
Contents

Part I The Basics

1	Problems to Be Solved	1
1.1	Optimisation, Modelling, and Simulation Problems	1
1.1.1	Optimisation	2
1.1.2	Modelling	3
1.1.3	Simulation	5
1.2	Search Problems	5
1.3	Optimisation Versus Constraint Satisfaction	6
1.4	The Famous NP Problems	9
2	Evolutionary Computing: The Origins	13
2.1	The Main Evolutionary Computing Metaphor	13
2.2	Brief History	14
2.3	The Inspiration from Biology	15
2.3.1	Darwinian Evolution	15
2.3.2	Genetics	17
2.3.3	Putting It Together	19
2.4	Evolutionary Computing: Why?	20
3	What Is an Evolutionary Algorithm?	25
3.1	What Is an Evolutionary Algorithm?	25
3.2	Components of Evolutionary Algorithms	28
3.2.1	Representation (Definition of Individuals)	28
3.2.2	Evaluation Function (Fitness Function)	30
3.2.3	Population	30
3.2.4	Parent Selection Mechanism	31
3.2.5	Variation Operators (Mutation and Recombination)	31
3.2.6	Survivor Selection Mechanism (Replacement)	33
3.2.7	Initialisation	34
3.2.8	Termination Condition	34

3.3	An Evolutionary Cycle by Hand	34
3.4	Example Applications	36
3.4.1	The Eight-Queens Problem	36
3.4.2	The Knapsack Problem	39
3.5	The Operation of an Evolutionary Algorithm	41
3.6	Natural Versus Artificial Evolution	44
3.7	Evolutionary Computing, Global Optimisation, and Other Search Algorithms	46
4	Representation, Mutation, and Recombination	49
4.1	Representation and the Roles of Variation Operators	49
4.2	Binary Representation	51
4.2.1	Mutation for Binary Representation	52
4.2.2	Recombination for Binary Representation	52
4.3	Integer Representation	54
4.3.1	Mutation for Integer Representations	55
4.3.2	Recombination for Integer Representation	56
4.4	Real-Valued or Floating-Point Representation	56
4.4.1	Mutation for Real-Valued Representation	56
4.4.2	Self-adaptive Mutation for Real-Valued Representation ..	57
4.4.3	Recombination Operators for Real-Valued Representation	65
4.5	Permutation Representation	67
4.5.1	Mutation for Permutation Representation	69
4.5.2	Recombination for Permutation Representation	70
4.6	Tree Representation	75
4.6.1	Mutation for Tree Representation	77
4.6.2	Recombination for Tree Representation	78
5	Fitness, Selection, and Population Management	79
5.1	Population Management Models	79
5.2	Parent Selection	80
5.2.1	Fitness Proportional Selection	80
5.2.2	Ranking Selection	81
5.2.3	Implementing Selection Probabilities	83
5.2.4	Tournament Selection	84
5.2.5	Uniform Parent Selection	86
5.2.6	Overselection for Large Populations	86
5.3	Survivor Selection	87
5.3.1	Age-Based Replacement	88
5.3.2	Fitness-Based Replacement	88
5.4	Selection Pressure	90
5.5	Multimodal Problems, Selection, and the Need for Diversity ..	91
5.5.1	Multimodal Problems	91

5.5.2	Characterising Selection and Population Management Approaches for Preserving Diversity	92
5.5.3	Fitness Sharing	92
5.5.4	Crowding.....	93
5.5.5	Automatic Speciation Using Mating Restrictions	95
5.5.6	Running Multiple Populations in Tandem: Island Model EAs	95
5.5.7	Spatial Distribution Within One Population: Cellular EAs	97
6	Popular Evolutionary Algorithm Variants	99
6.1	Genetic Algorithms	99
6.2	Evolution Strategies	101
6.3	Evolutionary Programming	103
6.4	Genetic Programming.....	104
6.5	Learning Classifier Systems	107
6.6	Differential Evolution	110
6.7	Particle Swarm Optimisation.....	112
6.8	Estimation of Distribution Algorithms	113
<hr/>		
Part II Methodological Issues		
<hr/>		
7	Parameters and Parameter Tuning	119
7.1	Evolutionary Algorithm Parameters.....	119
7.2	EAs and EA Instances	120
7.3	Designing Evolutionary Algorithms	121
7.4	The Tuning Problem	123
7.5	Algorithm Quality: Performance and Robustness	125
7.6	Tuning Methods.....	128
8	Parameter Control.....	131
8.1	Introduction	131
8.2	Examples of Changing Parameters.....	132
8.2.1	Changing the Mutation Step Size.....	133
8.2.2	Changing the Penalty Coefficients	134
8.3	Classification of Control Techniques.....	136
8.3.1	<i>What Is Changed?</i>	136
8.3.2	<i>How Are Changes Made?</i>	136
8.3.3	<i>What Evidence Informs the Change?</i>	138
8.3.4	<i>What Is the Scope of the Change?</i>	138
8.3.5	Summary.....	139
8.4	Examples of Varying EA Parameters.....	139
8.4.1	Representation	139
8.4.2	Evaluation Function	140

8.4.3	Mutation	141
8.4.4	Crossover	141
8.4.5	Selection	142
8.4.6	Population	142
8.4.7	Varying Several Parameters Simultaneously	143
8.5	Discussion	144
9	Working with Evolutionary Algorithms	147
9.1	What Do You Want an EA to Do?	147
9.2	Performance Measures	150
9.2.1	Different Performance Measures	151
9.2.2	Peak Versus Average Performance	155
9.3	Test Problems for Experimental Comparisons	158
9.3.1	Using Predefined Problem Instances	158
9.3.2	Using Problem Instance Generators	160
9.3.3	Using Real-World Problems	160
9.4	Example Applications	161
9.4.1	Bad Practice	161
9.4.2	Better Practice	162
<hr/>		
Part III Advanced Topics		
<hr/>		
10	Hybridisation with Other Techniques: Memetic Algorithms	167
10.1	Motivation for Hybridising EAs	167
10.2	A Brief Introduction to Local Search	170
10.2.1	Lamarckianism and the Baldwin Effect	171
10.3	Structure of a Memetic Algorithm	172
10.3.1	Heuristic or Intelligent Initialisation	172
10.3.2	Hybridisation Within Variation Operators: Intelligent Crossover and Mutation	174
10.3.3	Local Search Acting on the Output from Variation Operators	175
10.3.4	Hybridisation During Genotype to Phenotype Mapping	176
10.4	Adaptive Memetic Algorithms	177
10.5	Design Issues for Memetic Algorithms	179
10.6	Example Application: Multistage Memetic Timetabling	181
11	Nonstationary and Noisy Function Optimisation	185
11.1	Characterisation of Nonstationary Problems	185
11.2	The Effect of Different Sources of Uncertainty	187
11.3	Algorithmic Approaches	189
11.3.1	Approaches That Increase Robustness or Reduce Noise	189
11.3.2	Pure Evolutionary Approaches to Dynamic Environments	189

11.3.3	Memory-Based Approaches for Switching or Cyclic Environments	190
11.3.4	Explicitly Increasing Diversity in Dynamic Environments	190
11.3.5	Preserving Diversity and Resampling: Modifying Selection and Replacement Policies	191
11.3.6	Example Application: Time-Varying Knapsack Problem	193
12	Multiobjective Evolutionary Algorithms	195
12.1	Multiobjective Optimisation Problems	195
12.2	Dominance and Pareto Optimality	196
12.3	EA Approaches to Multiobjective Optimisation	198
12.3.1	Nonelitist Approaches	198
12.3.2	Elitist Approaches	199
12.3.3	Diversity Maintenance in MOEAs	199
12.3.4	Decomposition-Based Approaches	200
12.4	Example Application: Distributed Coevolution of Job Shop Schedules	200
13	Constraint Handling	203
13.1	Two Main Types of Constraint Handling	203
13.2	Approaches to Handling Constraints	204
13.2.1	Penalty Functions	206
13.2.2	Repair Functions	208
13.2.3	Restricting Search to the Feasible Region	209
13.2.4	Decoder Functions	210
13.3	Example Application: Graph Three-Colouring	211
14	Interactive Evolutionary Algorithms	215
14.1	Characteristics of Interactive Evolution	215
14.1.1	The Effect of Time	216
14.1.2	The Effect of Context: What Has Gone Before	216
14.1.3	Advantages of IEAs	217
14.2	Algorithmic Approaches to the Challenges of IEAs	217
14.2.1	Interactive Selection and Population Size	217
14.2.2	Interaction in the Variation Process	218
14.2.3	Methods for Reducing the Frequency of User Interactions	218
14.3	Interactive Evolution as Design vs. Optimisation	219
14.4	Example Application: Automatic Elicitation of User Preferences	220
15	Coevolutionary Systems	223
15.1	Coevolution in Nature	223
15.2	Cooperative Coevolution	224
15.2.1	Partnering Strategies	225
15.3	Competitive Coevolution	226

15.4	Summary of Algorithmic Adaptations for Context-Dependent Evaluation	227
15.5	Example Application: Coevolving Checkers Players	228
16	Theory	231
16.1	Competing Hyperplanes in Binary Spaces: The Schema Theorem	232
16.2	Criticisms and Recent Extensions of the Schema Theorem ...	236
16.3	Gene Linkage: Identifying and Recombining Building Blocks ..	237
16.4	Dynamical Systems	238
16.5	Markov Chain Analysis	239
16.6	Statistical Mechanics Approaches	241
16.7	Reductionist Approaches	241
16.8	Black Box Analysis	242
16.9	Analysing EAs in Continuous Search Spaces	243
16.10	No Free Lunch Theorem	243
17	Evolutionary Robotics	245
17.1	What Is It All About?	245
17.2	Introductory Example	246
17.3	Offline and Online Evolution of Robots	248
17.4	Evolutionary Robotics: The Problems Are Different	250
17.5	Evolutionary Robotics: The Algorithms Are Different	253
17.6	A Glimpse into the Future	256
	References	259
	Index	283