

# *Optimal Control Theory*

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Optimal control theory is a mature mathematical discipline with numerous applications in both science and engineering. It is emerging as the computational framework of choice for studying the neural control of movement, in much the same way that probabilistic inference is emerging as the computational framework of choice for studying sensory information processing. Despite the growing popularity of optimal control models, however, the elaborate mathematical machinery behind them is rarely exposed and the big picture is hard to grasp without reading a few technical books on the subject. While this chapter cannot replace such books, it aims to provide a self-contained mathematical introduction to optimal control theory that is sufficiently broad and yet sufficiently detailed when it comes to key concepts. The text is not tailored to the field of motor control (apart from the last section, and the overall emphasis on systems with continuous state) so it will hopefully be of interest to a wider audience. Of special interest in the context of this book is the material on the duality of optimal control and probabilistic inference; such duality suggests that neural information processing in sensory and motor areas may be more similar than currently thought. The chapter is organized in the following sections:

1. Dynamic programming, Bellman equations, optimal value functions, value and policy iteration, shortest paths, Markov decision processes.
2. Hamilton-Jacobi-Bellman equations, approximation methods, finite and infinite horizon formulations, basics of stochastic calculus.
3. Pontryagin's maximum principle, ODE and gradient descent methods, relationship to classical mechanics.
4. Linear-quadratic-Gaussian control, Riccati equations, iterative linear approximations to nonlinear problems.
5. Optimal recursive estimation, Kalman filter, Zakai equation.
6. Duality of optimal control and optimal estimation (including new results).
7. Optimality models in motor control, promising research directions.

# Optimal Control Theory Optimal Control Theory

**Daniel Léonard, Ngo van Long**



## **Optimal Control Theory Optimal Control Theory:**

Optimal Control Theory Donald E. Kirk, 2012-04-26 Upper level undergraduate text introduces aspects of optimal control theory dynamic programming Pontryagin's minimum principle and numerical techniques for trajectory optimization Numerous figures tables Solution guide available upon request 1970 edition **Introduction to Control Theory,**

**Including Optimal Control** David N. Burghes, Alexander Graham, 1980 *Solutions Manual for Optimal Control Theory* Suresh P. Sethi, Gerald L. Thompson, 1981-04-30 **Optimal Control** Michael Athans, Peter L. Falb, 2007-01-01 Geared toward advanced undergraduate and graduate engineering students this text introduces the theory and applications of optimal control It serves as a bridge to the technical literature enabling students to evaluate the implications of theoretical control work and to judge the merits of papers on the subject Rather than presenting an exhaustive treatise Optimal Control offers a detailed introduction that fosters careful thinking and disciplined intuition It develops the basic mathematical background with a coherent formulation of the control problem and discussions of the necessary conditions for optimality based on the maximum principle of Pontryagin In depth examinations cover applications of the theory to minimum time minimum fuel and to quadratic criteria problems The structure properties and engineering realizations of several optimal feedback control systems also receive attention Special features include numerous specific problems carried through to engineering realization in block diagram form The text treats almost all current examples of control problems that permit analytic solutions and its unified approach makes frequent use of geometric ideas to encourage students intuition

Optimal Control Theory Robert Pallu de La Barrière, 1980 *An Introduction to Optimal Control Theory* Aaron Strauss, 2012-12-06 This paper is intended for the beginner It is not a state of the art paper for research workers in the field of control theory Its purpose is to introduce the reader to some of the problems and results in control theory to illustrate the application of these results and to provide a guide for his further reading on this subject I have tried to motivate the results with examples especially with one canonical simple example described in 3 Many results such as the maximum principle have long and difficult proofs I have omitted these proofs In general I have included only the proofs which are either 1 not too difficult or 2 fairly enlightening as to the nature of the result I have however usually attempted to draw the strongest conclusion from a given proof For example many existing proofs in control theory for compact targets and uniqueness of solutions also hold for closed targets and non uniqueness Finally at the end of each section I have given references to generalizations and origins of the results discussed in that section I make no claim of completeness in the references however as I have often been content merely to refer the reader either to an exposition or to a paper which has an extensive bibliography IV These lecture notes are revisions of notes I used for a series of nine lectures on control theory at the International Summer School on Mathematical Systems and Economics held in Varenna Italy June 1967 **Nonlinear Optimal Control Theory** Leonard David Berkovitz, Negash G. Medhin, 2012-08-25 Nonlinear Optimal Control Theory

presents a deep wide ranging introduction to the mathematical theory of the optimal control of processes governed by ordinary differential equations and certain types of differential equations with memory Many examples illustrate the mathematical issues that need to be addressed when using optimal control techniques in diverse areas Drawing on classroom tested material from Purdue University and North Carolina State University the book gives a unified account of bounded state problems governed by ordinary integrodifferential and delay systems It also discusses Hamilton Jacobi theory By providing a sufficient and rigorous treatment of finite dimensional control problems the book equips readers with the foundation to deal with other types of control problems such as those governed by stochastic differential equations partial differential equations and differential games

### **Introduction to Optimal Control Theory** Jack Macki, Aaron

Strauss, 2012-12-06 This monograph is an introduction to optimal control theory for systems governed by vector ordinary differential equations It is not intended as a state of the art handbook for researchers We have tried to keep two types of reader in mind 1 mathematicians graduate students and advanced undergraduates in mathematics who want a concise introduction to a field which contains nontrivial interesting applications of mathematics for example weak convergence convexity and the theory of ordinary differential equations 2 economists applied scientists and engineers who want to understand some of the mathematical foundations of optimal control theory In general we have emphasized motivation and explanation avoiding the definition axiom theorem proof approach We make use of a large number of examples especially one simple canonical example which we carry through the entire book In proving theorems we often just prove the simplest case then state the more general results which can be proved Many of the more difficult topics are discussed in the Notes sections at the end of chapters and several major proofs are in the Appendices We feel that a solid understanding of basic facts is best attained by at first avoiding excessive generality We have not tried to give an exhaustive list of references preferring to refer the reader to existing books or papers with extensive bibliographies References are given by author s name and the year of publication e g Waltman 1974

*Primer on Optimal Control Theory* Jason L. Speyer, David H. Jacobson, 2010-05-13 A rigorous introduction to optimal control theory which will enable engineers and scientists to put the theory into practice

**Optimal Control Theory and Static Optimization in Economics** Daniel Léonard, Ngo van Long, 1992-01-31 Optimal control theory is a technique being used increasingly by academic economists to study problems involving optimal decisions in a multi period framework This textbook is designed to make the difficult subject of optimal control theory easily accessible to economists while at the same time maintaining rigour Economic intuitions are emphasized and examples and problem sets covering a wide range of applications in economics are provided to assist in the learning process Theorems are clearly stated and their proofs are carefully explained The development of the text is gradual and fully integrated beginning with simple formulations and progressing to advanced topics such as control parameters jumps in state variables and bounded state space For greater economy and elegance optimal control theory is introduced directly without recourse to the calculus of

variations The connection with the latter and with dynamic programming is explained in a separate chapter A second purpose of the book is to draw the parallel between optimal control theory and static optimization Chapter 1 provides an extensive treatment of constrained and unconstrained maximization with emphasis on economic insight and applications Starting from basic concepts it derives and explains important results including the envelope theorem and the method of comparative statics This chapter may be used for a course in static optimization The book is largely self contained No previous knowledge of differential equations is required

Optimal Control Theory Zhongjing Ma,Suli Zou,2021-01-30 This book focuses on how to implement optimal control problems via the variational method It studies how to implement the extrema of functional by applying the variational method and covers the extrema of functional with different boundary conditions involving multiple functions and with certain constraints etc It gives the necessary and sufficient condition for the continuous time optimal control solution via the variational method solves the optimal control problems with different boundary conditions analyzes the linear quadratic regulator tracking problems respectively in detail and provides the solution of optimal control problems with state constraints by applying the Pontryagin s minimum principle which is developed based upon the calculus of variations And the developed results are applied to implement several classes of popular optimal control problems and say minimum time minimum fuel and minimum energy problems and so on As another key branch of optimal control methods it also presents how to solve the optimal control problems via dynamic programming and discusses the relationship between the variational method and dynamic programming for comparison Concerning the system involving individual agents it is also worth to study how to implement the decentralized solution for the underlying optimal control problems in the framework of differential games The equilibrium is implemented by applying both Pontryagin s minimum principle and dynamic programming The book also analyzes the discrete time version for all the above materials as well since the discrete time optimal control problems are very popular in many fields

*Geometric Optimal Control* Heinz Schättler,Urszula Ledzewicz,2012-06-26 This book gives a comprehensive treatment of the fundamental necessary and sufficient conditions for optimality for finite dimensional deterministic optimal control problems The emphasis is on the geometric aspects of the theory and on illustrating how these methods can be used to solve optimal control problems It provides tools and techniques that go well beyond standard procedures and can be used to obtain a full understanding of the global structure of solutions for the underlying problem The text includes a large number and variety of fully worked out examples that range from the classical problem of minimum surfaces of revolution to cancer treatment for novel therapy approaches All these examples in one way or the other illustrate the power of geometric techniques and methods The versatile text contains material on different levels ranging from the introductory and elementary to the advanced Parts of the text can be viewed as a comprehensive textbook for both advanced undergraduate and all level graduate courses on optimal control in both mathematics and engineering departments The text moves smoothly from the more introductory topics to

those parts that are in a monograph style were advanced topics are presented While the presentation is mathematically rigorous it is carried out in a tutorial style that makes the text accessible to a wide audience of researchers and students from various fields including the mathematical sciences and engineering Heinz Sch tler is an Associate Professor at Washington University in St Louis in the Department of Electrical and Systems Engineering Urszula Ledzewicz is a Distinguished Research Professor at Southern Illinois University Edwardsville in the Department of Mathematics and Statistics

**Foundations of Optimal Control Theory** Ernest Bruce Lee, Lawrence Markus, 1967 **Principles of Optimal Control Theory** R. Gamkrelidze, 2013-03-09 In the late 1950 s the group of Soviet mathematicians consisting of L S Pontryagin V G Boltyanskii R V Gamkrelidze and E F Mishchenko made fundamental contributions to optimal control theory Much of their work was collected in their monograph The Mathematical Theory of Optimal Processes Subsequently Professor Gamkrelidze made further important contributions to the theory of necessary conditions for problems of optimal control and general optimization problems In the present monograph Professor Gamkrelidze presents his current view of the fundamentals of optimal control theory It is intended for use in a one semester graduate course or advanced undergraduate course We are now making these ideas available in English to all those interested in optimal control theory West Lafayette Indiana USA Leonard D Berkovitz Translation Editor VII Preface This book is based on lectures I gave at the Tbilisi State University during the fall of 1974 It contains in essence the principles of general control theory and proofs of the maximum principle and basic existence theorems of optimal control theory Although the proofs of the basic theorems presented here are far from being the shortest I think they are fully justified from the conceptual view point In any case the notions we introduce and the methods developed have one unquestionable advantage they are constantly used throughout control theory and not only for the proofs of the theorems presented in this book **Optimal Control**

Bulirsch, Miele, Stoer, Well, 2013-03-08 Optimal Control reports on new theoretical and practical advances essential for analysing and synthesizing optimal controls of dynamical systems governed by partial and ordinary differential equations New necessary and sufficient conditions for optimality are given Recent advances in numerical methods are discussed These have been achieved through new techniques for solving large sized nonlinear programs with sparse Hessians and through a combination of direct and indirect methods for solving the multipoint boundary value problem The book also focuses on the construction of feedback controls for nonlinear systems and highlights advances in the theory of problems with uncertainty Decomposition methods of nonlinear systems and new techniques for constructing feedback controls for state and control constrained linear quadratic systems are presented The book offers solutions to many complex practical optimal control problems **Optimal Control Theory** Suresh P. Sethi, 2018-11-28 This fully revised 3rd edition offers an introduction to optimal control theory and its diverse applications in management science and economics It brings to students the concept of the maximum principle in continuous as well as discrete time by using dynamic programming and Kuhn Tucker theory While

some mathematical background is needed the emphasis of the book is not on mathematical rigor but on modeling realistic situations faced in business and economics The book exploits optimal control theory to the functional areas of management including finance production and marketing and to economics of growth and of natural resources In addition this new edition features materials on stochastic Nash and Stackelberg differential games and an adverse selection model in the principal agent framework The book provides exercises for each chapter and answers to selected exercises to help deepen the understanding of the material presented Also included are appendices comprised of supplementary material on the solution of differential equations the calculus of variations and its relationships to the maximum principle and special topics including the Kalman filter certainty equivalence singular control a global saddle point theorem Sethi Skiba points and distributed parameter systems Optimal control methods are used to determine optimal ways to control a dynamic system The theoretical work in this field serves as a foundation for the book which the author has applied to business management problems developed from his research and classroom instruction The new edition has been completely refined and brought up to date Ultimately this should continue to be a valuable resource for graduate courses on applied optimal control theory but also for financial and industrial engineers economists and operational researchers concerned with the application of dynamic optimization in their fields

**Optimal Control Theory and Economic Analysis 2** Gustav Feichtinger,1985 Optimal Control with Aerospace Applications James M Longuski,José J. Guzmán,John E. Prussing,2013-11-04 Want to know not just what makes rockets go up but how to do it optimally Optimal control theory has become such an important field in aerospace engineering that no graduate student or practicing engineer can afford to be without a working knowledge of it This is the first book that begins from scratch to teach the reader the basic principles of the calculus of variations develop the necessary conditions step by step and introduce the elementary computational techniques of optimal control This book with problems and an online solution manual provides the graduate level reader with enough introductory knowledge so that he or she can not only read the literature and study the next level textbook but can also apply the theory to find optimal solutions in practice No more is needed than the usual background of an undergraduate engineering science or mathematics program namely calculus differential equations and numerical integration Although finding optimal solutions for these problems is a complex process involving the calculus of variations the authors carefully lay out step by step the most important theorems and concepts Numerous examples are worked to demonstrate how to apply the theories to everything from classical problems e g crossing a river in minimum time to engineering problems e g minimum fuel launch of a satellite Throughout the book use is made of the time optimal launch of a satellite into orbit as an important case study with detailed analysis of two examples launch from the Moon and launch from Earth For launching into the field of optimal solutions look no further

**Optimal Control Theory** ,1967 *Calculus of Variations and Optimal Control Theory* Magnus Rudolph Hestenes,1966

The book delves into Optimal Control Theory Optimal Control Theory. Optimal Control Theory Optimal Control Theory is a vital topic that must be grasped by everyone, from students and scholars to the general public. The book will furnish comprehensive and in-depth insights into Optimal Control Theory Optimal Control Theory, encompassing both the fundamentals and more intricate discussions.

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    - Chapter 4: Optimal Control Theory Optimal Control Theory in Specific Contexts
    - Chapter 5: Conclusion
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  3. In chapter 2, the author will delve into the foundational concepts of Optimal Control Theory Optimal Control Theory. This chapter will elucidate the essential principles that need to be understood to grasp Optimal Control Theory Optimal Control Theory in its entirety.
  4. In chapter 3, this book will examine the practical applications of Optimal Control Theory Optimal Control Theory in daily life. The third chapter will showcase real-world examples of how Optimal Control Theory Optimal Control Theory can be effectively utilized in everyday scenarios.
  5. In chapter 4, the author will scrutinize the relevance of Optimal Control Theory Optimal Control Theory in specific contexts. This chapter will explore how Optimal Control Theory Optimal Control Theory is applied in specialized fields, such as education, business, and technology.
  6. In chapter 5, the author will draw a conclusion about Optimal Control Theory Optimal Control Theory. This chapter will summarize the key points that have been discussed throughout the book.
- The book is crafted in an easy-to-understand language and is complemented by engaging illustrations. This book is highly recommended for anyone seeking to gain a comprehensive understanding of Optimal Control Theory Optimal Control Theory.

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