

Partially finite convex programming, Part I: Quasi relative interiors and duality theory

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We study convex programs that involve the minimization of a convex function over a convex subset of a topological vector space, subject to a finite number of linear inequalities. We develop the notion of the quasi relative interior of a convex set, an extension of the relative interior in finite dimensions. We use this idea in a constraint qualification for a fundamental Fenchel duality result, and then deduce duality results for these problems despite the almost invariable failure of the standard Slater condition. Part II of this work studies applications to more concrete models, whose dual problems are often finite-dimensional and computationally tractable.

AMS 1985 Subject Classifications: Primary 90C25, 49B27; Secondary 90C48, 52A07, 65K05.

Key words: Convex programming, duality, constraint qualification, Fenchel duality, semi-infinite programming.

1. Introduction

Duality theorems are central to the study of constrained optimization problems. From the point of view of problems arising in practice, their usefulness is twofold: under appropriate conditions (constraint qualifications), first they enable us to check whether a given feasible solution is optimal, and secondly we can often find the optimal solution by first solving the corresponding dual problem. When the primal problem is infinite-dimensional two difficulties become apparent. The most straightforward constraint qualification (the "Slater" condition) is frequently not met in practice, since it requires the existence of an interior point of a convex set which often has empty interior. Furthermore, since the dual problem will generally also be infinite-dimensional, it may be very hard to solve.

In this paper we shall primarily be concerned with problems of the form

$$\begin{aligned} \text{(P)} \quad & \inf && f(x) \\ & \text{subject to} && Ax \leq b, \\ & && x \in C, \end{aligned}$$

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Theory Of Convex Programming

Dimitri Bertsekas



Theory Of Convex Programming:

Theory of Convex Programming E. G. Golstein, 2008

Theory of Convex Programming E.G. Gol'Stein, 1972

Theory of Convex Programming E. G. Golstein, 2008-07-21 *Convex Optimization Algorithms* Dimitri

Bertsekas, 2015-02-01 This book provides a comprehensive and accessible presentation of algorithms for solving convex optimization problems. It relies on rigorous mathematical analysis but also aims at an intuitive exposition that makes use of visualization where possible. This is facilitated by the extensive use of analytical and algorithmic concepts of duality which by nature lend themselves to geometrical interpretation. The book 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 book is aimed at students, researchers and practitioners roughly at the first year graduate level. It is similar in style to the author's 2009 *Convex Optimization Theory* book but can be read independently. The latter book focuses on convexity theory and optimization duality while the present book focuses on algorithmic issues. The two books share notation and together cover the entire finite dimensional convex optimization methodology. To facilitate readability the statements of definitions and results of the theory book are reproduced without proofs in Appendix B.

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> **Theory of Convex Programming** Evgenii Grigor'evich Gol'shtein,1972 [Theory of Convex Programming](#) Evgenij Grigor'evich Gol'shtein,1972 *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 *Optimality Conditions in Convex Optimization* Anulekha Dhara,Joydeep Dutta,2011-10-17 Optimality Conditions in Convex Optimization explores an important and central issue in the field of convex optimization optimality conditions It brings together the most important and recent results in this area that have been scattered in the literature notably in the area of convex analysis essential in developing many of the important results

Convexity and Optimization in Banach Spaces Viorel Barbu,Teodor Precupanu,2012-01-03 An updated and revised edition of the 1986 title Convexity and Optimization in Banach Spaces this book provides a self contained presentation of basic results of the theory of convex sets and functions in infinite dimensional spaces The main emphasis is on applications to convex optimization and convex optimal control problems in Banach spaces A distinctive feature is a strong emphasis on the connection between theory and application This edition has been updated to include new results pertaining to advanced concepts of subdifferential for convex functions and new duality results in convex programming The last chapter concerned with convex control problems has been rewritten and completed with new research concerning boundary control systems the dynamic programming equations in optimal control theory and periodic optimal control problems Finally the structure of the book has been modified to highlight the most recent progression in the field including fundamental results on the theory of

infinite dimensional convex analysis and includes helpful bibliographical notes at the end of each chapter

Convex Optimization—Theory, Algorithms and Applications Balendu Bhooshan Upadhyay, Shashi Kant Mishra, Pierre Maréchal, 2025-04-25 This volume includes chapters on topics presented at the conference on Recent Trends in Convex Optimization Theory Algorithms and Applications RTCOTAA 2020 held at the Department of Mathematics Indian Institute of Technology Patna Bihar India from 29-31 October 2020 It discusses a comprehensive exploration of the realm of optimization encompassing both the theoretical underpinnings and the multifaceted real life implementations of the optimization theory It meticulously features essential optimization concepts such as convex analysis generalized convexity monotonicity etc elucidating their theoretical advancements and significance in the optimization sphere Multiobjective optimization is a pivotal topic which addresses the inherent difficulties faced in conflicting objectives The book delves into various theoretical concepts and covers some practical algorithmic approaches to solve multiobjective optimization such as the line search and the enhanced non monotone quasi Newton algorithms It also deliberates on several other significant topics in optimization such as the perturbation approach for vector optimization and solution methods for set valued optimization Nonsmooth optimization is extensively covered with in depth discussions on various well known tools of nonsmooth analysis such as convexifiers limiting subdifferentials tangential subdifferentials quasi differentials etc Notable optimization algorithms such as the interior point algorithm and Lemke's algorithm are dissected in detail offering insights into their applicability and effectiveness The book explores modern applications of optimization theory for instance optimized image encryption resource allocation target tracking problems deep learning entropy optimization etc Ranging from gradient based optimization algorithms to metaheuristic approaches such as particle swarm optimization the book navigates through the intersection of optimization theory and deep learning thereby unravelling new research perspectives in artificial intelligence machine learning and other fields of modern science Designed primarily for graduate students and researchers across a variety of disciplines such as mathematics operations research electrical and electronics engineering computer science robotics deep learning image processing and artificial intelligence this book serves as a comprehensive resource for someone interested in exploring the multifaceted domain of mathematical optimization and its myriad applications

Introduction to Linear and Convex Programming Neil Cameron, 1985-09-05 This introduction to optimization emphasizes the need for both a pure and an applied mathematical point of view Beginning with a chapter on linear algebra and Euclidean geometry the author then applies this theory with an introduction to linear programming There follows a discussion of convex analysis which finds application in non linear programming The book ends with an extensive commentary to the exercises that are given at the end of each chapter The author's straightforward geometrical approach makes this an attractive textbook for undergraduate students of mathematics engineering operations research and economics

Convex Analysis and Nonlinear Optimization Jonathan M. Borwein, Adrian S. Lewis, 2013-06-29 Optimization is a rich and thriving mathematical discipline

The theory underlying current computational optimization techniques grows ever more sophisticated. The powerful and elegant language of convex analysis unifies much of this theory. The aim of this book is to provide a concise accessible account of convex analysis and its applications and extensions for a broad audience. It can serve as a teaching text at roughly the level of first year graduate students. While the main body of the text is self contained each section concludes with an often extensive set of optional exercises. The new edition adds material on semismooth optimization as well as several new proofs that will make this book even more self contained.

Convex Programming in Optimal Control and Information Theory Tobias Samuel Sutter, 2017

Convex Optimization Arto Ruud, 2019

Over the past two decades it has been recognized that advanced image processing techniques provide valuable information to physicians for the diagnosis image guided therapy and surgery and monitoring of human diseases. *Convex Optimization Theory Methods and Applications* introduces novel and sophisticated mathematical problems which encourage the development of advanced optimization and computing methods especially convex optimization. The authors go on to study Steffensen King type methods of convergence to approximate a locally unique solution of a nonlinear equation and also in problems of convex optimization. Real world applications are also provided. The following study is focused on the design and testing of a Matlab code of the Frank Wolfe algorithm. The Nesterov step is proposed in order to accelerate the algorithm and the results of some numerical experiments of constraint optimization are also provided. Lagrangian methods for numerical solutions to constrained convex programs are also explored. For enhanced algorithms the traditional Lagrange multiplier update is modified to take a soft reflection across the zero boundary. This coupled with a modified drift expression is shown to yield improved performance. Next Newton's mesh independence principle was used to solve a certain class of optimal design problems from earlier studies. Motivated by optimization considerations the authors show that under the same computational cost a finer mesh independence principle can be given than before. This compilation closes with a presentation on a local convergence analysis for eighth order variants of Hansen Patrick's family for approximating a locally unique solution of a nonlinear equation. The radius of convergence and computable error bounds on the distances involved are also provided.

Quasiconvex Optimization and Location Theory J.A. dos Santos Gromicho, 2013-12-01

grams of which the objective is given by the ratio of a convex by a positive over a convex domain concave function. As observed by Sniedovich Ref 102 103 most of the properties of fractional programs could be found in other programs given that the objective function could be written as a particular composition of functions. He called this new field C programming standing for composite concave programming. In his seminal book on dynamic programming Ref 104 Sniedovich shows how the study of such compositions can help tackling non separable dynamic programs that otherwise would defeat solution. Barros and Frenk Ref 9 developed a cutting plane algorithm capable of optimizing C programs. More recently this algorithm has been used by Carrizosa and Plastria to solve a global optimization problem in facility location Ref 16. The distinction between global optimization problems Ref 54 and generalized convex

problems can sometimes be hard to establish That is exactly the reason why so much effort has been placed into finding an exhaustive classification of the different weak forms of convexity establishing a new definition just to satisfy some desirable property in the most general way possible This book does not aim at all the subtleties of the different generalizations of convexity but concentrates on the most general of them all quasiconvex programming Chapter 5 shows clearly where the real difficulties appear *Optimization Theory and Applications* Jochen Werner,2013-03-09 **Convex Optimization** Mikhail Moklyachuk,2020-12-16 This book provides easy access to the basic principles and methods for solving constrained and unconstrained convex optimization problems Included are sections that cover basic methods for solving constrained and unconstrained optimization problems with differentiable objective functions convex sets and their properties convex functions and their properties and generalizations and basic principles of sub differential calculus and convex programming problems Convex Optimization provides detailed proofs for most of the results presented in the book and also includes many figures and exercises for a better understanding of the material Exercises are given at the end of each chapter with solutions and hints to selected exercises given at the end of the book Undergraduate and graduate students researchers in different disciplines as well as practitioners will all benefit from this accessible approach to convex optimization methods

Interior-point Polynomial Algorithms in Convex Programming Yurii Nesterov,Arkadii Nemirovskii,1994-01-01 Specialists working in the areas of optimization mathematical programming or control theory will find this book invaluable for studying interior point methods for linear and quadratic programming polynomial time methods for nonlinear convex programming and efficient computational methods for control problems and variational inequalities A background in linear algebra and mathematical programming is necessary to understand the book The detailed proofs and lack of numerical examples might suggest that the book is of limited value to the reader interested in the practical aspects of convex optimization but nothing could be further from the truth An entire chapter is devoted to potential reduction methods precisely because of their great efficiency in practice **Sequential Convex Programming in Theory and Praxis** Christian Zillober,2009

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Table of Contents Theory Of Convex Programming

1. Understanding the eBook Theory Of Convex Programming
 - The Rise of Digital Reading Theory Of Convex Programming
 - Advantages of eBooks Over Traditional Books
2. Identifying Theory Of Convex Programming
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Theory Of Convex Programming
 - User-Friendly Interface
4. Exploring eBook Recommendations from Theory Of Convex Programming
 - Personalized Recommendations
 - Theory Of Convex Programming User Reviews and Ratings
 - Theory Of Convex Programming and Bestseller Lists
5. Accessing Theory Of Convex Programming Free and Paid eBooks
 - Theory Of Convex Programming Public Domain eBooks
 - Theory Of Convex Programming eBook Subscription Services
 - Theory Of Convex Programming Budget-Friendly Options

6. Navigating Theory Of Convex Programming eBook Formats
 - ePub, PDF, MOBI, and More
 - Theory Of Convex Programming Compatibility with Devices
 - Theory Of Convex Programming Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Theory Of Convex Programming
 - Highlighting and Note-Taking Theory Of Convex Programming
 - Interactive Elements Theory Of Convex Programming
8. Staying Engaged with Theory Of Convex Programming
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Theory Of Convex Programming
9. Balancing eBooks and Physical Books Theory Of Convex Programming
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Theory Of Convex Programming
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Theory Of Convex Programming
 - Setting Reading Goals Theory Of Convex Programming
 - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Theory Of Convex Programming
 - Fact-Checking eBook Content of Theory Of Convex Programming
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
 - Integration of Multimedia Elements

- Interactive and Gamified eBooks

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