

Table of Contents

Preface	VII
Table of Contents	XIII
1 The Motivation for Differential Evolution	1
1.1 Introduction to Parameter Optimization	1
1.1.1 Overview	1
1.1.2 Single-Point, Derivative-Based Optimization	6
1.1.3 One-Point, Derivative-Free Optimization and the Step Size Problem	11
1.2 Local Versus Global Optimization	16
1.2.1 Simulated Annealing	18
1.2.2 Multi-Point, Derivative-Based Methods.....	19
1.2.3 Multi-Point, Derivative-Free Methods	20
1.2.4 Differential Evolution – A First Impression.....	30
References	34
2 The Differential Evolution Algorithm.....	37
2.1 Overview	37
2.1.1 Population Structure	37
2.1.2 Initialization.....	38
2.1.3 Mutation	38
2.1.4 Crossover.....	39
2.1.5 Selection	40
2.1.6 DE at a Glance.....	41
2.1.7 Visualizing DE	43
2.1.8 Notation	47
2.2 Parameter Representation	48
2.2.1 Bit Strings.....	48
2.2.2 Floating-Point.....	50
2.2.3 Floating-Point Constraints.....	52
2.3 Initialization.....	53
2.3.1 Initial Bounds	53

2.3.2 Initial Distributions.....	56
2.4 Base Vector Selection.....	61
2.4.1 Choosing the Base Vector Index, $r0$	61
2.4.2 One-to-One Base Vector Selection.....	63
2.4.3 A Comparison of Random Base Index Selection Methods	64
2.4.4 Degenerate Vector Combinations.....	65
2.4.5 Implementing Mutually Exclusive Indices.....	68
2.4.6 Gauging the Effects of Degenerate Combinations: The Sphere.....	70
2.4.7 Biased Base Vector Selection Schemes.....	72
2.5 Differential Mutation.....	74
2.5.1 The Mutation Scale Factor: F	75
2.5.2 Randomizing the Scale Factor	79
2.6 Recombination.....	91
2.6.1 Crossover.....	92
2.6.2 The Role of Cr in Optimization.....	97
2.6.3 Arithmetic Recombination	104
2.6.4 Phase Portraits	112
2.6.5 The Either/Or Algorithm	117
2.7 Selection	118
2.7.1 Survival Criteria	119
2.7.2 Tournament Selection.....	121
2.7.3 One-to-One Survivor Selection	122
2.7.4 Local Versus Global Selection	124
2.7.5 Permutation Selection Invariance.....	124
2.7.6 Crossover-Dependent Selection Pressure	125
2.7.7 Parallel Performance	127
2.7.8 Extensions.....	128
2.8 Termination Criteria	128
2.8.1 Objective Met	129
2.8.2 Limit the Number of Generations.....	129
2.8.3 Population Statistics	129
2.8.4 Limited Time	130
2.8.5 Human Monitoring	130
2.8.6 Application Specific	130
References	131
3 Benchmarking Differential Evolution.....	135
3.1 About Testing	135
3.2 Performance Measures	137
3.3 DE Versus DE	139
3.3.1 The Algorithms.....	139

3.3.2 The Test Bed.....	142
3.3.3 Phase Portraits	142
3.3.4 Summary.....	154
3.4 DE Versus Other Optimizers	156
3.4.1 Comparative Performance: Thirty-Dimensional Functions...	157
3.4.2 Comparative Studies: Unconstrained Optimization	167
3.4.3 Performance Comparisons from Other Problem Domains	171
3.4.4 Application-Based Performance Comparisons.....	175
3.5 Summary.....	182
References	182
4 Problem Domains.....	189
4.1 Overview	189
4.2 Function and Parameter Quantization	189
4.2.1 Uniform Quantization.....	190
4.2.2 Non-Uniform Quantization.....	191
4.2.3 Objective Function Quantization.....	192
4.2.4 Parameter Quantization	195
4.2.5 Mixed Variables	201
4.3 Optimization with Constraints.....	201
4.3.1 Boundary Constraints	202
4.3.2 Inequality Constraints.....	206
4.3.3 Equality Constraints	220
4.4 Combinatorial Problems	227
4.4.1 The Traveling Salesman Problem.....	229
4.4.2 The Permutation Matrix Approach.....	230
4.4.3 Relative Position Indexing.....	231
4.4.4 Onwubolu's Approach.....	233
4.4.5 Adjacency Matrix Approach	233
4.4.6 Summary.....	237
4.5 Design Centering	239
4.5.1 Divergence, Self-Steering and Pooling.....	239
4.5.2 Computing a Design Center	242
4.6 Multi-Objective Optimization	244
4.6.1 Weighted Sum of Objective Functions.....	244
4.6.2 Pareto Optimality.....	246
4.6.3 The Pareto-Front: Two Examples.....	247
4.6.4 Adapting DE for Multi-Objective Optimization.....	250
4.7 Dynamic Objective Functions	255
4.7.1 Stationary Optima.....	256
4.7.2 Non-Stationary Optima.....	259
References	262

5 Architectural Aspects and Computing Environments	267
5.1 DE on Parallel Processors.....	267
5.1.1 Background.....	267
5.1.2 Related Work.....	267
5.1.3 Drawbacks of the Standard Model	271
5.1.4 Modifying the Standard Model.....	272
5.1.5 The Master Process.....	273
5.2 DE on Limited Resource Devices.....	276
5.2.1 Random Numbers	276
5.2.2 Permutation Generators	279
5.2.3 Efficient Sorting	282
5.2.4 Memory-Saving DE Variants	282
References	284
6 Computer Code.....	287
6.1 DeMat – Differential Evolution for MATLAB®	287
6.1.1 General Structure of DeMat	287
6.1.2 Naming and Coding Conventions.....	288
6.1.3 Data Flow Diagram	291
6.1.4 How to Use the Graphics.....	293
6.2 DeWin – DE for MS Windows®: An Application in C	295
6.2.1 General Structure of DeWin	296
6.2.2 Naming and Coding Conventions.....	300
6.2.3 Data Flow Diagram	300
6.2.4 How To Use the Graphics	304
6.2.5 Functions of graphics.h	305
6.3 Software on the Accompanying CD	307
References	309
7 Applications.....	311
7.1 Genetic Algorithms and Related Techniques for Optimizing Si–H Clusters: A Merit Analysis for Differential Evolution.....	313
7.1.1 Introduction	313
7.1.2 The System Model.....	315
7.1.3 Computational Details	317
7.1.4 Results and Discussion	318
7.1.5 Concluding Remarks	325
References	325
7.2 Non-Imaging Optical Design Using Differential Evolution.....	327
7.2.1 Introduction	327
7.2.2 Objective Function	328
7.2.3 A Reverse Engineering Approach to Testing	331

7.2.4 A More Difficult Problem: An Extended Source	334
7.2.5 Conclusion	337
References	337
7.3 Optimization of an Industrial Compressor Supply System	339
7.3.1 Introduction	339
7.3.2 Background Information on the Test Problem	340
7.3.3 System Optimization	340
7.3.4 Demand Profiles	341
7.3.5 Modified Differential Evolution; Extending the Generality of DE	342
7.3.6 Component Selection from the Database	343
7.3.7 Crossover Approaches	343
7.3.8 Testing Procedures	348
7.3.9 Obtaining 100% Certainty of the Results	348
7.3.10 Results	349
7.3.11 Summary	350
References	351
7.4 Minimal Representation Multi-Sensor Fusion Using Differential Evolution	353
7.4.1 Introduction	353
7.4.2 Minimal Representation Multi-Sensor Fusion	357
7.4.3 Differential Evolution for Multi-Sensor Fusion	361
7.4.4 Experimental Results	364
7.4.5 Comparison with a Binary Genetic Algorithm	372
7.4.6 Conclusion	374
References	375
7.5 Determination of the Earthquake Hypocenter: A Challenge for the Differential Evolution Algorithm	379
7.5.1 Introduction	379
7.5.2 Brief Outline of Direct Problem Solution	382
7.5.3 Synthetic Location Test	384
7.5.4 Convergence Properties	385
7.5.5 Conclusions	389
References	389
7.6 Parallel Differential Evolution: Application to 3-D Medical Image Registration	393
7.6.1 Introduction	393
7.6.2 Medical Image Registration Using Similarity Measures	395
7.6.3 Optimization by Differential Evolution	398
7.6.4 Parallelization of Differential Evolution	401
7.6.5 Experimental Results	404
7.6.6 Conclusions	408

Acknowledgments	408
References	408
7.7 Design of Efficient Erasure Codes with Differential Evolution ...	413
7.7.1 Introduction	413
7.7.2 Codes from Bipartite Graphs	414
7.7.3 Code Design	418
7.7.4 Differential Evolution	421
7.7.5 Results	423
Acknowledgments	426
References	426
7.8 FIWIZ – A Versatile Program for the Design of Digital Filters Using Differential Evolution	429
7.8.1 Introduction	429
7.8.2 Unconventional Design Tasks	432
7.8.3 Approach	435
7.8.4 Examples	444
7.8.5 Conclusion	445
References	445
7.9 Optimization of Radial Active Magnetic Bearings by Using Differential Evolution and the Finite Element Method	447
7.9.1 Introduction	447
7.9.2 Radial Active Magnetic Bearings	448
7.9.3 Magnetic Field Distribution and Force Computed by the Two-Dimensional FEM	454
7.9.4 RAMB Design Optimized by DE and the FEM	455
7.9.5 Conclusion	461
Acknowledgments	461
References	462
7.10 Application of Differential Evolution to the Analysis of X-Ray Reflectivity Data	463
7.10.1 Introduction	463
7.10.2 The Data-Fitting Procedure	466
7.10.3 The Model and Simulation	469
7.10.4 Examples	471
7.10.5 Conclusions	477
References	477
7.11 Inverse Fractal Problem	479
7.11.1 General Introduction	479
7.11.2 Conclusion	495
References	497
7.12 Active Compensation in RF-Driven Plasmas by Means of Differential Evolution	499

7.12.1 Introduction	499
7.12.2 RF-Driven Plasmas.....	500
7.12.3 Langmuir Probes.....	501
7.12.4 Active Compensation in RF-Driven Plasmas	501
7.12.5 Automated Control System Structure and Fitness Function.....	502
7.12.6 Experimental Setup.....	504
7.12.7 Parameters and Experimental Design	505
7.12.8 Results	509
7.12.9 Conclusion	509
Acknowledgments	510
References	510
Appendix.....	513
A.1 Unconstrained Uni-Modal Test Functions.....	514
A.1.1 Sphere	514
A.1.2 Hyper-Ellipsoid.....	515
A.1.3 Generalized Rosenbrock.....	515
A.1.4 Schwefel's Ridge.....	516
A.1.5 Neumaier #3	517
A.2 Unconstrained Multi-Modal Test Functions.....	518
A.2.1 Ackley.....	518
A.2.2 Griewangk	519
A.2.3 Rastrigin.....	520
A.2.4 Salomon	521
A.2.5 Whitley	522
A.2.6 Storn's Chebyshev	523
A.2.7 Lennard-Jones.....	525
A.2.8 Hilbert.....	526
A.2.9 Modified Langerman	526
A.2.10 Shekel's Foxholes.....	528
A.2.11 Odd Square	529
A.2.12 Katsuura.....	530
A.3 Bound-Constrained Test Functions	531
A.3.1 Schwefel	531
A.3.2 Epistatic Michalewicz.....	531
A.3.3 Rana	532
References	533
Index.....	535