



Image Analysis

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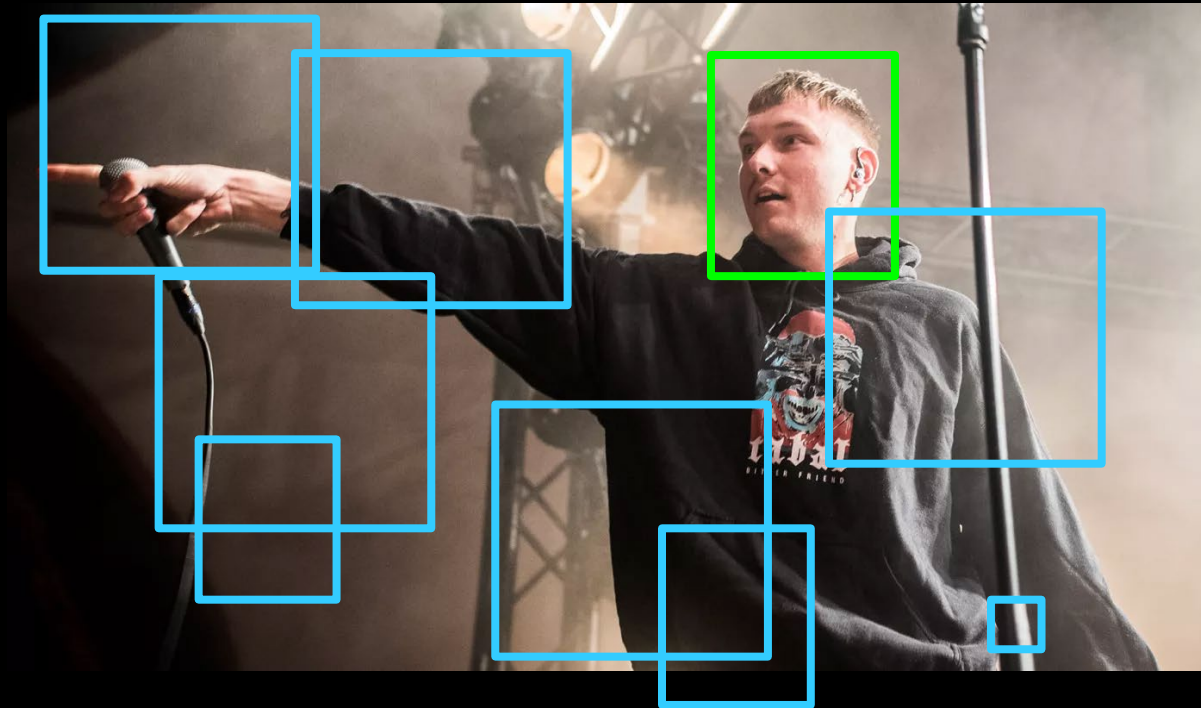
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Lecture 11 – Face detection using the Viola Jones method





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

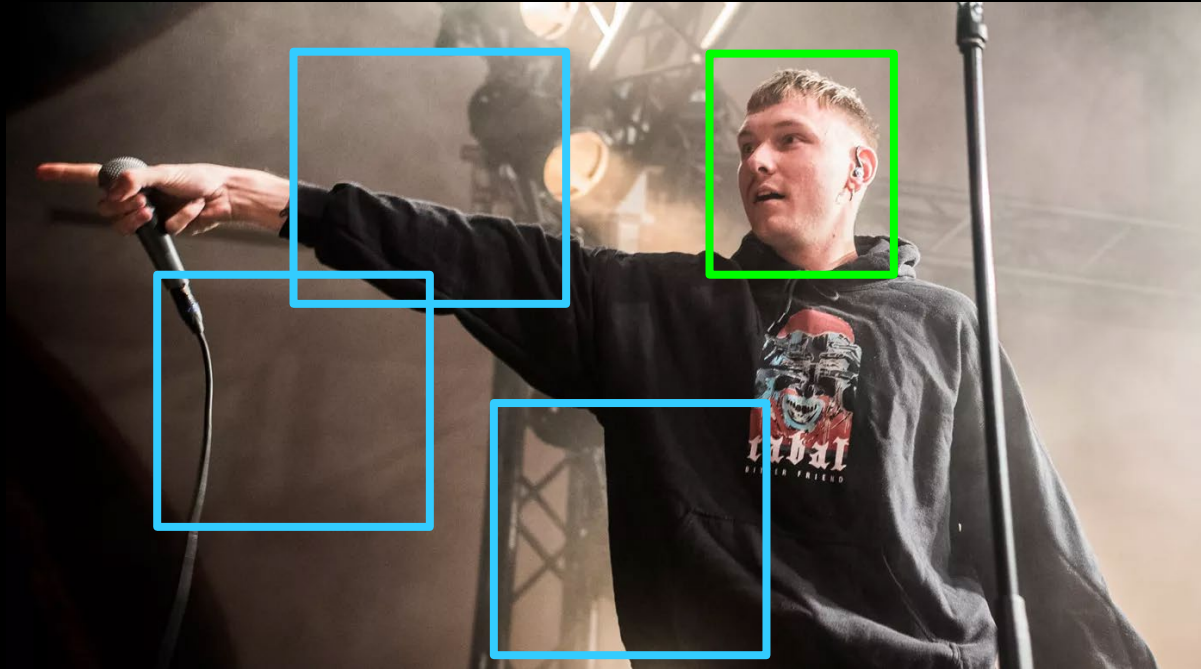
Face detection



■ First problem

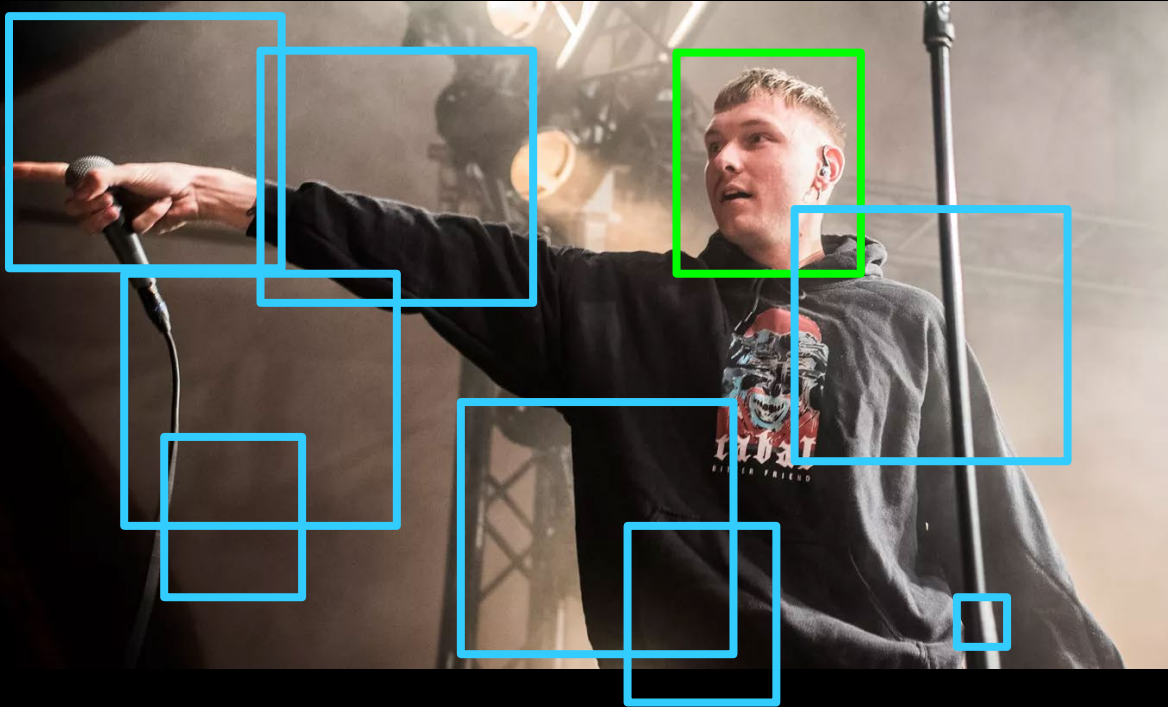
- Analyze a **window** in an image
- Is there a face in that window?

Face detection



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

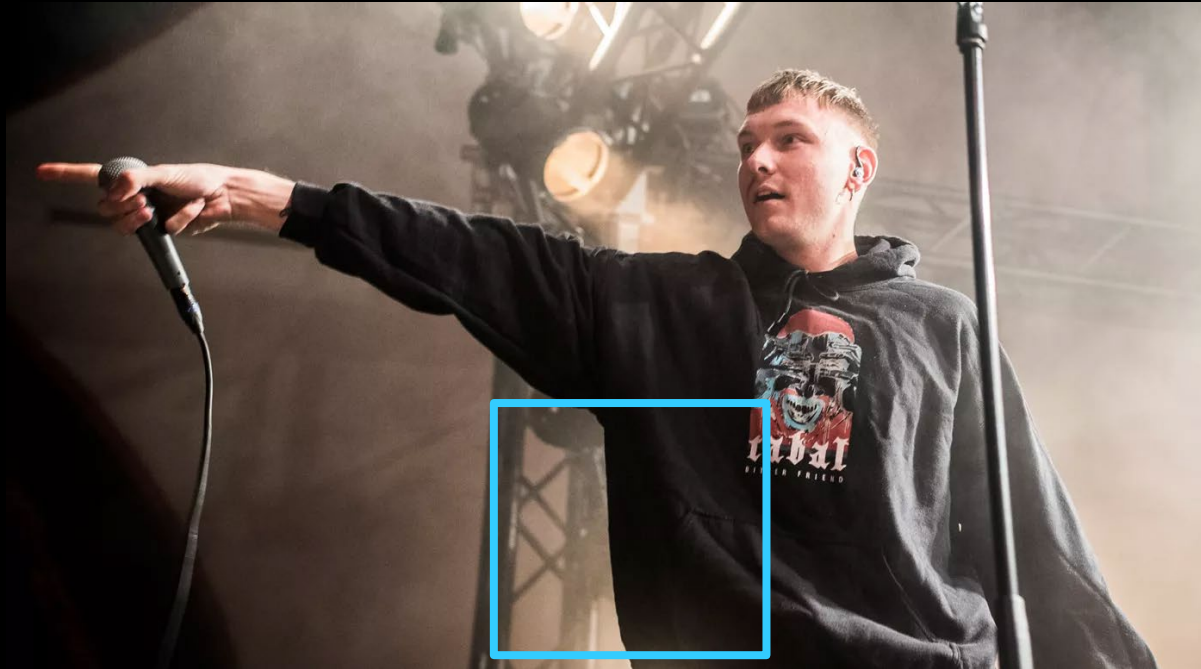
Face detection



■ 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

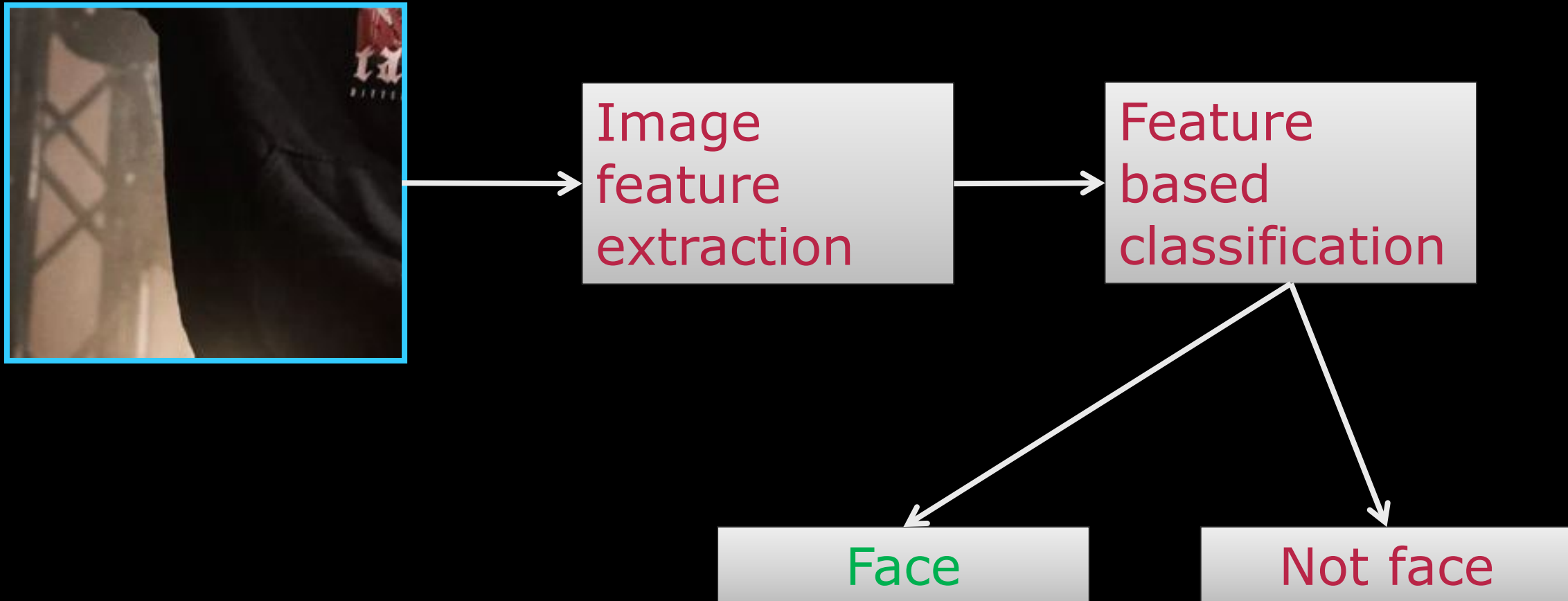
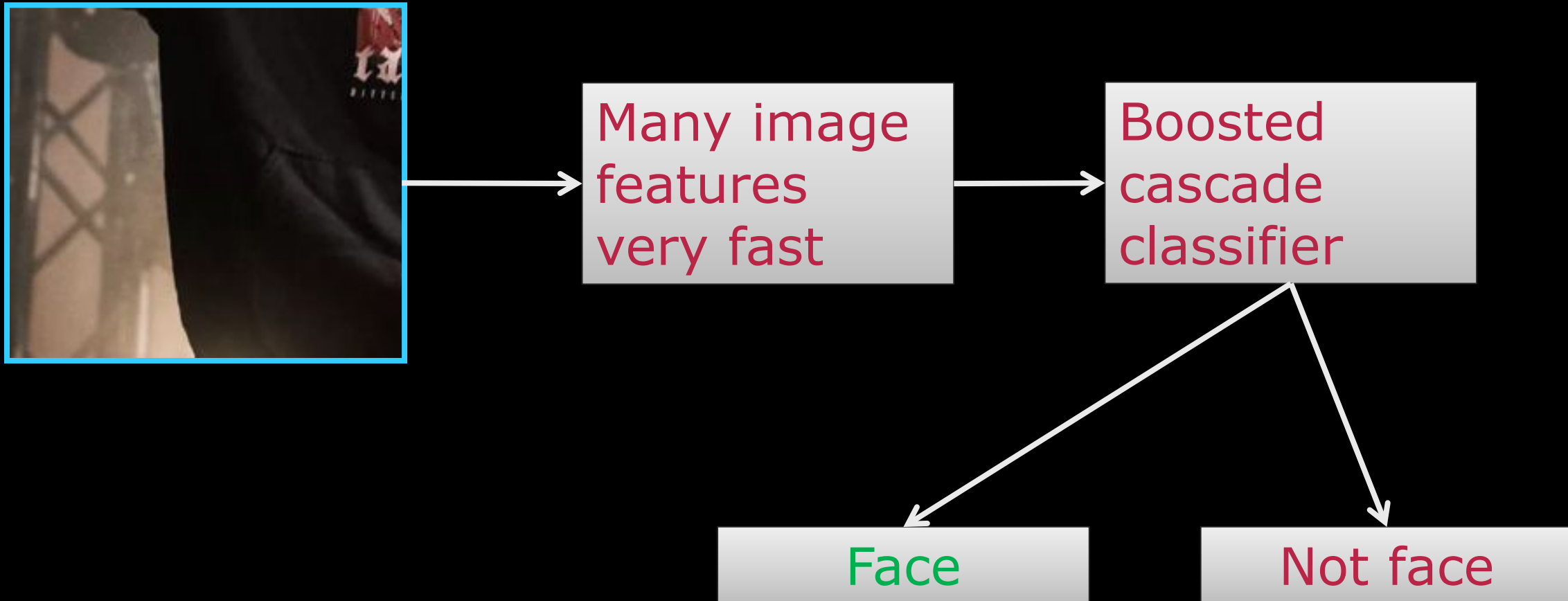


Image based features - what features can you think of?



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Viola Jones – fast features and smart classification



Training data



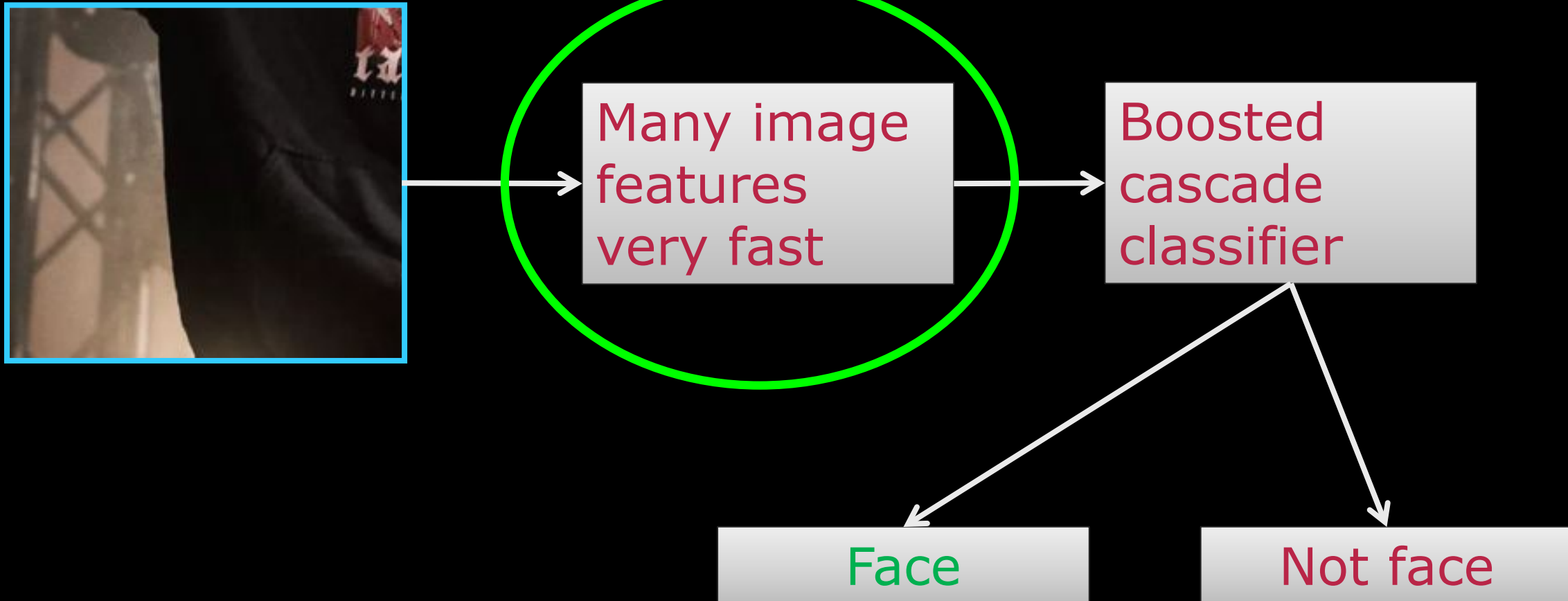
■ Face images:

- 4916 hand labelled faces
- Aligned and scaled to 24x24 pixels

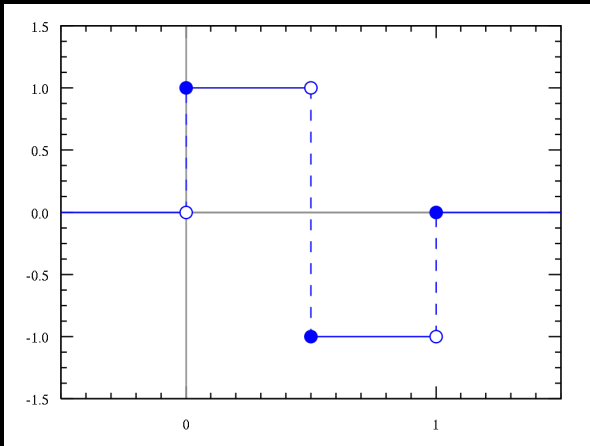
■ Non-face images:

- 9544 images with no faces
- 350 million sub-windows sampled from these

Viola Jones – fast features and smart classification



Haar features



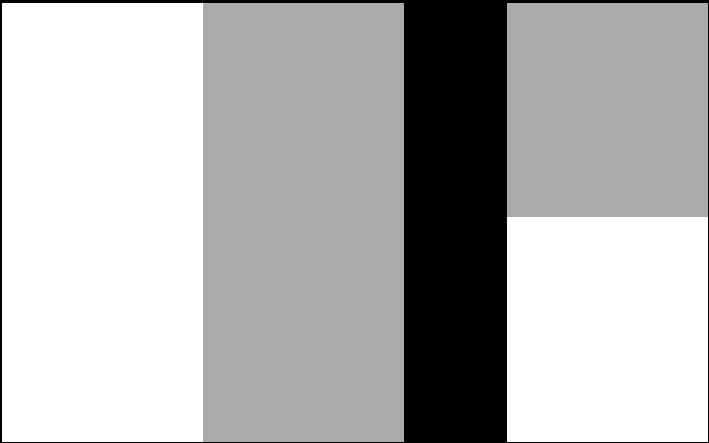
https://en.wikipedia.org/wiki/Haar_wavelet

- 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

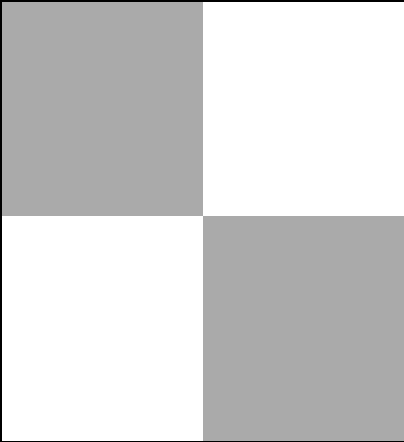
B

Three rectangle feature



C

Four rectangle feature



D

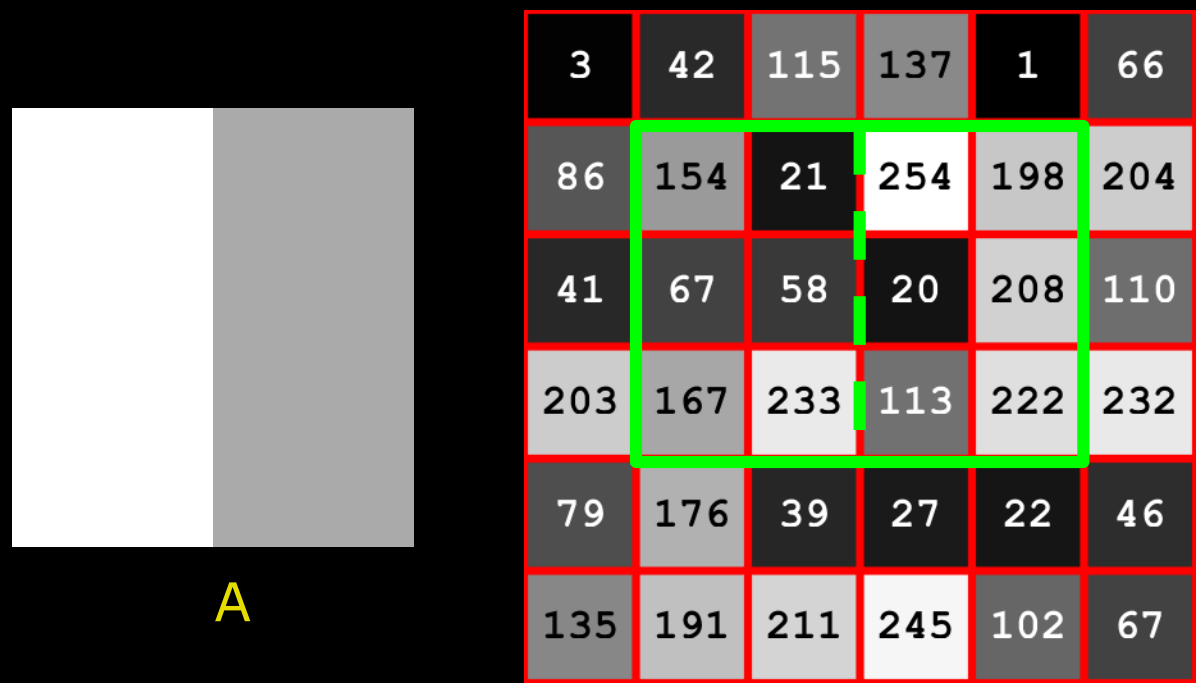
Feature =

Sum of
pixel
values
in image

-

Sum of
pixel
values
in image

One Haar feature



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

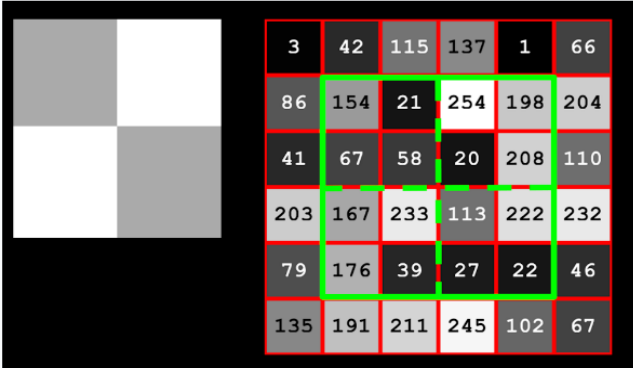
-113

76

I do not know

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Four rectangle Haar feature - what is the feature value?



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Four rectangle Haar feature - what is the feature value?



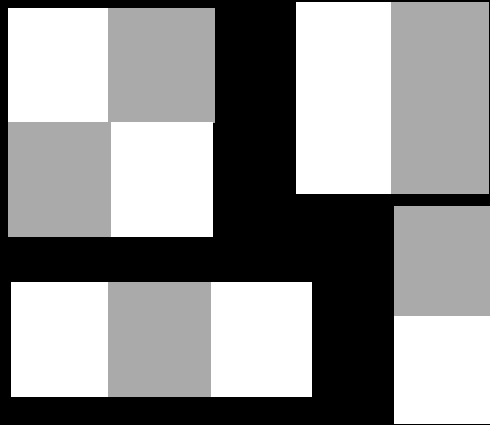
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Fast computing of Haar features



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?

15

6

9

21

3

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



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



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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?



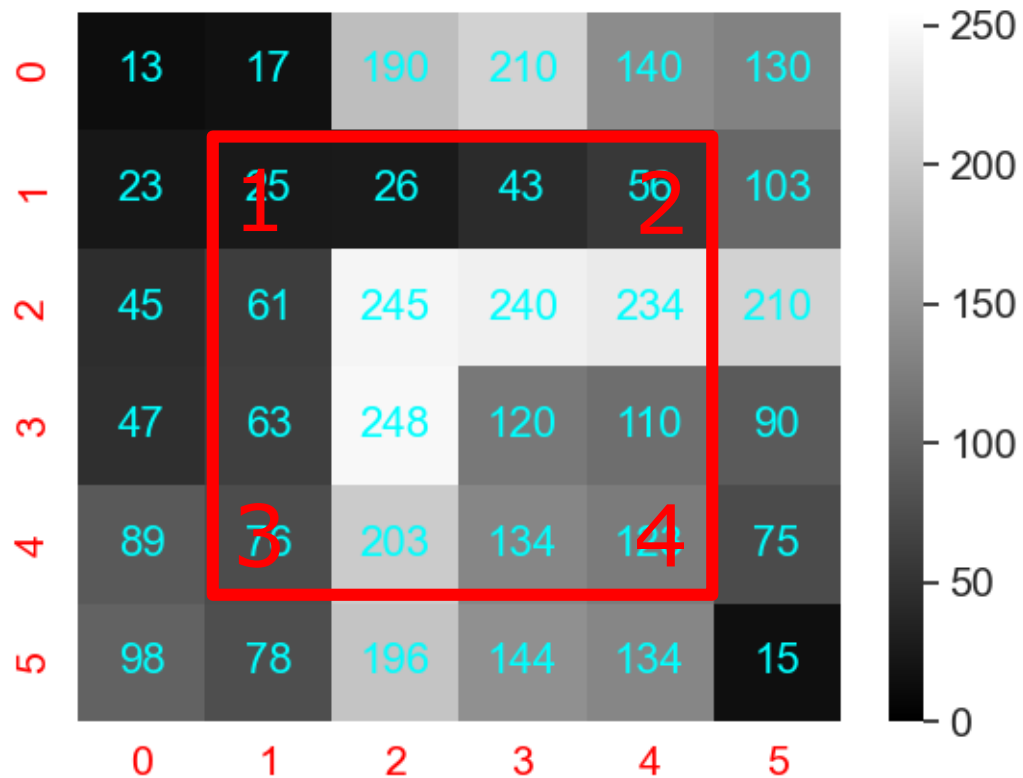
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Computing the integral image - what is the value in the marked pixel?

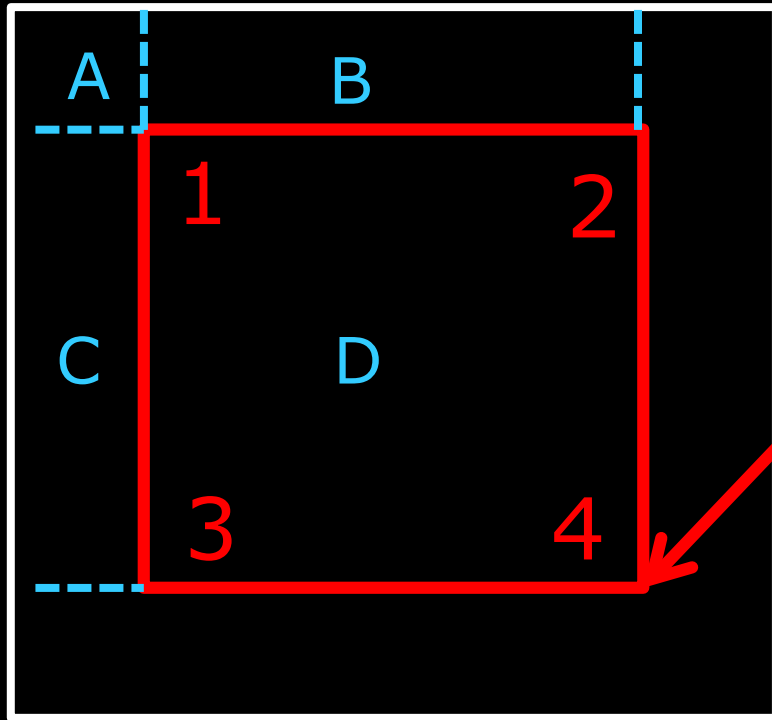


Using the integral image



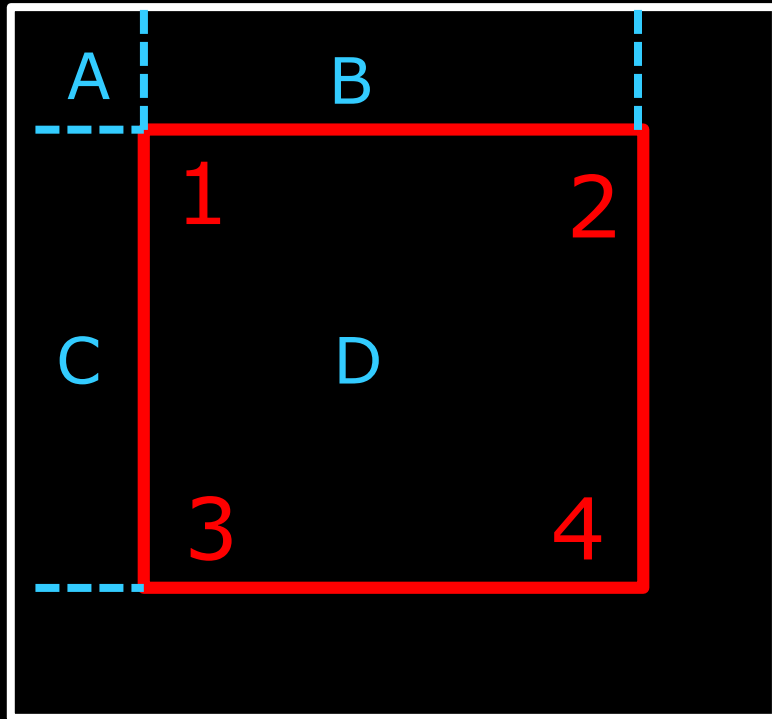
- We want to compute the pixel sum in the rectangle
- Defined by four corners: 1, 2, 3, 4

Using the integral image



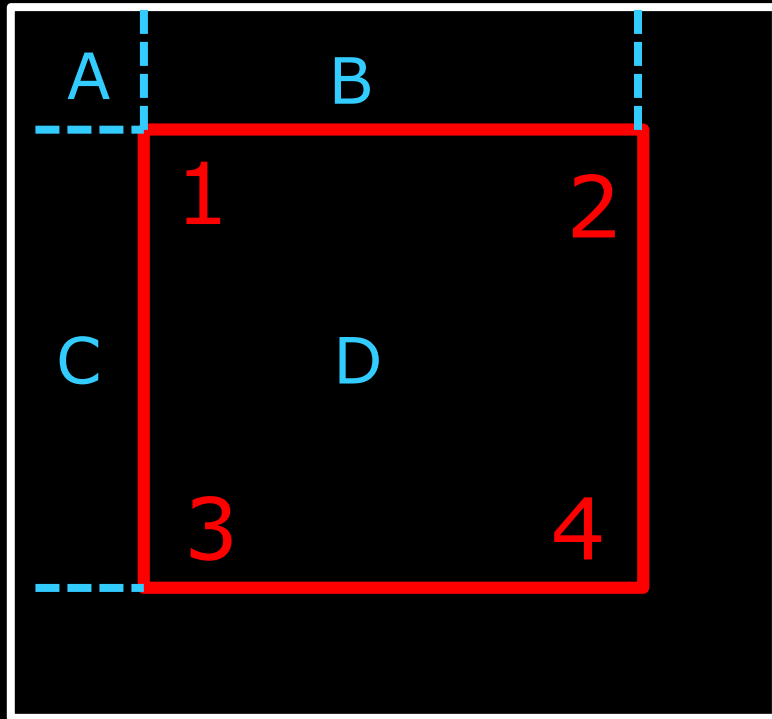
- Define four regions:
 - A, B, C, D
- The sum of pixels in the area
 - $A+B+C+D$ is the value of the integral image at point 4

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

– $ii(2) = A+B$

– $ii(3) = A+C$

– $ii(4) = A+B+C+D$

– $ii(1) = A$

– $ii(4)-ii(3)-ii(2) = D - A$

■ $ii(4)-ii(3)-ii(2)+ii(1) = D$

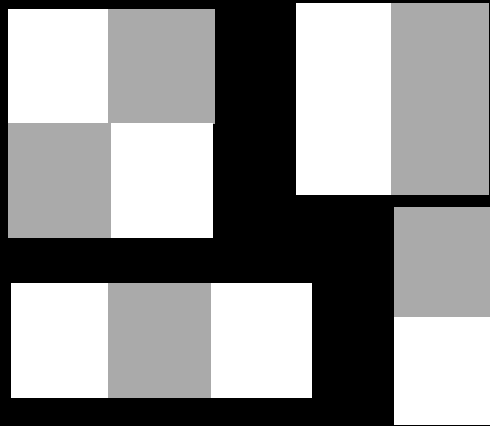
Course evaluation

- Very important to get your feedback on the course
- Please do it now – log into DTU Inside and fill in the evaluation
- What works well – so we should keep it and strengthen that part
- What can be improved and how?
- The question about “The teacher gave me feedback on my progress”
 - Very hard with large courses
 - We try with quizzes, TAs, exercise solutions

Haar features in an image window



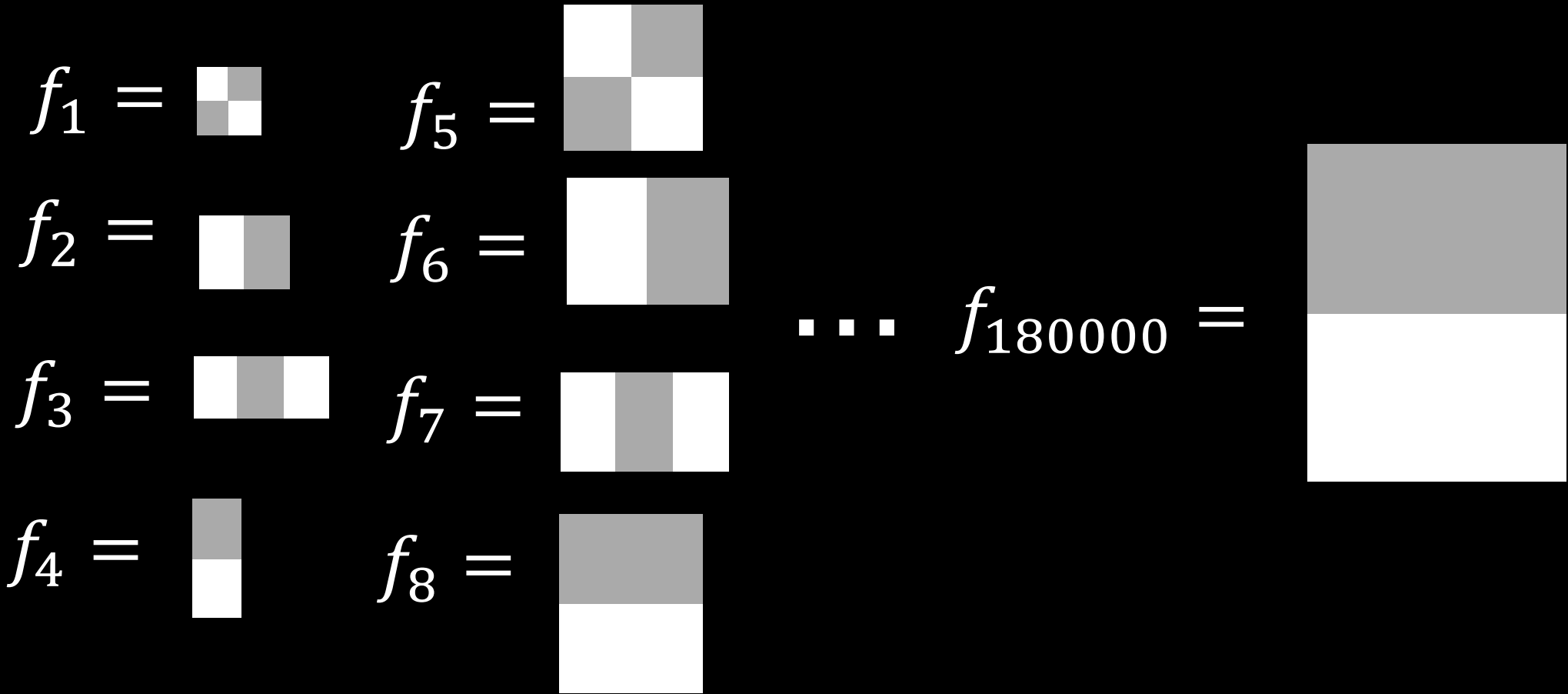
24 x 24 pixels



- 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



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



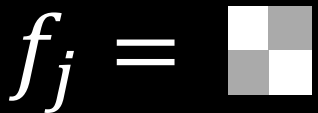
Learning Classification Functions

Weak classifier

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



24 x 24 sub-window



Feature value computed on the sub-window

$$p_j \in [-1, 1]$$

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

$$\theta_j$$

Feature threshold

Weak classifier

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

$$x = \text{[Image of a person's leg]} \quad f_j(\text{[Crop of leg]}) = \text{[4x4 Grayscale Feature Map]} = 2049$$

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

$$\rightarrow 1 * 2049 < 1 * 456 \rightarrow h_j(\text{[Crop of leg]}) = 0$$



What is this parity?

Weak classifier

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

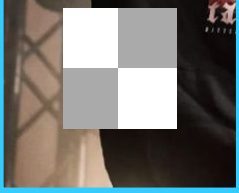
$$x = \text{[Image of a person's arm]} \quad f_j(\text{[Crop of image]}) = \text{[2x2 Grayscale Patch]} = 2049$$

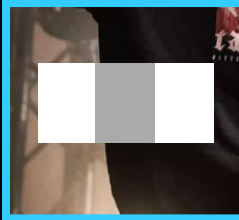
Learnt by training: $p_j = -1$ $\theta_j = 456$

$$\rightarrow -1 * 2049 < -1 * 456 \rightarrow h_j(\text{[Crop of image]}) = 1$$

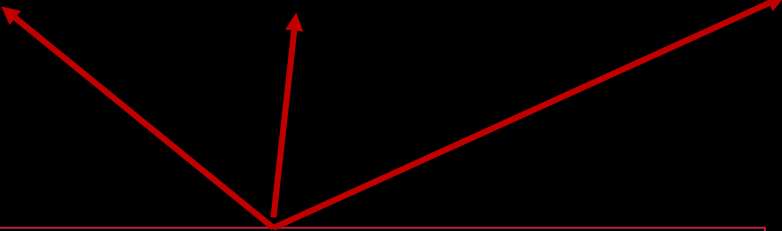
Creating a strong classifier from weak classifiers

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

$$h_1(\text{img}) = \text{img}$$


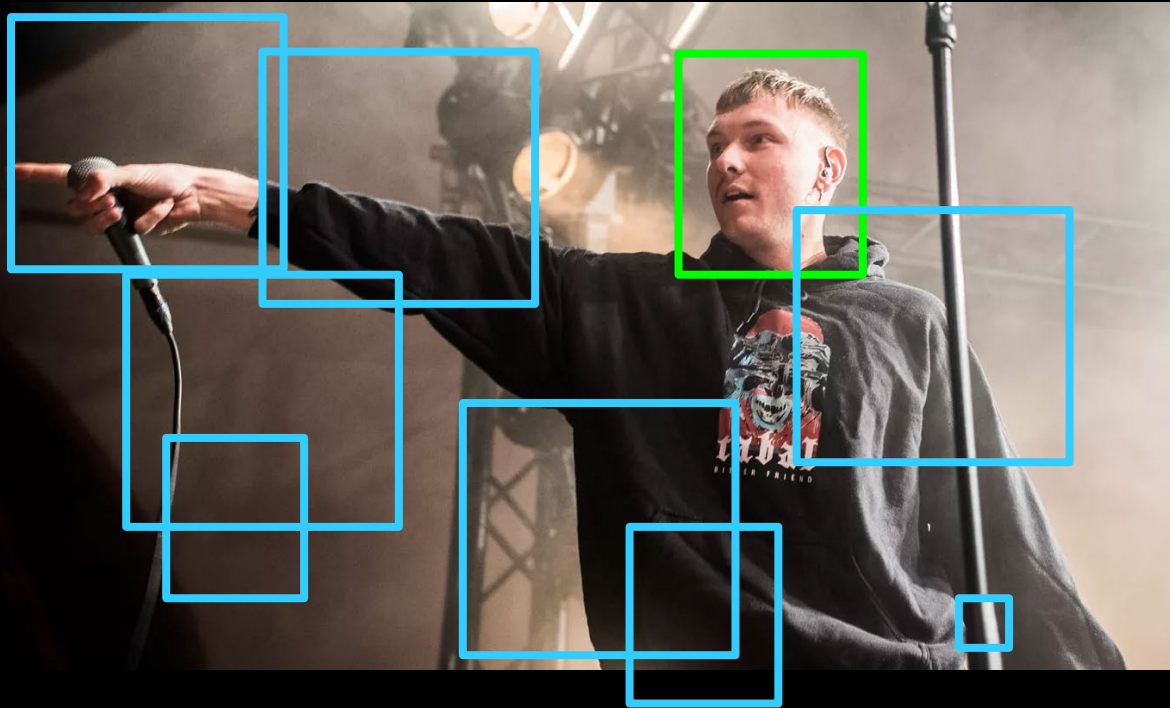
$$h_2(\text{img}) = \text{img}$$


...

$$h(\text{img}) = \alpha_1 h_1 + \alpha_2 h_2 + \dots + \alpha_T h_T$$


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

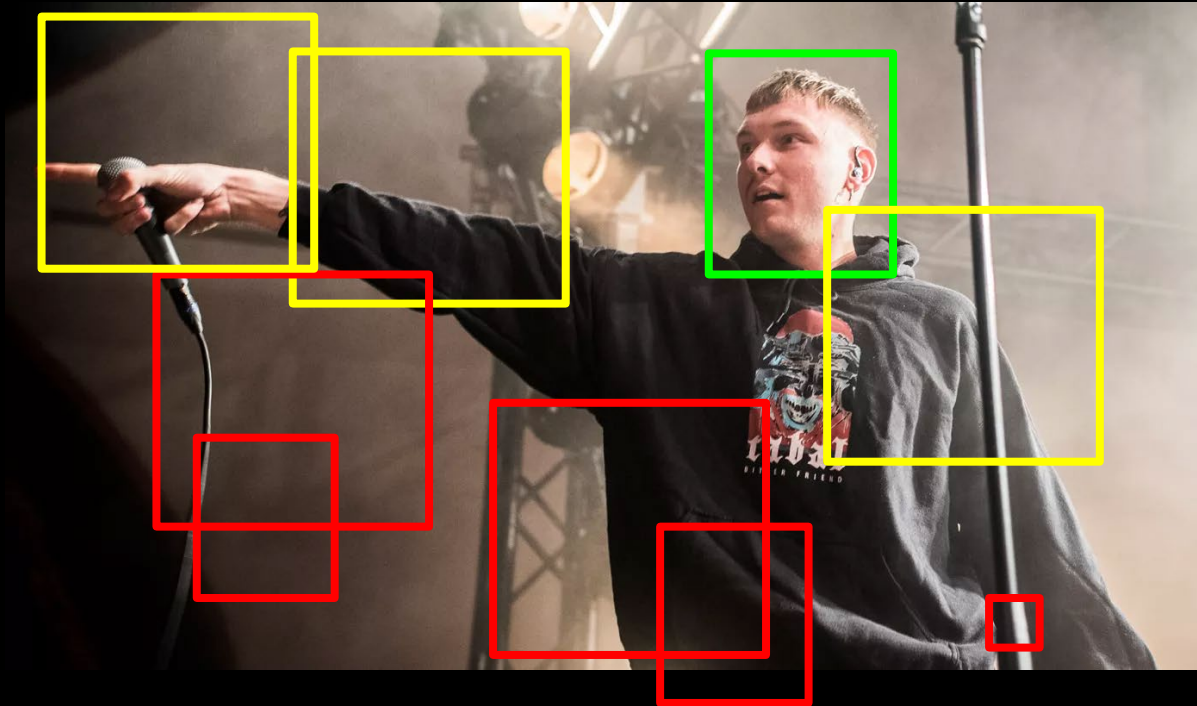
$$h_1(\text{image}) = \alpha_1 h_1 + \alpha_2 h_2 + \dots + \alpha_T h_T$$

The Attentional Cascade



Image Attention

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



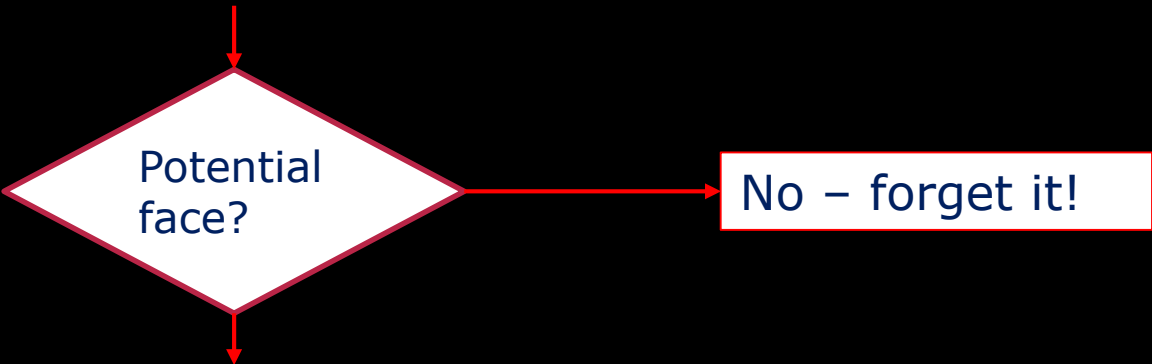
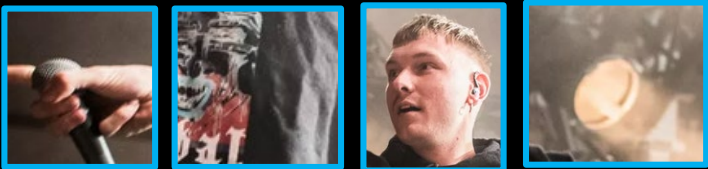
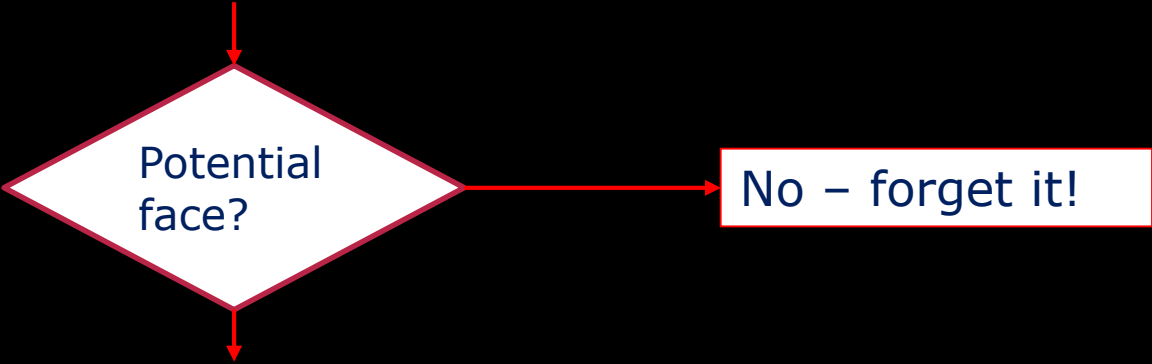
Focusing on potential face regions



Cascaded classifier



Also called a *degenerate decision tree*



What is a false negative?

A face window classified as face window

A background window classified as a face window

A face window classified as a background window

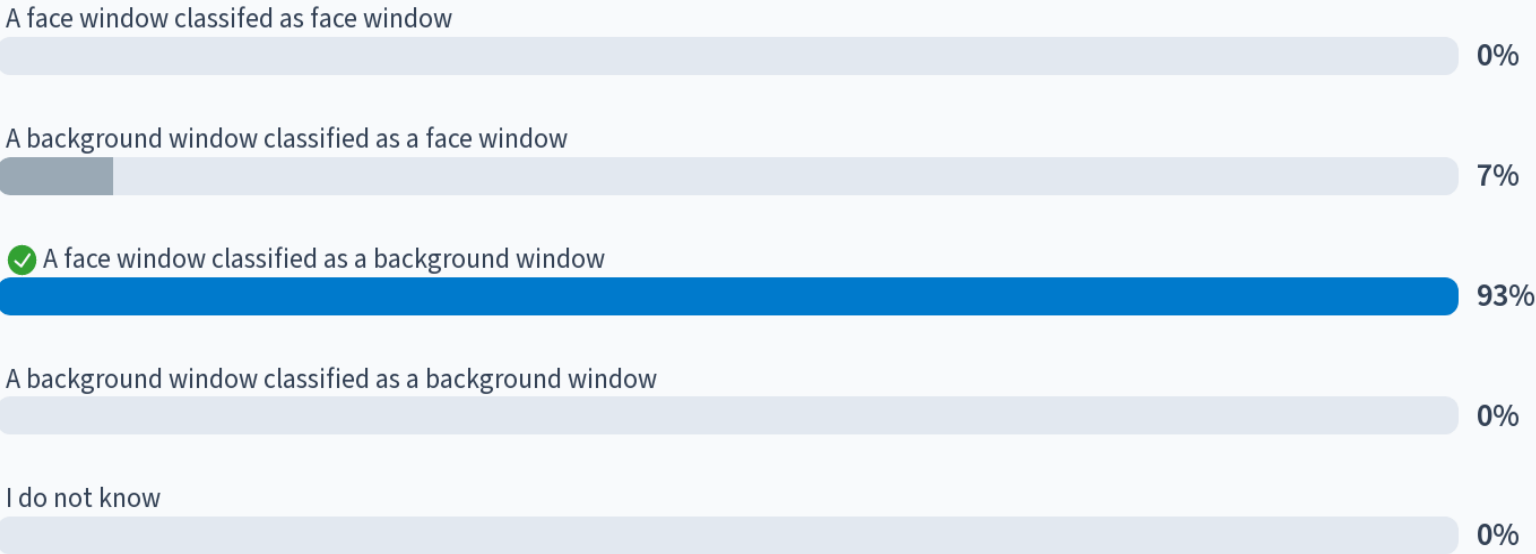
A background window classified as a background window

I do not know

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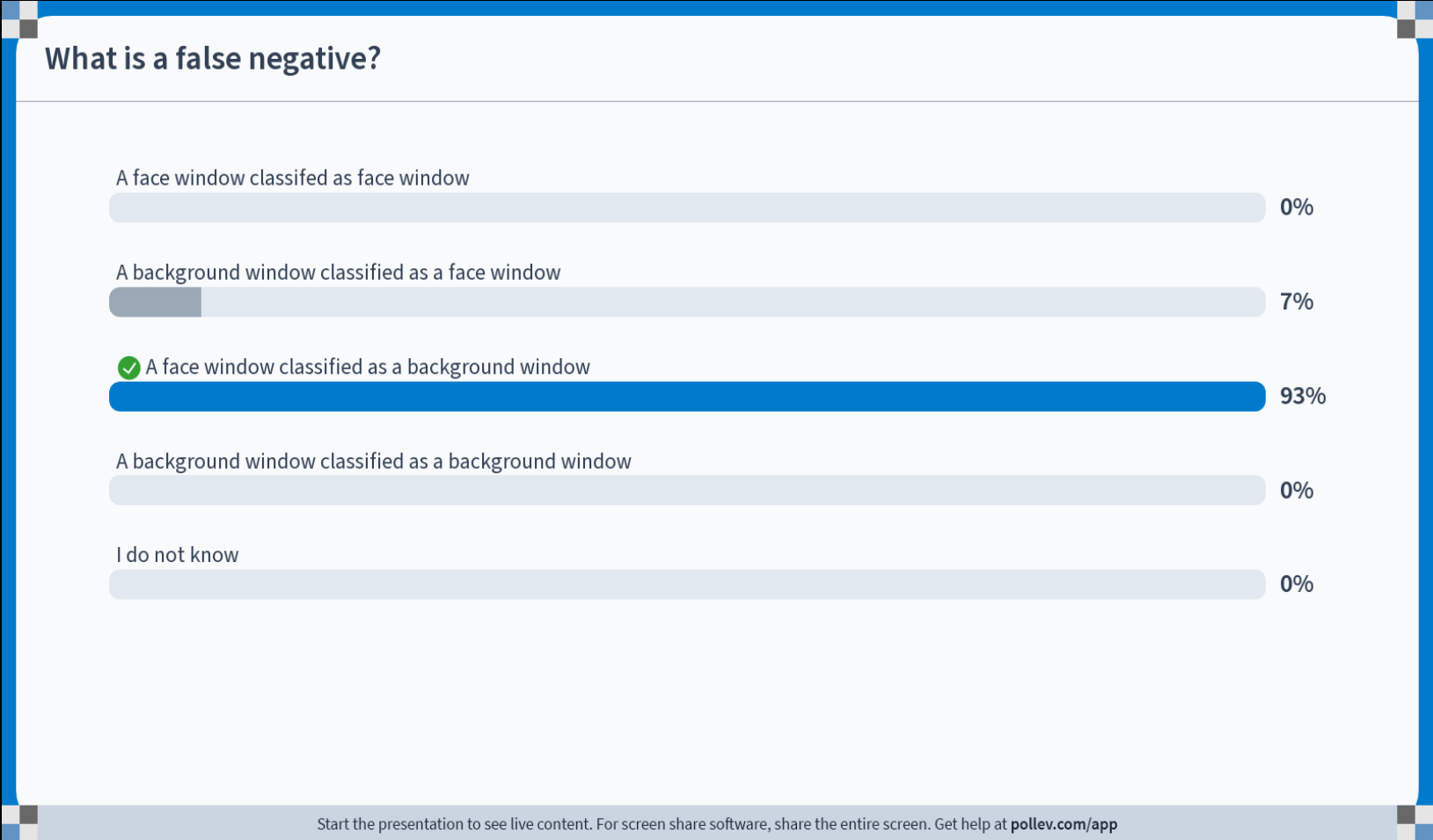


What is a false negative?



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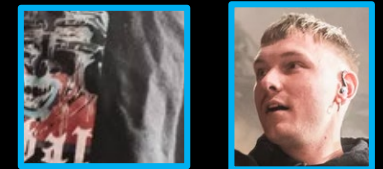
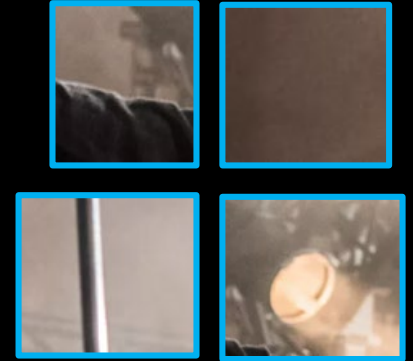




The attentional cascade



- 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



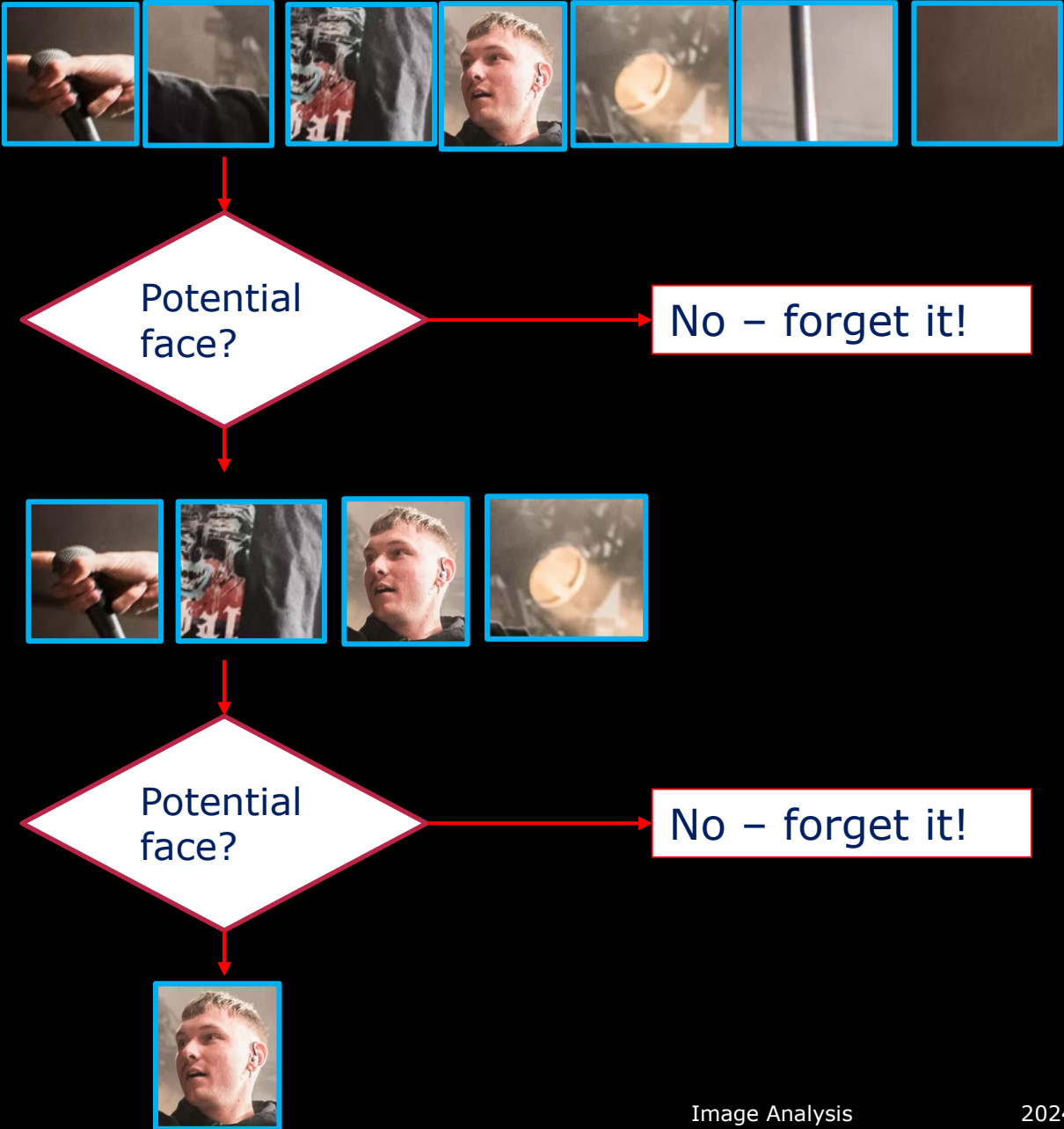
Training a cascade

$h(\text{img}) = \alpha_1 h_1 + \alpha_2 h_2 + \dots + \alpha_T h_T$

Learnt using AdaBoost

$h(\text{img}) = \alpha_1 h_1 + \alpha_2 h_2 + \dots + \alpha_T h_T$

Learnt using AdaBoost



First stage classifier

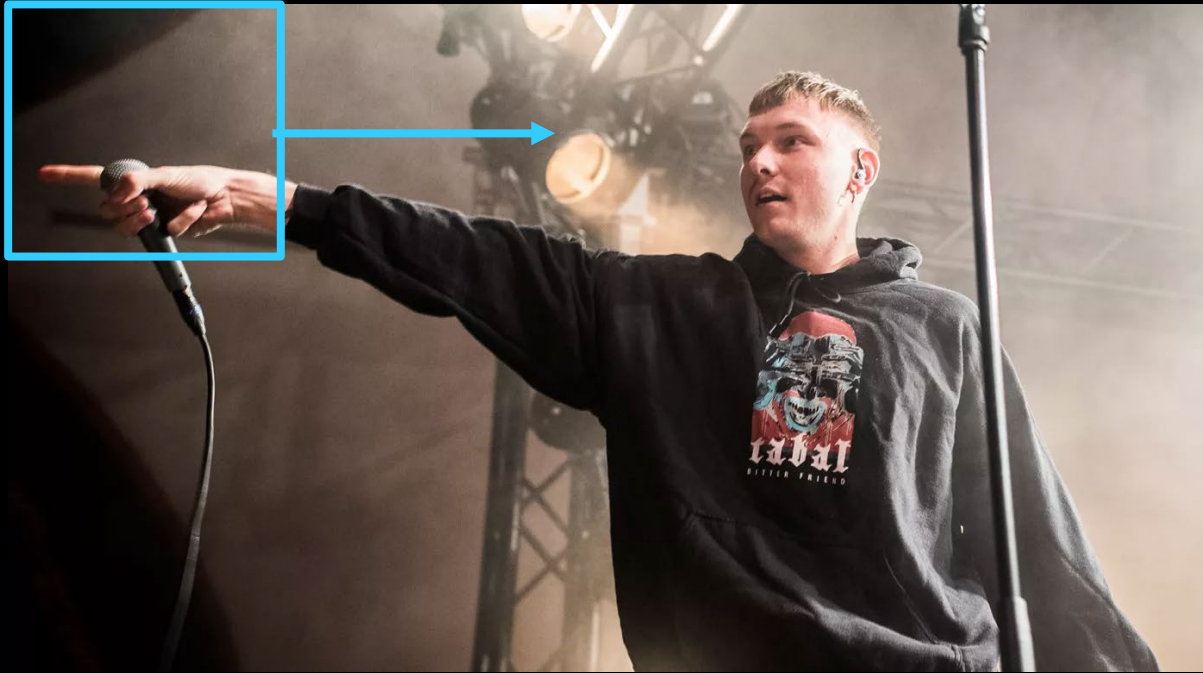


Final classifier



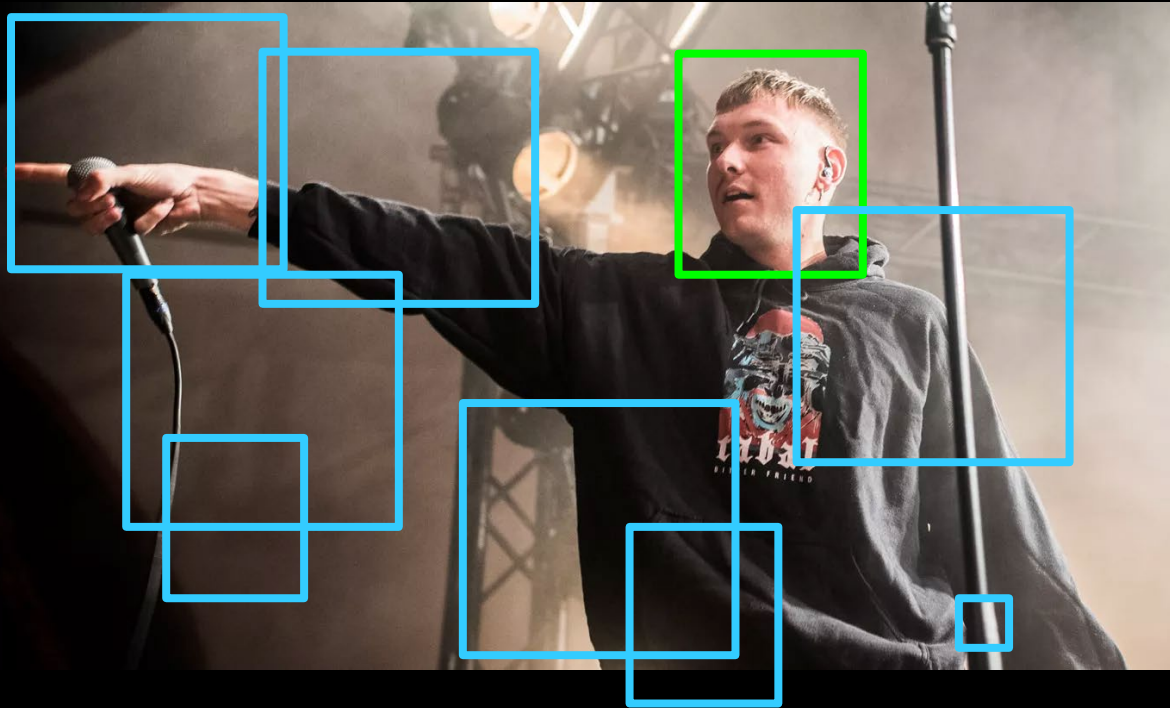
- 38 stages (step in the cascade)
- Total 6000 features (over the entire cascade)
- Faces are detected using on average 10 features per sub-window

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(s)

- Advanced topics
- Statistical models of shape and appearance