Face Image Analysis

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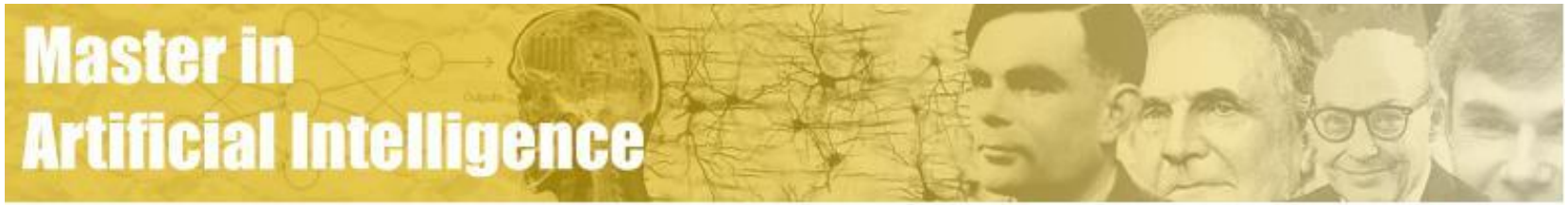

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Outline

1. Face image analysis: an introduction
2. Face detection
    1. Basic Concepts
    2. Visual features
    3. Ensemble learning
    4. Cascade of classifiers
    5. Applications
3. Face matching
4. Face recognition

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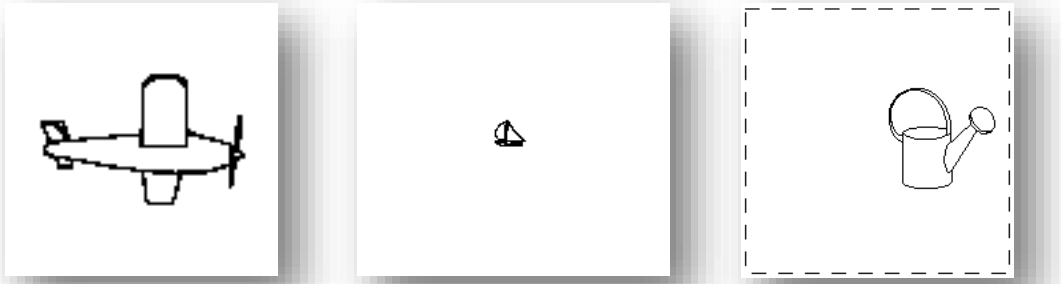
Introduction

- Human Visual System:
  - Robust in object recognition tasks



Rotational Invariance

Size Invariance

Translational Invariance

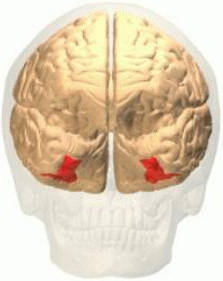
  - Are faces recognized just as another object?

Introduction

- Human Visual System:
  - Faces are considered a special class of objects.

> The human behavior when recognizing faces is widely discussed in the psychology and neuro-psychological literature. The deeply studied response of human observers, both normal and with cognitive deficits or pathologies, and the new medical imaging technologies have allow to accumulate experimental evidence related to how people perceive, encode, and recognize faces.

  - Designated areas for face recognition. A part of the brain is used for face processing.
    - Damage of that part causes the so-called prosopagnosia.



Fusiform face area (FFA)

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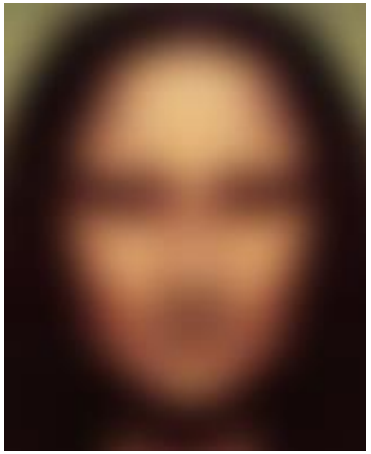
Introduction

- Why face recognition is such important?
  - Evolutionary reasons:
    - We need to find friends in our group
  - Sociocultural reasons:
    - We need to predict behaviors from facial expressions.
- Some basic tasks related to face recognition:
  - Identification
  - Emotions and social signals recognition
  - Other information: Attention focus, Sexual attraction, Age, Gender, Lip-reading, Personality

Introduction

- How good is our visual system performing face recognition?

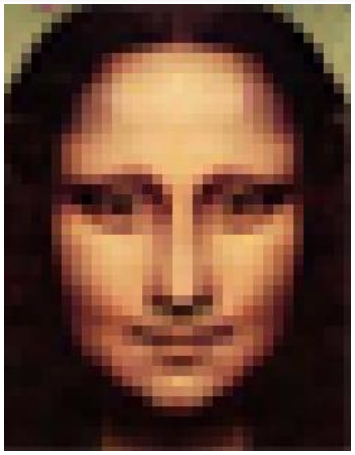
It is generally accepted [129] that different face processing task are solved by the HVS making use of the information contained in different image frequency channels. In this way, it is assumed that low frequency information is enough for face detection and sex categorization, meanwhile tasks such that identity recognition or facial expression recognition require higher image frequencies.



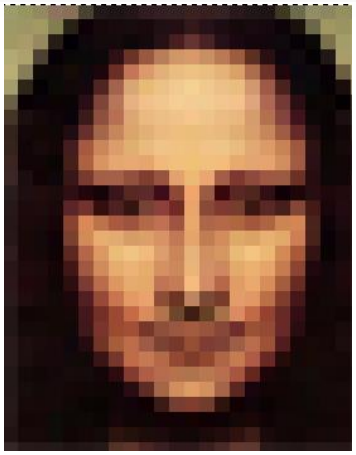
Introduction

- How good is our visual system performing face recognition?

Bhatia et al [6] [71] studied how the image resolution degrades the capabilities of discriminating between face and non face stimulus. They concluded that an image of just 16×16 pixels blocks is enough for distinguishing between a face and a non-face image (using scrambled faces, mammalian face and inanimate object as non-facial stimulus).



36x36

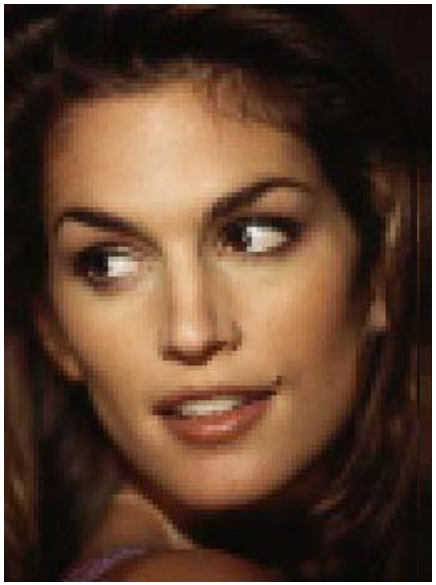


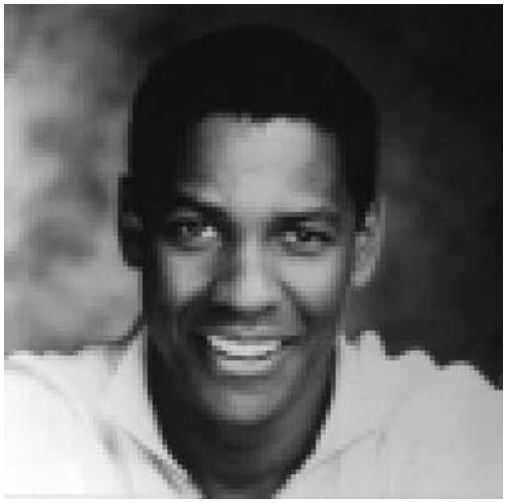
24x24

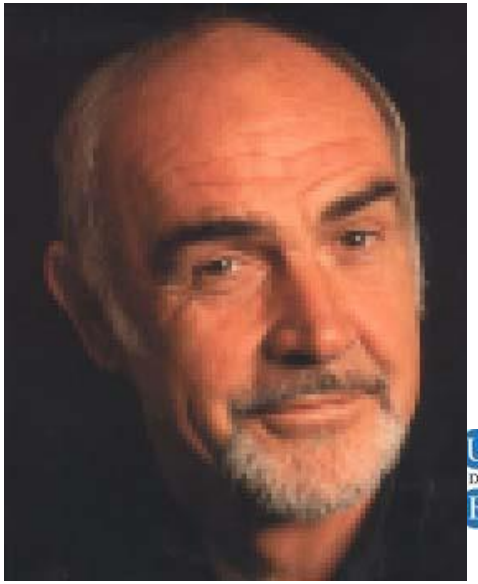
16x16

Introduction

- Can you identify the person in the images or at least the gender?







Introduction

- **Mr. Clinton** use to be rather easy to identify.

On average, people were correctly identifying the pixelated image as Clinton by sharpen level 7.33.

They were able to say it is a male wearing a black and white suit by level 4.

- The picture of **Cindy Crawford** is one of the more dubious images.

Although the sex of the pixelated image was never in question (people were able to tell it was a female by level 2.5), people are not able to identify her until average level 8.85.

Introduction

- **Denzel Washington** is known for having a symmetrical face and is hence easily identifiable.

Some people who were aware of this fact, were able to correctly guess Mr. Washington at level 5 or 6.

Most people ranged around 8 and 9.

- Although **Madonna**'s picture is not a very typical of her, people scored around 9.55.

With a more typical picture, she is recognized at around 6 or 7.

- **Sean Connery** turned out to be the most identifiable face of this group.

People were identifying Mr. Connery at levels 4 or 5! (Put the sharpen level to 5 and take a few steps back from your screen and you will see it)

Introduction

- Our visual system is optimized for some orientations.
  - ***Thatcher illusion***: Experiment to see the poor performance even in judging if an upside-down image is depicting a real face image.

Introduction

- Recognize people from other ethnics is most difficult, while recognition using caricatures seems easier.

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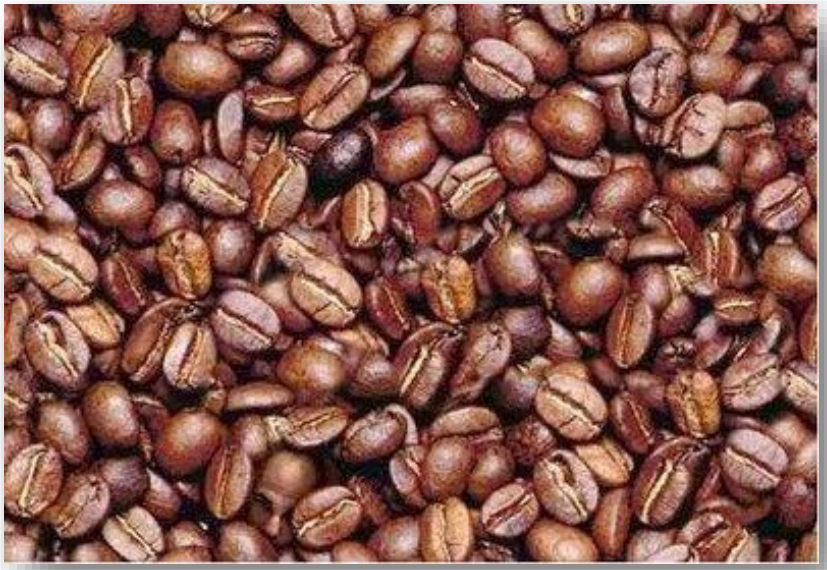
Face detection

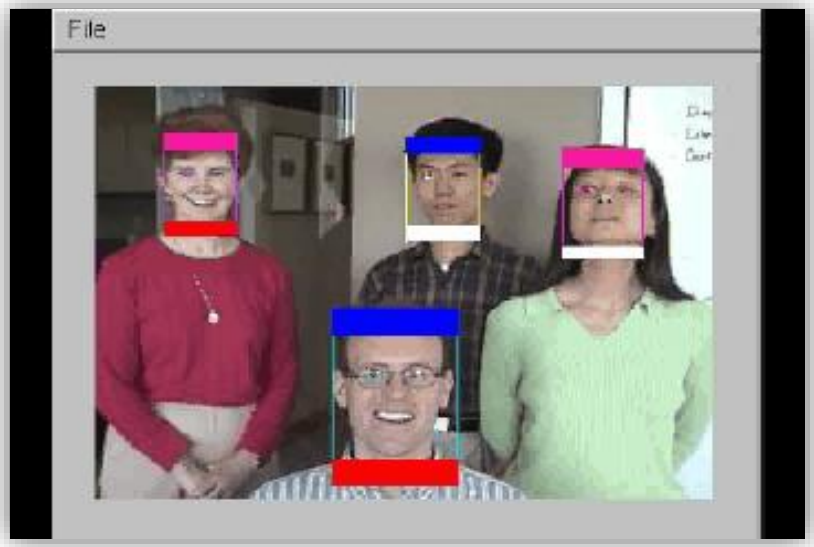


“Hidden Face by Coffee Beans”

Face detection

Face detection

- The first step to face analysis
  - Given an image, where are the faces?



•Identify and locate human faces in an image regardless of their position, scale, in plane rotation, orientation, pose and illumination.
•A very difficult problem

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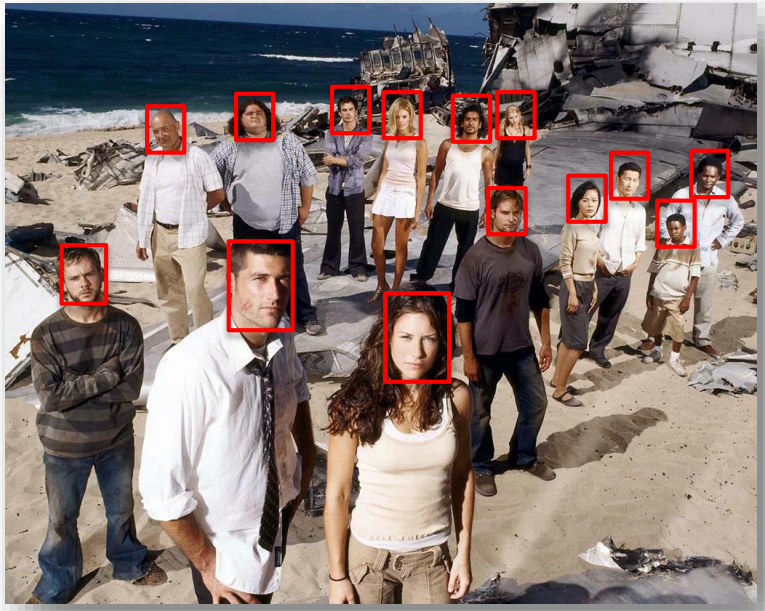
Detection vs. Recognition

Detection



Recognition

Jack

Kate

Sawyer

?

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Face detection

- Intra-class variability

- Inter-class confusion

Paul Newman/Marlon Brando

Face detection

- Classical approach to face detection
  - P. Viola and M. Jones. Rapid object detection using a boosted cascade of simple features. Proc. CVPR, 1:511-518, 2001.

- Implemented in some public libraries
  - OpenCV

Face detection

Objetives of Viola& Jones method:

- Accurate detection of faces
- Fast Algorithm
- Real-time detección (video processing)

With a camera, we do not want to wait too much time to take a picture!

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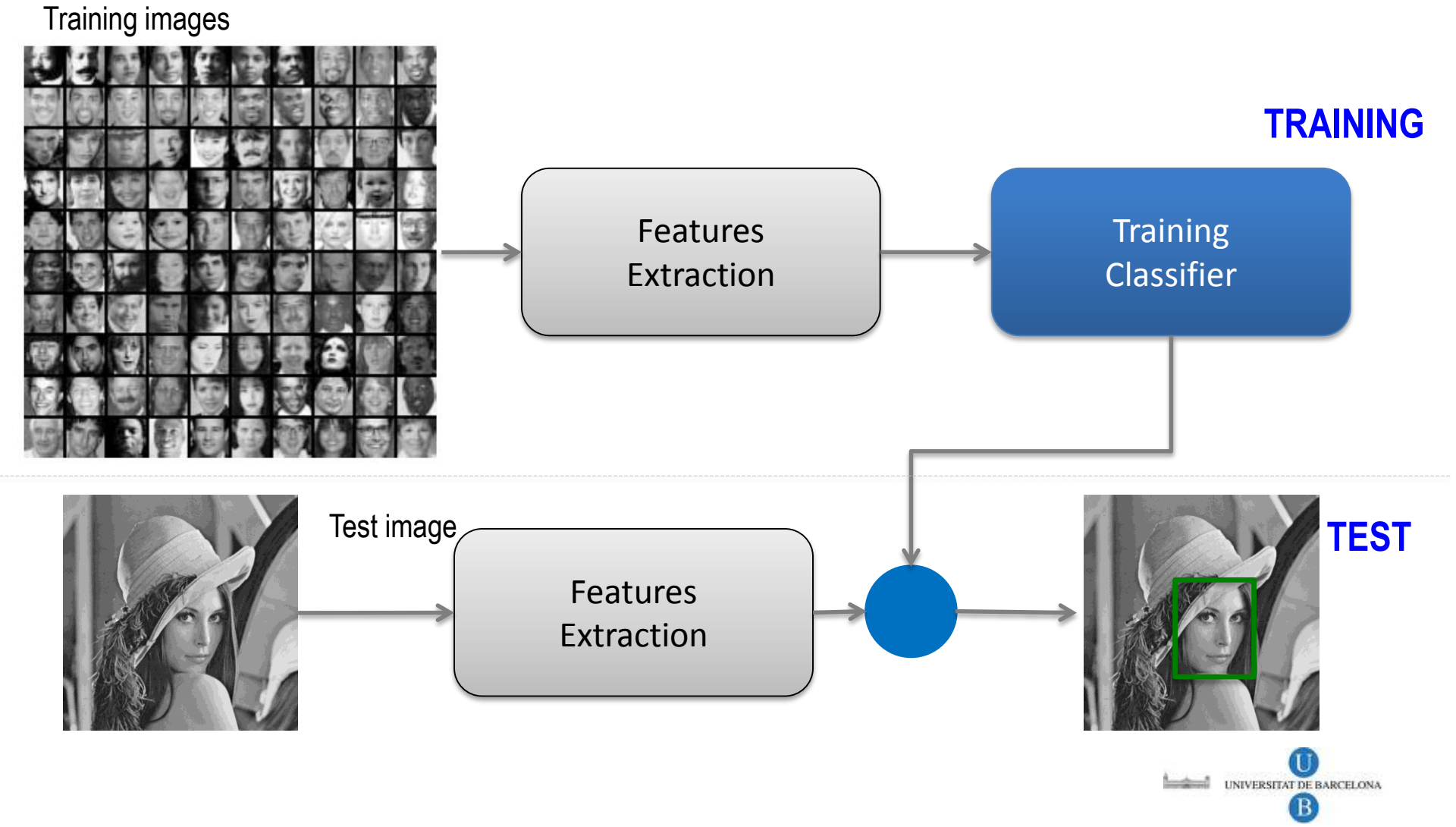
Face detection

Viola & Jones method

- Posed as a standard *pattern recognition problem*
- The main steps of a pattern recognition problem are:

1) Feature extraction from the image
2) Training of a classifier
3) Test of new images using the trained classifier

Pattern recognition scheme



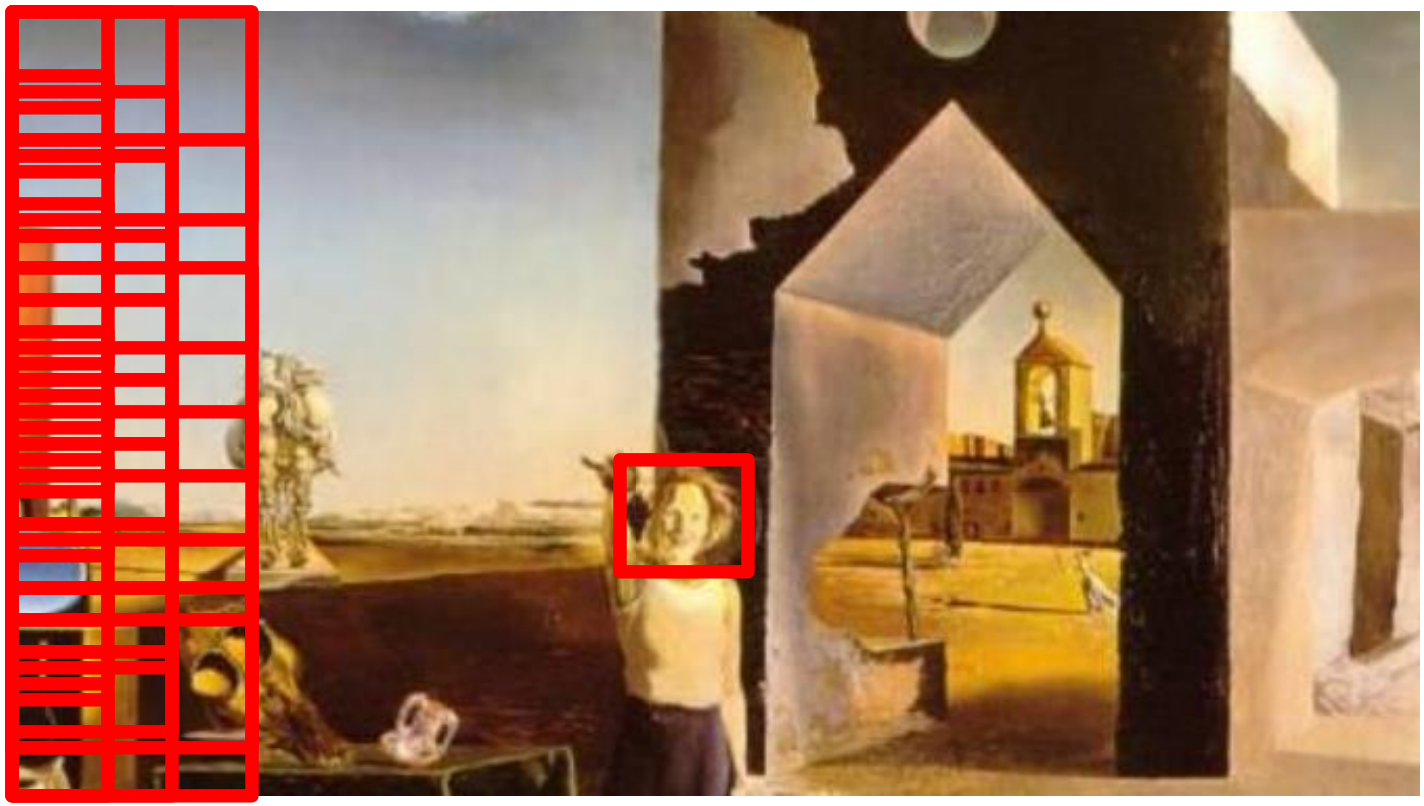
Face detection

Basic concepts for understanding Viola & Jones method:

1) “Rectangular” features (Haar-like features)
2) Integral Images
3) AdaBoost
4) Cascade of clasifiers

Face detection

- Windowing strategy



Face detection

- Basic Concepts

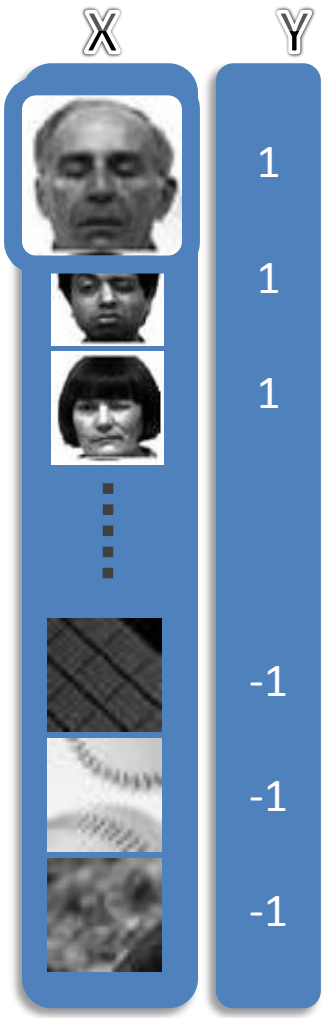
Regions of the image

Hypothesis

Face detection

- Restrictions
  - Large number of regions to analyze
  - Unbalanced problem
    - Most of the regions are from non-face class
    - Only few windows or none have a face

Face detection

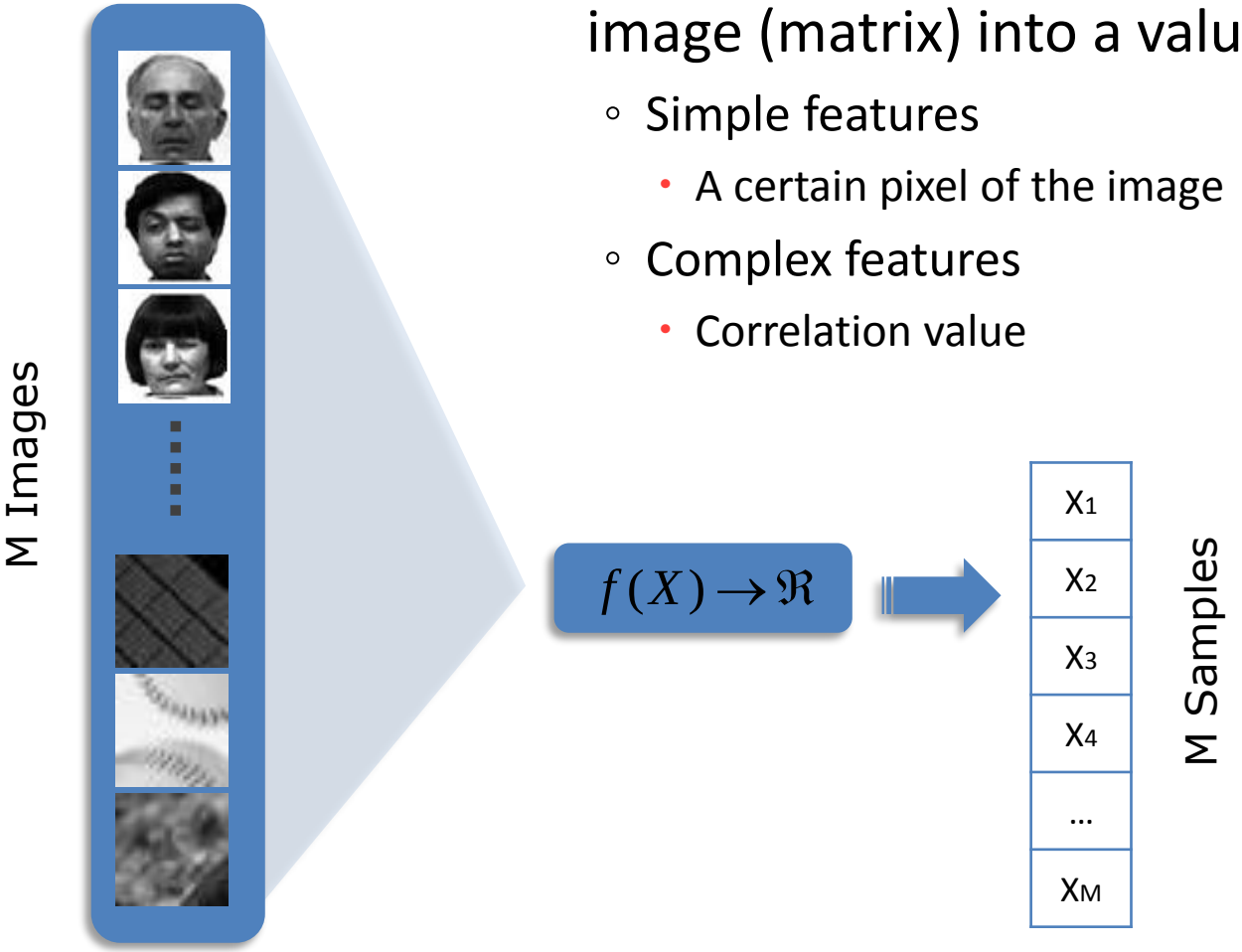


- Samples set
  - Positive and negative image samples (X)
  - Labels (Y)
- An image is a matrix
  - Each position is the illumination level in a certain position of a sensor

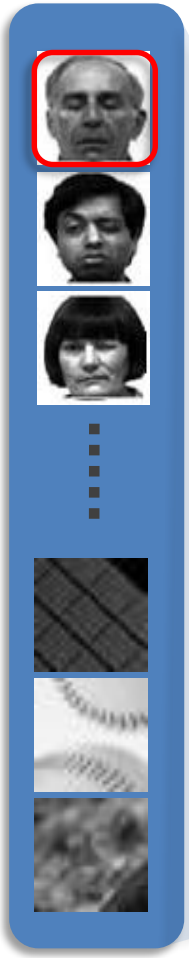
140	140	140	121	121	140
141	142	120	121	121	142
143	121	121	200	200	50
121	121	204	201	200	50
121	204	202	198	250	2
204	203	198	150	250	5

Face detection

- *Feature*: function that transforms an image (matrix) into a value
  - Simple features
    - A certain pixel of the image
  - Complex features
    - Correlation value



Face detection



- *Feature Set*
  - Pixels of the image
  - Family of functions
    - Filter banks
  - …

$$f_1(X) \rightarrow \Re$$
$$f_2(X) \rightarrow \Re$$
$$\dots$$
$$f_N(X) \rightarrow \Re$$

N features

X_{11}	X_{12}	X_{13}	…	…	X_{1N}
X_{21}	X_{22}	X_{23}	…	…	X_{2N}
X_{31}	X_{32}	X_{33}	…	…	X_{3N}
X_{41}	…	…	…	…	X_{4N}
…	…	…	…	…	…
X_{M1}	…	…	…	…	X_{MN}

M Samples

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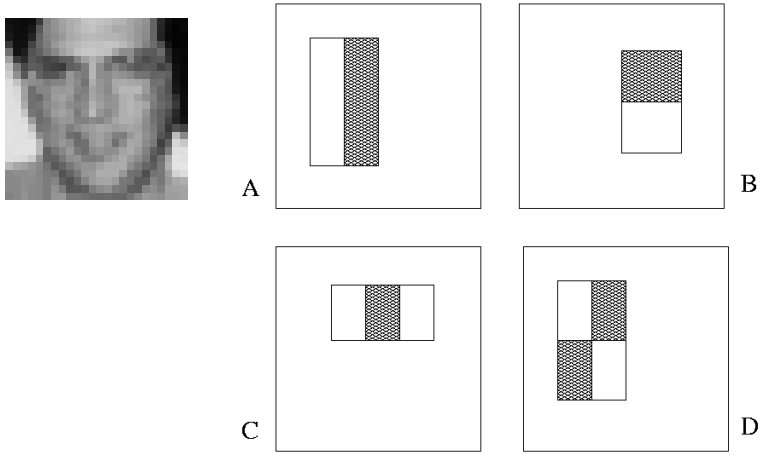
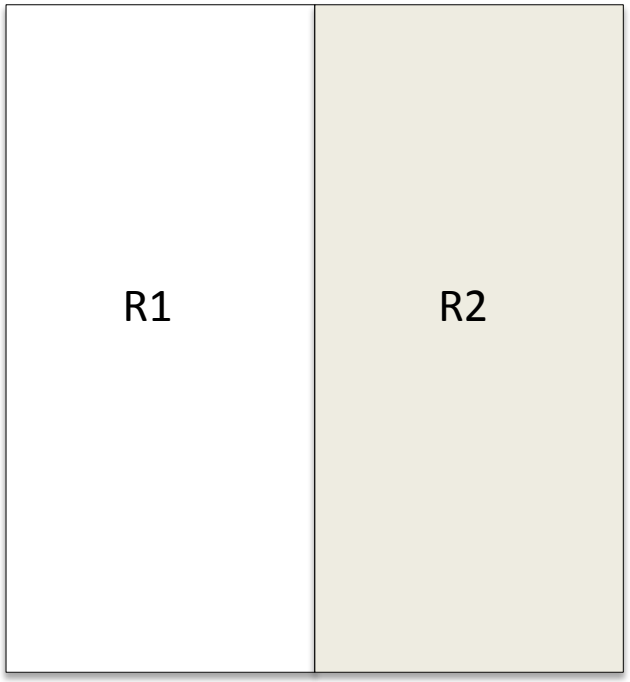
Face detection

- Visual Features
  - Designed to be sensitive to visual artifacts in the objects
    - Contrasted regions
      - Edges
      - Corners
      - …

Face detection

- *Rectangle features*



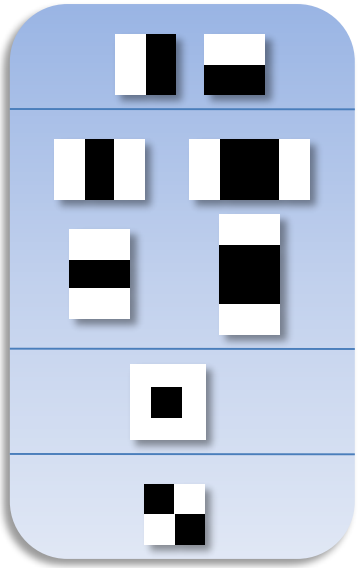


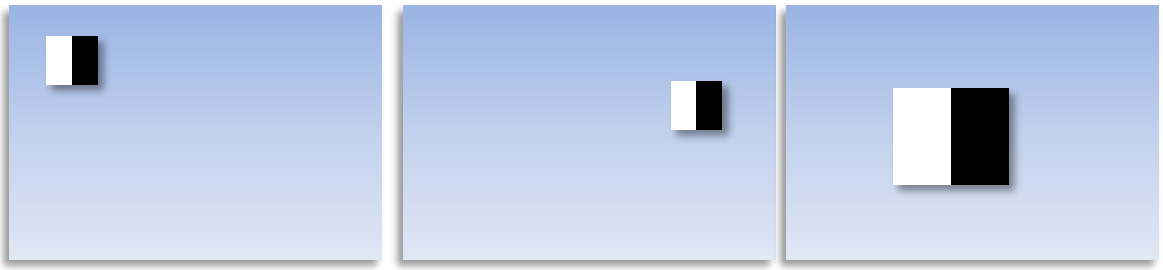
The k-th feature:

$$F_k = \sum_{(i,j)\in R1} I(i,j) - \sum_{(i,j)\in R2} I(i,j)$$

Face detection

- Set of features: different sizes, shapes and positions of the regions wrt the window.
- Region configurations to detect
  - Edges
  - Lines
  - Center-surround structures
- Definition in a training window



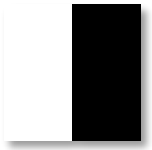


- For a 24x24 detection region, the number of possible rectangle features is over 160,000.

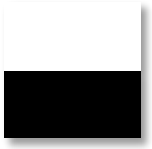
Face detection

- Feature interpretation:

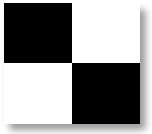
  Which structures of the image are they showing?



Vertical changes



Horizontal changes

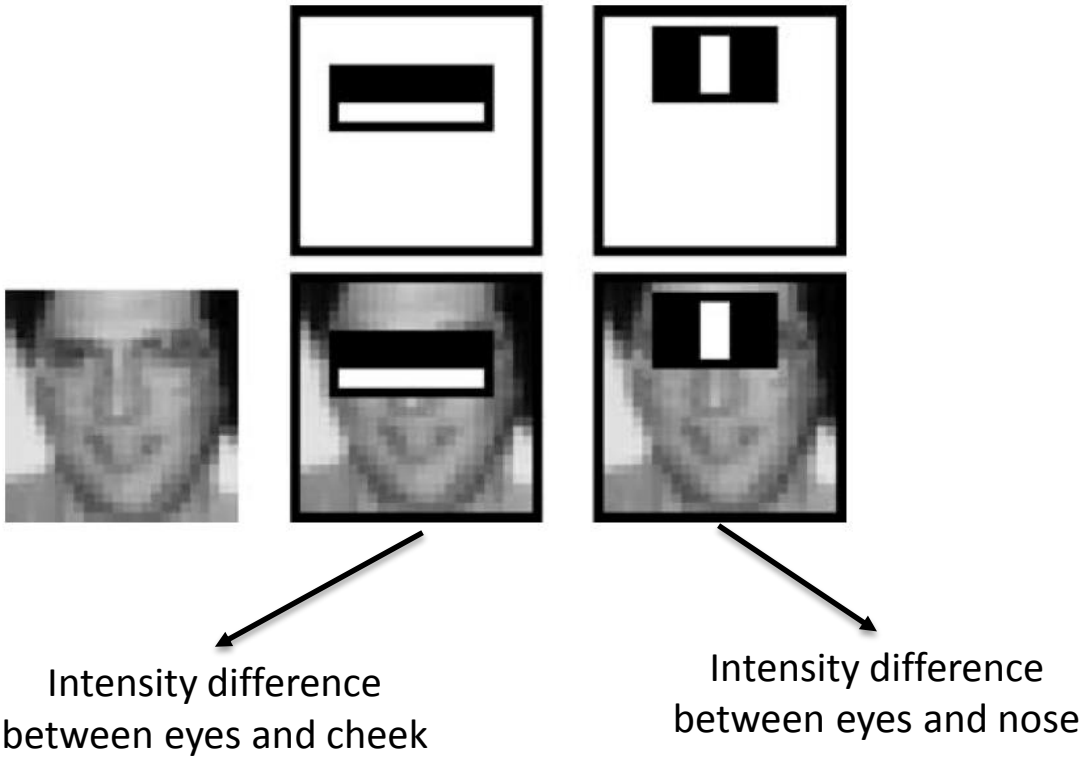


Diagonal changes

Face detection

- Feature interpretation:

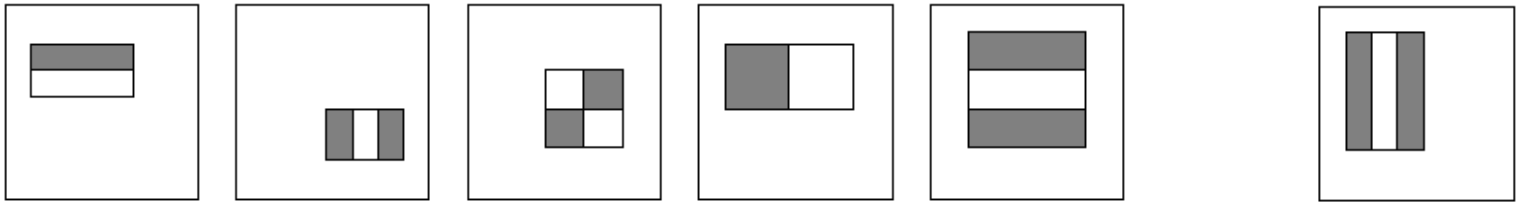
  And apply to faces, which information are they providing?



Face detection

- Feature extraction:

  Given the set of masks, a feature vector of the window is built:



$$\mathbf{X} = [\, F_1, F_2, F_3, F_4, F_5, \ldots, F_K]$$

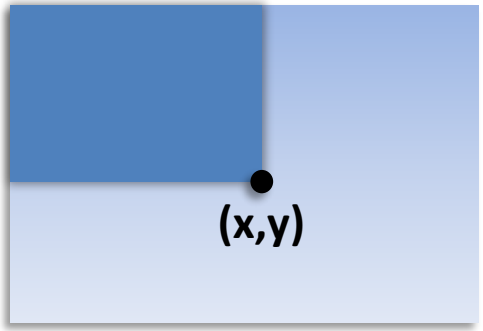
The feature vector describes the content of the window and it is used to train the classifier and to detect the faces.

Face detection

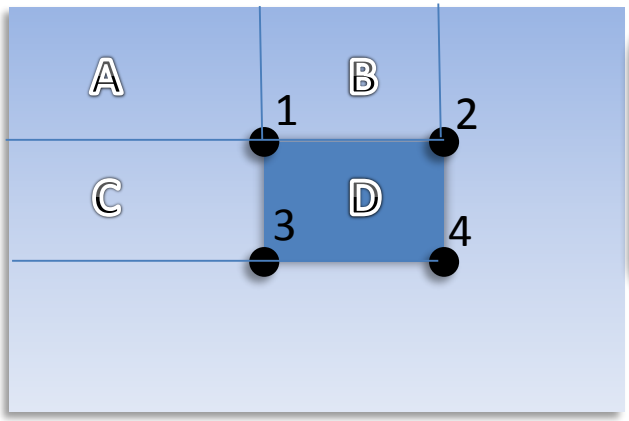
- **Integral Image***:*

  How rectangle features are computed in a fast way:

$$II(x,y) = \sum_{i=1}^{x}\sum_{j=1}^{y} I(i,j)$$



We use it to efficiently compute rectangle areas:



$$\begin{aligned} D &= 1+4-(2+3) \\ &= A+(A+B+C+D)-(A+B+A+C) \\ &= D \end{aligned}$$

Any rectangular sum can be computed in constant time.

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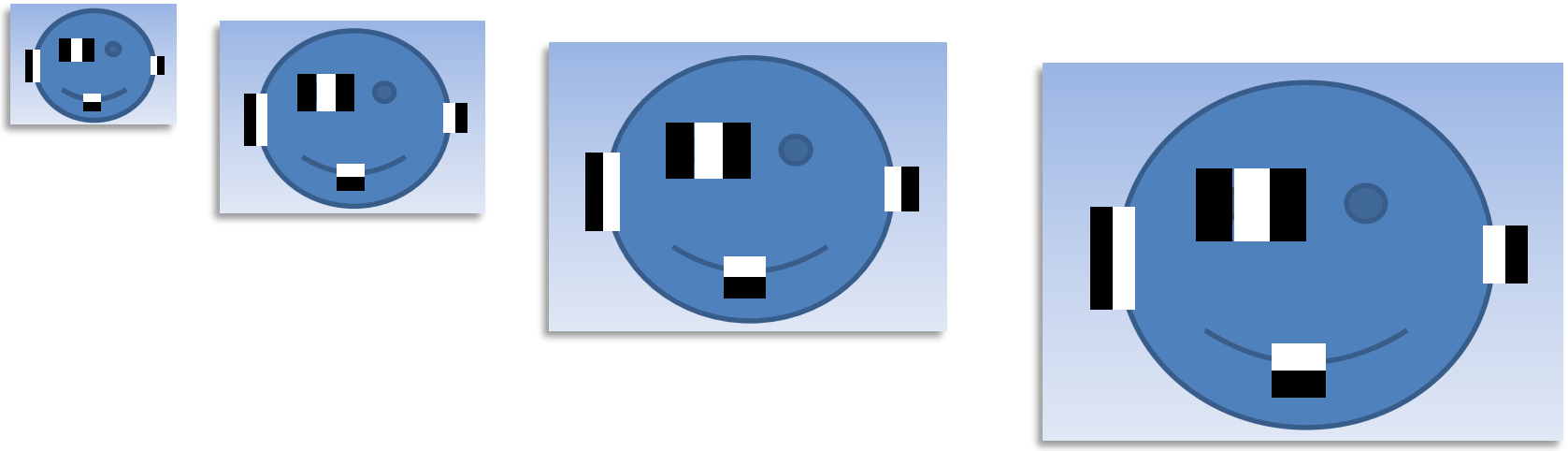
Face detector

In MATLAB:

- `I = imread('cameraman.tif');`
- `S = cumsum(cumsum(double(I),2));`

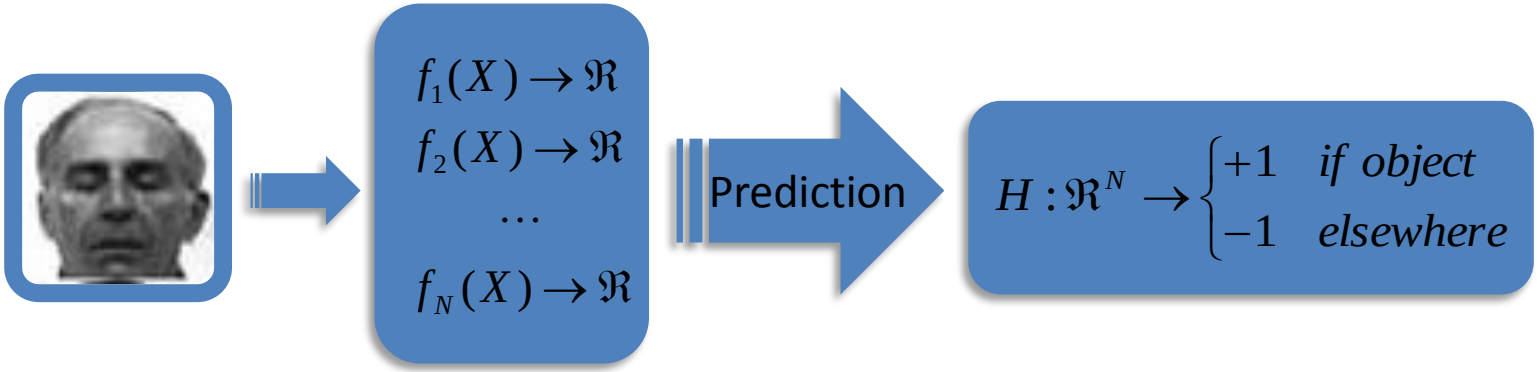
Face detection

- Multi-scale detection by means of regions scaling
  - Just scale the parameters of the features

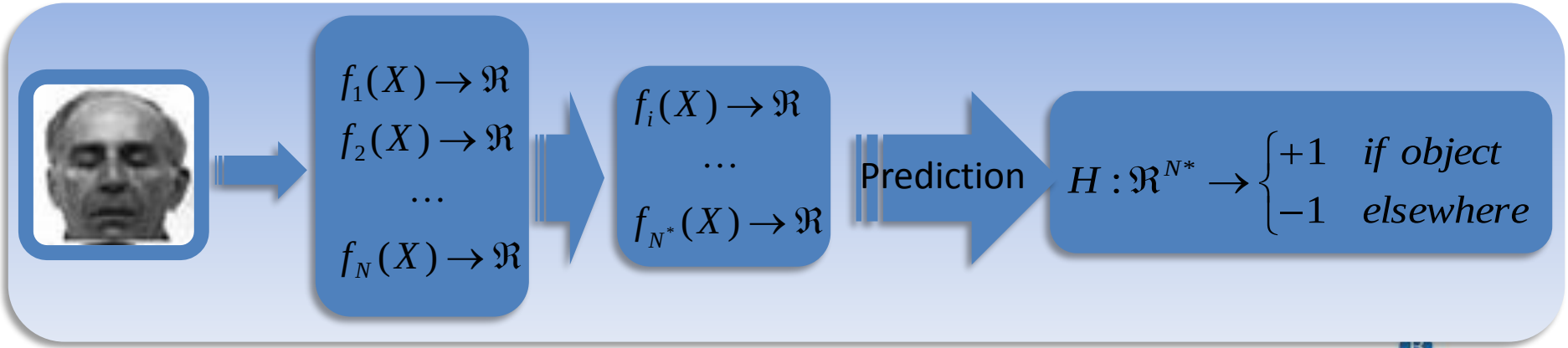


Face detection

- Given an image (region), predicts its class
  - Using all the N features



  - Using a subset of N^* features: **Feature selection**



Face detection

- Feature selection
  - Remove noisy features
  - Time restriction
    - Repetitions of the method (Object detection)
    - Large feature sets
- Classification algorithm:

  AdaBoost (Adaptive Boosting)
  - Feature selection
  - Strong classifiers from simple classifiers
    - Ensemble of classifiers

Face detection

AdaBoost

- Introduced by Freund & Schapire in 1999.

- Combine several weak classifiers to build a single strong classifier

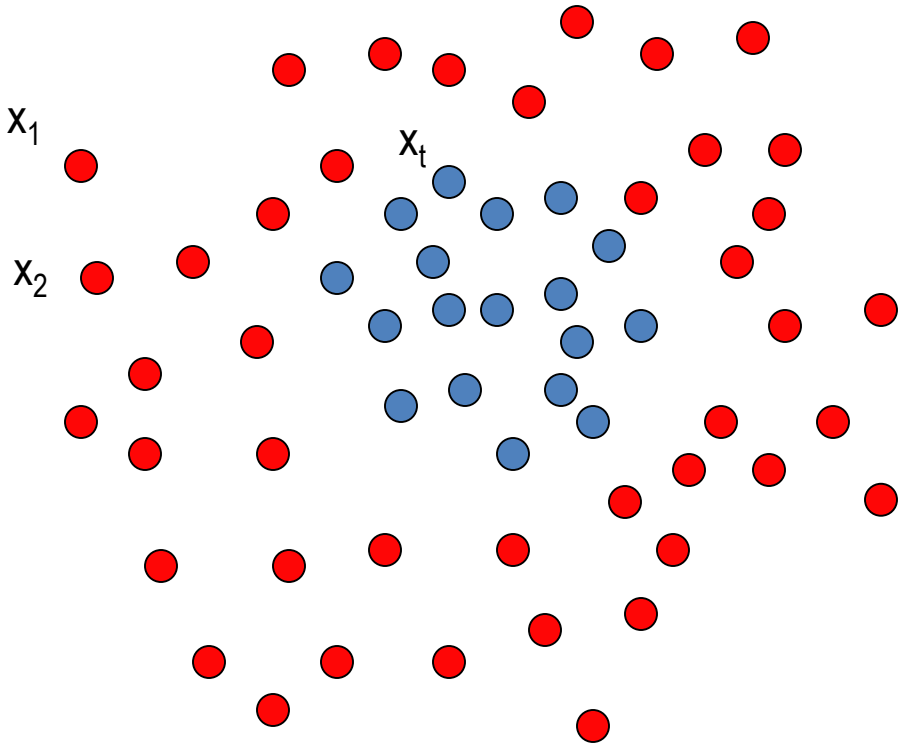
  >> BOOSTING

- Weak classifiers are defined in each iteration and are devoted to misclassified examples

  >> ADAPTIVE

Face detection

AdaBoost



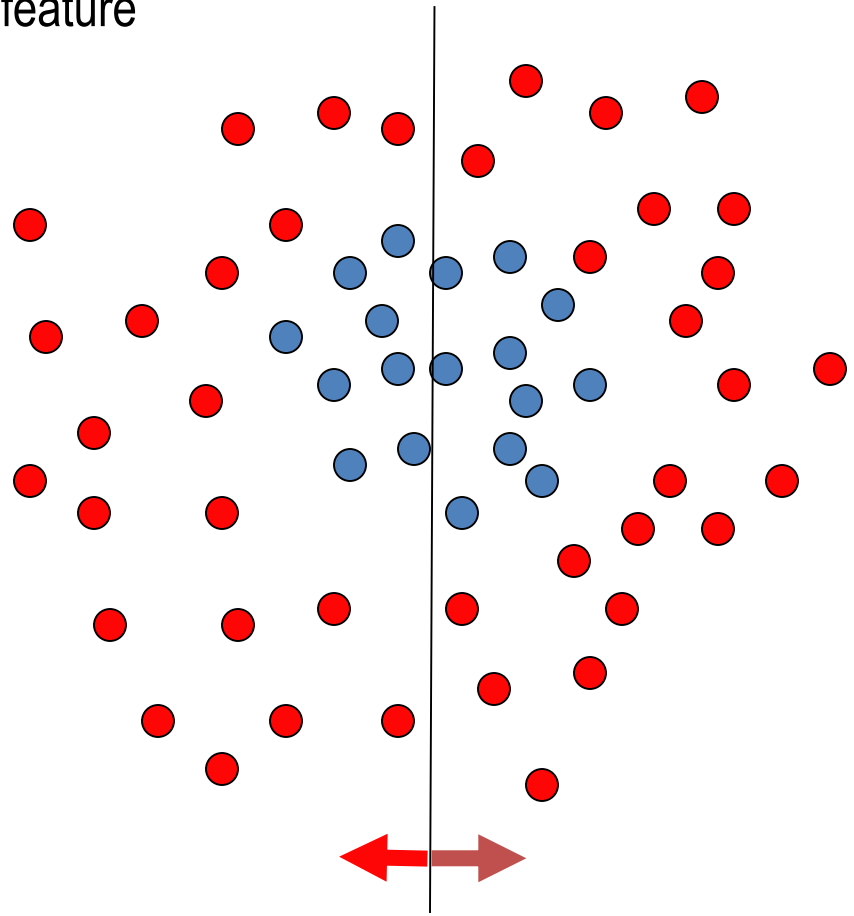
Each point of the training set has the label of the class:

$$y_t = \begin{cases} +1 \text{ (●)} \\ -1 \text{ (●)} \end{cases}$$

And the initial weight: $w_t = 1/N$,
where N = number of points

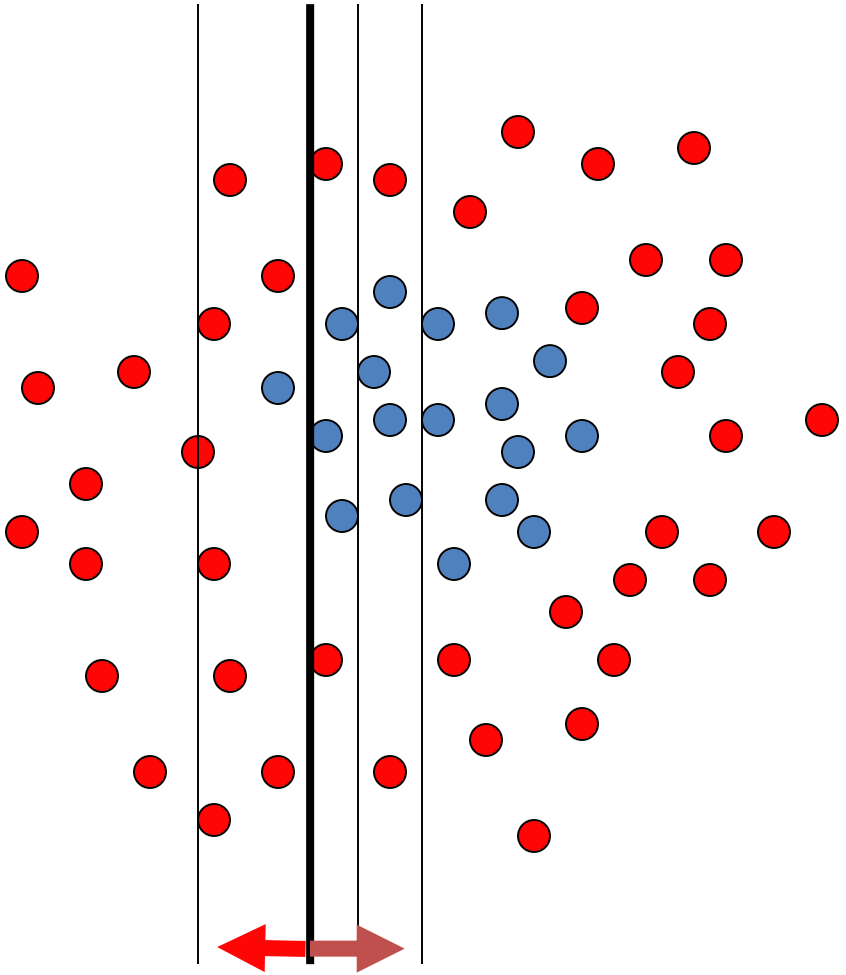
AdaBoost

Look for the weak classifier that achieves the lowest weighted training error based on one rectangle feature



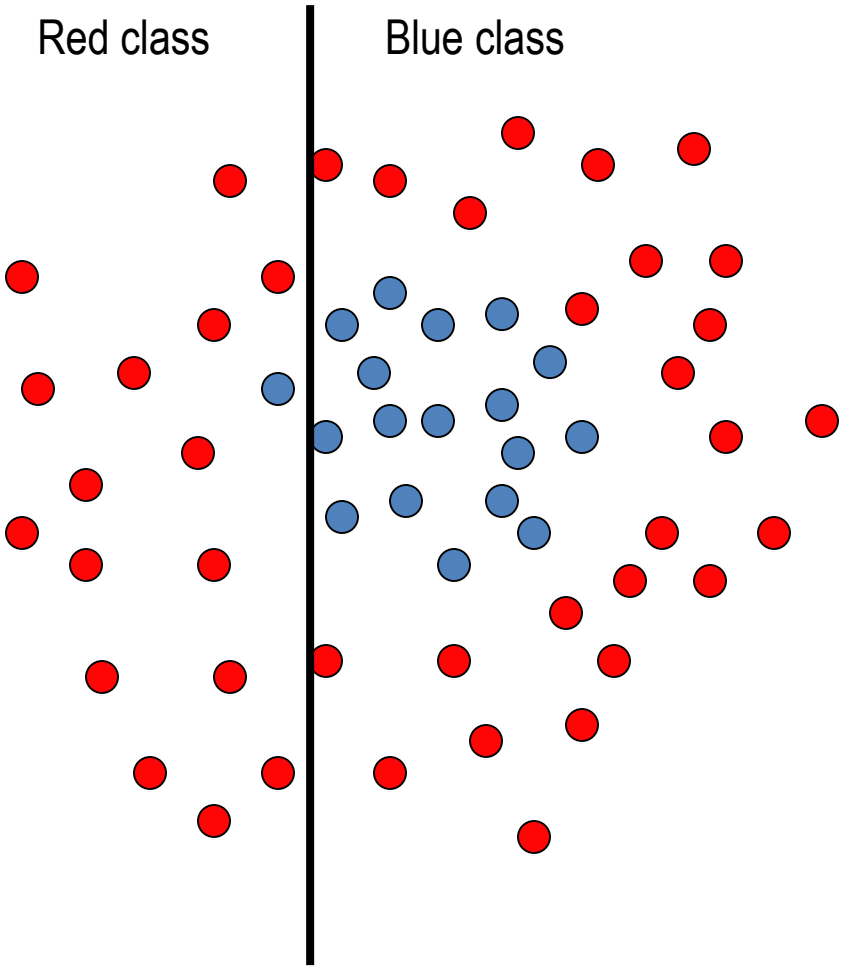
h => p(error) = 0.5 random

AdaBoost



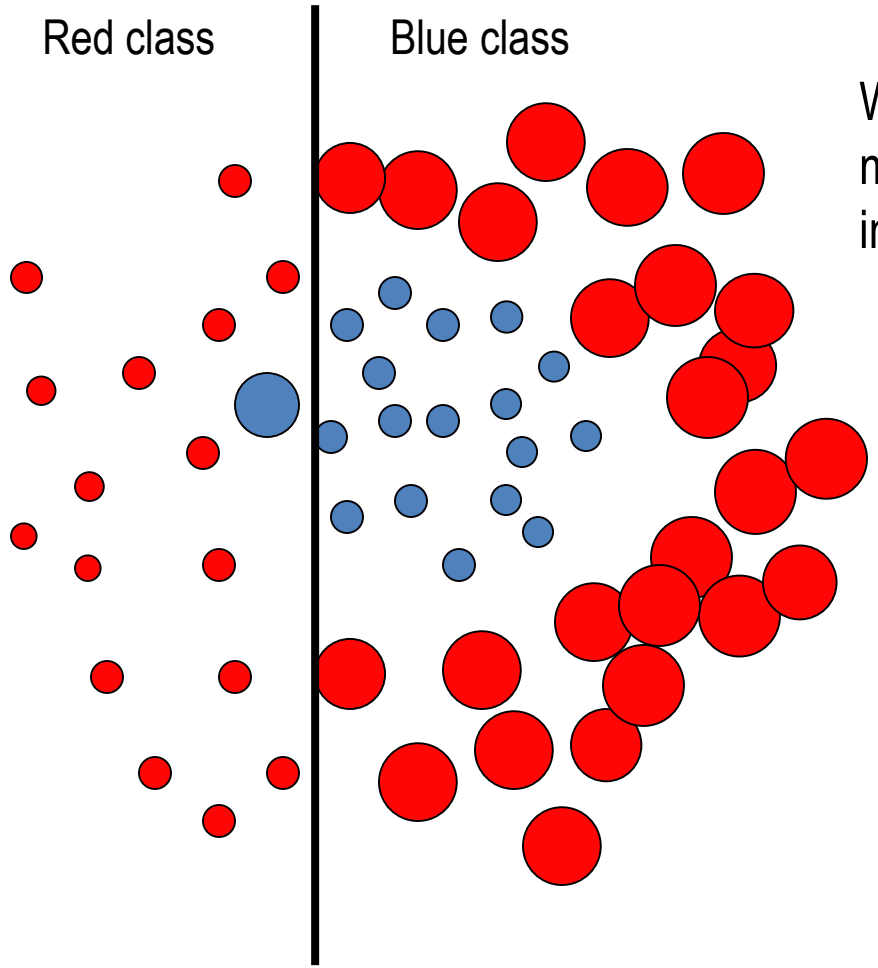
This one seems the best

AdaBoost



This one seems the best

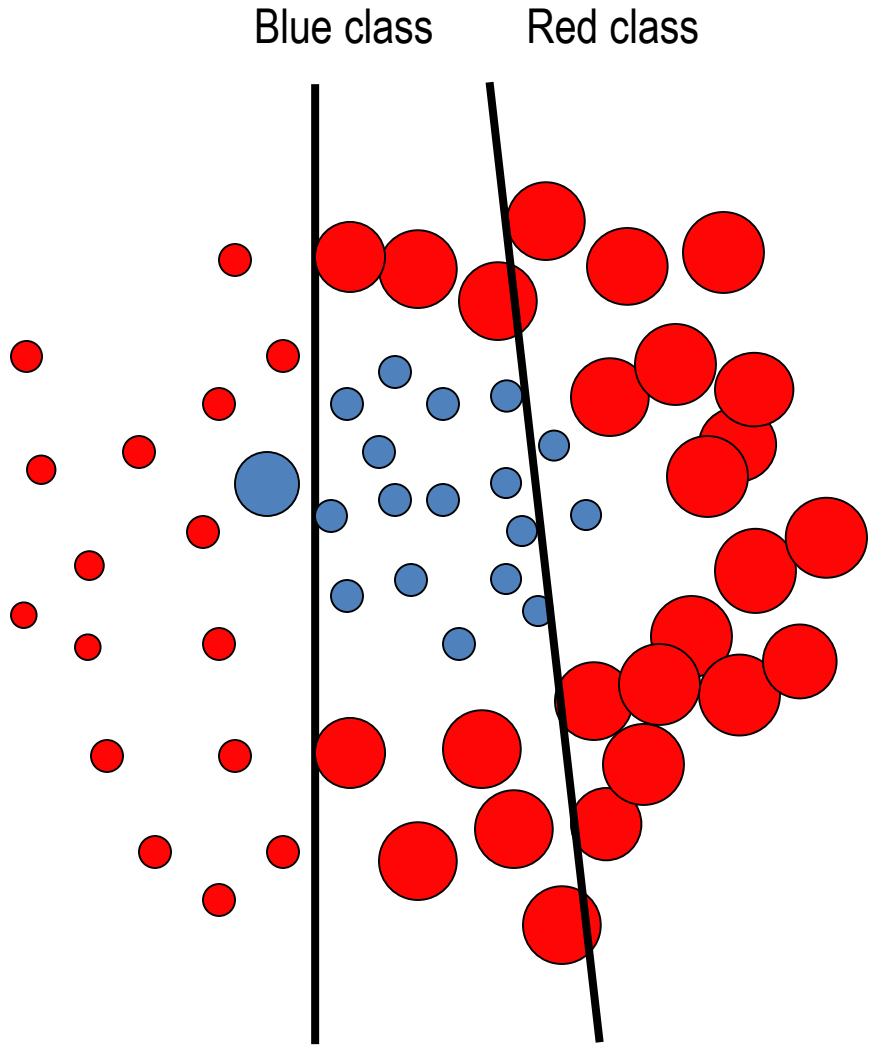
AdaBoost



Weights of the misclassified points increase.

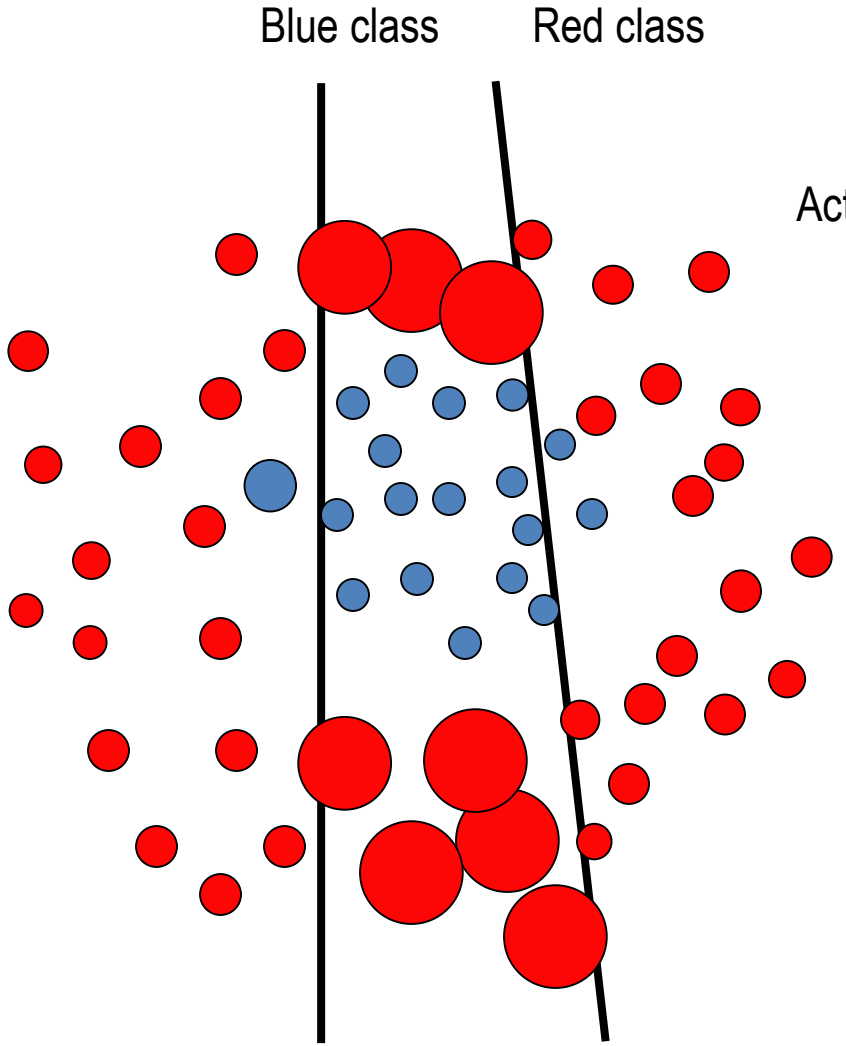
Consider the new problem and look for the best weak classifier

AdaBoost



This one seems the best

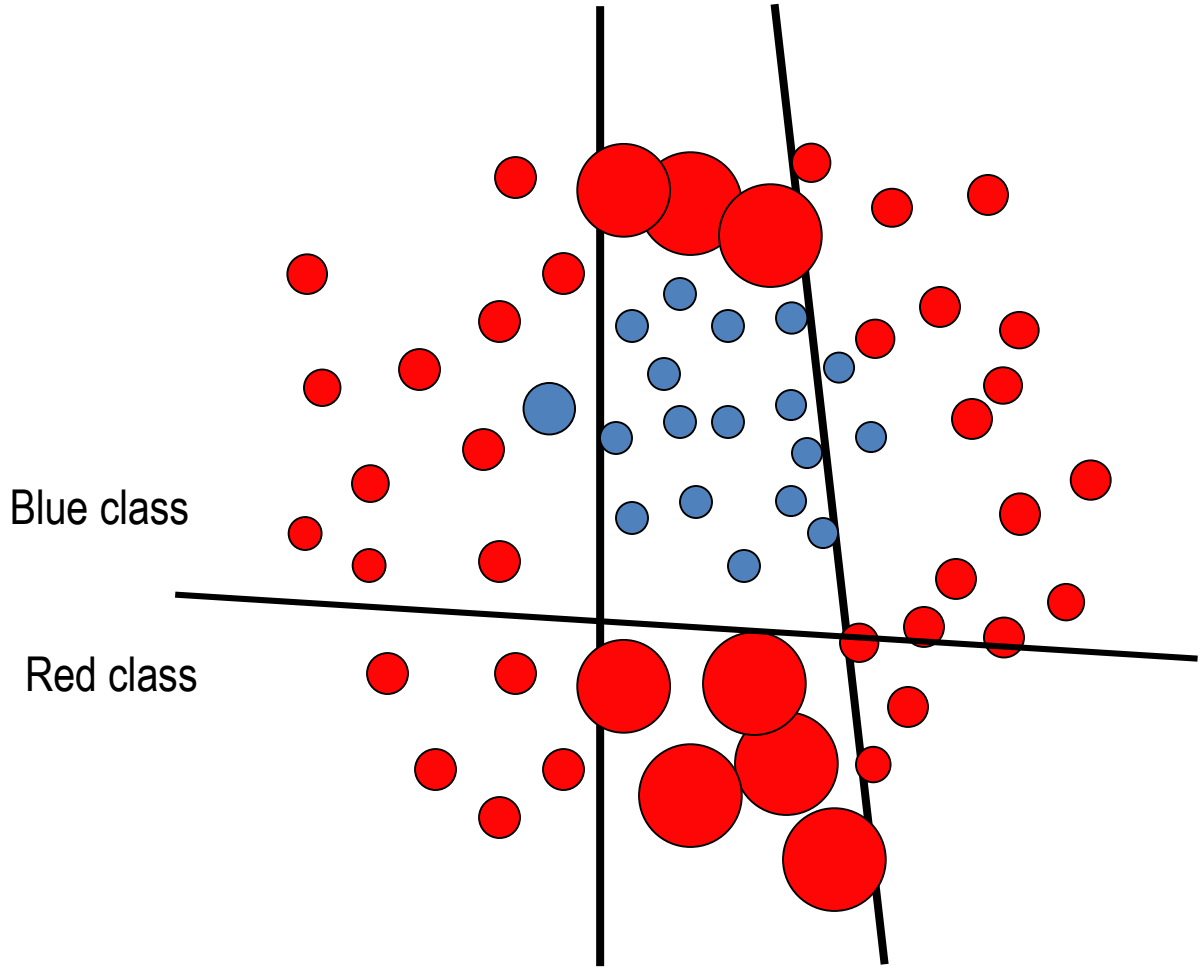
AdaBoost



Actualize the weights

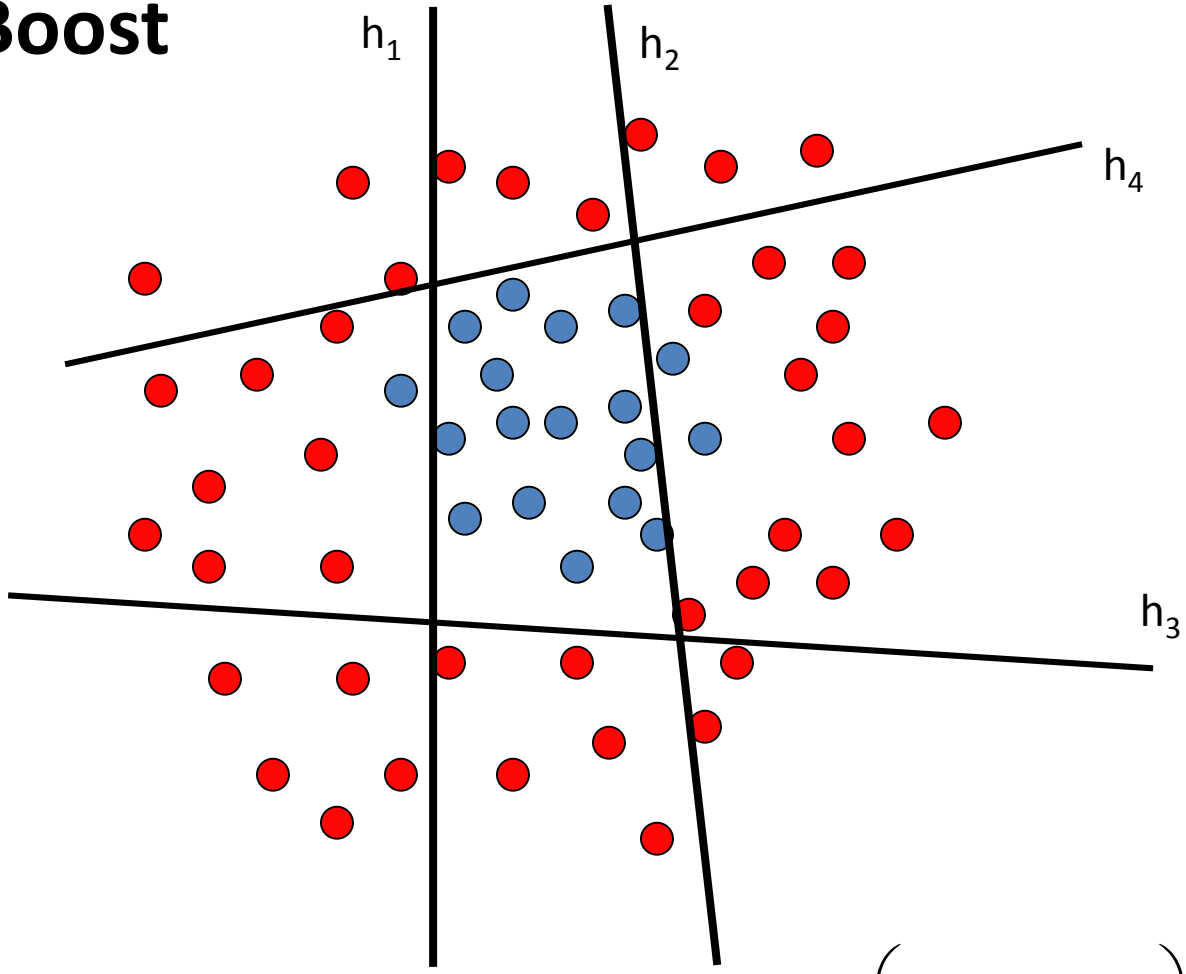
Consider the new problem and look for the best weak classifier

AdaBoost



Face detection

AdaBoost



The strong classifier H (final) is the sum of all the weak classifiers:

$$H_{final}(x) = sign\left(\sum_t w_t h_t(x)\right)$$

Face detection

AdaBoost revision

- Weak classifier/hypothesis
  - Decision stumps
    - 1 feature + Threshold

X = 

$$f_i(X) \rightarrow \Re$$

$$h(X) = \begin{cases} +1 & if \ \ f(X) \geq Thr \\ -1 & elsewhere \end{cases}$$

- Strong classifier/hypothesis

X = 

$$h_1(X) \rightarrow \{-1,+1\}$$
$$h_2(X) \rightarrow \{-1,+1\}$$
$$\ldots$$
$$h_m(X) \rightarrow \{-1,+1\}$$

$$H(X) = sign\left(\sum_{i=1}^{m} h_i(X)\right)$$

Face detection

AdaBoost revision

- Weighting strategy
  - Focus on **difficult samples** by adding a weight to each sample:

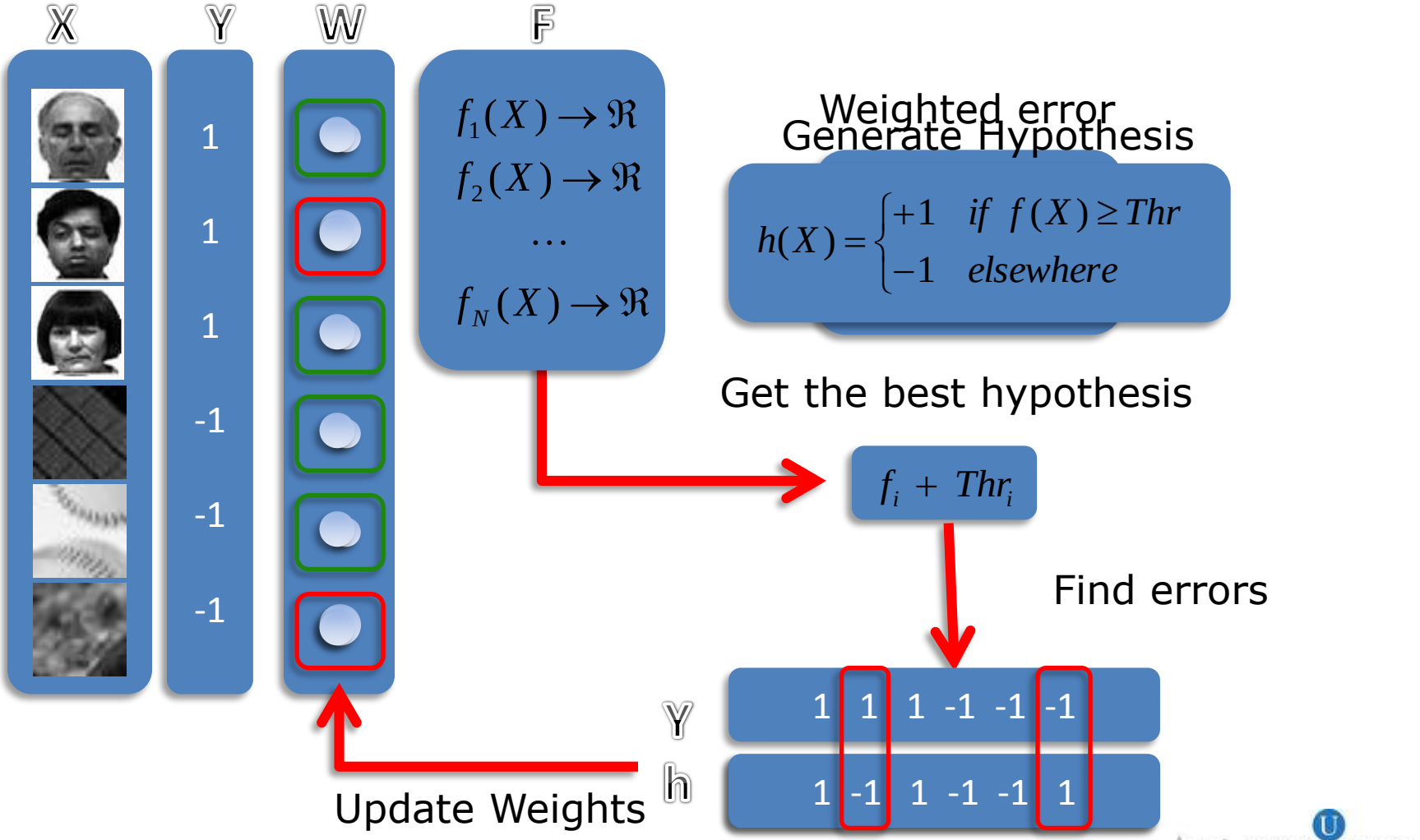
$$X = \{x_i \,|\, i = 1:N\}$$
$$Y = \{y_i \,|\, i = 1:N\}$$
$$W = \{\omega_i \,|\, i = 1:N\}$$
$$\sum_{i=1}^{N} \omega_i = 1$$

- Weak Learner
  - Find the weak hypothesis that minimizes the weighted error:

$$\varepsilon = \sum_{h(x_i) \neq y_i}^{N} \omega_i$$

Face detection

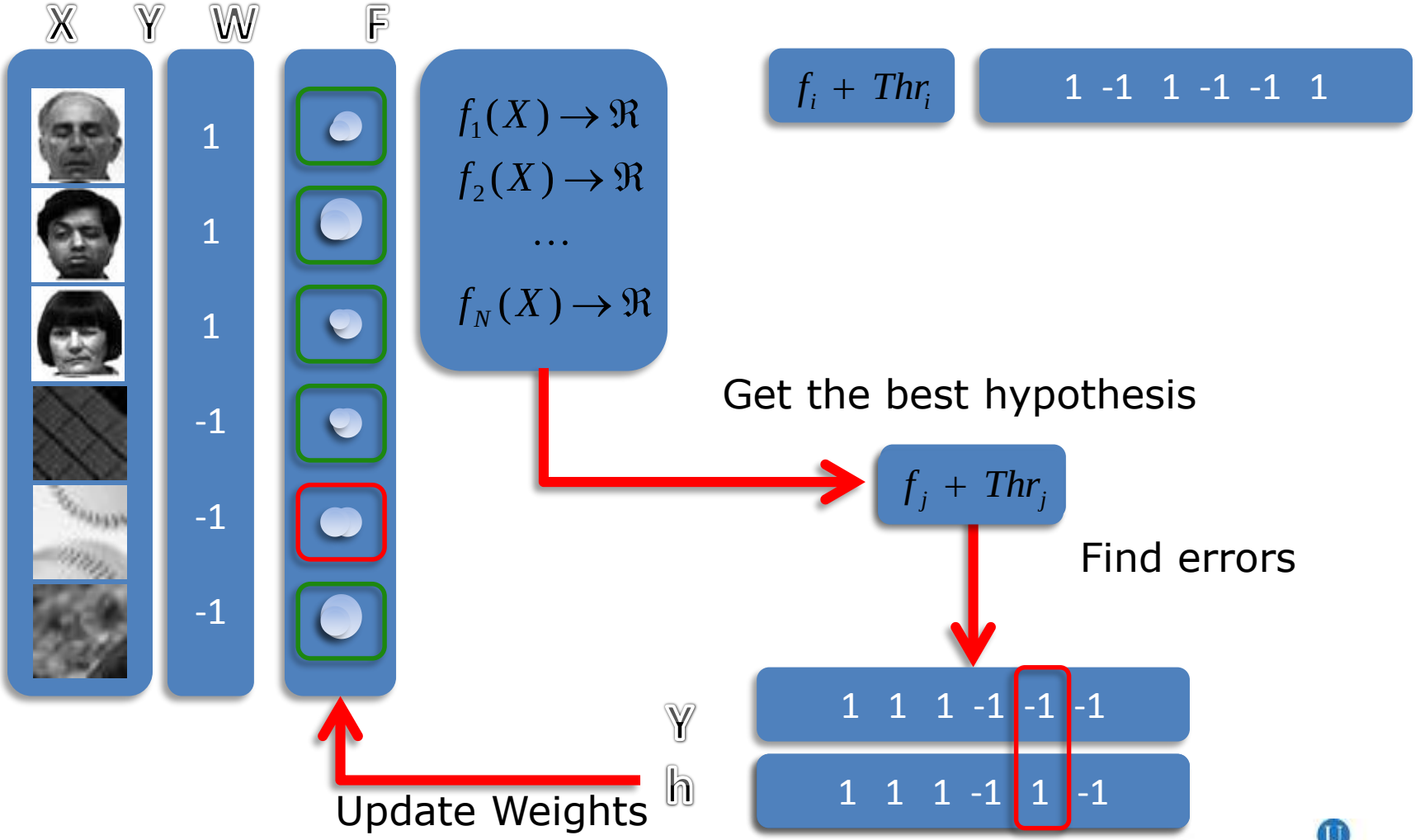
AdaBoost revision



First Iteration

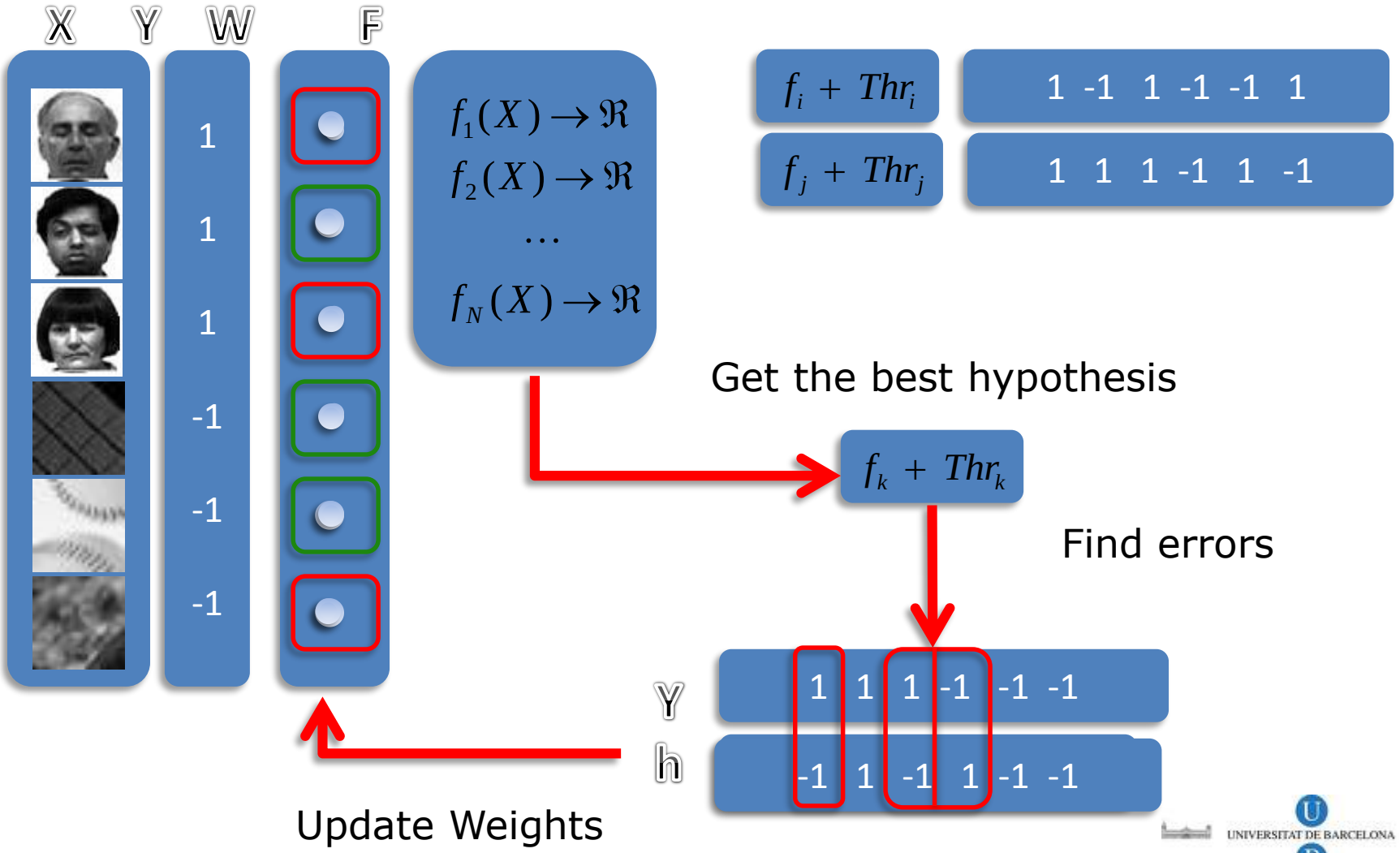
Face detection

AdaBoost revision



Second Iteration

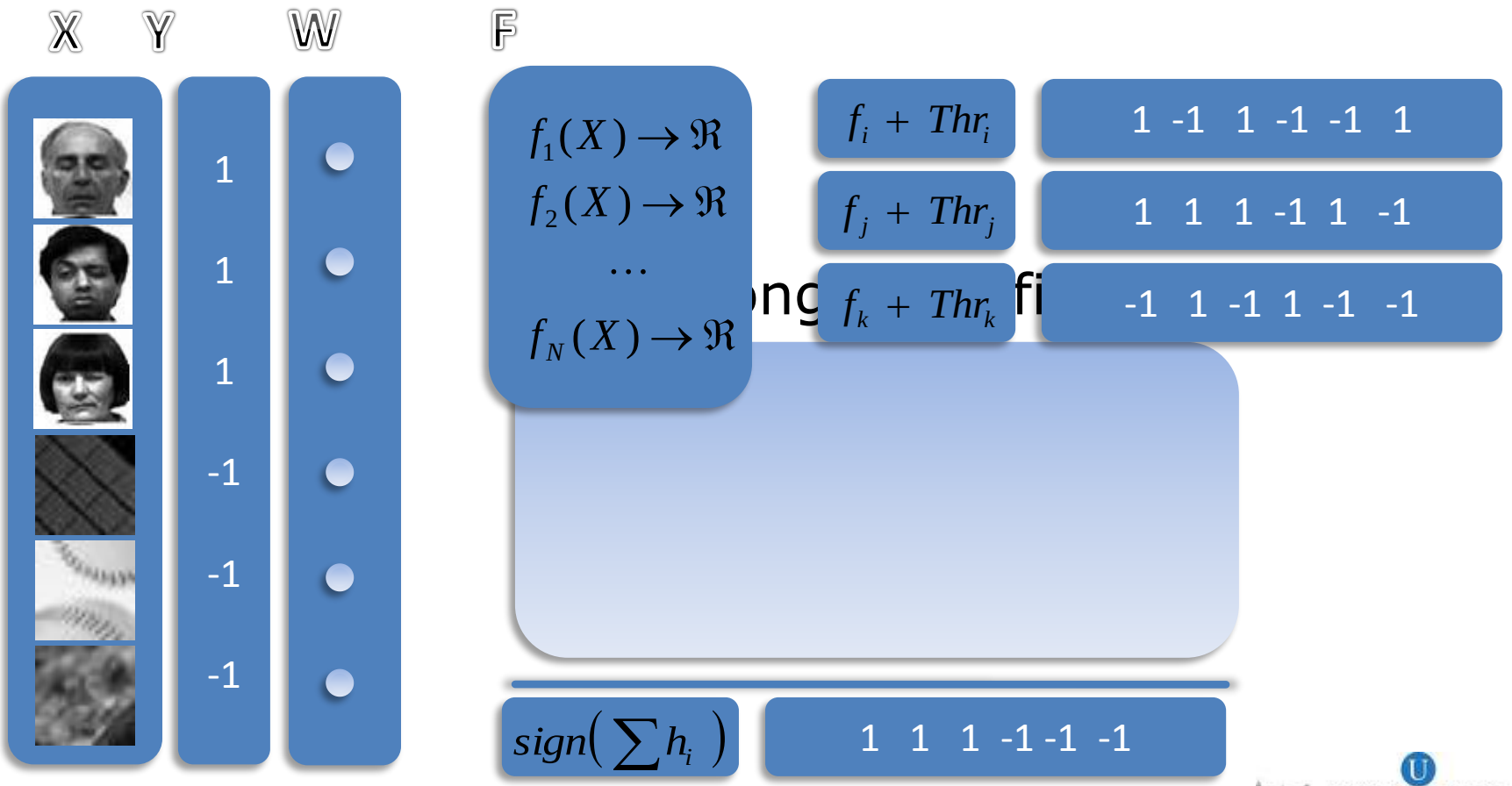
Face detection



Third Iteration

Face detection

AdaBoost revision



Face detection

AdaBoost revision

Strong Classifier

Detector

$f_i + Thr_i$

$f_j + Thr_j$

$f_k + Thr_k$

Hypothesis

$$h(X) = \begin{cases} +1 & if \ f(X) \geq Thr \\ -1 & elsewhere \end{cases}$$

Final decision

$$H(X) = sign\left(\sum_{i=1}^{m} h_i(X)\right)$$

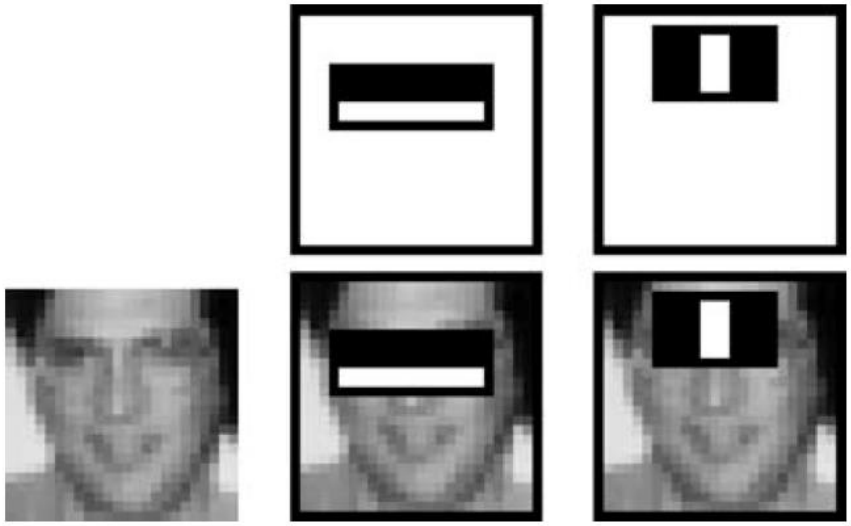
Input image

$h_1 + h_2 + h_3 = H$

Face detection

- After some experiments:

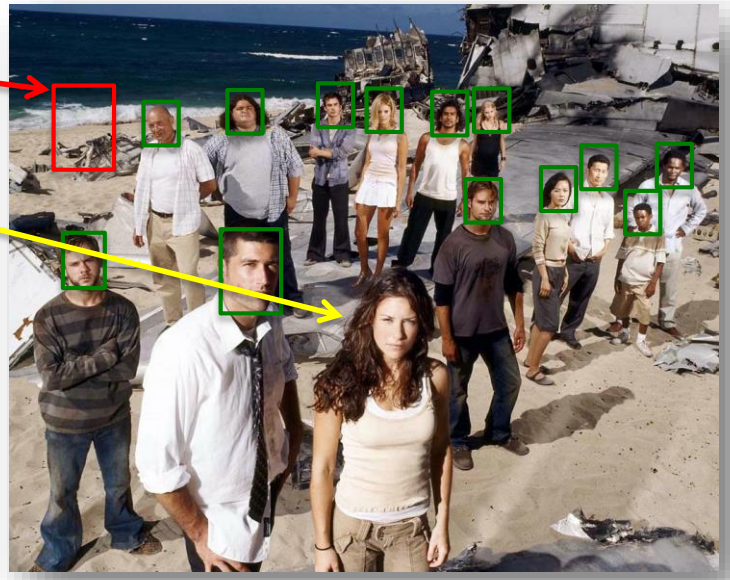
  The initial rectangle features selected by Adaboost are:



Face detection

In general, detection error is measured in:

- **False Positive** (FP)
- **False Negative** (FN)



Viola & Jones method accepts FP, but not a FN.

→**Faces can not be lost!!**

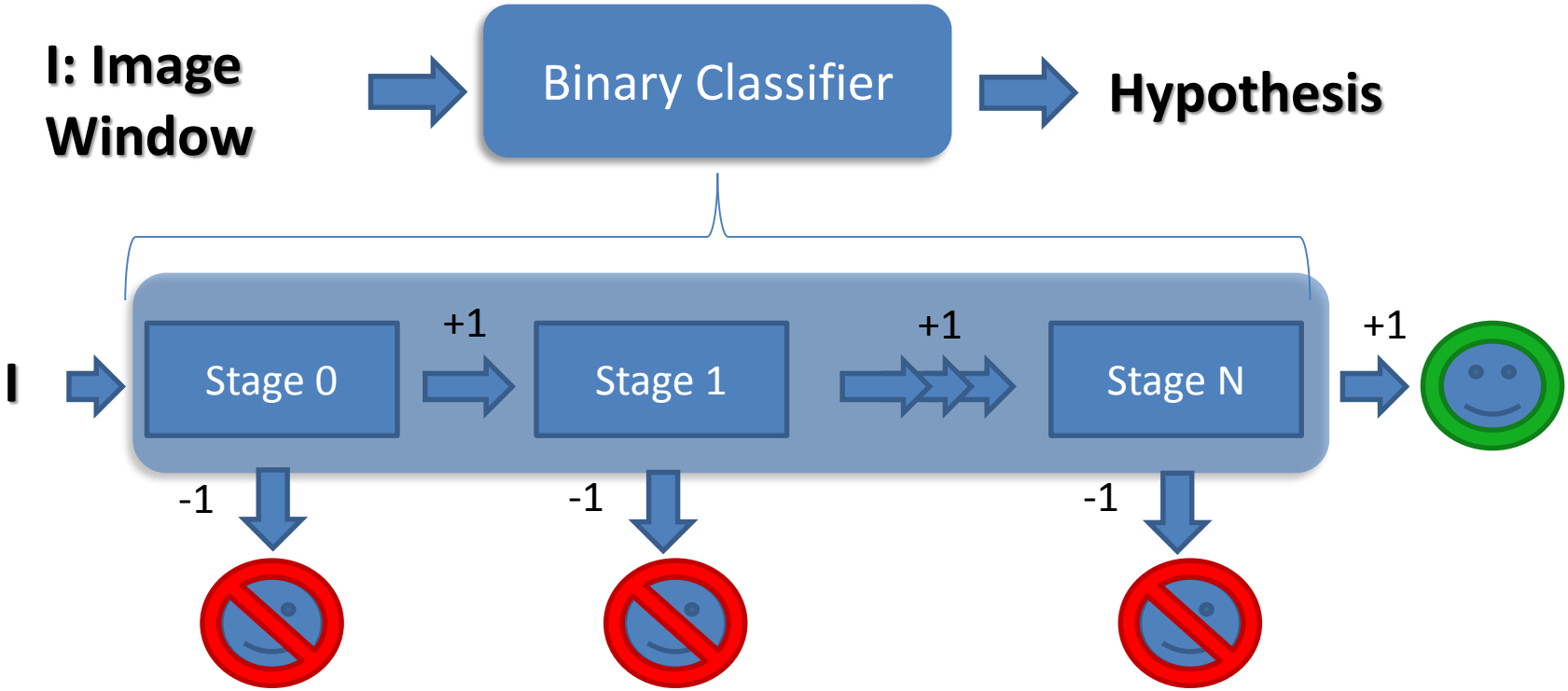
→**CASCADE**

Face detection

Cascade of classifiers

- Method to speed-up the detection process. Typical when windowing is used.
- We start with simple classifiers which reject many of the negative sub-windows while detecting almost all positive sub-windows
- Each stage only process regions classified as faces by the previous stages.
  - Number of regions processed by each stage decrease exponentially
  - Similarity between faces/non-faces regions increments each stage, incrementing the difficulty of the problem

Face detection



#windows	Stage 0	Stage 1	Stage 5	Stage 10	Stage 15
FA = 0.5	1.000.000	500.000	31.250	976	30
FA = 0.4	1.000.000	400.000	10.240	105	1

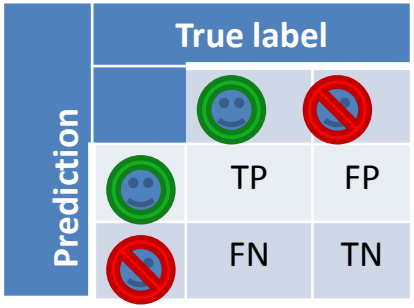
Face detection

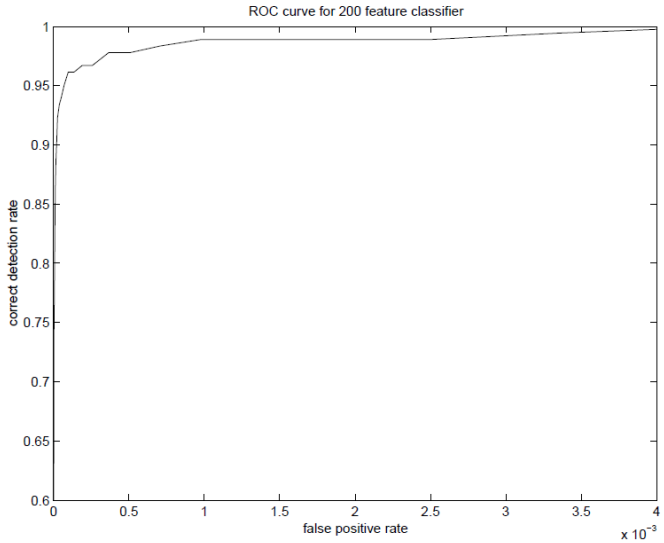
Basic evaluation concepts:

- Proportion of correct: PC=(TP+TN)/Total
- Probability of detection (POD) or Detection Rate (DR):

  DR = TP/(TP+FN) = TP/P
- False alarm rate (FA) or False Positive rate:

  FA = FP/(TN+FP) = FP/N





Receiver operating characteristic (ROC) curve

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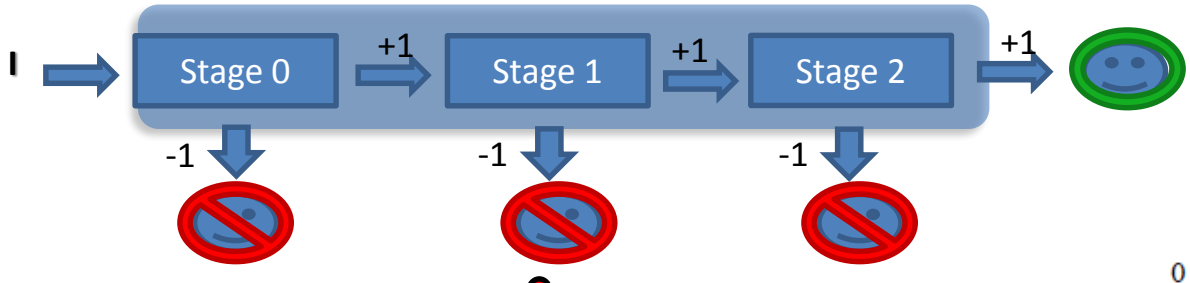
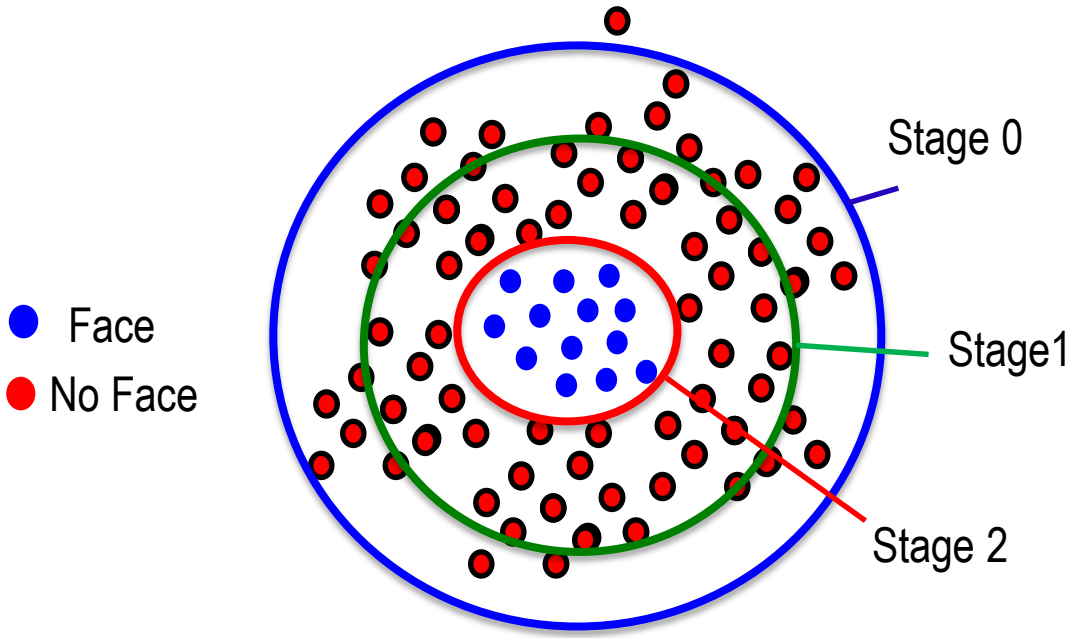
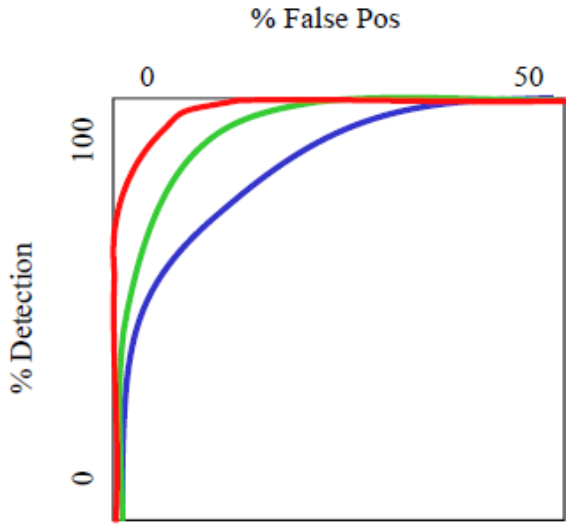
Face detection

- Chain classifiers that are progressively more complex and have lower false positive rates







Face detection

Criteria for cascade design:

1) Each classifier of the cascade is an AdaBoost
2) The first classifier C_1 is the simplest one, and it classifies only based on a **single feature**
3) Following classifiers are more complex, and use more features, to refine the results of previous classifiers.
4) For every classifier C_i (during training stage), we decide the value of **False Alarm Rate** which we want to obtain and add features while we do not obtain the indicated value.
5) If the False Alarm Rate for the output of C_i is not enough, we add a new classifier C_{i+1}
6) Use false positives from current stage as the negative training examples for the next stage

Face detection

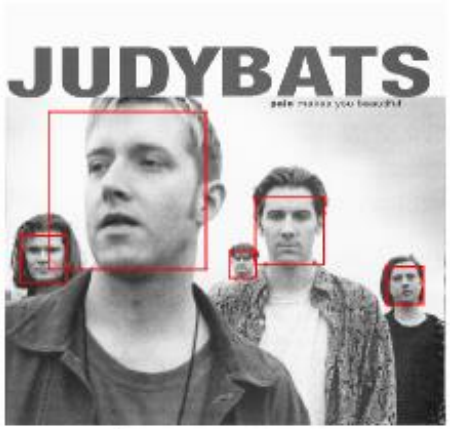
- Viola & Jones prepared their final Detector cascade:
  - 38 layers (stages), 6060 total features included
  - 1st classifier- layer, 2-features
    - 50% FP rate, 99.9% TP rate
  - 2nd classifier- layer, 10-features
    - 20% FP rate, 99.9% TP rate
  - Next 2 layers 25-features each, next 3 layers 50-features each and so on…
- Tested on the MIT+MCU test set
- A 384x288 pixel image on a PC (dated 2001) took about 0.067 seconds

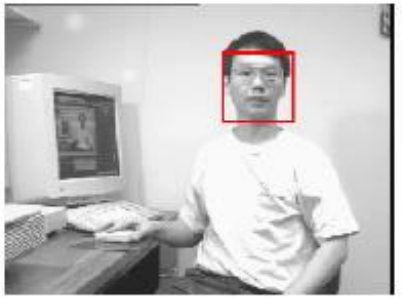
	False detections:							
Detector:	10	31	50	65	78	95	167	422
Viola-Jones	76,1%	88,4%	91,4%	92,0%	92,1%	92,9%	93,9%	94,1%
Rowley-Baluja-Kanade	83,2%	86,0%	-	-	89,2%	89,2%	90,1%	89,9%
Schneiderman-Kanade	-	-	-	94,4%	-	-	-	-

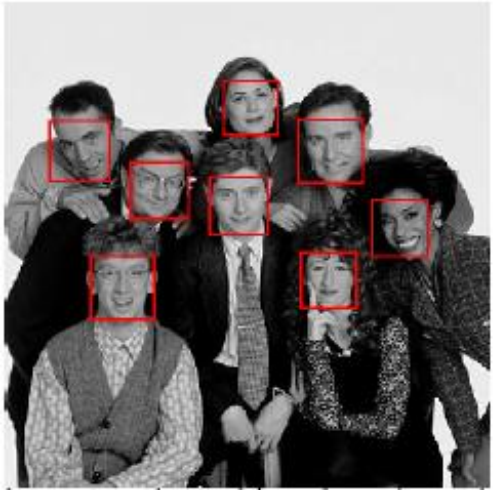
Detection rates for various numbers of false positives on the MIT+MCU test set containing 130 images and 507 faces (Viola & Jones 2002)

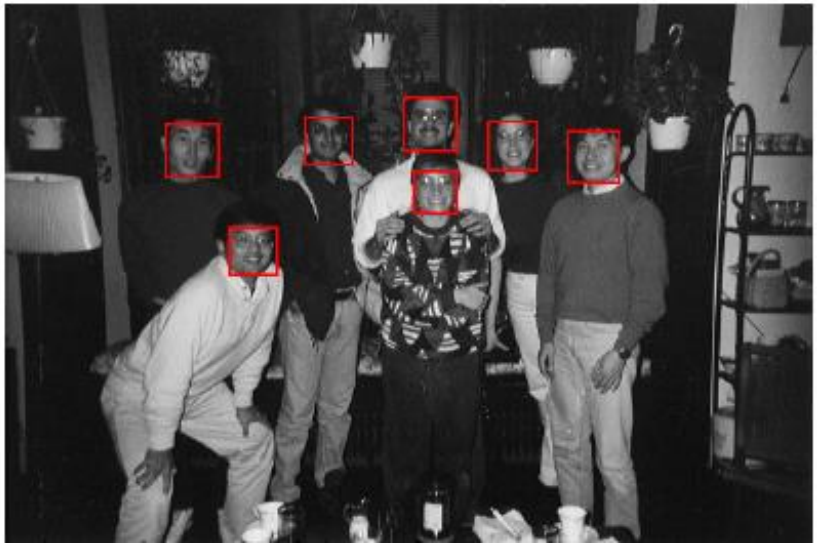
Face detection

Results









Summary

- Viola & Jones algorithm is a method of automatic detection of faces in an image.
- **Rectangle Haar-like features** provide a description of the window features of the image
- By means of **integral images**, the rectangle features can be computed fast!
- Rectangle features are robust in front of noise
- **AdaBoost** is used for feature selection and classification
- Cascade of classifiers allows to obtain a very low false negative rate detecting faces at **real-time**!

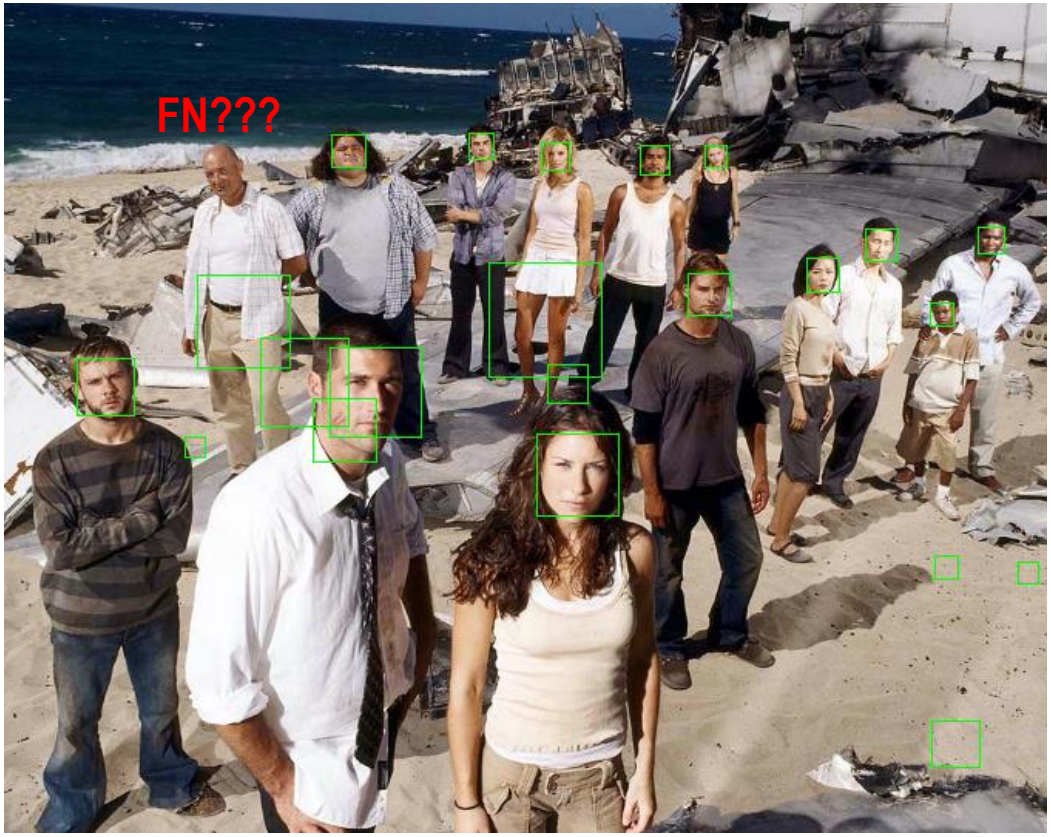
Bibliography

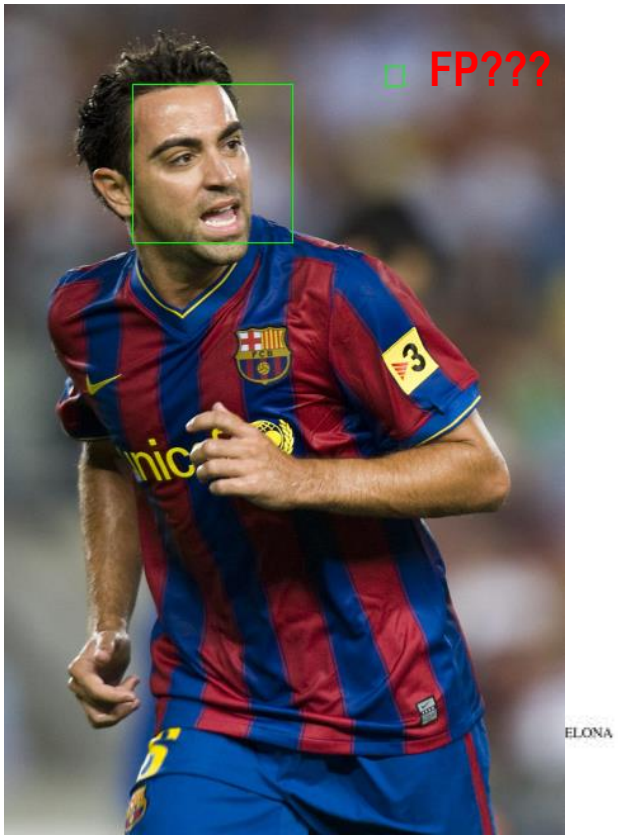
Bibliography:

- Szelisky, “Computer Vision: algorithms and applications”.
- P. Viola and M. Jones. “Rapid object detection using a boosted cascade of simple features”. Proc. CVPR, 1:511-518, 2001.
- P. Viola and M. Jones: ”Robust Real-time Object Detection”, IJCV 2001.

References

- MATLAB codes: http://es.mathworks.com/help/vision/ref/vision.cascadeobjectdetector-class.html
- http://www.mathworks.com/matlabcentral/fileexchange/19912
- Just works under Windows 32 bits. Based on **.MEX** file

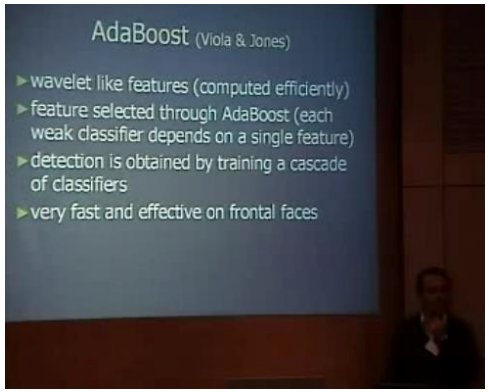




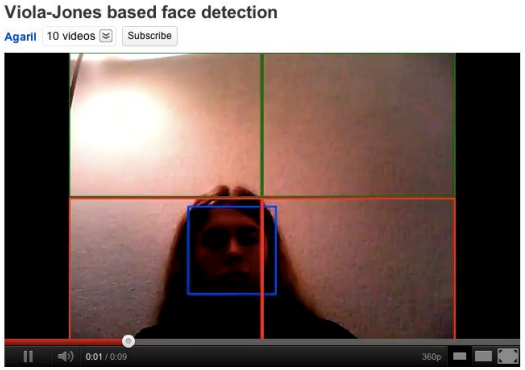
References

Some interesting video references:

http://videolectures.net/lmcv04_verri_clafa1



http://www.youtube.com/watch?NR=1&v=lvBvFHEX-CY



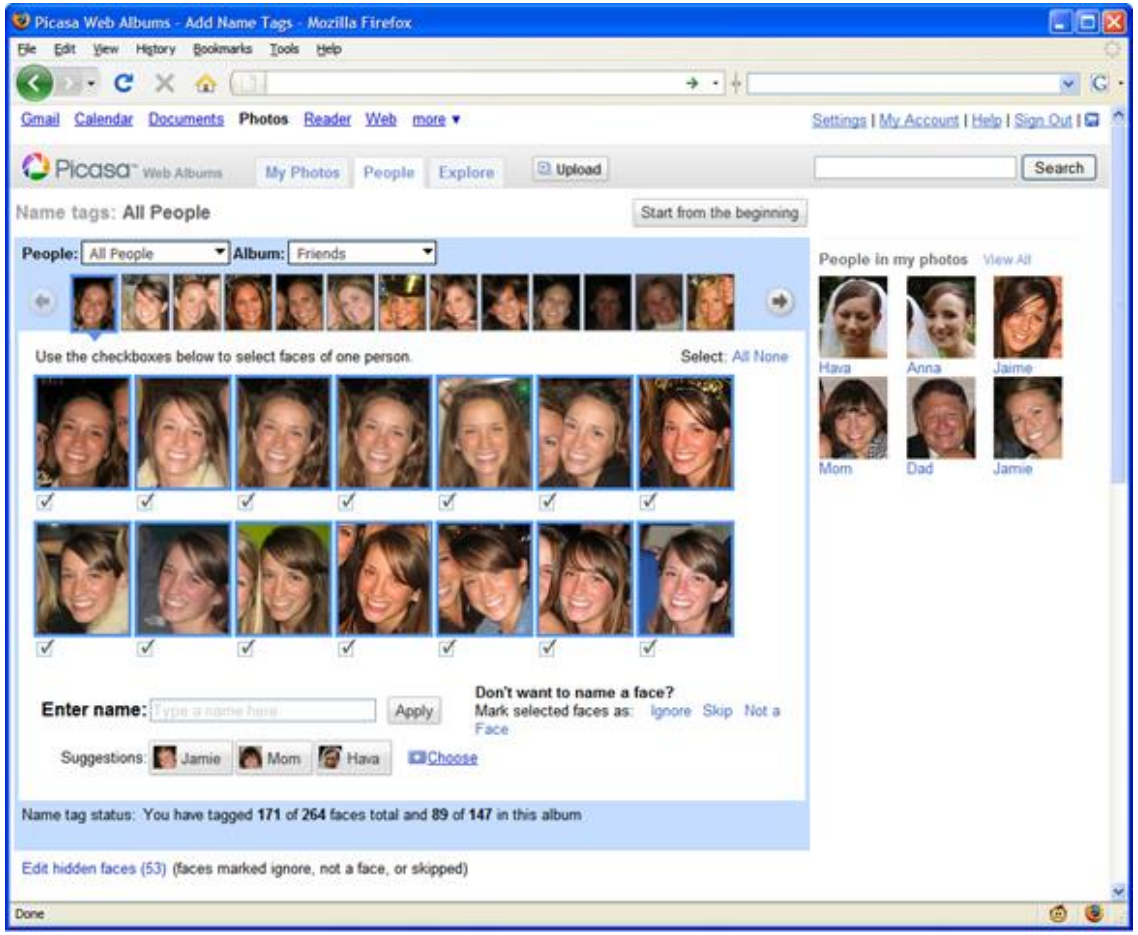
http://www.youtube.com/watch?NR=1&v=JyBMxeVCQkc

Outline

1. Face image analysis: an introduction
2. Face detection
    1. Basic Concepts
    2. Visual features
    3. Ensemble learning
    4. Cascade of classifiers
3. Applications

Applications

- Large pictures database indexation (Picasa)



Applications

- Surveillance & access

- Authentication systems
- Surveillance by security cameras

Applications

- Face detection in digital cameras