

## Chapter 18

# Principal Components Analysis

Principal components analysis (PCA) is one of a family of techniques for taking high-dimensional data, and using the dependencies between the variables to represent it in a more tractable, lower-dimensional form, without losing too much information. PCA is one of the simplest and most robust ways of doing such **dimensionality reduction**. It is also one of the oldest, and has been rediscovered many times in many fields, so it is also known as the Karhunen-Loève transformation, the Hotelling transformation, the method of empirical orthogonal functions, and singular value decomposition<sup>1</sup>. We will call it PCA.

### 18.1 Mathematics of Principal Components

We start with  $p$ -dimensional vectors, and want to summarize them by projecting down into a  $q$ -dimensional subspace. Our summary will be the projection of the original vectors on to  $q$  directions, the **principal components**, which span the subspace.

There are several equivalent ways of deriving the principal components mathematically. The simplest one is by finding the projections which maximize the variance. The first principal component is the direction in space along which projections have the largest variance. The second principal component is the direction which maximizes variance among all directions orthogonal to the first. The  $k^{\text{th}}$  component is the variance-maximizing direction orthogonal to the previous  $k - 1$  components. There are  $p$  principal components in all.

Rather than maximizing variance, it might sound more plausible to look for the projection with the smallest average (mean-squared) distance between the original vectors and their projections on to the principal components; this turns out to be equivalent to maximizing the variance.

Throughout, assume that the data have been “centered”, so that every variable has mean 0. If we write the centered data in a matrix  $\mathbf{x}$ , where rows are objects and

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<sup>1</sup>Strictly speaking, singular value decomposition is a matrix algebra trick which is used in the most common algorithm for PCA.

# Principal Components Analysis Cmu Statistics



**RM Cervero**

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## **Table of Contents Principal Components Analysis Cmu Statistics**

1. Understanding the eBook Principal Components Analysis Cmu Statistics
  - The Rise of Digital Reading Principal Components Analysis Cmu Statistics
  - Advantages of eBooks Over Traditional Books
2. Identifying Principal Components Analysis Cmu Statistics
  - 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 Principal Components Analysis Cmu Statistics
  - User-Friendly Interface

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



12. Sourcing Reliable Information of Principal Components Analysis Cmu Statistics
  - Fact-Checking eBook Content of Principal Components Analysis Cmu Statistics
  - 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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