Image Analysis
Lecture 9.3 - Introduction to Machine Learning

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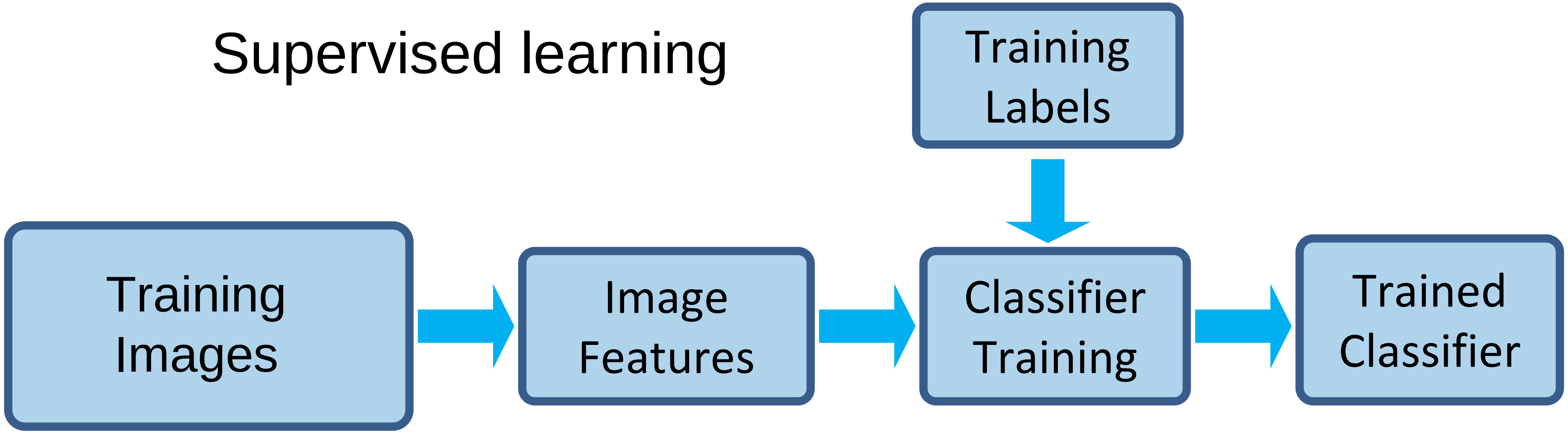
Machine learning (Pattern recognition)

- Recognition of individuals (instance recognition)
- Discrimination between classes (pattern recognition, classification)



Pattern recognition in practice

Working applications of Image Pattern recognition:

- Reading license plates, postal codes, bar codes
- Character recognition
- Automatic diagnosis of medical samples
- Fingerprint recognition
- Face detection and recognition
- …

Classification system

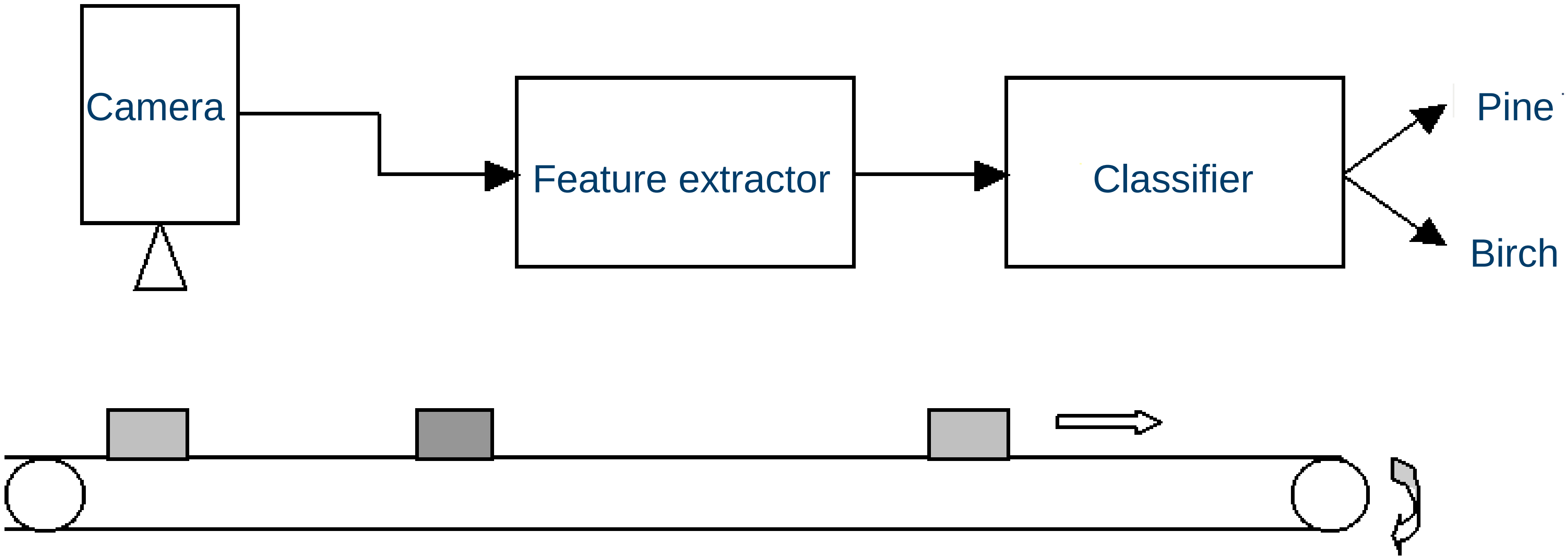
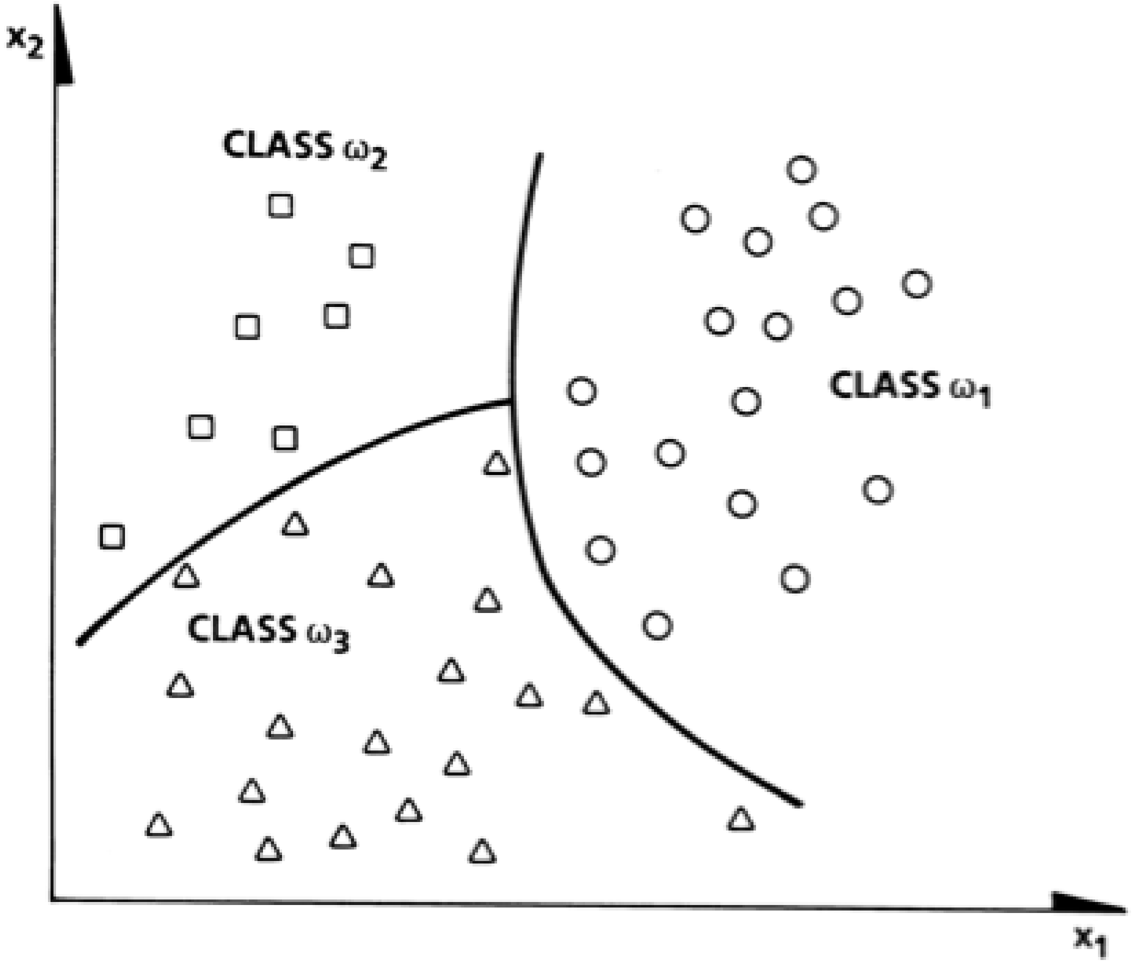


Image features for object recognition

$$\boldsymbol{x} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_d \end{bmatrix}$$

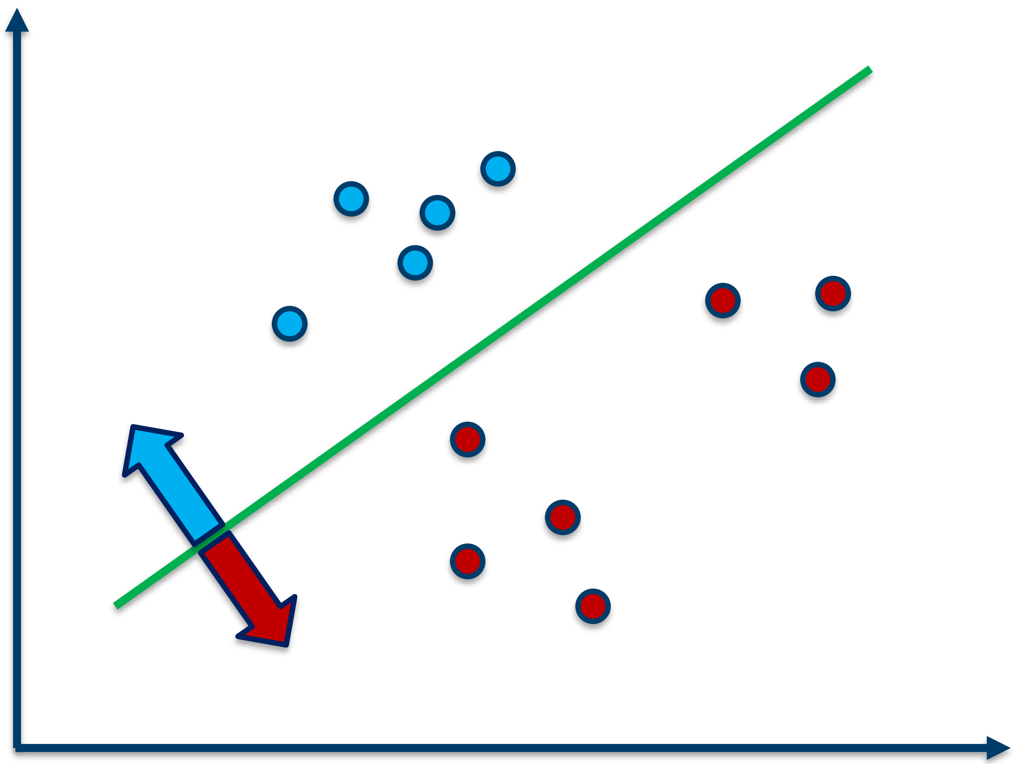
Feature vector and feature space

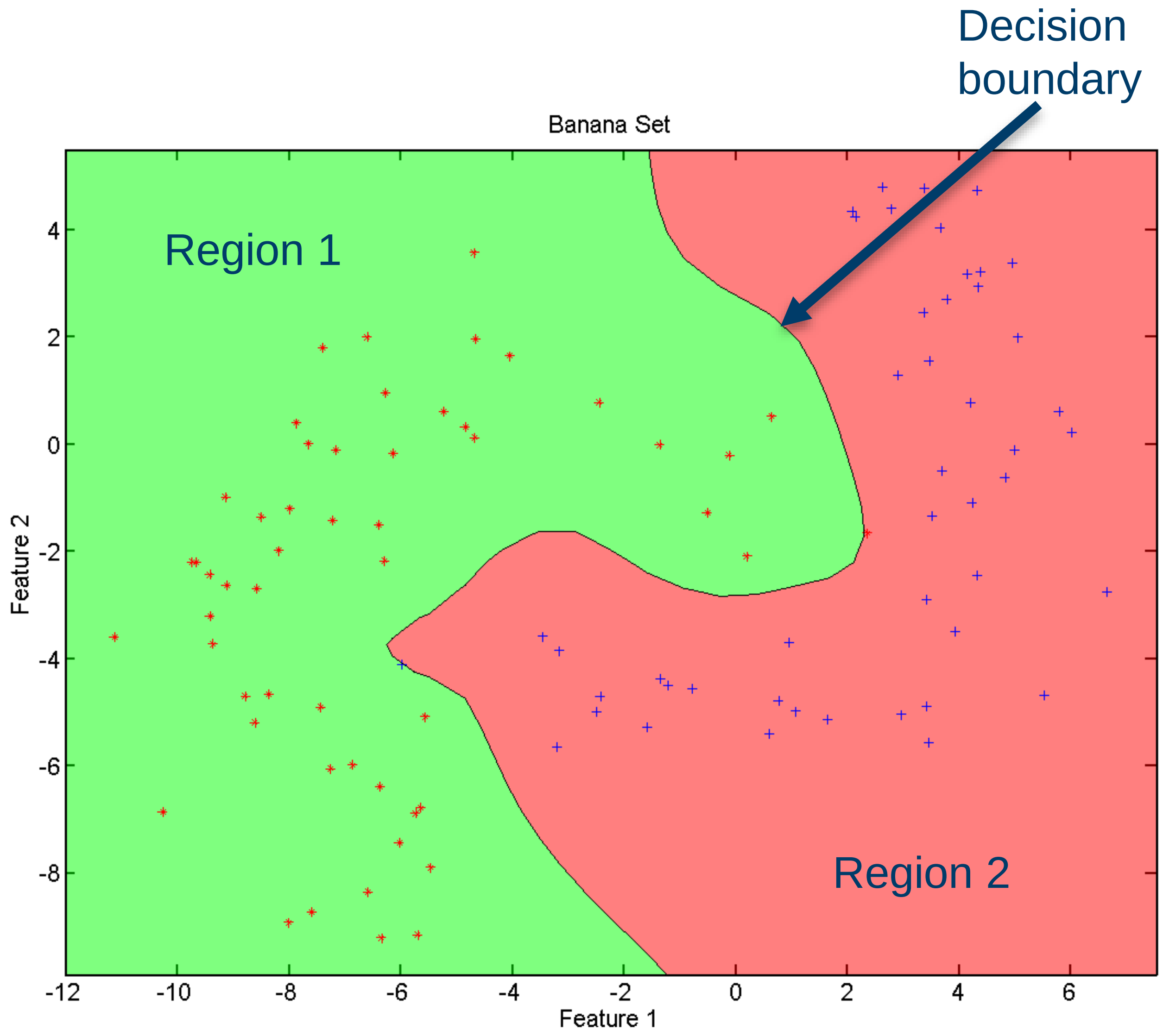
$$\boldsymbol{x} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_d \end{bmatrix}$$



Training of classifiers

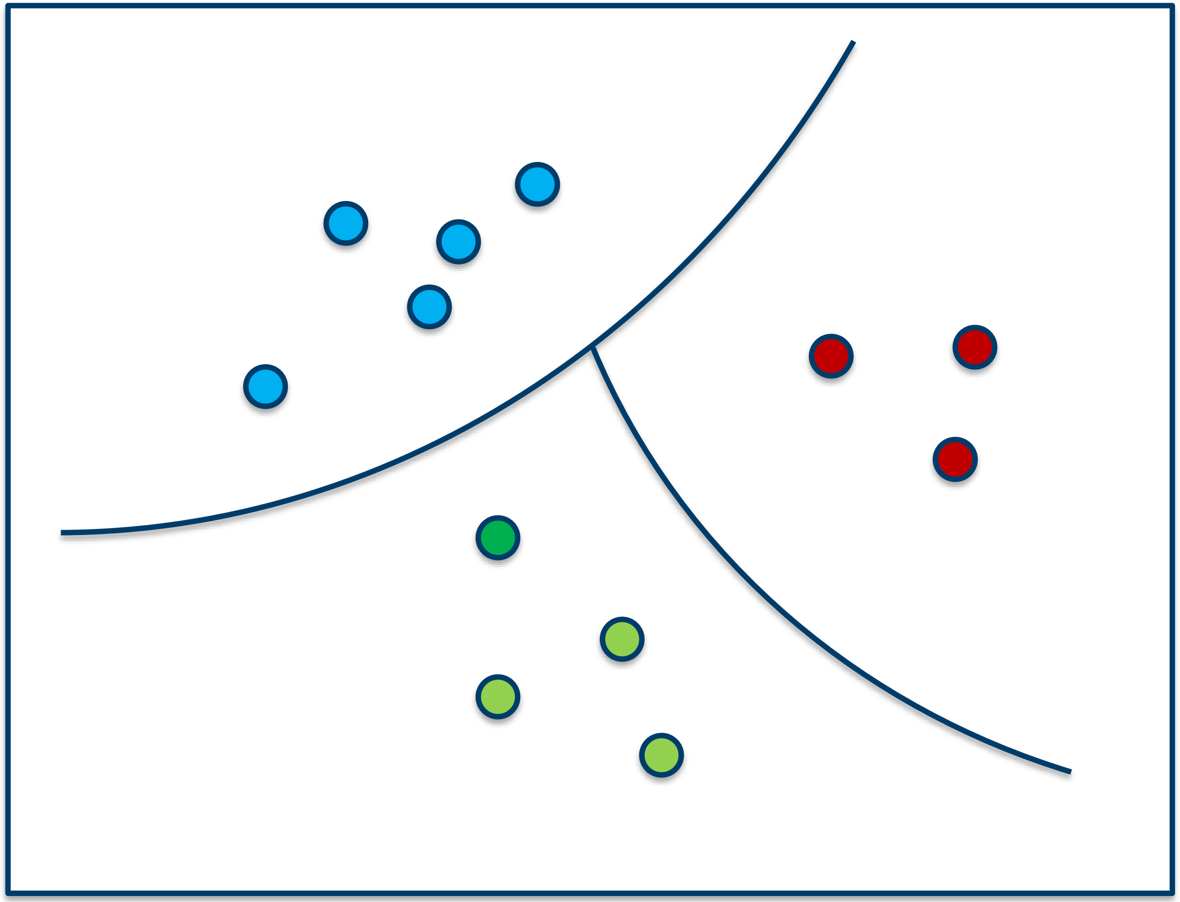
Learn a function to predict the class from the given features



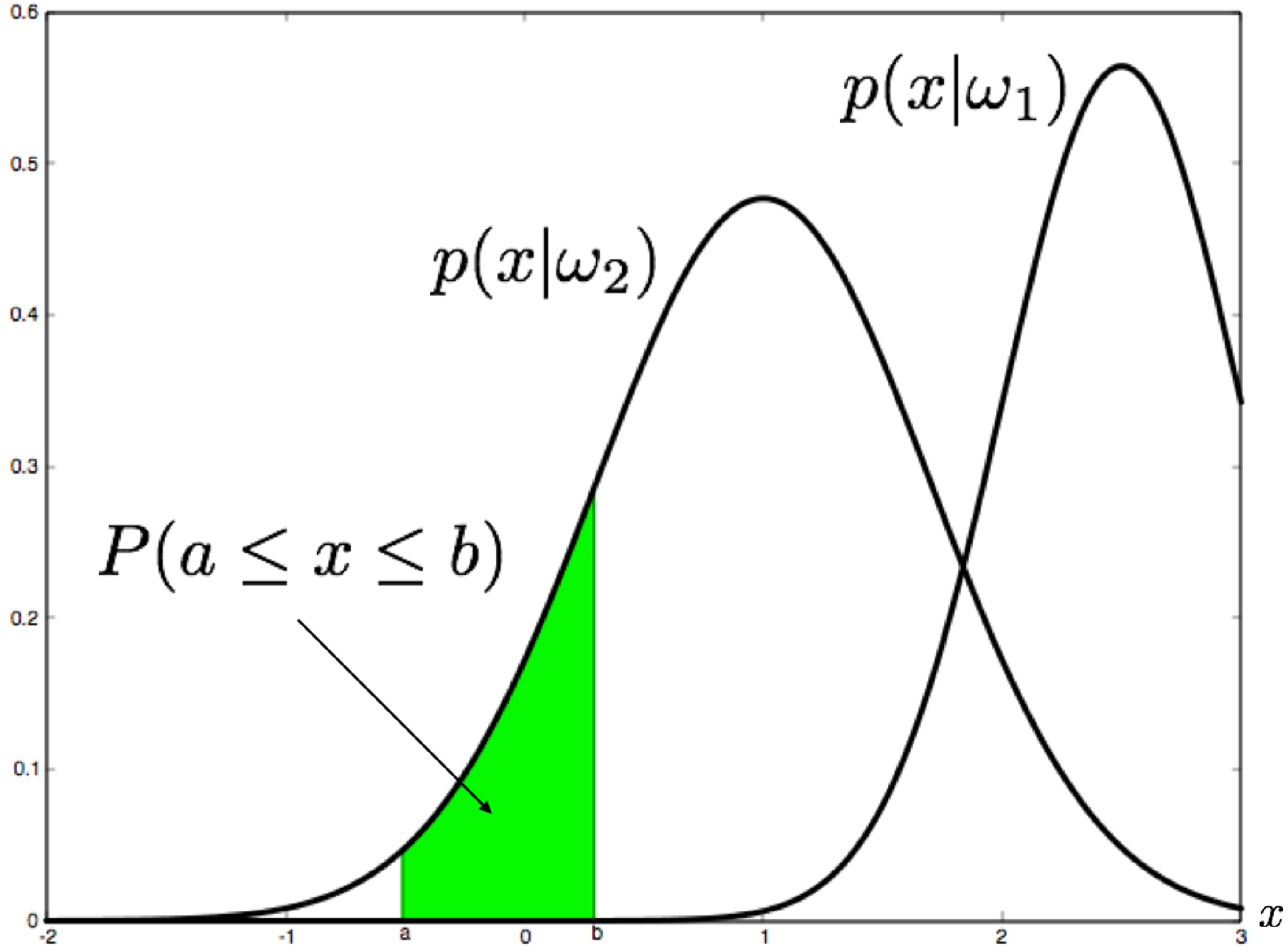


Classifiers and training methods

- Bayes classifier
- Nearest-neighbors and K-nearest-neighbors
- Parzen windows
- Linear and higher order discriminant functions
- Neural nets
- Support Vector Machines (SVM)
- …



Class conditional probability density functions



Bayesian decision theory

Overview

Class conditional densities:

$$p(\boldsymbol{x}|\omega_i), \text{ for each class } \omega_1, \omega_2, \ldots, \omega_c$$

Prior probabilities:

$$P(\omega_1), P(\omega_2), \ldots, P(\omega_c)$$

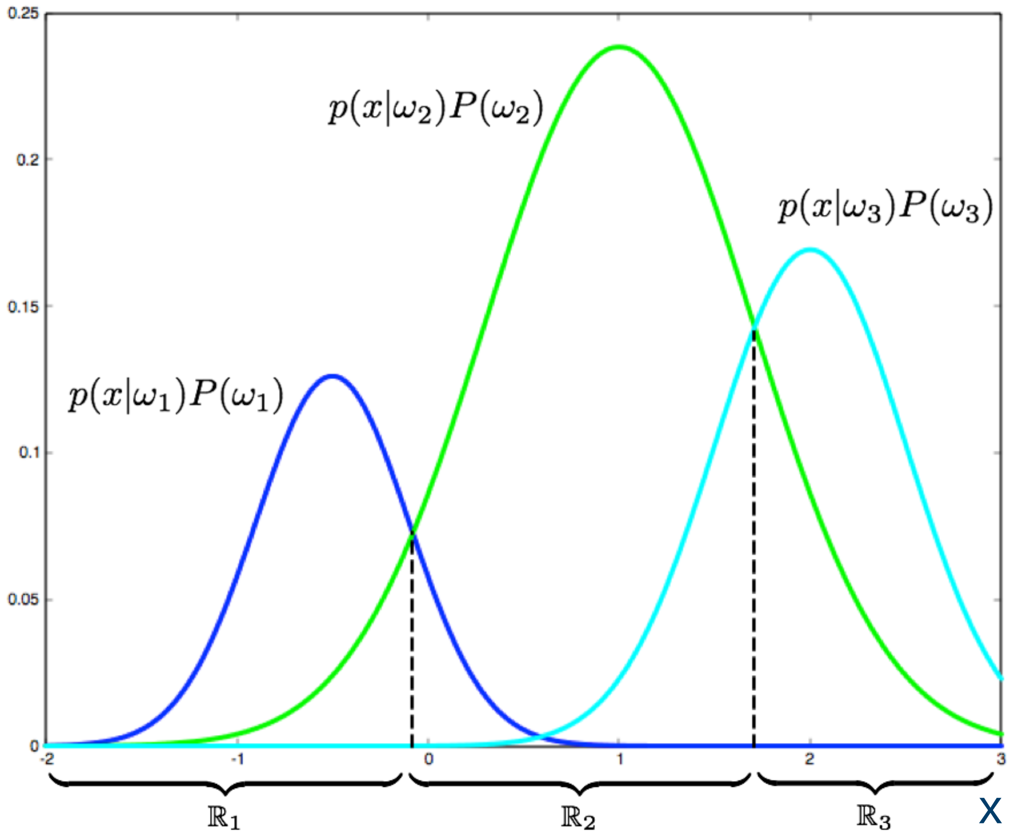
Posterior probabilities given by Bayes rule:

$$P(\omega_i|\boldsymbol{x}) = \frac{p(\boldsymbol{x}|\omega_i)P(\omega_i)}{\sum_{j=1}^{c} p(\boldsymbol{x}|\omega_j)P(\omega_j)}, \; i = 1, \ldots, c$$

(a function of the measured feature vector $\boldsymbol{x} = [x_1, x_2, \ldots, x_d]^t$).

Minimum error rate classification:

Assign the unknown object to the class with maximum posterior probability!



Density estimation

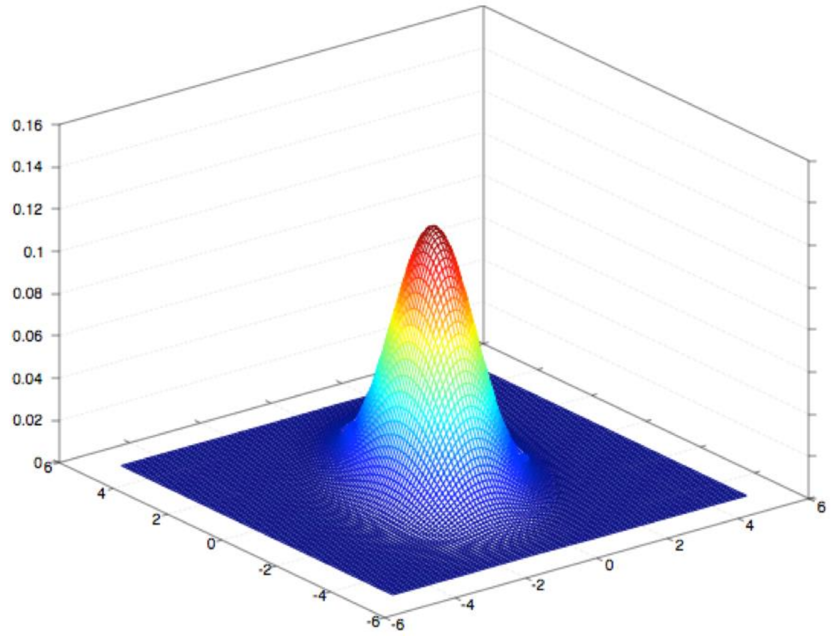
Parametric methods:

- Assume a given shape of the density function
- Use the training set to estimate the unknown parameters.

Non-parametric (distribution free) methods:

- Point estimation of the density using the training set directly
- Parzen windows
- Nearest neighbor estimation (leads directly to the nearest-neighbor and k-nearest-neighbor classifiers).

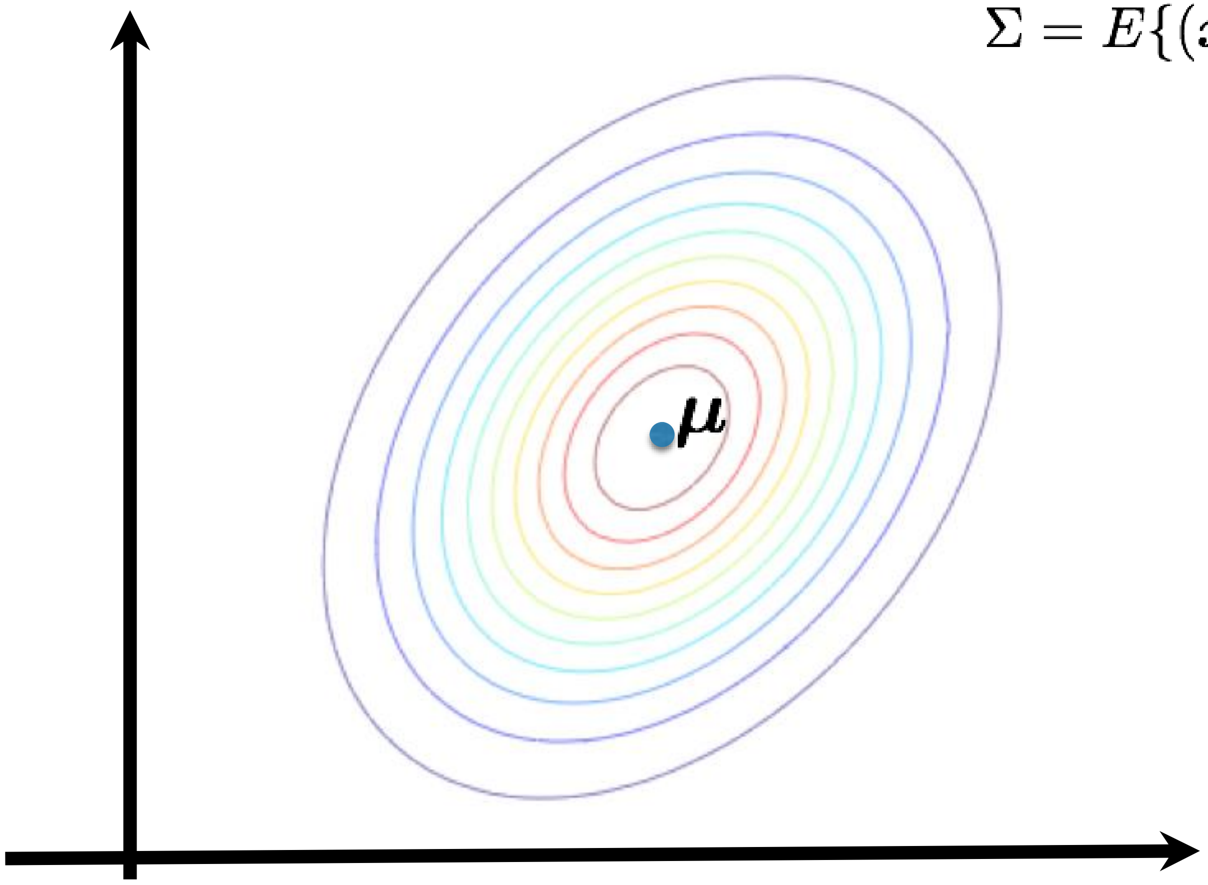
Example – Gaussian distribution:



$$p(\boldsymbol{x}|\omega_i) = \frac{1}{(2\pi)^{\frac{d}{2}}|\Sigma_i|^{\frac{1}{2}}} \exp\left[-\frac{1}{2}(\boldsymbol{x}-\boldsymbol{\mu}_i)^t\Sigma_i^{-1}(\boldsymbol{x}-\boldsymbol{\mu}_i)\right]$$

Parameters: $\boldsymbol{\mu}_i$ and Σ_i

Parameter estimation



$$\Sigma = E\{(\boldsymbol{x}-\boldsymbol{\mu})(\boldsymbol{x}-\boldsymbol{\mu})^t\} = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \cdots & \sigma_{1d} \\ \vdots & \vdots & & \vdots \\ \sigma_{d1} & \sigma_{d2} & \cdots & \sigma_{dd} \end{bmatrix}$$

Parameter estimates:

$$\hat{\boldsymbol{\mu}} = \boldsymbol{m} = \frac{1}{n}\sum_{k=1}^{n} \boldsymbol{x}_k$$

$$\hat{\boldsymbol{\Sigma}} = \frac{1}{n}\sum_{k=1}^{n} (\boldsymbol{x}_k - \boldsymbol{m})(\boldsymbol{x}_k - \boldsymbol{m})^t$$

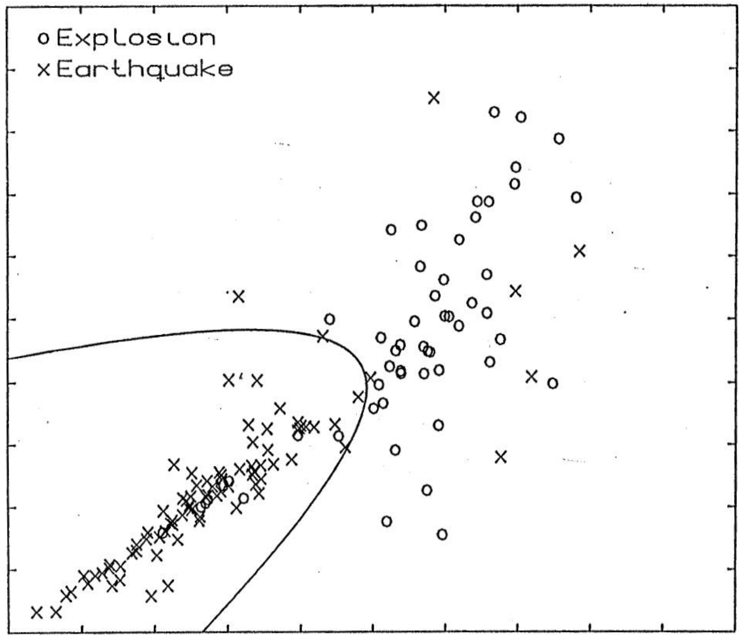
Discriminant functions

Estimate of the density in a given point:

$$\hat{p}(\boldsymbol{x}|\omega_i) = \frac{1}{(2\pi)^{\frac{d}{2}}|\hat{\Sigma}_i|^{\frac{1}{2}}} \exp\left[-\frac{1}{2}(\boldsymbol{x}-\hat{\boldsymbol{\mu}}_i)^t\hat{\Sigma}_i^{-1}(\boldsymbol{x}-\hat{\boldsymbol{\mu}}_i)\right]$$

From Bayes rule:

$$\hat{P}(\omega_i|\boldsymbol{x}) = \frac{\hat{p}(\boldsymbol{x}|\omega_i)P(\omega_i)}{\sum_{j=1}^{c}\hat{p}(\boldsymbol{x}|\omega_j)P(\omega_j)}$$



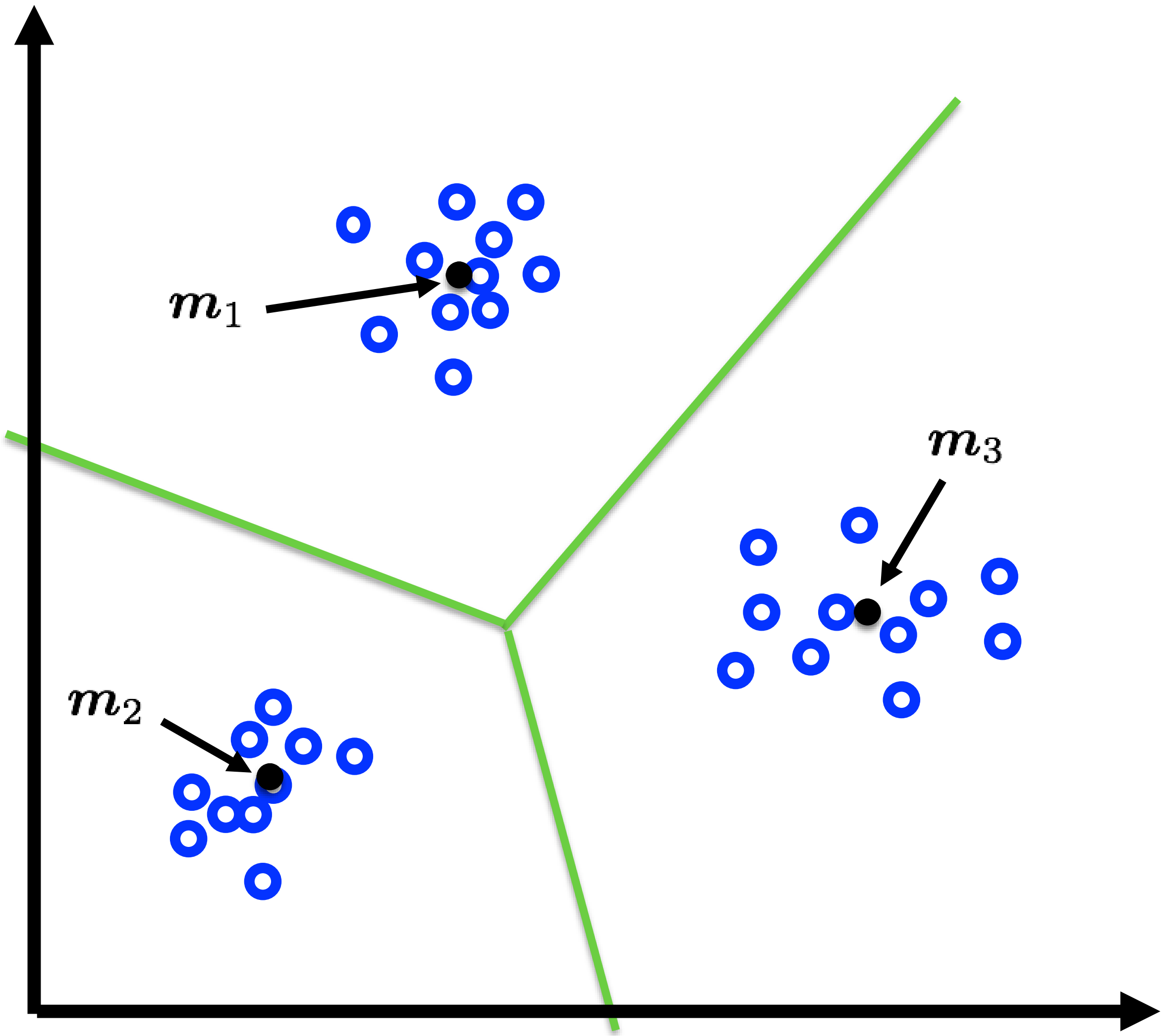
Examples of discriminant functions:

$$g_i(\boldsymbol{x}) = \ln\hat{P}(\omega_i|\boldsymbol{x}) \quad \text{or} \quad g_i(\boldsymbol{x}) = \ln\hat{p}(\boldsymbol{x}|\omega_i) + \ln P(\omega_i)$$

Decision rule:

Choose the class with maximum discriminant function value.

Example - linear classifier



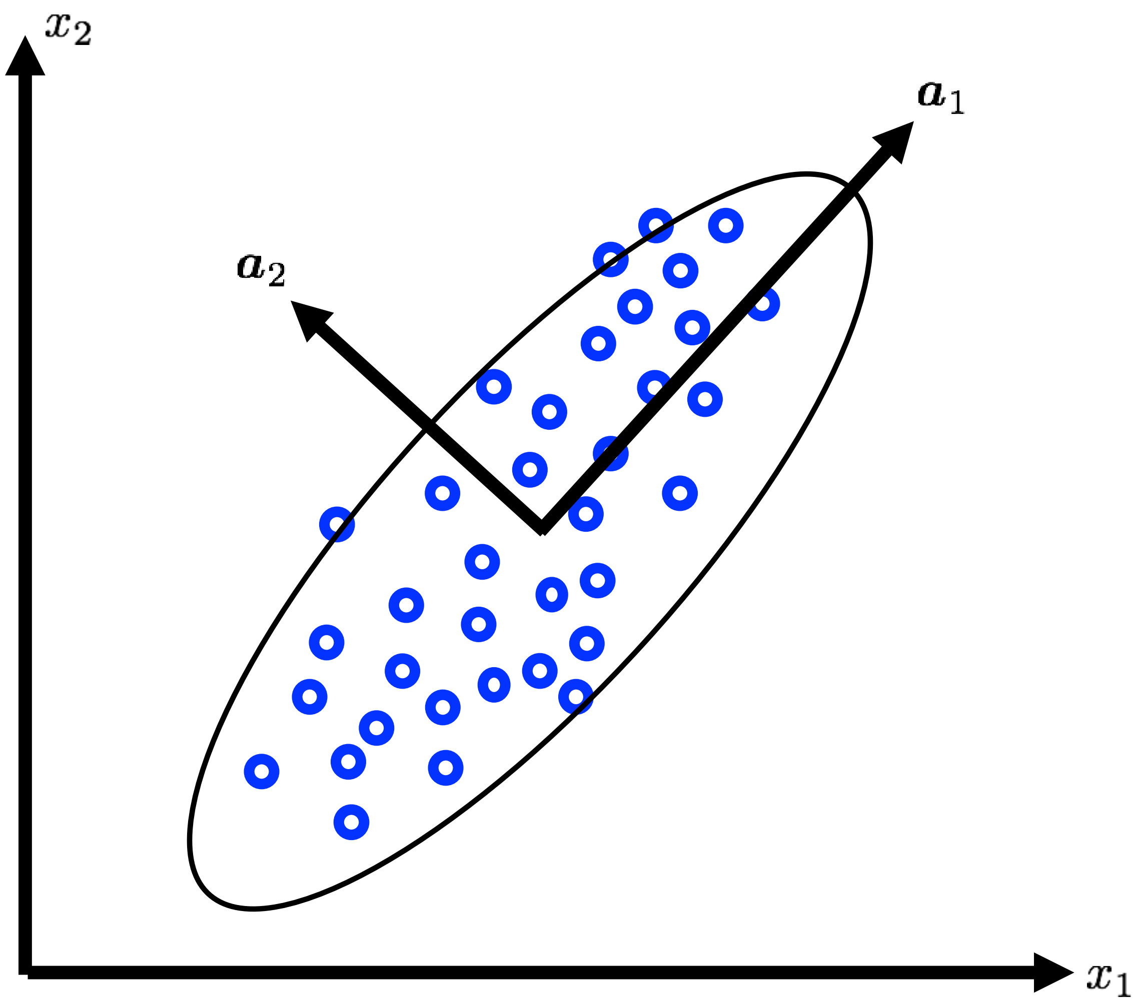
Uncorrelated features and
common covariance matrices

$\Downarrow$

Linear decision boundaries

Dimensionality reduction - linear transformations

- **PCA**, ICA, LLE, Isomap
- PCA (Principal Components Analysis) is one of the most important techniques for dimensionality reduction
- It takes advantage of correlations between the features to produce the best possible lower dimensional representation of the data with respect to reconstruction error
- The eigenvectors of the lumped covariance matrix defines the new features in the transformed feature space.



Summary

Machine learning:

- Pattern classification
- Training of classifiers (supervised learning)
- Parametric and non-parametric methods
- Discriminant functions
- Dimensionality reduction

More information: Szeliski 14.1