Stochastic Approximation for Expectation Objective and Expectation Inequality-Constrained Nonconvex Optimization

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1 Introduction

In this paper we consider the constrained optimization problem,

$$\min_{x \in \mathbb{R}^n} \quad F(x),$$
$$\text{s.t.} \quad C(x) \le 0, \tag{1}$$

where $F : \mathbb{R}^n \to \mathbb{R}$ and $C : \mathbb{R}^n \to \mathbb{R}^m$ are (generally nonconvex) continuously differentiable. We assume that this is a stochastic optimization problem wherein for all x, $F(x)$ and $C(x)$ are defined to be expectations of functions that depend on random variables ξ and ζ, respectively, defined on a probability space $(\Omega^f \times \Omega^c, \Sigma^f \times \Sigma^c, P_g)$, i.e.,

$$F(x) = \mathbb{E}_{P_g}\left[f(x, \xi)\right], \quad \text{and} \quad C(x) = \mathbb{E}_{P_g}\left[c(x, \zeta)\right]$$

In the sequel we discard, in the notation, the stochastic dependence on P_g. We do not assume any functional form in regards to the dependence of f and c on ξ and ζ. We do allow for dependence between ξ and ζ, in general, however. Thus each noisy function evaluation involves sampling $\sigma \in \Sigma^f \times \Sigma^c$ from the product σ-algebra on the sample space $\Omega^f \times \Omega^c$ based on the probability measure P_g.

As standard for stochastic optimization, this framework is appropriate for large scale instances of learning, where data cannot be stored entirely in memory and mini batch samples must be taken to compute problem information used to calculate the iterate update at each iteration. For instance, a model can be trained on some data while satisfying some maximal loss on another set of data. Alternatively, the optimization problem can define some engineering process that is inherently stochastic and the functions represent its operational performance on some criteria.

We assume, as is standard, that the second moments of the uncertain problem functions are bounded,

$$\exists M, \text{ s.t. } \forall x \in \mathbb{R}^n, \ \mathbb{E}[\|\nabla f(x, \xi)\|^2] \le M, \ \mathbb{E}[\|\nabla c(x, \zeta)\|^2] \le M, \ \mathbb{E}[\|c(x, \zeta)\|^2] \le M,$$
$$\exists T, M, \text{ s.t., } \forall t \le T, x \in \mathbb{R}^n, \ \mathbb{E}\left[e^{t\|\nabla f(x, \xi)\|}\right] \le M, \ \mathbb{E}\left[e^{t\|\nabla c(x, \zeta)\|}\right] \le M, \ \mathbb{E}\left[e^{t\|c(x, \zeta)\|}\right] \le M, \tag{2}$$

We are interested in developing a stochastic approximation algorithm for solving (1). The algorithm and convergence theory will be based upon the method and Ghost penalty framework presented in [11]. There it was shown, among other results, that a modified sequential convex

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Stochastic Approximation and Nonlinear Regression Arthur E. Albert,Leland A. Gardner, Jr.,2003-02-01 This monograph addresses the problem of real time curve fitting in the presence of noise from the computational and statistical viewpoints It examines the problem of nonlinear regression where observations are made on a time series whose mean value function is known except for a vector parameter In contrast to the traditional formulation data are imagined to arrive in temporal succession The estimation is carried out in real time so that at each instant the parameter estimate fully reflects all available data Specifically the monograph focuses on estimator sequences of the so called differential correction type The term differential correction refers to the fact that the difference between the components of the updated and previous estimators is proportional to the difference between the current observation and the value that would be predicted by the regression function if the previous estimate were in fact the true value of the unknown vector parameter The vector of proportionality factors which is generally time varying and can depend upon previous estimates is called the gain or smoothing vector The main purpose of this research is to relate the large sample statistical behavior of such estimates consistency rate of convergence large sample distribution theory asymptotic efficiency to the properties of the regression function and the choice of smoothing vectors Furthermore consideration is given to the tradeoff that can be effected between computational simplicity and statistical efficiency through the choice of gains Part I deals with the special cases of an unknown scalar parameter discussing probability one and mean square convergence rates of mean square convergence and asymptotic distribution theory of the estimators for various choices of the smoothing sequence Part II examines the probability one and mean square convergence of the estimators in the vector case for various choices of smoothing vectors Examples are liberally sprinkled throughout the book Indeed the last chapter is devoted entirely to the discussion of examples at varying levels of generality If one views the stochastic approximation literature as a study in the asymptotic behavior of solutions to a certain class of nonlinear first order difference equations with stochastic driving terms then the results of this monograph also serve to extend and complement many of the results in that literature which accounts for the authors choice of title The book is written at the first year graduate level although this level of maturity is not required uniformly Certainly the reader should understand the concept of a limit both in the deterministic and probabilistic senses i e almost sure and quadratic mean convergence This much will assure a comfortable journey through the first fourth of the book Chapters 4 and 5 require an acquaintance with a few selected central limit theorems A familiarity with the standard techniques of large sample theory will also prove useful but is not essential Part II Chapters 6 through 9 is couched in the language of matrix algebra but none of the classical results used are deep The reader who appreciates the elementary properties of eigenvalues eigenvectors and matrix norms will feel at home MIT Press Research Monograph No 42

Backpropagation Yves Chauvin,David E. Rumelhart,2013-02-01 Composed of three sections this book presents the most

popular training algorithm for neural networks backpropagation The first section presents the theory and principles behind backpropagation as seen from different perspectives such as statistics machine learning and dynamical systems The second presents a number of network architectures that may be designed to match the general concepts of Parallel Distributed Processing with backpropagation learning Finally the third section shows how these principles can be applied to a number of different fields related to the cognitive sciences including control speech recognition robotics image processing and cognitive psychology The volume is designed to provide both a solid theoretical foundation and a set of examples that show the versatility of the concepts Useful to experts in the field it should also be most helpful to students seeking to understand the basic principles of connectionist learning and to engineers wanting to add neural networks in general and backpropagation in particular to their set of problem solving methods **Inference and Learning from Data: Volume 1** Ali H. Sayed,2022-12-22 This extraordinary three volume work written in an engaging and rigorous style by a world authority in the field provides an accessible comprehensive introduction to the full spectrum of mathematical and statistical techniques underpinning contemporary methods in data driven learning and inference This first volume Foundations introduces core topics in inference and learning such as matrix theory linear algebra random variables convex optimization and stochastic optimization and prepares students for studying their practical application in later volumes A consistent structure and pedagogy is employed throughout this volume to reinforce student understanding with over 600 end of chapter problems including solutions for instructors 100 figures 180 solved examples datasets and downloadable Matlab code Supported by sister volumes Inference and Learning and unique in its scale and depth this textbook sequence is ideal for early career researchers and graduate students across many courses in signal processing machine learning statistical analysis data science and inference **Design Methods of Control Systems** D. Franke,F. Kraus,2014-05-23 These Proceedings contain a selection of papers presented at the first IFAC Symposium on Design Methods of Control Systems The volume contains three plenary papers and 97 technical papers the latter classified under 15 section headings as listed in the contents

Recursive Nonlinear Estimation Rudolf Kulhavý,1996-06-25 In a close analogy to matching data in Euclidean space this monograph views parameter estimation as matching of the empirical distribution of data with a model based distribution Using an appealing Pythagorean like geometry of the empirical and model distributions the book brings a new solution to the problem of recursive estimation of non Gaussian and nonlinear models which can be regarded as a specific approximation of Bayesian estimation The cases of independent observations and controlled dynamic systems are considered in parallel the former case giving initial insight into the latter case which is of primary interest to the control community A number of examples illustrate the key concepts and tools used This unique monograph follows some previous results on the Pythagorean theory of estimation in the literature e g Chentsov Csiszar and Amari but extends the results to the case of controlled dynamic systems *Statistical Games and Human Affairs* Roger J. Bowden,1989-03-31 This book puts the

underlying methodology of socioeconomic statistics on a firmer footing by placing it within the ambit of inferential and predictive games It covers such problems as learning publication non response strategic response the nature and possibility of rational expectations time inconsistency intrinsic nonstationarity and the existence of probabilities   *System Identification* James L Melsa,1971-06-26 System Identification   **Applied Mechanics Reviews** ,1986   **Scientific and Technical Aerospace Reports** ,1988-11   *Proceedings of the 1995 American Control Conference* American Automatic Control Council,1995   *Mathematical Reviews* ,2005   **Self-organization and Associative Memory** Teuvo Kohonen,1984   *Cybernetics Abstracts* ,1972   **Asymptotic Convergence of Non-linear, Continuous-time Filters** Michael Wesley Bird,1969   **Design Methods of Control Systems** Dieter Franke,F. Kraus,1992   **Proceedings** ,1973   **Learning from Data** Vladimir S. Cherkassky,Filip Mulier,1998-03-25 Accommodating both beginning and advanced students this book establishes a general conceptual framework in which various learning methods from statistics neural networks and fuzzy logic can be applied showing that a few fundamental principles underlie most new methods being proposed today in the fields of statistics engineering and computer science   The 1996 IEEE International Conference on Neural Networks, June 3-6, 1996, Sheraton Washington Hotel, Washington, DC, USA.: Proceedings ,1996   *Journal of the American Statistical Association* ,1994   **Proceedings of the Joint Automatic Control Conference** ,1980

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