EE655: Computer Vision & Deep Learning

Lecture 05

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Lecture Outline

Haar Features

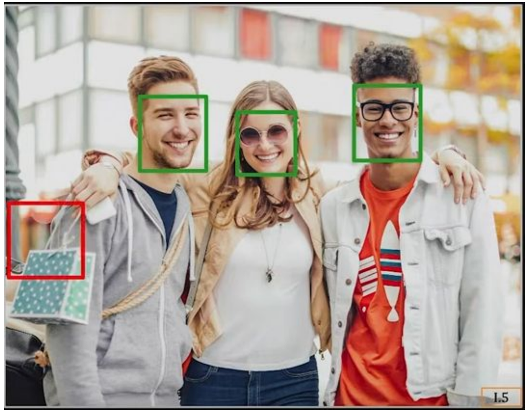
Harris Corner Detection

Shi-Tomasi Corner Detector

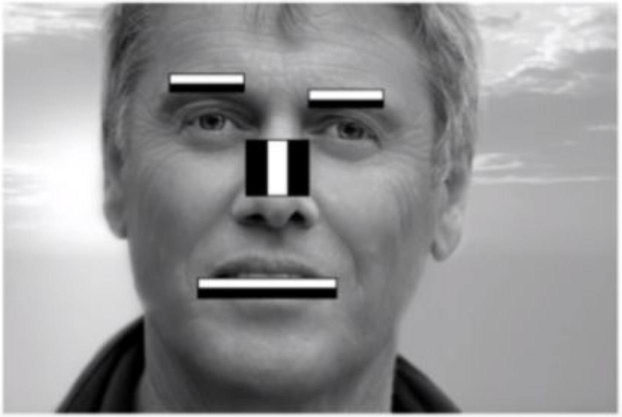
How can we use features for face detection

Start with a window, with roughly the size of the face we are looking for

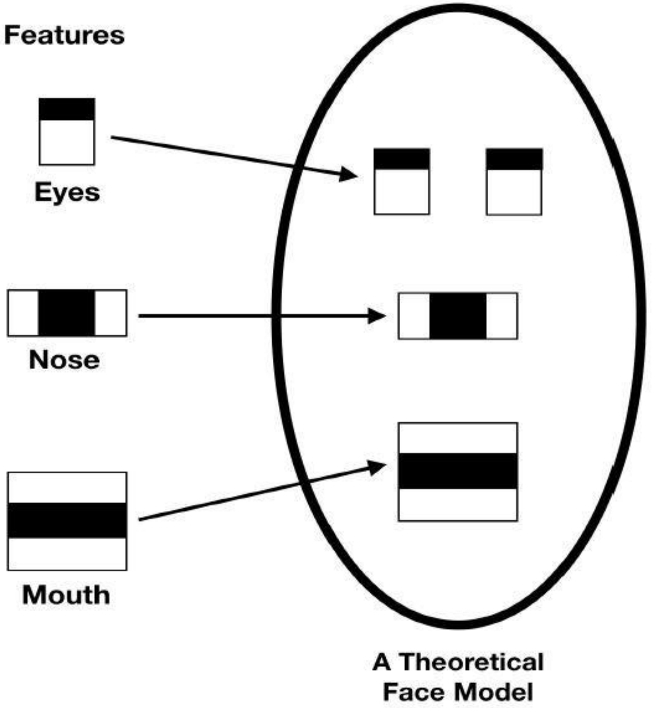
Keep moving it and extract features

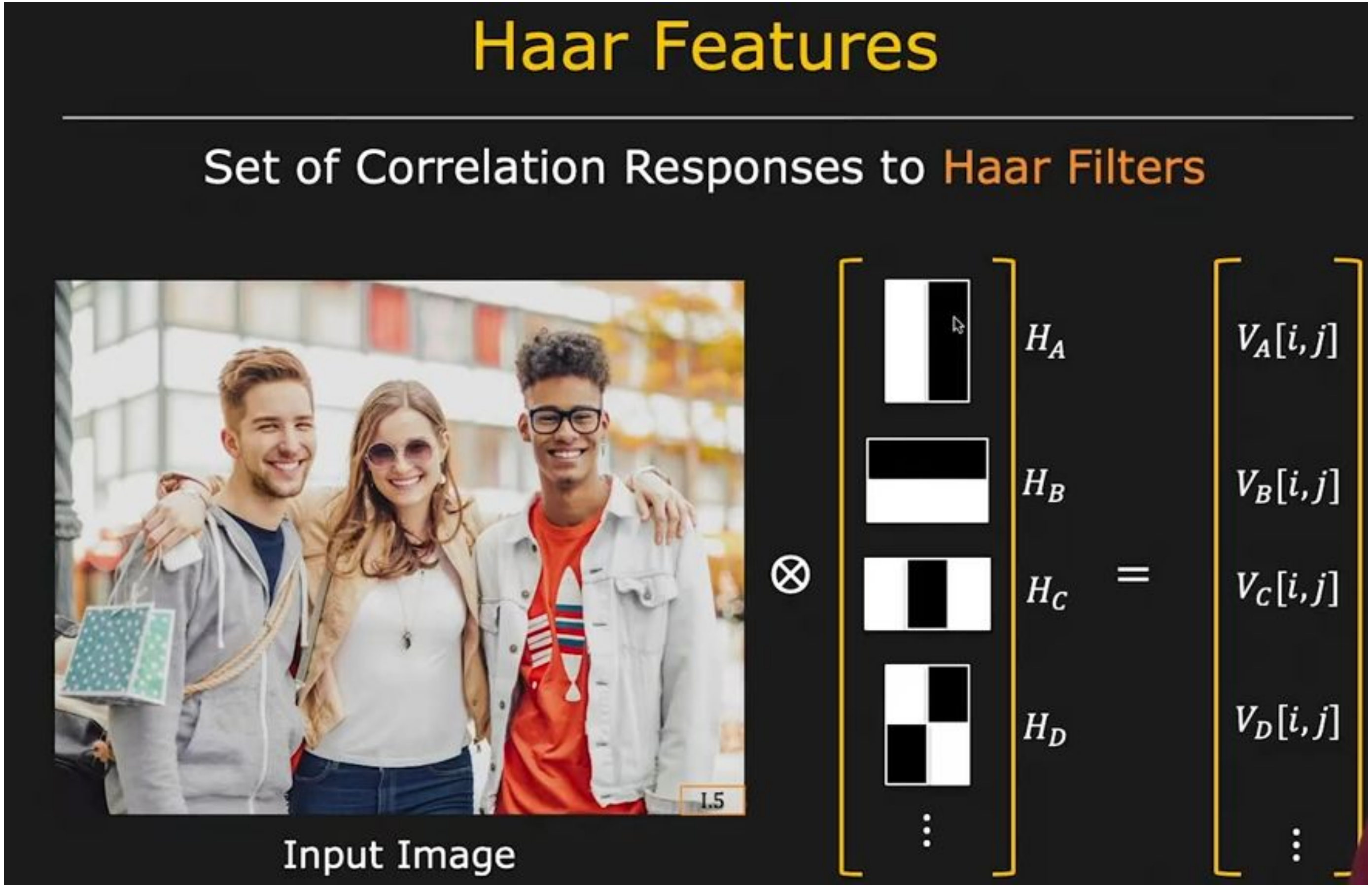


Use a classifier to identify if the features extracted represent a face

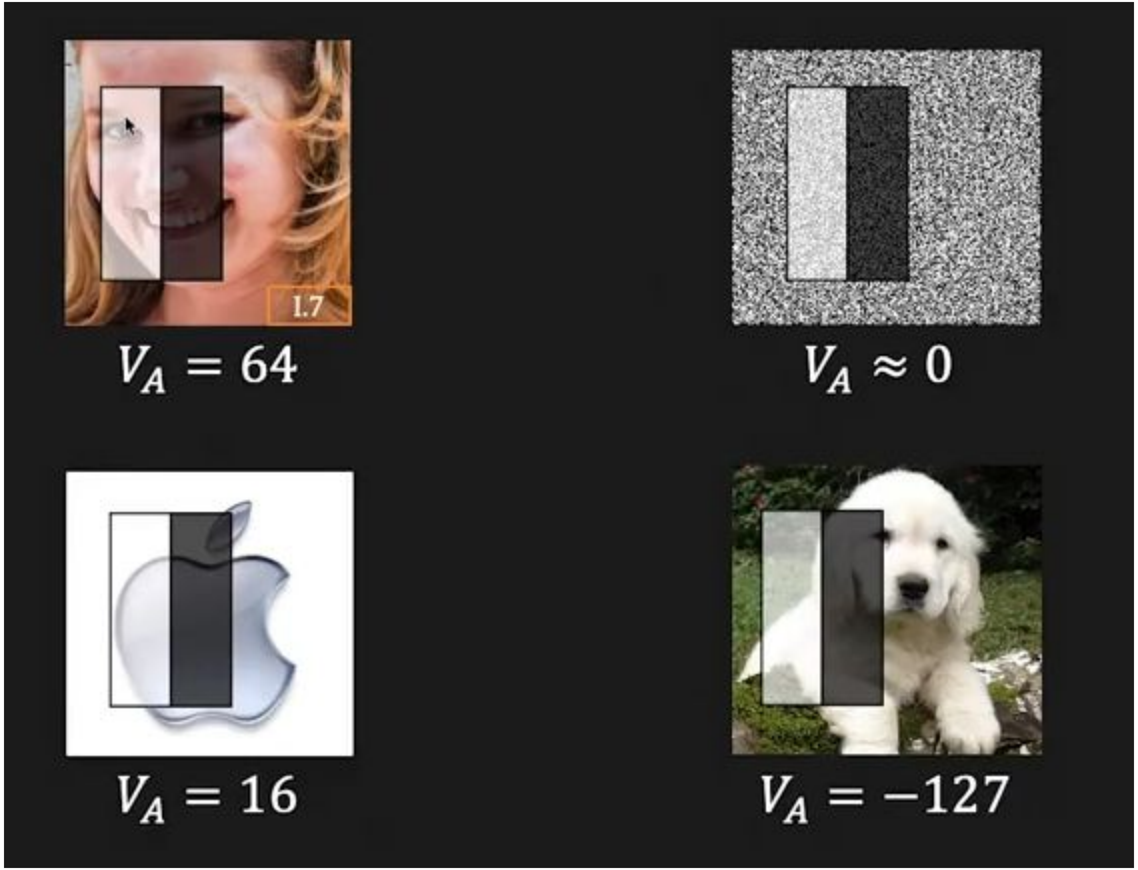


WE CAN REPRESENT THE MOST RELEVANT FEATURES WITH HAAR-FEATURES !!!


Features
Eyes
Nose
Mouth
A Theoretical
Face Model

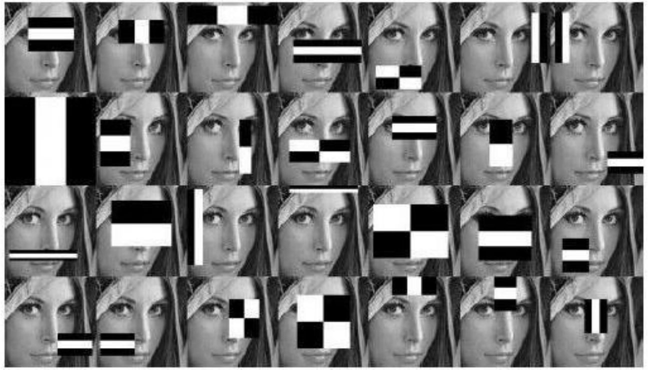


Need to perform correlation with these 2-valued Haar filters (1 or -1)

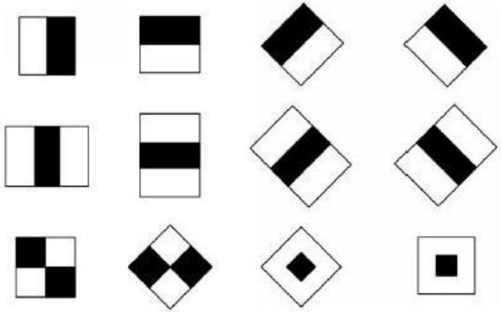

1.7
$V_A = 64$
$V_A \approx 0$
$V_A = 16$
$V_A = -127$

Haar features

- Face detection



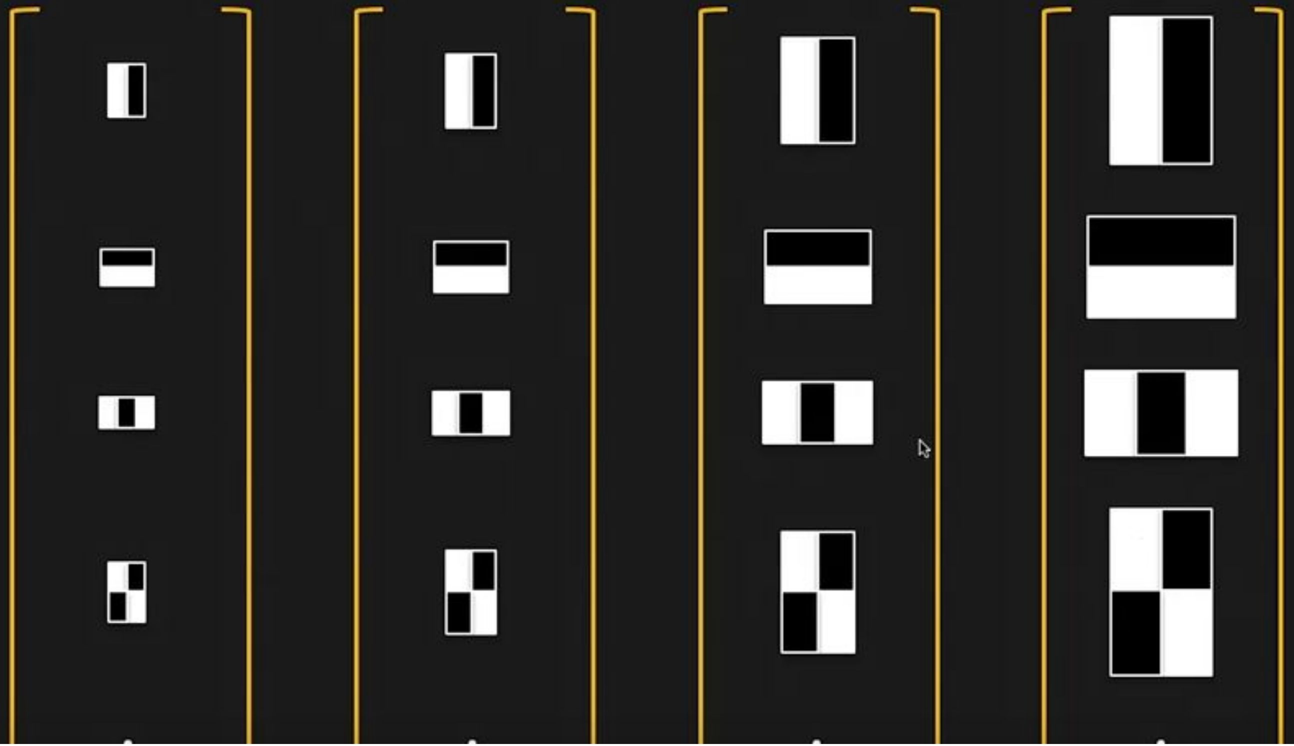
Haar feature: $f(x,y) = \sum I(R_{white}) - \sum I(R_{black})$

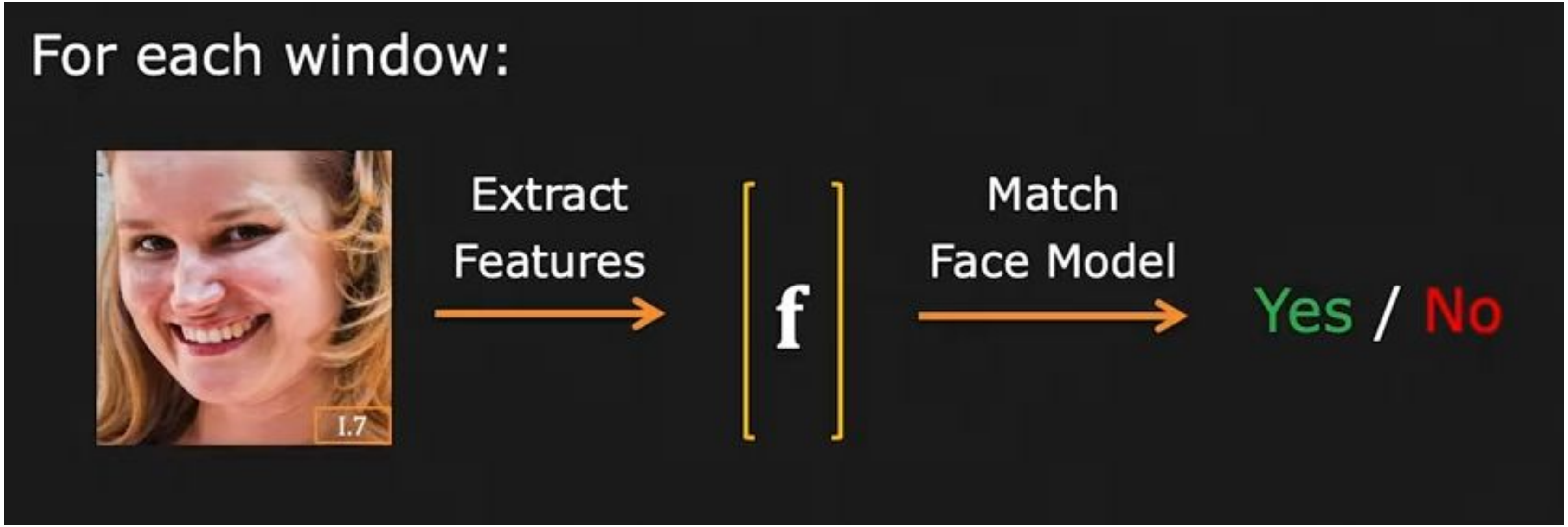


Haar filters

Detecting Faces of Different Size

Compute Haar Features at different scales to detect faces of different sizes.




For each window:
Extract Features
f
Match Face Model
Yes / No
I.7

Computing A Haar Feature

$\otimes$

H_A

White = 1, Black = -1

Response to Filter H_A at location (i,j):

$$V_A[i,j] = \sum_m \sum_n I[m-i, n-j] H_A[m,n]$$

$$V_A[i,j] = \sum (\text{pixel intensities in white area}) - \sum (\text{pixels intensities in black area})$$

And it needs to be done efficiently

Integral Image

A table that holds the sum of all pixel values to the left and top of a given pixel, inclusive.

98	110	121	125	122	129
99	110	120	116	116	129
97	109	124	111	123	134
98	112	132	108	123	133
97	113	147	108	125	142
95	111	168	122	130	137
96	104	172	130	126	130

Image I

98	208	329	454	576	705
197	417	658	899	1137	1395
294	623	988	1340	1701	2093
392	833	1330	1790	2274	2799
489	1043	1687	2255	2864	3531
584	1249	2061	2751	3490	4294
680	1449	2433	3253	4118	5052

Integral Image II

Integral Image concept is introduced to do it efficiently

98	110	121	125	122	129
99	110	120	116	116	129
97	109	124	111	123	134
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97	113	147	108	125	142
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Integral Image II

$$Sum = II_P - II_Q - II_S + II_R$$
$$= 3490 - 1137 - 1249 + 417 = 1521$$

Computational Cost: Only 3 additions

Haar Response using Integral Image

98	110	121	125	122	129
99	110	120	116	116	129
97	109	124	111	123	134
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Image I

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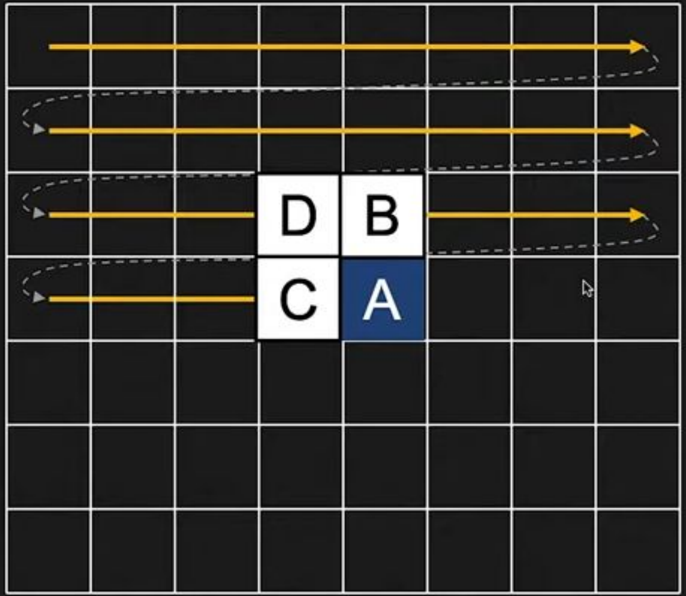
Integral Image II

$$V_A = \sum(\textit{pixel intensities in white}) - \sum(\textit{pixel intensities in black})$$

$$= (II_O - II_T + II_R - II_S) - (II_P - II_Q + II_T - II_O)$$

Computational Cost: Only 7 additions

Computing Integral Image



Raster Scanning

Let I_A and II_A be the values of Image and Integral Image, respectively, at pixel A.

$$\boxed{II_A = II_B + II_C - II_D + I_A}$$

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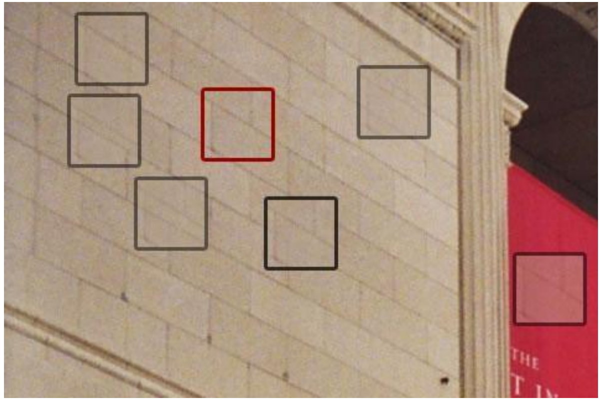
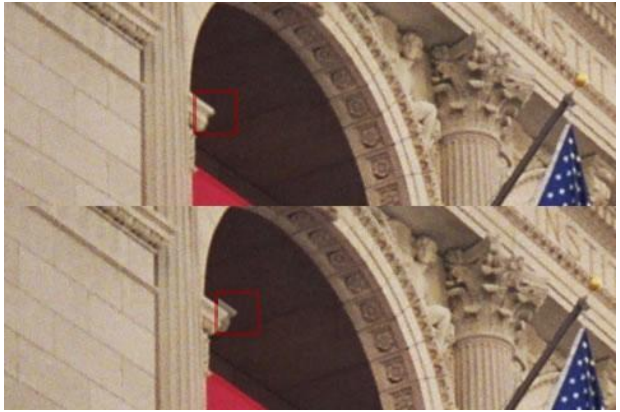
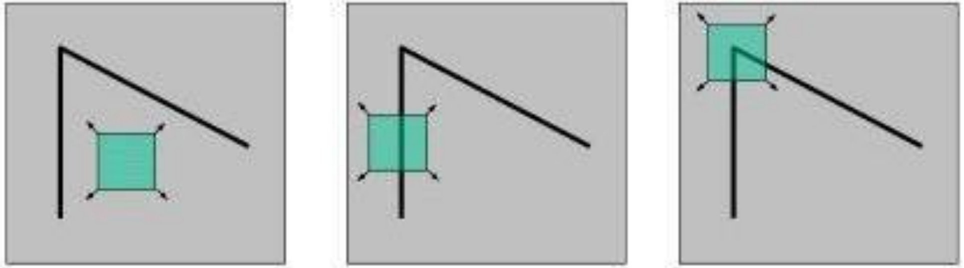
Harris Corner Detection



Slightly shifting windows of homogeneous regions doesn’t change the window content.

In contrast, Slightly shifting windows of corners change the window content very much.





"flat" region:
no change in all
directions

"edge":
no change along the
edge direction

"corner":
significant change in
all directions

Mathematical Formulation

$$f(\Delta x, \Delta y) = \sum_{(x_k, y_k) \in W} \left(I(x_k, y_k) - I(x_k + \Delta x, y_k + \Delta y) \right)^2$$

$I(x + \Delta x, y + \Delta y)$ can be approximated by a Taylor expansion. Let I_x and I_y be the partial derivatives of I, such that

$$I(x + \Delta x, y + \Delta y) \approx I(x, y) + I_x(x, y)\Delta x + I_y(x, y)\Delta y$$

This produces the approximation

$$f(\Delta x, \Delta y) \approx \sum_{(x,y) \in W} \left(I_x(x, y)\Delta x + I_y(x, y)\Delta y \right)^2,$$

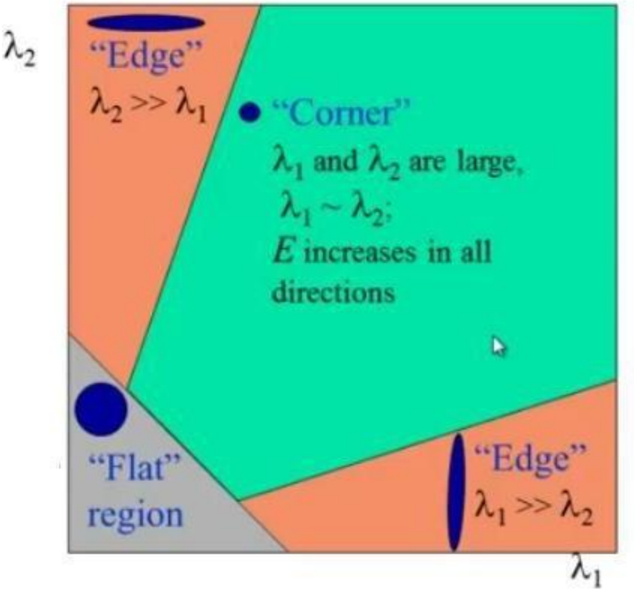
which can be written in matrix form:

$$f(\Delta x, \Delta y) \approx \begin{pmatrix} \Delta x & \Delta y \end{pmatrix} M \begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix},$$

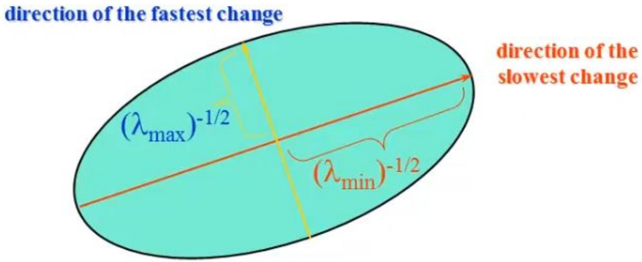
where M is the structure tensor,

$$M = \sum_{(x,y) \in W} \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} = \begin{bmatrix} \sum_{(x,y) \in W} I_x^2 & \sum_{(x,y) \in W} I_x I_y \\ \sum_{(x,y) \in W} I_x I_y & \sum_{(x,y) \in W} I_y^2 \end{bmatrix}$$

- f(dx,dy) is an equation of ellipse.
- M can be viewed as a covariance matrix.
- The eigenvectors of M represent the principal directions of gradient variation.
- The eigenvalues represent the magnitude of variation in those directions.

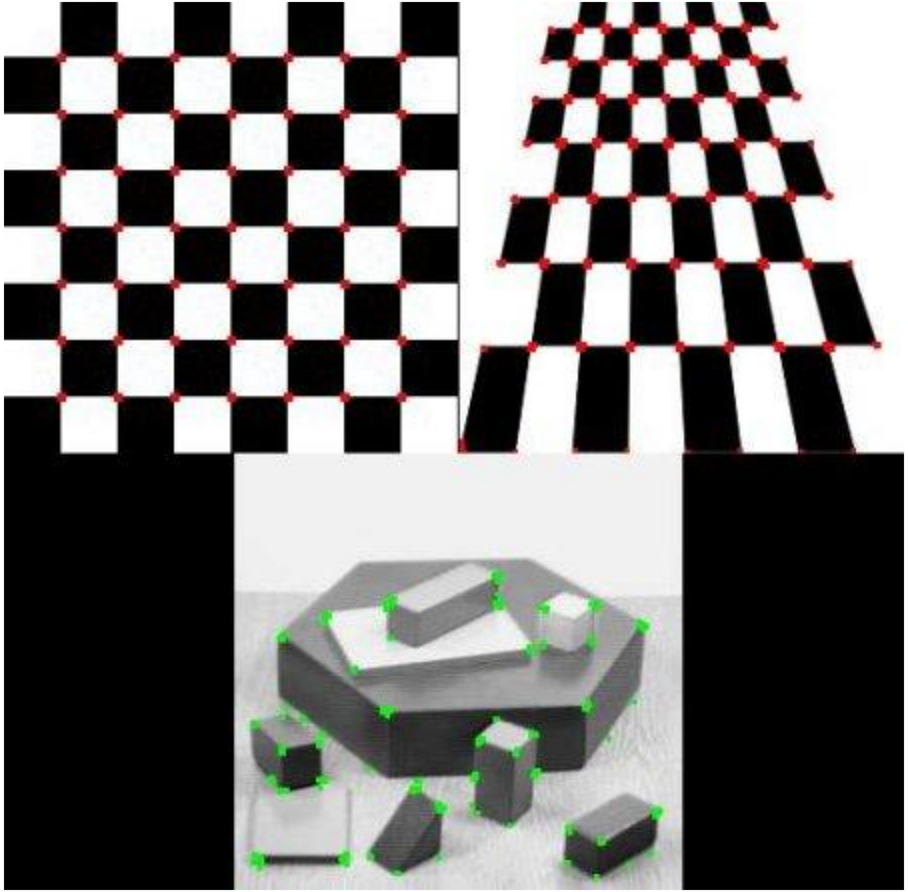


Note:
E=f(dx,dy)



$$R = \lambda_1 \lambda_2 - k \cdot (\lambda_1 + \lambda_2)^2 = \det(M) - k \cdot \mathrm{tr}(M)^2$$

where k is an empirically determined constant; $k \in [0.04, 0.06]$



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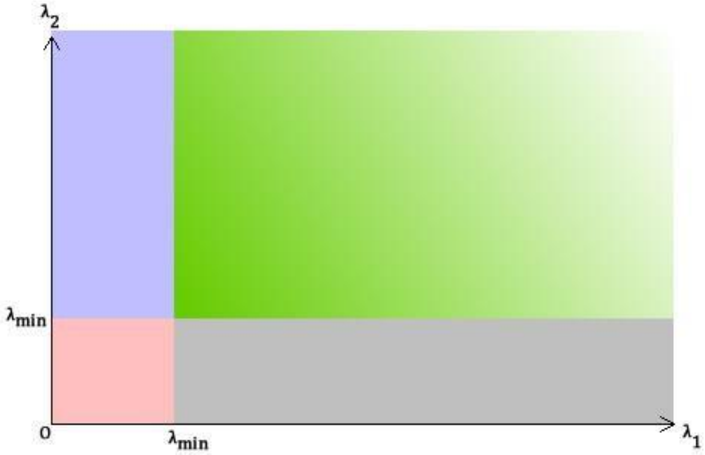
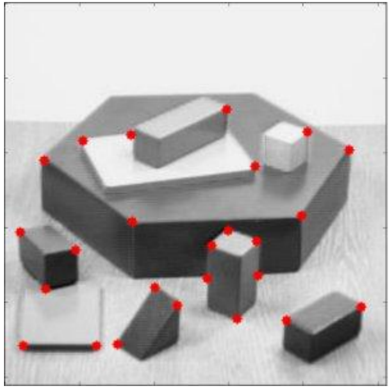
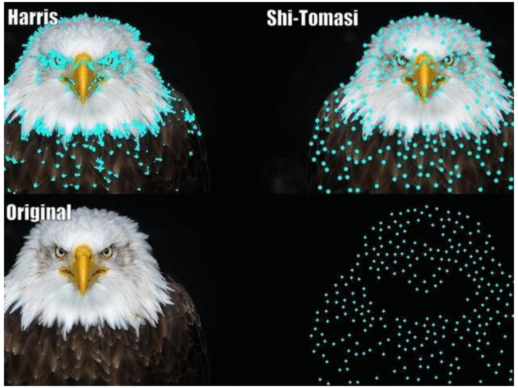
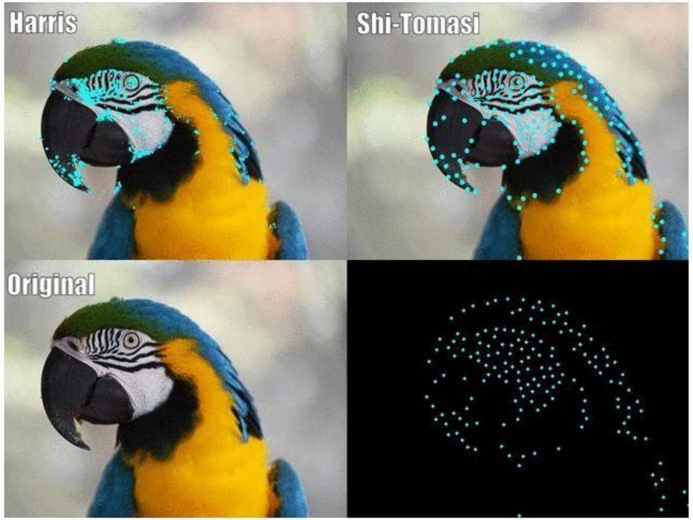
Shi-Tomasi Corner Detector



$$R = min(\lambda_1, \lambda_2)$$




Harris
Shi-Tomasi
Original


Harris
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