Image Analysis

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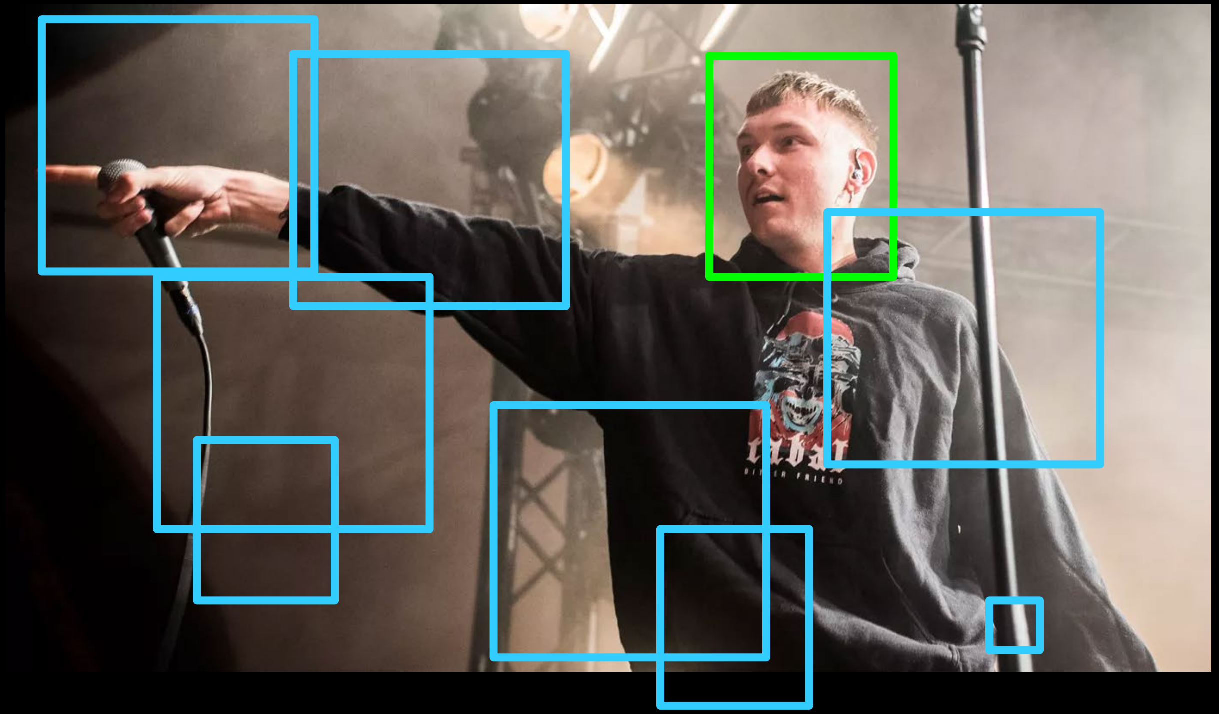
Lecture 11 – Face detection using the Viola Jones method



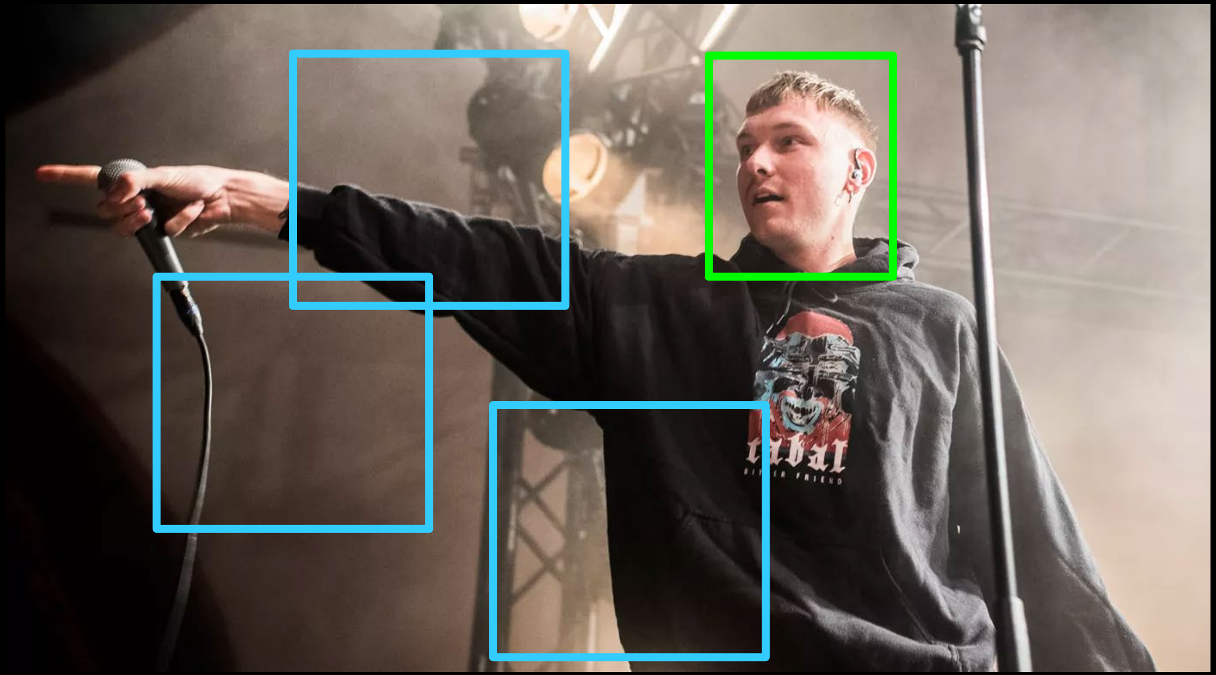
What can you do after today?

- Describe the concept of face detection
- Describe the concept of Haar features
- Compute the values of 2, 3 and 4 rectangle Haar features
- Describe the integral image
- Compute the sum of pixels values in a rectangle using an integral image
- Describe the concept of a weak classifier
- Describe how several weak classifiers can be combined into a strong classifier
- Describe the attentional cascade
- Describe how faces can be detected using a moving window

Face detection

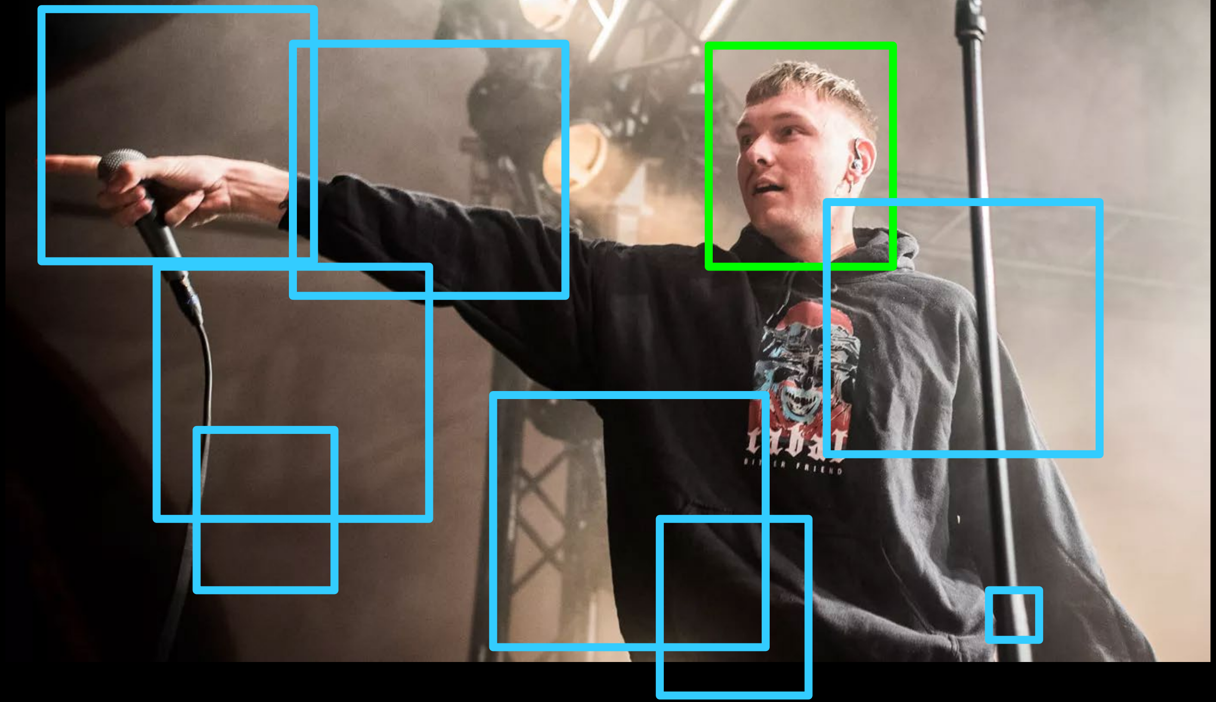
- First problem
  - Analyze a window in an image
  - Is there a face in that window?

Face detection



- Slightly more advanced
  - Analyze many windows in an image
  - How many (if any) windows contain faces?

Face detection



- Ideal
  - Analyze (almost) all possible windows in an image
  - How many (if any) windows contain faces?

What is needed?

- A fast method to determine if a *window* contains a face

Primary task – image feature based classification

Image feature extraction

Feature based classification

Face

Not face

Image based features - what features can you think of?

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Viola Jones – fast features and smart classification

Many image features very fast

Boosted cascade classifier

Face

Not face

Training data

- Face images:
  - 4916 hand labelled faces
  - Aligned and scaled to 24x24 pixels
- Non-face images:
  - 9544 images with no faces
  - 350 million sub-windows sampled from these

Viola Jones – fast features and smart classification

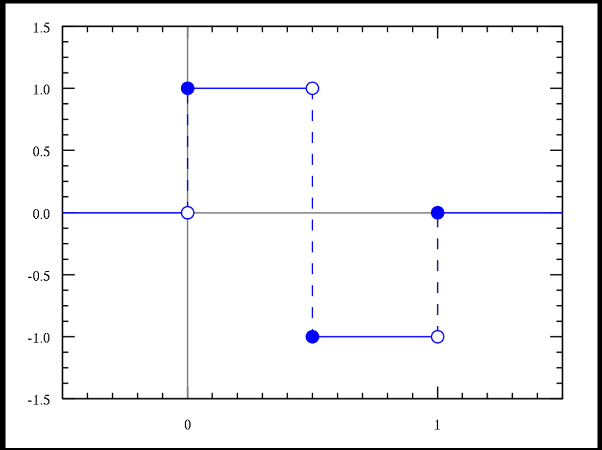
Many image features very fast

Boosted cascade classifier

Face

Not face

Haar features



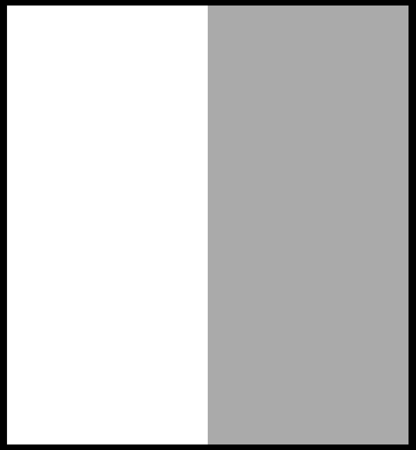
https://en.wikipedia.org/wiki/Haar_wavelet

- Alfred Haar (1885-1933)
  - Hungarian Mathematician
- Introduced the Haar wavelet in 1909
- *A wavelet is a wave-like oscillation with an amplitude that begins at zero, increases or decreases, and then returns to zero one or more times.*
- Simplest possible wavelet

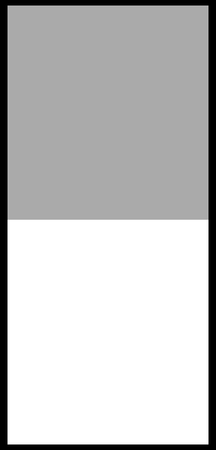
https://en.wikipedia.org/wiki/Wavelet

Haar features

Two rectangle features



A

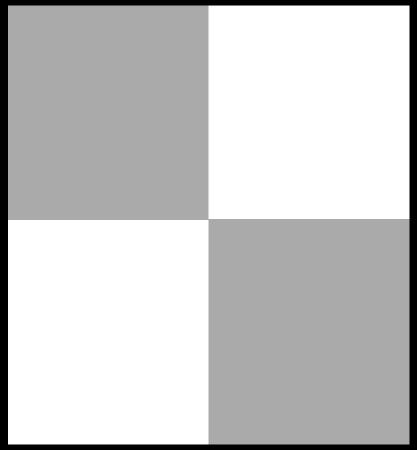


B

Three rectangle feature

C

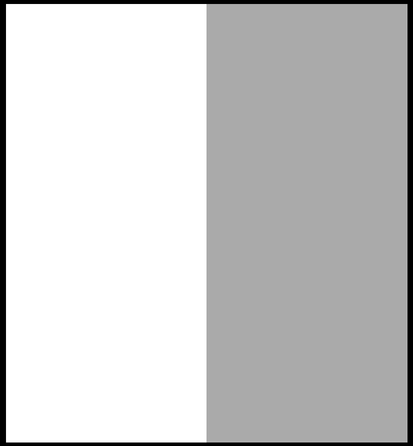
Four rectangle feature



D

Feature = Sum of pixel values in image - Sum of pixel values in image

One Haar feature

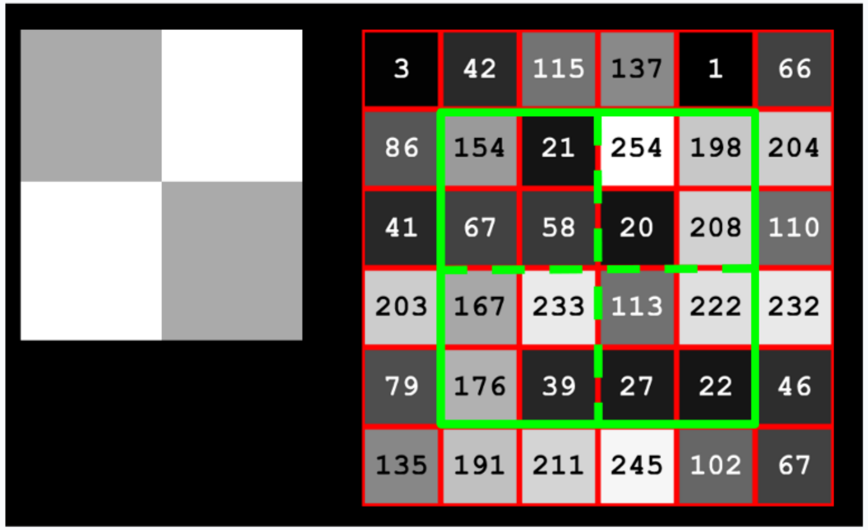


A

3	42	115	137	1	66
86	154	21	254	198	204
41	67	58	20	208	110
203	167	233	113	222	232
79	176	39	27	22	46
135	191	211	245	102	67

Feature = 254+198+20+208+113+222-154-21-67-58-167-233 = 1015-700 = 315

Four rectangle Haar feature - what is the feature value?



- 567
- 179
- -611
- -113
- 76
- I do not know

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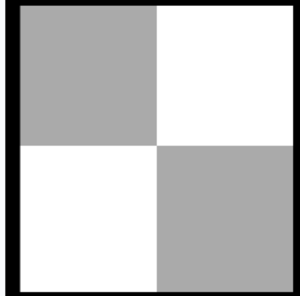
Four rectangle Haar feature - what is the feature value?



3	42	115	137	1	66
86	154	21	254	198	204
41	67	58	20	208	110
203	167	233	113	222	232
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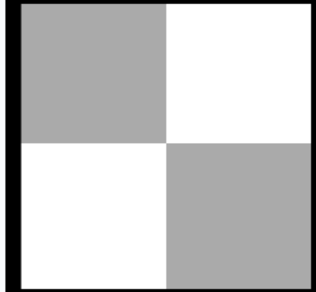
Four rectangle Haar feature - what is the feature value?



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41	67	58	20	208	110
203	167	233	113	222	232
79	176	39	27	22	46
135	191	211	245	102	67

567

179

-611 ✓ 0%

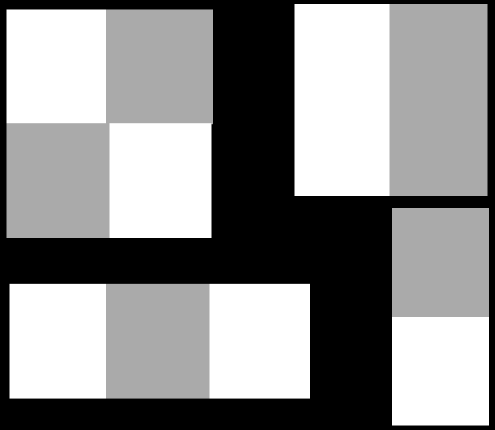
-113

76

I do not know

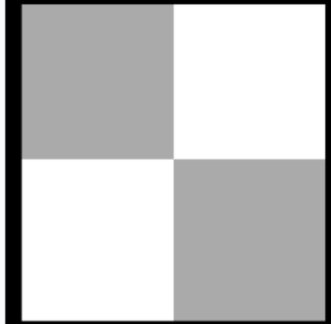
Fast computing of Haar features

24 x 24 pixels



- Even for small Haar features, there are quite a lot of basic operations
- The larger the Haar feature, the more operations
- We need a fast way to compute Haar features

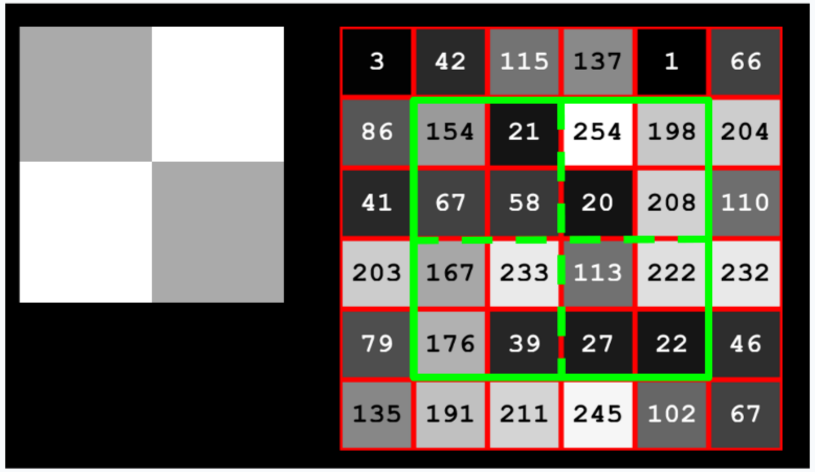
How many basic operations (plus and minus) are needed to compute the feature?



3	42	115	137	1	66
86	154	21	254	198	204
41	67	58	20	208	110
203	167	233	113	222	232
79	176	39	27	22	46
135	191	211	245	102	67

- 15
- 6
- 9
- 21
- 3
- I do not know

How many basic operations (plus and minus) are needed to compute the feature?



15

6

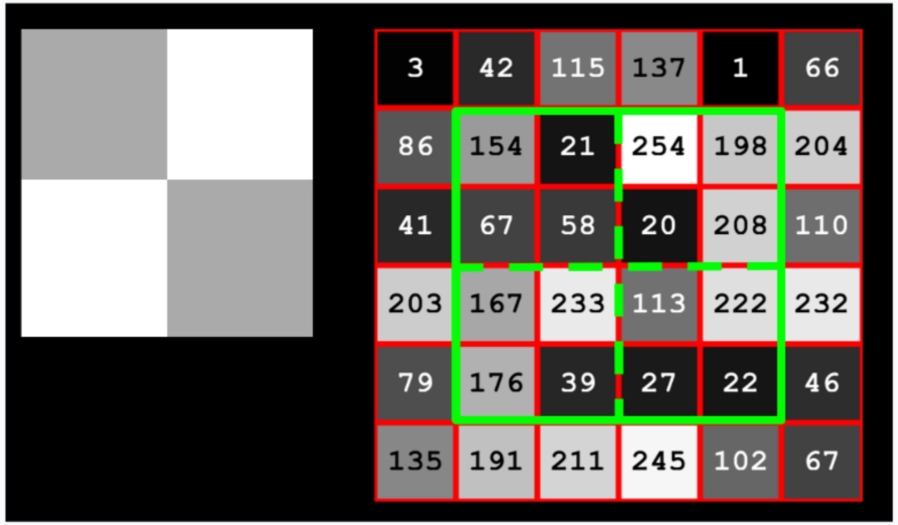
9

21

3

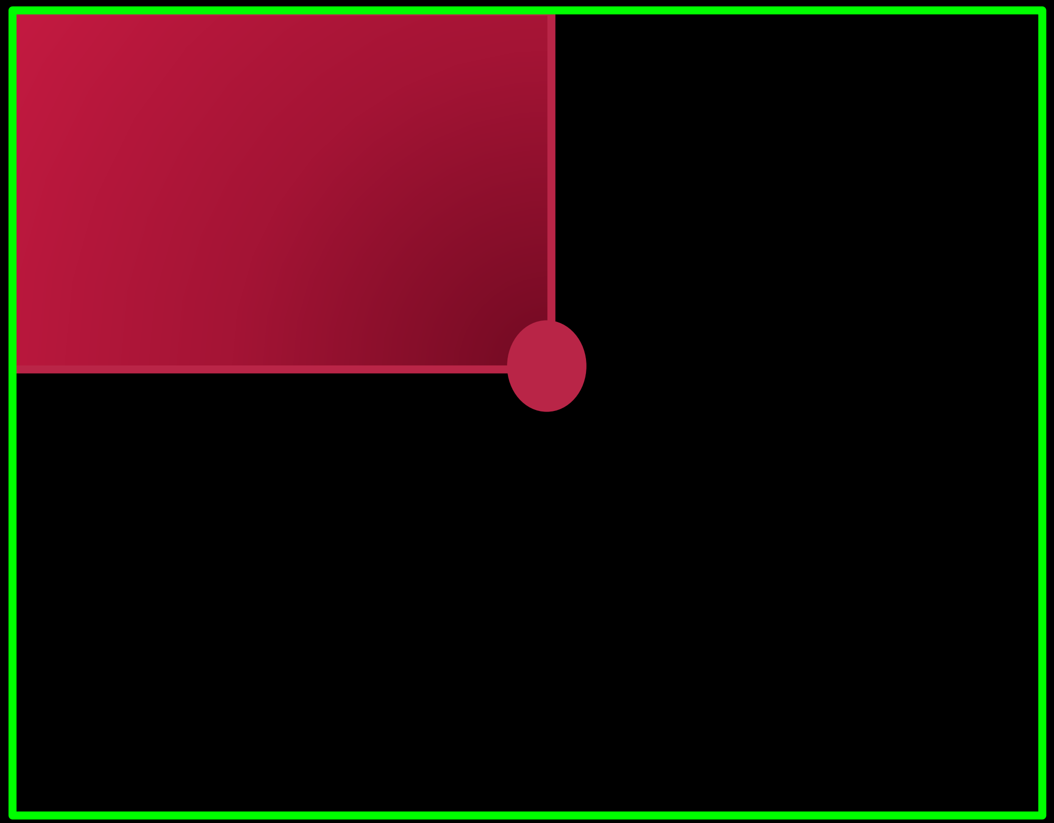
I do not know

How many basic operations (plus and minus) are needed to compute the feature?



- 15 ✓ 0%
- 6
- 9
- 21
- 3
- I do not know

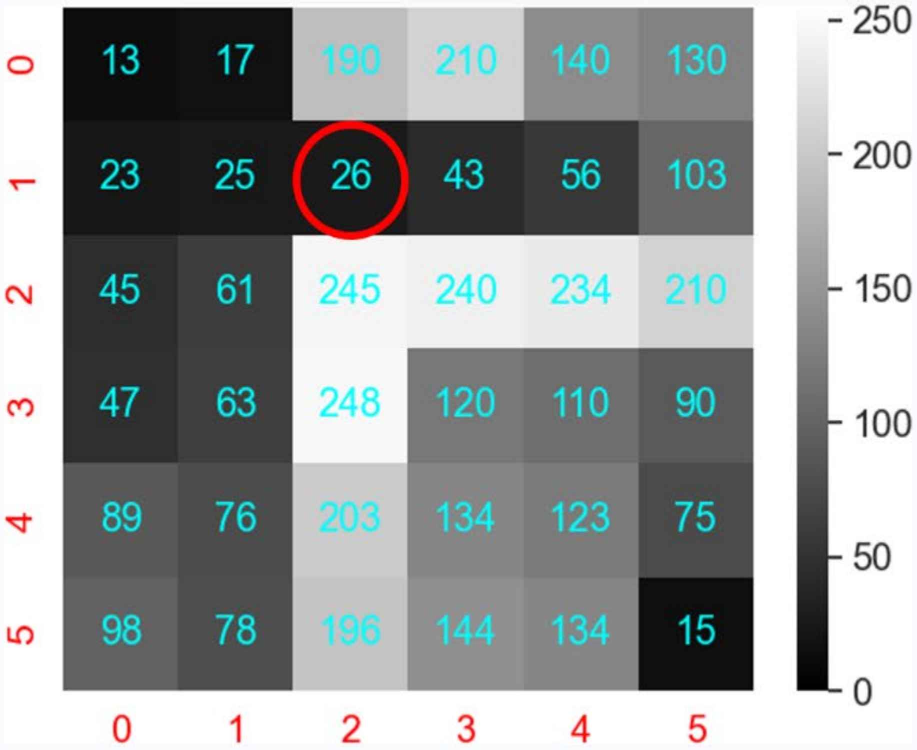
Fast computation of Haar features – the integral image



- In an integral image the pixel value is:
  - The sum of pixel above it and to the left of it in the original image
  - Including the pixel itself

- Can be computed very fast

Computing the integral image - what is the value in the marked pixel?



- 15
- 134
- 198
- 294
- 315
- Do not know

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Computing the integral image - what is the value in the marked pixel?

	0	1	2	3	4	5
0	13	17	190	210	140	130
1	23	25	26	43	56	103
2	45	61	245	240	234	210
3	47	63	248	120	110	90
4	89	76	203	134	123	75
5	98	78	196	144	134	15

250
200
150
100
50
0

15

134

198

294

315

Do not know

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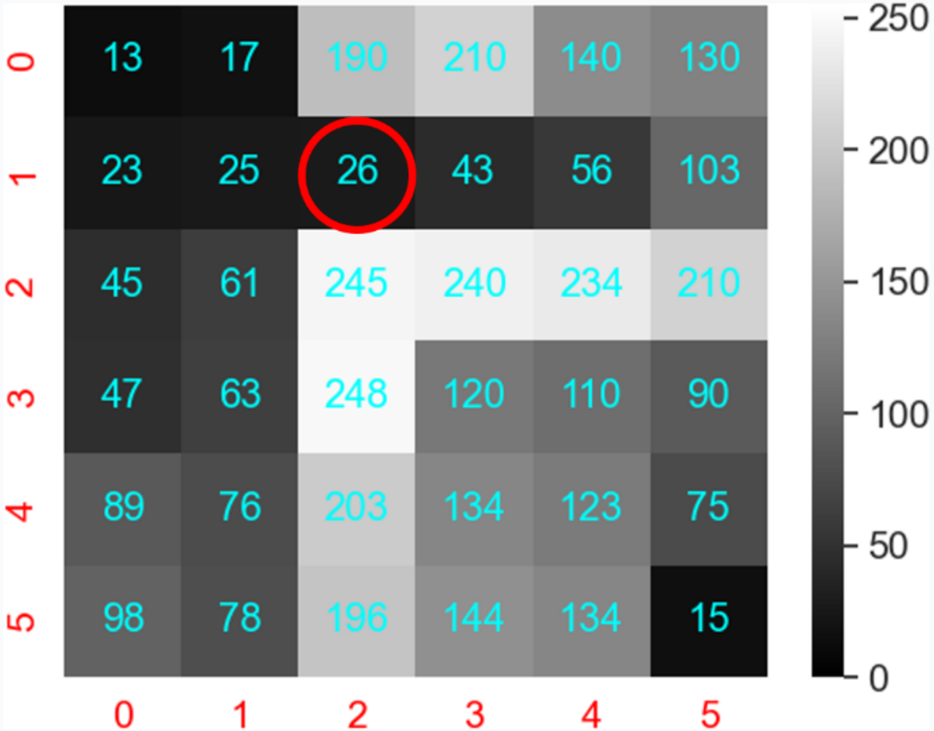
Computing the integral image - what is the value in the marked pixel?



15

134

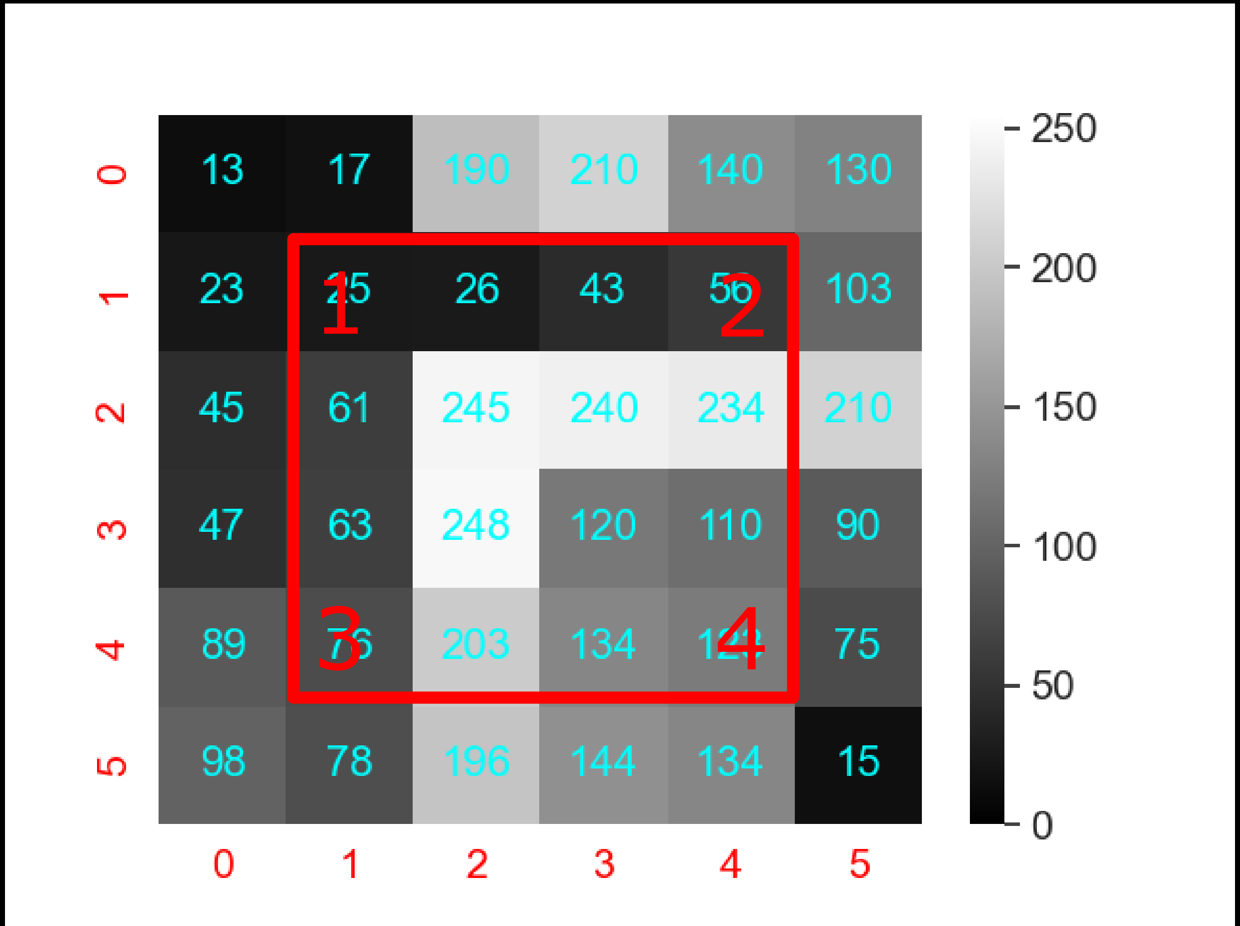
198

294

315

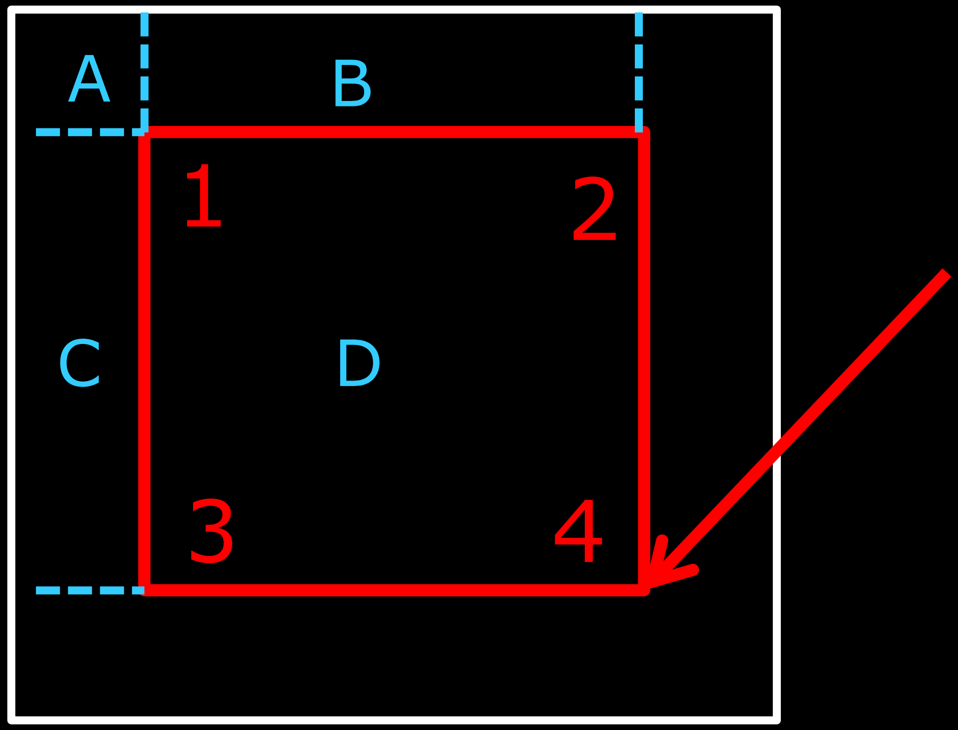
Do not know

Using the integral image



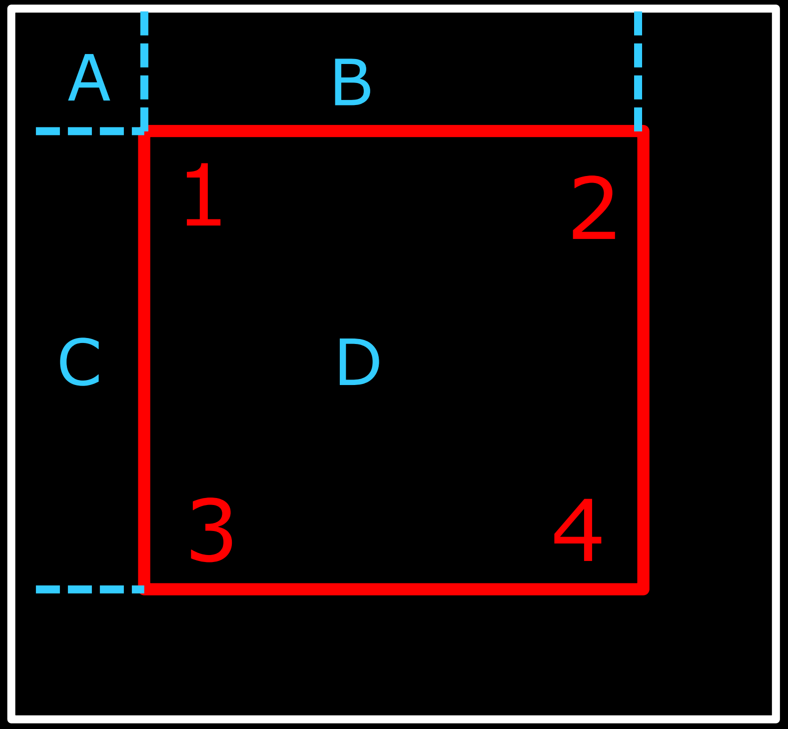
- We want to compute the pixel sum in the rectangle
- Defined by four corners: 1, 2, 3, 4

Using the integral image



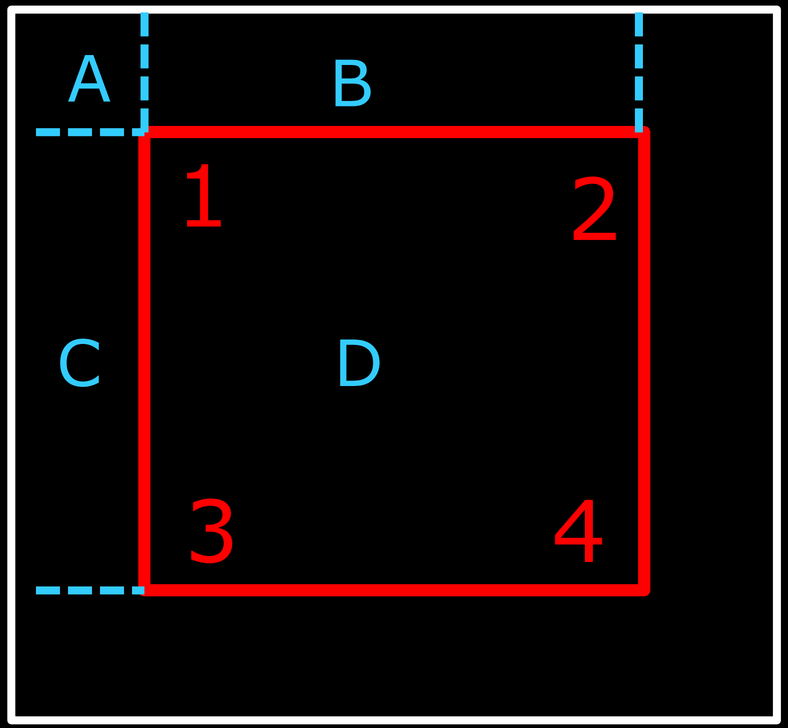
- Define four regions:
  - A, B, C, D
- The sum of pixels in the area
  - A+B+C+D is the value of the integral image at point 4

Using the integral image



- The sum of pixels in the area
  - A+B is the value of the integral image at point 2
  - A+C is the value of the integral image at point 3

Using the integral image – short notation

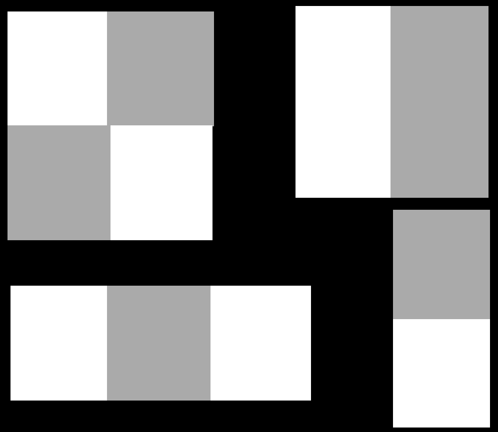


- The sum of pixels in the area
  - ii(2) = A+B
  - ii(3) = A+C
  - ii(4) = A+B+C+D
  - ii(1) = A

  - ii(4)-ii(3)-ii(2) = D – A
- ii(4)-ii(3)-ii(2)+ii(1) = D

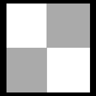
Haar features in an image window

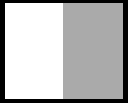
24 x 24 pixels

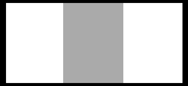


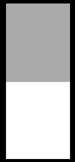
- Image window of 24 x 24 pixels
- All possible sizes and shapes of Haar features
- More than 180.000 features according to Viola and Jones
- They are *overcomplete* – meaning there is a very high redundancy
- We need *feature selection*

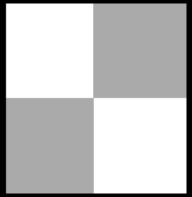
Possible features

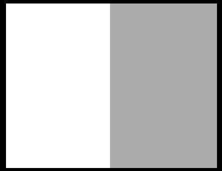
$f_1 =$ 

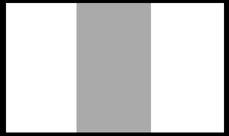
$f_2 =$ 

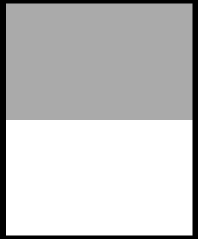
$f_3 =$ 

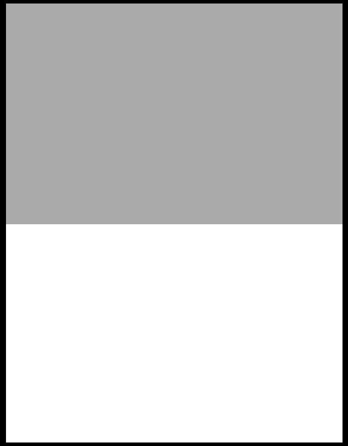
$f_4 =$ 

$f_5 =$ 

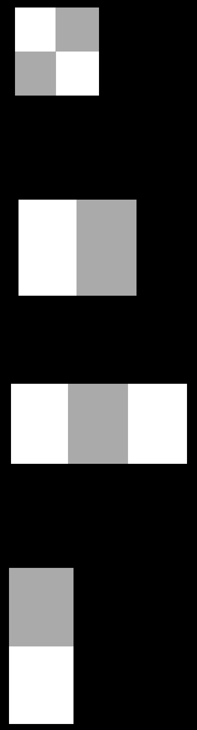
$f_6 =$ 

$f_7 =$ 

$f_8 =$ 

$\cdots \quad f_{180000} =$ 

Feature selection – from the article



- There are over 180,000 rectangle features associated with each image sub-window, a number far larger than the number of pixels.
- Even though each feature can be computed very efficiently, computing the complete set is prohibitively expensive.
- Our hypothesis, which is borne out by experiment, is that a very small number of these features can be combined to form an effective classifier.
- The main challenge is to find these features

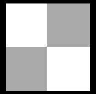
Learning Classification Functions

Weak classifier

$$h_j(x) = \begin{cases} 1 \text{ if } & p_j f_j(x) < p_j \theta_j \\ & 0 \text{ otherwise} \end{cases}$$

$x =$ 

24 x 24 sub-window

$f_j =$ 

Feature value computed on the sub-window

$p_j \in [-1, 1]$

Parity – determines if the feature value should be positive or negative

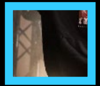
θ_j

Feature threshold

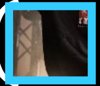
Weak classifier

$$h_j(x) = \begin{cases} 1 \text{ if } & p_j f_j(x) < p_j \theta_j \\ & 0 \text{ otherwise} \end{cases}$$

$x =$ 

$f_j($  $) =$  $= 2049$

Learnt by training: $p_j = 1 \qquad \theta_j = 456$

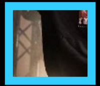
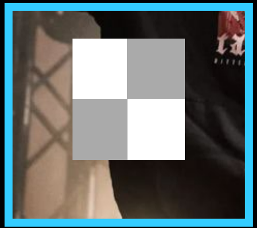
$\rightarrow 1 * 2049 < 1 * 456 \rightarrow h_j($  $) = 0$

What is this parity?

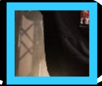
Weak classifier

$$h_j(x) = \begin{cases} 1 \text{ if } & p_j f_j(x) < p_j \theta_j \\ & 0 \text{ otherwise} \end{cases}$$

$x =$ 

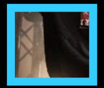
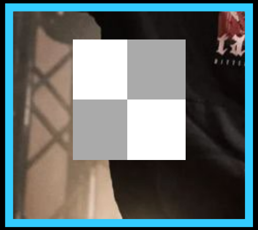
$f_j($  $) =$  $= 2049$

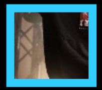
Learnt by training: $p_j = -1$ $\quad \theta_j = 456$

$\rightarrow -1 * 2049 < -1 * 456 \rightarrow h_j($  $) = 1$

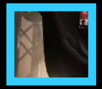
Creating a strong classifier from weak classifiers

$$h(x) = \begin{cases} 1 & \sum_{t=1}^{T} \alpha_t h_t(x) \geq \frac{1}{2} \sum_{t=1}^{T} \alpha_t \\ 0 & \text{otherwise} \end{cases}$$

$h_1($  $) =$ 

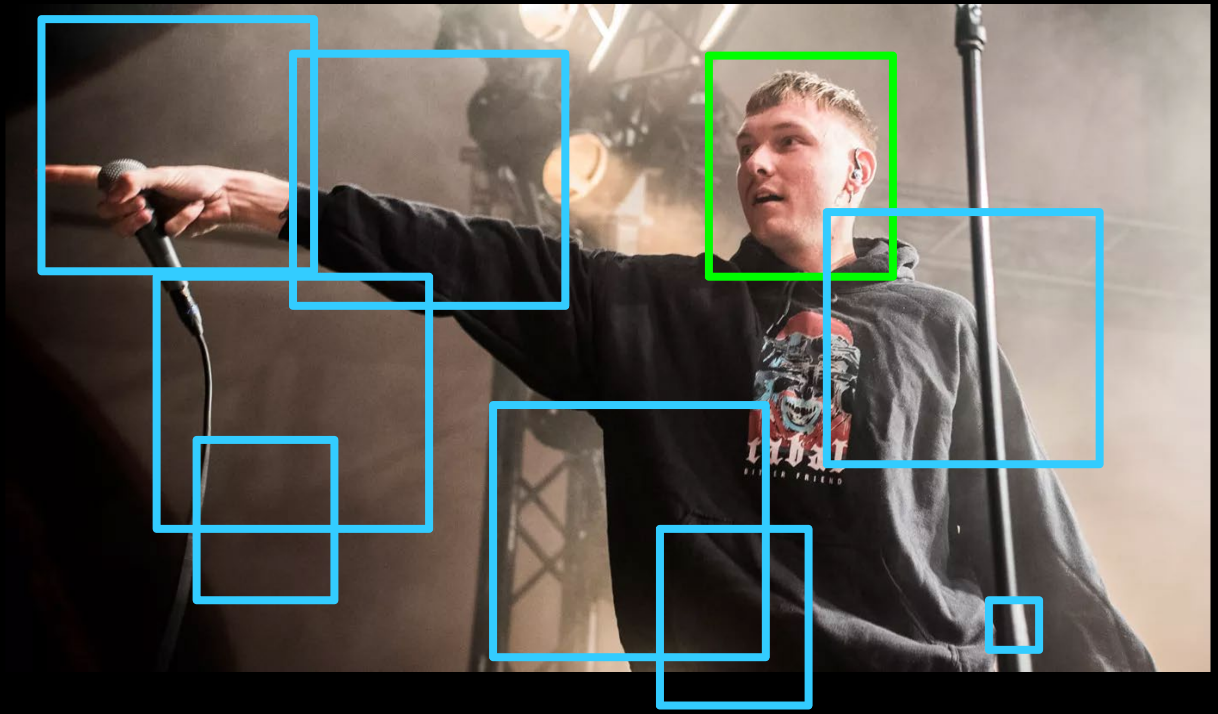
$h_2($  $) =$ 

...

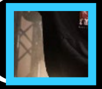
$h($  $) = \alpha_1 h_1 + a_2 h_2 + \cdots + a_T h_T$

Learnt using AdaBoost

Boosted features – good performance but not enough



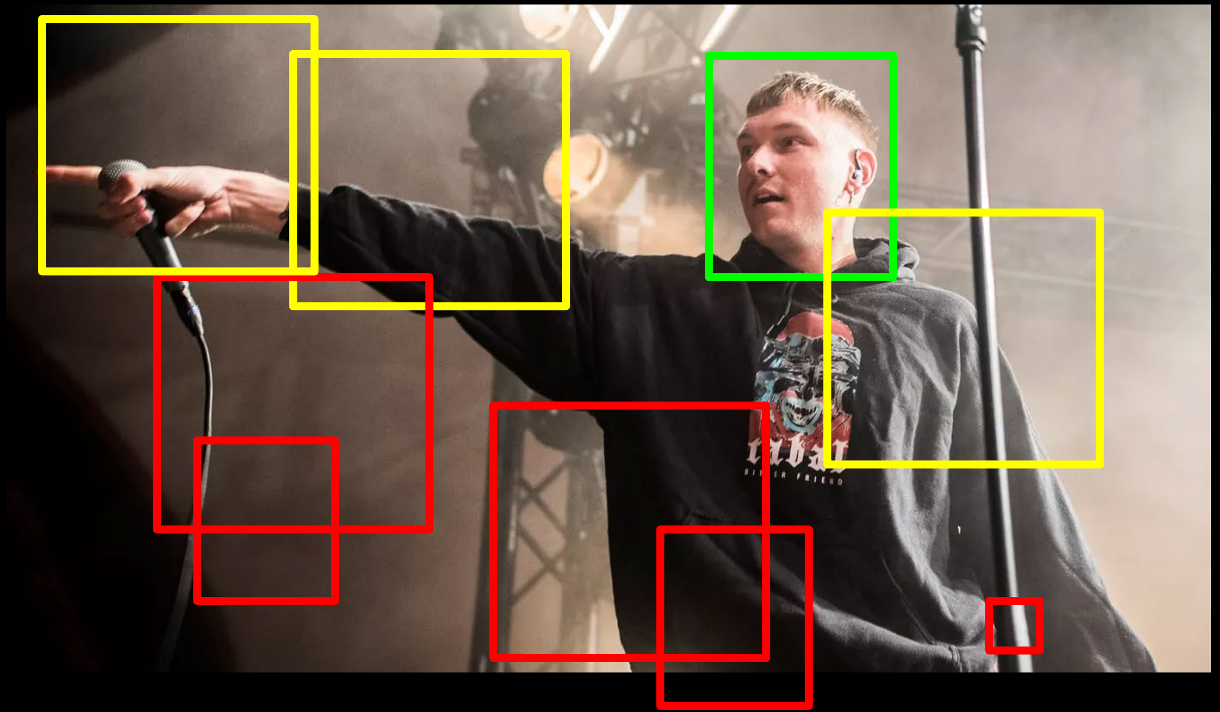
- Frontal face classifier with
  - T=200 features
  - Detection rate 95%
  - False positives 1 in 14084
  - 0.7 seconds for a 384 x 288

$h_1($  $) = \alpha_1 h_1 + a_2 h_2 + \cdots + a_T h_T$

The Attentional Cascade

Image Attention

- The process of focusing on specific parts of an image
  - Followed by fine grained analysis of selected windows

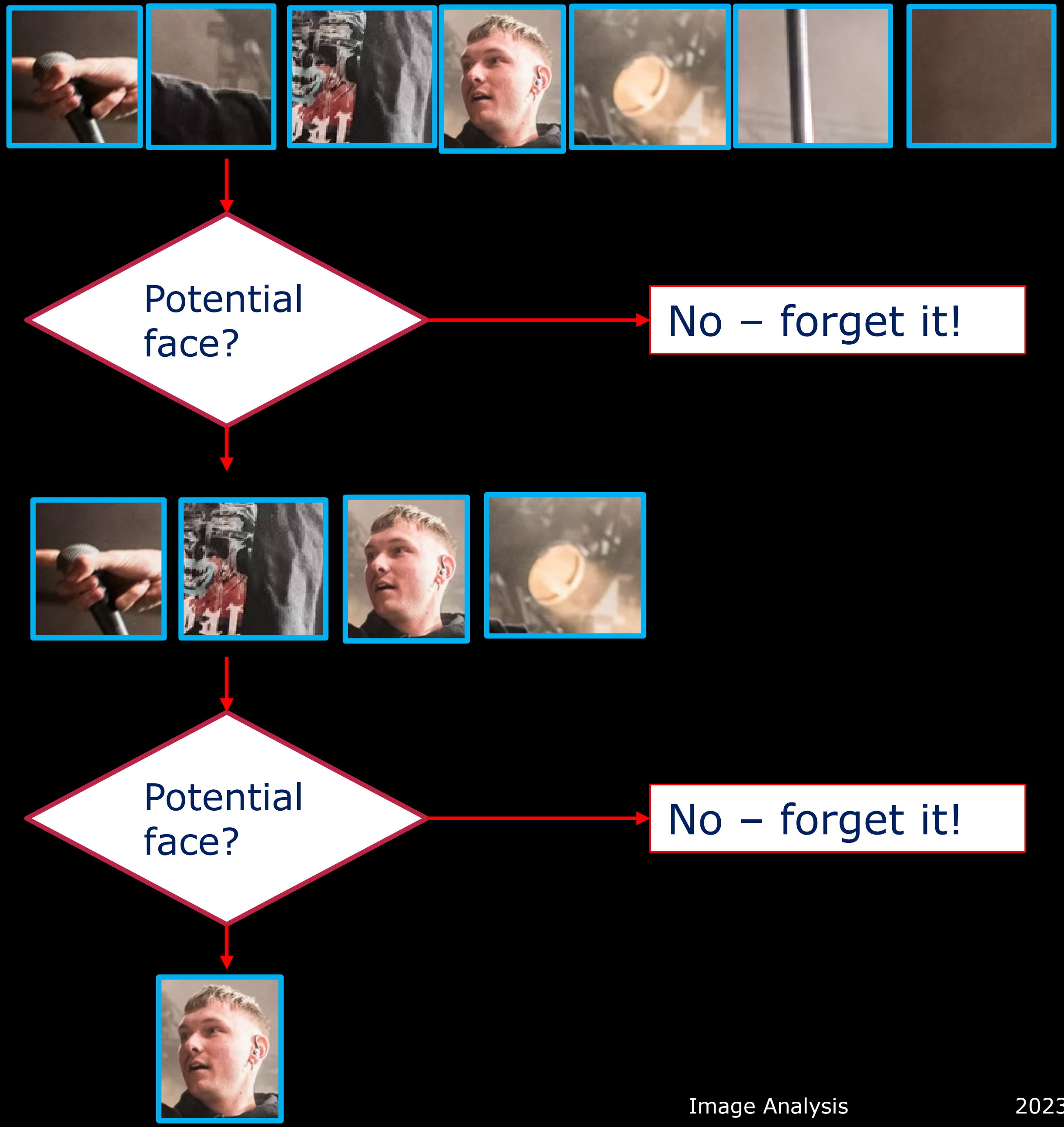


Focusing on potential face regions

Cascaded classifier

Also called a *degenerate decision* tree

Input image windows



What is a false negative?

- A face window classifed as face window
- A background window classified as a face window
- A face window classified as a background window
- A background window classified as a background window
- I do not know

What is a false negative?

A face window classifed as face window

A background window classified as a face window

A face window classified as a background window

A background window classified as a background window

I do not know

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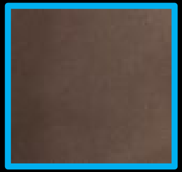
What is a false negative?

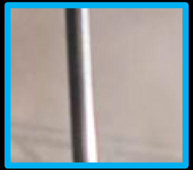
A face window classifed as face window	
A background window classified as a face window	
A face window classified as a background window	✓ 0%
A background window classified as a background window	
I do not know	

Start the presentation to see live content. For screen share software, share the entire screen. Get help at **pollev.com/app**

The attentional cascade

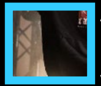
- Quickly reject negative sub-windows
  - Detect almost all positive sub-windows
  - False-negatives close to zero
    - Keep all potential face windows
  - Using the training set to find weights that fulfils this criterion



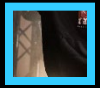


- Later more complex classifier
  - Low false positive rate

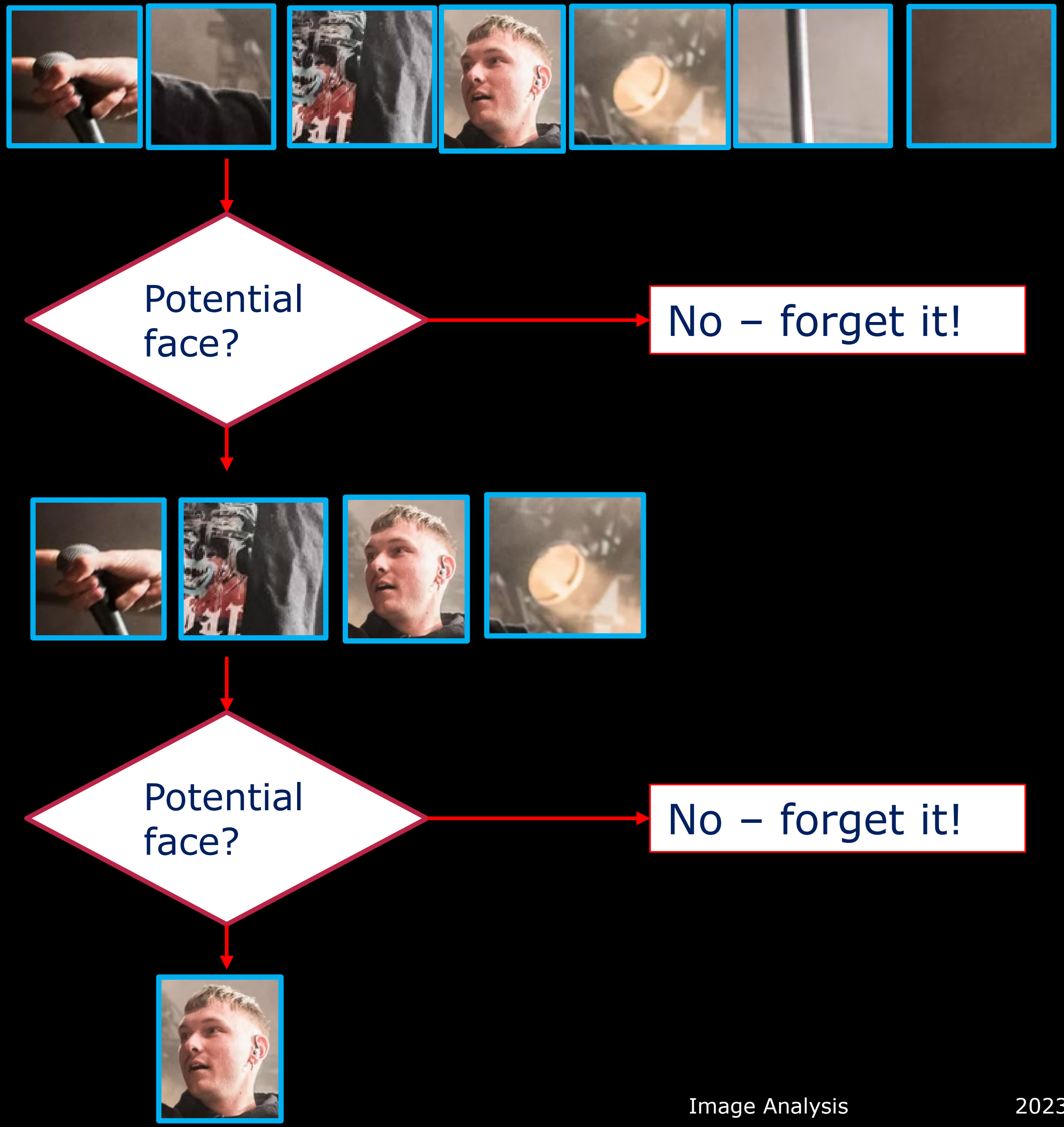
Training a cascade

$h($$) = \alpha_1 h_1 + a_2 h_2 + \cdots + a_T h_T$

Learnt using AdaBoost

$h($$) = \alpha_1 h_1 + a_2 h_2 + \cdots + a_T h_T$

Learnt using AdaBoost

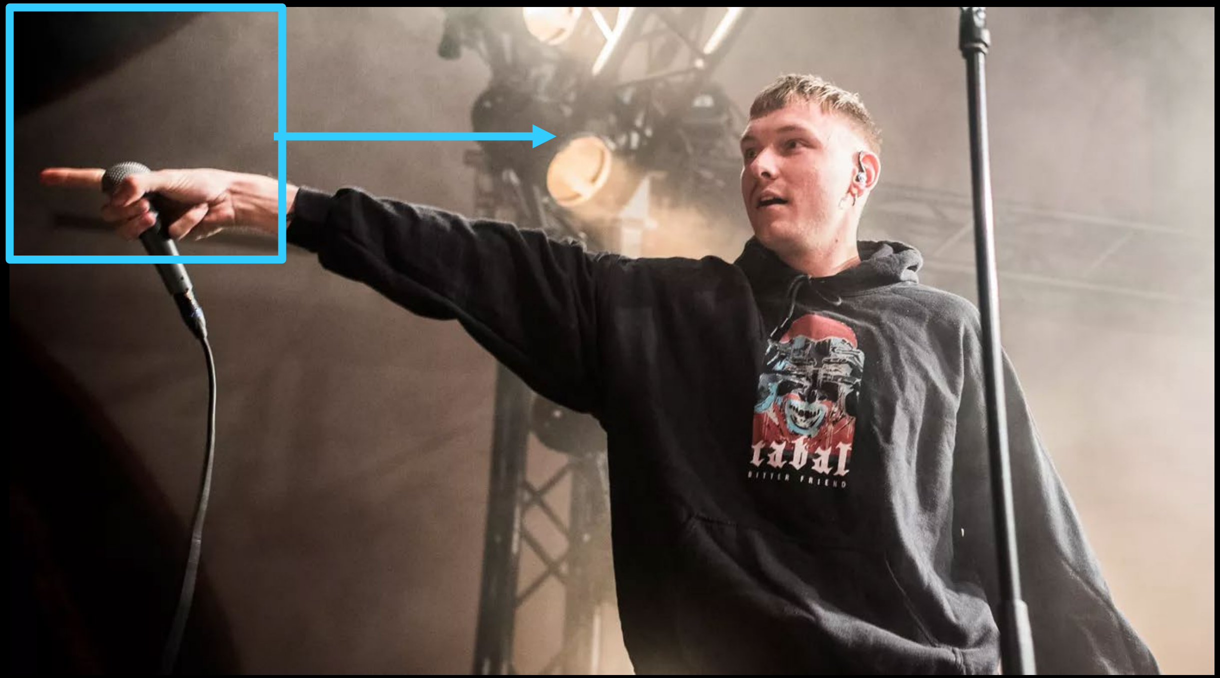


First stage classifier

Final classifier

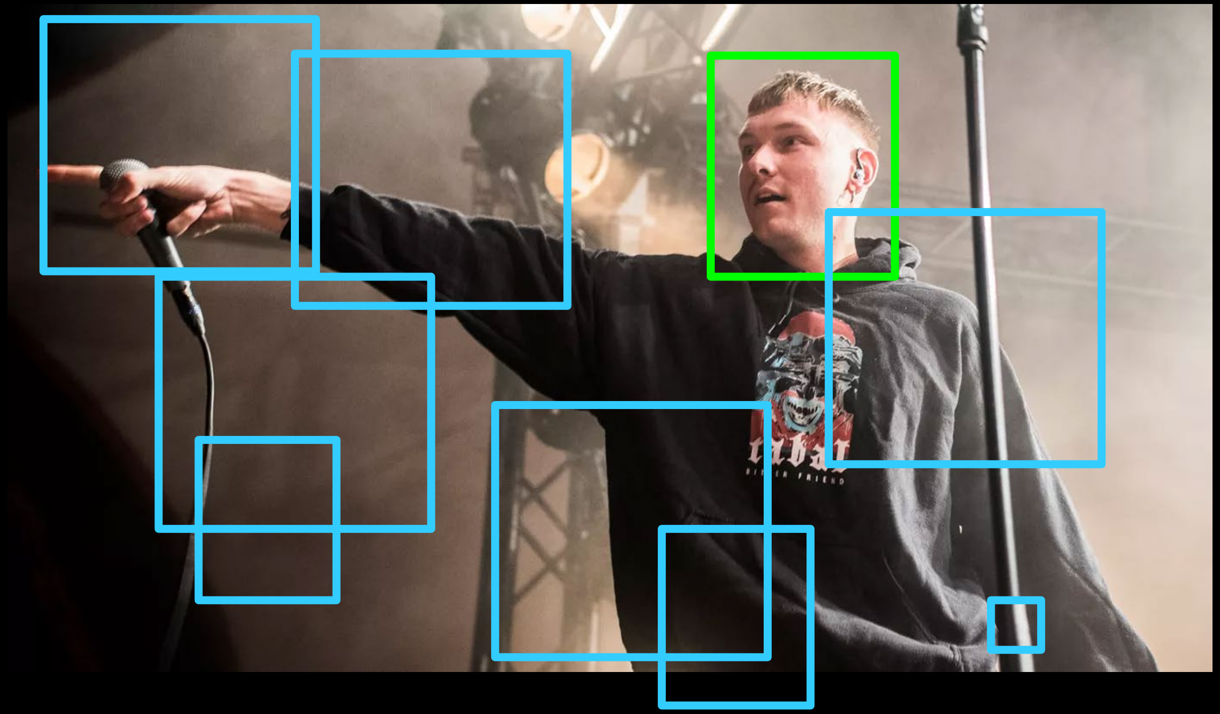
- 38 stages (step in the cascade)
- Total 6000 features (over the entire cascade)
- Faces are detected using on average 10 features per sub-window

Finding all faces in an image



- Slide a sub-window over the entire image
- Do a face detection for all positions
- Scale the features in a certain interval
  - To find faces of different sizes

Conclusion



- One of the most important algorithms before deep learning
- Uses many interesting concepts
  - Attention
  - Boosted weak classifiers
  - Very fast feature computation

Demo

Next week

- Statistical models of shape and appearance