

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,

$$\begin{aligned} \min_{x \in \mathbb{R}^n} \quad & F(x), \\ \text{s.t.} \quad & C(x) \leq 0, \end{aligned} \quad (1)$$

where $F : \mathbb{R}^n \rightarrow \mathbb{R}$ and $C : \mathbb{R}^n \rightarrow \mathbb{R}^m$ 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 $(\Omega^f \times \Omega^c, \Sigma^f \times \Sigma^c, P_x)$, i.e.,

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

In the sequel we discard, in the notation, the stochastic dependence on P_x . 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_x .

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,

$$\begin{aligned} \exists M, \text{ s.t. } \forall x \in \mathbb{R}^n, \mathbb{E}[\|\nabla f(x, \xi)\|^2] &\leq M, \mathbb{E}[\|\nabla c(x, \zeta)\|^2] \leq M, \mathbb{E}[\|c(x, \zeta)\|^2] \leq M, \\ \exists T, M, \text{ s.t. }, \forall t \leq T, x \in \mathbb{R}^n, \mathbb{E}[e^{t\|\nabla f(x, \xi)\|}] &\leq M, \mathbb{E}[e^{t\|\nabla c(x, \zeta)\|}] \leq M, \mathbb{E}[e^{t\|c(x, \zeta)\|}] \leq M, \end{aligned} \quad (2)$$

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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Yves Chauvin, David E. Rumelhart



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Stochastic Approximation and Optimization of Random Systems L. Ljung, G. Pflug, H. Walk, 2012-12-06 The DMV seminar Stochastische Approximation und Optimierung zufälliger Systeme was held at Blaubeuren 28.5.4.6.1989 The goal was to give an approach to theory and application of stochastic approximation in view of optimization problems especially in engineering systems These notes are based on the seminar lectures They consist of three parts I Foundations of stochastic approximation H Walk n Applicational aspects of stochastic approximation G Pflug In Applications to adaptation algorithms L Ljung The prerequisites for reading this book are basic knowledge in probability mathematical statistics optimization We would like to thank Prof M Barner and Prof G Fischer for the organization of the seminar We also thank the participants for their cooperation and our assistants and secretaries for typing the manuscript November 1991 L Ljung G Pflug H Walk Table of contents I Foundations of stochastic approximation H Walk 1 Almost sure convergence of stochastic approximation procedures 2 2 Recursive methods for linear problems 17 3 Stochastic optimization under stochastic constraints 22 4 A learning model recursive density estimation 27 5 Invariance principles in stochastic approximation 30 6 On the theory of large deviations 43 References for Part I 45 11 Applicational aspects of stochastic approximation G Pflug 7 Markovian stochastic optimization and stochastic approximation procedures 53 8 Asymptotic distributions 71 9 Stopping times 79 10 Applications of stochastic approximation methods 80 References for Part II 90 III Applications to adaptation algorithms L

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 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

Applied Mechanics Reviews ,1974 **Scientific and Technical Aerospace Reports** ,1994 **NASA Scientific and Technical Reports** United States. National Aeronautics and Space Administration Scientific and Technical Information Division,1965 Adaptive Systems in Control and Signal Processing 1992 L. Dugard,M. M'Saad,I.D. Landau,2014-06-28 Adaptive Systems remain a very interesting field of theoretical research extended by methodological studies and an increasing number of applications The plenary papers invited sessions and contributed sessions focused on many aspects of adaptive systems such as systems identification and modelling adaptive control of nonlinear systems and theoretical issues in adaptive control Also covered were methodological aspects and applications of adaptive control intelligent tuning and adaptive signal processing **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

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