Q9-VP according to different criteria.	168
9.6	Worth of partial meta-solutions found by AC1 (left) and AC2 (right) agents for the system Q9-VP.	168
9.7	Worths of partial meta-solutions found by both AC1 and AC2 agents for the system Q9-VP.	169
9.8	User problem-related results for the system Q9-VP.	170
9.9	Variation of the solution quality when using different worth equations.	171
9.10	Quality of both the most significant singular meta-solutions and the Pareto-optimal ones with respect to the number of function evaluations.	172
9.11	Elapsed time of interaction protocols for the experiment <i>E-6&8a</i>	173
9.12	Pareto sets that are obtained when varying the weight vector.	175
9.13	Variation of the solution quality when using different weight vectors.	176
9.14	Elapsed time of interaction protocols for the experiment <i>E-8a&d</i>	176
9.15	Sets of singular meta-solutions obtained with respect to the time (left) and to the number of function evaluations (right) for two and eight neighbors.	178
9.16	Configurations that are generated when varying the number of neighbors.	179
9.17	Configurations that are generated for four (left) and eight (right) neighbors, near the optimum values.	180
9.18	Variation of the solution quality when changing the number of neighbors.	180
9.19	Elapsed time of both the ABRRHC configuration algorithm and the user problem solver when varying the number of neighbors.	181
9.20	Elapsed time in milliseconds of both the ABRRHC configuration algorithm and the user problem solver for two neighbors after five repetitions.	182
9.21	Configurations that are generated (left) and sets of singular meta-solutions (right) when varying the proportion of AC agents per parameter to fine-tune.	184
9.22	Variation of the solution quality (left) and the worth (right) when changing the proportion of AC agents per parameter to fine-tune.	185
9.23	Elapsed time of the Engagement IP when varying the proportion of AC agents per parameter to fine-tune.	186
9.24	Elapsed time in milliseconds of both the ABRRHC configuration algorithm and the user problem solver, when varying the proportion of AC agents per parameter to fine-tune.	187

9.25 Distribution of singular meta-solutions over the analysis intervals.	188
9.26 Solution qualities for varying control parameters.	189
9.27 Solution qualities in the whole interval (left) and zoomed in (right) for both control parameters.	190
9.28 Distribution of Pareto-optimal singular meta-solutions over the analysis intervals.	190
9.29 Pareto-optimal singular meta-solutions according to their qualities.	191
9.30 Pareto-optimal singular meta-solutions and the parameter values that they represent.	191
9.31 Elapsed time of the Engagement IPs.	192
9.32 Elapsed time of both the ABRRHC configuration algorithm and the user problem solver.	192

List of Tables

7.1	Lists of agents	104
7.2	States from the ABRHC algorithm and their abbreviations	119
7.3	+CARPS technical information	134
8.1	Some configuration methods and the algorithms that they configure.	137
8.2	Some disadvantages when using optimization methods.	145
8.3	GA technical information	154
9.1	Observed data for the system Q9-VP.	162
9.2	Settings for the experiment $E\text{-}q9vp$	164
9.3	GA fixed parameters for the experiment $E\text{-}q9vp$	164
9.4	Settings for the experiment $E\text{-}6\mathcal{E}8a$	171
9.5	Pareto-optimal meta-solutions from the experiment $E\text{-}6\mathcal{E}8a$	173
9.6	Settings for the experiment $E\text{-}8a\mathcal{E}d$	175
9.7	Settings for the experiment $E\text{-}1prop\mathcal{E}n$	177
9.8	Settings for the experiment $E\text{-}4n\mathcal{E}ACprop$	183
9.9	Settings for the experiment $E\text{-}60t$	188
9.10	Statistics for singular meta-solutions, experiment $E\text{-}60t$	188
9.11	Pareto-optimal singular meta-solutions from the experiment $E\text{-}60t$.	191