
Contents

1	Introduction	1
1.1	Aims of this Chapter	1
1.2	The Main Evolutionary Computing Metaphor	1
1.3	Brief History	2
1.4	The Inspiration from Biology	3
1.4.1	Darwinian Evolution	3
1.4.2	Genetics	5
1.5	Evolutionary Computing: Why?	7
1.6	Exercises	13
1.7	Recommended Reading for this Chapter	13
2	What is an Evolutionary Algorithm?	15
2.1	Aims of this Chapter	15
2.2	What is an Evolutionary Algorithm?	15
2.3	Components of Evolutionary Algorithms	18
2.3.1	Representation (Definition of Individuals)	18
2.3.2	Evaluation Function (Fitness Function)	19
2.3.3	Population	20
2.3.4	Parent Selection Mechanism	20
2.3.5	Variation Operators	21
2.3.6	Survivor Selection Mechanism (Replacement)	22
2.3.7	Initialisation	23
2.3.8	Termination Condition	23
2.4	Example Applications	24
2.4.1	The Eight-Queens Problem	24
2.4.2	The Knapsack Problem	27
2.5	Working of an Evolutionary Algorithm	29
2.6	Evolutionary Computing and Global Optimisation	32
2.7	Exercises	35
2.8	Recommended Reading for this Chapter	35

3	Genetic Algorithms	37
3.1	Aims of this Chapter	37
3.2	Introductory Example	37
3.3	Representation of Individuals	40
3.3.1	Binary Representations	40
3.3.2	Integer Representations	41
3.3.3	Real-Valued or Floating-Point Representation	41
3.3.4	Permutation Representations	41
3.4	Mutation	42
3.4.1	Mutation for Binary Representations	43
3.4.2	Mutation Operators for Integer Representations	43
3.4.3	Mutation Operators for Floating-Point Representations	44
3.4.4	Mutation Operators for Permutation Representations ..	45
3.5	Recombination	46
3.5.1	Recombination Operators for Binary Representations ..	47
3.5.2	Recombination Operators for Integer Representations ..	49
3.5.3	Recombination Operators for Floating-Point Representations	50
3.5.4	Recombination Operators for Permutation Representations	52
3.5.5	Multiparent Recombination	57
3.6	Population Models	57
3.7	Parent Selection	59
3.7.1	Fitness Proportional Selection	59
3.7.2	Ranking Selection	60
3.7.3	Implementing Selection Probabilities	61
3.7.4	Tournament Selection	63
3.8	Survivor Selection	64
3.8.1	Age-Based Replacement	65
3.8.2	Fitness-Based Replacement	65
3.9	Example Application: Solving a Job Shop Scheduling Problem	66
3.10	Exercises	68
3.11	Recommended Reading for this Chapter	69
4	Evolution Strategies	71
4.1	Aims of this Chapter	71
4.2	Introductory Example	71
4.3	Representation	73
4.4	Mutation	73
4.4.1	Uncorrelated Mutation with One Step Size	75
4.4.2	Uncorrelated Mutation with n Step Sizes	76
4.4.3	Correlated Mutations	78
4.5	Recombination	80
4.6	Parent Selection	81
4.7	Survivor Selection	81

4.8	Self-Adaptation	82
4.9	Example Applications	84
4.9.1	The Ackley Function	84
4.9.2	Subjective Evolution of Colour Mixes	85
4.10	Exercises	86
4.11	Recommended Reading for this Chapter	87
5	Evolutionary Programming	89
5.1	Aims of this Chapter	89
5.2	Introductory Example	89
5.2.1	Representation	92
5.2.2	Mutation	92
5.3	Recombination	94
5.4	Parent Selection	94
5.5	Survivor Selection	95
5.6	Example Application	95
5.6.1	The Ackley Function	95
5.6.2	Evolving Checkers Players	96
5.7	Exercises	97
5.8	Recommended Reading for this Chapter	98
6	Genetic Programming	101
6.1	Aims of this Chapter	101
6.2	Introductory Example	101
6.3	Representation	103
6.4	Mutation	106
6.5	Recombination	107
6.6	Parent Selection	109
6.7	Survivor Selection	109
6.8	Initialisation	109
6.9	Bloat in Genetic Programming	110
6.10	Problems Involving “Physical” Environments	110
6.11	Example Application: Symbolic Regression	112
6.12	Exercises	113
6.13	Recommended Reading for this Chapter	113
7	Learning Classifier Systems	115
7.1	Aims of this Chapter	115
7.2	Introductory Example	115
7.3	General Background	118
7.4	ZCS: A “Zeroth-Level” Classifier System	120
7.5	XCS	122
7.5.1	Motivation	122
7.5.2	Description	123
7.6	Extensions	124

7.7	Example Applications	126
7.7.1	Modelling Financial Market Traders	126
7.7.2	A Multistep Problem	127
7.8	Exercises	128
7.9	Recommended Reading for this Chapter	128
8	Parameter Control in Evolutionary Algorithms	129
8.1	Aims of this Chapter	129
8.2	Introduction	129
8.3	Examples of Changing Parameters	132
8.3.1	Changing the Mutation Step Size	132
8.3.2	Changing the Penalty Coefficients	134
8.3.3	Summary	136
8.4	Classification of Control Techniques	137
8.4.1	<i>What</i> is Changed?	137
8.4.2	<i>How</i> are Changes Made?	138
8.4.3	What <i>Evidence</i> Informs the Change?	139
8.4.4	What is the <i>Scope</i> of the Change?	140
8.4.5	Summary	141
8.5	Examples of Varying EA Parameters	142
8.5.1	Representation	142
8.5.2	Evaluation function	143
8.5.3	Mutation	144
8.5.4	Crossover	145
8.5.5	Selection	146
8.5.6	Population	147
8.5.7	Varying Several Parameters Simultaneously	148
8.6	Discussion	150
8.7	Exercises	150
8.8	Recommended Reading for this Chapter	151
9	Multimodal Problems and Spatial Distribution	153
9.1	Aims of this Chapter	153
9.2	Introduction: Multimodal Problems and the Need for Diversity	154
9.2.1	Multimodal Problems	154
9.2.2	Genetic Drift	155
9.2.3	Biological Motivations and Algorithmic Approaches	155
9.2.4	Algorithmic Versus Genetic Versus Solution Space	156
9.2.5	Summary	157
9.3	Implicit Measures	158
9.3.1	Multiple Populations in Tandem: Island Model EAs	158
9.3.2	Spatial Distribution Within One Population: Diffusion Model EAs	160
9.3.3	Automatic Speciation Using Mating Restrictions	161
9.4	Explicit Diversity Maintenance	162

9.4.1	Fitness Sharing	163
9.4.2	Crowding.....	164
9.5	Multiobjective Evolutionary Algorithms	164
9.5.1	Multiobjective Optimisation Problems	164
9.5.2	Dominance and Pareto Optimality	166
9.5.3	EA Approaches to Multiobjective Optimisation	167
9.6	Example Application: Distributed Coevolution of Job Shop Schedules.....	170
9.7	Exercises	171
9.8	Recommended Reading for this Chapter	172
10	Hybridisation with Other Techniques: Memetic Algorithms	173
10.1	Aims of this Chapter.....	173
10.2	Motivation for Hybridising EAs	173
10.3	A Brief Introduction to Local Search.....	175
10.3.1	Lamarckianism and the Baldwin Effect.....	177
10.4	Structure of a Memetic Algorithm	178
10.4.1	Heuristic or Intelligent Initialisation	178
10.4.2	Hybridisation Within Variation Operators: Intelligent Crossover and Mutation	180
10.4.3	Local Search Acting on the Output from Variation Operators	181
10.4.4	Hybridisation During Genotype to Phenotype Mapping	182
10.5	Design Issues for Memetic Algorithms	183
10.5.1	Preservation of Diversity	183
10.5.2	Choice of Operators	184
10.5.3	Use of Knowledge	185
10.6	Example Application: Multistage Memetic Timetabling.....	185
10.7	Exercises	187
10.8	Recommended Reading for this Chapter	188
11	Theory	189
11.1	Aims of this Chapter.....	189
11.2	Competing Hyperplanes in Binary Spaces: the Schema Theorem	190
11.2.1	What is a Schema?	190
11.2.2	Holland's Formulation for the SGA	190
11.2.3	Schema-Based Analysis of Variation Operators	192
11.2.4	Walsh Analysis and Deception	192
11.2.5	Criticisms and Recent Extensions of the Schema Theorem	194
11.2.6	Gene Linkage: Identifying and Recombining Building Blocks	195
11.3	Dynamical Systems	196
11.4	Markov Chain Analysis	197
11.5	Statistical Mechanics Approaches	199

11.6	Reductionist Approaches	200
11.7	Analysing EAs in Continuous Search Spaces	201
11.8	No Free Lunch Theorems	201
11.9	Exercises	202
11.10	Recommended Reading for this Chapter	203
12	Constraint Handling	205
12.1	Aims of this Chapter	205
12.2	Constrained Problems	205
12.2.1	Free Optimisation Problems	207
12.2.2	Constraint Satisfaction Problems	207
12.2.3	Constrained Optimisation Problems	208
12.3	Two Main Types of Constraint Handling	209
12.4	Ways to Handle Constraints in EAs	210
12.4.1	Penalty Functions	212
12.4.2	Repair Functions	214
12.4.3	Restricting Search to the Feasible Region	215
12.4.4	Decoder Functions	216
12.5	Application Example: Graph Three-Colouring	217
12.5.1	Indirect Approach	217
12.5.2	Mixed Mapping – Direct Approach	218
12.6	Exercises	219
12.7	Recommended Reading for this Chapter	219
13	Special Forms of Evolution	221
13.1	Aims of this Chapter	221
13.2	Coevolution	221
13.2.1	Cooperative coevolution	222
13.2.2	Competitive coevolution	224
13.2.3	Example Application: Coevolutionary Constraint Satisfaction	226
13.3	Interactive Evolution	226
13.3.1	Optimisation, Design, Exploration	228
13.3.2	Interactive Evolutionary Design and Art	228
13.3.3	Example Application: The Mondriaan Evolver	229
13.4	Nonstationary Function Optimisation	232
13.4.1	Algorithmic Approaches	233
13.4.2	Selection and Replacement Policies	235
13.4.3	Example Application: Time-Varying Knapsack Problem	238
13.5	Exercises	239
13.6	Recommended Reading for this Chapter	240

14 Working with Evolutionary Algorithms	241
14.1 Aims of this Chapter	241
14.2 What Do You Want an EA to Do?	241
14.3 Performance Measures	244
14.3.1 Different Performance Measures	245
14.3.2 Peak versus Average Performance	250
14.4 Test Problems for Experimental Comparisons	252
14.4.1 Using Predefined Problem Instances	253
14.4.2 Using Problem Instance Generators	254
14.4.3 Using Real-World Problems	256
14.5 Example Applications	256
14.5.1 Bad Practice	256
14.5.2 Better Practice	257
14.6 Exercises	258
14.7 Recommended Reading for this Chapter	258
15 Summary	259
15.1 What Is in This Book?	259
15.2 What Is Not in This Book?	263
A Gray Coding	265
B Test Functions	267
B.1 Unimodal Functions	267
B.1.1 OneMax	267
B.1.2 The Sphere Model	267
B.1.3 Royal Road Function	268
B.2 Multimodal Functions	268
B.2.1 Ackley Function	268
B.2.2 Schwefel's function	268
B.2.3 Generalized Rastrigin's function	268
B.2.4 Deb's Deceptive 4-Bit Function	269
B.3 Randomised Test Function Generators	269
B.3.1 Kauffman's NK Landscapes	269
B.3.2 NKC Landscapes	271
B.3.3 Random L-SAT	271
References	273
Index	295