
VC 10/11 – T13

Pattern Recognition

Mestrado em Ciência de Computadores
Mestrado Integrado em Engenharia de Redes e
Sistemas Informáticos

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Outline

- Introduction to Pattern Recognition
- Statistical Pattern Recognition
- Classifiers

Topic: Introduction to Pattern Recognition

- Introduction to Pattern Recognition
- Statistical Pattern Recognition
- Classifiers

This is a
horse



This is a
horse



andrea.lindenberg © 2007

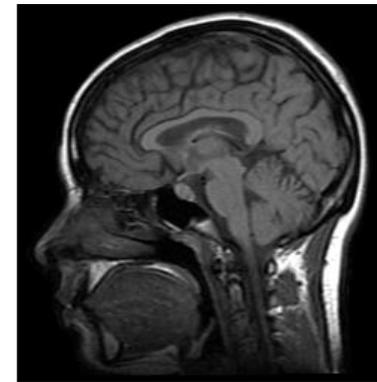
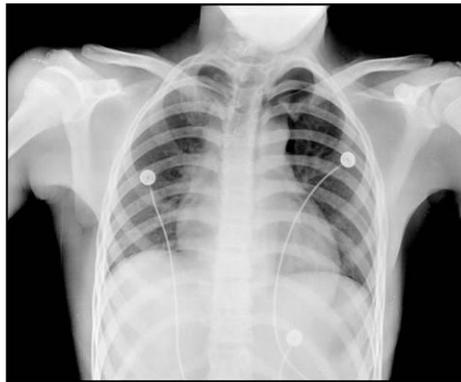
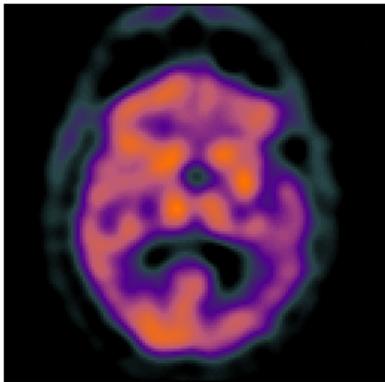
<http://www.flickr.com/photos/genewolf/2031802050/>



This is a...
Horse?

Decisions

- I can **manipulate** images.
- I want to make **decisions!**



- Classify / Identify **features**.
- Recognize **patterns**.

One definition

- **Pattern recognition**

"the act of taking in raw data and taking an action based on the category of the data".

Wikipedia

- How do I do this so well?
- How can I make machines do this?

The problem



Do you 'see'
a horse?

0	3	2	5	4	7	6	9	8
3	0	1	2	3	4	5	6	7
2	1	0	3	2	5	4	7	6
5	2	3	0	1	2	3	4	5
4	2	2	1	0	3	2	5	4
7	4	5	2	3	0	1	2	3
6	5	4	3	2	1	0	3	2
9	6	7	4	5	2	3	0	1
8	7	6	5	4	3	2	1	0

What a computer sees

Mathematics

- **We only deal with numbers.**
 - How do we represent knowledge?
 - How do we represent visual features?
 - How do we classify them?
- **Very complex problem!!**
 - Let's break it into smaller ones...

Typical PR system

Sensor

Gathers the observations to be classified or described



Feature Extraction

Computes numeric or symbolic information from the observations;



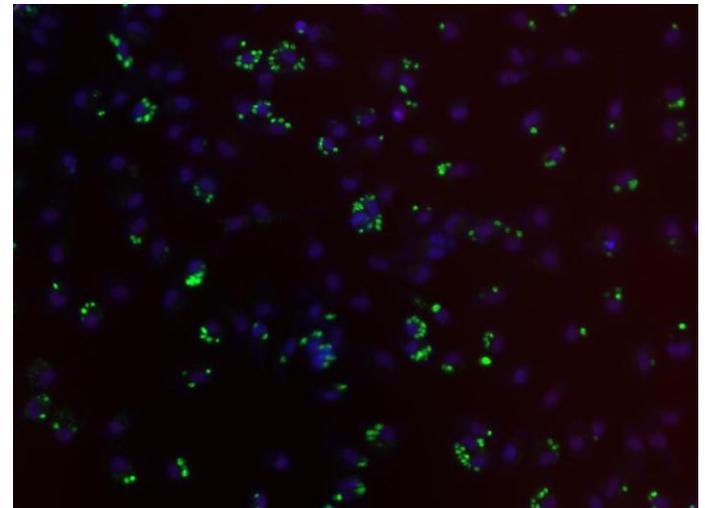
Classifier

Does the actual job of classifying or describing observations, relying on the extracted features.

Sensor

- In our specific case:
 - Image acquiring mechanism.
 - Let's assume we don't control it.

One observation = One Image
Video = Multiple Observations



Feature Extraction

- **What exactly are features?**
 - Colour, texture, shape, etc.
 - Animal with 4 legs.
 - Horse.
 - Horse jumping.
- **These vary a lot!**
- **Some imply some sort of ‘recognition’**
e.g. How do I know the horse is jumping?

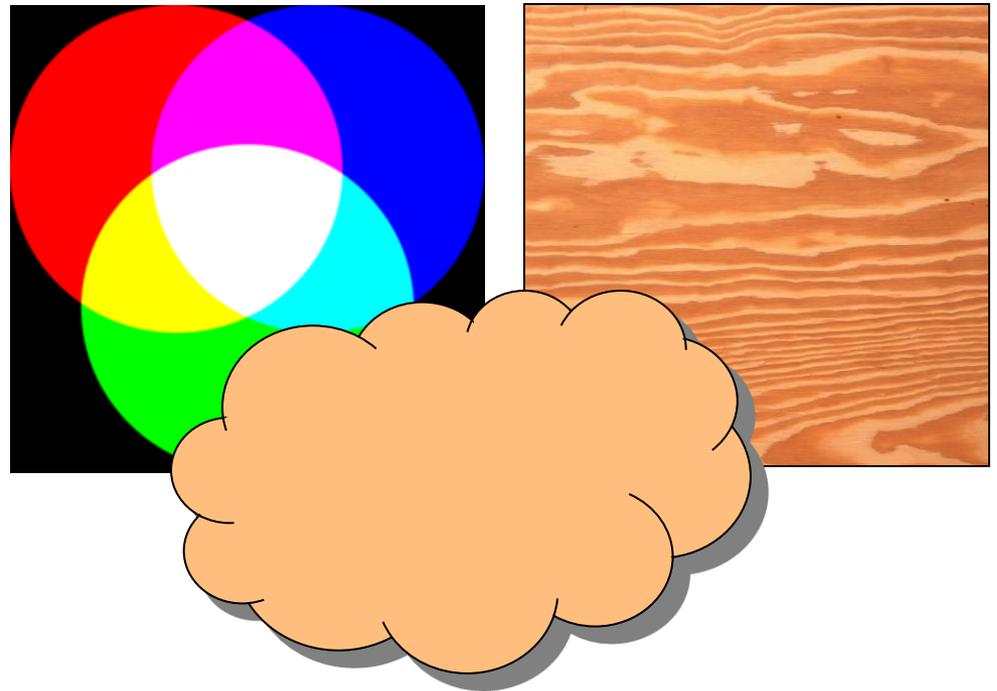
Broad classification of features

- **Low-level**
 - Colour, texture
- **Middle-level**
 - Object with head and four legs.
 - Object moving up.
 - Horse
- **High-level**
 - Horse jumping.
 - Horse competition.

Low-level features

- Objective
- Directly reflect specific image and video features.

- Colour
- Texture
- Shape
- Motion
- Etc.



Middle-level features

- Some degree of subjectivity
- They are typically one solution of a problem with multiple solutions.
- Examples:
 - Segmentation
 - Optical Flow
 - Identification
 - Etc.



High-level features

- Semantic Interpretation
- Knowledge
- Context
- Examples:



How do humans do this so well?

- This person suffers from epilepsy.
- The virus attacks the cell with some degree of intelligence.
- This person is running from that one.

The semantic gap

- Fundamental problem of current research!

Low-level:

- Colour
- Texture
- Shape
- ...



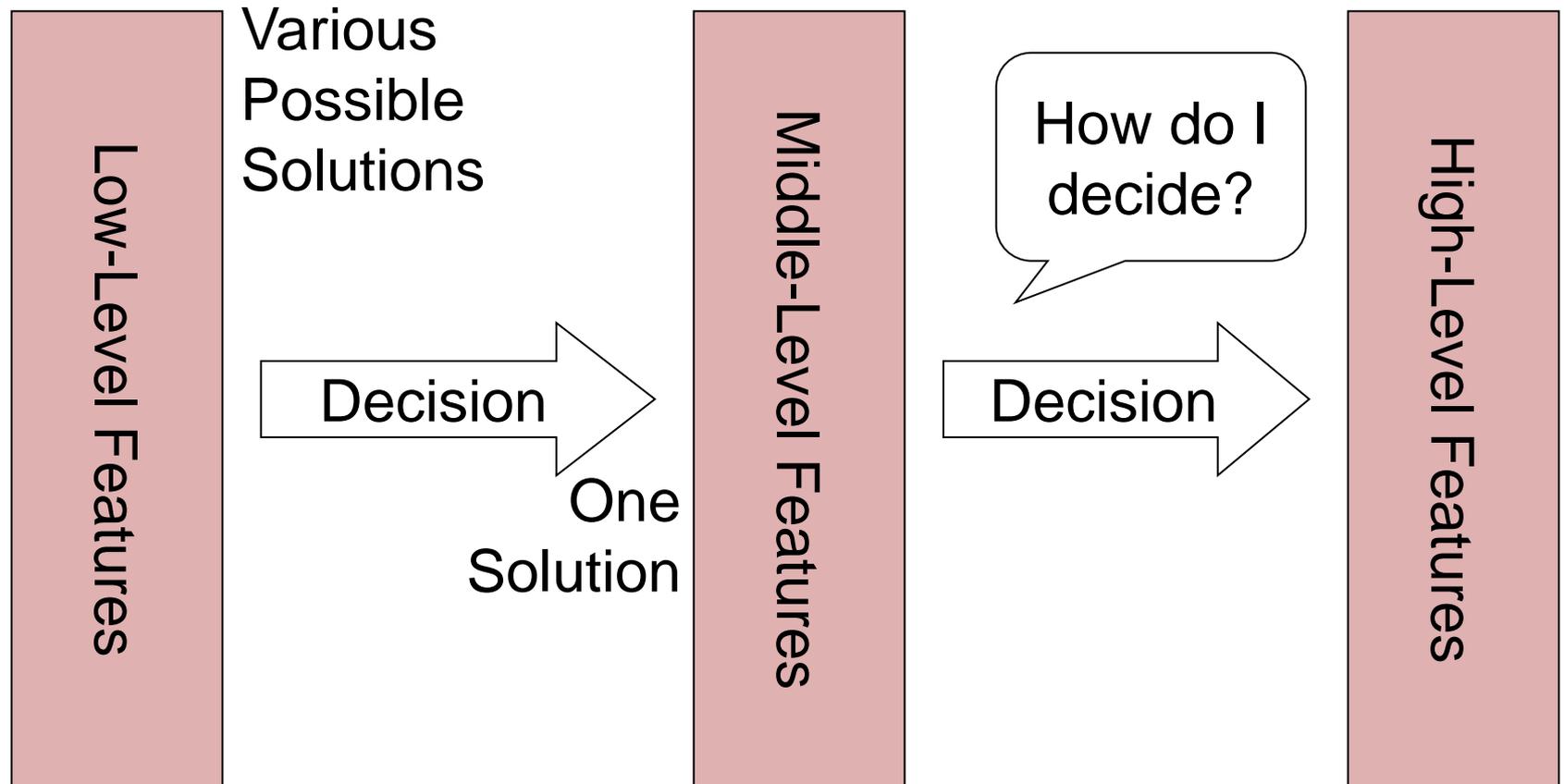
High-level:

- Interpretation
- Decision
- Understanding
- ...

Now what??
How do i cross this
bridge?



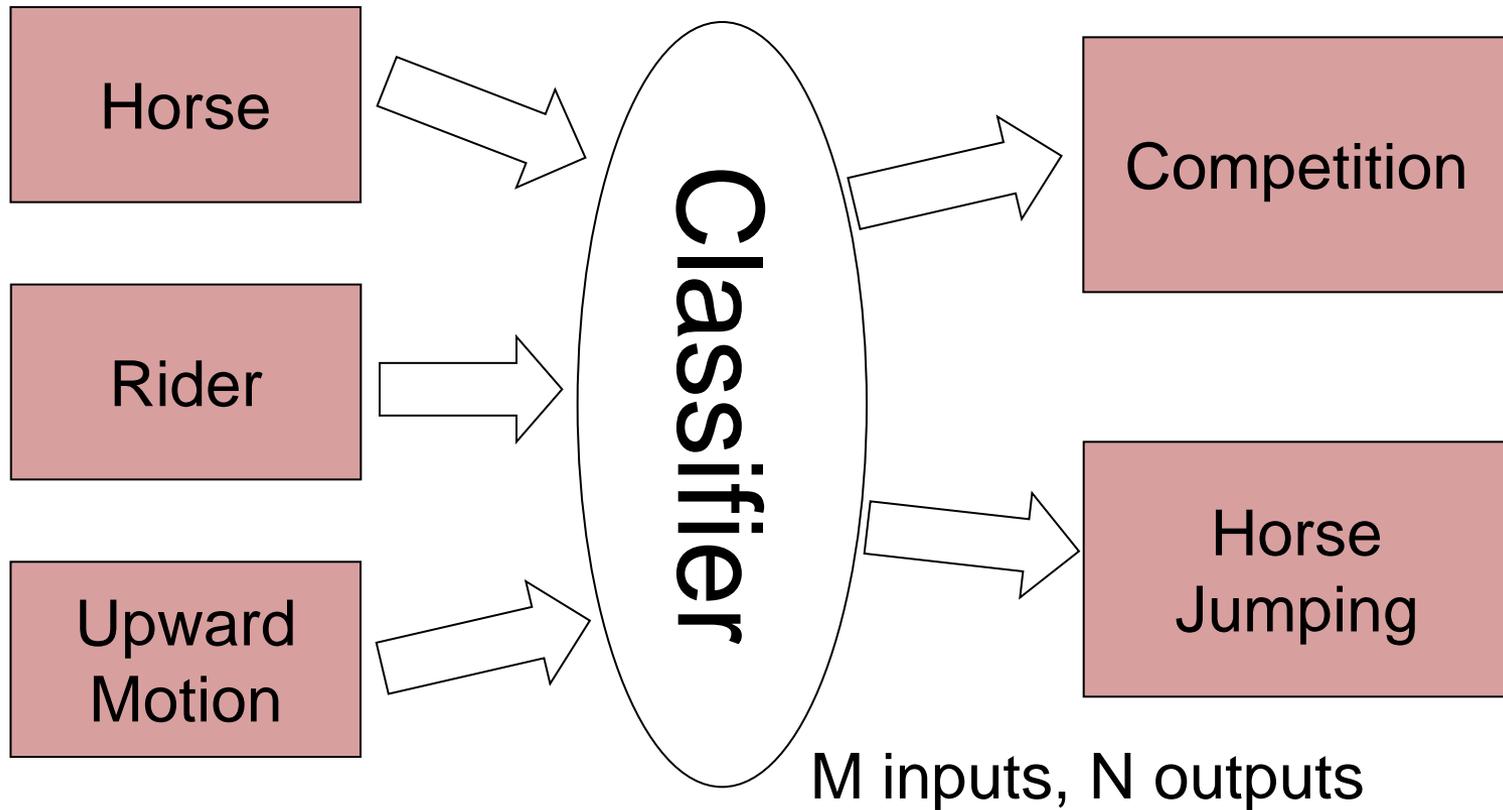
Features & Decisions



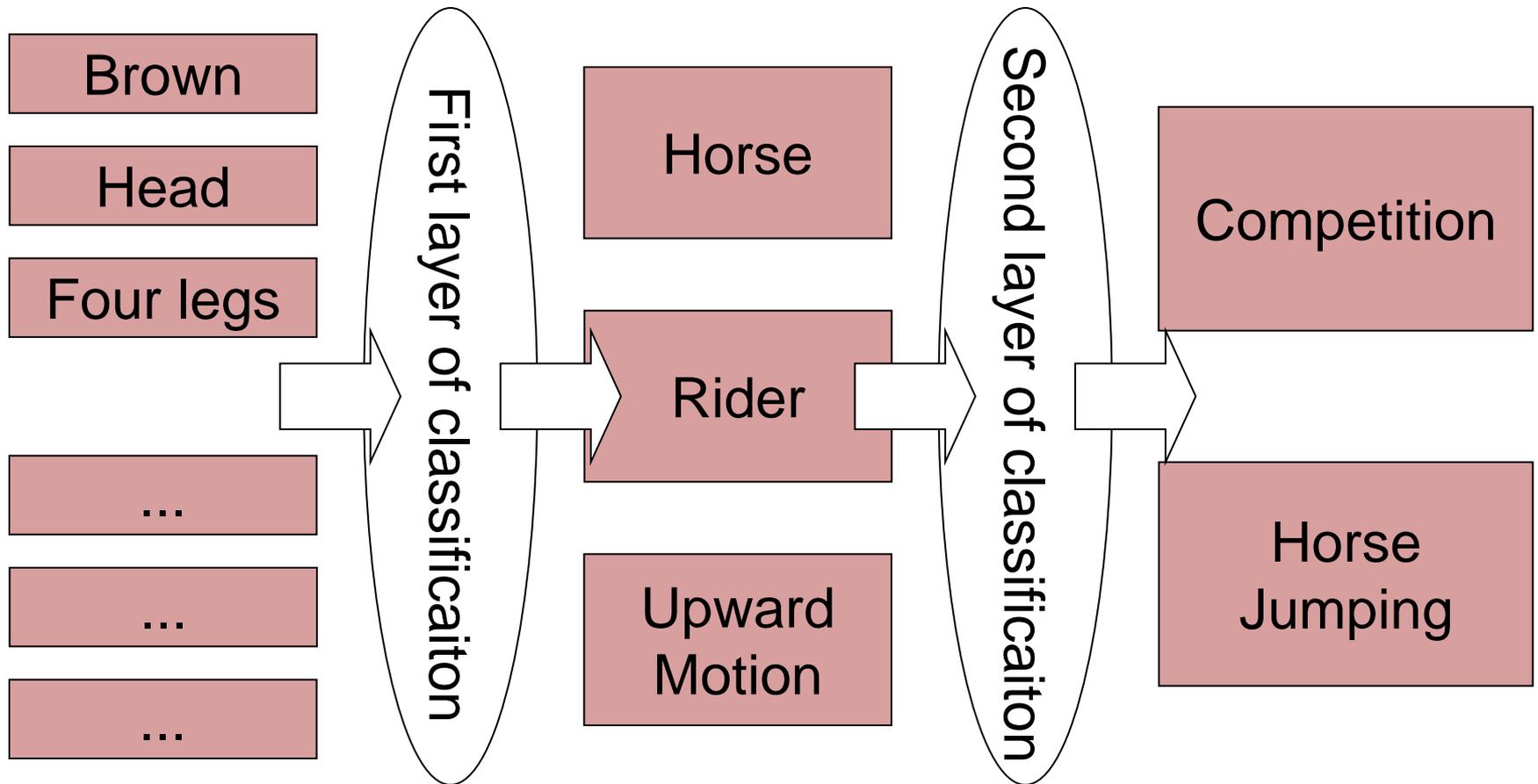
Classification

Middle-Level Features

High-Level Features



Layers of classification



Classifiers

- How do I map my M inputs to my N outputs?
- Mathematical tools:
 - Distance-based classifiers.
 - Rule-based classifiers.
 - Neural Networks.
 - Support Vector Machines
 - ...

Types of PR methods

- **Statistical pattern recognition**
 - based on statistical characterizations of patterns, assuming that the patterns are generated by a probabilistic system.
- **Syntactical (or structural) pattern recognition**
 - based on the structural interrelationships of features.

Topic: Statistical Pattern Recognition

- Introduction to Pattern Recognition
- **Statistical Pattern Recognition**
- Classifiers

Is Porto in Portugal?



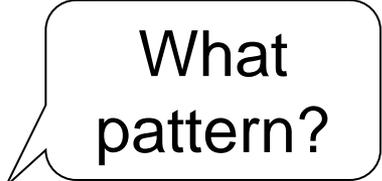
Porto is in Portugal

- I want to make decisions.
 - Is Porto in Portugal?
- I know certain things.
 - A world map including cities and countries.
- I can make this decision!
 - Porto is in Portugal.
- I had enough *a priori* knowledge to make this decision.

What if I don't have a map?

- I still want to make this decision.
- I observe:
 - Amarante has coordinates x_1, y_1 and is in Portugal.
 - Viseu has coordinates x_2, y_2 and is in Portugal.
 - Vigo has coordinates x_3, y_3 and is in Spain.
- I classify:
 - Porto is close to Amarante and Viseu so **Porto is in Portugal.**
- What if I try to classify *Valença*?

Statistical PR

- I used **statistics** to make a decision.
 - I can make **decisions** even when I don't have full a priori knowledge of the whole process.
 - I can make **mistakes**.
- How did I **recognize** this pattern?
 - I **learned** from previous observations where I knew the classification result.
 - I **classified** a new observation.

Back to the Features

- Feature F_i $F_i = [f_i]$

- Feature F_i with N values.

$$F_i = [f_{i1}, f_{i2}, \dots, f_{iN}]$$

- Feature vector F with M features.

$$F = [F_1 | F_2 | \dots | F_M]$$

- Naming conventions:
 - Elements of a **feature vector** are called **coefficients**.
 - **Features** may have one or more **coefficients**.
 - **Feature vectors** may have one or more **features**.

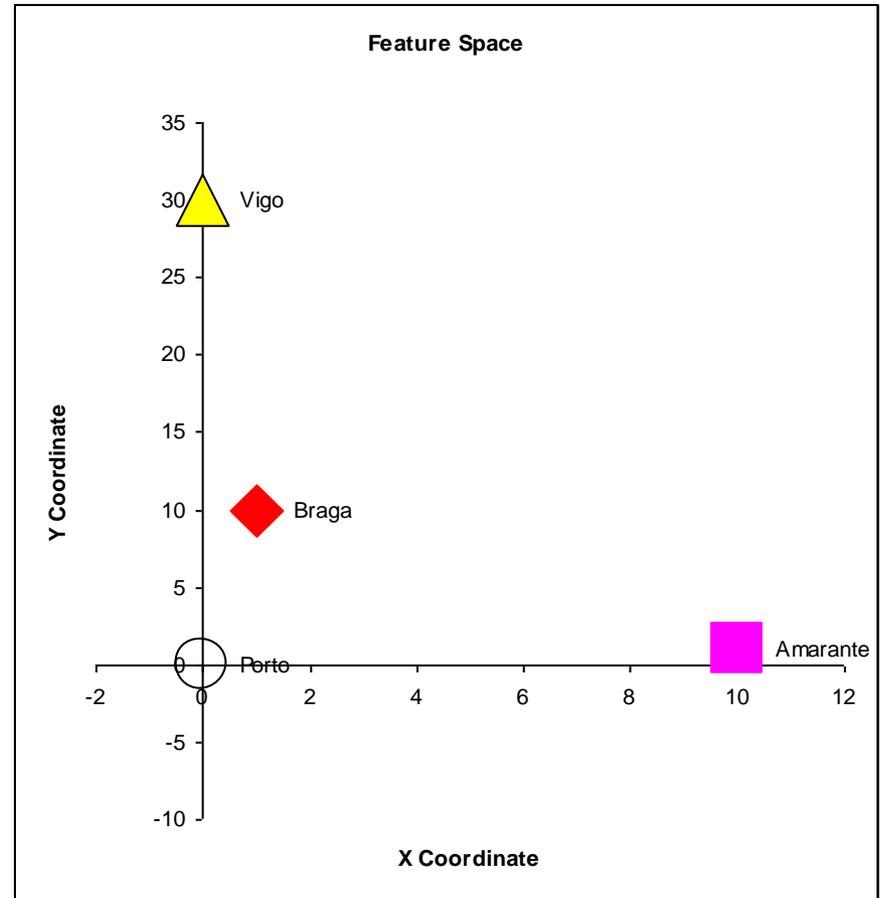
Back to our Porto example

- I've classified that Porto is in Portugal.
- What feature did I use?
 - Spatial location
- Let's get more formal
 - I've defined a feature vector \mathbf{F} with one feature \mathbf{F}_1 , which has two coefficients f_{1x} , f_{1y} .

$$\mathbf{F} = [\mathbf{F}_1] = [f_{1x}, f_{1y}]$$

Feature Space

- **Feature Vector**
 - Two total coefficients.
 - Can be seen as a feature 'space' with two orthogonal axis.
- **Feature Space**
 - Hyper-space with N dimensions where N is the total number of coefficients of my feature vector.



A *Priori* Knowledge

- I have a precise *model* of my feature space based on *a priori* knowledge.

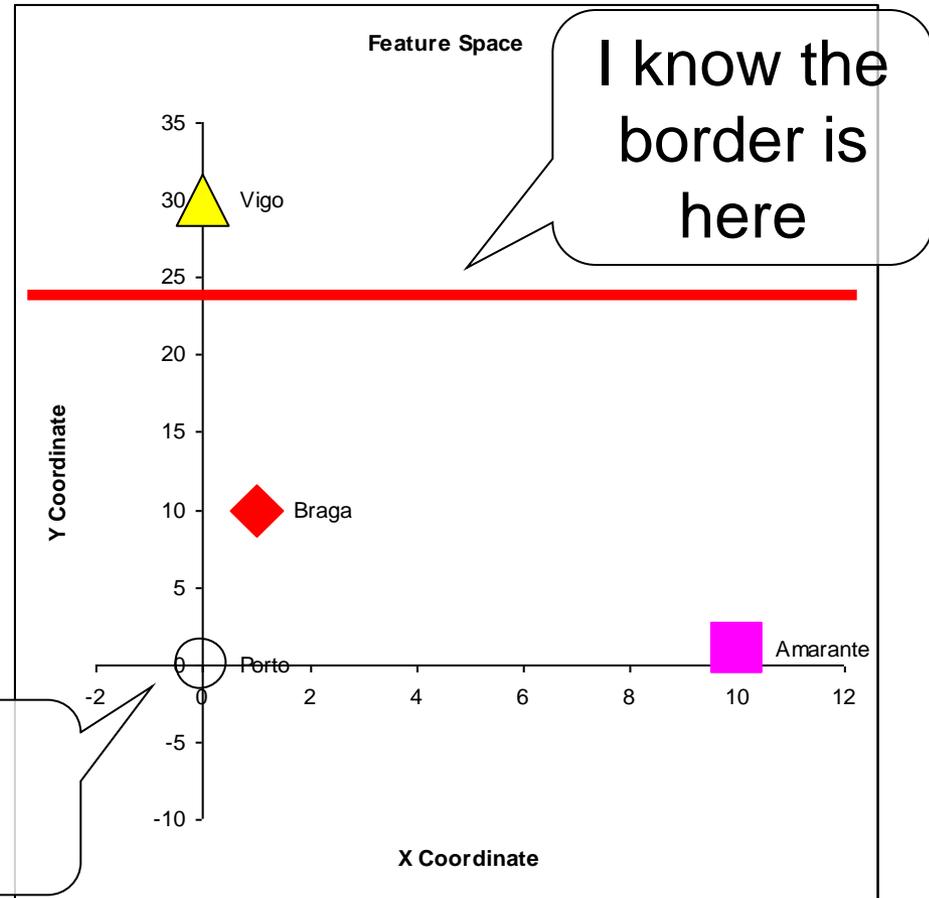
City is in Spain if $F_{1Y} > 23$

- Great models = Great classifications.

$F_{1Y}(\text{London}) = 100$

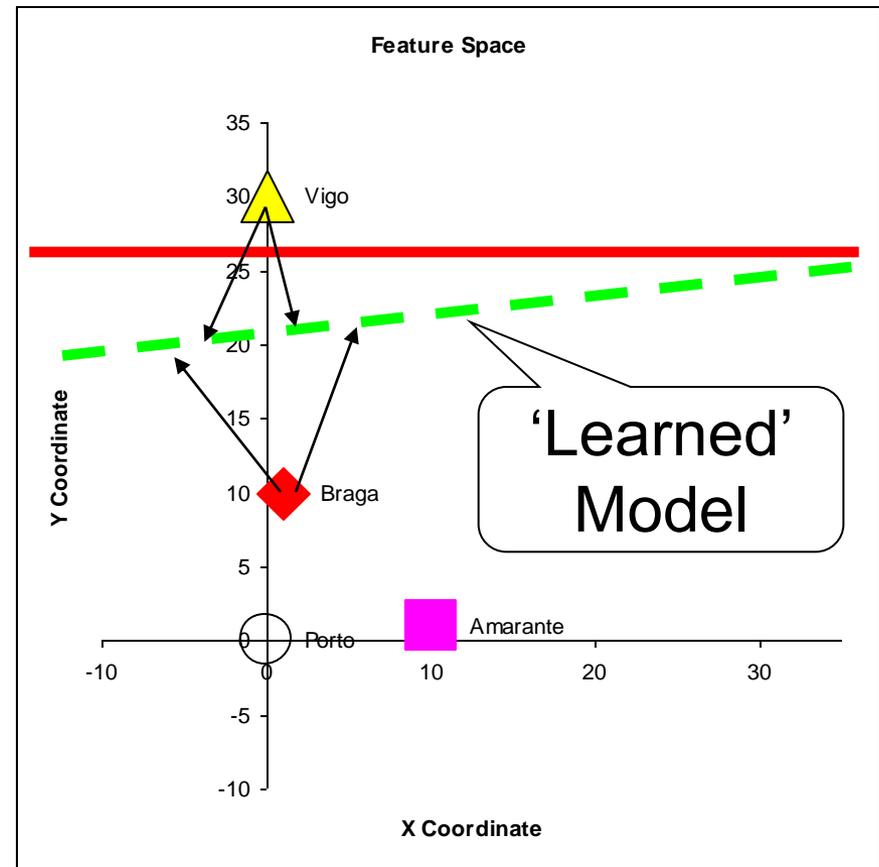
London is in Spain (??)

Porto is in Portugal!



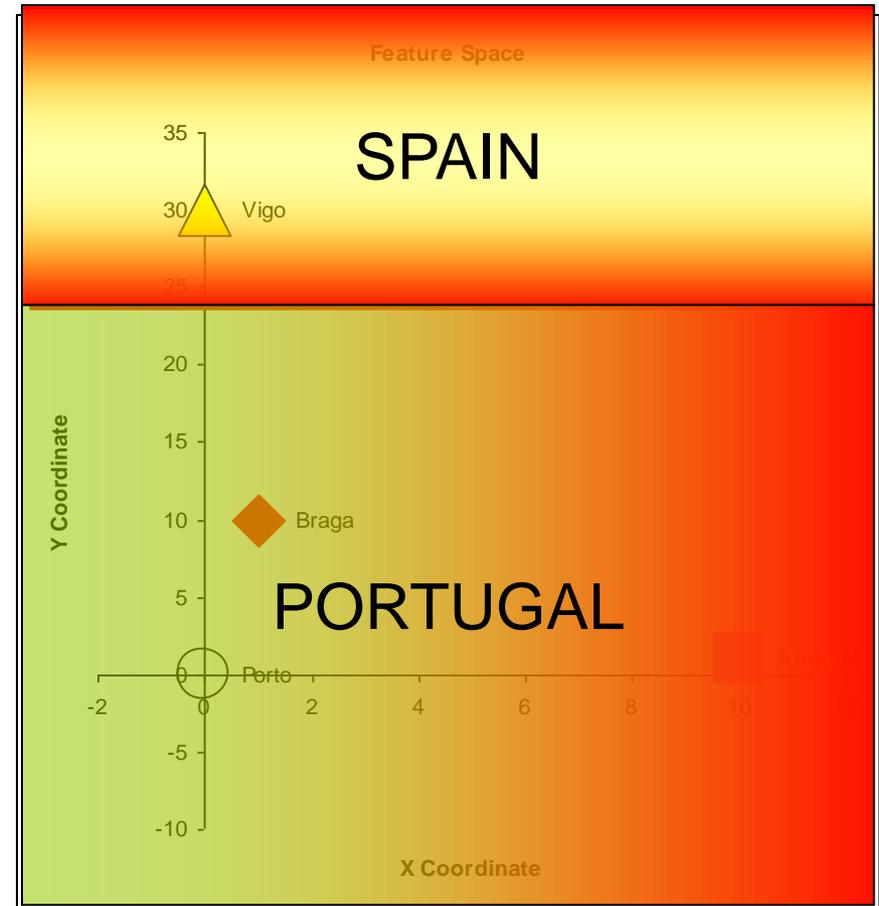
What if I don't have a model?

- I need to **learn** from observations.
 - Derive a model.
 - Direct classification.
- **Training stage.**
 - Learn model parameters.
- **Classification**



Classes

- In our example, cities can belong to:
 - Portugal
 - Spain
- I have two **classes** of cities.
- A **class** represents a sub-space of my feature space.



Classifiers

- A **Classifier C** maps a class into the feature space.

$$C_{\text{Spain}}(x, y) = \begin{cases} \textit{true} & , y > K \\ \textit{false} & , \textit{otherwise} \end{cases}$$

- Various types of classifiers.
 - Nearest-Neighbours.
 - Bayesian.
 - Soft-computing machines.
 - Etc...

Topic: Classifiers

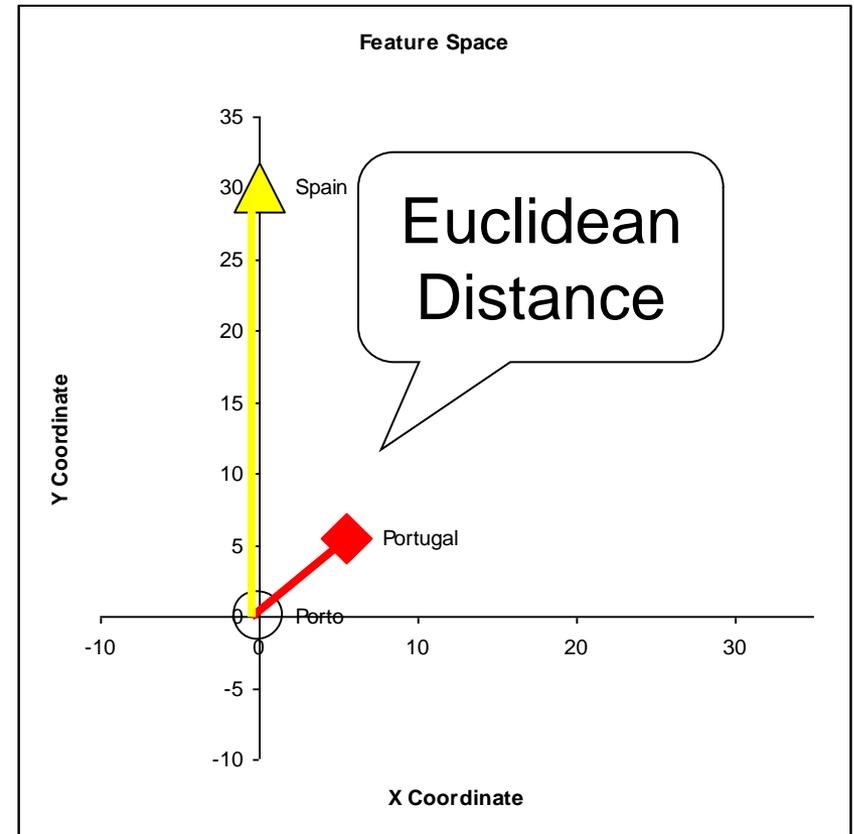
- Introduction to Pattern Recognition
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Distance to Mean

- I can represent a class by its mean feature vector.

$$C = \bar{F}$$

- To classify a new object, I choose the class with the closest mean feature vector.
- Different distance measures!



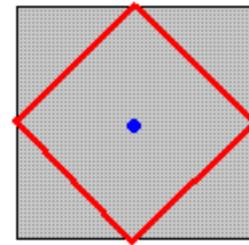
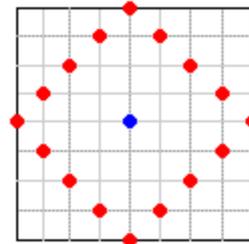
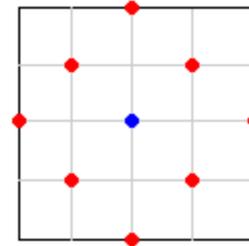
Possible Distance Measures

- L1 Distance

$$L1 = \frac{1}{N} \sum_{x=1}^N |S(x) - v(x)|$$

- Euclidean Distance
(L2 Distance)

$$L2 = \frac{1}{N} \sum_{x=1}^N \left(S(x) - v(x) \right)^2$$

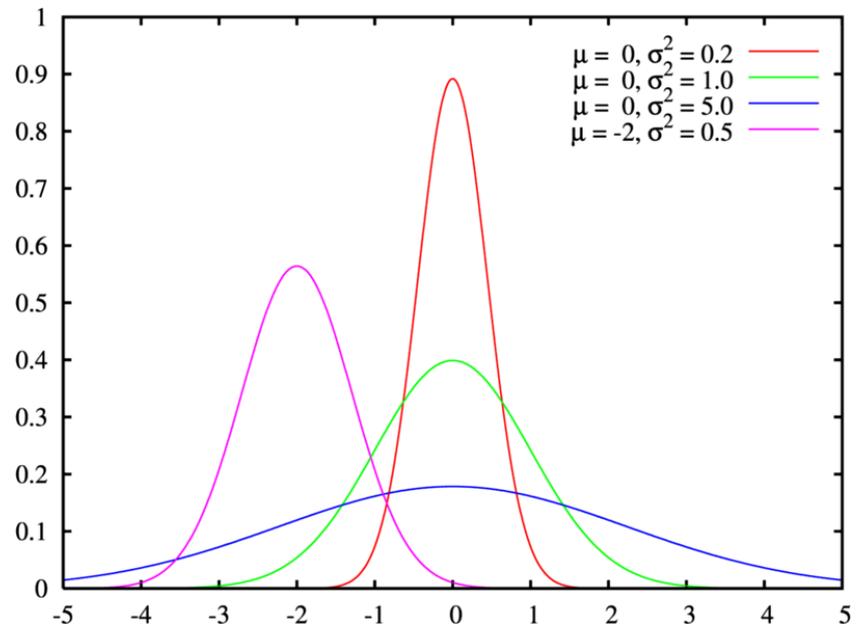


L1 or
Taxicab
Distance

Gaussian Distribution

- Defined by two parameters:
 - Mean: μ
 - Variance: σ^2
- Great approximation to the distribution of many phenomena.
 - *Central Limit Theorem*

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$$



Multivariate Distribution

- For N dimensions:

$$f_X(x_1, \dots, x_N) = \frac{1}{(2\pi)^{N/2} |\Sigma|^{1/2}} \exp \left(-\frac{1}{2} (x - \mu)^\top \Sigma^{-1} (x - \mu) \right)$$

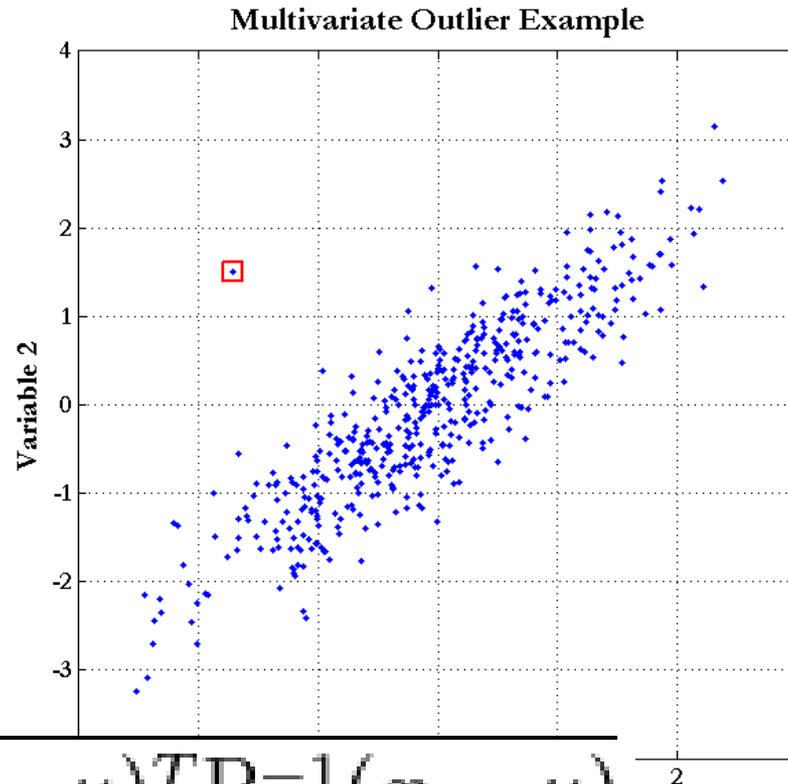
- Mean feature vector:
- Covariance Matrix:

$$\mu = \bar{F}$$

$$X = \begin{bmatrix} X_1 \\ \vdots \\ X_n \end{bmatrix} \quad \mu_i = \mathbb{E}(X_i) \quad \Sigma_{ij} = \mathbb{E}[(X_i - \mu_i)(X_j - \mu_j)]$$

Mahalanobis Distance

- Based on the covariance of coefficients.
- Superior to the Euclidean distance.



$$D_M(x) = \sqrt{(x - \mu)^T P^{-1} (x - \mu)}.$$

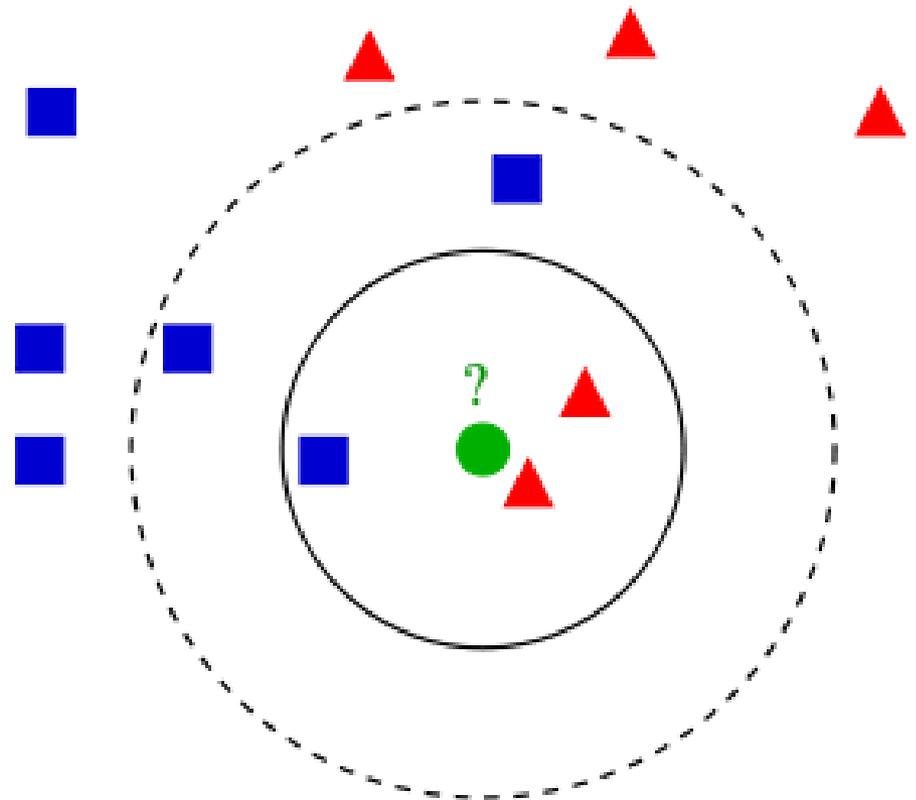
K-Nearest Neighbours

- **Algorithm**

- Choose the closest K neighbours to a new observation.
- Classify the new object based on the **class** of these K objects.

- **Characteristics**

- Assumes no model.
- Does not scale very well...



Resources

- Gonzalez & Woods, 3rd Ed, Chapter 12.
- Andrew Moore, Statistic Data Mining Tutorial, <http://www.autonlab.org/tutorials/>