



# CRM PROCEEDINGS & LECTURE NOTES

Centre de Recherches Mathématiques  
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## Optimal Control via Nonsmooth Analysis

Philip D. Loewen



American Mathematical Society

# Optimal Control Via Nonsmooth Analysis

**Boris S. Mordukhovich**

## **Optimal Control Via Nonsmooth Analysis:**

**Optimal Control Via Nonsmooth Analysis** Philip Daniel Loewen, 1993 This book provides a complete and unified treatment of deterministic problems of dynamic optimization from the classical themes of the calculus of variations to the forefront of modern research in optimal control. At the heart of the presentation is nonsmooth analysis a theory of local approximation developed over the last twenty years to provide useful first order information about sets and functions lying beyond the reach of classical analysis. The book includes an intuitive and geometrically transparent approach to nonsmooth analysis serving not only to introduce the basic ideas but also to illuminate the calculations and derivations in the applied sections dealing with the calculus of variations and optimal control. Written in a lively engaging style and stocked with numerous figures and practice problems this book offers an ideal introduction to this vigorous field of current research. It is suitable as a graduate text for a one semester course in optimal control or as a manual for self study. Each chapter closes with a list of references to ease the reader's transition from active learner to contributing researcher.

### **Optimal Control,**

**Stabilization and Nonsmooth Analysis** Marcio S. de Queiroz, Michael Malisoff, Peter Wolenski, 2004-04-20 This edited book contains selected papers presented at the Louisiana Conference on Mathematical Control Theory MCT 03 which brought together over 35 prominent world experts in mathematical control theory and its applications. The book forms a well integrated exploration of those areas of mathematical control theory in which nonsmooth analysis is having a major impact. These include necessary and sufficient conditions in optimal control, Lyapunov characterizations of stability, input to state stability, the construction of feedback mechanisms, viscosity solutions of Hamilton Jacobi equations, invariance approximation theory, impulsive systems, computational issues for nonlinear systems and other topics of interest to mathematicians and control engineers. The book has a strong interdisciplinary component and was designed to facilitate the interaction between leading mathematical experts in nonsmooth analysis and engineers who are increasingly using nonsmooth analytic tools.

*Applied Analysis, Optimization and Soft Computing* Tanmoy Som, Debdas Ghosh, Oscar Castillo, Adrian Petrusel, Dayaram Sahu, 2023-06-10 This book contains select contributions presented at the International Conference on Nonlinear Applied Analysis and Optimization ICNAAO 2021 held at the Department of Mathematics Sciences Indian Institute of Technology BHU Varanasi India from 21-23 December 2021. The book discusses topics in the areas of nonlinear analysis, fixed point theory, dynamical systems, optimization, fractals, applications to differential integral equations, signal and image processing, and soft computing and exposes the young talents with the newer dimensions in these areas with their practical approaches and to tackle the real life problems in engineering, medical and social sciences. Scientists from the U S A, Austria, France, Mexico, Romania and India have contributed their research. All the submissions are peer reviewed by experts in their fields.

**Nonsmooth Optimization: Analysis And Algorithms With Applications To Optimal Control** Marko M. Makela, Pekka Neittaanmaki, 1992-05-07 This book is a self-contained elementary study for nonsmooth analysis and

optimization and their use in solution of nonsmooth optimal control problems The first part of the book is concerned with nonsmooth differential calculus containing necessary tools for nonsmooth optimization The second part is devoted to the methods of nonsmooth optimization and their development A proximal bundle method for nonsmooth nonconvex optimization subject to nonsmooth constraints is constructed In the last part nonsmooth optimization is applied to problems arising from optimal control of systems covered by partial differential equations Several practical problems like process control and optimal shape design problems are considered

**Techniques of Variational Analysis** Jonathan Borwein, Qiji Zhu, 2006-06-18

Borwein is an authority in the area of mathematical optimization and his book makes an important contribution to variational analysis Provides a good introduction to the topic

**Principles of Dynamic Optimization**

Piernicola Bettoli, Richard B. Vinter, 2024-06-18 This monograph explores key principles in the modern theory of dynamic optimization incorporating important advances in the field to provide a comprehensive mathematically rigorous reference Emphasis is placed on nonsmooth analytic techniques and an in depth treatment of necessary conditions minimizer regularity and global optimality conditions related to the Hamilton Jacobi equation is given New streamlined proofs of fundamental theorems are incorporated throughout the text that eliminate earlier cumbersome reductions and constructions The first chapter offers an extended overview of dynamic optimization and its history that details the shortcomings of the elementary theory and demonstrates how a deeper analysis aims to overcome them Aspects of dynamic programming well matched to analytical techniques are considered in the final chapter including characterization of extended value functions associated with problems having endpoint and state constraints inverse verification theorems sensitivity relationships and links to the maximum principle This text will be a valuable resource for those seeking an understanding of dynamic optimization The lucid exposition insights into the field and comprehensive coverage will benefit postgraduates researchers and professionals in system science control engineering optimization and applied mathematics

*Variational Analysis and Generalized Differentiation II* Boris S. Mordukhovich, 2006-03-02 Comprehensive and state of the art study of the basic concepts and principles of variational analysis and generalized differentiation in both finite dimensional and infinite dimensional spaces Presents numerous applications to problems in the optimization equilibria stability and sensitivity control theory economics mechanics etc

**Methods of Dynamic and Nonsmooth Optimization** Frank H. Clarke, 1989-01-01 Presents the elements of a unified approach to optimization based on nonsmooth analysis a term introduced in the 1970 s by the author who is a pioneer in the field Based on a series of lectures given at a conference at Emory University in 1986 this volume presents its subjects in a self contained and accessible manner The topics treated here have been in an active state of development Focuses mainly on deterministic optimal control the calculus of variations and mathematical programming In addition it features a tutorial in nonsmooth analysis and geometry and demonstrates that the method of value function analysis via proximal normals is a powerful tool in the study of necessary conditions sufficient conditions controllability and sensitivity

analysis The distinction between inductive and deductive methods the use of Hamiltonians the verification technique and penalization are also emphasized     *SIAM Journal on Control and Optimization* Society for Industrial and Applied Mathematics,2009     **Unilateral Variational Analysis In Banach Spaces (In 2 Parts)** Lionel Thibault,2023-02-14 The monograph provides a detailed and comprehensive presentation of the rich and beautiful theory of unilateral variational analysis in infinite dimensions It is divided into two volumes named Part I and Part II Starting with the convergence of sets and the semilimits and semicontinuities of multimappings the first volume develops the theories of tangent cones of subdifferentials of convexity and duality in locally convex spaces of extended mean value inequalities in absence of differentiability of metric regularity of constrained optimization problems The second volume is devoted to special classes of non smooth functions and sets It expands the theory of subsmooth functions and sets of semiconvex functions and multimappings of primal lower regular functions of singularities of non smooth mappings of prox regular functions and sets in general spaces of differentiability of projection mapping and others for prox regular sets Both volumes I and II contain for each chapter extensive comments covering related developments and historical comments Connected area fields of the material are optimization optimal control variational inequalities differential inclusions mechanics economics The book is intended for PhD students researchers and practitioners using unilateral variational analysis tools     **Nonsmooth Analysis** Winfried Schirotzek,2007-06-11 This book treats various concepts of generalized derivatives and subdifferentials in normed spaces their geometric counterparts and their application to optimization problems It starts with the subdifferential of convex analysis passes to corresponding concepts for locally Lipschitz continuous functions and then presents subdifferentials for general lower semicontinuous functions All basic tools are presented where they are needed this concerns separation theorems variational and extremal principles as well as relevant parts of multifunction theory Each chapter ends with bibliographic notes and exercises     *Variational Analysis* R. Tyrrell Rockafellar,Roger J.-B. Wets,2009-06-26 From its origins in the minimization of integral functionals the notion of variations has evolved greatly in connection with applications in optimization equilibrium and control It refers not only to constrained movement away from a point but also to modes of perturbation and approximation that are best describable by set convergence variational convergence of functions and the like This book develops a unified framework and in finite dimension provides a detailed exposition of variational geometry and subdifferential calculus in their current forms beyond classical and convex analysis Also covered are set convergence set valued mappings epi convergence duality maximal monotone mappings second order subderivatives measurable selections and normal integrands The changes in this 3rd printing mainly concern various typographical corrections and reference omissions that came to light in the previous printings Many of these reached the authors notice through their own re reading that of their students and a number of colleagues mentioned in the Preface The authors also included a few telling examples as well as improved a few statements with slightly weaker assumptions or have strengthened the conclusions in a couple of

instances    **Nonsmooth Analysis and Geometric Methods in Deterministic Optimal Control** Boris S. Mordukhovich, Hector J. Sussmann, 2012-12-06 This IMA Volume in Mathematics and its Applications NONSMOOTH ANALYSIS AND GEOMETRIC METHODS IN DETERMINISTIC OPTIMAL CONTROL is based on the proceedings of a workshop that was an integral part of the 1992-93 IMA program on Control Theory. The purpose of this workshop was to concentrate on powerful mathematical techniques that have been developed in deterministic optimal control theory after the basic foundations of the theory. Existence theorems, maximum principle, dynamic programming, sufficiency theorems for sufficiently smooth fields of extremals were laid out in the 1960s. These advanced techniques make it possible to derive much more detailed information about the structure of solutions than could be obtained in the past and they support new algorithmic approaches to the calculation of such solutions. We thank Boris S. Mordukhovich and Hector J. Sussmann for organizing the workshop and editing the proceedings. We also take this opportunity to thank the National Science Foundation and the Army Research Office whose financial support made the workshop possible. A. Friedman, Willard Miller Jr. v. PREFACE. This volume contains the proceedings of the workshop on Nonsmooth Analysis and Geometric Methods in Deterministic Optimal Control held at the Institute for Mathematics and its Applications on February 8-17, 1993 during a special year devoted to Control Theory and its Applications. The workshop whose organizing committee consisted of V. Jurdjevic, B. S. Mordukhovich, R. T. Rockafellar, and H. J. **Algorithms for Chattering Approximations to Relaxed Optimal Controls** Xiaolin Ge, Anil Nerode, Wolf Kohn, Jeffrey B. Remmel, 1995    *Functional Analysis, Calculus of Variations and Optimal Control* Francis Clarke, 2013-02-06 Functional analysis owes much of its early impetus to problems that arise in the calculus of variations. In turn, the methods developed there have been applied to optimal control, an area that also requires new tools such as nonsmooth analysis. This self-contained textbook gives a complete course on all these topics. It is written by a leading specialist who is also a noted expositor. This book provides a thorough introduction to functional analysis and includes many novel elements as well as standard topics. A short course on nonsmooth analysis and geometry completes the first half of the book, whilst the second half concerns the calculus of variations and optimal control. The author provides a comprehensive course on these subjects from their inception through to the present. A notable feature is the inclusion of recent unifying developments on regularity, multiplier rules, and the Pontryagin maximum principle, which appear here for the first time in a textbook. Other major themes include existence and Hamilton-Jacobi methods. The many substantial examples and more than three hundred exercises treat such topics as viscosity solutions, nonsmooth Lagrangians, the logarithmic Sobolev inequality, periodic trajectories, and systems theory. They also touch lightly upon several fields of application: mechanics, economics, resources, finance, control engineering, Functional Analysis, Calculus of Variations, and Optimal Control. This book is intended to support several different courses at the first year or second year graduate level on functional analysis on the calculus of variations and optimal control, or on some combination. For this reason it has been organized with customization in

mind The text also has considerable value as a reference Besides its advanced results in the calculus of variations and optimal control its polished presentation of certain other topics for example convex analysis measurable selections metric regularity and nonsmooth analysis will be appreciated by researchers in these and related fields    **Optimal Control** Richard Vinter,2000-05-19 Each chapter contains a well written introduction and notes They include the author's deep insights on the subject matter and provide historical comments and guidance to related literature This book may well become an important milestone in the literature of optimal control Mathematical Reviews Thanks to a great effort to be self contained this book renders accessibly the subject to a wide audience Therefore it is recommended to all researchers and professionals interested in Optimal Control and its engineering and economic applications It can serve as an excellent textbook for graduate courses in Optimal Control with special emphasis on Nonsmooth Analysis Automatica    **Optimal Control**,

**Stabilization and Nonsmooth Analysis** Marcio S. de Queiroz,Michael Malisoff,Peter Wolenski,2014-03-12 This edited book contains selected papers presented at the Louisiana Conference on Mathematical Control Theory MCT 03 which brought together over 35 prominent world experts in mathematical control theory and its applications The book forms a well integrated exploration of those areas of mathematical control theory in which nonsmooth analysis is having a major impact These include necessary and sufficient conditions in optimal control Lyapunov characterizations of stability input to state stability the construction of feedback mechanisms viscosity solutions of Hamilton Jacobi equations invariance approximation theory impulsive systems computational issues for nonlinear systems and other topics of interest to mathematicians and control engineers The book has a strong interdisciplinary component and was designed to facilitate the interaction between leading mathematical experts in nonsmooth analysis and engineers who are increasingly using nonsmooth analytic tools

**Journal of Nonlinear and Convex Analysis** ,2007    **Transactions of the American Mathematical Society** ,1996  
**Notices of the American Mathematical Society** American Mathematical Society,1993

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