ISEL
INSTITUTO SUPERIOR
DE ENGENHARIA DE LISBOA

PROCESSAMENTO DE IMAGEM E BIOMETRIA

IMAGE PROCESSING AND BIOMETRICS

10. **PATTERN RECOGNITION SYSTEMS**

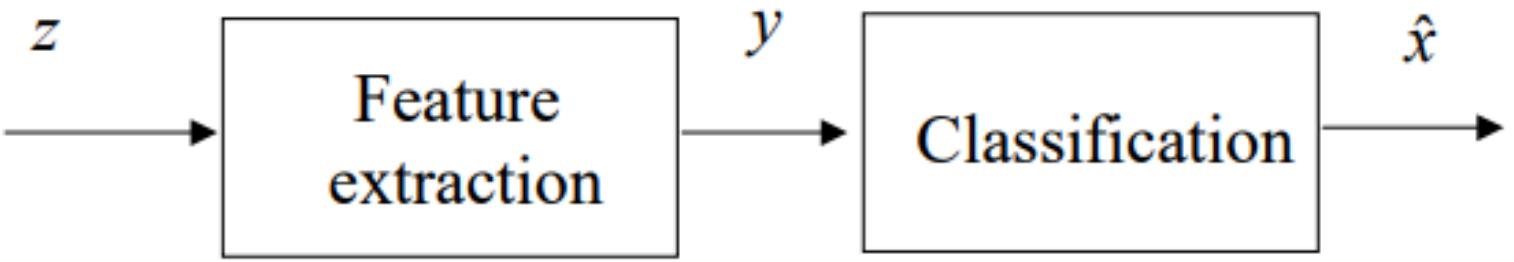
Summary

- Pattern Recognition Systems
- Feature Extraction
- Classification
- Machine Learning Techniques
- Classifier Evaluation
- Machine Learning and Data Mining Tools
- Exercises

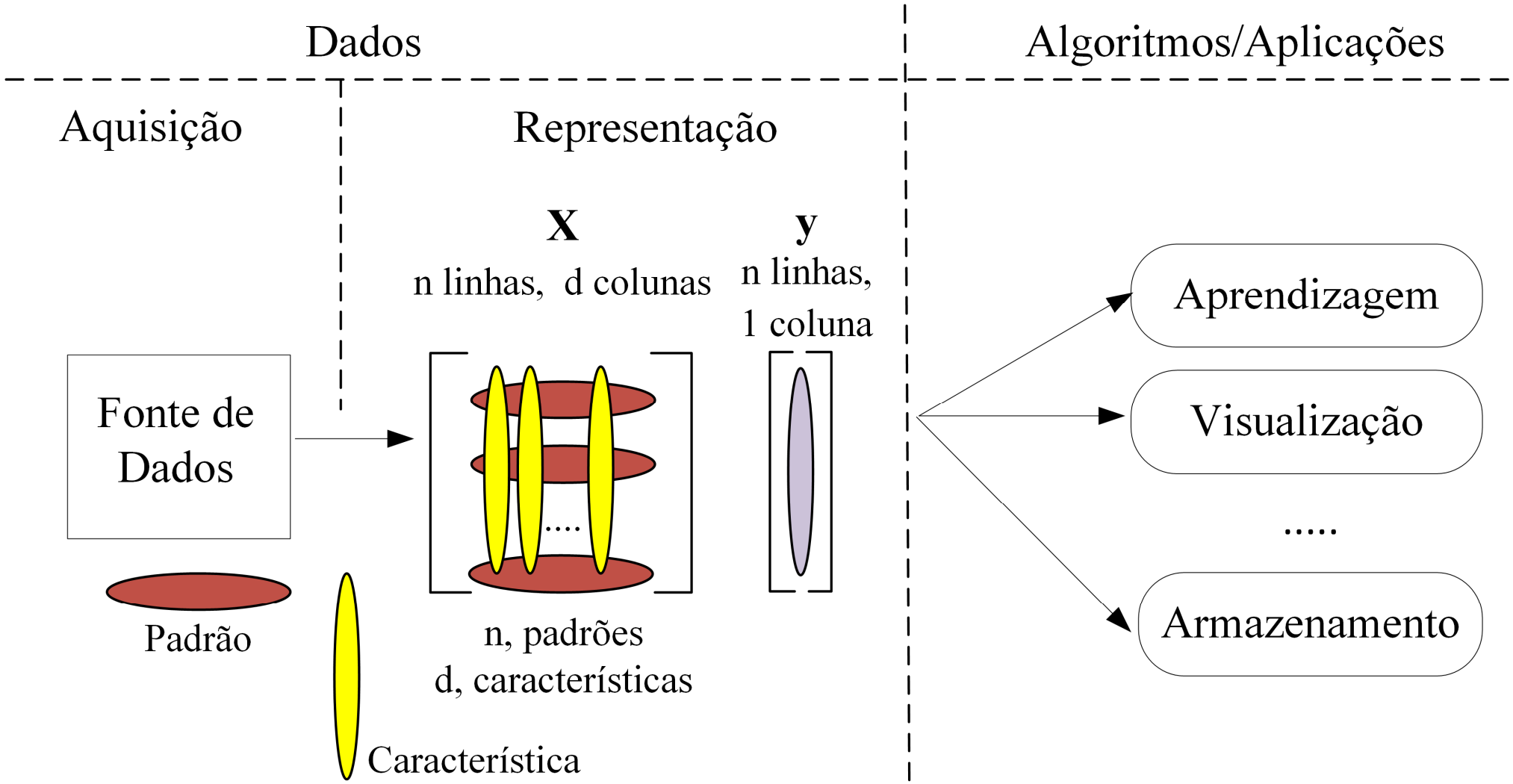
Pattern Recognition Systems

- Feature Extraction module
  - depends on the problem
  - the input data is represented by a feature vector (a pattern)

- Classification module
  - independent of the problem
  - it assigns class labels to each pattern
  - learned by some machine learning technique



Data and Data Mining Tasks



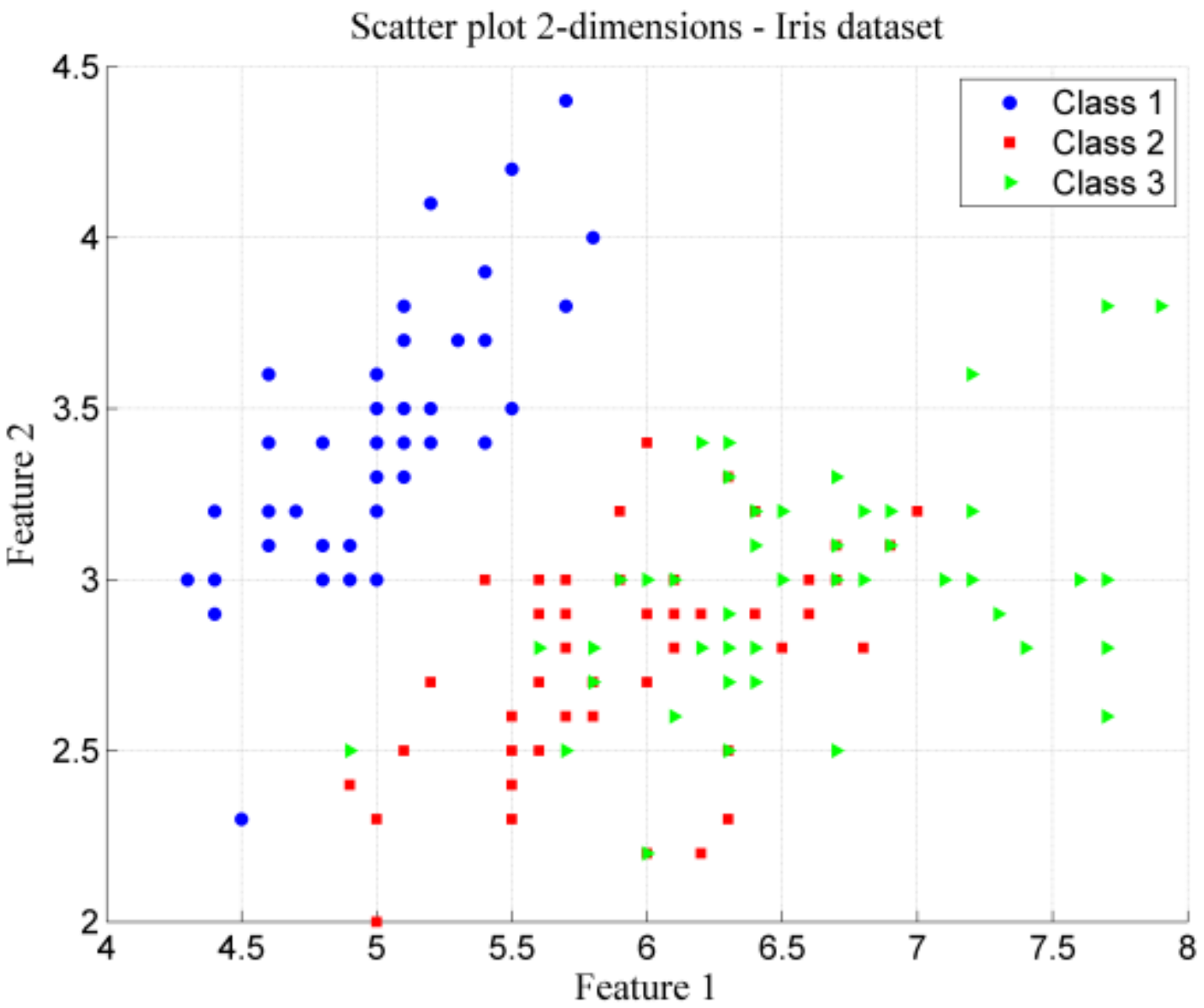
Data – Some terminology

- The data is organized into vectors/patterns/instances **x**
- Each pattern is a vector with d features **x=[x1, x2, …, xd]**
- Each element of **x** is a **feature** or an **attribute**
- Each feature/attribute represents a given measure
- A **dataset** is composed by *n patterns* with *d features*
- For each pattern, we may also have the corresponding class label - **supervised learning problem**
  - **The class labels can be 0, 1 or -1, +1 (binary problem, M=2)**
  - **The class labels can be 0, 1, 2, …, M-1 (multiclass problem, M > 2)**
- On the absence of the class label, we have an **unsupervised learning problem**

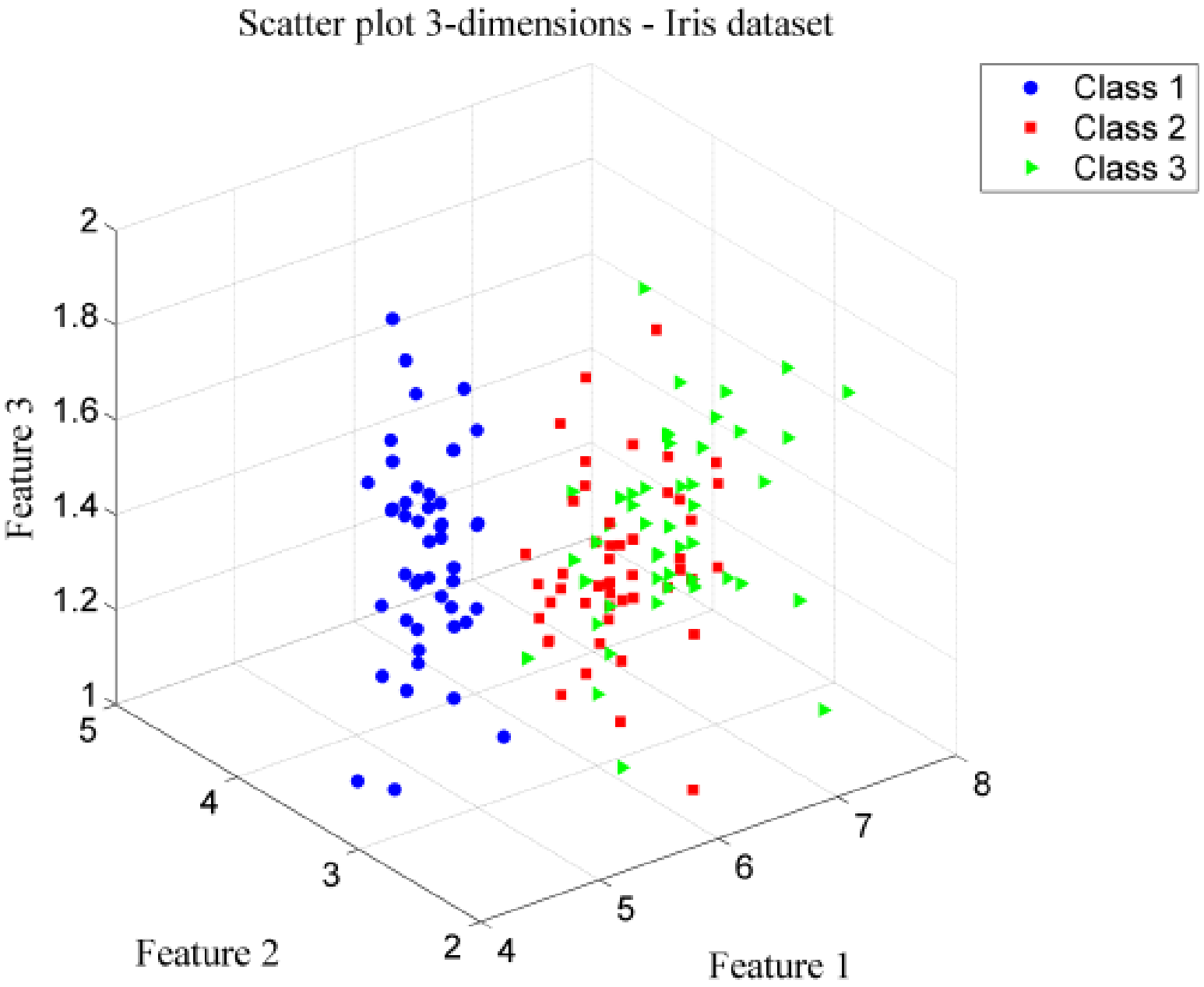
Data – Some concepts

- The features/attributes:
  - Should be in lowest number as possible
  - Should be as discriminative as possible
  - Should be relevant
  - Should not be redundant, on the presence of others

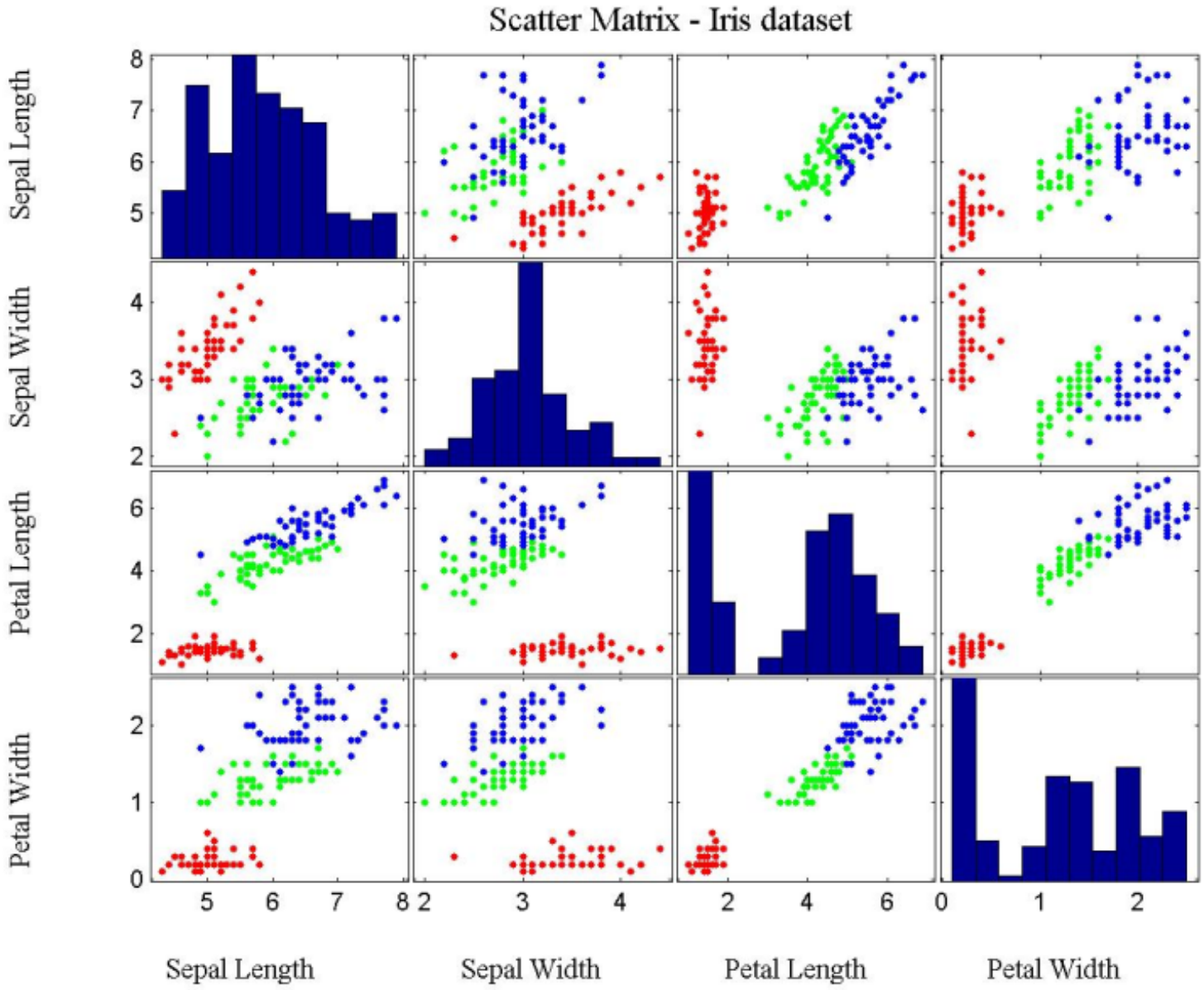
Data Visualization (1)



Data Visualization (2)



Data Visualization (3)



Data Representation (1)

- The Attribute-Relation File Format (ARFF)
- https://www.cs.waikato.ac.nz/ml/weka/arff.html

```
% 1. Title: Iris Plants Database
%
% 2. Sources:
% (a) Creator: R.A. Fisher
% (b) Donor: Michael Marshall (MARSHALL%PLU@io.arc.nasa.gov)
% (c) Date: July, 1988
%
@RELATION iris

@ATTRIBUTE sepallength NUMERIC
@ATTRIBUTE sepalwidth NUMERIC
@ATTRIBUTE petallength NUMERIC
@ATTRIBUTE petalwidth NUMERIC
@ATTRIBUTE class {Iris-setosa,Iris-versicolor,Iris-virginica}
```

Data Representation (2)

- The Attribute-Relation File Format (ARFF)
- https://www.cs.waikato.ac.nz/ml/weka/arff.html

```
@DATA
5.1,3.5,1.4,0.2,Iris-setosa
4.9,3.0,1.4,0.2,Iris-setosa
4.7,3.2,1.3,0.2,Iris-setosa
4.6,3.1,1.5,0.2,Iris-setosa
5.0,3.6,1.4,0.2,Iris-setosa
5.4,3.9,1.7,0.4,Iris-setosa
4.6,3.4,1.4,0.3,Iris-setosa
5.0,3.4,1.5,0.2,Iris-setosa
4.4,2.9,1.4,0.2,Iris-setosa
4.9,3.1,1.5,0.1,Iris-setosa
….
```

Data Representation (3)

- The Comma Separated Value (CSV) format

a01,a02,a03,a04,a05,class
1.4,6,0.99539,-0.05889,0.85243,g
1.2,4,1,-0.18829,0.93035,b
3.4,3,1,-0.03365,1,g
2.5,1,1,-0.45161,1,b
….

Dataset with
- d=5 features/attributes
- c=2 classes (g-good, b-bad)
- n=4 patterns

Common Classifiers

- Distance-based classifiers
- Decision trees
- Perceptrons and Neural Networks
- Support Vector Machines
- K-Nearest Neighboor (KNN)
- AdaBoost classifier

Data and Classification

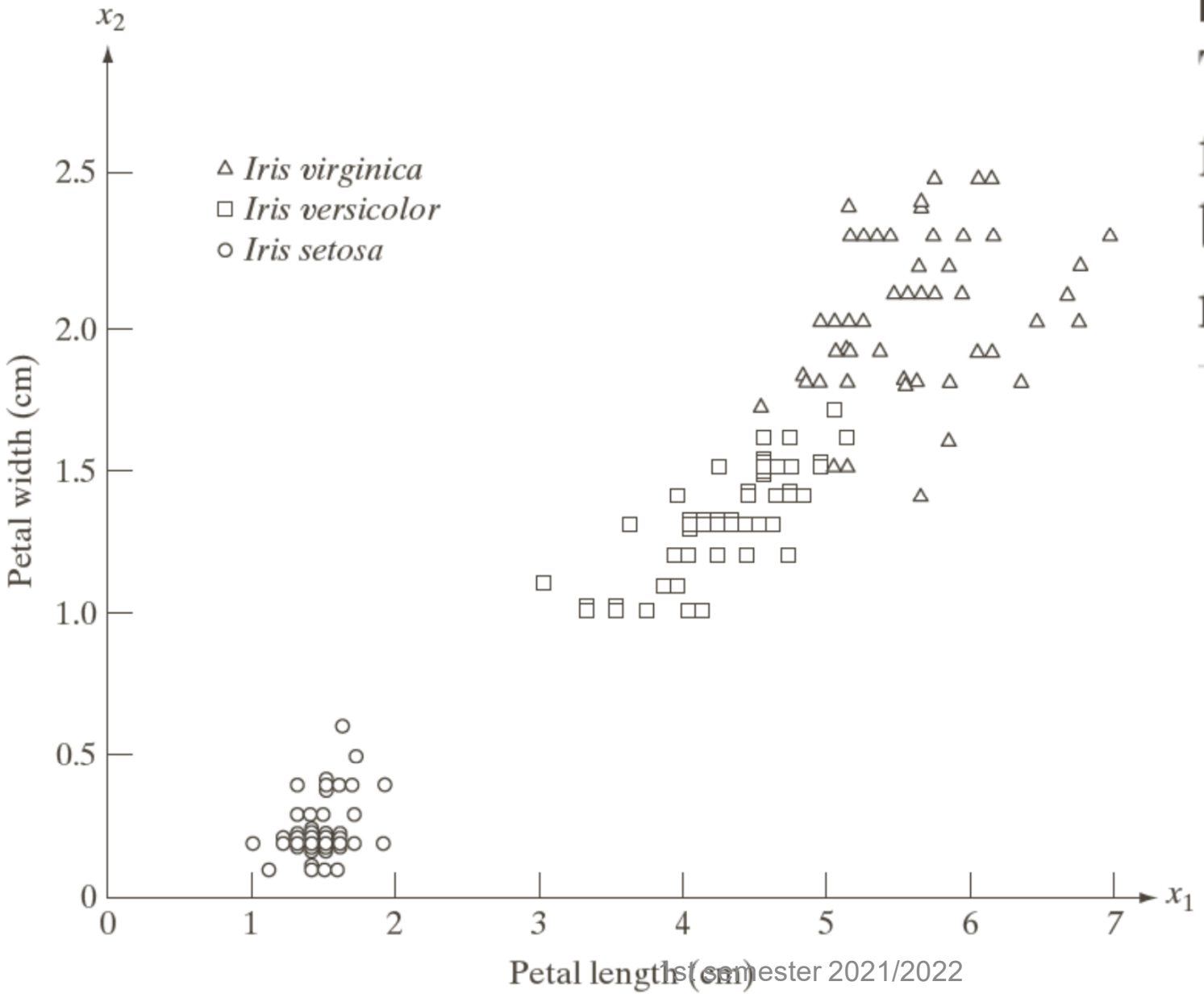


FIGURE 12.1
Three types of iris flowers described by two measurements.

Data and Classification

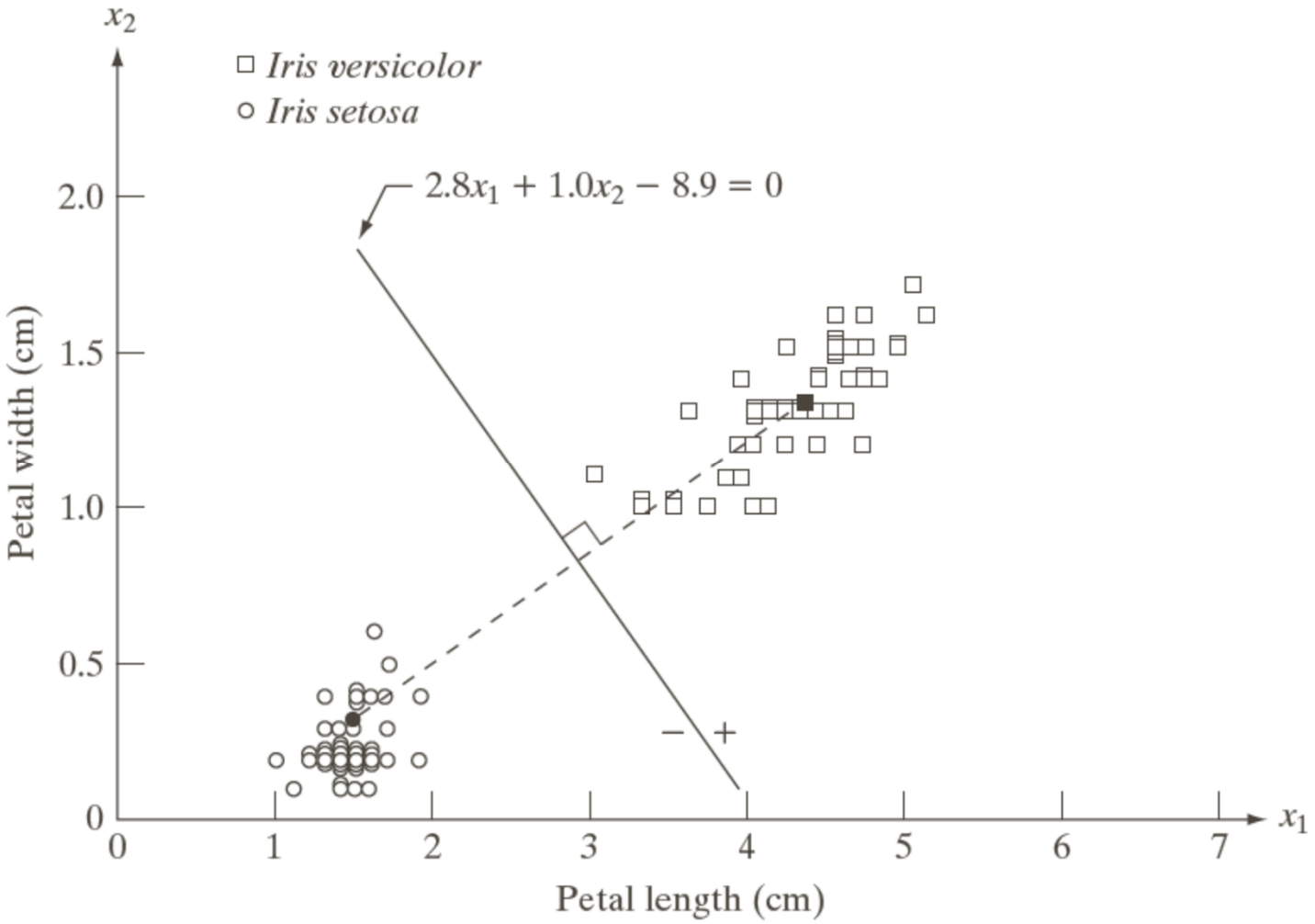
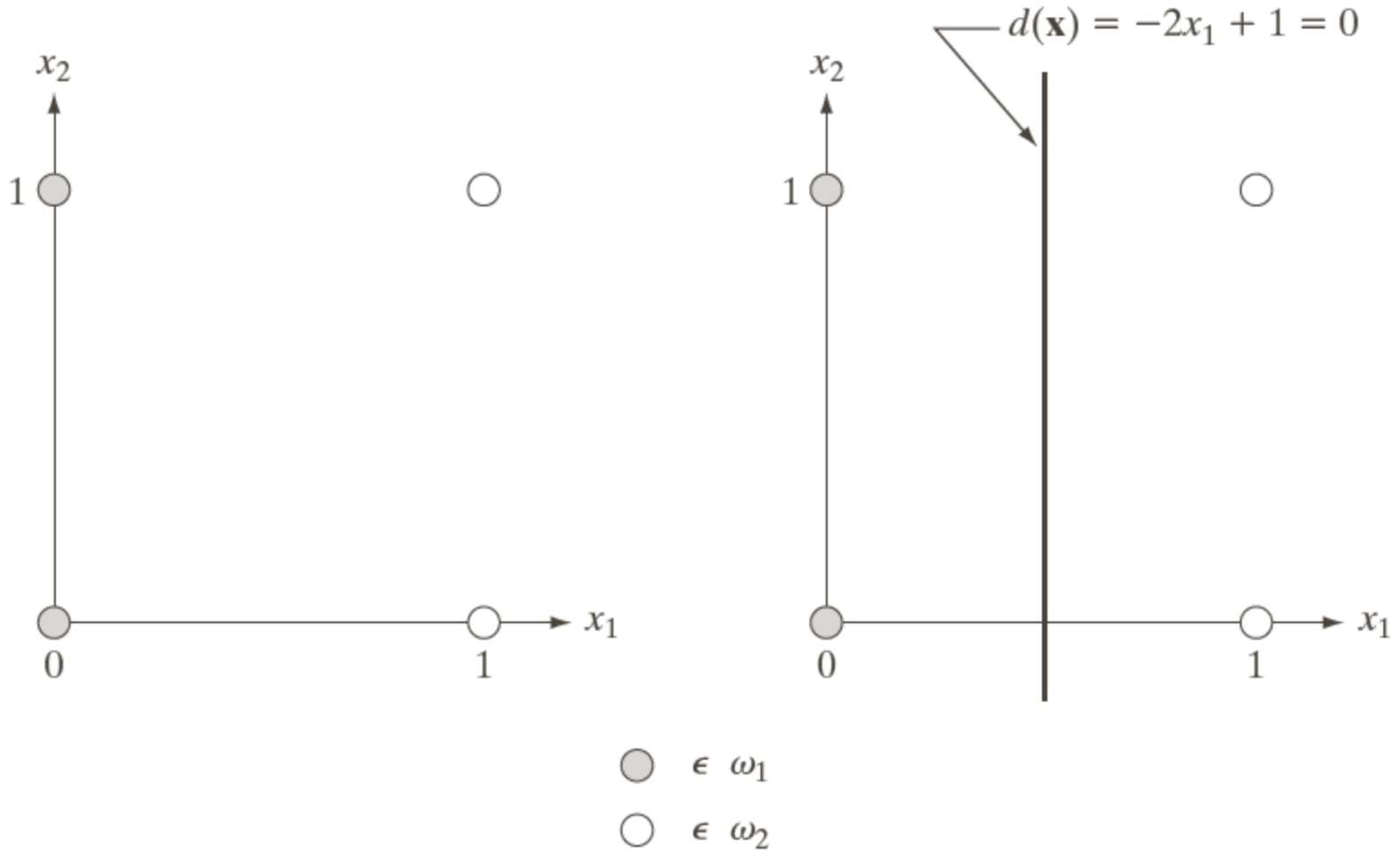


FIGURE 12.6
Decision boundary of minimum distance classifier for the classes of *Iris versicolor* and *Iris setosa*. The dark dot and square are the means.

Data and Classification



a b

FIGURE 12.15
(a) Patterns belonging to two classes.
(b) Decision boundary determined by training.

Data and Classification – Decision Tree

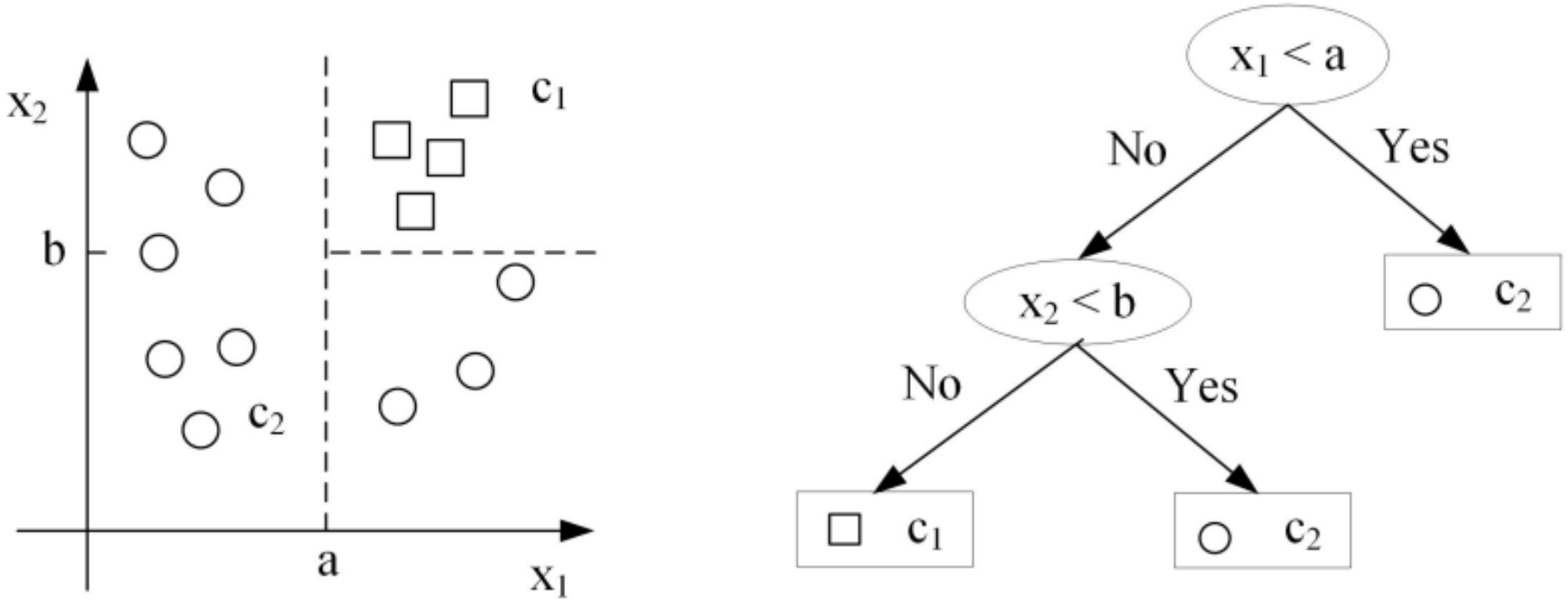


FIGURE 12.5 A tree description of the image in Fig. 12.4.

Data and Classification – Decision Tree

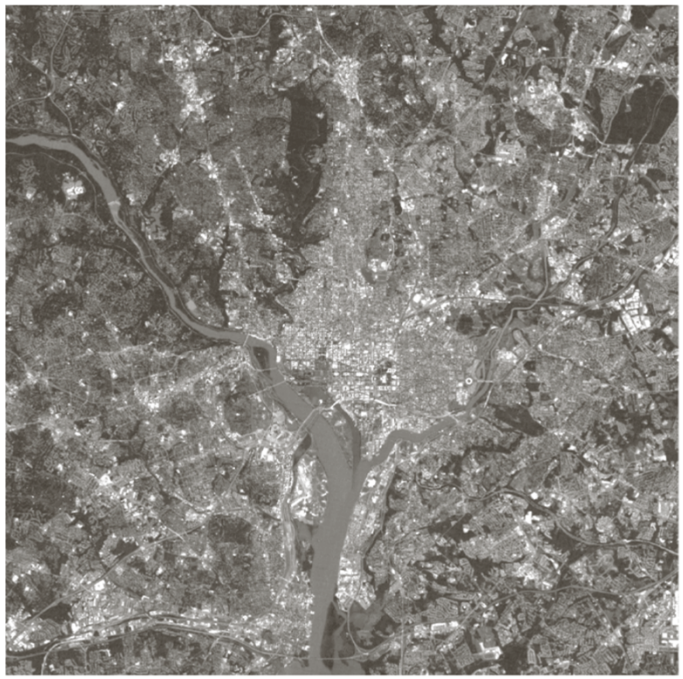


FIGURE 12.4
Satellite image of a heavily built downtown area (Washington, D.C.) and surrounding residential areas. (Courtesy of NASA.)

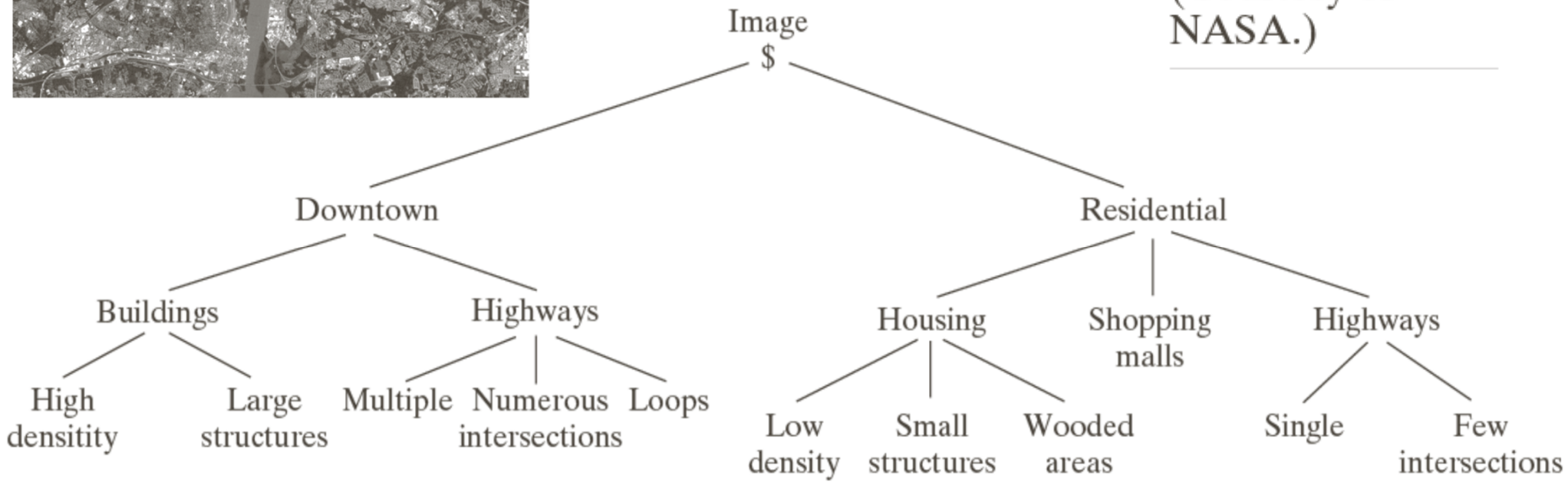
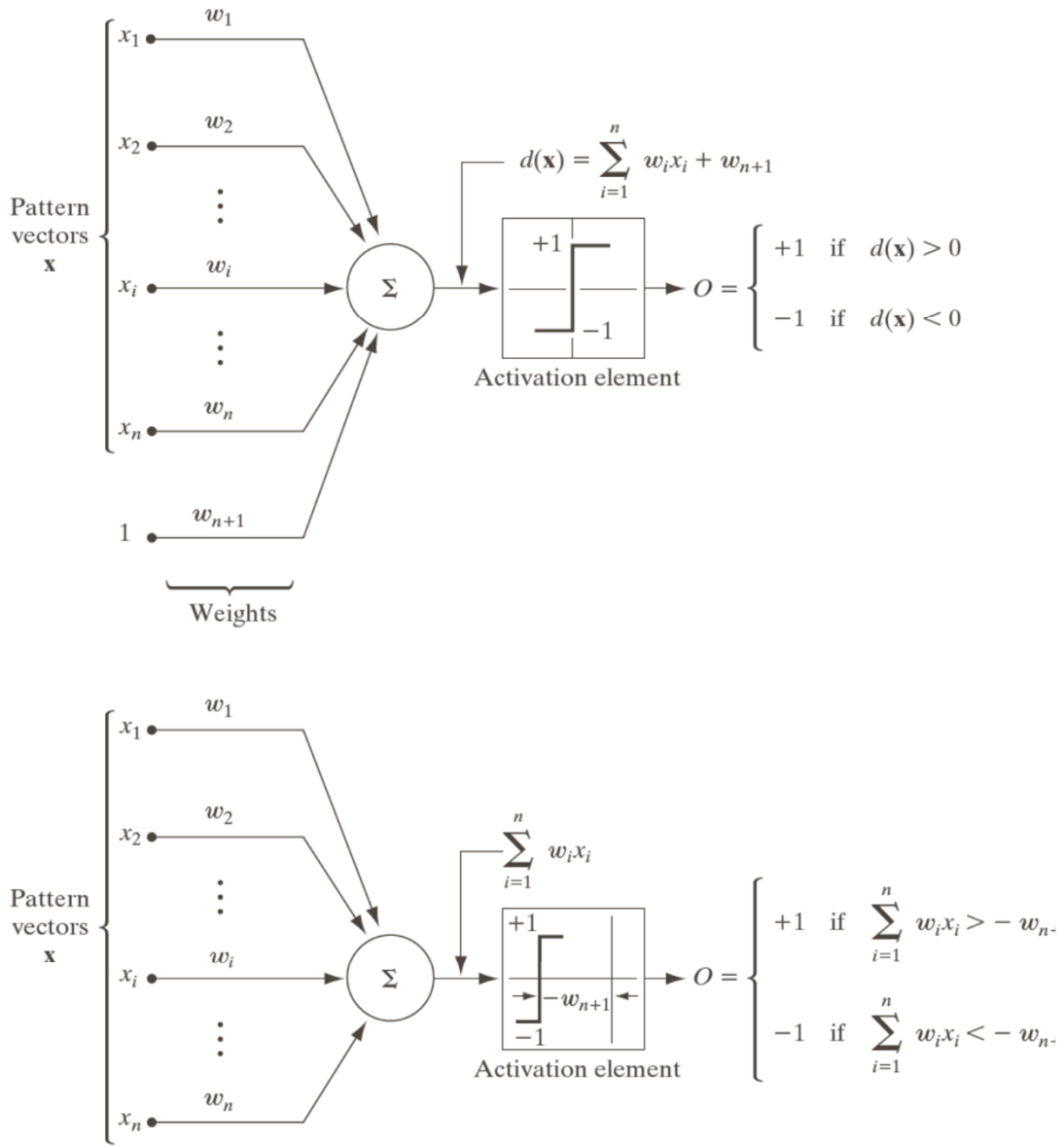


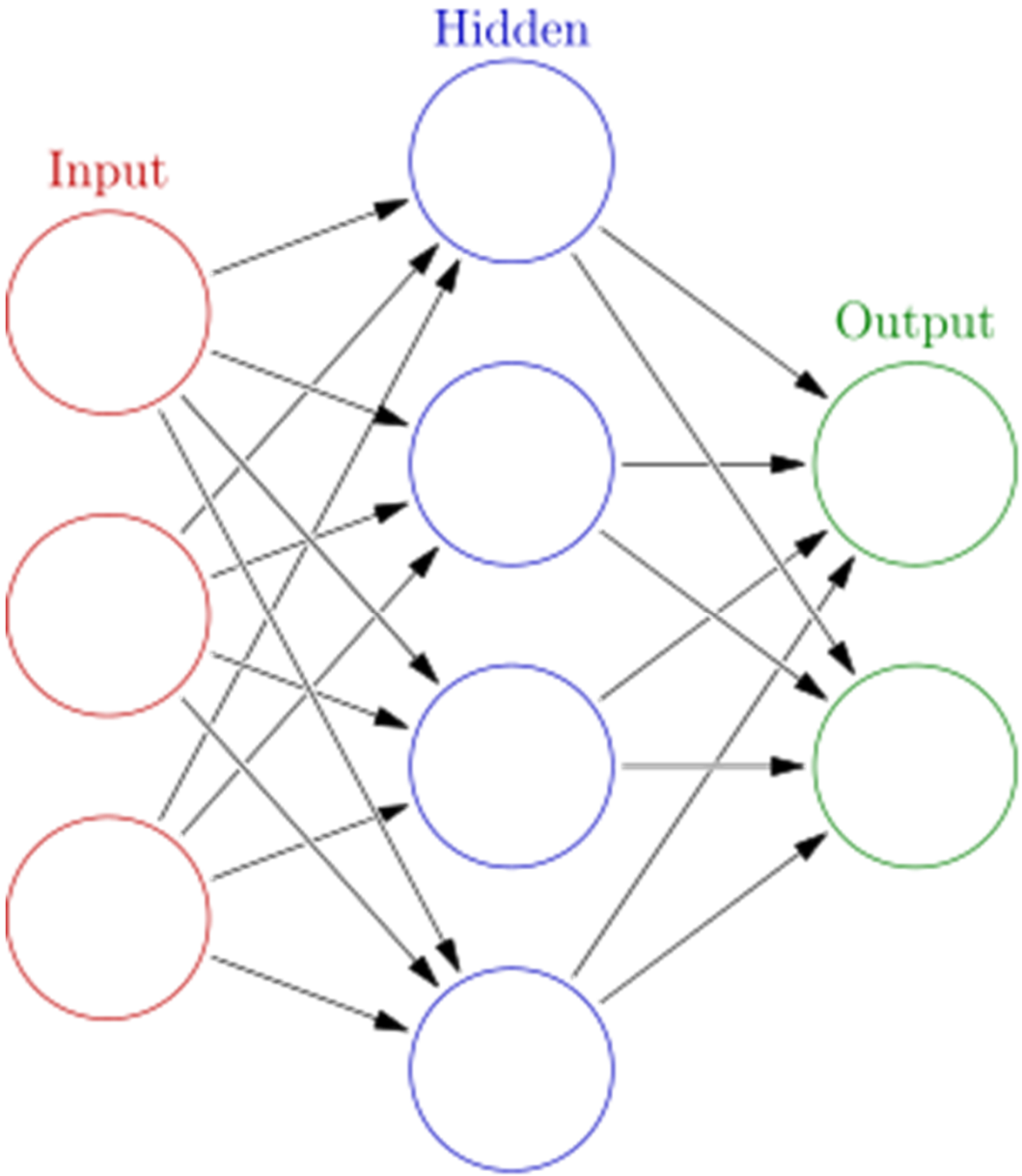
FIGURE 12.5 A tree description of the image in Fig. 12.4.

Data and Classification - Perceptron



a
b **FIGURE 12.14** Two equivalent representations of the perceptron model for two pattern classes.

Data and Classification – Neural Networks (1)



https://en.wikipedia.org/wiki/Artificial_neural_network

Data and Classification – Neural Networks (2)

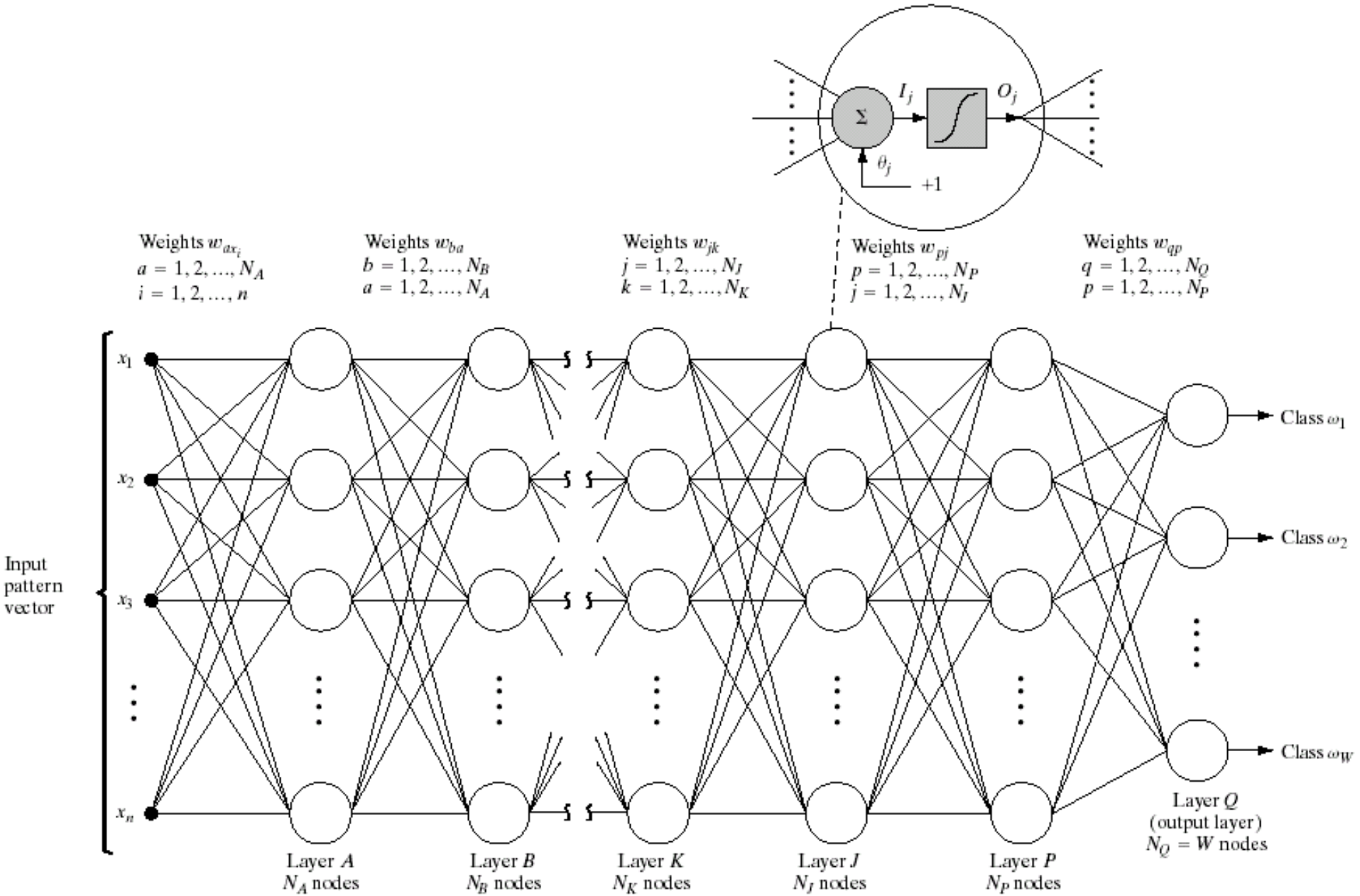


FIGURE 12.16 Multilayer feedforward neural network model. The blowup shows the basic structure of each neuron element throughout the network. The offset, θ_j, is treated as just another weight.

Data and Classification – Neural Networks (3)

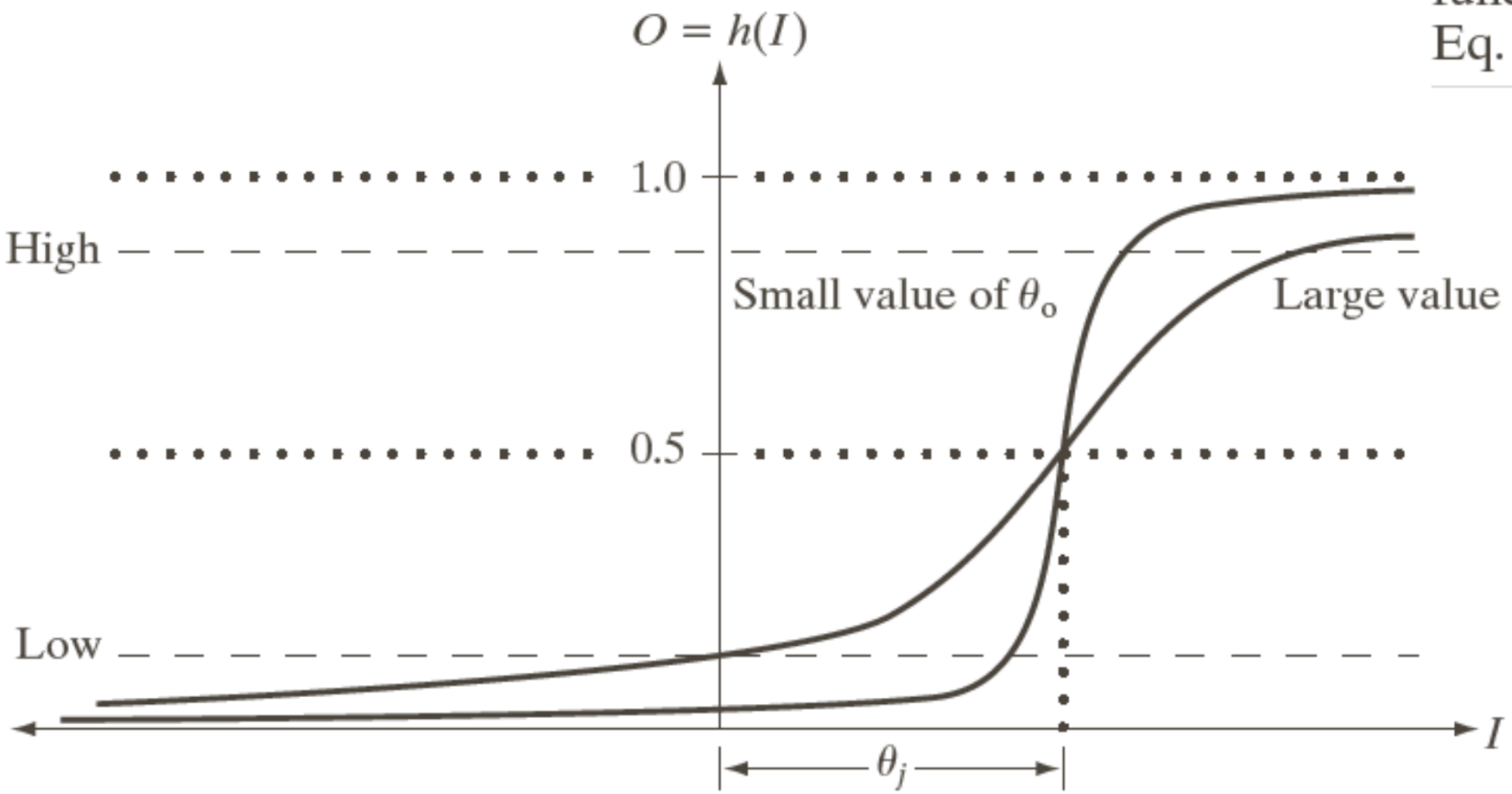
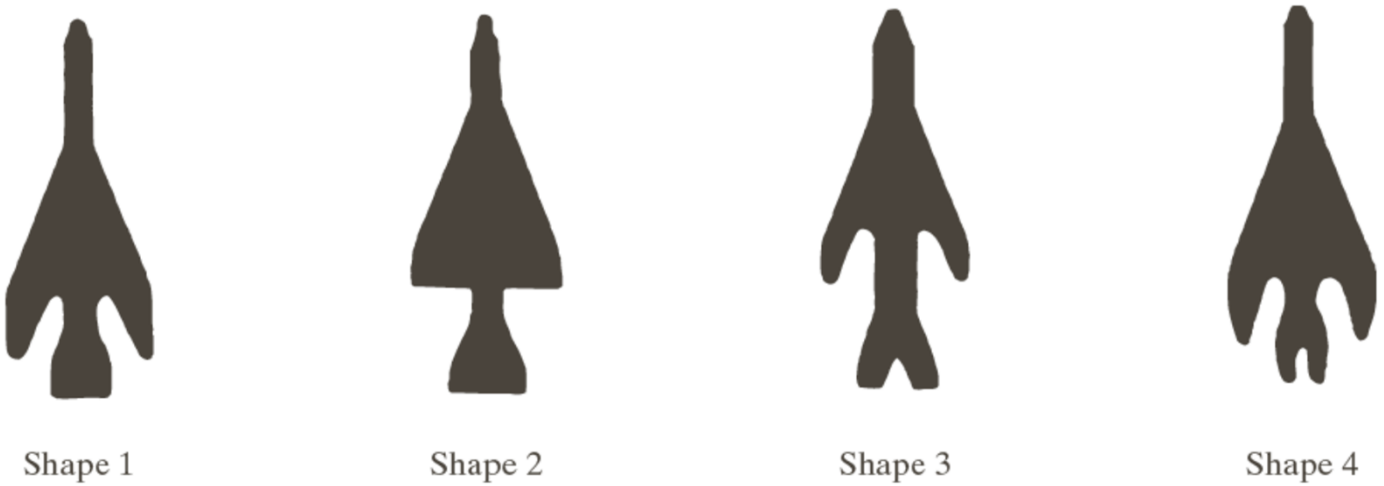
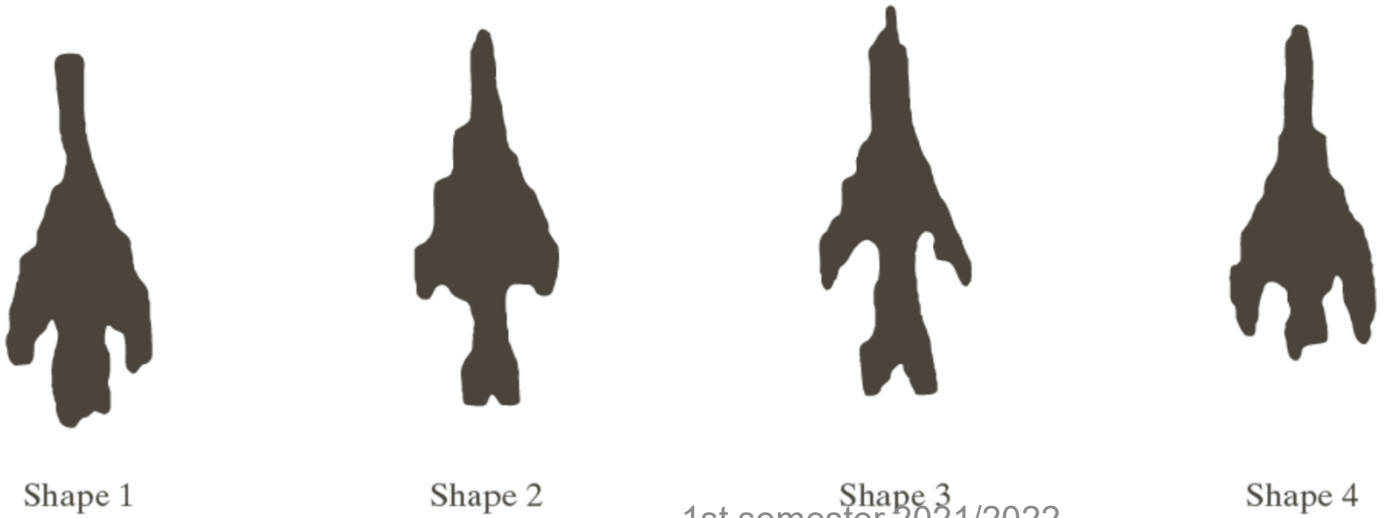


FIGURE 12.17
The sigmoidal activation function of Eq. (12.2-47).

Data and Classification – Neural Networks (4)





a
b

FIGURE 12.18 (a) Reference shapes and (b) typical noisy shapes used in training the neural network of Fig. 12.19. (Courtesy of Dr. Lalit Gupta, ECE Department, Southern Illinois University.)

Data and Classification – Neural Networks (5)

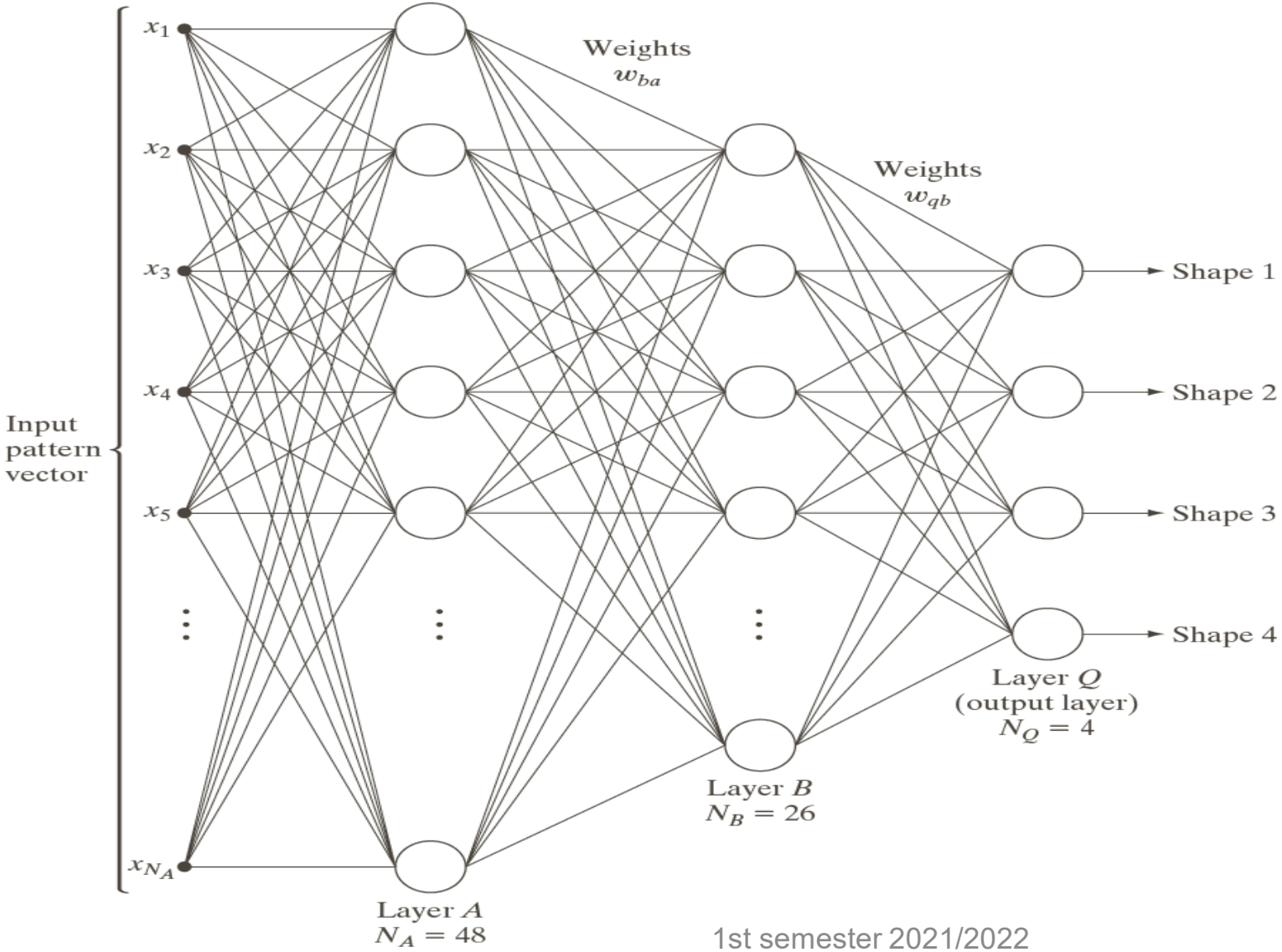
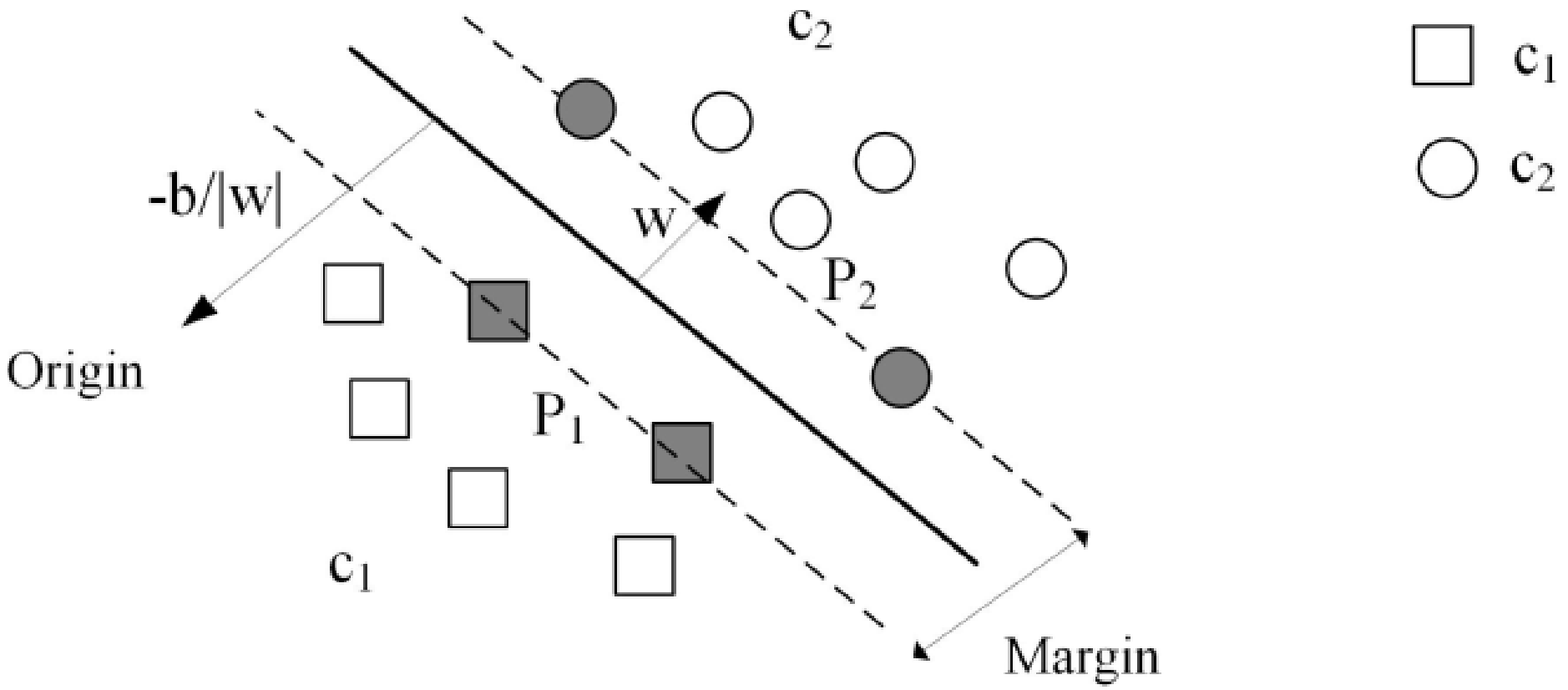


FIGURE 12.19 Three-layer neural network used to recognize the shapes in Fig. 12.18. (Courtesy of Dr. Lalit Gupta, ECE Department, Southern Illinois University.)

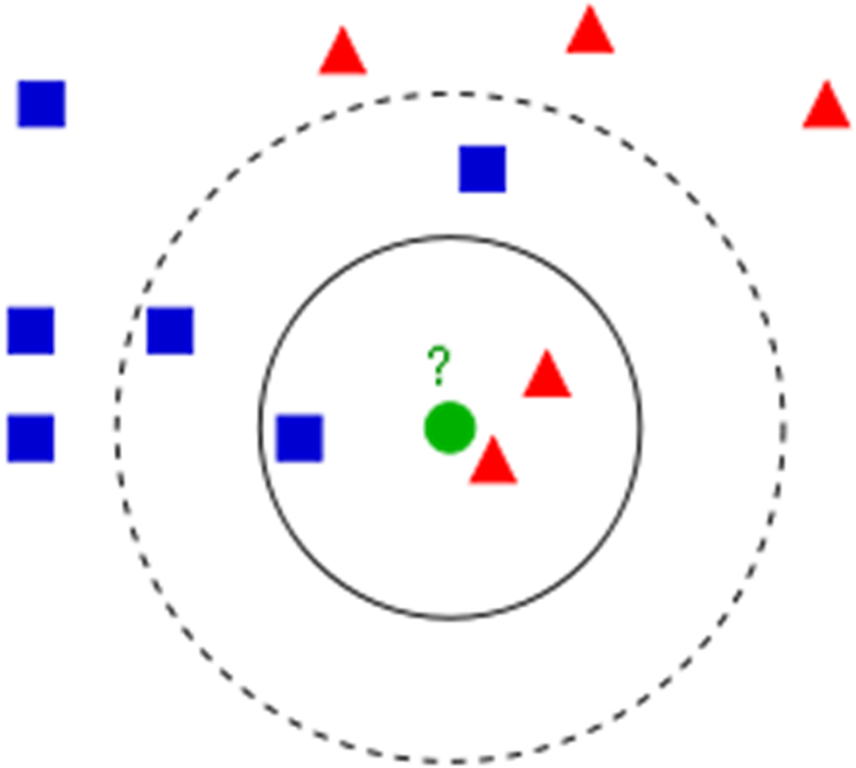
Data and Classification – Support Vector Machines



Data and Classification – K-Nearest Neighbors

Example of *k*-NN classification.

The test sample (green circle) should be classified either to the first class of blue squares or to the second class of red triangles.



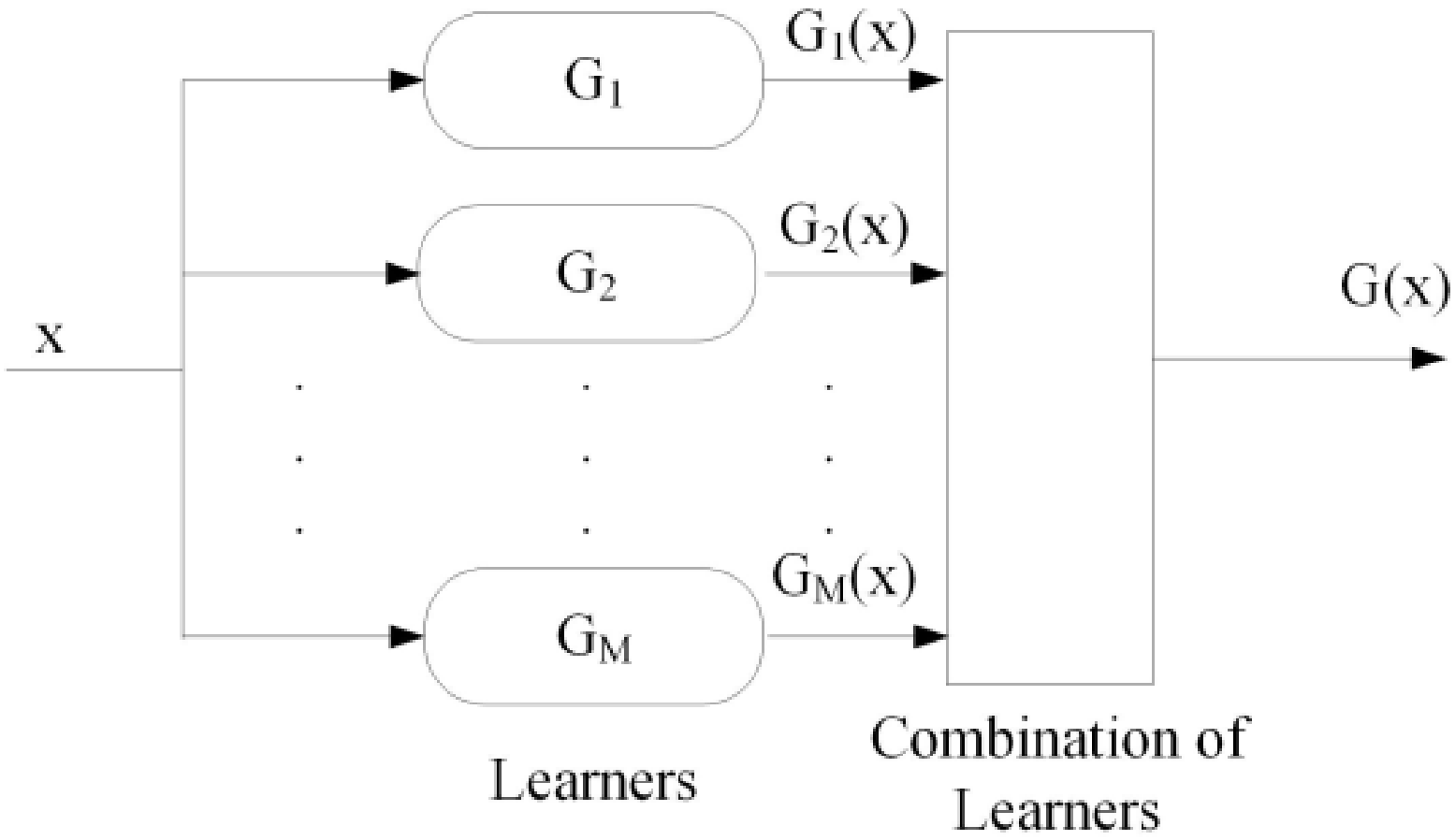
If *k* = *3* (solid line circle) it is assigned to the second class because there are 2 triangles and only 1 square inside the inner circle.

If *k* = *5* (dashed line circle) it is assigned to the first class (3 squares vs. 2 triangles inside the outer circle).

https://en.wikipedia.org/wiki/K-nearest_neighbors_algorithm

Data and Classification – AdaBoost

- AdaBoost = Adaptive Boosting
- A combination of weak learners



Data and Classification – Pattern

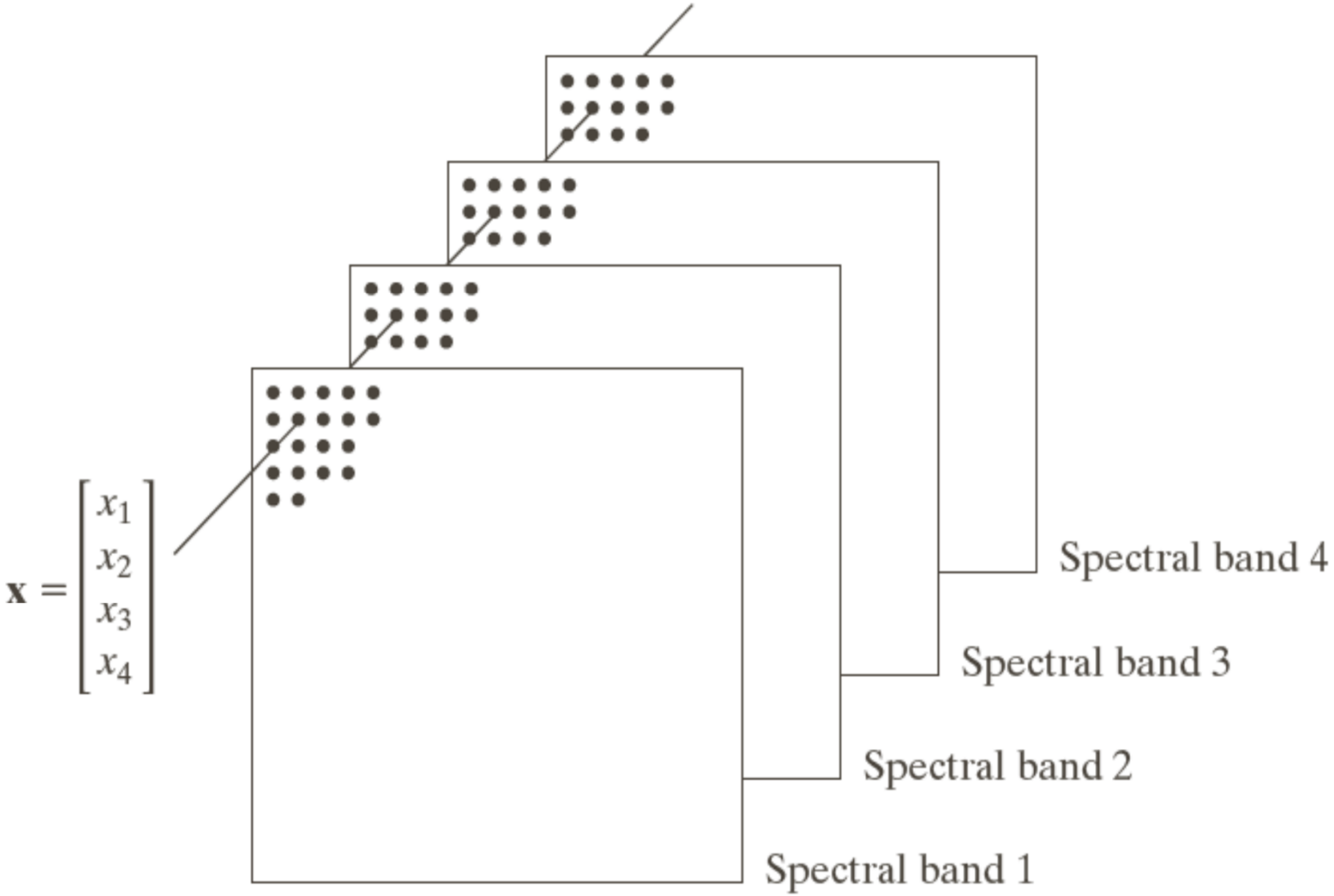
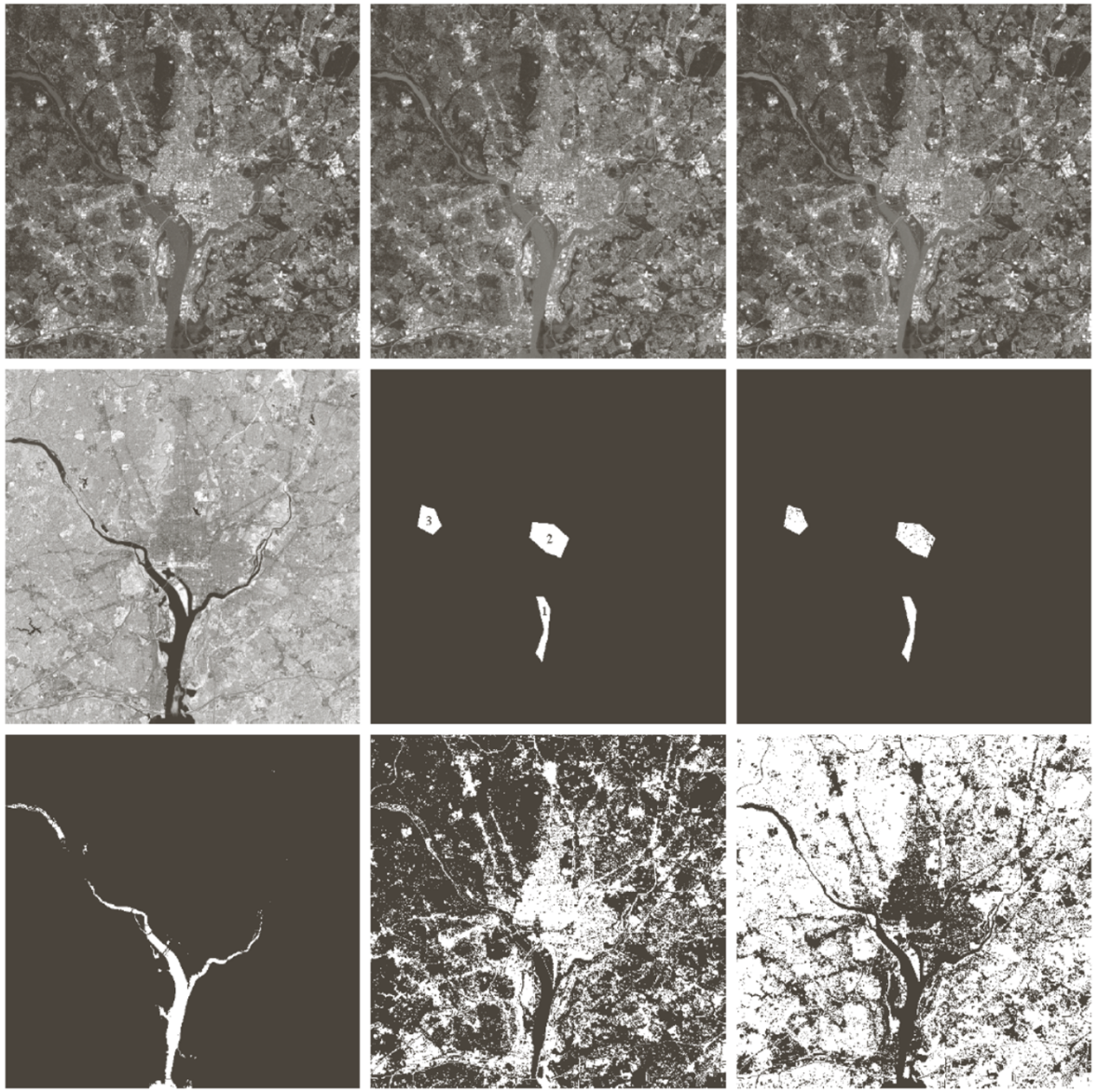


FIGURE 12.12 Formation of a pattern vector from registered pixels of four digital images generated by a multispectral scanner.



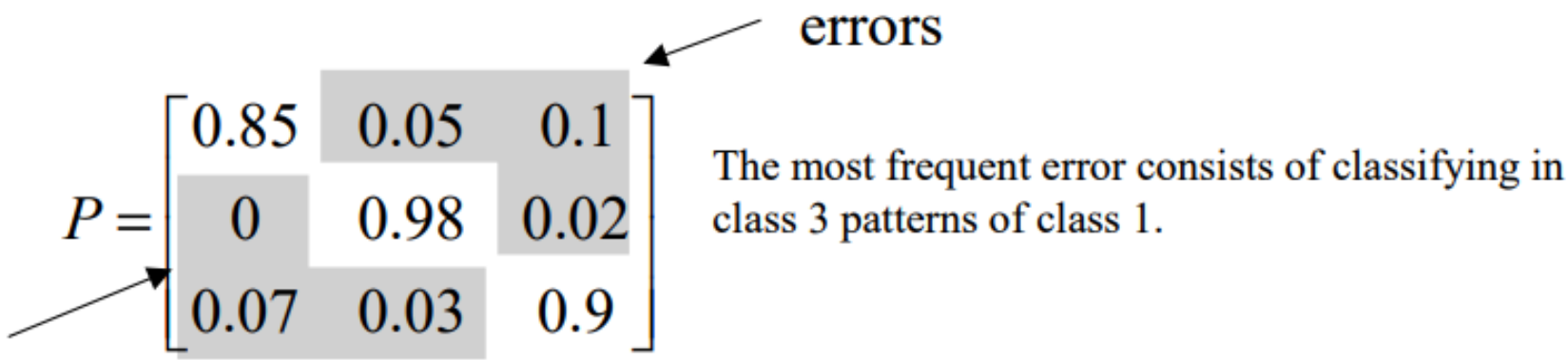
a b c
d e f
g h i

FIGURE 12.13 Bayes classification of multispectral data. (a)–(d) Images in the visible blue, visible green, visible red, and near infrared wavelengths. (e) Mask showing sample regions of water (1), urban development (2), and vegetation (3). (f) Results of classification; the black dots denote points classified incorrectly. The other (white) points were classified correctly. (g) All image pixels classified as water (in white). (h) All image pixels classified as urban development (in white). (i) All image pixels classified as vegetations (in white).

Evaluation – Confusion Matrix (1)

The **confusion matrix** evaluates the amount of error and the type of error

- Rows = true class
- Columns = estimated/predicted class



Evaluation – Confusion Matrix (2)

TABLE 12.1
Bayes classification of multispectral image data.

Training Patterns						Independent Patterns					
		Classified into Class						Classified into Class			
Class	No. of Samples	1	2	3	% Correct	Class	No. of Samples	1	2	3	% Correct
1	484	482	2	0	99.6	1	483	478	3	2	98.9
2	933	0	885	48	94.9	2	932	0	880	52	94.4
3	483	0	19	464	96.1	3	482	0	16	466	96.7

Exercises (1)

5. Determinado Sistema Biométrico (SB) contém na sua Base de Dados (BD) os registos indicados na tabela.

   a) {1,0} Em termos gerais, no projeto de SB, indique os procedimentos a seguir para estabelecer e decidir o conjunto final e definitivo de caraterísticas adequado (em número e significado) para representar os indivíduos.

   b) {1,0} Relativamente às caraterísticas escolhidas para o SB apresentado na tabela, indique a mais discriminativa e a menos discriminativa.

   c) {1,0} Apresente uma regra de classificação, à sua escolha, que seja adequada para o SB.

   d) {1,0} Considere agora que o SB usa o classificador do vizinho mais próximo, com $k = 1$ e critério de distância Euclideana. Na utilização do SB, a autenticação do indivíduo 1 foi realizada com insucesso (autenticação negativa). Apresente um exemplo de possível registo biométrico, diferente dos registos existentes na BD, que tenha originado esse resultado de autenticação.

Registo	Indivíduo
[8, 10, 1, 2, 5, 6]	1
[3, 8, 0, 2, 7, 5]	2
[5, 11, 2, 2, 8, 4]	3
[8, 9, 0, 2, 6, 3]	4
[8, 13, 5, 2, 7, 2]	5
[11, 13, 6, 2, 6, 1]	6

Exercises (2)

10. {R2||TG} As seguintes questões referem-se a Sistemas Biométricos (SB) e a sistemas de Reconhecimento de Padrões (RP).

    i) {1,25||1,0} Identifique os principais elementos constituintes de um sistema de RP. Indique as principais propriedades de cada um desses elementos.

    ii) {1,25||1,0} No âmbito de utilização de SB, com centenas de utilizadores registados, indique em que consiste: uma *autenticação negativa*; uma *identificação positiva*.

    iii) {1,25||1,0} No treino de determinado classificador num problema com três classes com etiquetas $\{1; 2; 3\}$, sobre padrões com quatro caraterísticas $[x_1; x_2; x_3; x_4]$, obteve-se o classificador que se apresenta de seguida.

```
if( x3 <= 0.6) return 1
if( x3 > 0.6) then
|   if( x3 <= 1.7 )
|   |   if( x2 <= 4.9) return 2
|   |   if( x2 > 4.9 )
|   |   |   if( x3 <= 1.5) return 3
|   |   |   if( x3 > 1.5 ) return 2
| if( x3 > 1.7) return 3
```

    Identifique qual o tipo de classificador representado através desta descrição. Indique: o resultado da classificação do padrão $p = [0; 2{,}2; 0{,}7; 0{,}6]$; a caraterística considerada a mais discriminativa por este classificador.

    iv) {1,25||1,0} Na avaliação de determinado classificador, obteve-se a seguinte matriz de confusão.

```
...
=== Confusion Matrix ===
   a   b   <-- classified as
 104  22 |   a = b
   8 217 |   b = g
```

    Indique o número de classes, o número de padrões por classe, o número total de padrões e a percentagem de erro.

Exercises (3)

8. Considere um sistema biométrico de autenticação de indivíduos, baseado em íris.

   a) {1,0} Apresente, de forma resumida, uma abordagem possível para o módulo de extração de caraterísticas, a utilizar pelo sistema.

   b) {1,0} Constata-se que o sistema biométrico baseado em íris não está a funcionar com desempenho satisfatório. Para resolver este problema, pretende-se adicionar ao sistema a funcionalidade de autenticação baseada na imagem de face. Indique, de forma detalhada, o procedimento a efetuar para que o sistema biométrico passe a realizar autenticação com íris e imagem de face. O módulo de extração de caraterísticas deverá ser o mesmo para as imagens de íris e imagens de face?

Exercises (4)

4. A tabela apresenta um conjunto de treino, utilizado para a aprendizagem supervisionada de determinado classificador.

Padrão	Etiqueta
[15, 10, 1, 2]	1
[15, 9, 2, 4]	1
[15, 11, 3, 6]	1
[15, 18, 4, 8]	2
[15, 17, 5, 10]	2
[15, 20, 3, 6]	2
[15, 12, 2, 4]	3
[15, 10, 3, 6]	3
[15, 11, 1, 2]	3

a) {1,25} Indique o número de caraterísticas e o número de classes que correspondem a este problema. A escolha das caraterísticas é adequada?

b) {1,25} Considere o classificador k-vizinhos mais próximos, com $k = 1$, treinado com os dados presentes na tabela. Qual o resultado da classificação do padrão $p = [15, 11, 2, 4]$ com este classificador?

Resources on machine laerning

- WEKA

https://www.cs.waikato.ac.nz/ml/weka/

https://en.wikipedia.org/wiki/Weka_(machine_learning)

- Open CV

https://docs.opencv.org/4.5.2/dc/dd6/ml_intro.html

- Accord Framework

http://accord-framework.net/