2. Basic Task of Pattern Classification
Definition of the Task
Informal Definition: Telling things apart
pattern recognition

An important field of computer science concerned with recognizing patterns, particularly visual and sound patterns. It is central to optical character recognition (OCR), voice recognition, and handwriting recognition.
Definition:
http://encyclopedia.thefreedictionary.com/Pattern%20recognition

Pattern recognition (also known as classification or pattern classification) is a field within the area of computer science and can be defined as "the act of taking in raw data and taking an action based on the category of the data" [1]. It uses methods from statistics, machine learning and other areas. Typical applications are automatic speech recognition, classification of text into several categories (e.g. spam/non-spam email messages), the automatic recognition of handwritten postal codes on postal envelopes, or the automatic recognition of images of human faces. The last three examples form the subtopic image analysis of pattern recognition that deals with digital images as input to pattern recognition systems.

Pattern recognition techniques

- Neural Networks
- Hidden Markov Models
- Bayesian networks
Definition (cont):  
http://encyclopedia.thefreedictionary.com/Pattern%20recognition

• Application domains
  • computer vision
  • machine vision
  • medical image analysis
  • optical character recognition
  • credit scoring

• See also:
  • artificial intelligence
  • machine learning
  • barcode
  • information retrieval
  • color histograms

• References
Definition

Pattern Recognition:
Automatic transformation of data \( x_i \) (observations, features) into a set of symbols \( \omega_i \) (classes).
Flow of Data in Pattern Recognition

Test Data $x_i$

Feature Extraction

Classifier

Model

Feature Extraction

Training Data

Training Algorithm

$\omega_1$ $\omega_2$ .... $\omega_n$
Classes and Class Regions

- Set of labels: \( \{ \omega_1, \ldots, \omega_K \} \)
- Each label corresponds to a region in feature space
- Complete feature space: \( \omega \)
Examples: Class Regions
Classes and Class Regions

- To make \( \{\omega_1, ..., \omega_K\} \) a set of classes the regions have to satisfy:

\[
\omega_k \neq \emptyset, k = 1...K
\]

\[
\omega_k \cap \omega_\lambda = \emptyset, k \neq \lambda
\]

\[
\bigwedge_{k=1}^{K} \omega_k \text{ covers the complete feature space}
\]

(may be necessary to introduce rejection class)
Supervised Learning

• Labeled data exist
• Task: label new data

• Question: Where to put the decision boundary

=? = new sample
Unsupervised Learning

• True labels are unknown
• Task: put similar objects into the same class
• How to cluster the data?
• Do you know the number of classes?
An Example
(from Duda+Hart)
An Example

- “Sorting incoming Fish on a conveyor according to species using optical sensing”

```
Species
  ├── Sea bass
  └── Salmon
```
Problem Analysis

- Set up a camera and take some sample images to extract features

  - Length
  - Lightness
  - Width
  - Number and shape of fins
  - Position of the mouth, etc…

- This is the set of all suggested features to explore for use in our classifier!
Preprocessing

- Use a segmentation operation to isolate fishes from one another and from the background

- Information from a single fish is sent to a feature extractor whose purpose is to reduce the data by measuring certain features

- The features are passed to a classifier
Classification: Select the length of the fish as a possible feature for discrimination
The length is a poor feature alone!

Select the lightness as a possible feature.
Threshold decision boundary and cost relationship

• Move our decision boundary toward smaller values of lightness in order to minimize the cost (reduce the number of sea bass that are classified salmon!)

• Task of decision theory
Adopt the lightness and add the width of the fish

- Fish

\[ \mathbf{x}^T = [x_1, x_2] \]

Lightness, Width
Two dimensional classification
• We might add other features that are not correlated with the ones we already have. A precaution should be taken not to reduce the performance by adding such “noisy features”

• What is the ideal decision boundary?
• Ideal classification of novel data?
• What happens with novel data

Issue of generalization!
Better decision Boundary?

Diagram showing a scatter plot with points labeled "salmon" and "sea bass".
Generic Classification Systems
and the Pipeline of creating
a Classification System
Pattern Recognition System: Overview
Pattern Recognition System: Overview

• Sensing
  • Use of a transducer (camera or microphone)
  • PR system depends of the bandwidth, the resolution sensitivity distortion of the transducer

• Segmentation and grouping
  • Patterns should be well separated and should not overlap
• Feature extraction
  • Discriminative features
  • Invariant features with respect to translation, rotation and scale.

• Classification
  • Use a feature vector provided by a feature extractor to assign the object to a category

• Post Processing
  • Exploit context input dependent information other than from the target pattern itself to improve performance
The Design Cycle

- start
- collect data
- choose features
  - prior knowledge (e.g., invariances)
- choose model
- train classifier
- evaluate classifier
- end
Design Cycle of a Pattern Recognition System:

Data Collection

• Collecting yourself:
  • Design decisions
    • Type of sensor
    • Annotation
  • Issues
    • Are you collecting typical examples?
    • Cost!!!
Design Cycle of a Pattern Recognition System:

Data Collection

• Use data
  • Speech: well organized
    • Linguistic Data Consortium
    • BAS (Germany)
    • …
  • Images: everywhere not organized
    • Ask you academic friends
    • Download from internet (e.g. http://vasc.ri.cmu.edu/idb/html/face/)
    • …
Design Cycle of a Pattern Recognition System: Feature Choice

• Depends on your problem
• Use prior knowledge
• Goal:
  – Separate the classes as good as possible
  – Be robust against noise
  – Limit unwanted variability (e.g. lighting conditions in face detection)
Design Cycle of a Pattern Recognition System: Feature Choice

- Invariant features: mirror image
Design Cycle of a Pattern Recognition System: Feature Choice

• Invariant features:
  – Objects in images:
    • Translation of objects
    • Rotation
    • Scale
    • Occlusion
    • Deformation
  – Speech recognition:
    • Speaking rate
    • Gender
    • Speaker
    • Dialect
Design Cycle of a Pattern Recognition System: Model Choice

- Try different kinds of models
  - Decision boundary
  - Learn more about the alternatives in this lecture
- How to decide which model is better?
- Trial and error of all possible models?
Design Cycle of a Pattern Recognition System: Training

- Process your training data to create a model
- No universal method available for solving all problems in pattern recognition
- Many different methods available
Design Cycle of a Pattern Recognition System: Evaluation

- Measure the performance of your system
- Use NEW (unseen) data
- Overtraining
  - Good performance on training data
  - Bad performance on NEW data
  - Depends on model complexity and amount of available training data
Measuring the Quality of a Classifier

• Two types of error
  – Classifying “salmon” as “sea bass”: $N_1$
  – Classifying “sea bass” as “salmon” $N_2$

• Task: minimize total cost:

$$C = C_1 N_1 + C_2 N_2$$

$C_1, C_2$: weights
Additional Criteria: Classification

- Effort
  - CPU time
  - Memory
- Robustness
  - Changes in conditions (e.g. background noise)
Types of Tasks and Signals
Types of Data (Patterns): Discrete

e.g. text classification

- Speech Recognition
- Information Retrieval
- Computer Linguistics
- Everything else
Types of Data (Patterns):
One Dimensional time series

Speech or other kinds of sounds

ECG or other bio signal

Even though the input is a time series, different types of Output may be produced
Types of Data (Patterns): Multi-dimensional time series

Controlling a car

- Motordrehzahl
- Geschwindigkeit
- Bremsdruck
- Lenkwinkel
- Vertikalbeschleunigung
- Seitenkraft
- Laengskraft

Stock prices

Many one dimensional signals at the same time
Output depends on task at hand

From: Schuckat-Talamazzini
Types of Data (Patterns):
two dimensional data: images
Types of Data (Patterns):
two dimensional time series

Video:
Sequence of images

Example:
Informedia project
Types of Data (Patterns):
three dimensional

3d reconstruction of CT images

Sequence of three dimensional “images” (e.g. CT scans)
Applications

• Quality control in manufacturing
• Speech recognition (e.g. dictation, dialogue system)
• Character recognition (PDAs, document collections)
• Robotics
• Face Detection (security applications)
• Text classification (e-mail routing)
• Medical image processing
• DNA-sequencing
Summary of Chapter 2

• Definition pattern recognition
• Examples
• Design cycle of a pattern recognition system
• Types of signals