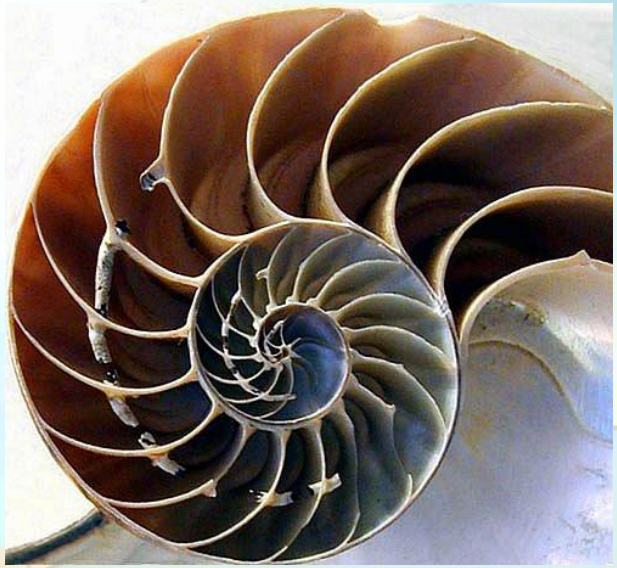


Pattern Recognition

Instructor

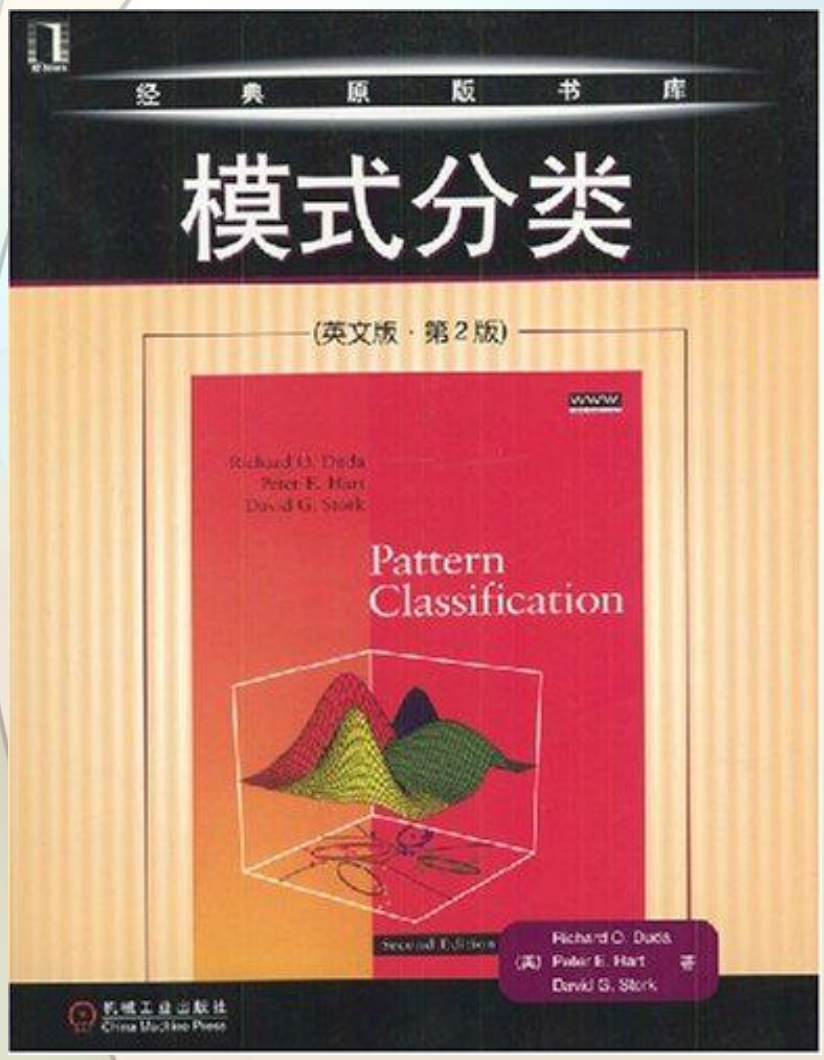
Hui XUE (薛晖)

Southeast University

The First Pattern

- Email:
  - hxue@seu.edu.cn
- URL:
  - http://palm.seu.edu.cn/hxue/

The Second Pattern



Richard O. Duda, Peter E. Hart, David G. Stork

Pattern Classification, 2nd edition

John Wiley & Sons, 2001

模式分类

(英文版·第2版)

机械工业出版社, 2004

The Third Pattern

- Credits
  - 3 credits with 48 teaching hours and 16 experimental hours
  - Week 2 – Week 16, Monday & Wednesday
- About scores
  - Attendance: 5%
  - Quiz: 10%
  - Project: 25%
  - Final Exam: 60%

References

- Books
  - S. Theodoridis, K. Koutroumbas. Pattern Recognition, 4th edition. Elsevier Publishers, 2009.
  - C. Bishop. Pattern Recognition and Machine Learning. Cambridge University Press, 2007.
  - 张学工. 模式识别(第三版). 清华大学出版社, 2010.
- Web Resources
  - International Association for Pattern Recognition (IAPR)
  - Pattern Recognition Journal (PRJ)
  - List of pattern recognition web sites

Remarks

- Mathematical background
  - **Linear algebra**
  - **Probability theory**
  - Statistics
  - Information theory
  - .....

Remarks (Cont.)

- **No pain, No gain**

Classroom lectures are important but not enough → Review what have been taught with at least 4~6 hours per week

- **Terminologies and Contents**

Representing in English, Teaching in Chinese → Examinations in English

Artificial Intelligence

Artificial Intelligence

国务院印发了《新一代人工智能发展规划》，提出了六方面的重点任务和一系列保障措施，要求到2020年人工智能总体技术和应用与世界先进水平同步，人工智能核心产业规模超过1500亿元，带动相关产业规模超过1万亿元；到2030年，我国人工智能理论、技术与应用总体达到世界领先水平。

Artificial Intelligence and COVID-19

- AI + CT Screening

Artificial Intelligence and COVID-19

- AI + Targeted Drug Research

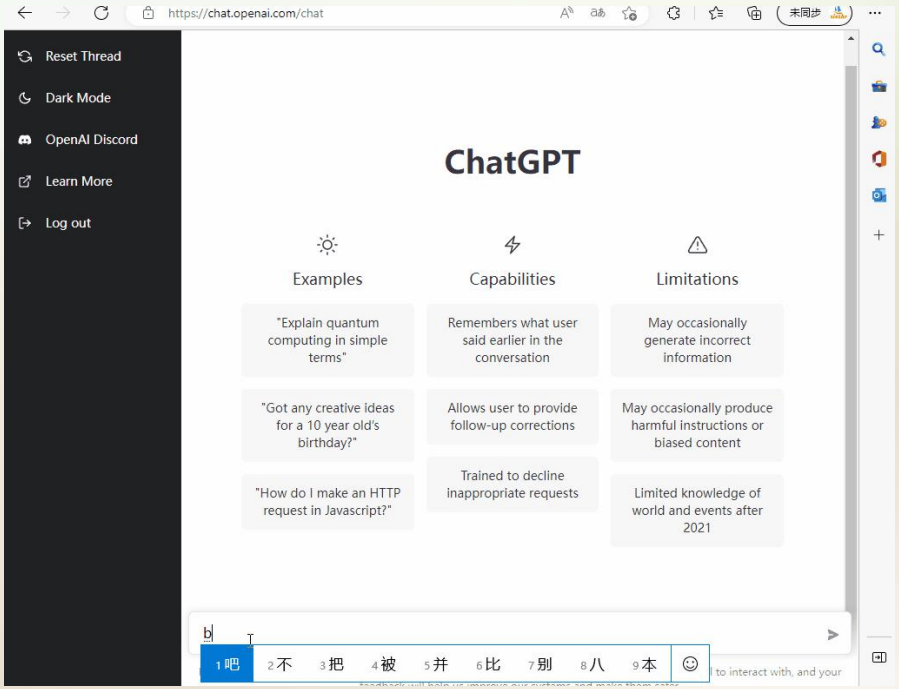
- AI + Check Body Temperature

Artificial Intelligence and COVID-19

- AI + Information Gathering

ChatGPT

ChatGPT（全名：Chat Generative Pre-trained Transformer），美国OpenAI研发的聊天机器人程序，于2022年11月30日发布。ChatGPT是人工智能技术驱动的自然语言处理工具，它能够通过学习和理解人类的语言来进行对话，还能根据聊天的上下文进行互动，真正像人类一样来聊天交流，甚至能完成撰写邮件、视频脚本、文案、翻译、代码，写论文等任务。



Remark

- What's the use of Pattern Recognition?
  - One of the core issues in AI：computer vision，natural language processing，speech recognition，…
  - One of the most hot research fields in computer science
  - Common interests of Microsoft、Google、Baidu、…
- So …
  - Find the most cool job
  - Research
  - …

Ch 01. Introduction

"*To understand is to perceive patterns*"

– Isaiah Berlin

The 3W of Pattern Recognition

- **W**hat is Pattern Recognition (PR)?

  What is **Pattern**?

  What is **Recognition**?

  What is **Pattern Recognition**?

- **W**hy do we need Pattern Recognition?

  The **necessity and importance** for pattern recognition

- Ho**W** to perform Pattern Recognition?

  The **building blocks** of a pattern recognition system

What's Pattern?

- “A pattern is the opposite of a chaos; it is an entity vaguely defined, that could be given a name.” – Satoshi Watanabe

What's Pattern?

- There are various kinds of patterns
  - Visual patterns (视觉模式) such as eyes, nose, mouth, face, fingerprint, etc.
  - Temporal patterns (时序模式) such as speech, audios, videos, data streams, etc.
  - Logical patterns (逻辑模式) such as characters, strings, images, etc.
  - ……

What's Recognition?

- "Identification of a pattern as a member of a category we already know, or we are familiar with" – Anil K. Jain
  - Classification (Known Classes)
  - Clustering (Unknown Classes)

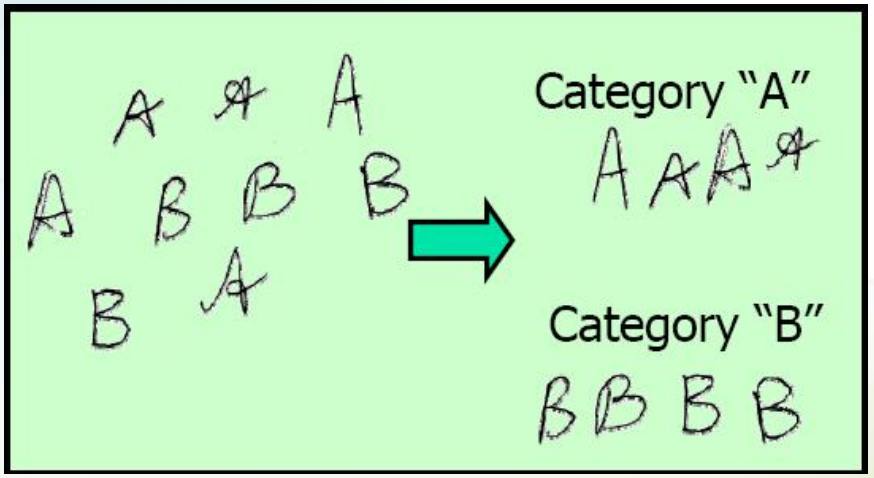
Classification (分类) → Categories are known and the task is to assign a proper class label for each pattern

Clustering (聚类) → Categories are unknown and the task is to learn categories and group the patterns accordingly

What's Recognition?

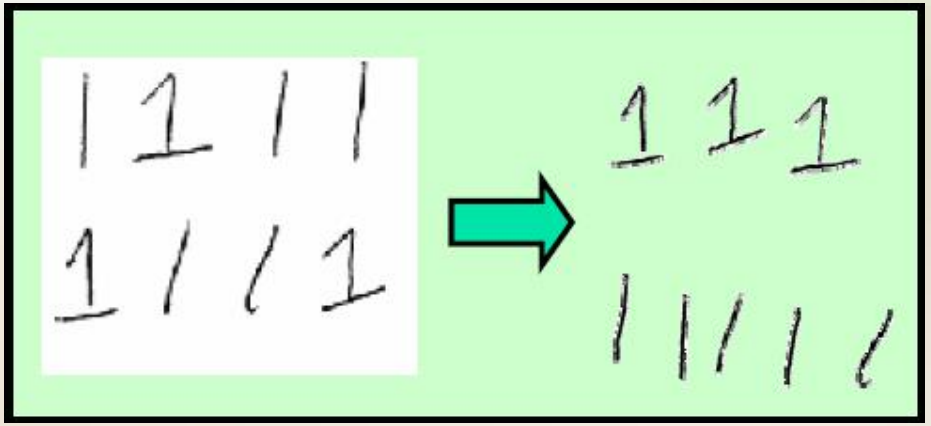
Classification: An example

We already know the categories of characters, and then classify the handwritten ones into category “A” and category “B”



Clustering: An example

We do not know the categories of symbols, and then learn the categories and group the symbols accordingly



What's Pattern Recognition?

- Pattern recognition is the procedure of processing and analyzing diverse information (numerical, literal, logical) characterizing the objects or phenomenon, so as to provide descriptions, identifications, classifications and interpretations for them.
- 对表征事物或现象的各种形式的（数值的，文字的和逻辑关系的）信息进行处理和分析，以对事物或现象进行描述、辨认、分类和解释的过程，是信息科学和人工智能的重要组成部分。

What's Pattern Recognition?

- “The real power of human thinking is based on recognizing patterns. The better computers get at pattern recognition, the more humanlike they will become”.
  – *Ray Kurzweil, NY Times, Nov 24, 2003*

What's Pattern Recognition?

A "Perceive + Process + Prediction" View

It is the study of how machines can

- ✓ **Perceive**: Observe the environment (i.e. interact with the real-world)
- ✓ **Process**: Learn to distinguish patterns of interest from their background
- ✓ **Prediction**: make sound and reasonable decisions about the categories of the patterns

Applications of Pattern Recognition

1) Character Recognition

[字符识别]

Input:
images with characters (normally contaminated with noise)

Output:
the identified character strings (Earham encourag)

Useful in scenarios such as automatic license plate recognition (ALPR), optical character recognition (OCR), etc.

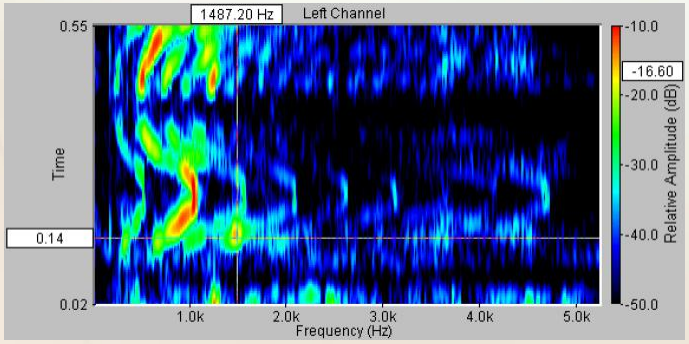
Applications of PR (Cont.)

2) Speech Recognition

[语音识别]

Input:

acoustic signal
(e.g. sound waves)



Output:

contents of the speech

Useful in scenarios such as speech-to-text (STT), voice command & control, etc.

Applications of PR (Cont.)

3) Fingerprint Recognition

[指纹识别]

Input:

fingerprints of some person

Output:

the person's identity

Useful in scenarios such as computerized access control, criminal pursuit, etc.

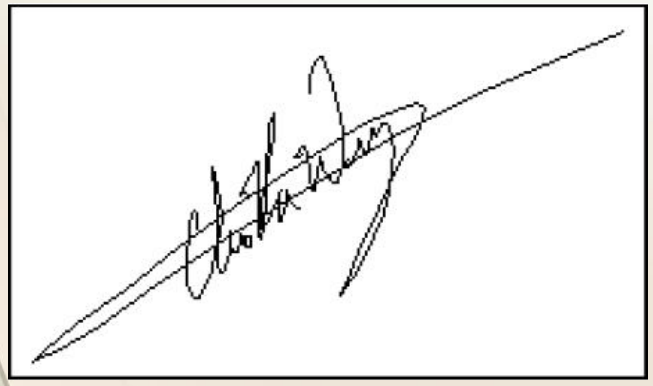
Applications of PR (Cont.)

4) Signature Identification

[签名验证]

Input:

signature of some person (sequence of dots)



Output:

the signatory's identity

Useful in scenarios such as digital signature verification, credit card anti-fraud, etc.

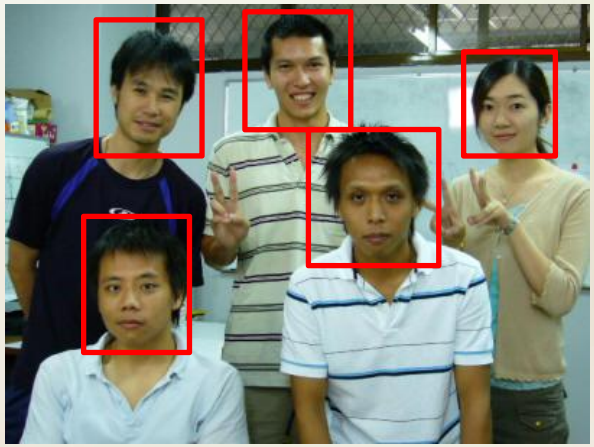
Applications of PR (Cont.)

5) Face Detection
[人脸检测]

Useful in scenarios such as digital camera capturing, video surveillance, etc.

Input:
images with several people

Output:
locations of the peoples' faces in the image



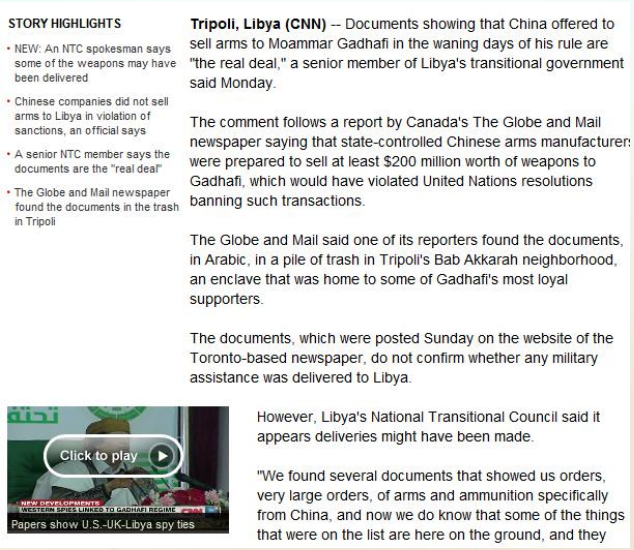
Applications of PR (Cont.)

6) Text Categorization

[文档分类]

Input:

document, web pages, etc.



STORY HIGHLIGHTS

- NEW: An NTC spokesman says some of the weapons may have been delivered
- Chinese companies did not sell arms to Libya in violation of sanctions, an official says
- A senior NTC member says the documents are the "real deal"
- The Globe and Mail newspaper found the documents in the trash in Tripoli

Tripoli, Libya (CNN) -- Documents showing that China offered to sell arms to Moammar Gadhafi in the waning days of his rule are "the real deal," a senior member of Libya's transitional government said Monday.

The comment follows a report by Canada's The Globe and Mail newspaper saying that state-controlled Chinese arms manufacturers were prepared to sell at least $200 million worth of weapons to Gadhafi, which would have violated United Nations resolutions banning such transactions.

The Globe and Mail said one of its reporters found the documents, in Arabic, in a pile of trash in Tripoli's Bab Akkarah neighborhood, an enclave that was home to some of Gadhafi's most loyal supporters.

The documents, which were posted Sunday on the website of the Toronto-based newspaper, do not confirm whether any military assistance was delivered to Libya.

However, Libya's National Transitional Council said it appears deliveries might have been made.

"We found several documents that showed us orders, very large orders, of arms and ammunition specifically from China, and now we do know that some of the things that were on the list are here on the ground, and they

Output:

category of the text, such as political, economic, military, sports, etc.

Useful in scenarios such as information retrieval, document organization, etc.

Applications of PR (Cont.)

7) Financial Forecast

[财务预测]

Input:

stock price time series

Output:

Bull market?

Bear market?

Applications of PR - More

Problem	Input	Output
Non-destructive testing	Ultrasound, eddy current, acoustic emission waveforms	Presence/absence of flaw, type of flaw
Detection and diagnosis of disease	ECG, EEG waveforms	Types of cardiac conditions, classes of brain conditions
Natural resource identification	Multispectral images	Terrain forms, vegetation cover
Aerial reconnaissance	Visual, infrared, radar images	Tanks, airfields
Character recognition (page readers, zip code, license plate)	Optical scanned image	Alphanumeric characters
Identification and counting of cells	Slides of blood samples, micro-sections of tissues	Type of cells
Inspection (PC boards, IC masks, textiles)	Scanned image (visible, infrared)	Acceptable/unacceptable
Manufacturing	3-D images (structured light, laser, stereo)	Identify objects, pose, assembly
Web search	Key words specified by a user	Text relevant to the user

Best pattern recognition system

Human Brain !

Why need pattern recognition?

For humans, pattern recognition is natural & easy

recognize a face understand spoken words

read handwritten characters identify items by feel

decide whether an apple is ripe by its smell ……

For computers, pattern recognition is never easy

All in all, pattern recognition is important, useful, attractive, but rather challenging

Challenges ➔ Opportunities

Basic Concepts

Model (模型)

Descriptions which are typically mathematical in form

[以数学形式表达的性质]

e.g. image ➔ matrix; sound waves ➔ frequency vector

Sample (样本)

Representatives of the patterns we want to classify

[分类的基本对象，模式的实例]

e.g. fingerprint of a suspect; ECG of a patient

Training Set (训练集)

A set of samples used to train classifiers

[用于训练分类器的样本集合]

Basic Concepts (Cont.)

Test Set (测试集)

A set of samples to be classified, usually being mutually exclusive to training set

[用于测试分类器的样本集合,通常与训练集无交集]

"Training set" vs. "Test set" ⇔ "Homeworks" vs. "Exams"

Feature (特征)

Attributes which characterize properties of the samples

[用于刻画样本性质的属性]

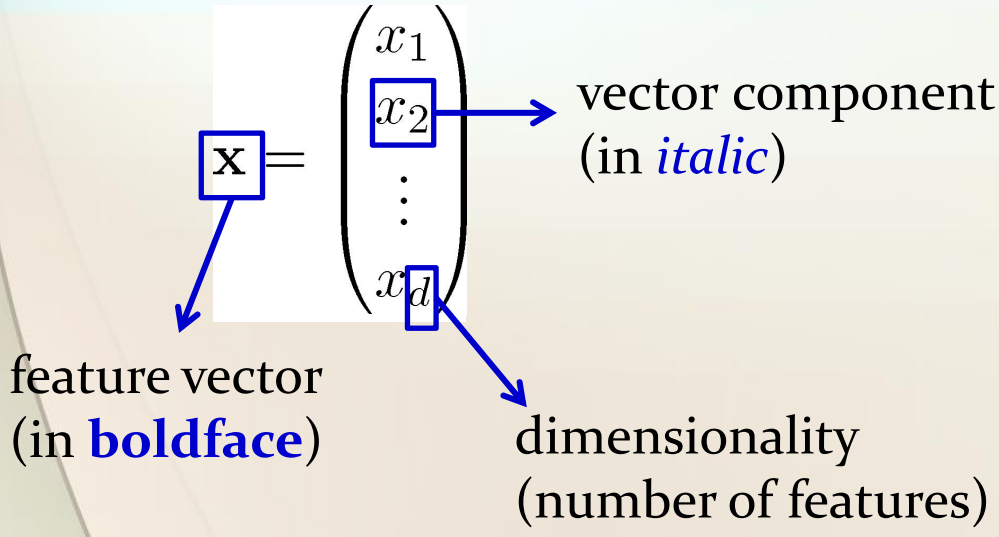
e.g. to characterize a person, we may use features such as height, weight, age, salary, occupation, etc.

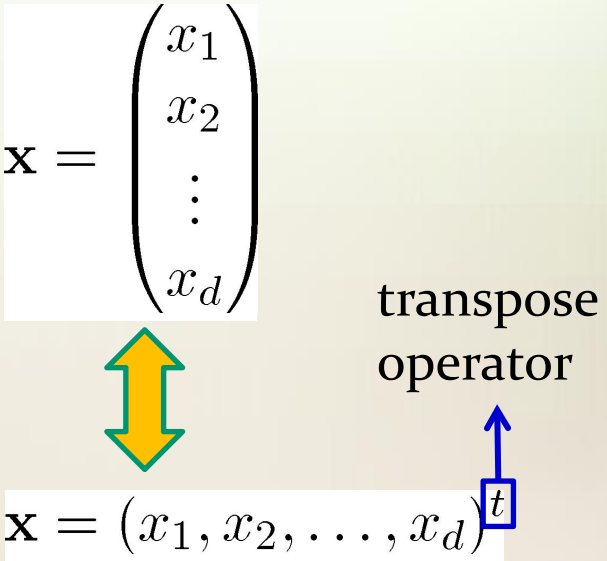
Basic Concepts (Cont.)

Feature Vector (特征向量)

Vector formed by a group of features, usually in column form

[由一组特征组成的向量，通常表示为列向量]





Basic Concepts (Cont.)

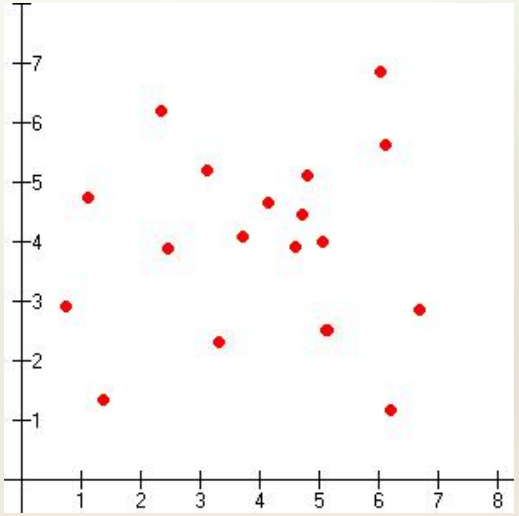
Feature Space (特征空间)

Space containing all the possible feature vectors
[由所有可能的特征向量组成的数据空间]

e.g. the d-dimensional Euclidean space $\mathbf{R}^d$

Scatter Plot (散布图)

Each sample is plotted as a point in the feature space
[将每个样本表示为特征空间中的一个点]

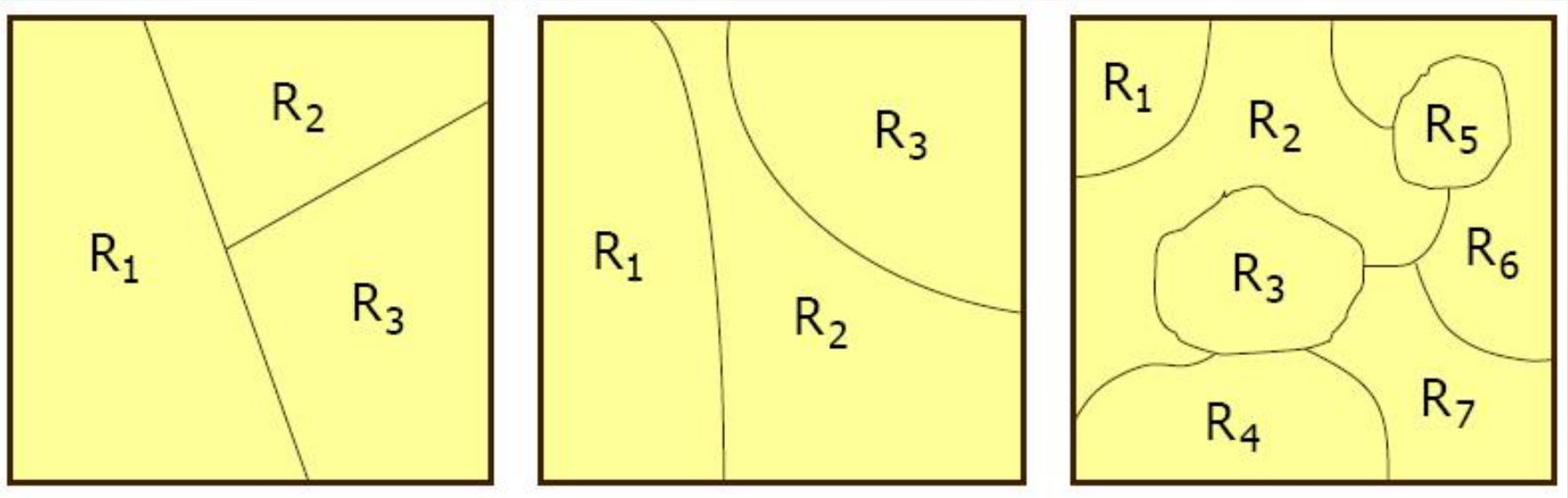


a 2D scatter plot

Basic Concepts (Cont.)

Decision Boundary (决策边界)

Boundaries in feature space which separate different categories [特征空间中区分各个类别的边界]



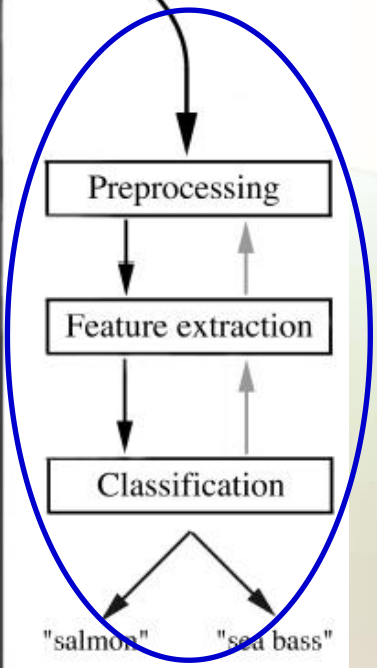
linear boundary quadratic boundary complex boundary

How to do pattern recognition?

An Example

The task: Automate the process of sorting incoming fish on a conveyor belt according to species

Separate *sea bass* from *salmon*
[鲈鱼 vs. 鲑鱼]



Three basic steps

Example: “Sea bass” vs. “Salmon”

Step I: Preprocessing (预处理)

Goal: Preprocess the image captured by the camera, such that subsequent operations could be simplified without losing relevant information

Routine image processing

- Adjust the level of illumination
- Denoising
- Enhance the level of contrast

segmentation

- Isolate different fishes from one another
- Isolate fishes from the background

……

Example: “Sea bass” vs. “Salmon”

Step II: Feature Extraction (特征抽取)

Goal: Extract features (with good distinguishing ability) from the preprocessed image to be used for subsequent classification

Sea bass is usually longer than a salmon

“length” could be a good candidate for features

Sea bass is usually brighter than a salmon

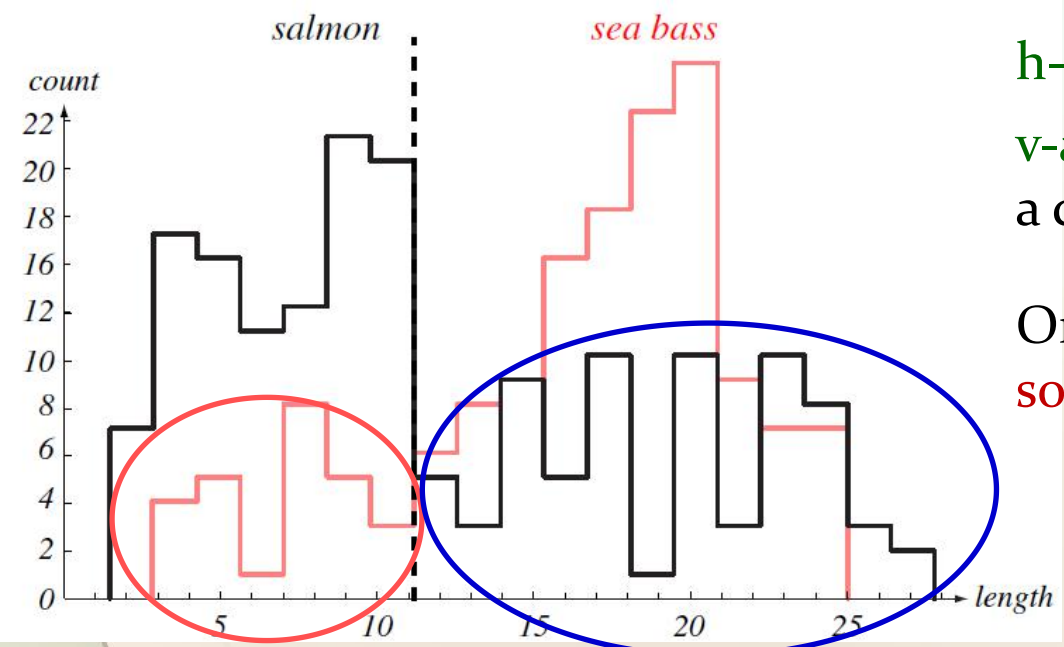
“lightness” of *fish scales* could be another good candidate for features

……

Example: “Sea bass” vs. “Salmon”

Step III: Classification (分类)

Goal: To distinguish different types of objects (in this case, *sea bass* vs. *salmon*) based on the extracted features



histogram for *length*

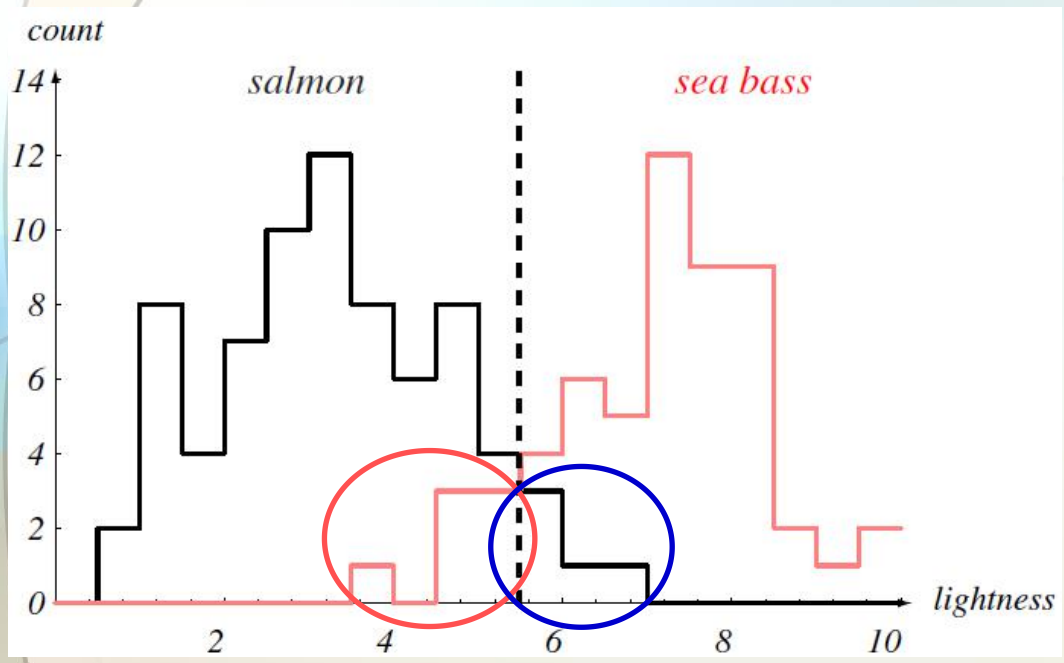
h-axis: length of fish

v-axis: number of fishes with a certain length

On average, sea bass is somewhat longer than salmon

Too much overlaps ➔ poor separation with the length feature

Example: “Sea bass” vs. “Salmon”



histogram for *lightness*

h-axis: lightness of fish scales

v-axis: number of fishes with a certain lightness

On average, sea bass is much brighter than salmon

Less overlaps ➔ better separation with the lightness feature, but still a bit unsatisfactory

What if no other single feature yields better performance?

Use more features at the same time!

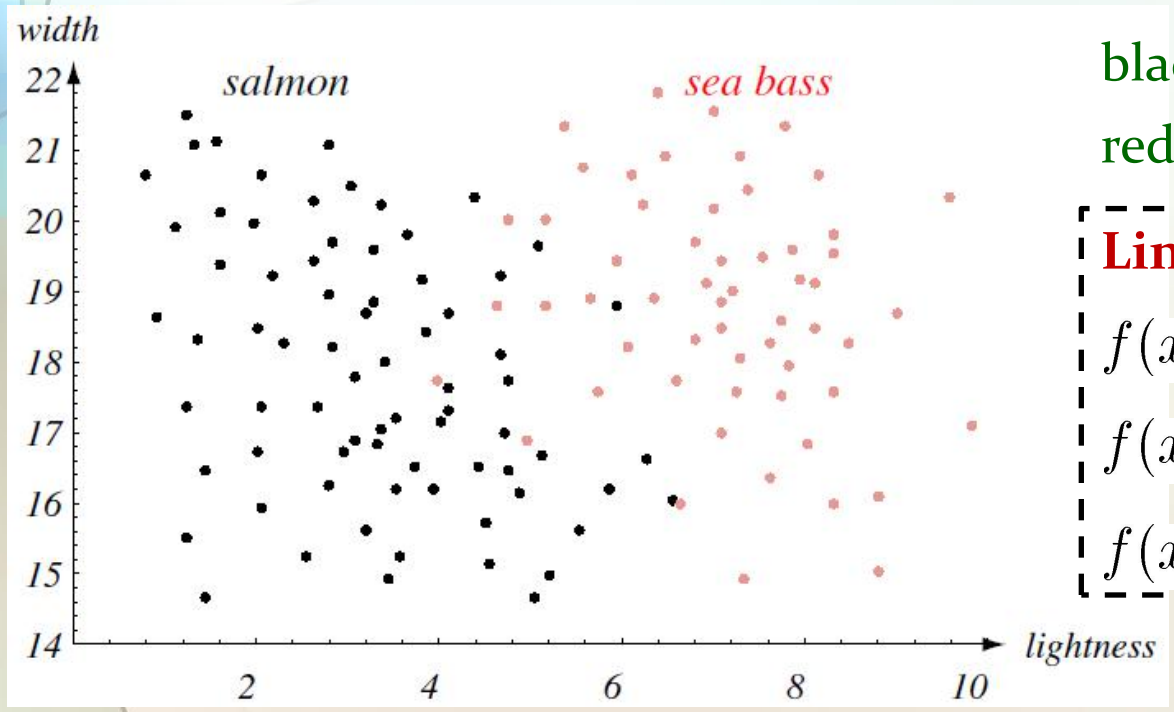
Example: “Sea bass” vs. “Salmon”

Using two features simultaneously

$$\mathbf{x} = \begin{pmatrix} x_1 \\ x_2 \end{pmatrix}$$

x_1 : fish width

x_2 : fish lightness



scatter plot for the feature vectors

black dots: salmon samples

red dots: sea bass samples

Linear decision boundary:

$$f(x_1, x_2) = a \cdot x_1 + b \cdot x_2 + c$$

$$f(x_1, x_2) > 0 \implies \text{sea bass}$$

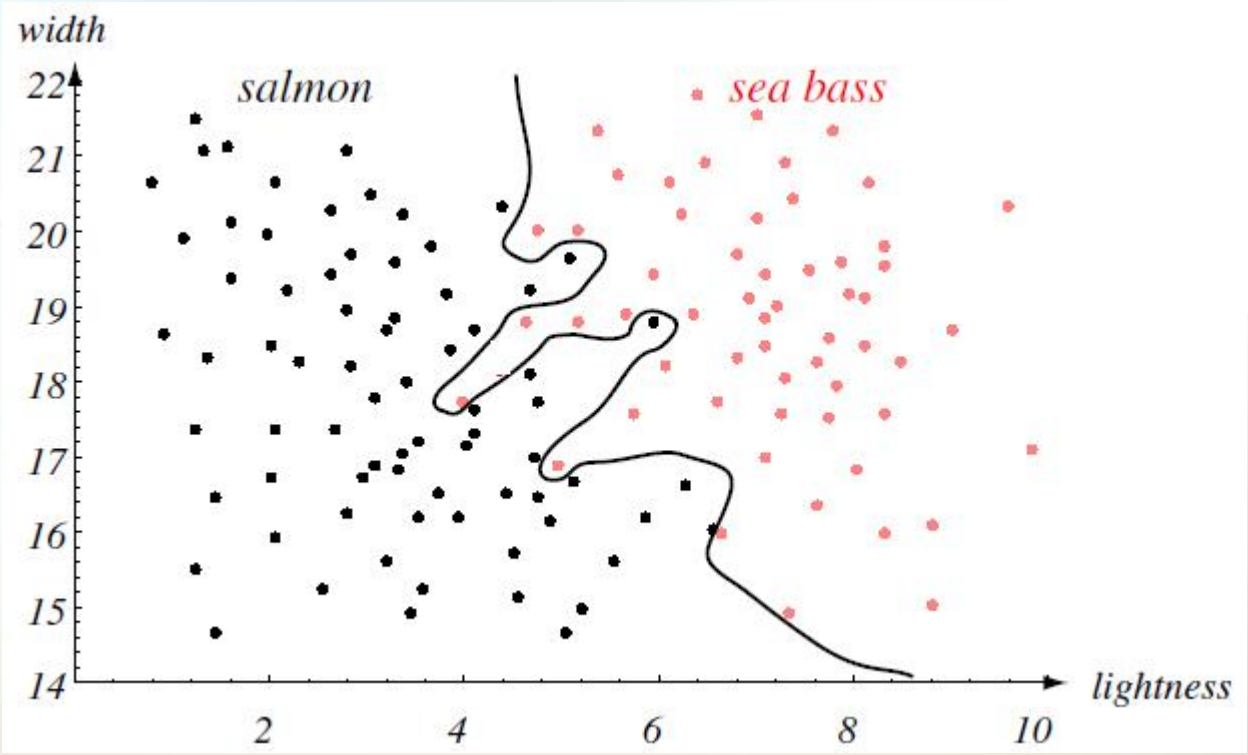
$$f(x_1, x_2) \leq 0 \implies \text{salmon}$$

Much better than single feature

Example: “Sea bass” vs. “Salmon”

Linear decision boundary:

Complex decision boundary



All the training samples (i.e. known patterns) have been separated perfectly

Can we truly feel satisfied?

Example: “Sea bass” vs. “Salmon”

Generalization

[泛化能力/推广能力]

The ultimate goal!

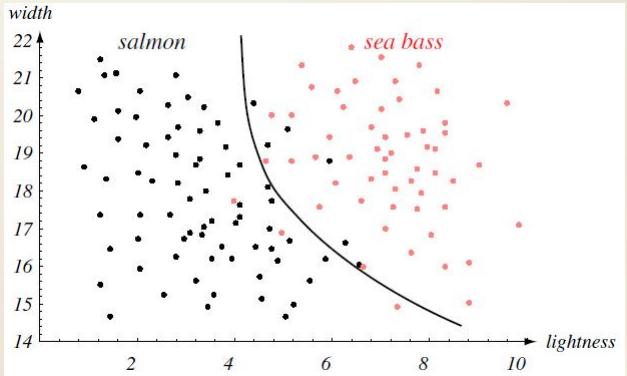
The central aim of designing a classifier is to make correct decisions when presented with *novel* (*unseen*/*test*) patterns, not on training patterns whose labels are already known

e.g. it’s useless to get 100% accuracy when answering homework questions while get low accuracy when answering exam questions

Performance on the training set

Simplicity of the classifier

Tradeoff



Related Fields to PR

Pattern Recognition: **Pattern ➔ Category**

- Hypothesis Testing (假设检验)
  - Null hypothesis ➔ Rejection or Not

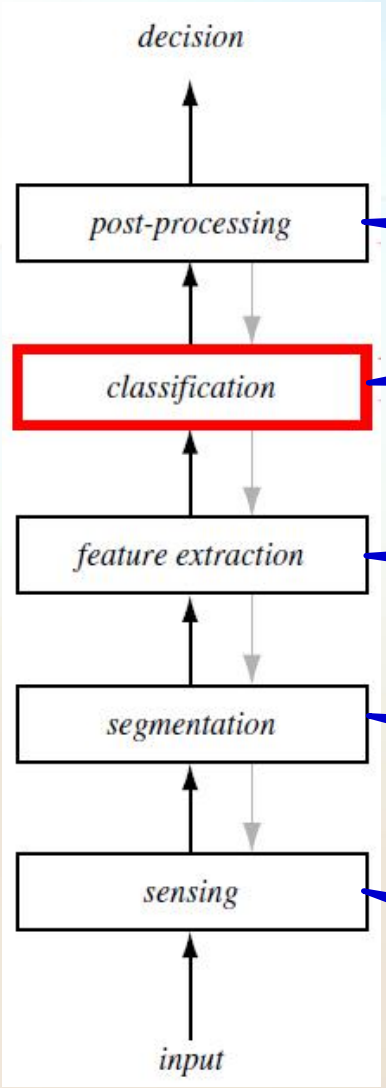
E.g.: To determine whether a drug is effective; Null hypothesis: it has not effect

- Image Processing (图像处理)
  - Image ➔ Image
- Regression (回归分析)
  - Pattern ➔ Real Value
- Interpolation (插值)
  - Pattern (unexplored input range) ➔ Interpolated Value
- Density Estimation (概率密度估计)
  - Patterns ➔ Probability density function (pdf) for different categories

Often employed as preliminary steps in pattern recognition

Pattern Recognition System

In addition to the usual "bottom-up" flow of data, some systems also employ feedback from higher levels back down to lower levels (gray arrows)



A post processor decide on the appropriate action based on the classification

A classifier uses extracted features to assign the sensed object to a category

A feature extractor measures object properties that are useful for classification

A segmentor isolates sensed objects from the background or from other object

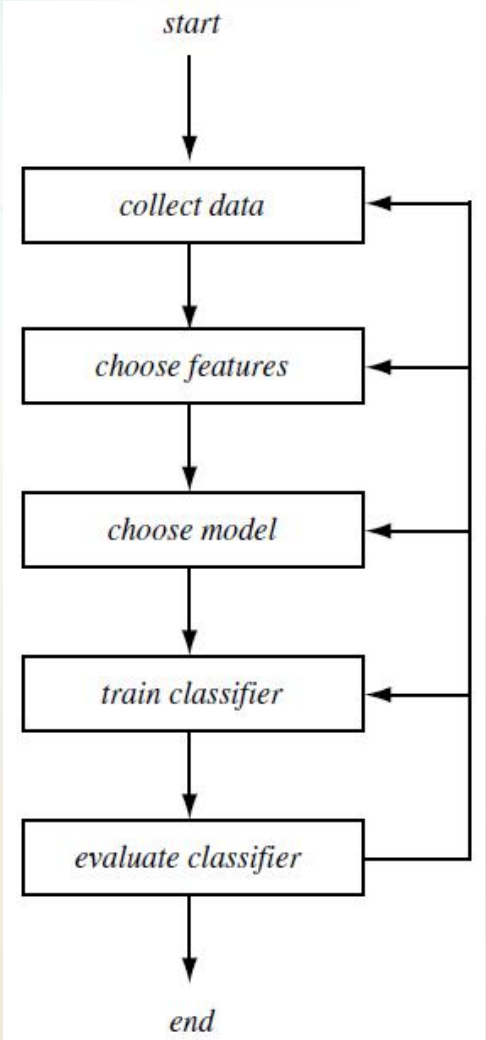
A sensor converts physical inputs (e.g. images, sounds) into digital signal data

Design Cycle of PR System

The design of a PR system usually entails a number of different activities, such as *data collection, feature choice, model choice, classifier training, classifier evaluation.*

- Data collection accounts for a large part of the cost of developing a PR system
- Feature choice and model choice are highly domain-dependent, where *prior knowledge* (先验知识) plays very important role

  e.g.: lightness might be a good feature for distinguishing sea bass and salmon; linear model might be preferred than nonlinear ones
- Various activities may be repeated in order to obtain satisfactory results



Important Issues in Pattern Recognition

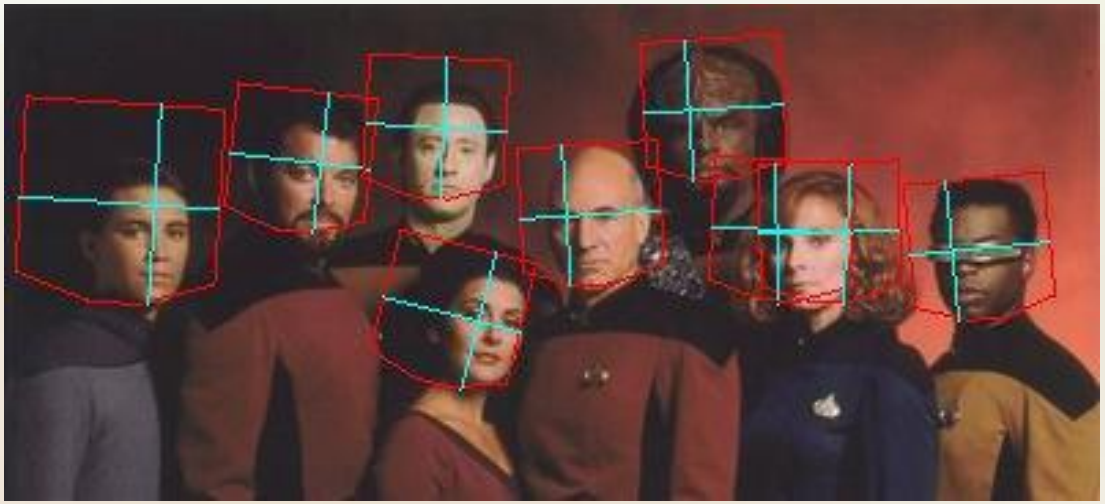
- Noise
  (噪声)
- Segmentation
  (分割)
- Data Collection
  (数据采集)
- Domain Knowledge
  (领域知识)
- Feature Extraction
  (特征抽取)
- Pattern Representation
  (模式表示)
- Missing Features
  (缺失特征)
- Model Selection
  (模型选择)
- Overfitting
  (过配)
- Context
  (上下文)
- Classifier Ensemble
  (分类器集成)
- Costs and Risks
  (代价与风险)
- Computational Complexity
  (计算复杂度)
- ……

噪声（noise）

- Various types of noise (e.g., shadows, conveyor belt might shake, etc.)
- Noise can reduce the reliability of the feature values measured.
- Knowledge of the noise process can help improve performance.

分割（Segmentation）

- Individual patterns have to be segmented.
  - How can we segment without having categorized them first ?
  - How can we categorize them without having segmented them first ?
- How do we "group" together the proper number of elements ?

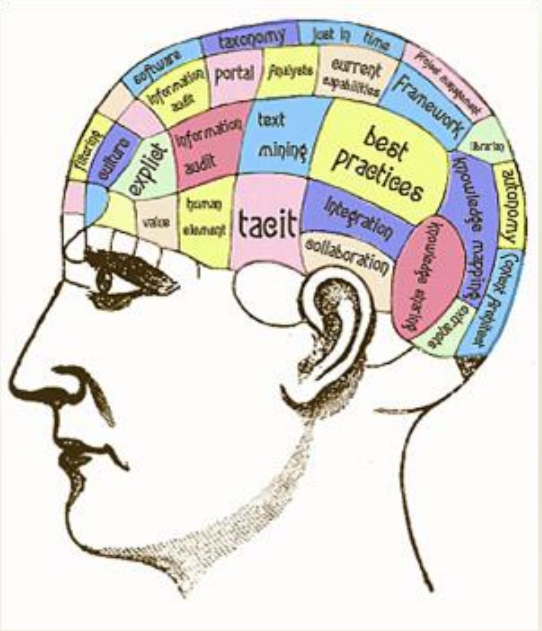


数据采集（Data Collection）

- How do we know that we have collected an adequately large and representative set of examples for training/testing the system?
- The cost of data collection could be prohibitively high

领域知识（Domain Knowledge）

- When there is not sufficient training data, incorporate domain knowledge:
  - Model how each pattern is generated - this is difficult !! (e.g., recognize all types of chairs).
  - Incorporate *some* knowledge about the pattern generation method. (e.g., optical character recognition (OCR) assuming characters are sequences of strokes)

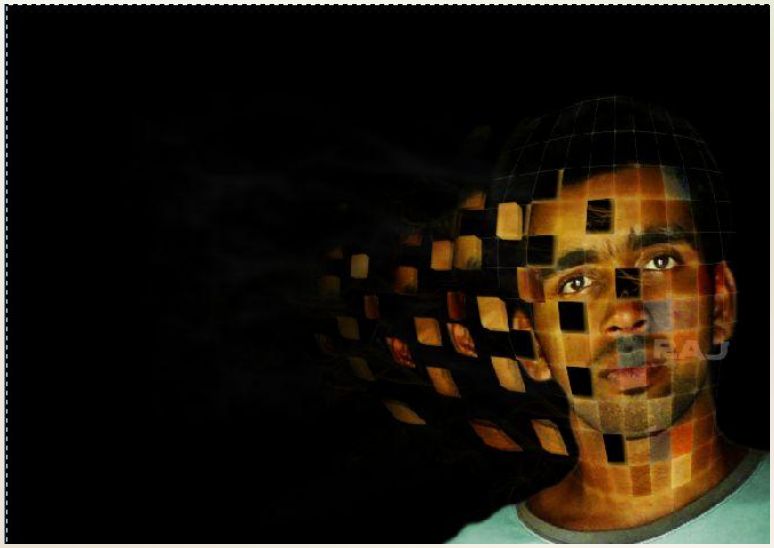


特征抽取（Feature Extraction）

- It is a domain-specific problem which influences classifier's performance.
- Which features are most promising ?
- Are there ways to automatically learn which features are best ?
- How many should we use ?
- Choose features that are robust to noise.
- Favor features that lead to simpler decision regions.

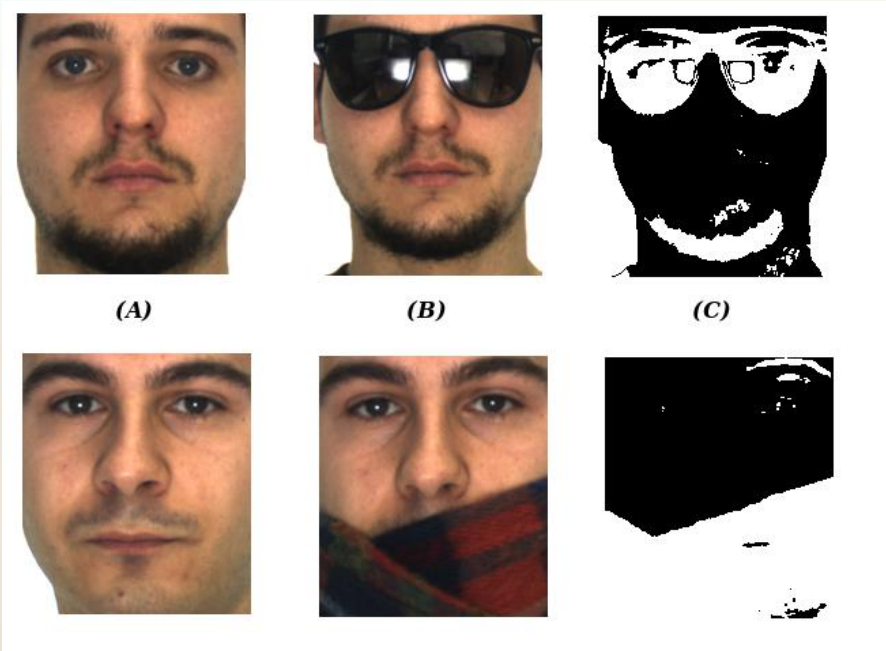
模式表示（Pattern Representation）

- Similar patterns should have similar representations.
- Patterns from different classes should have dissimilar representations.
- Pattern representations should be invariant to transformations such as:
  - translations, rotations, resize, reflections, non-rigid deformations
- Small intra-class variation, large inter-class variation.



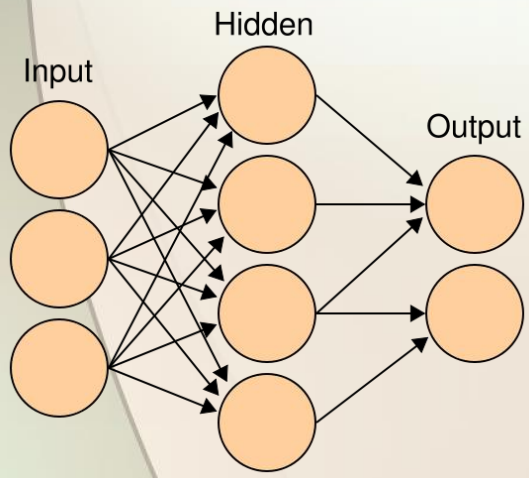
缺失特征（Missing Features）

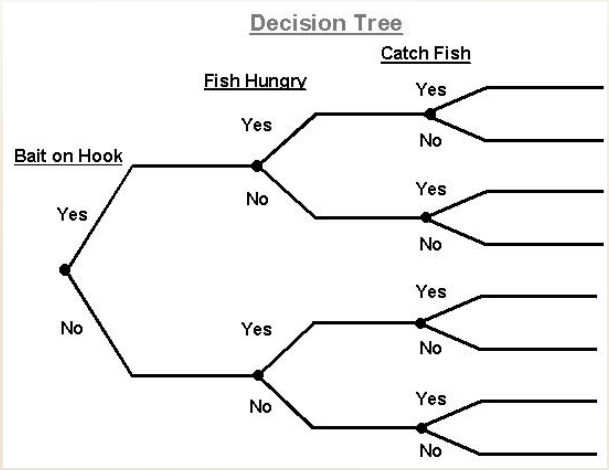
- Certain features might be missing (e.g., due to occlusion).
- How should the classifier make the best decision with missing features?
- How should we train the classifier with missing features ?

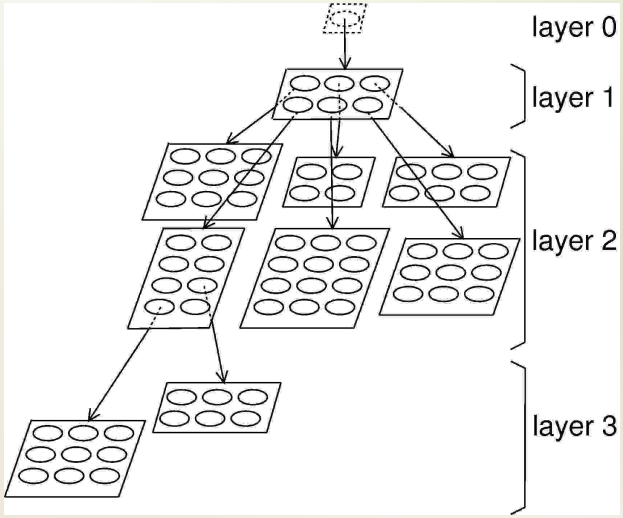


模型选择（Model Selection）

- How do we know when to reject a class of models and try another one ?
- Is the model selection process just a trial and error process ?
- Can we automate this process ?

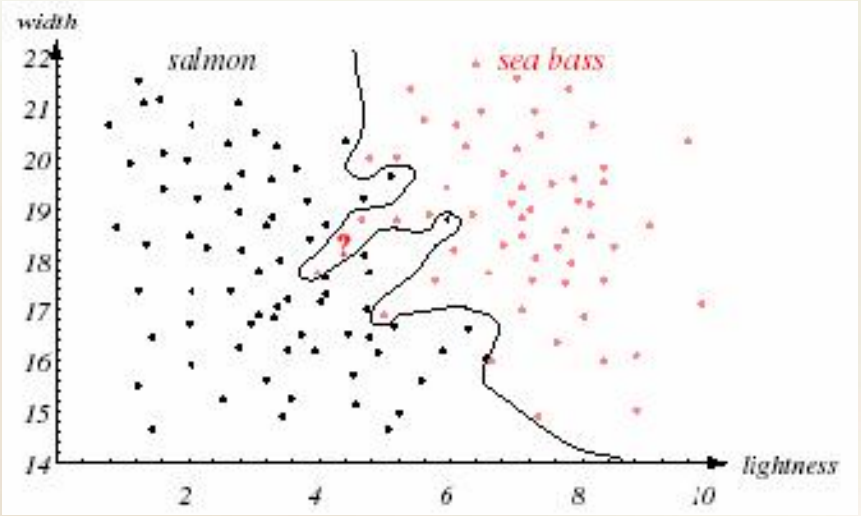






过配（Overfitting）

- Models complexer than necessary lead to *overfitting* (i.e., good performance on the training data but poor performance on novel data).
- How can we adjust the complexity of the model? (not very complex or simple).
- Are there principled methods for finding the best complexity?



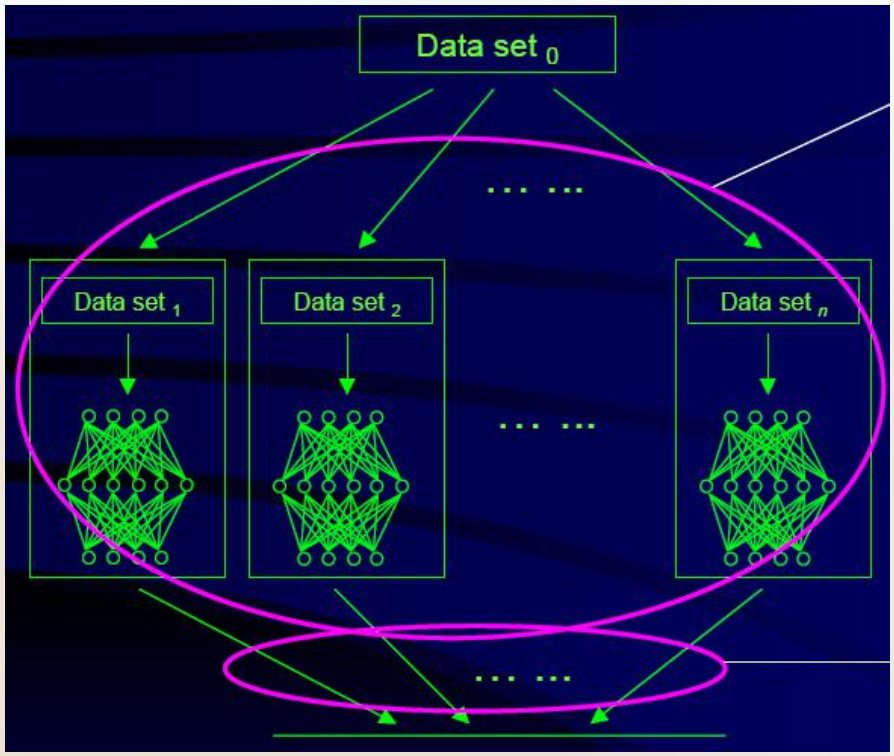
上下文（Context）

- The same pattern within different context might have different meanings
- Context is very helpful!

How m ch info mation
are y u mi sing

分类器集成（Classifier Ensemble）

- Performance can be improved using multiple classifiers.
- How should we combine multiple classifiers?



代价与风险（Costs and Risks）

- Each classification is associated with a cost or risk (e.g., classification error).
- How can we incorporate knowledge about such risks?
- Can we estimate the *lowest* possible risk of *any* classifier?

计算复杂度
（Computational Complexity）

- How does an algorithm *scale* with
  - the number of feature dimensions
  - number of patterns
  - number of categories
- Brute-force approaches might lead to perfect classifications results but usually have impractical time and memory requirements.
- What is the tradeoff between computational ease and performance?

计算复杂度
（Computational Complexity）

- “Universal” image recognizer
  - Mark all possible combinations of pixel values in a 100*100 gray image
  - For a new image, just use the "look-up table" method to find the same image in all tagged image libraries, and get its class
- **Unacceptable computational complexity**

$$256^{100\times100}$$

- **Computational complexity must be considered in practical applications**

Summary

- What is Pattern Recognition?
  - Pattern
    - The opposite of chaos
    - Various kinds: visual patterns, temporal patterns, logical patterns, etc.
  - Recognition
    - Identification of a pattern as a member of a category
    - **Classification**: categories known ➔ assign proper class label for each pattern
    - **Clustering**: categories unknown ➔ learn categories and group patterns
  - Pattern Recognition
    - **Perceive**: observe the environment (i.e. interact with the real-world)
    - **Process**: learn to distinguish patterns of interest
    - **Prediction**: make sound and reasonable decisions about the categories

Summary (Cont.)

- Why Pattern Recognition?
  - Pattern recognition is needed in designing almost all automated and intelligent systems
  - Applications of pattern recognition are ubiquitous
    - Character recognition (images ➔ characters)
    - Speech recognition (speech ➔ text)
    - Fingerprint recognition (fingerprints ➔ person's identity)
    - Signature identification (signature ➔ signatory's identity)
    - Face detection (images ➔ face locations)
    - Text categorization (documents ➔ semantic categories)
    - ……

Summary (Cont.)

- How Pattern Recognition?
  - Basic concepts
    - model, sample, training set, test set, feature, feature vector, feature space, scatter plot, decision boundary
    - An illustrative example: “sea bass” vs. “salmon”
    - **Generalization**: Make correct decisions given novel patterns
  - Components of Pattern Recognition System
    - sensing ➔ segmentation ➔ feature extraction ➔ classification ➔ post-processing ➔ ……

Summary (Cont.)

- How Pattern Recognition?
  - Design Cycle of Pattern Recognition System
    - collect data ➔ choose features ➔ choose model ➔ train classifier ➔ evaluate classifier ➔ ……
  - Important Issues
    - Noise
    - Segmentation
    - Data Collection
    - Domain Knowledge
    - Feature Extraction
    - Pattern Representation
    - Missing Features
    - Model Selection
    - Overfitting
    - Context
    - Classifier Ensemble
    - Costs and Risks
    - Computational Complexity
    - ……

Generalized Target

- Humans have the ability to switch rapidly and seamlessly between different pattern recognition tasks
- It is very difficult to design a device that is capable of performing a variety of classification tasks
  - Different decision tasks may require different features.
  - Different features might yield different solutions.
  - Different tradeoffs (e.g., classification error) exist for different tasks.

Generalized Target

- **The fundamental purpose of pattern recognition is to reconstruct the inner model of pattern generation**
- **Each pattern recognition technique relies on a hypothetical model**
- **Each pattern recognition problem implies an intrinsic model**
- "Best method"?
  - Effectiveness of a pattern recognition technique in a given problem depends on the degree of agreement between the hypothetical model of the technique and the internal model of the problem
  - **No pattern recognition technology for all problems**

There is no broad sense of "best method", but it is possible to find a solution to a problem "best method"

Basic methods

- **Based on Known knowledge**
  - For certain patterns, human knowledge can be well classified and recognized. In this case, a good classifier can be designed directly based on known knowledge.
  - **Rare**
- **Based on "Learning from samples"**
  - **Given a set of samples for a number of target patterns**
  - **Learning a classifier from these samples using a learning algorithm**
  - **Most cases, it is also the main topic of pattern recognition**

Basic methods

- Learning Models (学习范式)
  - Supervised Learning（有监督学习）
  - Unsupervised Learning（无监督学习）
  - Semi-supervised Learning（半监督学习）
  - Reinforcement Learning（强化学习）
  - Incremental Learning（增量学习）
  - …