

Additional Exercises for Chapter 4: Optimization

Stephen Boyd Lieven Vandenbergher
March 18, 2019

This is a list of additional exercises provided to supplement those found in the book *Convex Optimization*, by Stephen Boyd and Lieven Vandenbergher. These exercises were used in several courses in convex optimization, ECE689a (Stanford), MIT6.034 (MIT), usually the second, and sometimes as more optional, third, of the semester when available sections for the book, and were derived at some point. Many of these include a computational component using CVX, a Matlab package for convex optimization, that replaced the usual exercises and the third or the fourth and the last exercise, after “epilogue”. We use in the process of solving some of these problems to be consistent with the other packages for convex optimization: CVXOPT (Python) and CVXGEN (C/C++). Most of the exercises require a knowledge of elementary calculus.

Though we do not use these exercises as part of the final grading in ECE689a, provided you understand the exercise. In fact, we generally encourage the teaching assistants (and in some cases, students) who have helped us develop and bring these exercises. Their efforts helped develop some of the exercises that have originally used in CVX.

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CVX is a registered trademark of the Massachusetts Institute of Technology, and the authors would like to thank MIT for its support. We also thank the MIT students who helped us develop these exercises, as well as the other additional contributors. Some exercises are from other books, but we have modified them to fit the style of this book and to make them more consistent with the other exercises in the book.

Stephen Boyd and Lieven Vandenbergher

Additional Exercises For Convex Optimization Boyd Solutions

**Vitor Balestro, Horst Martini, Ralph
Teixeira**



Additional Exercises For Convex Optimization Boyd Solutions:

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

First-Order Methods in Optimization Amir Beck, 2017-10-02 The primary goal of this book is to provide a self contained comprehensive study of the main first order methods that are frequently used in solving large scale problems First order methods exploit information on values and gradients subgradients but not Hessians of the functions composing the model under consideration With the increase in the number of applications that can be modeled as large or even huge scale optimization problems there has been a revived interest in using simple methods that require low iteration cost as well as low memory storage The author has gathered reorganized and synthesized in a unified manner many results that are currently scattered throughout the literature many of which cannot be typically found in optimization books First Order Methods in Optimization offers comprehensive study of first order methods with the theoretical foundations provides plentiful examples and illustrations emphasizes rates of convergence and complexity analysis of the main first order methods used to solve large scale problems and covers both variables and functional decomposition methods

Optimization Techniques and Applications with Examples Xin-She Yang, 2018-08-30 A guide to modern optimization applications and techniques in newly emerging areas spanning optimization data science machine intelligence engineering and computer sciences Optimization Techniques and Applications with Examples introduces the fundamentals of all the commonly used techniques in optimization that encompass the broadness and diversity of the methods traditional and new and algorithms The author a noted expert in the field covers a wide range of topics including mathematical foundations optimization formulation optimality conditions algorithmic complexity linear programming convex

optimization and integer programming In addition the book discusses artificial neural network clustering and classifications constraint handling queueing theory support vector machine and multi objective optimization evolutionary computation nature inspired algorithms and many other topics Designed as a practical resource all topics are explained in detail with step by step examples to show how each method works The book s exercises test the acquired knowledge that can be potentially applied to real problem solving By taking an informal approach to the subject the author helps readers to rapidly acquire the basic knowledge in optimization operational research and applied data mining This important resource Offers an accessible and state of the art introduction to the main optimization techniques Contains both traditional optimization techniques and the most current algorithms and swarm intelligence based techniques Presents a balance of theory algorithms and implementation Includes more than 100 worked examples with step by step explanations Written for upper undergraduates and graduates in a standard course on optimization operations research and data mining

Optimization Techniques and Applications with Examples is a highly accessible guide to understanding the fundamentals of all the commonly used techniques in optimization

Large-Scale Convex Optimization Ernest K. Ryu, Wotao Yin, 2022-12 A unified analysis of first order optimization methods including parallel distributed algorithms using monotone operators *Set-Valued, Convex, and Nonsmooth Analysis in Dynamics and Control* Rafal K. Goebel, 2024-06-26 Set valued analysis convex analysis and nonsmooth analysis are relatively modern branches of mathematical analysis that have become increasingly relevant in current control theory and control engineering literature This book serves as a broad introduction to analytical tools in these fields and to their applications in dynamical and control systems and is the first to cover these topics with this scope and at this level Both continuous time and discrete time multivalued dynamics modeled by differential and difference inclusions are considered Set Valued Convex and Nonsmooth Analysis in Dynamics and Control An Introduction is aimed at graduate students in control engineering and applied mathematics and researchers in control engineering who have no prior exposure to set valued convex and nonsmooth analysis The book will also be of interest to advanced undergraduate mathematics students and mathematicians with no prior exposure to the topic The expected mathematical background is a course on nonlinear differential equations dynamical systems and a course on real analysis Knowledge of some control theory is helpful but not essential

Constructing Insurable Risk Portfolios Edward W. Frees, 2025-04-09 Constructing Insurable Risk Portfolios offers a data driven approach to devising risk retention programs that safeguard firms from a multitude of risks Because firms face many risks including fire damage to their buildings liability from management misconduct and external threats like cyberattacks this book treats these potential liabilities as a portfolio Drawing inspiration from Markowitz portfolio theory the text leverages techniques from probability statistics and optimization to build algorithms that construct optimal risk insurable portfolios under budget constraints Features Through engaging case studies and supporting statistical R code readers will learn how to build optimal insurable risk portfolios This book illustrates a frontier that depicts the trade

off between the uncertainty of a portfolio and the cost of risk transfer This visual representation mirroring familiar Markowitz investment tools enables informed decision making and easy adoption by risk advisors This book lays the mathematical groundwork for constructing optimal insurable risk portfolios in an effective and aesthetically pleasing manner For those interested in the detailed mathematical aspects of insurable risk portfolio optimization comprehensive proofs and derivations are available in an online supplement This book equips students academics and practitioners with quantitative tools to analyze real world risk portfolios Additionally it empowers financial analysts to provide data driven insights that enhance their advisory roles for risk managers

Forthcoming Books Rose Arny,2003-12 **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 International Aerospace Abstracts ,1995 **Bulletin** Institute of Mathematics and Its Applications,1994 *Conference Record of the Thirty-Eighth Asilomar Conference on Signals, Systems & Computers, November 7-10, 2004, Pacific Grove, California* Michael B. Matthews,2004 Books in Print Supplement ,1984

Mathematical Reviews ,1970 **Convexity from the Geometric Point of View: Exercises and Solutions** Vitor Balestro,Horst Martini,Ralph Teixeira,2025-05-24 This book provides the solutions to all 347 exercises contained in the text *Convexity from the Geometric Point of View* published in the same Cornerstones series All these exercises are restated and numbered analogously to those in the original text The corresponding solutions follow each exercise Besides the discussion of all solutions some additional facts about the main text are sprinkled throughout Sections of further reading are posted to the ends of each chapter supplying the reader with background literature to selected notions and tools that play a role in the exercises and or solutions to the chapter The original text gives a comprehensive introduction to the common core of convex geometry and is suitable as a primary text for courses in convex geometry and in discrete geometry including polytopes

Additionally it can be used as a single reference for a complete introduction to convex geometry. The content coverage is sufficiently broad that the reader may gain a glimpse of the entire breadth of the field, various subfields, and interesting connections to neighboring disciplines. Mainly directed to graduate and advanced undergraduates, the original text is self-contained in such a way that it can be read by anyone who has standard undergraduate knowledge of analysis and of linear algebra. The same is true for this book of solutions.

Lectures on Convex Sets Valeriu Soltan, 2020. The exposition is self-contained, detailed, and provides multiple cross-references that makes the book accessible to a large audience. An essential part of the text is adapted from various research articles never presented before in a textbook format. The book has a multidisciplinary nature; it can be useful to specialists in geometry, convex analysis, operations research, and optimization. The new edition contains new chapters and additional exercises with respective solutions. Despite the presence of a large number of monographs on convex sets, there are quite a few textbooks on this topic. This book is to the level of graduate study with a higher degree of complexity and essentially more research-related results and references.

Lectures on Modern Convex Optimization Aharon Ben-Tal, Arkadi Nemirovski, 2001-01-01. Here is a book devoted to well-structured and thus efficiently solvable convex optimization problems with emphasis on conic, quadratic, and semidefinite programming. The authors present the basic theory underlying these problems as well as their numerous applications in engineering, including synthesis of filters, Lyapunov stability analysis, and structural design. The authors also discuss complexity issues and provide an overview of the basic theory of state-of-the-art polynomial-time interior-point methods for linear, conic, quadratic, and semidefinite programming. The book's focus on well-structured convex problems in conic form allows for unified theoretical and algorithmical treatment of a wide spectrum of important optimization problems arising in applications.

Convex Analysis and Optimization Dimitri Bertsekas, Angelia Nedic, Asuman Ozdaglar, 2003-03-01. A uniquely pedagogical, insightful, and rigorous treatment of the analytical-geometrical foundations of optimization. The book provides a comprehensive development of convexity theory and its rich applications in optimization, including duality, minimax, saddle-point theory, Lagrange multipliers, and Lagrangian relaxation, nondifferentiable optimization. It is an excellent supplement to several of our books: *Convex Optimization Theory* (Athena Scientific, 2009), *Convex Optimization Algorithms* (Athena Scientific, 2015), *Nonlinear Programming* (Athena Scientific, 2016), *Network Optimization* (Athena Scientific, 1998), and *Introduction to Linear Optimization* (Athena Scientific, 1997). Aside from a thorough account of convex analysis and optimization, the book aims to restructure the theory of the subject by introducing several novel unifying lines of analysis, including:

1. A unified development of minimax theory and constrained optimization duality as special cases of duality between two simple geometrical problems.
2. A unified development of conditions for existence of solutions of convex optimization problems, conditions for the minimax equality to hold, and conditions for the absence of a duality gap in constrained optimization.
3. A unification of the major constraint qualifications allowing the use of Lagrange multipliers for nonconvex constrained optimization using the notion of constraint

pseudonormality and an enhanced form of the Fritz John necessary optimality conditions Among its features the book a Develops rigorously and comprehensively the theory of convex sets and functions in the classical tradition of Fenchel and Rockafellar b Provides a geometric highly visual treatment of convex and nonconvex optimization problems including existence of solutions optimality conditions Lagrange multipliers and duality c Includes an insightful and comprehensive presentation of minimax theory and zero sum games and its connection with duality d Describes dual optimization the associated computational methods including the novel incremental subgradient methods and applications in linear quadratic and integer programming e Contains many examples illustrations and exercises with complete solutions about 200 pages posted at the publisher s web site <http://www.athenasc.com/convexity.html>

Convex Optimization Via Domain-driven Barriers and Primal-dual Interior-point Methods Mehdi Karimi, 2017 This thesis studies the theory and implementation of infeasible start primal dual interior point methods for convex optimization problems Convex optimization has applications in many fields of engineering and science such as data analysis control theory signal processing relaxation and randomization and robust optimization In addition to strong and elegant theories the potential for creating efficient and robust software has made convex optimization very popular Primal dual algorithms have yielded efficient solvers for convex optimization problems in conic form over symmetric cones linear programming LP second order cone programming SOCP and semidefinite programming SDP However many other highly demanded convex optimization problems lack comparable solvers To close this gap we have introduced a general optimization setup called emph Domain Driven that covers many interesting classes of optimization Domain Driven means our techniques are directly applied to the given good formulation without a forced reformulation in a conic form Moreover this approach also naturally handles the cone constraints and hence the conic form A problem is in the Domain Driven setup if it can be formulated as minimizing a linear function over a convex set where the convex set is equipped with an efficient self concordant barrier with an easy to evaluate Legendre Fenchel conjugate We show how general this setup is by providing several interesting classes of examples LP SOCP and SDP are covered by the Domain Driven setup More generally consider all convex cones with the property that both the cone and its dual admit efficiently computable self concordant barriers Then our Domain Driven setup can handle any conic optimization problem formulated using direct sums of these cones and their duals Then we show how to construct interesting convex sets as the direct sum of the epigraphs of univariate convex functions This construction as a special case contains problems such as geometric programming p norm optimization and entropy programming the solutions of which are in great demand in engineering and science Another interesting class of convex sets that optimization over it is contained in the Domain Driven setup is the generalized epigraph of a matrix norm This as a special case allows us to minimize the nuclear norm over a linear subspace that has applications in machine learning and big data Domain Driven setup contains the combination of all the above problems for example we can have a problem with LP and SDP constraints combined with ones defined by

univariate convex functions or the epigraph of a matrix norm We review the literature on infeasible start algorithms and discuss the pros and cons of different methods to show where our algorithms stand among them This thesis contains a chapter about several properties for self concordant functions Since we are dealing with general convex sets many of these properties are used frequently in the design and analysis of our algorithms We introduce a notion of duality gap for the Domain Driven setup that reduces to the conventional duality gap if the problem is a conic optimization problem and prove some general results Then to solve our problems we construct infeasible start primal dual central paths A critical part in achieving the current best iteration complexity bounds is designing algorithms that follow the path efficiently The algorithms we design are predictor corrector algorithms Determining the status of a general convex optimization problem as being unbounded infeasible having optimal solutions etc is much more complicated than that of LP We classify the possible status seven possibilities for our problem as solvable strictly primal dual feasible strictly and strongly primal infeasible strictly and strongly primal unbounded and ill conditioned We discuss the certificates our algorithms return heavily relying on duality for each of these cases and analyze the number of iterations required to return such certificates For infeasibility and unboundedness we define a weak and a strict detector We prove that our algorithms return these certificates solve the problem in polynomial time with the current best theoretical complexity bounds The complexity results are new for the infeasible start models used The different patterns that can be detected by our algorithms and the iteration complexity bounds for them are comparable to the current best results available for infeasible start conic optimization which to the best of our knowledge is the work of Nesterov Todd Ye 1999 In the applications computation and software front based on our algorithms we created a Matlab based code called DDS that solves a large class of problems including LP SOCP SDP quadratically constrained quadratic programming QCQP geometric programming entropy programming and more can be added Even though the code is not finalized this chapter shows a glimpse of possibilities The generality of the code lets us solve problems that CVX a modeling system for convex optimization does not even recognize as convex The DDS code accepts constraints representing the epigraph of a matrix norm which as we mentioned covers minimizing the nuclear norm over a linear subspace For acceptable classes of convex optimization problems we explain the format of the input We give the formula for computing the gradient and Hessian of the corresponding self concordant barriers and their Legendre Fenchel conjugates and discuss the methods we use to compute them efficiently and robustly We present several numerical results of applying the DDS code to our constructed examples and also problems from well known libraries such as the DIMACS library of mixed semidefinite quadratic linear programs We also discuss different numerical challenges and our approaches for removing them

Convex Sets and Their Applications Steven R. Lay, 2007-01-01 Suitable for advanced undergraduates and graduate students this text introduces the broad scope of convexity It leads students to open questions and unsolved problems and it highlights diverse applications Author Steven R Lay Professor of Mathematics at Lee University in Tennessee

reinforces his teachings with numerous examples plus exercises with hints and answers The first three chapters form the foundation for all that follows starting with a review of the fundamentals of linear algebra and topology They also survey the development and applications of relationships between hyperplanes and convex sets Subsequent chapters are relatively self contained each focusing on a particular aspect or application of convex sets Topics include characterizations of convex sets polytopes duality optimization and convex functions Hints solutions and references for the exercises appear at the back of the book

Convex Analysis and Variational Problems Ivar Ekeland, Roger Temam, 1999-12-01 This book contains different developments of infinite dimensional convex programming in the context of convex analysis including duality minmax and Lagrangians and convexification of nonconvex optimization problems in the calculus of variations infinite dimension It also includes the theory of convex duality applied to partial differential equations no other reference presents this in a systematic way The minmax theorems contained in this book have many useful applications in particular the robust control of partial differential equations in finite time horizon First published in English in 1976 this SIAM Classics in Applied Mathematics edition contains the original text along with a new preface and some additional references

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