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Markov Chains Markov Processes and Potential Theory Markov Chains with Stationary Transition Probabilities An Introduction to Markov Processes Markov Chains and Stochastic Stability Markov Chain Monte Carlo in Practice Probability, Markov Chains, Queues, and Simulation Markov Chains: Models, Algorithms and Applications Markov Decision Processes Interactive Markov Chains Markov Processes Markov Random Fields Markov Chain Monte Carlo A First Course in Probability and Markov Chains Markov Chains Markov Processes, Structure and Asymptotic Behavior Finite Markov Processes and Their Applications Markov Processes Markov Chains Markov Chains Poisson Point Processes and Their Application to Markov Processes Handbook of Markov Chain Monte Carlo Gaussian Markov Random Fields Excursions of Markov Processes Approximate Quantum Markov Chains Markov Set-Chains Markov Chains and Mixing Times: Second Edition Markov Chains Markov Processes and Controlled Markov Chains Semi-Markov Processes and Reliability Markov Models for Handwriting Recognition Markov Chains Approximating Countable Markov Chains Inference in Hidden Markov Models Dirichlet Forms and Symmetric Markov Processes Hidden Markov Processes Adaptive Markov Control Processes Hands-On Markov Models with Python Input Modeling with Phase-Type Distributions and Markov Models Analysis and Geometry of Markov Diffusion Operators

This book is a comprehensive treatment of inference for hidden Markov models, including both algorithms and statistical theory. Topics range from filtering and smoothing of the hidden Markov chain to parameter estimation, Bayesian methods and estimation of the number of states. In a unified way the book covers both models with finite state spaces and models with continuous state spaces (also called state-space models) requiring approximate simulation-based algorithms that are also described in detail. Many examples illustrate the algorithms and theory. This book builds on recent developments to present a self-contained view. An extension problem (often called a boundary problem) of Markov processes has been studied, particularly in the case of one-dimensional diffusion processes, by W. Feller, K. Itô, and H. P. McKean, among others. In this book, Itô discussed a case of a general Markov process with state space S and a specified point a ? S called a boundary. The problem is to obtain all possible recurrent extensions of a given minimal process (i.e., the process on S \ {a} which is absorbed on reaching the boundary a). The study in this lecture is restricted to a simpler case of the boundary a being a discontinuous entrance point, leaving a more general case of a continuous entrance point to future works. He established a one-to-one correspondence between a recurrent extension and a pair of a positive measure k(db) on S \ {a} (called the jumping-in measure and a non-negative number m A long time ago I started writing a book about Markov chains, Brownian motion, and diffusion. I soon had two hundred pages of manuscript and my publisher was enthusiastic. Some years and several drafts later, I had a thousand pages of manuscript, and my publisher was less enthusiastic. So we made it a trilogy: Markov Chains Brownian Motion and Diffusion Approximating Countable Markov Chains familiarly - MC, B & D, and ACM. I wrote the first two books for beginning graduate students with some knowledge of probability; if you can follow Sections 10.4 to 10.9 of Markov Chains, you're in. The first two books are quite independent of one another, and completely independent of this one, which is a monograph explaining one way to think about chains with instantaneous states. The results here are supposed to be new, except when there are specific disclaimers. It's written in the framework of Markov chains; we wanted to reprint in this volume the MC chapters needed for reference. but this proved impossible. Most of the proofs in the trilogy are new, and I tried hard to make them explicit. The old ones were often elegant, but I seldom saw what made them go. With my own, I can sometimes show you why things work. And, as I will argue in a minute, my demonstrations are easier technically. If I wrote them down well enough, you may come to agree. For students in pure and applied probability; lots of applications, fairly self-contained. The general theory of stochastic processes and the more specialized theory of Markov processes evolved enormously in the second half of the last century. In parallel, the theory of controlled Markov chains (or Markov decision processes) was being pioneered by control engineers and operations researchers. Researchers in Markov processes and controlled Markov chains have been, for a long time, aware of the synergies between these two subject areas. However, this may be the first volume dedicated to highlighting these synergies and, almost certainly, it is the first volume that emphasizes the contributions of the vibrant and growing Chinese school of probability. The chapters that appear in this book reflect both the maturity and the vitality of modern day Markov processes and controlled Markov chains. They also will provide an opportunity to trace the connections that have emerged between the work done by members of the Chinese school of probability and the work done by the European, US, Central and South American and Asian scholars. The theory of Markov chains, although a special case of Markov processes, is here developed for its own sake and presented on its own merits. In general, the hypothesis of a denumerable state space, which is the defining hypothesis of what we call a "chain" here, generates more clear-cut questions and demands more precise and definitive an swers. For example, the principal limit theorem (§§ 1. 6, II. 10), still the object of research for general Markov processes, is here in its neat final form; and the strong Markov property (§ 11. 9) is here always applicable. While probability theory has advanced far enough that a degree of sophistication is needed even in the limited context of this book, it is still possible here to keep the proportion of definitions to theorems relatively low. . From the standpoint of the general theory of stochastic processes, a continuous parameter Markov chain appears to be the first essentially discontinuous process that has been studied in some detail. It is common that the sample functions of such a chain have discontinuities worse than jumps, and these baser discontinuities play a central role in the theory, of which the mystery remains to be completely unraveled. In this connection the basic concepts of separability and measurability, which are usually applied only at an early stage of the discussion to establish a certain smoothness of the sample functions, are here applied constantly as indispensable tools. Markov process theory provides a mathematical framework for analyzing the elements of randomness that are involved in most real-world dynamical processes. This introductory text, which requires an understanding of ordinary calculus, develops the concepts and results of random variable theory. The Wiley-Interscience Paperback Series consists of selected books that have been made more accessible to consumers in an effort to increase global appeal and general circulation. With these new unabridged softcover volumes, Wiley hopes to extend the lives of these works by making them available to future generations of statisticians, mathematicians, and scientists. "[A]nyone who works with Markov processes whose state space is uncountably infinite will need this most impressive book as a guide and reference." -American Scientist "There is no question but that space should immediately be reserved for [this] book on the library shelf. Those who aspire to mastery of the contents should also reserve a large number of long winter evenings." -Zentralblatt für Mathematik und ihre Grenzgebiete/Mathematics Abstracts "Ethier and Kurtz have produced an excellent treatment of the modern theory of Markov processes that [is] useful both as a reference work and as a graduate textbook." -Journal of Statistical Physics Markov Processes presents several different approaches to proving weak approximation theorems for Markov processes, emphasizing the interplay of methods of characterization and approximation. Martingale problems for general Markov processes are systematically developed for the first time in book form. Useful to the professional as a reference and suitable for the graduate student as a text, this volume features a table of the interdependencies among the theorems, an extensive bibliography, and end-of-chapter problems. The Wiley-Interscience Paperback Series consists of selected booksthat have been made more accessible to consumers in an effort toincrease global appeal and general circulation. With these newunabridged softcover volumes, Wiley hopes to extend the lives ofthese works by making them available to future generations ofstatisticians, mathematicians, and scientists. "This text is unique in bringing together so many resultshitherto found only in part in other texts and papers. . . . Thetext is fairly self-contained, inclusive of some basic mathematicalresults needed, and provides a rich diet of examples, applications,and exercises. The bibliographical material at the end of eachchapter is excellent, not only from a historical perspective, butbecause it is valuable for researchers in acquiring a goodperspective of the MDP research potential." —Zentralblatt fur Mathematik ". . . it is of great value to advanced-level students,researchers, and professional practitioners of this field to havenow a complete volume (with more than 600 pages) devoted to thistopic. . . . Markov Decision Processes: Discrete Stochastic DynamicProgramming represents an up-to-date, unified, and rigoroustreatment of theoretical and computational aspects of discrete-timeMarkov decision processes." —Journal of the American Statistical Association Markov Chains are widely used as stochastic models to study a broad spectrum of system performance and dependability characteristics. This monograph is devoted to compositional specification and analysis of Markov chains. Based on principles known from process algebra, the author systematically develops an algebra of interactive Markov chains. By presenting a number of distinguishing results, of both theoretical and practical nature, the author substantiates the claim that interactive Markov chains are more than just another formalism: Among other, an algebraic theory of interactive Markov chains is developed, devise algorithms to mechanize compositional aggregation are presented, and state spaces of several million states resulting from the study of an ordinary telefone system are analyzed. This book is concerned with a set of related problems in probability theory that are considered in the context of Markov processes. Some of these are natural to consider, especially for Markov processes. Other problems have a broader range of validity but are convenient to pose for Markov processes. The book can be used as the basis for an interesting course on Markov processes or stationary processes. For the most part these questions are considered for discrete parameter processes, although they are also of obvious interest for continuous time parameter processes. This allows one to avoid the delicate measure theoretic questions that might arise in the continuous parameter case. There is an attempt to motivate the material in terms of applications. Many of the topics concern general questions of structure and representation of processes that have not previously been presented in book form. A set of notes comment on the many problems that are still left open and related material in the literature. It is also hoped that the book will be useful as a reference to the reader who would like an introduction to these topics as well as to the reader interested in extending and completing results of this type. Provides an introduction to basic structures of probabilitywith a view towards applications in information technology A First Course in Probability and Markov Chains presentsan introduction to the basic elements in probability and focuses ontwo main areas. The first part explores notions and structures inprobability, including combinatorics, probability measures,probability distributions, conditional probability,inclusion-exclusion formulas, random variables, dispersion indexes,independent random variables as well as weak and strong laws oflarge numbers and central limit theorem. In the second part of thebook, focus is given to Discrete Time Discrete Markov Chains whichis addressed together with an introduction to Poisson processes andContinuous Time Discrete Markov Chains. This book also looks atmaking use of measure theory notations that unify all thepresentation, in particular avoiding the separate treatment ofcontinuous and discrete distributions. A First Course in Probability and Markov Chains: Presents the basic elements of probability. Explores elementary probability with combinatorics, uniformprobability, the inclusion-exclusion principle, independence andconvergence of random variables. Features applications of Law of Large Numbers. Introduces Bernoulli and Poisson processes as well as discreteand continuous time Markov Chains with discrete states. Includes illustrations and examples throughout, along withsolutions to problems featured in this book. The authors present a unified and comprehensive overview ofprobability and Markov Chains aimed at educating engineers workingwith probability and statistics as well as advanced undergraduatestudents in sciences and engineering with a basic background inmathematical analysis and linear algebra. This book is an introduction to quantum Markov chains and explains how this concept is connected to the question of how well a lost quantum mechanical system can be recovered from a correlated subsystem. To achieve this goal, we strengthen the data-processing inequality such that it reveals a statement about the reconstruction of lost information. The main difficulty in order to understand the behavior of quantum Markov chains arises from the fact that quantum mechanical operators do not commute in general. As a result we start by explaining two techniques of how to deal with non-commuting matrices: the spectral pinching method and complex interpolation theory. Once the reader is familiar with these techniques a novel inequality is presented that extends the celebrated Golden-Thompson inequality to arbitrarily many matrices. This inequality is the key ingredient in understanding approximate quantum Markov chains and it answers a question from matrix analysis that was open since 1973, i.e., if Lieb's triple matrix inequality can be extended to more than three matrices. Finally, we carefully discuss the properties of approximate quantum Markov chains and their implications. The book is aimed to graduate students who want to learn about approximate quantum Markov chains as well as more experienced scientists who want to enter this field. Mathematical majority is necessary, but no prior knowledge of quantum mechanics is required. This graduate-level text explores the relationship between Markov processes and potential theory, in addition to aspects of the theory of additive functionals. Topics include Markov processes, excessive functions, multiplicative functionals and subprocesses, and additive functionals and their potentials. A concluding chapter examines dual processes and potential theory. 1968 edition. Provides a more accessible introduction than other books on Markov processes by emphasizing the structure of the subject and avoiding sophisticated measure theory Leads the reader to a rigorous understanding of basic theory Since their first inception, automatic reading systems have evolved substantially, yet the recognition of handwriting remains an open research problem due to its substantial variation in appearance. With the introduction of Markovian models to the field, a promising modeling and recognition paradigm was established for automatic handwriting recognition. However, no standard procedures for building Markov model-based recognizers have yet been established. This text provides a comprehensive overview of the application of Markov models in the field of handwriting recognition, covering both hidden Markov models and Markov-chain or n-gram models. First, the text introduces the typical architecture of a Markov model-based handwriting recognition system, and familiarizes the reader with the essential theoretical concepts behind Markovian models. Then, the text reviews proposed solutions in the literature for open problems in applying Markov model-based approaches to automatic handwriting recognition. Fundamental concepts of Markov chains; The classical approach to markov chains; The algebraic approach to Markov chains; Nonstationary Markov chains and the ergodic coeficient; Analysis of a markov chain on a computer; Continuous time Markov chains. Self-contained treatment covers both theory and applications. Topics include the fundamental role of homogeneous infinite Markov chains in the mathematical modeling of psychology and genetics. 1980 edition. In a family study of breast cancer, epidemiologists in Southern California increase the power for detecting a gene-environment interaction. In Gambia, a study helps a vaccination program reduce the incidence of Hepatitis B carriage. Archaeologists in Austria place a Bronze Age site in its true temporal location on the calendar scale. And in France, researchers map a rare disease with relatively little variation. Each of these studies applied Markov chain Monte Carlo methods to produce more accurate and inclusive results. General state-space Markov chain theory has seen several developments that have made it both more accessible and more powerful to the general statistician. Markov Chain Monte Carlo in Practice introduces MCMC methods and their applications, providing some theoretical background as well. The authors are researchers who have made key contributions in the recent development of MCMC methodology and its application. Considering the broad audience, the editors emphasize practice rather than theory, keeping the technical content to a minimum. The examples range from the simplest application, Gibbs sampling, to more complex applications. The first chapter contains enough information to allow the reader to start applying MCMC in a basic way. The following chapters cover main issues, important concepts and results, techniques for implementing MCMC, improving its performance, assessing model adequacy, choosing between models, and applications and their domains. Markov Chain Monte Carlo in Practice is a thorough, clear introduction to the methodology and applications of this simple idea with enormous potential. It shows the importance of MCMC in real applications, such as archaeology, astronomy, biostatistics, genetics, epidemiology, and image analysis, and provides an excellent base for MCMC to be applied to other fields as well. This volume contains recent information on topics of fundamental importance in comparative endocrinology and reproduction. It comprises 35 chapters on the following topics: hypothalamus and pituitary, gonads and reproduction, pineal gland, hormones and general metabolism. The book will be a valuable source of recent information and reference for students, teachers and scientists engaged in teaching and research in comparative endocrinology and reproduction. This book is concerned with a class of discrete-time stochastic control processes known as controlled Markov processes (CMP's), also known as Markov decision processes or Markov dynamic programs. Starting in the mid-1950swith Richard Bellman, many contributions to CMP's have been made, and applications to engineering, statistics and operations research, among other areas, have also been developed. The purpose of this book is to present some recent developments on the theory of adaptive CMP's, i. e. , CMP's that depend on unknown parameters. Thus at each decision time, the controller or decision-maker must estimate the true parameter values, and then adapt the control actions to the estimated values. We do not intend to describe all aspects of stochastic adaptive control; rather, the selection of material reflects our own research interests. The prerequisite for this book is a knowledgeof real analysis and prob ability theory at the level of, say, Ash (1972) or Royden (1968), but no previous knowledge of control or decision processes is required. The pre sentation, on the other hand, is meant to beself-contained,in the sensethat whenever a result from analysisor probability is used, it is usually stated in full and references are supplied for further discussion, if necessary. Several appendices are provided for this purpose. The material is divided into six chapters. Chapter 1 contains the basic definitions about the stochastic control problems we are interested in; a brief description of some applications is also provided. In this book we study Markov random functions of several variables. What is traditionally meant by the Markov property for a random process (a random function of one time variable) is connected to the concept of the phase state of the process and refers to the independence of the behavior of the process in the future from its behavior in the past, given knowledge of its state at the present moment. Extension to a generalized random process immediately raises nontrivial questions about the definition of a suitable" phase state," so that given the state, future behavior does not depend on past behavior. Attempts to translate the Markov property to random functions of multi-dimensional "time," where the role of "past" and "future" are taken by arbitrary complementary regions in an appro priate multi-dimensional time domain have, until comparatively recently, been carried out only in the framework of isolated examples. How the Markov property should be formulated for generalized random functions of several variables is the principal question in this book. We think that it has been substantially answered by recent results establishing the Markov property for a whole collection of different classes of random functions. These results are interesting for their applications as well as for the theory. In establishing them, we found it useful to introduce a general probability model which we have called a random field. In this book we investigate random fields on continuous time domains. Contents CHAPTER 1 General Facts About Probability Distributions §1. Gaussian Markov Random Field (GMRF) models are most widely used in spatial statistics - a very active area of research in which few up-to-date reference works are available. This is the first book on the subject that provides a unified framework of GMRFs with particular emphasis on the computational aspects. This book includes extensive case-studie While there have been few theoretical contributions on the Markov Chain Monte Carlo (MCMC) methods in the past decade, current understanding and application of MCMC to the solution of inference problems has increased by leaps and bounds. Incorporating changes in theory and highlighting new applications, Markov Chain Monte Carlo: Stochastic Simulation for Bayesian Inference, Second Edition presents a concise, accessible, and comprehensive introduction to the methods of this valuable simulation technique. The second edition includes access to an internet site that provides the code, written in R and WinBUGS, used in many of the previously existing and new examples and exercises. More importantly, the self-explanatory nature of the codes will enable modification of the inputs to the codes and variation on many directions will be available for further exploration. Major changes from the previous edition: · More examples with discussion of computational details in chapters on Gibbs sampling and Metropolis-Hastings algorithms · Recent developments in MCMC, including reversible jump, slice sampling, bridge sampling, path sampling, multiple-try, and delayed rejection · Discussion of computation using both R and WinBUGS · Additional exercises and selected solutions within the text, with all data sets and software available for download from the Web · Sections on spatial models and model adequacy The self-contained text units make MCMC accessible to scientists in other disciplines as well as statisticians. The book will appeal to everyone working with MCMC techniques, especially research and graduate statisticians and biostatisticians, and scientists handling data and formulating models. The book has been substantially reinforced as a first reading of material on MCMC and, consequently, as a textbook for modern Bayesian computation and Bayesian inference courses. Primarily an introduction to the theory of stochastic processes at the undergraduate or beginning graduate level, the primary objective of this book is to initiate students in the art of stochastic modelling. However it is motivated by significant applications and progressively brings the student to the borders of contemporary research. Examples are from a wide range of domains, including operations research and electrical engineering. Researchers and students in these areas as well as in physics, biology and the social sciences will find this book of interest. This book explores important aspects of Markov and hidden Markov processes and the applications of these ideas to various problems in computational biology. The book starts from first principles, so that no previous knowledge of probability is necessary. However, the work is rigorous and mathematical, making it useful to engineers and mathematicians, even those not interested in biological applications. A range of exercises is provided, including drills to familiarize the reader with concepts and more advanced problems that require deep thinking about the theory. Biological applications are taken from post-genomic biology, especially genomics and proteomics. The topics examined include standard material such as the Perron-Frobenius theorem, transient and recurrent states, hitting probabilities and hitting times, maximum likelihood estimation, the Viterbi algorithm, and the Baum-Welch algorithm. The book contains discussions of extremely useful topics not usually seen at the basic level, such as ergodicity of Markov processes, Markov Chain Monte Carlo (MCMC), information theory, and large deviation theory for both i.i.d and Markov processes. The book also presents state-of-the-art realization theory for hidden Markov models. Among biological applications, it offers an in-depth look at the BLAST (Basic Local Alignment Search Technique) algorithm, including a comprehensive explanation of the underlying theory. Other applications such as profile hidden Markov models are also explored. At first there was the Markov property. The theory of stochastic processes, which can be considered as an exten sion of probability theory, allows the modeling of the evolution of systems through the time. It cannot be properly understood just as pure mathemat ics, separated from the body of experience and examples that have brought it to life. The theory of stochastic processes entered a period of intensive develop ment, which is not finished yet, when the idea of the Markov property was brought in. Not even a serious study of the renewal processes is possible without using the strong tool of Markov processes. The modern theory of Markov processes has its origins in the studies by A. A: Markov (1856-1922) of sequences of experiments "connected in a chain" and in the attempts to describe mathematically the physical phenomenon known as Brownian mo tion. Later, many generalizations (in fact all kinds of weakenings of the Markov property) of Markov type stochastic processes were proposed. Some of them have led to new classes of stochastic processes and useful applications. Let us mention some of them: systems with complete connections [90, 91, 45, 86]; K-dependent Markov processes [44]; semi-Markov processes, and so forth. The semi-Markov processes generalize the renewal processes as well as the Markov jump processes and have numerous applications, especially in relia bility. A long time ago I started writing a book about Markov chains, Brownian motion, and diffusion. I soon had two hundred pages of manuscript and my publisher was enthusiastic. Some years and several drafts later, I had a thousand pages of manuscript, and my publisher was less enthusiastic. So we made it a trilogy: Markov Chains Brownian Motion and Diffusion Approximating Countable Markov Chains familiarly - MC, B & D, and ACM. I wrote the first two books for beginning graduate students with some knowledge of probability; if you can follow Sections 10.4 to 10.9 of Markov Chains you're in. The first two books are quite independent of one another, and completely independent of the third. This last book is a monograph which explains one way to think about chains with instantaneous states. The results in it are supposed to be new, except where there are specific disclaim ers; it's written in the framework of Markov Chains. Most of the proofs in the trilogy are new, and I tried hard to make them explicit. The old ones were often elegant, but I seldom saw what made them go. With my own, I can sometimes show you why things work. And, as I will VB1 PREFACE argue in a minute, my demonstrations are easier technically. If I wrote them down well enough, you may come to agree. New up-to-date edition of this influential classic on Markov chains in general state spaces. Proofs are rigorous and concise, the range of applications is broad and knowledgeable, and key ideas are accessible to practitioners with limited mathematical background. New commentary by Sean Meyn, including updated references, reflects developments since 1996. The present volume is an extensive monograph on the analytic and geometric aspects of Markov diffusion operators. It focuses on the geometric curvature properties of the underlying structure in order to study convergence to equilibrium, spectral bounds, functional inequalities such as Poincaré, Sobolev or logarithmic Sobolev inequalities, and various bounds on solutions of evolution equations. At the same time, it covers a large class of evolution and partial differential equations. The book is intended to serve as an introduction to the subject and to be accessible for beginning and advanced scientists and non-specialists. Simultaneously, it covers a wide range of results and techniques from the early developments in the mid-eighties to the latest achievements. As such, students and researchers interested in the modern aspects of Markov diffusion operators and semigroups and their connections to analytic functional inequalities, probabilistic convergence to equilibrium and geometric curvature will find it especially useful. Selected chapters can also be used for advanced courses on the topic. Since the publication of the first edition in 1994, this book has attracted constant interests from readers and is by now regarded as a standard reference for the theory of Dirichlet forms. For the present second edition, the authors not only revise Let {Xti t ~ O} be a Markov process in Rl, and break up the path X t into (random) component pieces consisting of the zero set ({ tlX = O}) and t the "excursions away from 0," that is pieces of path X. : T ::5 s ::5 t, with Xr- = X = 0, but X. 1= 0 for T This book covers the classical theory of Markov chains on general state-spaces as well as many recent developments. The theoretical results are illustrated by simple examples, many of which are taken from Markov Chain Monte Carlo methods. The book is self-contained, while all the results are carefully and concisely proven. Bibliographical notes are added at the end of each chapter to provide an overview of the literature. Part I lays the foundations of the theory of Markov chain on general states-space. Part II covers the basic theory of irreducible Markov chains on general states-space, relying heavily on regeneration techniques. These two parts can serve as a text on general state-space applied Markov chain theory. Although the choice of topics is quite different from what is usually covered, where most of the emphasis is put on countable state space, a graduate student should be able to read almost all these developments without any mathematical background deeper than that needed to study countable state space (very little measure theory is required). Part III covers advanced topics on the theory of irreducible Markov chains. The emphasis is on geometric and subgeometric convergence rates and also on computable bounds. Some results appeared for a first time in a book and others are original. Part IV are selected topics on Markov chains, covering mostly hot recent developments. This book is an introduction to the modern theory of Markov chains, whose goal is to determine the rate of convergence to the stationary distribution, as a function of state space size and geometry. This topic has important connections to combinatorics, statistical physics, and theoretical computer science. Many of the techniques presented originate in these disciplines. The central tools for estimating convergence times, including coupling, strong stationary times, and spectral methods, are developed. The authors discuss many examples, including card shuffling and the Ising model, from statistical mechanics, and present the connection of random walks to electrical networks and apply it to estimate hitting and cover times. The first edition has been used in courses in mathematics and computer science departments of numerous universities. The second edition features three new chapters (on monotone chains, the exclusion process, and stationary times) and also includes smaller additions and corrections throughout. Updated notes at the end of each chapter inform the reader of recent research developments. Unleash the power of unsupervised machine learning in Hidden Markov Models using TensorFlow, pgmpy, and hmmlearn Key FeaturesBuild a variety of Hidden Markov Models (HMM)Create and apply models to any sequence of data to analyze, predict, and extract valuable insightsUse natural language processing (NLP) techniques and 2D-HMM model for image segmentationBook Description Hidden Markov Model (HMM) is a statistical model based on the Markov chain concept. Hands-On Markov Models with Python helps you get to grips with HMMs and different inference algorithms by working on real-world problems. The hands-on examples explored in the book help you simplify the process flow in machine learning by using Markov model concepts, thereby making it accessible to everyone. Once you've covered the basic concepts of Markov chains, you'll get insights into Markov processes, models, and types with the help of practical examples. After grasping these fundamentals, you'll move on to learning about the different algorithms used in inferences and applying them in state and parameter inference. In addition to this, you'll explore the Bayesian approach of inference and learn how to apply it in HMMs. In further chapters, you'll discover how to use HMMs in time series analysis and natural language processing (NLP) using Python. You'll also learn to apply HMM to image processing using 2D-HMM to segment images. Finally, you'll understand how to apply HMM for reinforcement learning (RL) with the help of Q-Learning, and use this technique for single-stock and multi-stock algorithmic trading. By the end of this book, you will have grasped how to build your own Markov and hidden Markov models on complex datasets in order to apply them to projects. What you will learnExplore a balance of both theoretical and practical aspects of HMMImplement HMMs using different datasets in Python using different packagesUnderstand multiple inference algorithms and how to select the right algorithm to resolve your problemsDevelop a Bayesian approach to inference in HMMsImplement HMMs in finance, natural language processing (NLP), and image processingDetermine the most likely sequence of hidden states in an HMM using the Viterbi algorithmWho this book is for Hands-On Markov Models with Python is for you if you are a data analyst, data scientist, or machine learning developer and want to enhance your machine learning knowledge and skills. This book will also help you build your own hidden Markov models by applying them to any sequence of data. Basic knowledge of machine learning and the Python programming language is expected to get the most out of the book Since their popularization in the 1990s, Markov chain Monte Carlo (MCMC) methods have revolutionized statistical computing and have had an especially profound impact on the practice of Bayesian statistics. Furthermore, MCMC methods have enabled the development and use of intricate models in an astonishing array of disciplines as diverse as fisheries science and economics. The wide-ranging practical importance of MCMC has sparked an expansive and deep investigation into fundamental Markov chain theory. The Handbook of Markov Chain Monte Carlo provides a reference for the broad audience of developers and users of MCMC methodology interested in keeping up with cutting-edge theory and applications. The first half of the book covers MCMC foundations, methodology, and algorithms. The second half considers the use of MCMC in a variety of practical applications including in educational research, astrophysics, brain imaging, ecology, and sociology. The in-depth introductory section of the book allows graduate students and practicing scientists new to MCMC to become thoroughly acquainted with the basic theory, algorithms, and applications. The book supplies detailed examples and case studies of realistic scientific problems presenting the diversity of methods used by the wide-ranging MCMC community. Those familiar with MCMC methods will find this book a useful refresher of current theory and recent developments. Containing a summary of several recent results on Markov-based input modeling in a coherent notation, this book introduces and compares algorithms for parameter fitting and gives an overview of available software tools in the area. Due to progress made in recent years with respect to new algorithms to generate PH distributions and Markovian arrival processes from measured data, the models outlined are useful alternatives to other distributions or stochastic processes used for input modeling. Graduate students and researchers in applied probability, operations research and computer science along with practitioners using simulation or analytical models for performance analysis and capacity planning will find the unified notation and up-to-date results presented useful. Input modeling is the key step in model based system analysis to adequately describe the load of a system using stochastic models. The goal of input modeling is to find a stochastic model to describe a sequence of measurements from a real system to model for example the inter-arrival times of packets in a computer network or failure times of components in a manufacturing plant. Typical application areas are performance and dependability analysis of computer systems, communication networks, logistics or manufacturing systems but also the analysis of biological or chemical reaction networks and similar problems. Often the measured values have a high variability and are correlated. It's been known for a long time that Markov based models like phase type distributions or Markovian arrival processes are very general and allow one to capture even complex behaviors. However, the parameterization of these models results often in a complex and non-linear optimization problem. Only recently, several new results about the modeling capabilities of Markov based models and algorithms to fit the parameters of those models have been published.? A fascinating and instructive guide to Markov chains for experienced users and newcomers alike This unique guide to Markov chains approaches the subject along the four convergent lines of mathematics, implementation, simulation, and experimentation. It introduces readers to the art of stochastic modeling, shows how to design computer implementations, and provides extensive worked examples with case studies. Markov Chains: From Theory to Implementation and Experimentation begins with a general introduction to the history of probability theory in which the author uses quantifiable examples to illustrate how probability theory arrived at the concept of discrete-time and the Markov model from experiments involving independent variables. An introduction to simple stochastic matrices and transition probabilities is followed by a simulation of a two-state Markov chain. The notion of steady state is explored in connection with the long-run distribution behavior of the Markov chain. Predictions based on Markov chains with more than two states are examined, followed by a discussion of the notion of absorbing Markov chains. Also covered in detail are topics relating to the average time spent in a state, various chain configurations, and n-state Markov chain simulations used for verifying experiments involving various diagram configurations. • Fascinating historical notes shed light on the key ideas that led to the development of the Markov model and its variants • Various configurations of Markov Chains and their limitations are explored at length • Numerous examples—from basic to complex—are presented in a comparative manner using a variety of color graphics • All algorithms presented can be analyzed in either Visual Basic, Java Script, or PHP • Designed to be useful to professional statisticians as well as readers without extensive knowledge of probability theory Covering both the theory underlying the Markov model and an array of Markov chain implementations, within a common conceptual framework, Markov Chains: From Theory to Implementation and Experimentation is a stimulating introduction to and a valuable reference for those wishing to deepen their understanding of this extremely valuable statistical tool. Paul A. Gagniuc, PhD, is Associate Professor at Polytechnic University of Bucharest, Romania. He obtained his MS and his PhD in genetics at the University of Bucharest. Dr. Gagniuc's work has been published in numerous high profile scientific journals, ranging from the Public Library of Science to BioMed Central and Nature journals. He is the recipient of several awards for exceptional scientific results and a highly active figure in the review process for different scientific areas. Probability, Markov Chains, Queues, and Simulation provides a modern and authoritative treatment of the mathematical processes that underlie performance modeling. The detailed explanations of mathematical derivations and numerous illustrative examples make this textbook readily accessible to graduate and advanced undergraduate students taking courses in which stochastic processes play a fundamental role. The textbook is relevant to a wide variety of fields, including computer science, engineering, operations research, statistics, and mathematics. The textbook looks at the fundamentals of probability theory, from the basic concepts of set-based probability, through probability distributions, to bounds, limit theorems, and the laws of large numbers. Discrete and continuous-time Markov chains are analyzed from a theoretical and computational point of view. Topics include the Chapman-Kolmogorov equations; irreducibility; the potential, fundamental, and reachability matrices; random walk problems; reversibility; renewal processes; and the numerical computation of stationary and transient distributions. The M/M/1 queue and its extensions to more general birth-death processes are analyzed in detail, as are queues with phase-type arrival and service processes. The M/G/1 and G/M/1 queues are solved using embedded Markov chains; the busy period, residual service time, and priority scheduling are treated. Open and closed queueing networks are analyzed. The final part of the book addresses the mathematical basis of simulation. Each chapter of the textbook concludes with an extensive set of exercises. An instructor's solution manual, in which all exercises are completely worked out, is also available (to professors only). Numerous examples illuminate the mathematical theories Carefully detailed explanations of mathematical derivations guarantee a valuable pedagogical approach Each chapter concludes with an extensive set of exercises Markov chains are a particularly powerful and widely used tool for analyzing a variety of stochastic (probabilistic) systems over time. This monograph will present a series of Markov models, starting from the basic models and then building up to higher-order models. Included in the higher-order discussions are multivariate models, higher-order multivariate models, and higher-order hidden models. In each case, the focus is on the important kinds of applications that can be made with the class of models being considered in the current chapter. Special attention is given to numerical algorithms that can efficiently solve the models. Therefore, Markov Chains: Models, Algorithms and Applications outlines recent developments of Markov chain models for modeling queueing sequences, Internet, re-manufacturing systems, reverse logistics, inventory systems, bio-informatics, DNA sequences, genetic networks, data mining, and many other practical systems.