



# Discrete-Time Markov Chain

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- Discrete-time stochastic process  $\{X_n: n = 0, 1, 2, \dots\}$
- Takes values in  $\{0, 1, 2, \dots\}$

- Memoryless property:

$$P\{X_{n+1} = j \mid X_n = i, X_{n-1} = i_{n-1}, \dots, X_0 = i_0\} = P\{X_{n+1} = j \mid X_n = i\}$$

$$P_{ij} = P\{X_{n+1} = j \mid X_n = i\}$$

- Transition probabilities  $P_{ij}$

$$P_{ij} \geq 0, \quad \sum_{j=0}^{\infty} P_{ij} = 1$$

- Transition probability matrix  $P = [P_{ij}]$

# Discrete Markov Chains

**Sean Meyn, Richard L. Tweedie**



## Discrete Markov Chains:

**Discrete-Time Markov Chains** G. George Yin, Qing Zhang, 2005-10-04 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 financial engineering Much of our effort in this book is devoted to designing system models arising from various applications analyzing them via analytic and probabilistic techniques and developing feasible computational schemes Our main concern is to reduce the inherent system complexity 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 One of the salient features of this book is the use of multi time scales in Markov processes and their applications Intuitively not all parts or components of a large scale system evolve at the same rate Some of them change rapidly and others vary slowly The different 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 independently 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 operational regime changes of the system An effective 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 Following the time scale separation we use singular perturbation methodology to treat the underlying systems

**Markov Chains** Bruno Sericola, 2013-08-05 Markov Chains Theory and Applications Markov chains are a fundamental class of stochastic processes They are widely used to solve problems in a large number of domains such as operational research computer science communication networks and manufacturing systems The success of Markov chains is mainly due to their simplicity of use the large number of available theoretical results and the quality of algorithms developed for the numerical evaluation of many metrics of interest The author presents the theory of both discrete time and continuous time homogeneous Markov chains He carefully examines the explosion phenomenon the Kolmogorov equations the convergence to equilibrium and the passage time distributions to a state and to a subset of states These results are applied to birth and death processes He then proposes a detailed study of the uniformization technique by means of Banach algebra This technique is used for the transient analysis of several queueing systems

**Markov Chains** Dean L. Isaacson, Richard W. Madsen, 1976-03-05 Fundamental concepts of Markov chains The classical approach to Markov chains The algebraic approach to Markov chains Nonstationary Markov chains and the ergodic coefficient Analysis of a Markov chain on a computer Continuous time Markov chains

*Markov Chains* Kai Lai Chung, 2012-12-06 From the reviews J Neveu 1962 in Zentralblatt für Mathematik 92 Band Heft 2 p 343 Ce livre crit par l'un des plus importants spécialistes en la matière est un exposé très détaillé de la théorie des processus de Markov définis sur un espace

dnombrable d tats et homognes dans le temps chaines stationnaires de Markov N Jain 2008 in Selected Works of Kai Lai Chung edited by Farid AitSahlia University of Florida USA Elton Hsu Northwestern University USA Ruth Williams University of California San Diego USA Chapter 1 p 15 This monograph deals with countable state Markov chains in both discrete time Part I and continuous time Part II Much of Kai Lai s fundamental work in the field is included in this monograph Here for the first time Kai Lai gave a systematic exposition of the subject which includes classification of states ratio ergodic theorems and limit theorems for functionals of the chain

**Markov Chains and Stochastic Stability** Sean Meyn, Richard L. Tweedie, 2009-04-02 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

Markov Chains David Freedman, 2012-12-06 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 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

*Understanding Markov Chains* Nicolas Privault, 2013-08-13 This book provides an undergraduate introduction to discrete and continuous time Markov chains and their applications A large focus is placed on the first step analysis technique and its applications to average hitting times and ruin probabilities Classical topics such as recurrence and transience stationary and limiting distributions as well as branching processes are also covered Two major examples gambling processes and random walks are treated in detail from the beginning before the general theory itself is presented in the subsequent chapters An introduction to discrete time martingales and their relation to ruin probabilities and mean exit times is also provided and the book includes a chapter on spatial Poisson processes with some recent results on moment identities and deviation inequalities for Poisson stochastic integrals The concepts presented are illustrated by examples and by 72 exercises and their complete solutions

**Discrete Markov Chains** Vsevolod Ivanovich Romanovskii, 1970

*Markov Chains* J. R. Norris, 1998-07-28 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

**Continuous Time Markov Processes** Thomas M. Liggett, 2025-08-27 Markov processes are among the most important stochastic processes for both theory and applications This book develops the general theory of these processes and applies this theory to various special examples The initial chapter is devoted to the most important classical example one dimensional Brownian motion This together with a chapter on continuous time Markov chains provides the motivation for the general setup based on semigroups and generators Chapters on stochastic calculus and probabilistic potential theory give an introduction to some of the key areas of application of Brownian motion and its relatives A chapter on interacting particle systems treats a more recently developed class of Markov processes that have as their origin problems in physics and biology This is a textbook for a graduate course that can follow one that covers basic probabilistic limit theorems and discrete time processes

Markov Processes for Stochastic Modeling Masaaki Kijima, 2013-12-19 This book presents an algebraic development of the theory of countable state space Markov chains with discrete and continuous time parameters A Markov chain is a stochastic process characterized by the Markov property that the distribution of future depends only on the current state not on the whole history Despite its simple form of dependency the Markov property has enabled us to develop a rich system of concepts and theorems and to derive many results that are useful in applications In fact the areas that can be modeled with varying degrees of success by Markov chains are vast and are still expanding The aim of this book is a discussion of the time dependent behavior called the transient behavior of Markov chains From the practical point of view when modeling a stochastic system by a Markov chain there are many instances in which time limiting results such as stationary distributions have no meaning Or even when the stationary distribution is of some importance it is often dangerous to use the stationary result alone without knowing the transient behavior of the Markov chain Not many books have paid much attention to this topic despite its obvious importance

**Markov Chains** Pierre Bremaud, 2013-03-09 In this book the author begins with the elementary theory of Markov chains and very progressively brings the reader to the more advanced topics He gives a useful review of probability that makes the book self contained and provides an appendix with detailed proofs of all the prerequisites from calculus algebra and number theory A number of carefully chosen problems of varying difficulty are proposed at the close of each chapter and the mathematics are slowly and carefully developed in order to make self study easier The author treats the classic topics of Markov chain theory both in discrete time and

continuous time as well as the connected topics such as finite Gibbs fields nonhomogeneous Markov chains discrete time regenerative processes Monte Carlo simulation simulated annealing and queuing theory The result is an up to date textbook on stochastic processes Students and researchers in operations research and electrical engineering as well as in physics and biology will find it very accessible and relevant

**Markov Chains** Wai-Ki Ching,Ximin Huang,Michael K. Ng,Tak-Kuen Siu,2013-03-27 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

*Discrete-Time Markov Jump Linear Systems* O.L.V. Costa,M.D. Fragoso,R.P. Marques,2006-03-30 Safety

critical and high integrity systems such as industrial plants and economic systems can be subject to abrupt changes for instance due to component or interconnection failure and sudden environment changes etc Combining probability and operator theory Discrete Time Markov Jump Linear Systems provides a unified and rigorous treatment of recent results for the control theory of discrete jump linear systems which are used in these areas of application The book is designed for experts in linear systems with Markov jump parameters but is also of interest for specialists in stochastic control since it presents stochastic control problems for which an explicit solution is possible making the book suitable for course use From the reviews This text is very well written it may prove valuable to those who work in the area are at home with its mathematics and are interested in stability of linear systems optimal control and filtering Journal of the American Statistical Association December 2005

**A First Course in Probability and Markov Chains** Giuseppe Modica, Laura Poggiolini, 2012-12-10 Provides an introduction to basic structures of probability with a view towards applications in information technology A First Course in Probability and Markov Chains presents an introduction to the basic elements in probability and focuses on two main areas The first part explores notions and structures in probability 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 of large numbers and central limit theorem In the second part of the book focus is given to Discrete Time Discrete Markov Chains which is addressed together with an introduction to Poisson processes and Continuous Time Discrete Markov Chains This book also looks at making use of measure theory notations that unify all the presentation in particular avoiding the separate treatment of continuous and discrete distributions A First Course in Probability and Markov Chains Presents the basic elements of probability Explores elementary probability with combinatorics uniform probability the inclusion exclusion principle independence and convergence of random variables Features applications of Law of Large Numbers Introduces Bernoulli and Poisson processes as well as discrete and continuous time Markov Chains with discrete states Includes illustrations and examples throughout along with solutions to problems featured in this book The authors present a unified and comprehensive overview of probability and Markov Chains aimed at educating engineers working with probability and statistics as well as advanced undergraduate students in sciences and engineering with a basic background in mathematical analysis and linear algebra

**Applications of Markov Chains in Chemical Engineering** A. Tamir, 1998-08-26 Markov chains make it possible to predict the future state of a system from its present state ignoring its past history Surprisingly despite the widespread use of Markov chains in many areas of science and technology their applications in chemical engineering have been relatively meager A possible reason for this phenomenon might be that books containing material on this subject have been written in such a way that the simplicity of Markov chains has been shadowed by the tedious mathematical derivations Thus the major objective of writing this book has been to try to change this situation There are many advantages detailed in

Chapter 1 of using the discrete Markov chain model in chemical engineering Probably the most important advantage is that physical models can be presented in a unified description via state vector and a one step transition probability matrix Consequently a process is demonstrated solely by the probability of a system to occupy or not occupy a state The book has been written in an easy and understandable form where complex mathematical derivations are abandoned The fundamentals of Markov chains are presented in Chapter 2 with examples from the bible art and real life problems An extremely wide collection is given of examples viz reactions reactors reactions and reactors as well as combined processes including their solution and a graphical presentation of it all of which demonstrates the usefulness of applying Markov chains in chemical engineering

**General Irreducible Markov Chains and Non-Negative Operators** Esa Nummelin, 2004-06-03 Presents the theory of general irreducible Markov chains and its connection to the Perron Frobenius theory of nonnegative operators

A First Look at Rigorous Probability Theory Jeffrey Seth Rosenthal, 2006 Features an introduction to probability theory using measure theory This work provides proofs of the essential introductory results and presents the measure theory and mathematical details in terms of intuitive probabilistic concepts rather than as separate imposing subjects

**Discrete-Time Markov Control Processes** Onesimo Hernandez-Lerma, Jean B. Lasserre, 2012-12-06 This book presents the first part of a planned two volume series devoted to a systematic exposition of some recent developments in the theory of discrete time Markov control processes MCPs Interest is mainly confined to MCPs with Borel state and control or action spaces and possibly unbounded costs and noncompact control constraint sets MCPs are a class of stochastic control problems also known as Markov decision processes controlled Markov processes or stochastic dynamic programs sometimes particularly when the state space is a countable set they are also called Markov decision or controlled Markov chains Regardless of the name used MCPs appear in many fields for example engineering economics operations research statistics renewable and nonrenewable resource management control of epidemics etc However most of the literature say at least 90% is concentrated on MCPs for which a the state space is a countable set and or b the costs per stage are bounded and or c the control constraint sets are compact But curiously enough the most widely used control model in engineering and economics namely the LQ Linear system Quadratic cost model satisfies none of these conditions Moreover when dealing with partially observable systems a standard approach is to transform them into equivalent completely observable systems in a larger state space in fact a space of probability measures which is uncountable even if the original state process is finite valued

*Discrete Markov chains, tr Vsevolod Ivanovich Romanovskii,*



## The Enigmatic Realm of **Discrete Markov Chains**: Unleashing the Language is Inner Magic

In a fast-paced digital era where connections and knowledge intertwine, the enigmatic realm of language reveals its inherent magic. Its capacity to stir emotions, ignite contemplation, and catalyze profound transformations is nothing in short supply of extraordinary. Within the captivating pages of **Discrete Markov Chains** a literary masterpiece penned by way of a renowned author, readers embark on a transformative journey, unlocking the secrets and untapped potential embedded within each word. In this evaluation, we shall explore the book's core themes, assess its distinct writing style, and delve into its lasting effect on the hearts and minds of those that partake in its reading experience.

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### Table of Contents **Discrete Markov Chains**

1. Understanding the eBook Discrete Markov Chains
  - The Rise of Digital Reading Discrete Markov Chains
  - Advantages of eBooks Over Traditional Books
2. Identifying Discrete Markov Chains
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Discrete Markov Chains
  - User-Friendly Interface
4. Exploring eBook Recommendations from Discrete Markov Chains
  - Personalized Recommendations
  - Discrete Markov Chains User Reviews and Ratings
  - Discrete Markov Chains and Bestseller Lists

5. Accessing Discrete Markov Chains Free and Paid eBooks
  - Discrete Markov Chains Public Domain eBooks
  - Discrete Markov Chains eBook Subscription Services
  - Discrete Markov Chains Budget-Friendly Options
6. Navigating Discrete Markov Chains eBook Formats
  - ePub, PDF, MOBI, and More
  - Discrete Markov Chains Compatibility with Devices
  - Discrete Markov Chains Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Discrete Markov Chains
  - Highlighting and Note-Taking Discrete Markov Chains
  - Interactive Elements Discrete Markov Chains
8. Staying Engaged with Discrete Markov Chains
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Discrete Markov Chains
9. Balancing eBooks and Physical Books Discrete Markov Chains
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Discrete Markov Chains
10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
11. Cultivating a Reading Routine Discrete Markov Chains
  - Setting Reading Goals Discrete Markov Chains
  - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Discrete Markov Chains
  - Fact-Checking eBook Content of Discrete Markov Chains
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning

- Utilizing eBooks for Skill Development
- Exploring Educational eBooks

#### 14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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