The Viola/Jones Face Detector
(2001)

- A widely used method for real-time object detection.
- Training is slow, but detection is very fast.

Classifier is Learned from Labeled Data

- Training Data
  - 5000 faces
    - All frontal
  - 300 million non faces
  - Faces are normalized
    - Scale, translation
- Many variations
  - Across individuals
  - Illumination
  - Pose (rotation both in plane and out)

Key Properties of Face Detection

- Each image contains 10 - 50 thousand locs/scales
- Faces are rare 0 - 50 per image
  - 1000 times as many non-faces as faces
- Extremely small # of false positives: $10^{-6}$

AdaBoost

- Given a set of weak classifiers
  - $h_i(x) \in \{+1, -1\}$
  - None much better than random
- Iteratively combine classifiers
  - Form a linear combination
    $$C(x) = \theta \left( \sum_i h_i(x) + b \right)$$
  - Training error converges to 0 quickly
  - Test error is related to training margin

AdaBoost: Super Efficient Feature Selector

- Features = Weak Classifiers
- Each round selects the optimal feature given:
  - Previous selected features
  - Exponential Loss
**Boosted Face Detection: Image Features**

“Rectangle filters”

Similar to Haar wavelets

Papageorgiou, et al.

\[
 h(x_i) = \begin{cases} 
 \alpha & \text{if } f(x_i) > \theta, \\
 \beta & \text{otherwise}
\end{cases}
\]

\[
 C(x) = \theta \sum h(x_i) + b
\]

60,000 features to choose from

**The Integral Image**

- The integral image computes a value at each pixel \((x, y)\) that is the sum of the pixel values above and to the left of \((x, y)\), inclusive.
- This can quickly be computed in one pass through the image

**Computing Sum within a Rectangle**

- Let \(A, B, C, D\) be the values of the integral image at the corners of a rectangle
- Then the sum of original image values within the rectangle can be computed:
  \[
  \text{sum} = A - B - C + D
  \]
- Only 3 additions are required for any size of rectangle!
  - This is now used in many areas of computer vision

**Feature Selection**

- For each round of boosting:
  - Evaluate each rectangle filter on each example
  - Sort examples by filter values
  - Select best threshold for each filter (min \(Z\))
  - Select best filter/threshold (= Feature)
  - Reweight examples
- \(M\) filters, \(T\) thresholds, \(N\) examples, \(L\) learning time
- \(O( MT L(MTN) )\)  Adaboost feature selector

**Example Classifier for Face Detection**

A classifier with 200 rectangle features was learned using AdaBoost

95% correct detection on test set with 1 in 14084 false positives.

Not quite competitive...

![ROC curve for 200 feature classifier](image)

**Building Fast Classifiers**

- Given a nested set of classifier hypothesis classes
- Computational Risk Minimization

![Building Fast Classifiers](image)
Cascaded Classifier

- A 1 feature classifier achieves 100% detection rate and about 50% false positive rate.
- A 5 feature classifier achieves 100% detection rate and 40% false positive rate (20% cumulative) — using data from previous stage.
- A 20 feature classifier achieves 100% detection rate with 10% false positive rate (2% cumulative)

Output of Face Detector on Test Images

Solving other “Face” Tasks

Facial Feature Localization
Profile Detection
Demographic Analysis

Feature Localization Features

- Learned features reflect the task

Profile Detection

Profile Features
**Review: Colour**

- Spectrum of illuminant and surface
- Human colour perception (trichromacy)
- Metameric lights, Grassman’s laws
- RGB and CIE colour spaces
- Uniform colour spaces
- Detection of specularities
- Colour constancy

**Review: Invariant features**

- Scale invariance, using image pyramid
- Orientation selection
- Local region descriptor (vector formation)
- Matching with nearest and 2nd nearest neighbours
- Object recognition
- Panorama stitching

**Review: Classifiers**

- Bayes risk, loss functions
- Histogram-based classifiers
- Kernel density estimation
- Nearest-neighbor classifiers
- Neural networks

*Viola/Jones face detector*

- Integral image
- Cascaded classifier