Markov Chains Springer

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 thot:sand 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 - Me, B & D, and ACM. I wrote the first two books for beginning graduate students with some knowledge of probability; if you can follow Sections 3.4 to 3.9 of Brownian Motion and Diffusion 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 spe cific disclaimers; 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 argue in a minute, my demonstrations are easier technically. If I wrote them down well enough, you may come to agree.

Since its inception by Perron and Frobenius, the theory of non-negative matrices has developed enormously and is now being used and extended in applied fields of study as diverse as probability theory, numerical analysis, demography, mathematical economics, and dynamic programming, while its development is still proceeding rapidly as a branch of pure mathematics in its own right. While there are books which cover this or that aspect of the theory, it is nevertheless not uncommon for workers in one or another branch of its development to be unaware of what is known in other branches, even though there is often formal overlap. One of the purposes of this book is to relate several aspects of the theory, insofar as this is possible. The author hopes that the book will be useful to mathematicians; but in particular to the workers in applied fields, so the mathematics has been kept as simple as could be managed. The mathematical requisites for reading it are: some knowledge of real-variable theory, and matrix theory; and a little knowledge of complex-variable; the emphasis is on real-variable methods. (There is only one part of the book, the second part of 55.5, which is of rather specialist interest, and requires deeper knowledge.) Appendices provide brief expositions of those areas of mathematics needed which may be less g- erally known to the average reader.

Discrete probability theory and the theory of algorithms have become close partners over the last ten years, though the roots of this partnership go back much longer. The papers in this volume address the latest developments in this active field. They are from the IMA Workshops "Probability and Algorithms" and "The Finite Markov Chain Renaissance." They represent the current thinking of many of the world's leading experts in the field. Researchers and graduate students in probability, computer science, combinatorics, and optimization theory will all be interested in this collection of articles. The techniques developed and surveyed in this volume are still undergoing rapid development, and many of the articles of the collection offer an expositionally pleasant entree into a research area of growing importance.

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.

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.

The emphasis in this book is placed on general models (Markov chains, random fields, random graphs), universal methods (the probabilistic method, the coupling method, the Stein-Chen method, martingale methods, the method of types) and versatile tools (Chernoff's bound, Hoeffding's inequality, Holley's inequality) whose domain of application extends far beyond the present text. Although the examples treated in the book relate to the possible applications, in the communication and computing sciences, in operations research and in physics, this book is in the first instance concerned with theory. The level of the book is that of a beginning graduate course. It is self-contained, the prerequisites consisting merely of basic calculus (series) and basic linear algebra (matrices). The reader is not assumed to be trained in probability since the first chapters give in considerable detail the background necessary to understand the rest of the book.

The study of M-matrices, their inverses and discrete potential theory is now a well-established part of linear algebra and the theory of Markov chains. The main focus of this monograph is the so-called inverse M-matrix problem, which asks for a characterization of nonnegative matrices whose inverses are M-matrices. We present an answer in terms of discrete potential theory based on the Choquet-Deny Theorem. A distinguished subclass of inverse M-matrices is ultrametric matrices, which are important in applications such as taxonomy. Ultrametricity is revealed to be a relevant concept in linear algebra and discrete potential theory because of its relation with trees in graph theory and mean expected value matrices in probability theory. Remarkable properties of Hadamard functions and products for the class of inverse M-matrices are developed and probabilistic insights are provided throughout the monograph.

Markov Chains and Stochastic Stability is part of the Communications and Control Engineering Series (CCES) edited by Professors B.W. Dickinson, E.D. Sontag, M. Thoma, A. Fettweis, J.L. Massey and J.W. Modestino. The area of Markov chain theory and application has matured over the past 20 years into something more accessible and complete. It is of increasing interest and importance. This publication deals with the action of Markov chains on general state spaces. It discusses the theories and the use to be gained, concentrating on the areas of engineering, operations research and control theory. Throughout, the theme of stochastic stability and the search for practical methods of verifying such stability, provide a new and powerful technique. This does not only affect applications but also the development of the theory itself. The impact of the theory on specific models is discussed in detail, in order to provide examples as well as to demonstrate the importance of these models. Markov Chains and

Stochastic Stability can be used as a textbook on applied Markov chain theory, provided that one concentrates on the main aspects only. It is also of benefit to graduate students with a standard background in countable space stochastic models. Finally, the book can serve as a research resource and active tool for practitioners.

Here is a work that adds much to the sum of our knowledge in a key area of science today. It is concerned with the estimation of discrete-time semi-Markov and hidden semi-Markov processes. A unique feature of the book is the use of discrete time, especially useful in some specific applications where the time scale is intrinsically discrete. The models presented in the book are specifically adapted to reliability studies and DNA analysis. The book is mainly intended for applied probabilists and statisticians interested in semi-Markov chains theory, reliability and DNA analysis, and for theoretical oriented reliability and bioinformatics engineers.

This book gives a systematic treatment of singularly perturbed systems that naturally arise in control and optimization, queueing networks, manufacturing systems, and financial engineering. It presents results on asymptotic expansions of solutions of Komogorov forward and backward equations, properties of functional occupation measures, exponential upper bounds, and functional limit results for Markov chains with weak and strong interactions. To bridge the gap between theory and applications, a large portion of the book is devoted to applications in controlled dynamic systems, production planning, and numerical methods for controlled Markovian systems with large-scale and complex structures in the real-world problems. This second edition has been updated throughout and includes two new chapters on asymptotic expansions of solutions for backward equations and hybrid LQG problems. The chapters on analytic and probabilistic properties of two-time-scale Markov chains have been almost completely rewritten and the notation has been streamlined and simplified. This book is written for applied mathematicians, engineers, operations researchers, and applied scientists. Selected material from the book can also be used for a one semester advanced graduate-level course in applied probability and stochastic processes.

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.

Building upon the previous editions, this textbook is a first course in stochastic processes taken by undergraduate and graduate students (MS and PhD students from math, statistics, economics, computer science, engineering, and finance departments) who have had a course in probability theory. It covers Markov chains in discrete and continuous time, Poisson processes, renewal processes, martingales, and option pricing. One can only learn a subject by seeing it in action, so there are a large number of examples and more than 300 carefully chosen exercises to deepen the reader's understanding. Drawing from teaching experience and student feedback, there are many new examples and problems with solutions that use TI-83 to eliminate the tedious details of solving linear equations by hand, and the collection of exercises is much improved, with many more biological examples. Originally included in previous editions, material too advanced for this first course in stochastic processes has been eliminated while treatment of other topics useful for applications has been expanded. In addition, the ordering of topics has been improved; for example, the difficult subject of martingales is delayed until its usefulness can be applied in the treatment of mathematical finance.

This book focuses on two-time-scale Markov chains in discrete time. Our motivation stems from existing and emerging applications in optimization and control of complex systems in manufacturing, wireless communication, and ?nancial engineering. Much of our e?ort in this book is devoted to designing system models arising from various applications, analyzing them via analytic and probabilistic techniques, and developing feasible compu- tionalschemes. Ourmainconcernistoreducetheinherentsystemcompl- ity. Although each of the applications has its own distinct characteristics, all of them are closely related through the modeling of uncertainty due to jump or switching random processes. Oneofthesalientfeaturesofthisbookistheuseofmulti-timescalesin Markovprocessesandtheirapplications. Intuitively,notallpartsorcom- nents of a large-scale system evolve at the same rate. Some of them change rapidly and others vary slowly. The di?erent rates of variations allow us to reduce complexity via decomposition and aggregation. It would be ideal if we could divide a large system into its smallest irreducible subsystems completely separable from one another and treat each subsystem indep- dently. However, this is often infeasible in reality due to various physical constraints and other considerations. Thus, we have to deal with situations in which the systems are only nearly decomposable in the sense that there are weak links among the irreducible subsystems, which dictate the oc- sional regime changes of the system. An e?ective way to treat such near decomposability is time-scale separation. That is, we set up the systems as if there were two time scales, fast vs. slow. xii Preface Followingthetime-scaleseparation,weusesingularperturbationmeth- ology to treat the underlying systems.

Continuous time parameter Markov chains have been useful for modeling various random phenomena occurring in queueing theory, genetics, demography, epidemiology, and competing populations. This is the first book about those aspects of the theory of continuous time Markov chains which are useful in applications to such areas. It studies continuous time Markov chains through the transition function and corresponding q-matrix, rather than sample paths. An extensive discussion of birth and death processes, including the Stieltjes moment problem, and the Karlin-McGregor method of solution of the birth and death processes and multidimensional population processes is included, and there is an extensive bibliography. Virtually all of this material is appearing in book form for the first time.

This book presents modern techniques for the analysis of Markov chain Monte Carlo (MCMC) methods. A central focus is the study of the number of iteration of MCMC and the relation to some indices, such as the number of observation, or the number of dimension of the parameter space. The approach in this book is based on the theory of convergence of probability measures for two kinds of randomness: observation randomness and simulation randomness. This method provides in particular the optimal bounds for the random walk Metropolis algorithm and useful asymptotic information on the data augmentation algorithm. Applications are given to the Bayesian mixture model, the cumulative probit model, and to some other categorical models. This approach yields new subjects, such as the degeneracy problem and optimal rate problem of MCMC. Containing asymptotic results of MCMC under a Bayesian statistical point of view, this volume will be useful to practical and theoretical researchers and to graduate students in the field of statistical computing.

This new edition of Markov Chains: Models, Algorithms and Applications has been completely reformatted as a text, complete with end-of-chapter exercises, a new focus on management science, new applications of the models, and new examples with applications in financial risk management and modeling of financial data. This book consists of eight chapters. Chapter 1 gives a brief introduction to the classical theory on both discrete and continuous time Markov chains. The relationship between Markov chains of finite states and matrix theory will also be highlighted. Some classical iterative methods for solving linear systems will be introduced for finding the stationary distribution of a Markov chain. The chapter then covers the basic theories and algorithms for hidden Markov models (HMMs) and Markov decision processes (MDPs). Chapter 2 discusses the applications of continuous time Markov chains to model queueing systems and discrete time Markov chain for computing the PageRank, the ranking of websites on the Internet. Chapter 3 studies Markovian models for manufacturing and re-manufacturing systems and presents closed form solutions and fast numerical algorithms for solving the captured systems. In Chapter 4, the authors present a simple hidden Markov model (HMM) with fast numerical algorithms for estimating the model parameters. An application of the HMM for customer classification is also presented. Chapter 5 discusses Markov decision processes for customer lifetime values. Customer Lifetime Values (CLV) is an important concept and quantity in marketing management. The authors present an approach based on Markov decision processes for the calculation of CLV using real data. Chapter 6 considers higher-order Markov chain models, particularly a class of parsimonious higher-order Markov chain models. Efficient estimation methods for model parameters based on linear programming are presented. Contemporary research results on applications to demand predictions, inventory control and financial risk measurement are also presented. In Chapter 7, a class of parsimonious multivariate Markov models is introduced. Again, efficient estimation methods based on linear programming are presented. Applications to demand predictions, inventory control policy and modeling credit ratings data are discussed. Finally, Chapter 8 re-visits hidden Markov models, and the authors present a new class of hidden Markov models with efficient algorithms for estimating the model parameters. Applications to modeling interest rates, credit ratings and default data are discussed. This book is aimed at senior undergraduate students, postgraduate students, professionals, practitioners, and researchers in applied mathematics, computational science, operational research, management science and finance, who are interested in the formulation and computation of queueing networks, Markov chain models and related topics. Readers are expected to have some basic knowledge of probability theory, Markov processes and matrix theory.

Kronecker products are used to define the underlying Markov chain (MC) in various modeling formalisms, including compositional Markovian models, hierarchical Markovian models, and stochastic process algebras. The motivation behind using a Kronecker structured representation rather than a flat one is to alleviate the storage requirements associated with the MC. With this approach, systems that are an order of magnitude larger can be analyzed on the same platform. The developments in the solution of such MCs are reviewed from an algebraic point of view and possible areas for further research are indicated with an emphasis on preprocessing using reordering, grouping, and lumping and numerical analysis using block iterative, preconditioned projection, multilevel, decompositional, and matrix analytic methods. Case studies from closed queueing networks and stochastic chemical kinetics are provided to motivate decompositional and matrix analytic methods, respectively.

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.

This book provides an undergraduate-level introduction to discrete and continuous-time Markov chains and their applications, with a particular focus on the first step analysis technique and its applications to average hitting times and ruin probabilities. It also discusses classical topics such as recurrence and transience, stationary and limiting distributions, as well as branching processes. It first examines in detail two important examples (gambling processes and random walks) before presenting the general theory itself in the subsequent chapters. It also provides an introduction to discrete-time martingales and their relation to ruin probabilities and mean exit times, together with a chapter on spatial Poisson processes. The concepts presented are illustrated by examples, 138 exercises and 9 problems with their solutions.

This book provides an introduction to probability theory and its applications. The emphasis is on essential probabilistic reasoning, which is illustrated with a large number of samples. The fourth edition adds material related to mathematical finance as well as expansions on stable laws and martingales. From the reviews: "Almost thirty years after its first edition, this charming book continues to be an excellent text for teaching and for self study." -- STATISTICAL PAPERS

Markov ChainsSpringer

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 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.

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.

in failure time distributions for systems modeled by finite chains. This introductory chapter attempts to provide an over view of the material and ideas covered. The presentation is loose and fragmentary, and should be read lightly initially. Subsequent perusal from time to time may help tie the mat erial together and provide a unity less readily obtainable otherwise. The detailed presentation begins in Chapter 1, and some readers may prefer to begin there directly. §O.I. Time-Reversibility and Spectral Representation. Continuous time chains may be discussed in terms of discrete time chains by a uniformizing procedure (§2.I) that simplifies and unifies the theory and enables results for discrete and continuous time to be discussed simultaneously. Thus if N(t) is any finite Markov chain in continuous time governed by transition rates vmn one may write for pet) = [Pmn(t)] • P[N(t) = n I N(O) = m] pet) = exp [-vt(I - a)] (0.1.1) v where v > Max r v ' and mn m n law ~ 1 - v-I * Hence N(t) where is governed r vmn Nk = NK(t) n K(t) is a Poisson process of rate v indep- by a ' and v dent of N • k Time-reversibility (§1.3, §2.4, §2.S) is important for many reasons. A) The only broad class of tractable chains suitable for stochastic models is the time-reversible class.

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.

This book provides a self-contained review of all the relevant topics in probability theory. A software package called MAXIM, which runs on MATLAB, is made available for downloading. Vidyadhar G. Kulkarni is Professor of Operations Research at the University of North Carolina at Chapel Hill.

This book is about discrete-time, time-homogeneous, Markov chains (Mes) and their ergodic behavior. To this end, most of the material is in fact about stable Mes, by which we mean Mes that admit an invariant probability measure. To state this more precisely and give an overview of the questions we shall be dealing with, we will first introduce some notation and terminology. Let (X,B) be a measurable space, and consider a X-valued Markov chain ~. = {~k' k = 0, 1, ... } with transition probability function (t.pJ.) P(x, B), i.e., P(x, B) := Prob (~k+1 E B I ~k = x) for each x E X, B E B, and k = 0,1, ... The Me ~. is said to be stable if there exists a probability measure (p.m.) /.l on B such that (*) VB EB. /.l(B) = Ix /.l(dx) P(x, B) If (*) holds then /.l is called an invariant p.m. for the Me ~. (or the t.p.f. P).

Despite the fears of university mathematics departments, mathematics educat,ion is growing rather than declining. But the truth of the matter is that the increases are occurring outside departments of mathematics. Engineers, computer scientists, physicists, chemists, economists, statis- cians, biologists, and even philosophers teach and learn a great deal of mathematics. The teaching is not always terribly rigorous, but it tends to be better motivated and better adapted to the needs of students. In my own experience teaching students of biostatistics and mathematical bi- ogy, I attempt to convey both the beauty and utility of probability. This is a tall order, partially because probability theory has its own vocabulary and habits of thought. The axiomatic presentation of advanced probability typically proceeds via measure theory. This approach has the advantage of rigor, but it inwitably misses most of the interesting applications, and many applied scientists rebel against the onslaught of technicalities. In the current book, I endeavor to achieve a balance between theory and app- cations in a rather short compass. While the combination of brevity apd balance sacrifices many of the proofs of a rigorous course, it is still cons- tent with supplying students with many of the relevant theoretical tools. In my opinion, it better to present the mathematical facts without proof rather than omit them altogether.

We have sold 4300 copies worldwide of the first edition (1999). This new edition contains five completely new chapters covering new developments.

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.

In this 2002 book, the author develops the necessary background in probability theory and Markov chains then discusses important computing applications.

These notes were written as a result of my having taught a "nonmeasure theoretic" course in probability and stochastic processes a few times at the Weizmann Institute in Israel. I have tried to follow two principles. The first is to prove things "probabilistically" whenever possible without recourse to other branches of mathematics and in a notation that is as "probabilistic" as possible. Thus, for example, the asymptotics of pn for large n, where P is a stochastic matrix, is developed in Section V by using passage probabilities and hitting times rather than, say, pulling in Perron Frobenius theory or spectral analysis. Similarly in Section II the joint normal distribution is studied through conditional expectation rather than quadratic forms. The second principle I have tried to follow is to only prove results in their simple forms and to try to eliminate any minor technical com putations from proofs, so as to expose the most important steps. Steps in proofs or derivations that involve algebra or basic calculus are not shown; only steps involving, say, the use of independence or a dominated convergence argument or an assumptjon in a theorem are displayed. For example, in proving inversion formulas for characteristic functions I omit steps involving evaluation of basic trigonometric integrals and display details only where use is made of Fubini's Theorem or the Dominated Convergence Theorem.

Markov chains are central to the understanding of random processes. This is not only because they pervade the applications of random processes, but also because one can calculate explicitly many quantities of interest. This textbook, aimed at advanced undergraduate or MSc students with some background in basic probability theory, focuses on Markov chains and quickly develops a coherent and rigorous theory whilst showing also how actually to apply it. Both discrete-time and continuous-time chains are studied. A distinguishing feature is an introduction to more advanced topics such as martingales and potentials in the established context of Markov chains. There are applications to simulation, economics, optimal control, genetics, queues and many other topics, and exercises and examples drawn both from theory and practice. It will therefore be an ideal text either for elementary courses on random processes or those that are more oriented towards applications.

Algebraic statistics is a rapidly developing field, where ideas from statistics and algebra meet and stimulate new research directions. One of the origins of algebraic statistics is the work by Diaconis and Sturmfels in 1998 on the use of Gröbner bases for constructing a connected Markov chain for performing conditional tests of a discrete exponential family. In this book we take up this topic and present a detailed summary of developments following the seminal work of Diaconis and Sturmfels. This book is intended for statisticians with minimal backgrounds in algebra. As we ourselves learned algebraic notions through working on statistical problems and collaborating with notable algebraists, we hope that this book with many practical statistical problems is useful for statisticians to start working on the field.

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.

Besides the investigation of general chains the book contains chapters which are concerned with eigenvalue techniques, conductance, stopping times, the strong Markov property, couplings, strong uniform times, Markov chains on arbitrary finite groups (including a crash-course in harmonic analysis), random generation and counting, Markov random fields, Gibbs fields, the Metropolis sampler, and simulated annealing. With 170 exercises.

The ultimate objective of this book is to present a panoramic view of the main stochastic processes which have an impact on applications, with complete proofs and exercises. Random processes play a central role in the applied sciences, including operations research, insurance, finance, biology, physics, computer and communications networks, and signal processing. In order to help the reader to reach a level of technical autonomy sufficient to understand the presented models, this book includes a reasonable dose of probability theory. On the other hand, the study of stochastic processes gives an opportunity to apply the main theoretical results of probability theory beyond classroom examples and in a non-trivial manner that makes this discipline look more attractive to the applications-oriented student. One can distinguish three parts of this book. The first four chapters are about probability theory, Chapters 5 to 8 concern random sequences, or discrete-time stochastic processes, and the rest of the book focuses on stochastic processes and point processes. There is sufficient modularity for the instructor or the self-teaching reader to design a course or a study program adapted to her/his specific needs. This book is in a large measure self-contained.