

# Stochastic Approximation

Cost function.  $J(\mathbf{w})$

Optimal solution.  $\mathbf{w}^{opt}$

Update procedure.  $\mathbf{w}_{t+1} = \mathbf{w}_t + \lambda_t d(\mathbf{w}_{old})$

Convergence.  $\mathbf{w} \rightarrow \mathbf{w}^{opt}$

Criteria.  $E[d(\mathbf{w})] = \nabla J(\mathbf{w})$

- $t \rightarrow \infty$
- $\lambda_t \rightarrow 0$
- $\sum \lambda_t = \infty$

$$\lambda_t = \frac{1}{t} \quad \text{or} \quad \lambda_t = \frac{1}{\sqrt{t}}$$

Caveat. Local minima

# Stochastic Approximation

**M. B. Nevel'son, R. Z. Has'minskii**



## Stochastic Approximation:

**Stochastic Approximation and Recursive Algorithms and Applications** Harold Kushner, G. George Yin, 2006-05-04

The basic stochastic approximation algorithms introduced by Robbins and

Monro and by Kiefer and Wolfowitz in the early 1950s have been the subject of an enormous literature both theoretical and applied. This is due to the large number of applications and the interesting theoretical issues in the analysis of dynamically defined stochastic processes. The basic paradigm is a stochastic difference equation such as  $Y_{n+1} = Y_n + \alpha_n (g(Y_n) + \epsilon_n)$  where  $Y_n$  takes its values in some Euclidean space,  $Y$  is a random variable and the step size  $\alpha_n$  is small and might go to zero as  $n \rightarrow \infty$ . In its simplest form  $Y_n$  is a parameter of a system and the random vector  $\epsilon_n$  is a function of  $n$  noise corrupted observations taken on the system when the parameter is set to  $Y_n$ . One recursively adjusts the parameter so that some goal is met asymptotically.

This book is concerned with the qualitative and asymptotic properties of such recursive algorithms in the diverse forms in which they arise in applications. There are analogous continuous time algorithms but the conditions and proofs are generally very close to those for the discrete time case. The original work was motivated by the problem of finding a root of a continuous function  $g$  where the function is not known but the experimenter is able to take noisy measurements at any desired value of  $Y$ . Recursive methods for root finding are common in classical numerical analysis and it is reasonable to expect that appropriate stochastic analogs would also perform well.

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; II Application aspects of stochastic approximation, G. Pflug; III 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

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III Applications to adaptation algorithms, L. Ljung

**Stochastic Approximation and Its Applications** Hanfu Chen, 2002-08-31

Estimating unknown parameters based on observation data containing information about the parameters is ubiquitous in

diverse areas of both theory and application For example in system identification the unknown system coefficients are estimated on the basis of input output data of the control system in adaptive control systems the adaptive control gain should be defined based on observation data in such a way that the gain asymptotically tends to the optimal one in blind channel identification the channel coefficients are estimated using the output data obtained at the receiver in signal processing the optimal weighting matrix is estimated on the basis of observations in pattern classification the parameters specifying the partition hyperplane are searched by learning and more examples may be added to this list All these parameter estimation problems can be transformed to a root seeking problem for an unknown function To see this let  $\theta$  denote the observation at time  $t$  and  $\theta_t$  the information available about the unknown parameters at time  $t$  It can be assumed that the parameter under estimation denoted by  $\theta$  is a root of some unknown function  $f(\theta)$  This is not a restriction because for example  $f(\theta) = f(\theta) - \theta$  may serve as such a function

Stochastic Approximation Vivek S. Borkar, 2009-01-01      **Stochastic Approximation and Optimization of Random Systems** Lennart Ljung, Georg Ch. Pflug, Harro Walk, 1992-03-31 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 M. T. Wasan, 2004-06-03 A rigorous mathematical treatment of the technique for studying the properties of an experimental situation      **Stochastic Approximation and Recursive Estimation** M. B. Nevel'son, R. Z. Has'minskii, 1976-10-01 This book is devoted to sequential methods of solving a class of problems to which belongs for example the problem of finding a maximum point of a function if each measured value of this function contains a random error Some basic procedures of stochastic approximation are investigated from a single point of view namely the theory of Markov processes and martingales Examples are considered of applications of the theorems to some problems of estimation theory educational theory and

control theory and also to some problems of information transmission in the presence of inverse feedback

Stochastic Approximation and Recursive Estimation Rafail Zalmanovich Has'minskii, B. Silver, **American-Type Options** Dmitrii S. Silvestrov, 2015-03-03 The book gives a systematical presentation of stochastic approximation methods for discrete time Markov price processes Advanced methods combining backward recurrence algorithms for computing of option rewards and general results on convergence of stochastic space skeleton and tree approximations for option rewards are applied to a variety of models of multivariate modulated Markov price processes The principal novelty of presented results is based on consideration of multivariate modulated Markov price processes and general pay off functions which can depend not only on price but also an additional stochastic modulating index component and use of minimal conditions of smoothness for transition probabilities and pay off functions compactness conditions for log price processes and rate of growth conditions for pay off functions The volume presents results on structural studies of optimal stopping domains Monte Carlo based approximation reward algorithms and convergence of American type options for autoregressive and continuous time models as well as results of the corresponding experimental studies

*Adaptive Algorithms and Stochastic Approximations* Albert Benveniste, Michel Metivier, Pierre Priouret, 2012-12-06 Adaptive systems are widely encountered in many applications ranging through adaptive filtering and more generally adaptive signal processing systems identification and adaptive control to pattern recognition and machine intelligence adaptation is now recognised as keystone of intelligence within computerised systems These diverse areas echo the classes of models which conveniently describe each corresponding system Thus although there can hardly be a general theory of adaptive systems encompassing both the modelling task and the design of the adaptation procedure nevertheless these diverse issues have a major common component namely the use of adaptive algorithms also known as stochastic approximations in the mathematical statistics literature that is to say the adaptation procedure once all modelling problems have been resolved The juxtaposition of these two expressions in the title reflects the ambition of the authors to produce a reference work both for engineers who use these adaptive algorithms and for probabilists or statisticians who would like to study stochastic approximations in terms of problems arising from real applications Hence the book is organised in two parts the first one user oriented and the second providing the mathematical foundations to support the practice described in the first part The book covers the topics of convergence convergence rate permanent adaptation and tracking change detection and is illustrated by various realistic applications originating from these areas of applications

American-type Options Dmitrii Sergeevich Sil'vestrov, 2013-11 The book gives a systematical presentation of stochastic approximation methods for models of American type options with general pay off functions for discrete time Markov price processes This book is the first volume of the comprehensive two volumes monograph

Stochastic Approximation and Its Applications Han-Fu Chen, 2013-04-18 Estimating unknown parameters based on observation data containing information about the parameters is ubiquitous in diverse areas of both theory and application For

example in system identification the unknown system coefficients are estimated on the basis of input output data of the control system in adaptive control systems the adaptive control gain should be defined based on observation data in such a way that the gain asymptotically tends to the optimal one in blind channel identification the channel coefficients are estimated using the output data obtained at the receiver in signal processing the optimal weighting matrix is estimated on the basis of observations in pattern classification the parameters specifying the partition hyperplane are searched by learning and more examples may be added to this list All these parameter estimation problems can be transformed to a root seeking problem for an unknown function To see this let note the observation at time  $i$  i.e. the information available about the unknown parameters at time  $i$  It can be assumed that the parameter under estimation denoted by  $\theta$  is a root of some unknown function This is not a restriction because for example  $\theta$  may serve as such a function

Stochastic Approximation: A Dynamical Systems Viewpoint Vivek S. Borkar, 2024-02-05 This book serves as an advanced text for a graduate course on stochastic algorithms for the students of probability and statistics engineering economics and machine learning This second edition gives a comprehensive treatment of stochastic approximation algorithms based on the ordinary differential equation ODE approach which analyses the algorithm in terms of a limiting ODE It has a streamlined treatment of the classical convergence analysis and includes several recent developments such as concentration bounds avoidance of traps stability tests distributed and asynchronous schemes multiple time scales general noise models etc and a category wise exposition of many important applications It is also a useful reference for researchers and practitioners in the field

American-Type Options Dmitrii S. Silvestrov, 2013-11-27 The book gives a systematic presentation of stochastic approximation methods for models of American type options with general pay off functions for discrete time Markov price processes Advanced methods combining backward recurrence algorithms for computing of option rewards and general results on convergence of stochastic space skeleton and tree approximations for option rewards are applied to a variety of models of multivariate modulated Markov price processes The principal novelty of presented results is based on consideration of multivariate modulated Markov price processes and general pay off functions which can depend not only on price but also on an additional stochastic modulating index component and use of minimal conditions of smoothness for transition probabilities and pay off functions compactness conditions for log price processes and rate of growth conditions for pay off functions The book also contains an extended bibliography of works in the area This book is the first volume of the comprehensive two volumes monograph The second volume will present results on structural studies of optimal stopping domains Monte Carlo based approximation reward algorithms and convergence of American type options for autoregressive and continuous time models as well as results of the corresponding experimental studies

Stochastic Approximation and Its Applications Han-Fu Chen, 2010-12-10 Estimating unknown parameters based on observation data containing information about the parameters is ubiquitous in diverse areas of both theory and application For example in system identification the unknown system coefficients are estimated on the basis

of input output data of the control system in adaptive control systems the adaptive control gain should be defined based on observation data in such a way that the gain asymptotically tends to the optimal one in blind channel identification the channel coefficients are estimated using the output data obtained at the receiver in signal processing the optimal weighting matrix is estimated on the basis of observations in pattern classification the parameters specifying the partition hyperplane are searched by learning and more examples may be added to this list All these parameter estimation problems can be transformed to a root seeking problem for an unknown function To see this let note the observation at time  $i$  i.e. the information available about the unknown parameters at time  $i$  It can be assumed that the parameter under estimation denoted by  $\theta$  is a root of some unknown function This is not a restriction because for example  $f(\theta) = \theta - \theta^*$  may serve as such a function

**On Stochastic Approximation** Aryeh Dvoretzky, 1955

**Stochastic Approximation Methods for Constrained and Unconstrained Systems** H.J. Kushner, D.S. Clark, 2012-12-06 The book deals with a powerful and convenient approach to a great variety of types of problems of the recursive monte carlo or stochastic approximation type Such recursive algorithms occur frequently in stochastic and adaptive control and optimization theory and in statistical estimation theory Typically a sequence  $X_n$  of estimates of a  $n$  parameter is obtained by means of some recursive statistical procedure The  $n$  estimate is some function of the  $n-1$  estimate and of some new observational data and the aim is to study the convergence rate of convergence and the parametric dependence and other qualitative properties of the algorithms In this sense the theory is a statistical version of recursive numerical analysis The approach taken involves the use of relatively simple compactness methods Most standard results for Kiefer Wolfowitz and Robbins Monro like methods are extended considerably Constrained and unconstrained problems are treated as is the rate of convergence problem While the basic method is rather simple it can be elaborated to allow a broad and deep coverage of stochastic approximation like problems The approach relating algorithm behavior to qualitative properties of deterministic or stochastic differential equations has advantages in algorithm conceptualization and design It is often possible to obtain an intuitive understanding of algorithm behavior or qualitative dependence upon parameters etc without getting involved in a great deal of detail

*A New Dynamic Stochastic Approximation Procedure* David Ruppert, 1977

*Handbook of Sequential Analysis* B.K. Ghosh, P.K. Sen, 1991-04-24 Sequential analysis refers to the body of statistical theory and methods where the sample size may depend in a random manner on the accumulating data A formal theory in which optimal tests are derived for simple statistical hypotheses in such a framework was developed by Abraham Wald in the early 1940s

**Handbook of Simulation Optimization** Michael C Fu, 2014-11-13 The Handbook of Simulation Optimization presents an overview of the state of the art of simulation optimization providing a survey of the most well established approaches for optimizing stochastic simulation models and a sampling of recent research advances in theory and methodology Leading contributors cover such topics as discrete optimization via simulation ranking and selection efficient simulation budget allocation random search methods response

surface methodology stochastic gradient estimation stochastic approximation sample average approximation stochastic constraints variance reduction techniques model based stochastic search methods and Markov decision processes This single volume should serve as a reference for those already in the field and as a means for those new to the field for understanding and applying the main approaches The intended audience includes researchers practitioners and graduate students in the business engineering fields of operations research management science operations management and stochastic control as well as in economics finance and computer science

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