Chapter 1
Pattern Analysis and Statistical Learning

Abstract This chapter presents the fundamentals of statistical pattern recognition and statistical learning. First, we present the general framework of a statistical pattern recognition system and discuss pattern representation and classification, two important components of such a system. Second, we introduce the concept of statistical learning and examine the three main approaches to statistical learning: supervised learning, semi-supervised learning, and unsupervised learning.

1.1 Introduction

In the communities of artificial intelligence, one of ultimate goals is to build a vision machine that can make sense of the world by discovering meaningful visual patterns from the light falls on its image sensors. Visual pattern analysis plays an important role in pursuing this goal. Visual pattern can be roughly defined as the repeatable components of an image, and image (or image sequence) always contain an overwhelming number of visual patterns. The purpose of visual pattern analysis is to compute a hierarchy of increasingly abstract interpretations of the observed images (or image sequence) and this has also been one of the most important topics in the field of vision, biologic and machine.

Two facts make the problem of visual pattern analysis complicated. Firstly, visual pattern analysis is considered to be a general data collection and analysis problem, where existing concepts and methods in statistical theory and information theory can in principle be used to model and interpret the image data. Secondly, visual pattern analysis also proves to be a highly specialized data collection and analysis task. We must understand the special characteristics of the nature image data in order to develop realistic models and efficient algorithms for representing and recognizing the wide variety of natural image patterns. Taking the image parsing problem as an example, depending on the types of visual patterns that a visual task is interested in, the image parsing problem is called (1) perceptual grouping on the pixel level, (2) image segmentation on the region level, and (3) object recognition on the object
level, respectively. This requests a common and mathematically sound framework for visual pattern analysis.

The idea of establishing a unifying theory for the various concepts and models encountered in visual pattern analysis is not new. Visual pattern has been studied in four directions (Zhu 2003): (1) studying natural image statistics, in which the natural images are studied from the perspective of image coding and redundancy reduction, or are used to predict or explain the neuron response; (2) analyzing natural image components, in which image is transformed into a superposition of image components for the purposes of variable decoupling and dimension reduction; (3) grouping natural image elements, in which the global perception of images is achieved by grouping local elements according to Gestalt laws; and (4) modeling visual patterns, in which explicit models for the visual patterns have been developed.

In recent years, modeling visual pattern stochastically and making inference statistically become more and more obvious trend in visual pattern analysis. In this line of thinking, a visual pattern is defined as an abstraction of some properties decided by a certain vision tasks. These properties can be featured as statistical computing from either raw image data or some hidden descriptions inferred from raw image data. In both ways, a visual pattern is equalized to a set of observable signals governed by a statistical model. There are two major research areas in this trend: statistical pattern recognition, pattern theory. In the following, we present a historic overview of them.

### 1.1.1 Statistical Pattern Recognition

The term pattern recognition can be traced back to the work of Nobel Laureate Herbert Simon, in which the central observation is that pattern recognition is critical in most human decision-making tasks. Simon stated that “the more relevant the patterns at your disposal, the better your decision will be.” This motivates the belief that pattern recognition is the best possible way to utilize existing sensors, processors, and domain knowledge to make decisions automatically. Rapidly growing and readily available computing power, while enabling faster processing of huge data sets, has facilitated the use of elaborate and diverse methods for data analysis and classification. At the same time, demands on automatic pattern recognition systems are rising enormously due to the availability of large databases and stringent performance requirements (speed, accuracy, and cost). Driven by the above trends, the automatic recognition, description, classification, and grouping of patterns are important problems in a variety of engineering and scientific disciplines such as biology, psychology, medicine, marketing, computer vision, artificial intelligence, and remote sensing.

Pattern recognition aims to classify data (patterns) based on either a priori knowledge or statistical information extracted from the patterns. The patterns to be classified are usually groups of measurements or observations, defining points in an appropriate multidimensional space. This is different to the pattern matching, where