

Application of Markov Chains to Analyze and Predict the Time Series

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Abstract

Markov chains are usually used in modeling many practical problems. They are also effective in modeling time series. In this paper, we apply the Markov chains model to analyze and predict the time series. Some series can be expressed by a first-order discrete-time Markov chain and others must be expressed by a higher-order Markov chain model. Numerical examples are given. The results show that the performance and effectiveness of the Markov chain model to predict the time series is very well.

Keywords: Markov chains, Time series analysis, Mathematical Modeling

1. Introduction

Markov chains are useful tools in modeling many practical systems such as queuing systems (Ching, 2001 and Sharma, 1995.), manufacturing systems (Buzacott & Shanbhikumar, 1993.) and inventory systems (Ching, Fung & Ng, 2003, pp.291–298 and Nahmias, 1997). Applications of Markov chains in modeling categorical data sequences can also be found in (Ching, Fung & Ng, 2002, pp.87–199 and MacDonald & Zucchini, 1997). Time series occur frequently in many real world applications. If one can model the time series accurately, then one can make good predictions and also optimal planning in a decision process (Ching, Ng & Fung, 2008, pp.492–507).

In this paper, we apply the Markov chains model to analysis and predict the time series. Some series can be expressed by a first-order discrete-time Markov chain and others must be expressed by a higher-order Markov chain model. Numerical examples are given. The results show that the performance and effectiveness of the Markov chain model to predict the time series is very well.

2. Markov chain model

2.1 The first-order Markov chain model

We consider modeling a time series x_t by a first-order Markov chains having k states $E = \{1, 2, \dots, k\}$. A first-order discrete-time Markov chain having k states satisfies the following relationship:

$$P(x_{t+1} = i_{t+1} | x_t = i_t, x_{t-1} = i_{t-1}, \dots, x_1 = i_1) = P(x_{t+1} = i_{t+1} | x_t = i_t),$$

where x_t is the state of a time series at time t and $i_j \in E$. The conditional probabilities

$$P(x_{t+1} = i_{t+1} | x_t = i_t)$$

are called the one-step transition probabilities of the Markov chain. These probabilities can be written as $p_{ij} = P(x_{t+1} = i | x_t = j)$ for i and j in E . The matrix $P = (p_{ij})_{k \times k}$ is called the one-step transition probability matrix. We note that the elements of the matrix P satisfy the following two properties:

$$0 \leq p_{ij} \leq 1 \quad \forall i, j \in E \quad \text{and} \quad \sum_{i=1}^k p_{ij} = 1, \quad \forall j \in E$$

A first-order Markov chain model

$$x_{t+1} = Px_t \quad (1)$$

is then constructed for the observed time series.

We have the following well-known proposition for a transition matrix P . The proof can be found in (Horn & Johnson, 1985, pp. 508–511) and therefore omitted here.

Proposition 1. *The matrix P has an eigenvalue equal to one and all the eigenvalues of P must have modulus less than or equal to one.*

Generally one has the following proposition for a non-negative matrix, see for instance (Horn & Johnson, 1985, pp. 508–511).

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Simulation and Analysis of Mathematical Methods in Real-Time Engineering Applications T. Ananth Kumar,E. Golden Julie,Y. Harold Robinson,S. M. Jaisakthi,2021-08-16 SIMULATIONS AND ANALYSIS of Mathematical Methods Written and edited by a group of international experts in the field this exciting new volume covers the state of the art of real time applications of computer science using mathematics This breakthrough edited volume highlights the security privacy artificial intelligence and practical approaches needed by engineers and scientists in all fields of science and technology It highlights the current research which is intended to advance not only mathematics but all areas of science research and development and where these disciplines intersect As the book is focused on emerging concepts in machine learning and artificial intelligence algorithmic approaches and soft computing techniques it is an invaluable tool for researchers academicians data scientists and technology developers The newest and most comprehensive volume in the area of mathematical methods for use in real time engineering this groundbreaking new work is a must have for any engineer or scientist s library Also useful as a textbook for the student it is a valuable contribution to the advancement of the science both a working handbook for the new hire or student and a reference for the veteran engineer A Markov-chain Model for the Prediction and Control of College Enrollment Juris Christopher Lasmanis,1969 **Advances in Network Analysis and its Applications** Evangelos Kranakis,2012-10-24 As well as highlighting potentially useful applications for network analysis this volume identifies new targets for mathematical research that promise to provide insights into network systems theory as well as facilitating the cross fertilization of ideas between sectors Focusing on financial security and social aspects of networking the volume adds to the growing body of evidence showing that network analysis has applications to transportation communication health finance and social policy more broadly It provides powerful models for understanding the behavior of complex systems that in turn will impact numerous cutting edge sectors in science and engineering such as wireless communication network security distributed computing and social networking financial analysis and cyber warfare The volume offers an insider s view of cutting edge research in network systems including methodologies with immense potential for interdisciplinary application The contributors have all presented material at a series of workshops organized on behalf of Canada s MITACS initiative which funds projects and study grants in mathematics for information technology and complex systems These proceedings include papers from workshops on financial networks network security and cryptography and social networks MITACS has shown that the partly ghettoized nature of network systems research has led to duplicated work in discrete fields and thus this initiative has the potential to save time and accelerate the pace of research in a number of areas of network systems research **Geographic Data Analysis Using R** Xindong He,2024-08-02 This book is structured to encompass both the foundational and specialized aspects of quantitative analysis in geography The basic content covers descriptive statistical analysis and correlation analysis of geographical data while the professional

content delves into more advanced topics like linear regression analysis geographically weighted regression analysis time series analysis cluster analysis principal component analysis Markov chain analysis and geographical network analysis The methodologies span from widely utilized techniques to more recent developments and the data primarily originates from reputable sources in China The example code provided in the book can be executed using R packages available on the CRAN website This book is an invaluable resource for undergraduate and graduate students as well as researchers interested in learning and applying R for processing visualizing and analyzing geographic data It serves as an introductory course in quantitative methods in geography for students in geography departments Additionally it is an ideal supplementary text for applied methods courses across various disciplines that involve geographic data such as human and physical geography geographic information science ecology public health crime and economics

The Credit Scoring Toolkit Raymond Anderson, 2007-08-30 The Credit Scoring Toolkit provides an all encompassing view of the use of statistical models to assess retail credit risk and provide automated decisions In eight modules the book provides frameworks for both theory and practice It first explores the economic justification and history of Credit Scoring risk linkages and decision science statistical and mathematical tools the assessment of business enterprises and regulatory issues ranging from data privacy to Basel II It then provides a practical how to guide for scorecard development including data collection scorecard implementation and use within the credit risk management cycle Including numerous real life examples and an extensive glossary and bibliography the text assumes little prior knowledge making it an indispensable desktop reference for graduate students in statistics business economics and finance MBA students credit risk and financial practitioners

Signal Analysis and Prediction Ales Prochazka, N.G. Kingsbury, P.J.W. Payner, J. Uhler, 2013-11-11 Methods of signal analysis represent a broad research topic with applications in many disciplines including engineering technology biomedicine seismography econometrics and many others based upon the processing of observed variables Even though these applications are widely different the mathematical background behind them is similar and includes the use of the discrete Fourier transform and z transform for signal analysis and both linear and non linear methods for signal identification modelling prediction segmentation and classification These methods are in many cases closely related to optimization problems statistical methods and artificial neural networks This book incorporates a collection of research papers based upon selected contributions presented at the First European Conference on Signal Analysis and Prediction ECSAP 97 in Prague Czech Republic held June 24-27 1997 at the Strahov Monastery Even though the Conference was intended as a European Conference at first initiated by the European Association for Signal Processing EURASIP it was very gratifying that it also drew significant support from other important scientific societies including the IEE Signal Processing Society of IEEE and the Acoustical Society of America The organizing committee was pleased that the response from the academic community to participate at this Conference was very large 128 summaries written by 242 authors from 36 countries were received In addition the

Conference qualified under the Continuing Professional Development Scheme to provide PD units for participants and contributors

Re-envisioning Remote Sensing Applications Ripudaman Singh, 2021-03-03 Re envisioning Remote Sensing Applications Perspectives from Developing Countries aims at discussing varied applications of remote sensing with respect to upcoming technologies with diverse themes Organized into four sections of overlapping areas of research the book covers chapters with themes related to agriculture soil and land degradation studies hydrology microclimates and climate change impacts land use land cover analysis applications resource analysis and bibliometric studies culminating with future research agenda All the topics are supported via case studies and spatial data analysis Features Provides the applications of remote sensing in all fields through varied case studies and spatial data analysis Includes soil and land degradation microclimates and climate change impacts Covers remote sensing applications in broad areas of agriculture hydrology land use land cover change and resource analysis Discusses usage of GPS enabled smartphones and digital gadgets used for mapping and spatial analysis Explores future research agenda for applications of remote sensing in post COVID scenario This book is of interest to researchers and graduate students in environmental sciences remote sensing GIS agricultural scientists and managers forestry scientists and managers and water resources scientists and managers

Symmetry in Mathematical Analysis and Application Luigi Rodino, 2020-07-01 This book appeals to scientists teachers and graduate students in mathematics and will be of interest for scholars in applied sciences as well in particular in medicine biology and social sciences The models in this connection apply in particular to the study of the immune system response and to the predator prey dynamic The efficiency of public transport is also considered and blast waves in explosions are studied Other contributions concern pure mathematics in particular Pythagorean means sequences of matrices and Markov chains and these give evidence of deep links with Symmetry

Decision Methods for Forest Resource Management Joseph Buongiorno, J. Keith Gilless, 2003-02-06 Decision Methods for Forest Resource Management focuses on decision making for forests that are managed for both ecological and economic objectives The essential modern decision methods used in the scientific management of forests are described using basic algebra computer spreadsheets and numerous examples and applications Balanced treatment is given throughout the book to the ecological and economic impacts of alternative management decisions in both even aged and uneven aged forests In depth coverage of both ecological and economic issues Hands on examples with Excel spreadsheets electronic versions available on the authors website Many related exercises with solutions Instructor s Manual available upon request

Applications of Operations Research to Health Care Delivery Systems Brant E. Fries, 2013-03-13 L icoI io 0 lllL aL On n iI c tehniC

Proceedings of the 9th International Performance Analysis Workshop and Conference & 5th IACSS Conference Arnold Baca, Juliana Exel, Martin Lames, Nic James, Nimai Parmar, 2022-04-09 This covers the PACSS 2021 which approached interdisciplinary collaboration between theoretical computer science and practical performance analysis through an online workshop and conference Readers find in this book

the peer reviewed and discussed evidences on how computer scientists and performance analysts can and have worked together to solve both applied and research based problems in elite sport using the methods of computer science In this edition we organize the content according to four major topics machine learning text mining best practice and interdisciplinary collaboration This is a refined material written by leading experts with up to date overview of research in the multidisciplinary field of computer science and elite sport performance analysis

Sustainable Human-Nature Relations Giuseppe T. Cirella, 2020-04-03 This book addresses sustainability thinking and the bigger picture by taking into consideration how and from where contemporary schools of thought emerged approximately a quarter century ago Evidence from the literature illustrates a number of key concepts and techniques that have been tested and continue to be tested within various multi disciplinary fields on societal functionality Research into sustainable societies needs to be sound ethical and creative A cross sectoral interdisciplinary examination of challenges and strategies is used to interlink sustainability thinking and human nature relations With an ever growing number of people now concentrated within urban areas providing not only environmental quality and livable space but also security and resilient urban systems is becoming increasingly important This urbanization trend has overlapped with environmental degradation consumption of natural resources habitat loss and overall ecosystem change Consequently the goal is for cleaner safer societies with higher standards of living to excel in support of current and future generational communities The book tackles these challenges by integrating environmental scholarship economic evaluation and urban strategies under one umbrella of thought The relational paradigms presented include examples that correlate developed and developing countries socioeconomics and community development and governance of knowledge and education As such the book argues furthering of knowhow should be accessible and shared in order to achieve maximum innovation and benefit Sustainability thinking after all is a metric for intrinsic human nature relations in terms of past performance present development and future goals This book discusses this metric and offers novel approaches to growing societies and what we can do next

Life Cycle Analysis and Assessment in Civil Engineering: Towards an Integrated Vision Robby Caspeele, Luc Taerwe, Dan M. Frangopol, 2018-10-15 This volume contains the papers presented at IALCCE2018 the Sixth International Symposium on Life Cycle Civil Engineering IALCCE2018 held in Ghent Belgium October 28-31 2018 It consists of a book of extended abstracts and a USB device with full papers including the Fazlur R Khan lecture 8 keynote lectures and 390 technical papers from all over the world Contributions relate to design inspection assessment maintenance or optimization in the framework of life cycle analysis of civil engineering structures and infrastructure systems Life cycle aspects that are developed and discussed range from structural safety and durability to sustainability serviceability robustness and resilience Applications relate to buildings bridges and viaducts highways and runways tunnels and underground structures off shore and marine structures dams and hydraulic structures prefabricated design infrastructure systems etc During the IALCCE2018 conference a particular focus is put on the cross fertilization

between different sub areas of expertise and the development of an overall vision for life cycle analysis in civil engineering The aim of the editors is to provide a valuable source of cutting edge information for anyone interested in life cycle analysis and assessment in civil engineering including researchers practising engineers consultants contractors decision makers and representatives from local authorities **Second National Conference on Management Science and Practice, March 9-11, 2007** ,2008 Papers presented at the conference held at Indian Institute of Technology Madras in 2007 **Digital Business** Srikanta Patnaik,Xin-She Yang,Madjid Tavana,Florin Popentiu-Vlădicescu,Feng Qiao,2018-07-26 This edited book presents contributions from three different areas cloud computing digital mess and business algorithms on a single platform i e Digital Business The book is divided into four sections i Digital Business Transformation ii Cloud Computing iii IOT Mobility and iv Information Management Social Media which are part of a holistic approach to information management and connecting the value chains of businesses to derive more throughput in the entire business ecosystem Digital business is a niche area of computer science and business management and its dimension is vast it includes technologies such as cloud computing Internet of Things mobile platforms big data applied in areas like ERP data mining and business intelligence Digital technologies have also challenged existing business models and will continue to do so One of the key driving forces is the capacity of innovation and the commercialization of information and communication technologies Providing insights into the new paradigm of digital business the book is a valuable resource for research scholars academics and professionals

Geographic Information Systems in Urban Planning and Management Manish Kumar,R. B. Singh,Anju Singh,Ram Pravesh,Syed Irtiza Majid,Akash Tiwari,2023-02-02 Geographic Information Systems GIS play a pivotal role in the field of urban planning and management and provide better solutions for numerous urban problems With GIS one has the ability to better understand existing requirements of a city and its design to fulfill those needs This book contributes to developing scientific knowledge based on geospatial technologies among planners researchers scientists professionals students and laymen and providing them with better understanding for urban planning and management at various levels The book manifests the importance of GIS in better understanding of current urban challenges and provides new insights on how to apply GIS in urban planning It also encourages the various stakeholders of society to participate in the decision making process and assists planners and authorities to formulate suitable plans for sustainable urban growth of a region The book is divided into two parts The first part describes the fundamental concepts of GIS and also deals with the advanced techniques of spatial planning The second part addresses real world case studies using various applications of GIS The case studies include urban land use changes simulation of future urban growth urban heat island alternate landfill site selection and urban flood susceptibility mapping among others This book shows how to integrate GIS with remote sensing geostatistics artificial intelligence machine learning techniques and other cutting edge technologies Readers find this book to be an invaluable resource for understanding and solving problems relating to sustainable urban planning and management

Artificial Intelligence in Forecasting Sachi Mohanty, Preethi Nanjundan, Tejaswini Kar, 2024-07-19 Forecasting deals with the uncertainty of the future To be effective forecasting models should be timely available accurate reliable and compatible with existing database Accurate projection of the future is of vital importance in supply chain management inventory control economic condition technology growth trend social change political change business weather forecasting stock price prediction earthquake prediction etc AI powered tools and techniques of forecasting play a major role in improving the projection accuracy The software running AI forecasting models use machine learning to improve accuracy The software can analyse the past data and can make better prediction about the future trends with higher accuracy and confidence that favours for making proper future planning and decision In other words accurate forecasting requires more than just the matching of models to historical data The book covers the latest techniques used by managers in business today discover the importance of forecasting and learn how it s accomplished Readers will also be familiarised with the necessary skills to meet the increased demand for thoughtful and realistic forecasts Adaptive Search and the Management of Logistic Systems Christian Bierwirth, 2012-09-05 Global competition and growing costumer expectations force indus trial enterprises to reorganize their business processes and to support cost effective customer services Realizing the potential savings to be gained by exacting customer delivery processes logistics is currently sub ject to incisive changes This upheaval aims at making competitive ad vantage from logistic services instead of viewing them simply as business necessity With respect to this focus logistics management comprises the process of planning implementing and controlling the efficient effective flow and storage of goods and services and related information from point of origin to point of consumption for the purpose of conforming customer requirements I This definition implies a holistic view on the logistic network where the actors are suppliers manufacturers stock keepers shipping agents distributors retailers and finally consumers The flow of goods along the supply chain considers raw materials work in process parts intermedi ate and finished products and possibly waste The prevailing manage ment of logistics operation is driven by aggregated forecasting of these material flows Modern logistics management propagates a disaggregated view of the material flow in order to meet the precise requirements at the interface between actors in the supply chain Replacing aggregated information by detailed values establishes the prerequisites for an integrated process planning which goes for the shift from anticipatory towards response based logistic81 Smaller units of goods are considered at shorter periods for planning implementing and controlling the material flow From Icf the Council of Logistics Management 1995 **Statistics Every Programmer Needs** Gary Sutton, 2025-08-26 Put statistics into practice with Python Data driven decisions rely on statistics Statistics Every Programmer Needs introduces the statistical and quantitative methods that will help you go beyond gut feeling for tasks like predicting stock prices or assessing quality control with examples using the rich tools of the Python ecosystem Statistics Every Programmer Needs will teach you how to Apply foundational and advanced statistical techniques Build predictive models and simulations Optimize decisions

under constraints Interpret and validate results with statistical rigor Implement quantitative methods using Python In this hands on guide stats expert Gary Sutton blends the theory behind these statistical techniques with practical Python based applications offering structured reproducible and defensible methods for tackling complex decisions Well annotated and reusable Python code listings illustrate each method with examples you can follow to practice your new skills About the technology Whether you re analyzing application performance metrics creating relevant dashboards and reports or immersing yourself in a numbers heavy coding project every programmer needs to know how to turn raw data into actionable insight Statistics and quantitative analysis are the essential tools every programmer needs to clarify uncertainty optimize outcomes and make informed choices About the book Statistics Every Programmer Needs teaches you how to apply statistics to the everyday problems you ll face as a software developer Each chapter is a new tutorial You ll predict ultramarathon times using linear regression forecast stock prices with time series models analyze system reliability using Markov chains and much more The book emphasizes a balance between theory and hands on Python implementation with annotated code and real world examples to ensure practical understanding and adaptability across industries What s inside Probability basics and distributions Random variables Regression Decision trees and random forests Time series analysis Linear programming Monte Carlo and Markov methods and much more About the reader Examples are in Python About the author Gary Sutton is a business intelligence and analytics leader and the author of Statistics Slam Dunk Statistical analysis with R on real NBA data Table of Contents 1 Laying the groundwork 2 Exploring probability and counting 3 Exploring probability distributions and conditional probabilities 4 Fitting a linear regression 5 Fitting a logistic regression 6 Fitting a decision tree and a random forest 7 Fitting time series models 8 Transforming data into decisions with linear programming 9 Running Monte Carlo simulations 10 Building and plotting a decision tree 11 Predicting future states with Markov analysis 12 Examining and testing naturally occurring number sequences 13 Managing projects 14 Visualizing quality control **Revealing**

Ecosystem Services Through Geospatial Technologies Onesimo Mutanga,Prem Chandra Pandey,Sandipan Das,Uday Chatterjee,2025-08-30 This book covers the quantification of forests grasslands and woodlands ecosystem services from the supply side e g regulatory and provisioning services to the demand side including human cultural needs The Millennium Ecosystem Assessment MA 2005 defines ecosystem services as simply the benefits that are derived from ecosystems for human well being Board 2005 The report has documented that ecosystems have contributed more than 50% of the world s GDP However as a result of climate change and anthropogenic impacts about 60% of the world s ecosystem services have been degraded This significant reduction of services has serious consequences on food production climate regulation and net primary production among other services which directly affect human well being In order to appreciate the benefits of various ecosystems to humanity and monitor their degradation a systematic quantification of ecosystem services and their change in both time and space is critical In particular there is a need to characterize the ecological infrastructures processes

and ecosystem functions that underpin the ecosystem services in ways that can be evaluated and tracked Potschin and Haines Young 2016 In addition various intervention measures to restore degraded ecosystems require constant and accurate measurement of the ecosystem characteristics in order to assess the benefits of ecological restoration Vegetation in particular provides a number of provisioning forage production food regulatory climate temperature supporting primary production nutrient cycling and cultural educational recreation ecosystem services as well as biodiversity maintenance Masenyama et al 2022 Remote sensing data contributes significantly to mapping modeling and quantitative valuation of the ecosystem services in a spatially explicit manner It provides an opportunity to use standard protocols at various spatial scales as well as wall to wall mapping of phenomena through time which is critical for monitoring on a continuous basis

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web r z m i n 3 8 r a 0 95 r z m a x 14 5 r a 0 75 converting between ra and rz is not a good engineering practice it is always recommended to measure according to the method in which surface roughness is indicated on the drawing as you can see in the below graphs the inaccuracy grows in higher r a r z values

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