
Contents

<i>Preface to the Third Edition</i>	<i>page</i> xiii
<i>Notation</i>	xvii
1 Optimization Models	1
1.1 Mathematical Modeling	1
The System Concept • Hierarchical Levels • Mathematical Models • Elements of Models • Analysis and Design Models • Decision Making	
1.2 Design Optimization	10
The Optimal Design Concept • Formal Optimization Models • Multicriteria Models • Nature of Model Functions • The Question of Design Configuration • Systems and Components • System Partitioning	
1.3 Feasibility and Boundedness	24
Feasible Domain • Boundedness • Activity	
1.4 Topography of the Design Space	31
Interior and Boundary Optima • Local and Global Optima • Constraint Interaction	
1.5 Modeling and Computation	39
1.6 Design Projects	40
1.7 Summary	41
Notes Exercises	
2 Model Construction	46
2.1 Modeling Data	46
Graphical and Tabular Data • Families of Curves • Numerically Generated Data	
2.2 Best-Fit Curves and Least Squares	51

viii	Contents	
2.3	Neural Networks	53
2.4	Kriging	57
2.5	Modeling a Drive Screw Linear Actuator Assembling the Model Functions • Model Assumptions • Model Parameters • Negative Null Form	60
2.6	Modeling an Internal Combustion Engine Flat Head Chamber Design • Compound Valve Head Chamber Design	66
2.7	Design of a Geartrain Model Development • Model Summary • Model Reduction	75
2.8	Modeling Considerations Prior to Computation Natural and Practical Constraints • Asymptotic Substitution • Feasible Domain Reduction	83
2.9	Summary Notes Exercises	87
3	Model Boundedness	91
3.1	Bounds, Extrema, and Optima Well-Bounded Functions • Nonminimizing Lower Bound • Multivariable Extension • Air Tank Design	92
3.2	Constrained Optimum Partial Minimization • Constraint Activity • Cases	97
3.3	Underconstrained Models Monotonicity • First Monotonicity Principle • Criticality • Optimizing a Variable Out • Adding Constraints	103
3.4	Recognizing Monotonicity Simple and Composite Functions • Integrals	108
3.5	Inequalities Conditional Criticality • Multiple Criticality • Dominance • Relaxation • Uncriticality	110
3.6	Equality Constraints Equality and Activity • Replacing Monotonic Equalities by Inequalities • Directing an Equality • Regional Monotonicity of Nonmonotonic Constraints	114
3.7	Variables Not in the Objective Hydraulic Cylinder Design • Second Monotonicity Principle	118
3.8	Nonmonotonic Functions	121
3.9	Parametric Solution Particular Optimum and Parametric Procedures • Branching • Graphical Interpretation • Parametric Tests	124
3.10	Monotonicity Table and Model Reduction Model Reduction • Monotonicity Table • Setting Up	132

Contents

ix

	• First New Table: Reduction • Second New Table: Two Directions and Reductions • Third New Table: Final Reduction	
3.11	Functional Monotonicity Analysis Explicit Algebraic Elimination • Implicit Numerical Solution	136
3.12	Discrete Variables	140
3.13	Discrete Design Activity and Optimality Constraint Activity Extended • Discrete Local Optima	142
3.14	Model Preparation Procedure	150
3.15	Summary Notes Exercises	152
4	Interior Optima	162
4.1	Existence The Weierstrass Theorem • Sufficiency	163
4.2	Local Approximation Taylor Series • Quadratic Functions • Vector Functions	165
4.3	Optimality First-Order Necessity • Second-Order Sufficiency • Nature of Stationary Points	171
4.4	Convexity Convex Sets and Functions • Differentiable Functions	177
4.5	Local Exploration Gradient Descent • Newton's Method	183
4.6	Searching Along a Line Gradient Method • Modified Newton's Method	188
4.7	Stabilization Modified Cholesky Factorization	191
4.8	Trust Regions Moving with Trust • Trust Region Algorithms	194
4.9	Summary Notes Exercises	197
5	Boundary Optima	202
5.1	Feasible Directions	202
5.2	Describing the Constraint Surface Regularity • Tangent and Normal Hyperplanes	205
5.3	Equality Constraints Reduced (Constrained) Gradient • Lagrange Multipliers	209
5.4	Curvature at the Boundary Constrained Hessian • Second-Order Sufficiency • Bordered Hessians	214
5.5	Feasible Iterations Generalized Reduced Gradient Method • Gradient Projection Method	220

x	Contents	
5.6	Inequality Constraints	228
	Karush–Kuhn–Tucker Conditions • Lagrangian Standard Forms	
5.7	Geometry of Boundary Optima	232
	Interpretation of KKT Conditions • Interpretation of Sufficiency Conditions	
5.8	Linear Programming	236
	Optimality Conditions • Basic LP Algorithm	
5.9	Sensitivity	249
	Sensitivity Coefficients	
5.10	Summary	251
	Notes Exercises	
	6 Local Computation	258
6.1	Numerical Algorithms	259
	Local and Global Convergence • Termination Criteria	
6.2	Single-Variable Minimization	266
	Bracketing, Sectioning, and Interpolation • The Davies, Swann, and Campey Method • Inexact Line Search	
6.3	Quasi-Newton Methods	276
	Hessian Matrix Updates • DFP and BFGS Formulas	
6.4	Active Set Strategies	280
	Adding and Deleting Constraints • Lagrange Multiplier Estimates	
6.5	Moving Along the Boundary	285
6.6	Penalties and Barriers	287
	Barrier Functions • Penalty Functions • Augmented Lagrangian (Multiplier) Methods	
6.7	Sequential Quadratic Programming	294
	The Lagrange–Newton Equations • Enhancements of the Basic Algorithm • Solving the Quadratic Subproblem	
6.8	Trust Regions with Constraints	301
	Relaxing Constraints • Using Exact Penalty Functions • Modifying the Trust Region and Accepting Steps • Yuan’s Trust Region Algorithm	
6.9	Convex Approximation Algorithms	305
	Convex Linearization • Moving Asymptotes • Choosing Moving Asymptotes and Move Limits	
6.10	Summary	310
	Notes Exercises	
	7 Nongradient Search	318
7.1	Direct Search	319
	Coordinate Search • Extensions to Coordinate Search • Generalized Pattern Search • Nelder–Mead Algorithm	

Contents	xi
7.2 Heuristic Methods	326
Simulated Annealing • Genetic Algorithm • Multiobjective Genetic Algorithm (MOGA) • Particle Swarm Optimization • Extensions to Basic PSO	
7.3 Black-Box Methods	338
Dividing Rectangles (DIRECT) • Extensions to DIRECT • Efficient Global Optimization	
7.4 Summary	348
Notes Exercises	
8 Systems Design	355
8.1 Decomposition-Based Design Optimization	356
8.2 Representation of System Interactions	357
Functional Representation • Structure Matrix • Design Structure Matrix • Functional Dependence Table	
8.3 Optimal System Design Properties	363
Coupling, Shared, Linking, and Local Variables • System Consistency • System Optimality • Distributed Optimization	
8.4 Partitioning Methods	365
Hierarchical and Nonhierarchical Partitioning • Partitioning Synthesis with Linking Variables • Partitioning Synthesis with Linking Functions	
8.5 Coordination Strategies	374
Multidisciplinary Feasible • Individual Disciplinary Feasible	
8.6 Airflow Sensor Design	376
Problem Setup • MDF and IDF Solutions	
8.7 Turbine Blade Design	381
Problem Setup • Structural Analysis • Thermal Analysis • Surrogate Models • System Analysis • MDF and IDF Solutions	
8.8 Analytical Target Cascading	387
Target Cascading in Product Development • Mathematical Formulation • Numerical Solution • Augmented Lagrangian Penalty Function	
8.9 Nonhierarchical ATC	398
8.10 Heavy-Duty Truck Suspension Design	400
Problem Formulation • Solution Results	
8.11 Optimal Design and Control	405
Coupling • Measures of Coupling • Solution Strategies	
8.12 Summary	415
Notes Exercises	
9 Principles and Practice	421
9.1 Preparing Models for Numerical Computation	422

xii **Contents**

	Modeling the Constraint Set • Modeling the Functions • Modeling the Objective	
9.2	Computing Derivatives Finite Differences • Automatic Differentiation	426
9.3	Scaling	433
9.4	Interpreting Numerical Results Code Output Data • Degeneracy	437
9.5	Global Optimization	438
9.6	Selecting Algorithms and Software Partial List of Software Packages • Partial List of Internet Sites	439
9.7	Optimization Checklist Problem Identification • Initial Problem Statement • Analysis Models • Optimal Design Model • Model Transformation • Local Iterative Techniques • Global Verification • Final Review	444
9.8	Concepts and Principles Model Building • Model Analysis • Local Searching • Global Searching • System Design	449
9.9	Summary	454
	Notes	
	<i>References</i>	456
	<i>Index</i>	477