
Table of Contents

Preface	3
I An introduction to the techniques	11
1 An introduction to approximation algorithms	13
1.1 The whats and whys of approximation algorithms	13
1.2 An introduction to the techniques and to linear programming: the set cover problem	16
1.3 A deterministic rounding algorithm	19
1.4 Rounding a dual solution	20
1.5 Constructing a dual solution: the primal-dual method	23
1.6 A greedy algorithm	24
1.7 A randomized rounding algorithm	28
2 Greedy algorithms and local search	35
2.1 Scheduling jobs with deadlines on a single machine	36
2.2 The k -center problem	37
2.3 Scheduling jobs on identical parallel machines	39
2.4 The traveling salesman problem	43
2.5 Maximizing float in bank accounts	47
2.6 Finding minimum-degree spanning trees	49
2.7 Edge coloring	54
3 Rounding data and dynamic programming	65
3.1 The knapsack problem	65
3.2 Scheduling jobs on identical parallel machines	68
3.3 The bin-packing problem	73
4 Deterministic rounding of linear programs	81
4.1 Minimizing the sum of completion times on a single machine	82
4.2 Minimizing the weighted sum of completion times on a single machine	84

4.3	Solving large linear programs in polynomial time via the ellipsoid method	86
4.4	The prize-collecting Steiner tree problem	88
4.5	The uncapacitated facility location problem	91
4.6	The bin-packing problem	95
5	Random sampling and randomized rounding of linear programs	105
5.1	Simple algorithms for MAX SAT and MAX CUT	106
5.2	Derandomization	108
5.3	Flipping biased coins	110
5.4	Randomized rounding	111
5.5	Choosing the better of two solutions	114
5.6	Non-linear randomized rounding	116
5.7	The prize-collecting Steiner tree problem	118
5.8	The uncapacitated facility location problem	120
5.9	Scheduling a single machine with release dates	124
5.10	Chernoff bounds	128
5.11	Integer multicommodity flows	132
5.12	Random sampling and coloring dense 3-colorable graphs	133
6	Randomized rounding of semidefinite programs	141
6.1	A brief introduction to semidefinite programming	141
6.2	Finding large cuts	143
6.3	Approximating quadratic programs	147
6.4	Finding a correlation clustering	150
6.5	Coloring 3-colorable graphs	153
7	The primal-dual method	161
7.1	The set cover problem: a review	161
7.2	Choosing variables to increase: the feedback vertex set problem in undirected graphs	164
7.3	Cleaning up the primal solution: the shortest s - t path problem	168
7.4	Increasing multiple variables at once: the generalized Steiner tree problem	170
7.5	Strengthening inequalities: the minimum knapsack problem	178
7.6	The uncapacitated facility location problem	180
7.7	Lagrangian relaxation and the k -median problem	184
8	Cuts and metrics	195
8.1	The multiway cut problem and a minimum-cut based algorithm	196
8.2	The multiway cut problem and an LP rounding algorithm	197
8.3	The multicut problem	203
8.4	Balanced cuts	208
8.5	Probabilistic approximation of metrics by tree metrics	211
8.6	An application of tree metrics: Buy-at-bulk network design	216
8.7	Spreading metrics, tree metrics, and linear arrangement	220

II	Further uses of the techniques	231
9	Further uses of greedy and local search algorithms	233
9.1	A local search algorithm for the uncapacitated facility location problem	234
9.2	A local search algorithm for the k -median problem	239
9.3	Minimum-degree spanning trees	243
9.4	A greedy algorithm for the uncapacitated facility location problem	247
10	Further uses of rounding data and dynamic programming	257
10.1	The Euclidean traveling salesman problem	257
10.2	The maximum independent set problem in planar graphs	269
11	Further uses of deterministic rounding of linear programs	281
11.1	The generalized assignment problem	282
11.2	Minimum-cost bounded-degree spanning trees	286
11.3	Survivable network design and iterated rounding	297
12	Further uses of random sampling and randomized rounding of linear programs	309
12.1	The uncapacitated facility location problem	310
12.2	The single-source rent-or-buy problem	313
12.3	The Steiner tree problem	316
12.4	Everything at once: finding a large cut in a dense graph	322
13	Further uses of randomized rounding of semidefinite programs	333
13.1	Approximating quadratic programs	334
13.2	Coloring 3-colorable graphs	340
13.3	Unique games	344
14	Further uses of the primal-dual method	355
14.1	The prize-collecting Steiner tree problem	355
14.2	The feedback vertex set problem in undirected graphs	360
15	Further uses of cuts and metrics	369
15.1	Low distortion embeddings and the sparsest cut problem	369
15.2	Oblivious routing and cut-tree packings	376
15.3	Cut-tree packings and the minimum bisection problem	382
15.4	The uniform sparsest cut problem	385
16	Techniques in proving the hardness of approximation	407
16.1	Reductions from NP-complete problems	407
16.2	Reductions that preserve approximation	412
16.3	Reductions from probabilistically checkable proofs	420
16.4	Reductions from label cover	425
16.5	Reductions from unique games	437
17	Open Problems	447
A	Linear programming	453

B NP-completeness	457
Bibliography	461
Author index	481