COMPUTATIONAL VISION: Face Detection

Master in Artificial Intelligence

Department of Mathematics and Computer Science

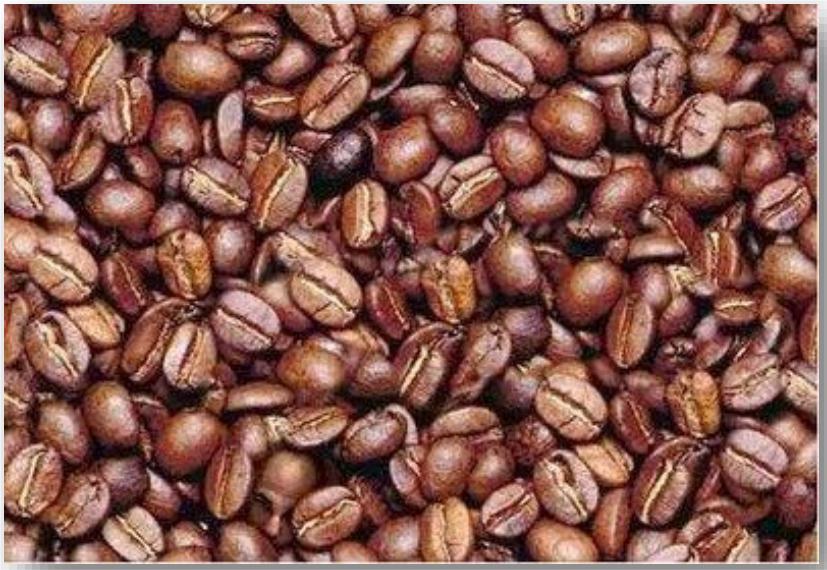
2019-2020

UNIVERSITAT DE BARCELONA

Outline

1. Basic Concepts
2. Visual features
3. Ensemble learning
4. Cascade of classifiers

Face detection

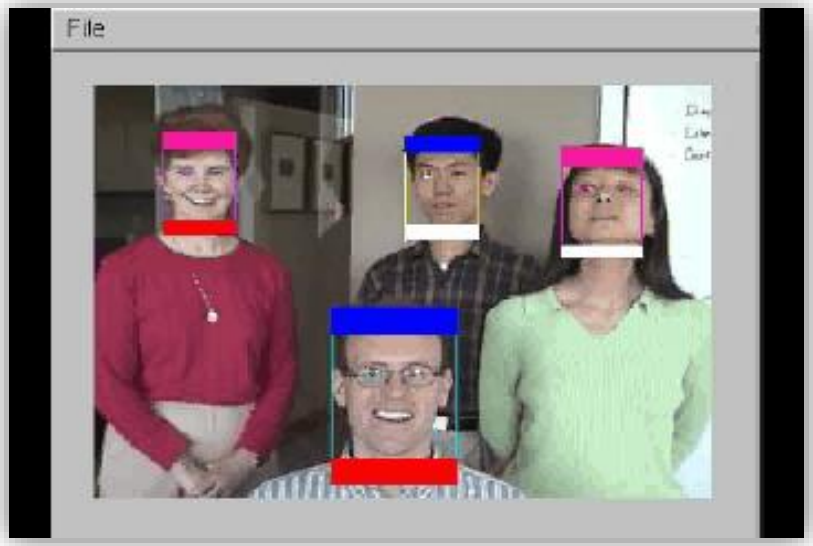


“Hidden Face by Coffee Beans”

Face detection

Face detection

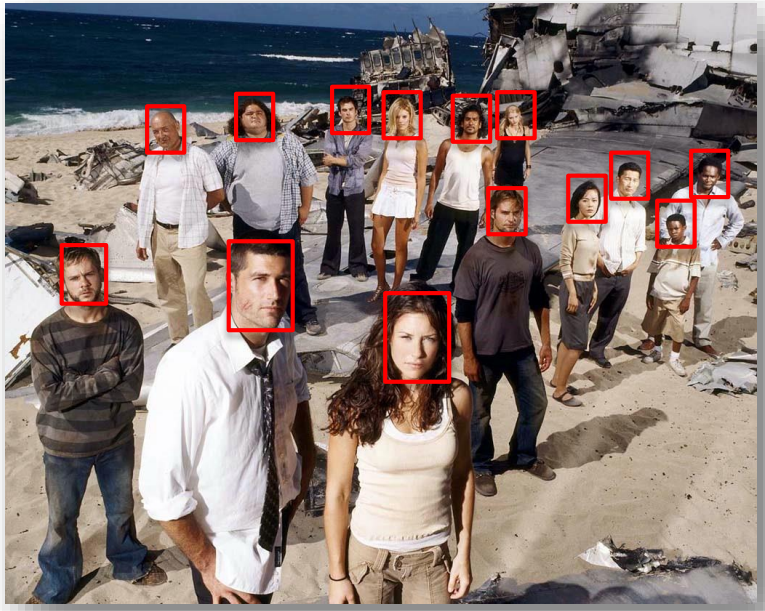
- The first step to face analysis
  - Given an image, where are the faces?



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

Detection vs. Recognition

Detection



Recognition

Face detection

- Intra-class variability

- Inter-class confusion

Paul Newman/Marlon Brando

Face detection

- Classical approach for face detection:

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

Face detection

Objectives of Viola & Jones method:

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

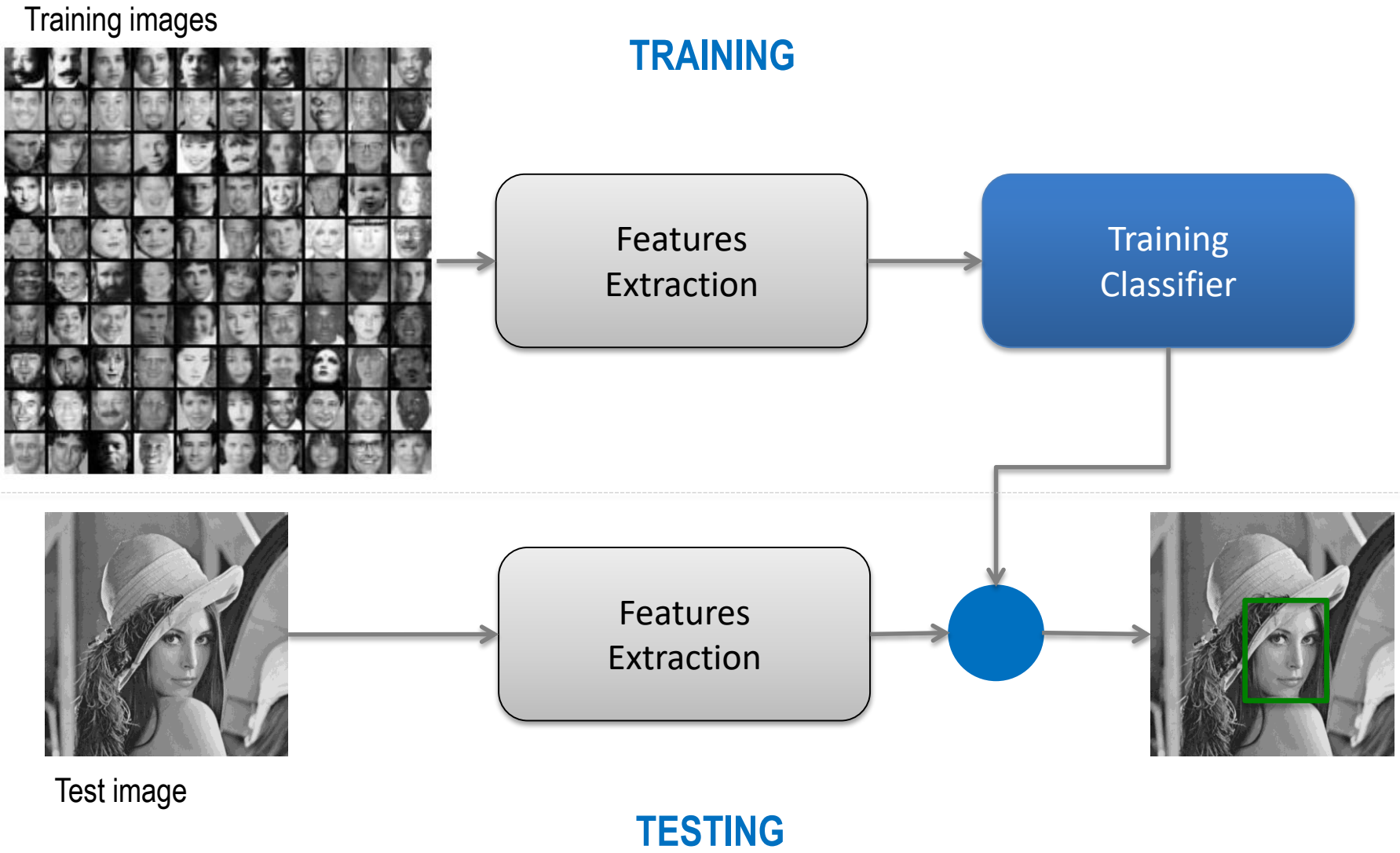
With a camera, we do not want to wait too much time to take a picture!

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



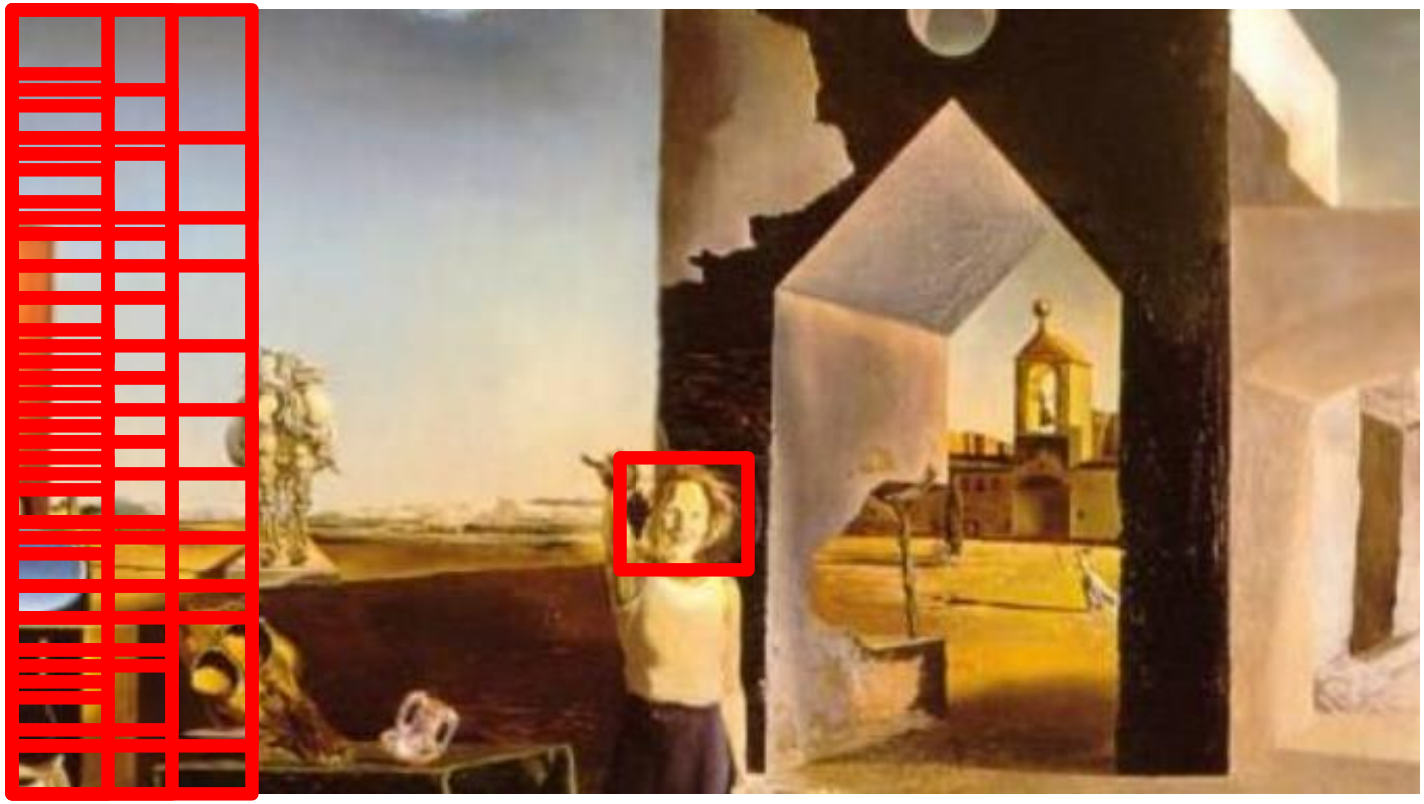
Face detection

Basic concepts for understanding Viola & Jones method:

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

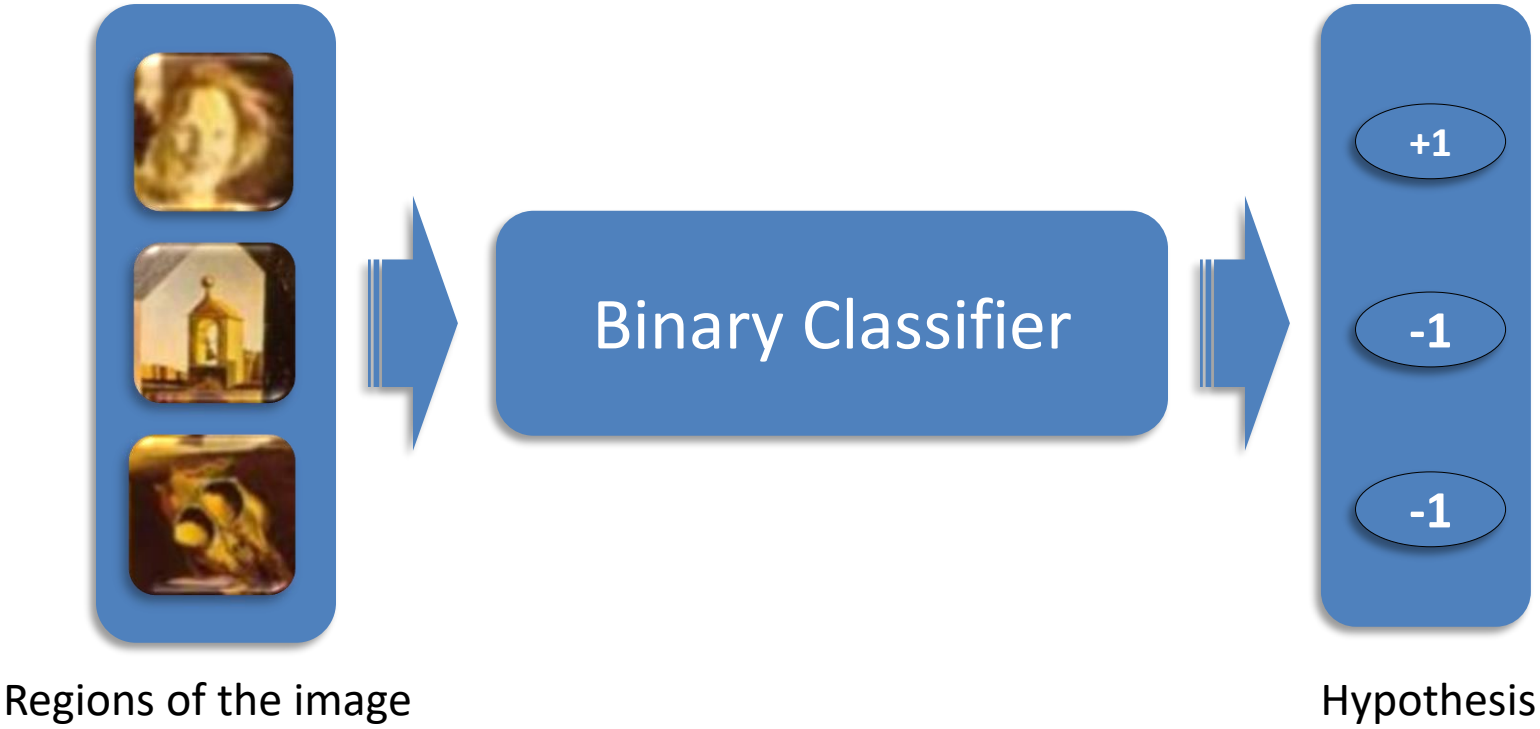
Face detection

- Windowing strategy



Face detection

- Basic Concepts

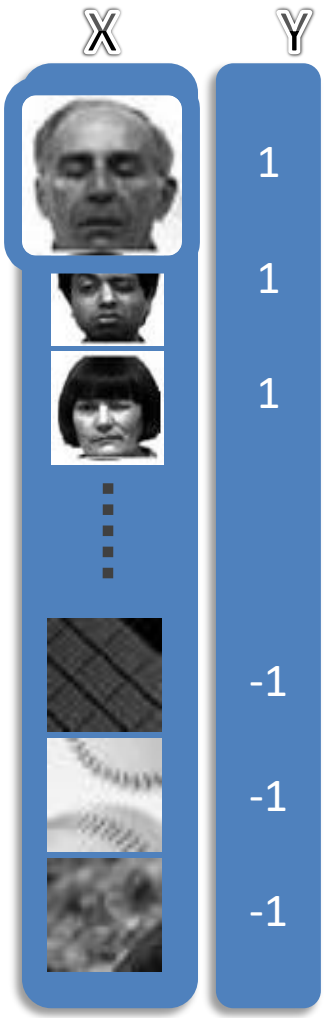


Face detection

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

Face detection

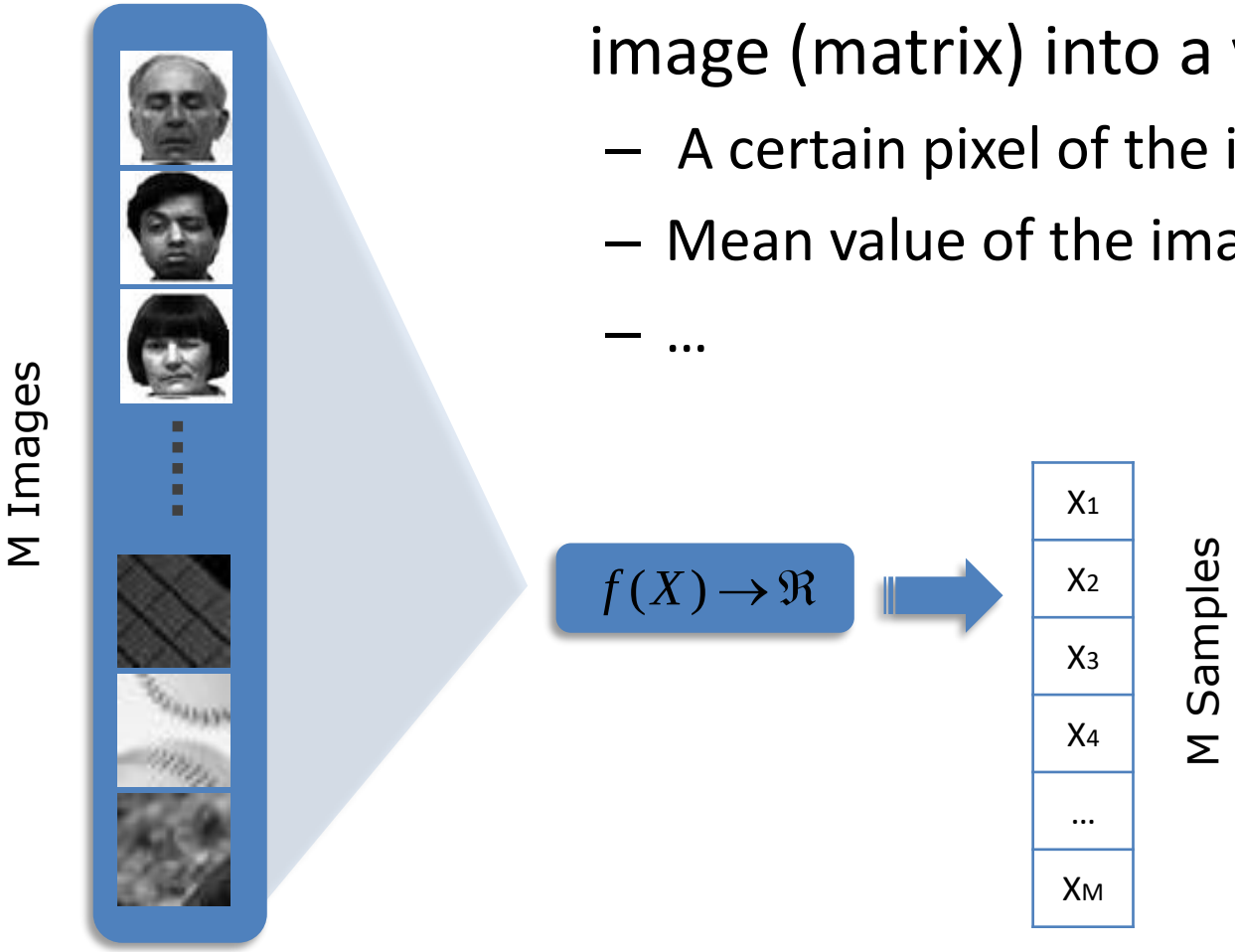
- Samples set
  - Positive and negative image samples (X)
  - Labels (Y)
- An image is a matrix



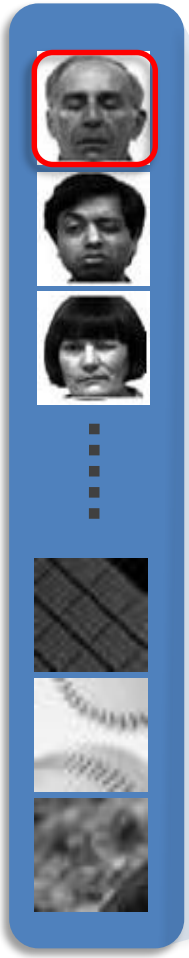
140	140	140	121	121	140
141	142	120	121	121	142
143	121	121	200	200	50
121	121	204	201	200	50
121	204	202	198	250	2
204	203	198	150	250	5

Face detection

- *Feature*: function that transforms an image (matrix) into a value
  - A certain pixel of the image
  - Mean value of the image
  - …



Face detection



- *Feature Set*
  - All pixels of the image
  - Family of functions
    - Filter banks
  - SIFT descriptor

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

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}

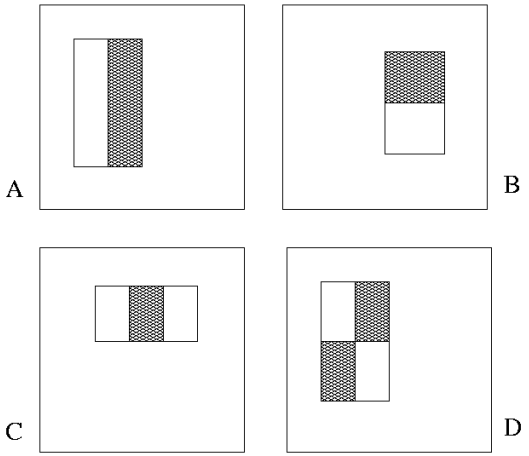
M Samples

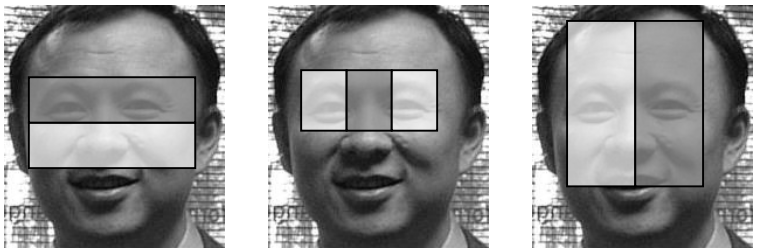
Face detection

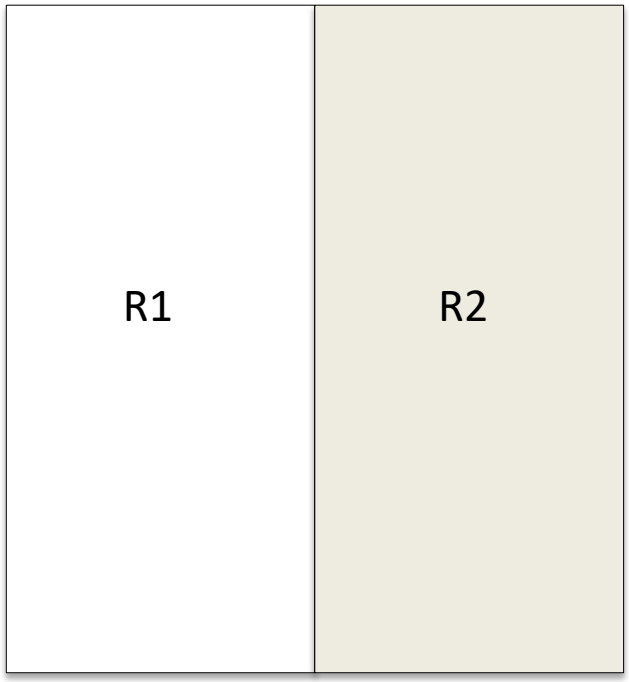
- Visual Features
  - Designed to be sensitive to visual artifacts in the objects
    - Contrasted regions
      - Edges
      - Corners
      - …

Face detection

- *Rectangle features*





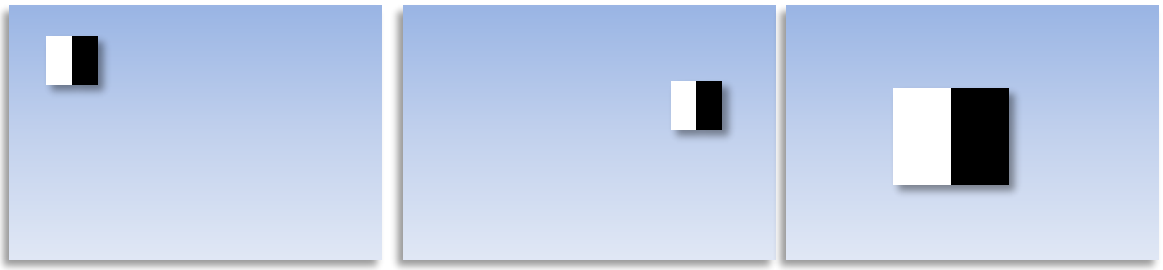


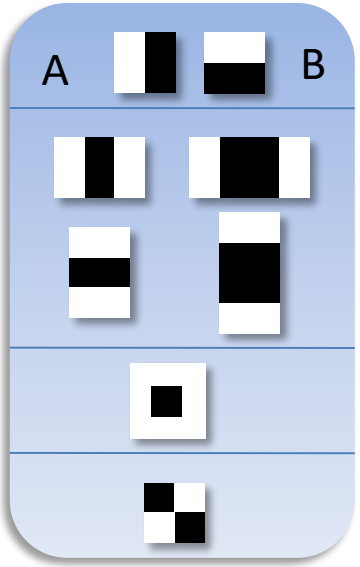
The k-th feature:

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

Face detection

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



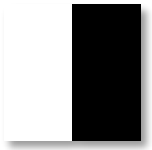


- For a 24x24 detection region, the number of possible rectangle features (A and B) is over 180,000.

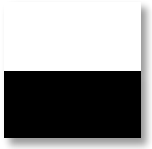
Face detection

- Feature interpretation:

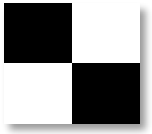
  Which structures of the image are they showing?



Vertical changes



Horitzontal changes

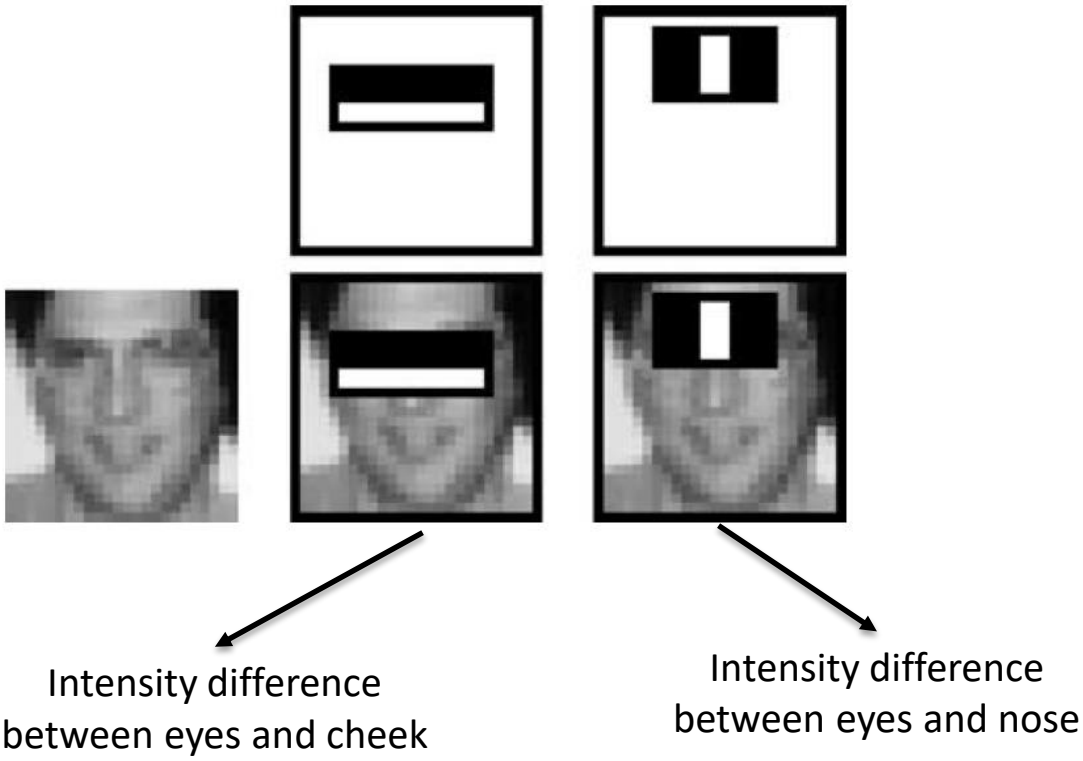


Diagonal changes

Face detection

- Feature interpretation:

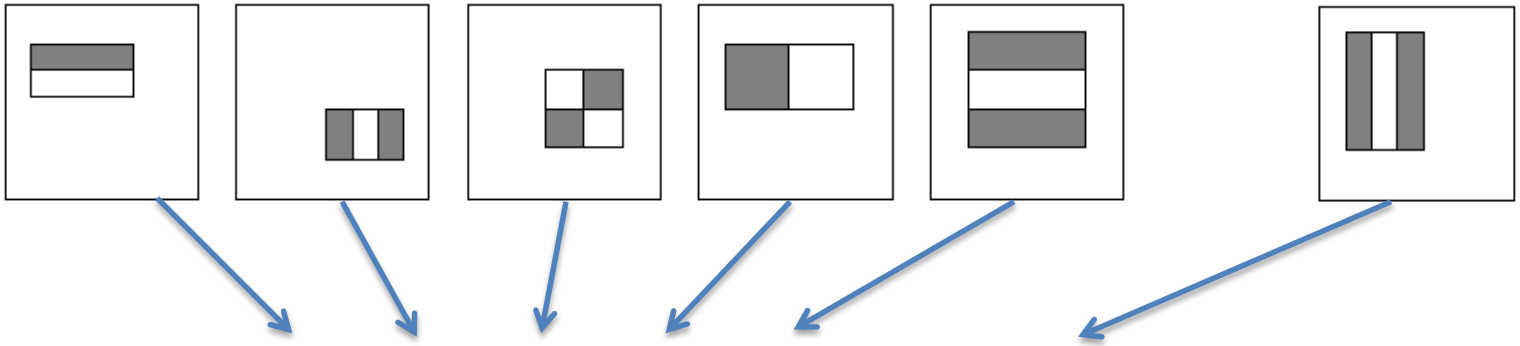
  And apply to faces, which information are they providing?



Face detection

- Feature extraction:

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



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

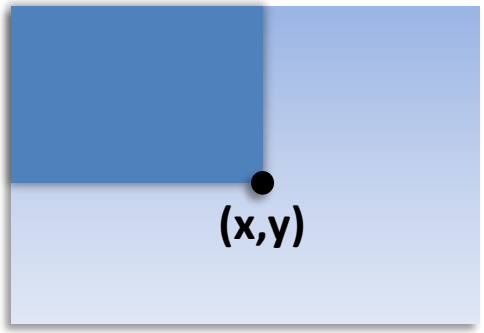
The feature vector describes the content of the window and it is used to train the classifier and to detect faces.

Face detection

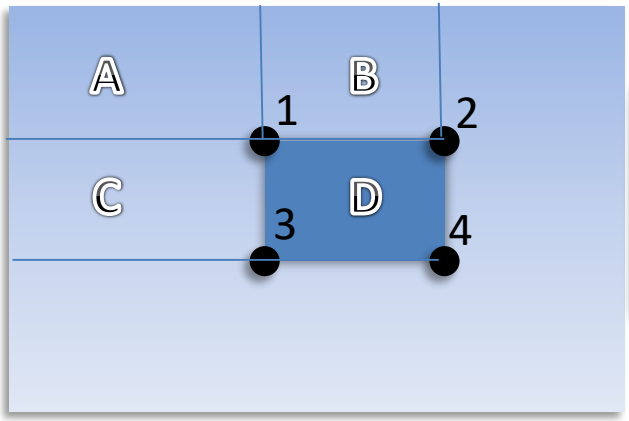
How rectangle features are computed in a fast way:

- Integral Image

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



We use the intergral image to efficiently compute rectangle sums:



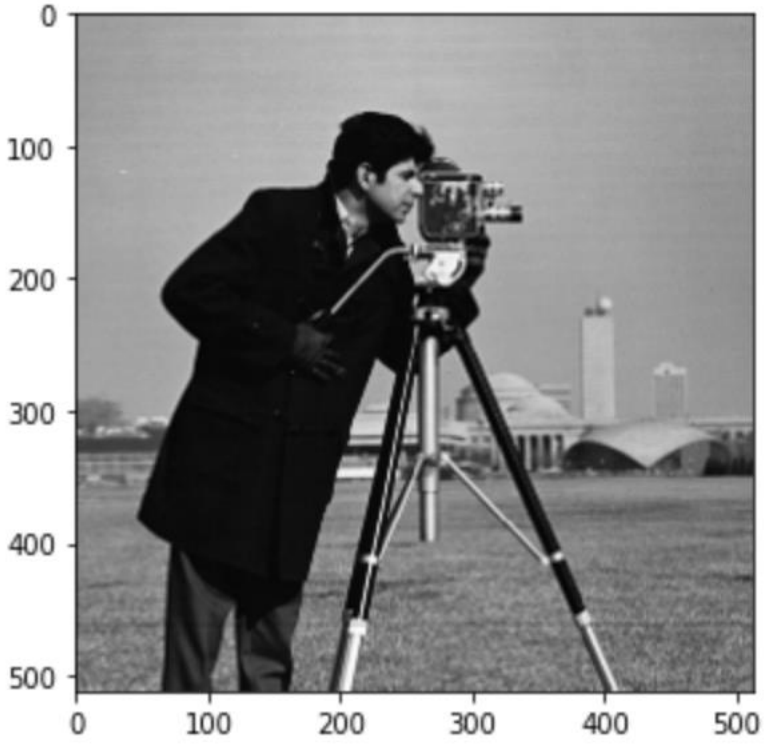
$$\begin{aligned} D &= 1+4-(2+3) \\ &= A+(A+B+C+D)-(A+B+A+C) \\ &= D \end{aligned}$$

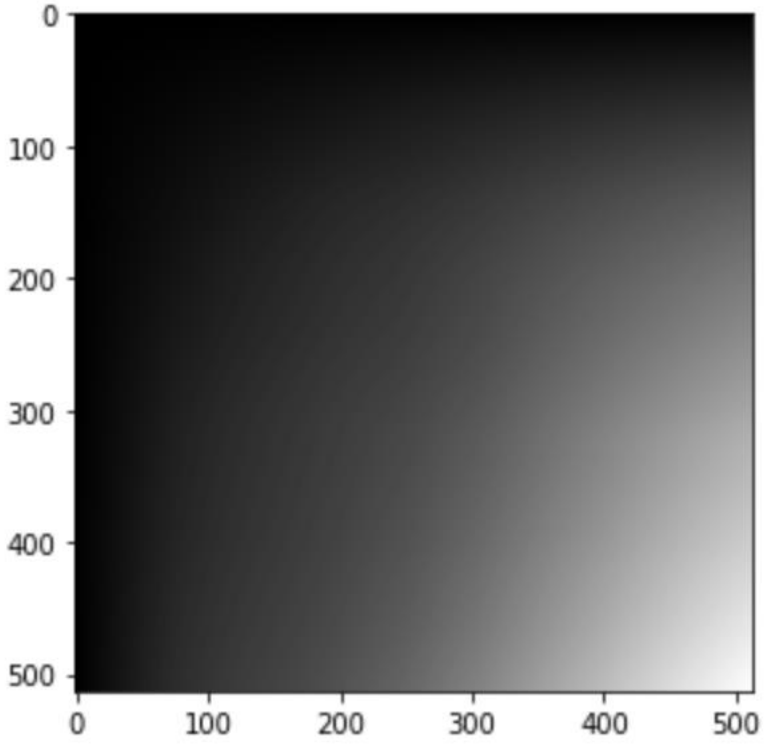
Any rectangular sum can be computed in constant time and it is independent of the size of the rectangular area.

Face detection

In Python:

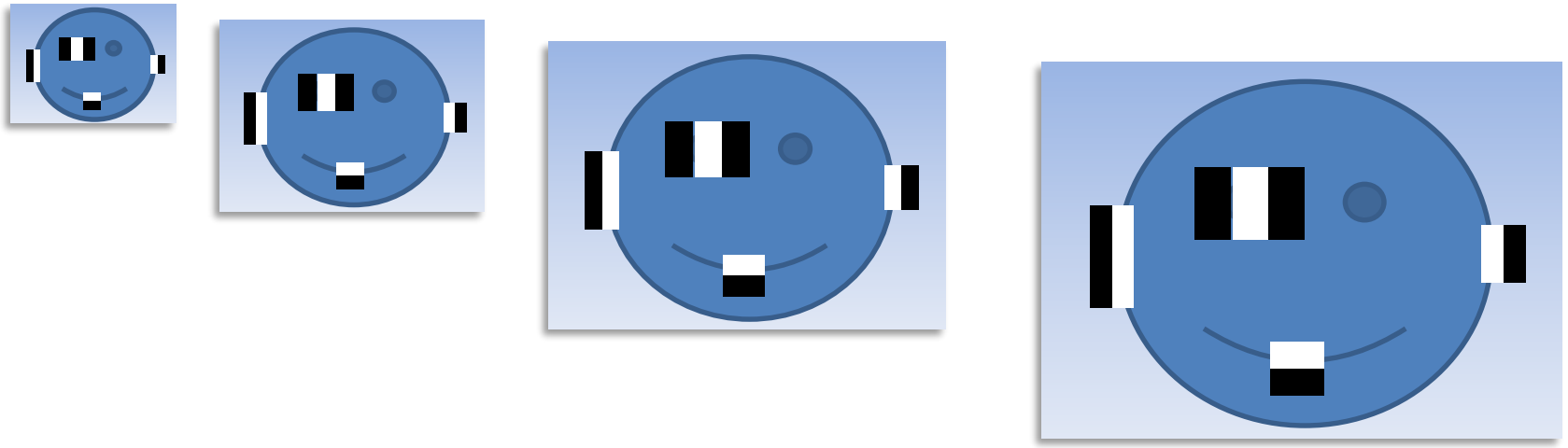
- `np.cumsum(np.cumsum(img_arr, axis=0), axis=1);`





Face detection

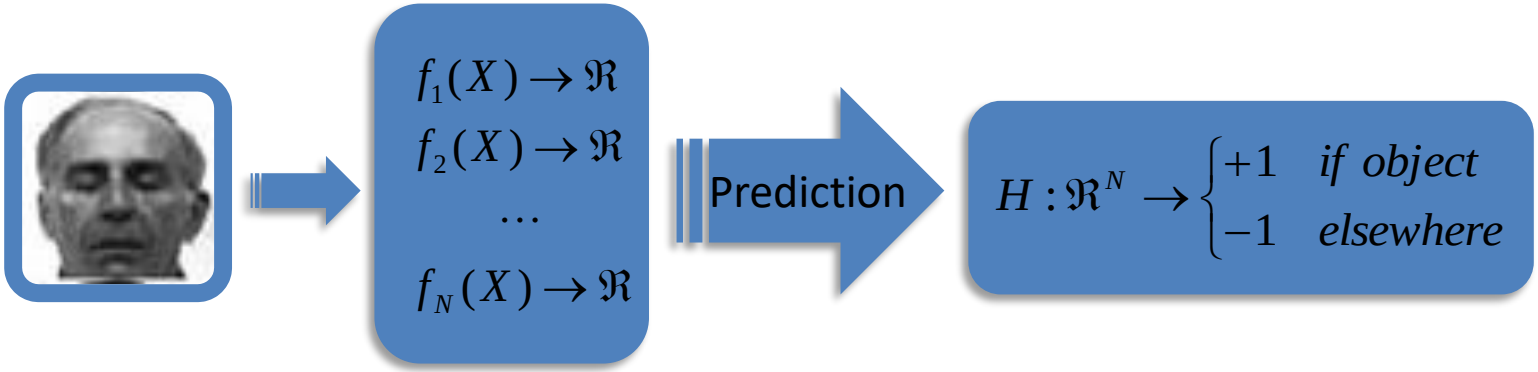
- Integral Image enables to evaluate all rectangle sizes in constant time. Therefore, no image scaling is necessary.



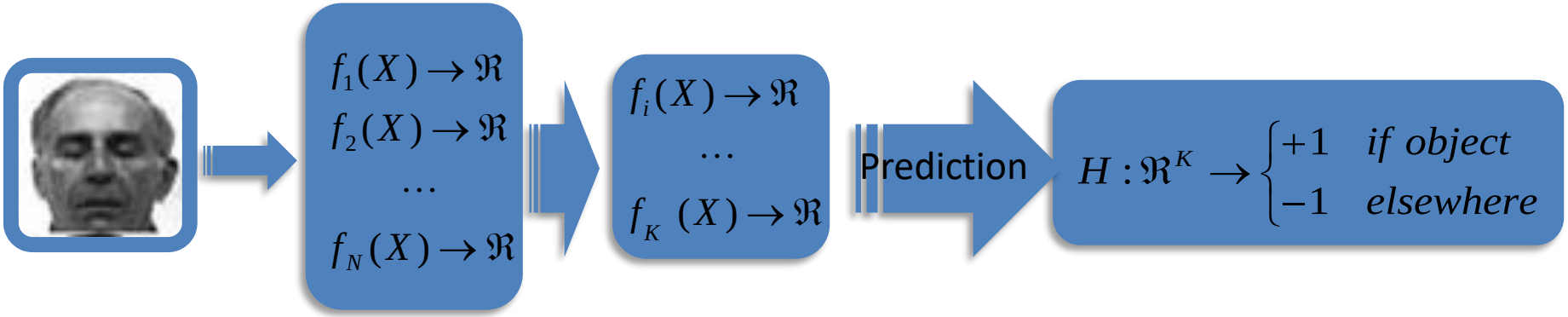
- Multi-scale detection by means of region scaling
  - Just scale the parameters of the features

Face detection

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



  - Using a subset of K 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 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

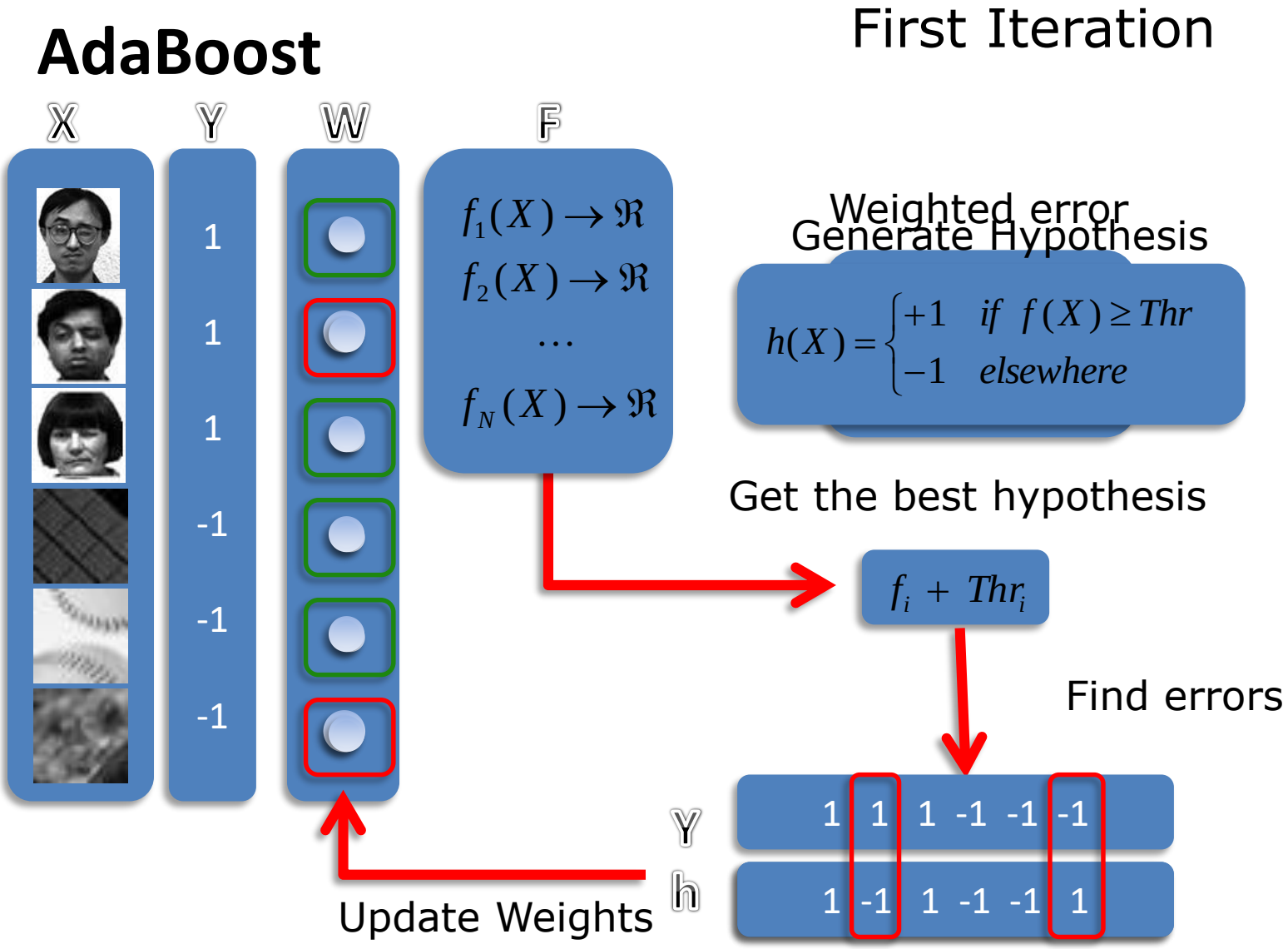
- Weighting strategy
  - Focus on **difficult samples** by adding a weight to each sample:

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

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

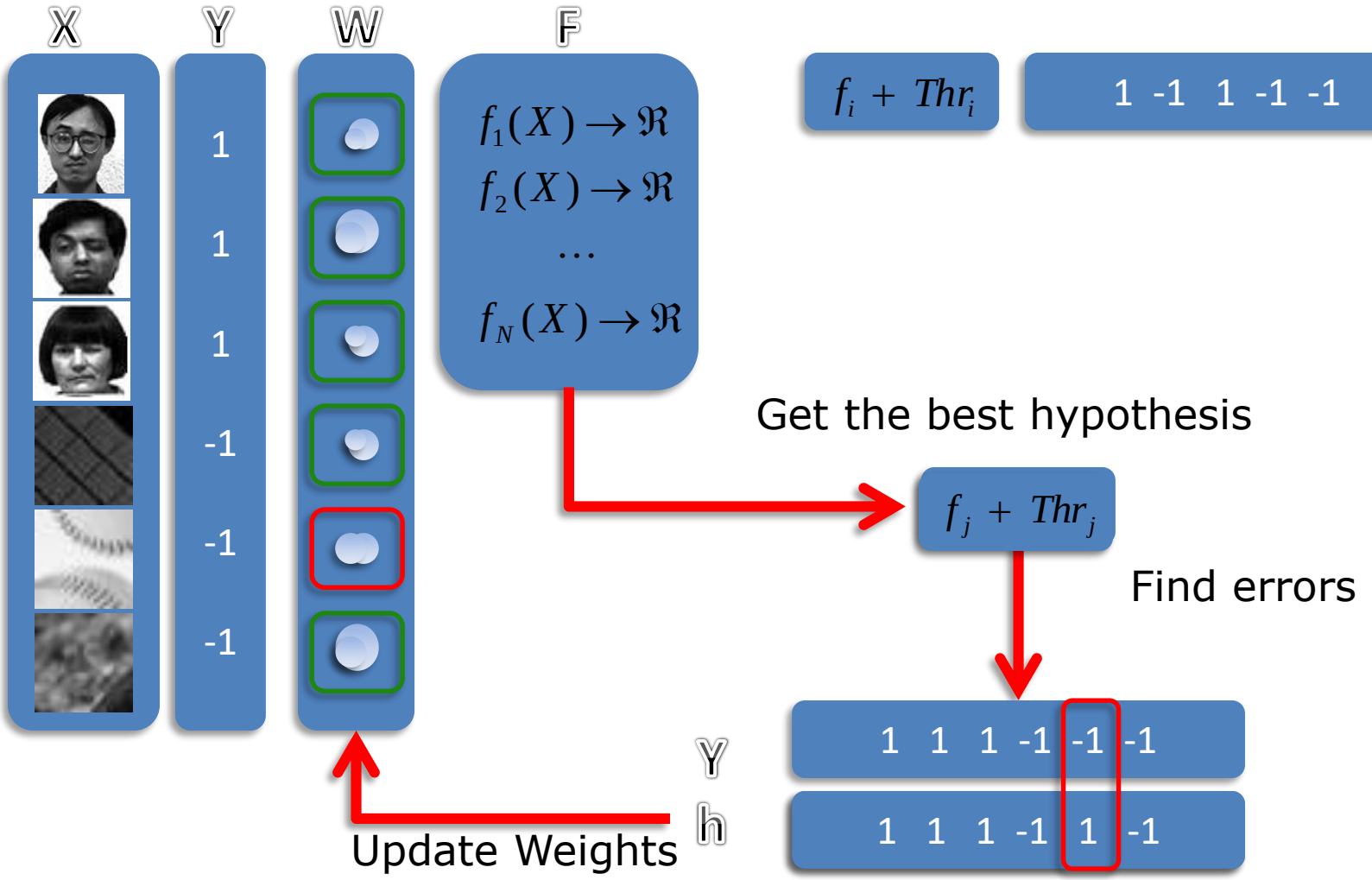
$$\varepsilon = \sum_{h(x_i) \neq y_i}^{N} \omega_i$$

Face detection

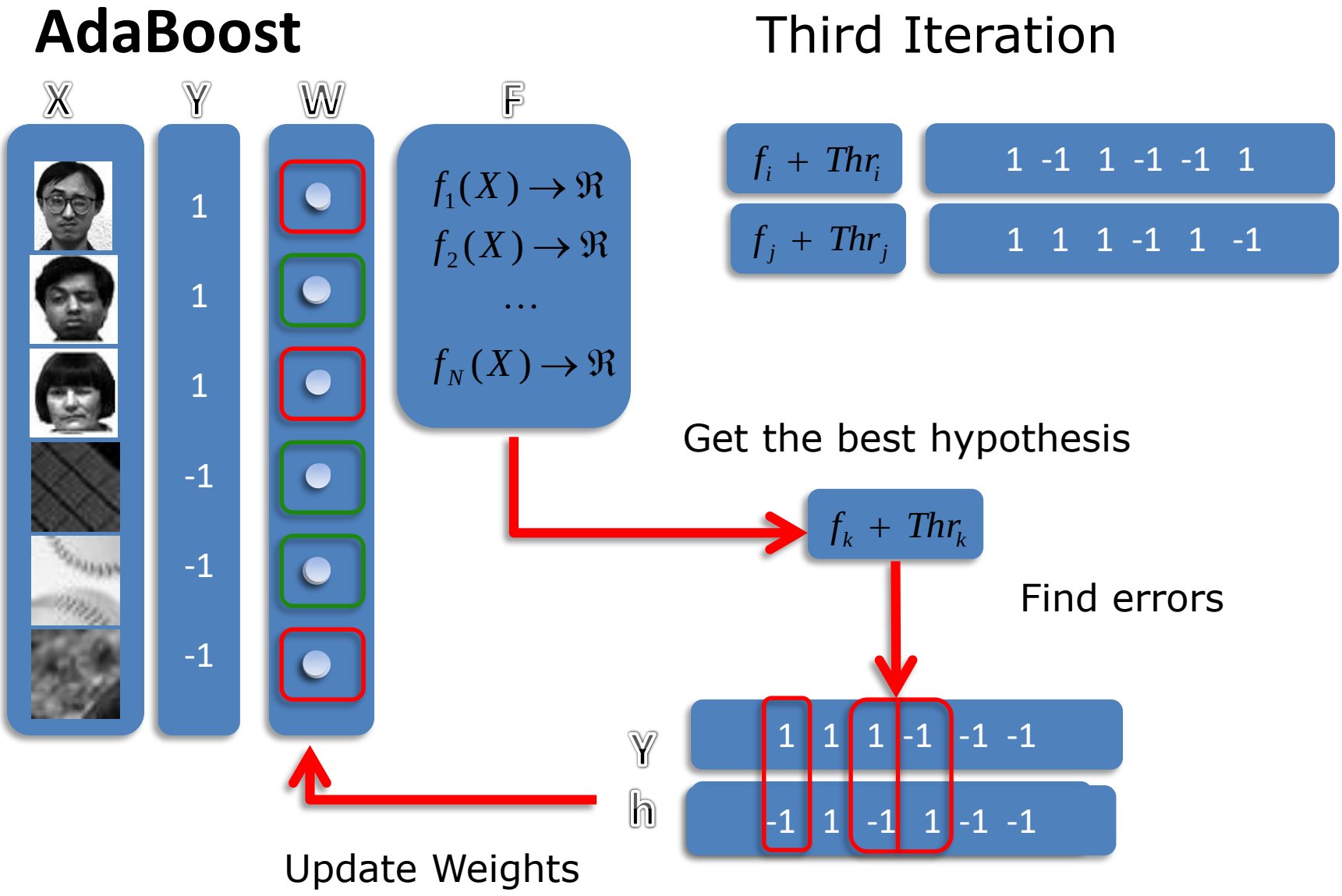


Face detection

AdaBoost

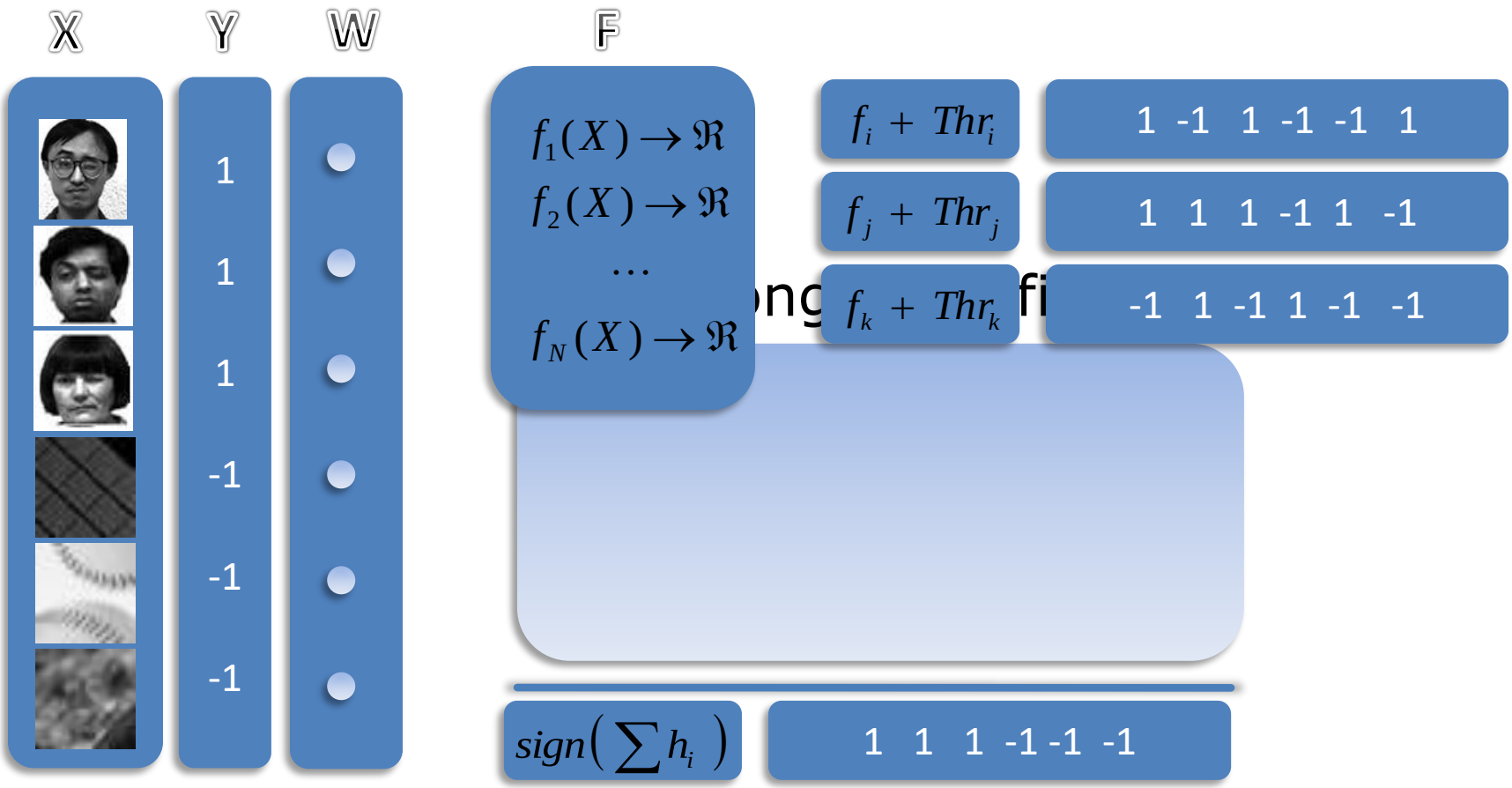


Face detection



Face detection

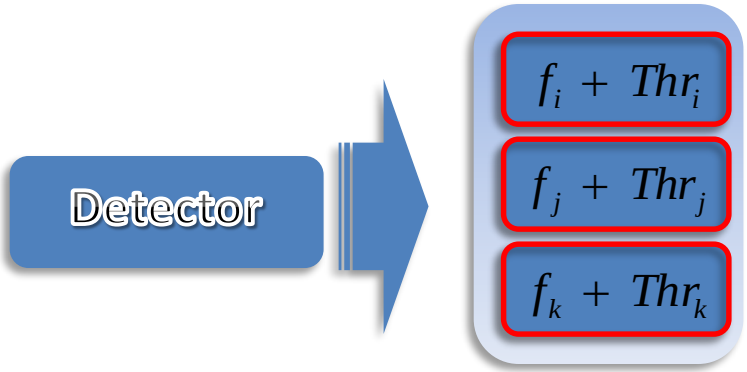
AdaBoost



Face detection

AdaBoost

Strong Classifier



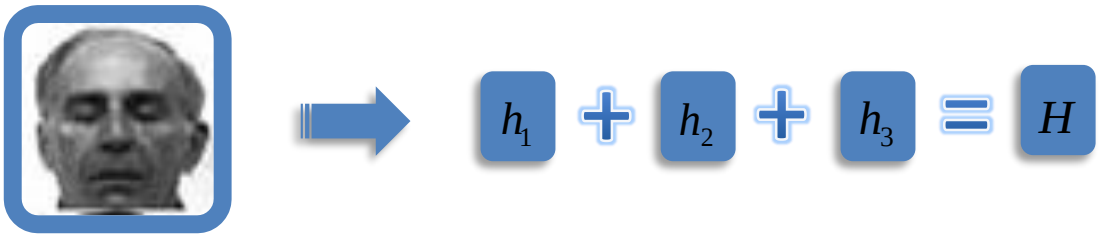
Hypothesis

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

Final decision

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

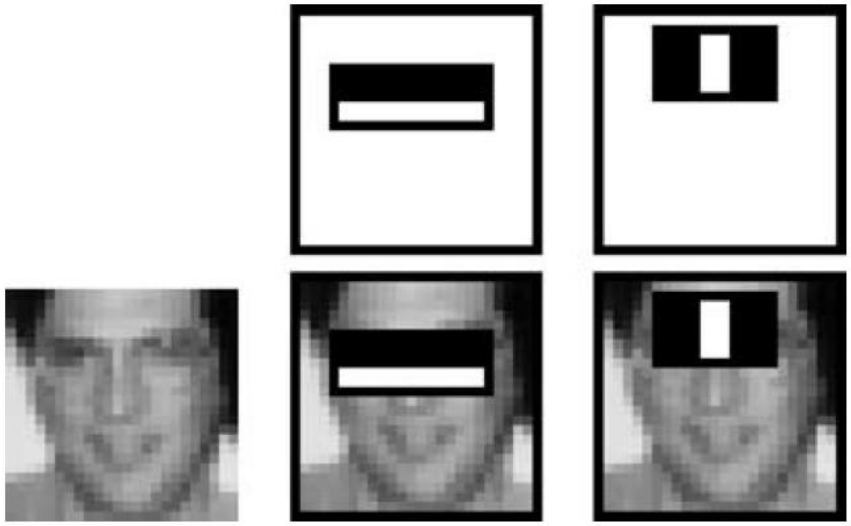
Input test image



Face detection

- After some experiments:

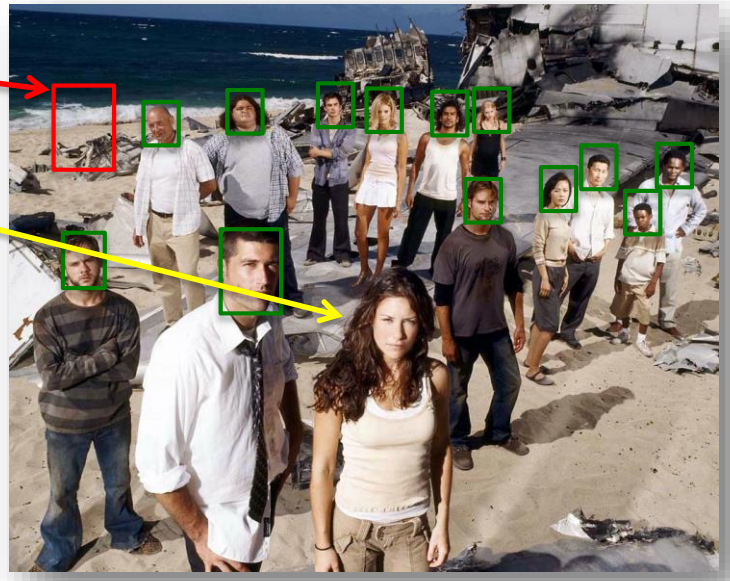
  The initial rectangle features selected by Adaboost are:



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**

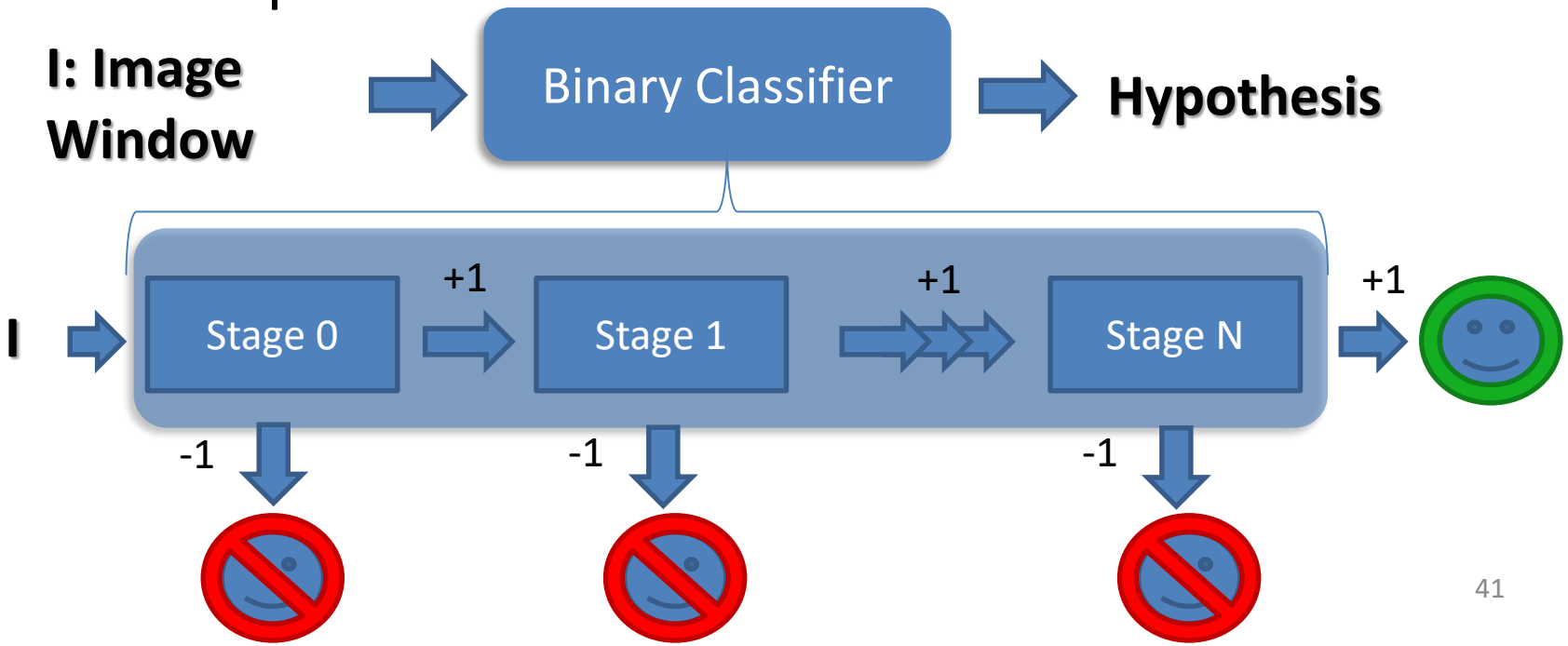
Face detection

Cascade of classifiers

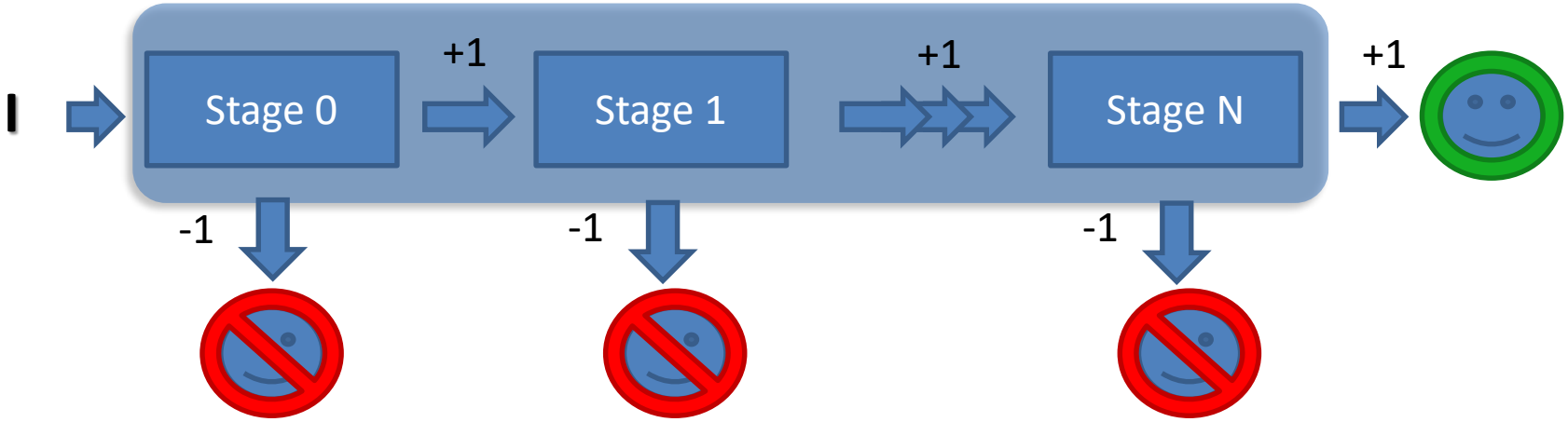
- Method to speed-up the detection process. Typical when windowing is used.
- We start with simple classifiers which reject many of the negative sub-windows while detecting almost all positive sub-windows

Face detection

- Each stage only process regions classified as faces by the previous stages.
  - Similarity between faces/non-faces regions increments each stage, incrementing the difficulty of the problem.



Face detection



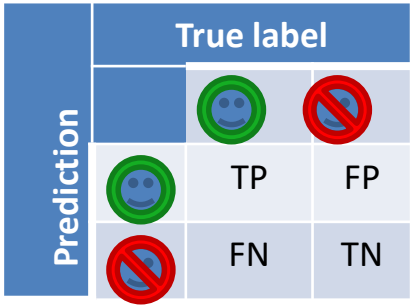
Number of regions processed by each stage decrease exponentially:

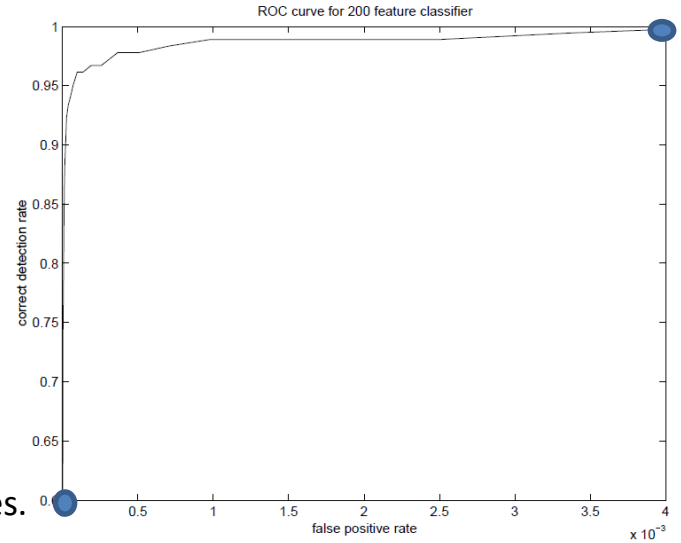
#windows	Stage 0	Stage 1	Stage 5	Stage 10	Stage 15
FA = 0.5	1.000.000	500.000	31.250	976	30

Face detection

Basic evaluation concepts:

- 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





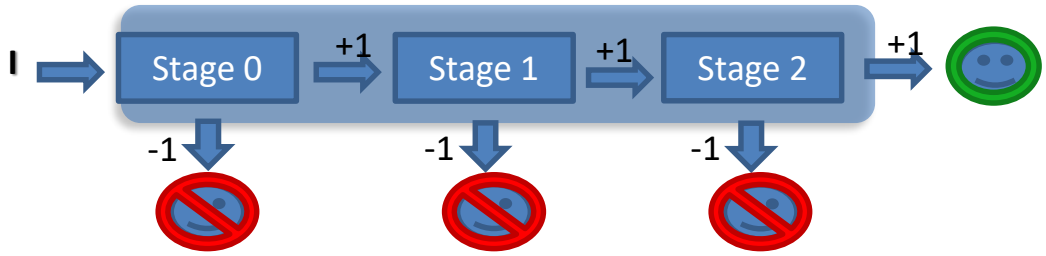
Prediction of all the samples as positives.

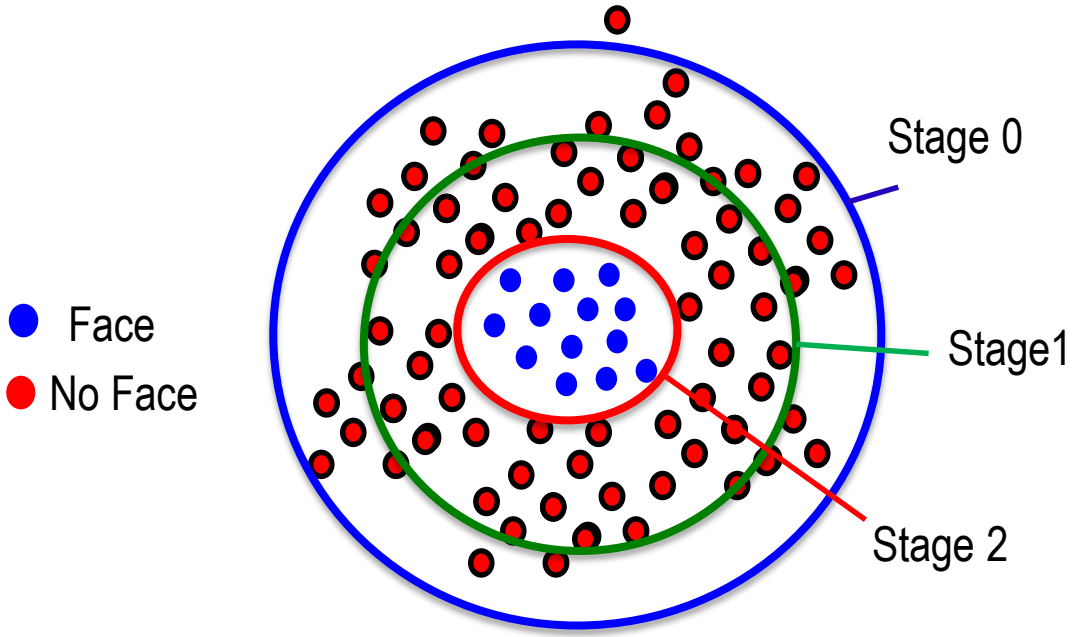
Prediction of all the samples as negatives.

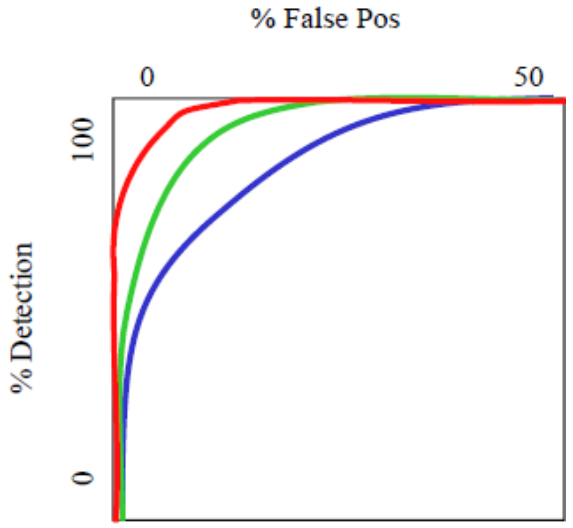
Receiver operating characteristic (ROC) curve

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
3) Following classifiers are more complex to refine the results of previous classifiers.

Face detection

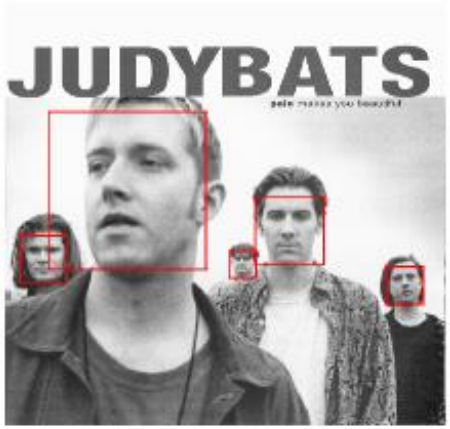
Training the cascade

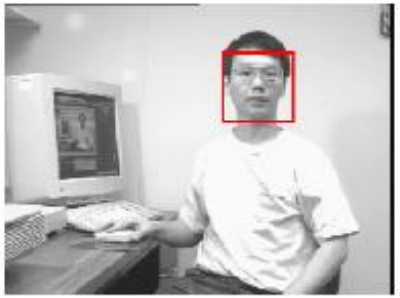
- Set target detection and false positive rates for each stage
- Keep adding features to the current stage until its target rates have been met
- Test on a *validation set*
- If the overall false positive rate is not low enough, then add another stage
- Use false positives from current stage as the negative training examples for the next stage

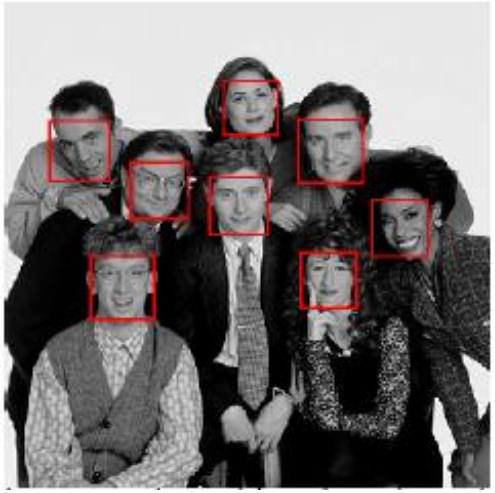
Face detection

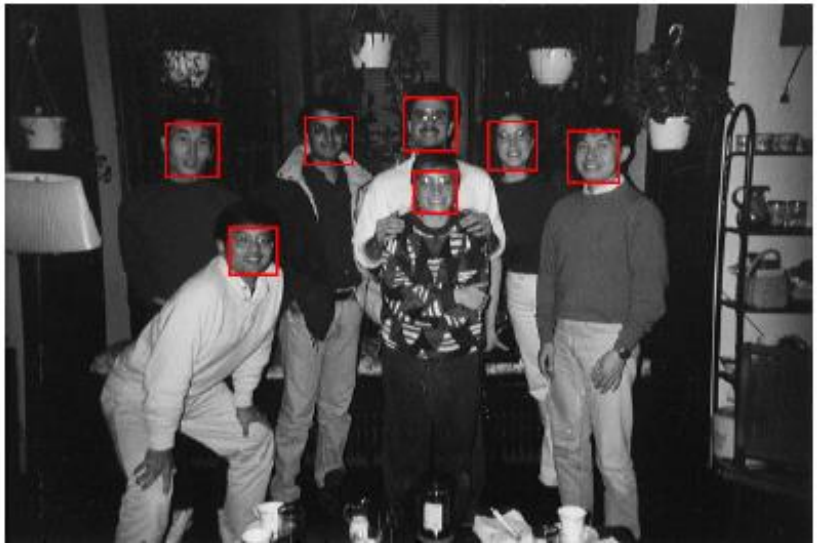
- Viola & Jones prepared their final Detector cascade:
  - 38 layers (stages), 6060 total features included
  - 1st classifier- layer, 2-features
    - 50% FP rate, 99.9% TP rate
  - 2nd classifier- layer, 10-features
    - 20% FP rate, 99.9% TP rate
  - Next 2 layers 25-features each, next 3 layers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

Results









Summary

- Viola & Jones algorithm is a method for 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**!

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