

# 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:

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

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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### **Table of Contents Application Of Markov Chains To Analyze And Predict The**

1. Understanding the eBook Application Of Markov Chains To Analyze And Predict The
  - The Rise of Digital Reading Application Of Markov Chains To Analyze And Predict The
  - Advantages of eBooks Over Traditional Books
2. Identifying Application Of Markov Chains To Analyze And Predict The
  - 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 Application Of Markov Chains To Analyze And Predict The
  - User-Friendly Interface
4. Exploring eBook Recommendations from Application Of Markov Chains To Analyze And Predict The

- Personalized Recommendations
  - Application Of Markov Chains To Analyze And Predict The User Reviews and Ratings
  - Application Of Markov Chains To Analyze And Predict The and Bestseller Lists
5. Accessing Application Of Markov Chains To Analyze And Predict The Free and Paid eBooks
    - Application Of Markov Chains To Analyze And Predict The Public Domain eBooks
    - Application Of Markov Chains To Analyze And Predict The eBook Subscription Services
    - Application Of Markov Chains To Analyze And Predict The Budget-Friendly Options
  6. Navigating Application Of Markov Chains To Analyze And Predict The eBook Formats
    - ePub, PDF, MOBI, and More
    - Application Of Markov Chains To Analyze And Predict The Compatibility with Devices
    - Application Of Markov Chains To Analyze And Predict The Enhanced eBook Features
  7. Enhancing Your Reading Experience
    - Adjustable Fonts and Text Sizes of Application Of Markov Chains To Analyze And Predict The
    - Highlighting and Note-Taking Application Of Markov Chains To Analyze And Predict The
    - Interactive Elements Application Of Markov Chains To Analyze And Predict The
  8. Staying Engaged with Application Of Markov Chains To Analyze And Predict The
    - Joining Online Reading Communities
    - Participating in Virtual Book Clubs
    - Following Authors and Publishers Application Of Markov Chains To Analyze And Predict The
  9. Balancing eBooks and Physical Books Application Of Markov Chains To Analyze And Predict The
    - Benefits of a Digital Library
    - Creating a Diverse Reading Collection Application Of Markov Chains To Analyze And Predict The
  10. Overcoming Reading Challenges
    - Dealing with Digital Eye Strain
    - Minimizing Distractions
    - Managing Screen Time
  11. Cultivating a Reading Routine Application Of Markov Chains To Analyze And Predict The
    - Setting Reading Goals Application Of Markov Chains To Analyze And Predict The
    - Carving Out Dedicated Reading Time
  12. Sourcing Reliable Information of Application Of Markov Chains To Analyze And Predict The

- Fact-Checking eBook Content of Application Of Markov Chains To Analyze And Predict The
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning
- Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
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