Additional Exercises for *Convex Optimization*

Stephen Boyd   Lieven Vandenberghe

March 18, 2016

This is a collection of additional exercises, meant to supplement those found in the book *Convex Optimization*, by Stephen Boyd and Lieven Vandenberghe. These exercises were used in several courses on convex optimization, EE364a (Stanford), EE236b (UCLA), or 6.975 (MIT), usually for homework, but sometimes as exam questions. Some of the exercises were originally written for the book, but were removed at some point. Many of them include a computational component using CVX, a Matlab package for convex optimization; files required for these exercises can be found at the book web site `www.stanford.edu/~boyd/cvxbook/`. We are in the process of adapting many of these problems to be compatible with two other packages for convex optimization: CVXPY (Python) and Convex.jl (Julia). Some of the exercises require a knowledge of elementary analysis.

You are free to use these exercises any way you like (for example in a course you teach), provided you acknowledge the source. In turn, we gratefully acknowledge the teaching assistants (and in some cases, students) who have helped us develop and debug these exercises. Pablo Parrilo helped develop some of the exercises that were originally used in 6.975.

Course instructors can obtain solutions by email to us. Please specify the course you are teaching and give its URL.

We'll update this document as new exercises become available, so the exercise numbers and sections will occasionally change. We have categorized the exercises into sections that follow the book chapters, as well as various additional application areas. Some exercises fit into more than one section, or don't fit well into any section, so we have just arbitrarily assigned these.

Stephen Boyd and Lieven Vandenberghe

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Convex Optimization Theory Dimitri Bertsekas,2009-06-01 An insightful concise and rigorous treatment of the basic theory of convex sets and functions in finite dimensions and the analytical geometrical foundations of convex optimization and duality theory Convexity theory is first developed in a simple accessible manner using easily visualized proofs Then the focus shifts to a transparent geometrical line of analysis to develop the fundamental duality between descriptions of convex functions in terms of points and in terms of hyperplanes Finally convexity theory and abstract duality are applied to problems of constrained optimization Fenchel and conic duality and game theory to develop the sharpest possible duality results within a highly visual geometric framework This on line version of the book includes an extensive set of theoretical problems with detailed high quality solutions which significantly extend the range and value of the book The book may be used as a text for a theoretical convex optimization course the author has taught several variants of such a course at MIT and elsewhere over the last ten years It may also be used as a supplementary source for nonlinear programming classes and as a theoretical foundation for classes focused on convex optimization models rather than theory It is an excellent supplement to several of our books Convex Optimization Algorithms Athena Scientific 2015 Nonlinear Programming Athena Scientific 2017 Network Optimization Athena Scientific 1998 Introduction to Linear Optimization Athena Scientific 1997 and Network Flows and Monotropic Optimization Athena Scientific 1998 **Undergraduate Convexity: Problems And Solutions** Mikkel Slot Nielsen,Victor Ulrich Rohde,2016-09-08 This solutions manual thoroughly goes through the exercises found in Undergraduate Convexity From Fourier and Motzkin to Kuhn and Tucker Several solutions are accompanied by detailed illustrations and intuitive explanations This book will pave the way for students to easily grasp the multitude of solution methods and aspects of convex sets and convex functions Companion Textbook here **Nonlinear Programming** Dimitri Bertsekas,2016-09-01 This book provides a comprehensive and accessible presentation of algorithms for solving continuous optimization problems It relies on rigorous mathematical analysis but also aims at an intuitive exposition that makes use of visualization where possible It places particular emphasis on modern developments and their widespread applications in fields such as large scale resource allocation problems signal processing and machine learning The 3rd edition brings the book in closer harmony with the companion works Convex Optimization Theory Athena Scientific 2009 Convex Optimization Algorithms Athena Scientific 2015 Convex Analysis and Optimization Athena Scientific 2003 and Network Optimization Athena Scientific 1998 These works are complementary in that they deal primarily with convex possibly nondifferentiable optimization problems and rely on convex analysis By contrast the nonlinear programming book focuses primarily on analytical and computational methods for possibly nonconvex differentiable problems It relies primarily on calculus and variational analysis yet it still contains a detailed presentation of duality theory and its uses for both convex and nonconvex problems This on line edition contains detailed solutions to all the theoretical book exercises Among its special features the

book Provides extensive coverage of iterative optimization methods within a unifying framework Covers in depth duality theory from both a variational and a geometric point of view Provides a detailed treatment of interior point methods for linear programming Includes much new material on a number of topics such as proximal algorithms alternating direction methods of multipliers and conic programming Focuses on large scale optimization topics of much current interest such as first order methods incremental methods and distributed asynchronous computation and their applications in machine learning signal processing neural network training and big data applications Includes a large number of examples and exercises Was developed through extensive classroom use in first year graduate courses *Computer Age Statistical Inference, Student Edition* Bradley Efron,Trevor Hastie,2021-06-17 The twenty first century has seen a breathtaking expansion of statistical methodology both in scope and influence Data science and machine learning have become familiar terms in the news as statistical methods are brought to bear upon the enormous data sets of modern science and commerce How did we get here And where are we going How does it all fit together Now in paperback and fortified with exercises this book delivers a concentrated course in modern statistical thinking Beginning with classical inferential theories Bayesian frequentist Fisherian individual chapters take up a series of influential topics survival analysis logistic regression empirical Bayes the jackknife and bootstrap random forests neural networks Markov Chain Monte Carlo inference after model selection and dozens more The distinctly modern approach integrates methodology and algorithms with statistical inference Each chapter ends with class tested exercises and the book concludes with speculation on the future direction of statistics and data science **Design of Modern Heuristics** Franz Rothlauf,2011-07-17 Most textbooks on modern heuristics provide the reader with detailed descriptions of the functionality of single examples like genetic algorithms genetic programming tabu search simulated annealing and others but fail to teach the underlying concepts behind these different approaches The author takes a different approach in this textbook by focusing on the users needs and answering three fundamental questions First he tells us which problems modern heuristics are expected to perform well on and which should be left to traditional optimization methods Second he teaches us to systematically design the right modern heuristic for a particular problem by providing a coherent view on design elements and working principles Third he shows how we can make use of problem specific knowledge for the design of efficient and effective modern heuristics that solve not only small toy problems but also perform well on large real world problems This book is written in an easy to read style and it is aimed at students and practitioners in computer science operations research and information systems who want to understand modern heuristics and are interested in a guide to their systematic design and use This book is written in an easy to read style and it is aimed at students and practitioners in computer science operations research and information systems who want to understand modern heuristics and are interested in a guide to their systematic design and use This book is written in an easy to read style and it is aimed at students and practitioners in computer science operations research and information

systems who want to understand modern heuristics and are interested in a guide to their systematic design and use

Introduction to Civil Engineering Systems Samuel Labi,2014-04-07 This book presents an integrated systems approach to the evaluation analysis design and maintenance of civil engineering systems Addressing recent concerns about the world s aging civil infrastructure and its environmental impact the author makes the case for why any civil infrastructure should be seen as part of a larger whole He walks readers through all phases of a civil project from feasibility assessment to construction to operations explaining how to evaluate tasks and challenges at each phase using a holistic approach Unique coverage of ethics legal issues and management is also included   Routing, Flow, and Capacity Design in Communication and Computer Networks Michal Pioro,Deep Medhi,2004-07-21 In network design the gap between theory and practice is woefully broad This book narrows it comprehensively and critically examining current network design models and methods You will learn where mathematical modeling and algorithmic optimization have been under utilized At the opposite extreme you will learn where they tend to fail to contribute to the twin goals of network efficiency and cost savings Most of all you will learn precisely how to tailor theoretical models to make them as useful as possible in practice Throughout the authors focus on the traffic demands encountered in the real world of network design Their generic approach however allows problem formulations and solutions to be applied across the board to virtually any type of backbone communication or computer network For beginners this book is an excellent introduction For seasoned professionals it provides immediate solutions and a strong foundation for further advances in the use of mathematical modeling for network design Written by leading researchers with a combined 40 years of industrial and academic network design experience Considers the development of design models for different technologies including TCP IP IDN MPLS ATM SONET SDH and WDM Discusses recent topics such as shortest path routing and fair bandwidth assignment in IP MPLS networks Addresses proper multi layer modeling across network layers using different technologies for example IP over ATM over SONET IP over WDM and IDN over SONET Covers restoration oriented design methods that allow recovery from failures of large capacity transport links and transit nodes Presents at the end of each chapter exercises useful to both students and practitioners   **Parallel Computing in Optimization** A. Migdalas,Panos M. Pardalos,Sverre Storøy,1997-05-31 During the last three decades breakthroughs in computer technology have made a tremendous impact on optimization In particular parallel computing has made it possible to solve larger and computationally more difficult problems The book covers recent developments in novel programming and algorithmic aspects of parallel computing as well as technical advances in parallel optimization Each contribution is essentially expository in nature but of scholarly treatment In addition each chapter includes a collection of carefully selected problems The first two chapters discuss theoretical models for parallel algorithm design and their complexity The next chapter gives the perspective of the programmer practicing parallel algorithm development on real world platforms Solving systems of linear equations efficiently is of great importance not only because they arise in many scientific and engineering

applications but also because algorithms for solving many optimization problems need to call system solvers and subroutines chapters four and five Chapters six through thirteen are dedicated to optimization problems and methods They include parallel algorithms for network problems parallel branch and bound techniques parallel heuristics for discrete and continuous problems decomposition methods parallel algorithms for variational inequality problems parallel algorithms for stochastic programming and neural networks Audience Parallel Computing in Optimization is addressed not only to researchers of mathematical programming but to all scientists in various disciplines who use optimization methods in parallel and multiprocessing environments to model and solve problems   *Dissertation Abstracts International* ,2001

   Mathematical Reviews ,2003   **Linear Semi-Infinite Optimization** Miguel A. Goberna,Marco A. López,1998-03-11 A linear semi infinite program is an optimization problem with linear objective functions and linear constraints in which either the number of unknowns or the number of constraints is finite The many direct applications of linear semi infinite optimization or programming have prompted considerable and increasing research effort in recent years The authors aim is to communicate the main theoretical ideas and applications techniques of this fascinating area from the perspective of convex analysis The four sections of the book cover Modelling with primal and dual problems the primal problem space of dual variables the dual problem Linear semi infinite systems existence theorems alternative theorems redundancy phenomena geometrical properties of the solution set Theory of linear semi infinite programming optimality duality boundedness perturbations well posedness Methods of linear semi infinite programming an overview of the main numerical methods for primal and dual problems Exercises and examples are provided to illustrate both theory and applications The reader is assumed to be familiar with elementary calculus linear algebra and general topology An appendix on convex analysis is provided to ensure that the book is self contained Graduate students and researchers wishing to gain a deeper understanding of the main ideas behind the theory of linear optimization will find this book to be an essential text

   Combinatorial Optimization William Cook,1997-11-26 Combinatorial optimization is a topic in discrete mathematics and theoretical computer science This book covers the theory algorithms and applications in a manner which should be accessible to researchers and post graduate students in mathematics and computer science   **New Technical Books** New York Public Library,1994   SIAM Journal on Control and Optimization Society for Industrial and Applied Mathematics,1984   *Technology Transfer in Developing Countries 2000 - Automation in Infrastructure Creation* I.K. Craig,F.R. Camisani-Calzolari,2001-06-11 This Proceedings contains the papers presented at the IFAC Conference on Technology Transfer in Developing Countries Automation in Infrastructure Creation held in Pretoria South Africa on 5 7 July 2000 With its focus on developing countries this is the first publication of its kind Particular emphasis is put on the application and adaptation of first world automation technologies to developing countries in the following areas power systems telecommunications systems transportation systems water supply and purification In addition papers on technology transfer

in developing countries control education and measurement and control applications are presented Included in this proceedings are a keynote address 4 plenary papers and 40 regular papers **INFORMS Annual Meeting** Institute for Operations Research and the Management Sciences. National Meeting,2002 <u>Structural Optimization</u> Gianantonnio Sacchi,1985 After the IUTAM Symposium on Optimization in Structural Design held in Warsaw in 1973 it was clear to me that the time had come for organizing into a consistent body of thought the enormous quantity of results obtained in this domain studied from so many different points of view with so many different methods and at so many levels of practical applicability My colleague and friend Gianantonnio Sacchi from Milan and I met with Professor Prager in Savognin in July 1974 where I submitted to them my first ideas for a treatise on structural optimization It should cover the whole domain from basic theory to practical applications and deal with various materials various types of structures various functions required of the structures and various types of cost Obviously this was to be a team effort to total three or four volumes to be written in a balanced manner as textbooks and handbooks Nothing similar existed at that time and indeed nothing has been published to date Professor Prager was immedi ately in favor of such a project He agreed to write a first part on optimality criteria with me and to help me in the general organization of the series Since Professor Sacchi was willing to write the text on variational methods it remained to find authors for parts on the mathematical programming approach to structural optimization and more generally on numerical methods and on practical optimal design procedures in metal and concrete **Introduction to Optimization** Boris Teodorovich Poliak,1987 **Notices of the American Mathematical Society** American Mathematical Society,1992 **Memoirs of the Scientific Sections of the Academy of the Socialist Republic of Romania** ,2013

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