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Haar-Like Feature

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Outline

- Introduction
- Response Definition
- Fast Computation

Introduction

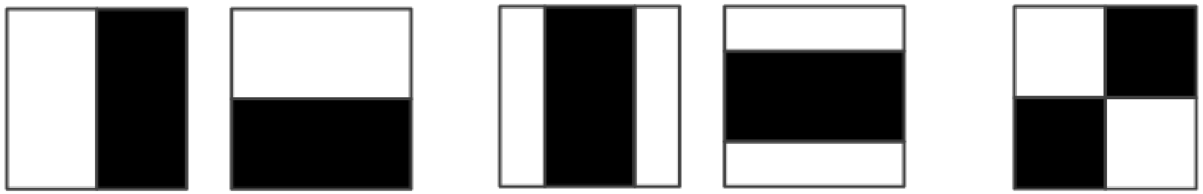
- Origin of Haar-Like Feature
  - Haar-like features are derived from Haar wavelet functions proposed by Alfred Haar in 1909.
  - They are firstly used in the computer vision area for object detection in 1998.
  - They became well-known since its use in real-time face detection by Viola and Jones in 2001.

C. Papageorgiou, et. al., "A General Framework for Object Detection", *IEEE Intl. Conf. on Computer Vision*, 1998.

P. Viola and M. Jones, "Rapid Object Detection using a Boosted Cascade of Simple Features, " *IEEE Intl. Conf. on CVPR*, 2001.

Introduction

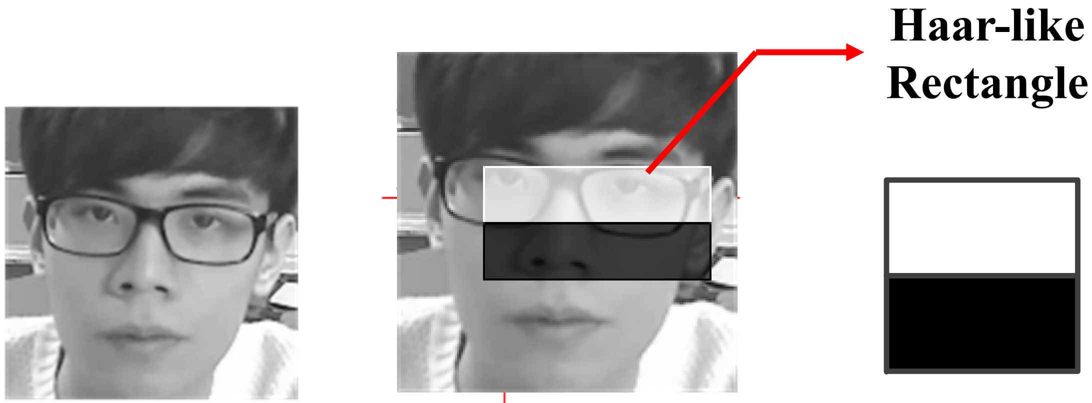
- About Haar-Like Feature
  - A Haar-Like feature is a response from a rectangle in the form of Haar-like prototype.
    - A prototype is composed of black and white rectangular regions
    - The size of black and white regions are equal.



Edge Prototype　　Line Prototype　　Diagonal Prototype

Response Definition

- Definition $\phi_t(I, \theta)$
  - I: gray-level image
  - $\theta = (l, t, w, h)$: rectangle configuration
  - t: selected prototype

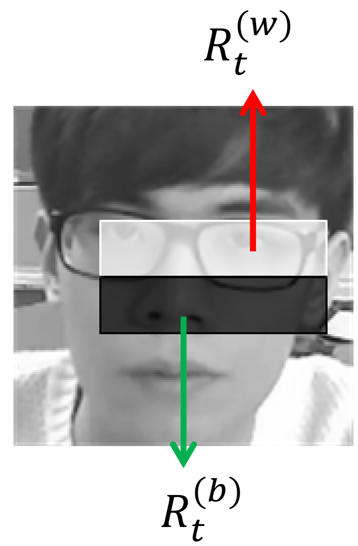


I: image　　θ: configuration　　t: prototype

Response Definition

- Definition $\phi_t(I,\theta)$

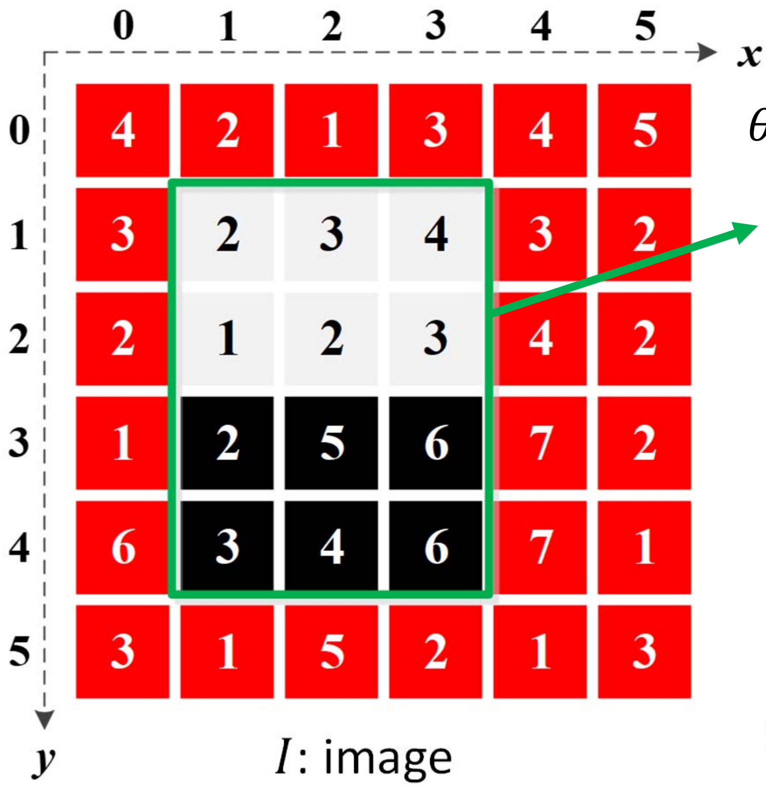
$$\phi_t(I,\theta) = \sum_{(x,y)\in R_t^{(w)}} I(x,y) - \sum_{(x,y)\in R_t^{(b)}} I(x,y)$$



- sum up point intensities in $R_t^{(w)}$ (white)
- sum up point intensities in $R_t^{(b)}$ (black)
- calculate the different between them.

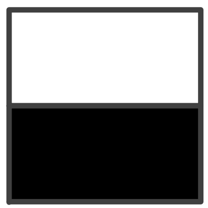
Response Definition

- Definition $\phi_t(I, \theta)$



I: image

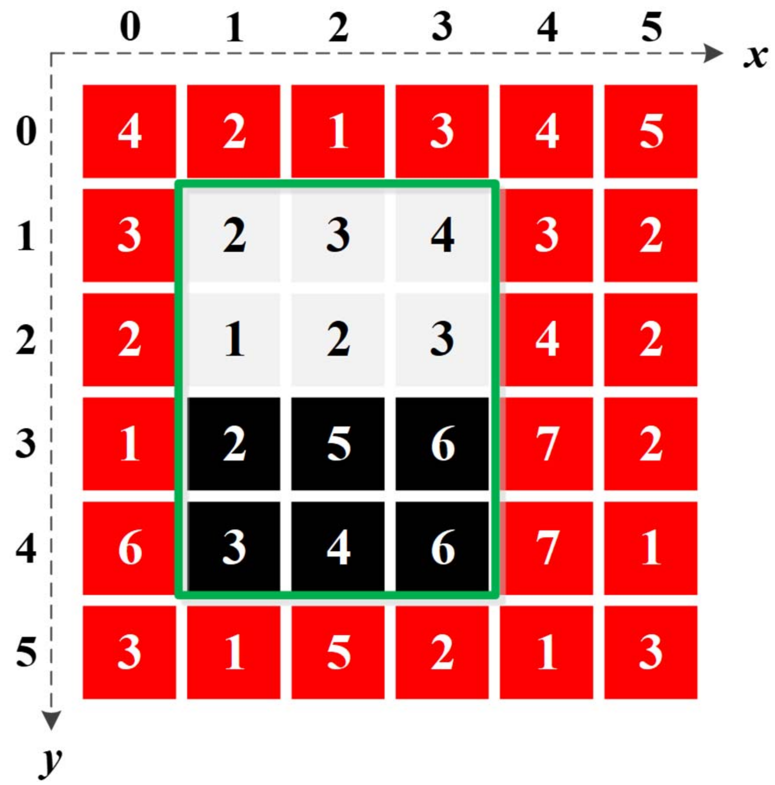
$\theta = (l, t, w, h)$
$= (1,1,3,4)$



t: selected prototype

Response Definition

- Definition $\phi_t(I, \theta)$



$$\phi_t(I, \theta) = \sum \begin{pmatrix} 2+3+4+ \\ 1+2+3 \end{pmatrix} - \sum \begin{pmatrix} 2+5+6+ \\ 3+4+6 \end{pmatrix}$$

$$\phi_t(I, \theta) = 15 - 26 = -11$$

Response Definition

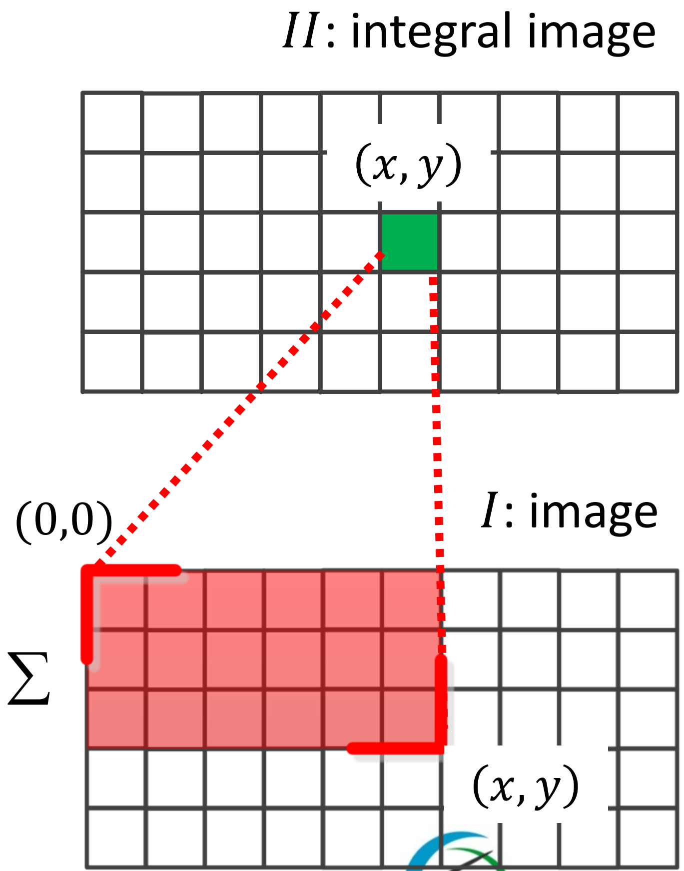
- Computation Issue
  - Computing Haar-like features in this direct way is computational expensive.
    - Time complexity for computing a Haar-like feature is $O(w \times h)$
    - An effective descriptor is generally composed of thousands of Haar-like features.
  - Integral image is used to address this issue

$$O(w \times h) \rightarrow O(1)$$

Fast Computation

- Integral Image $II(.)$
  - $II(x, y)$ is defined as intensity sum of points in rectangle $(0,0, x, y)$
    - (0,0):left-top point
    - (x, y):right-bottom point

$$II(x, y) = \sum_{u=0}^{u=x} \sum_{v=0}^{v=y} I(u, v)$$



Fast Computation

- Integral Image $II(.)$

$$II(2,3)=\sum_{u=0}^{u=2}\sum_{v=0}^{v=3} I(u,v)$$

$$=(4+2+1)$$
$$+(3+2+3)$$
$$+(2+1+2)$$
$$+(1+2+5)$$
$$=7+8+5+8$$
$$=28$$

y \ x	0	1	2	3	4	5
0	4	2	1	3	4	5
1	3	2	3	4	3	2
2	2	1	2	3	4	2
3	1	2	5	6	7	2
4	6	3	4	6	7	1
5	3	1	5	2	1	3

I: image

y \ x	0	1	2	3	4	5
0	4	6	7	10	14	19
1	7	11	15	22	29	36
2	9	14	[illegible]	[illegible]	[illegible]	50
3	10	17	28	44	62	73
4	16	26	41	63	88	100
5	19	30	50	74	100	115

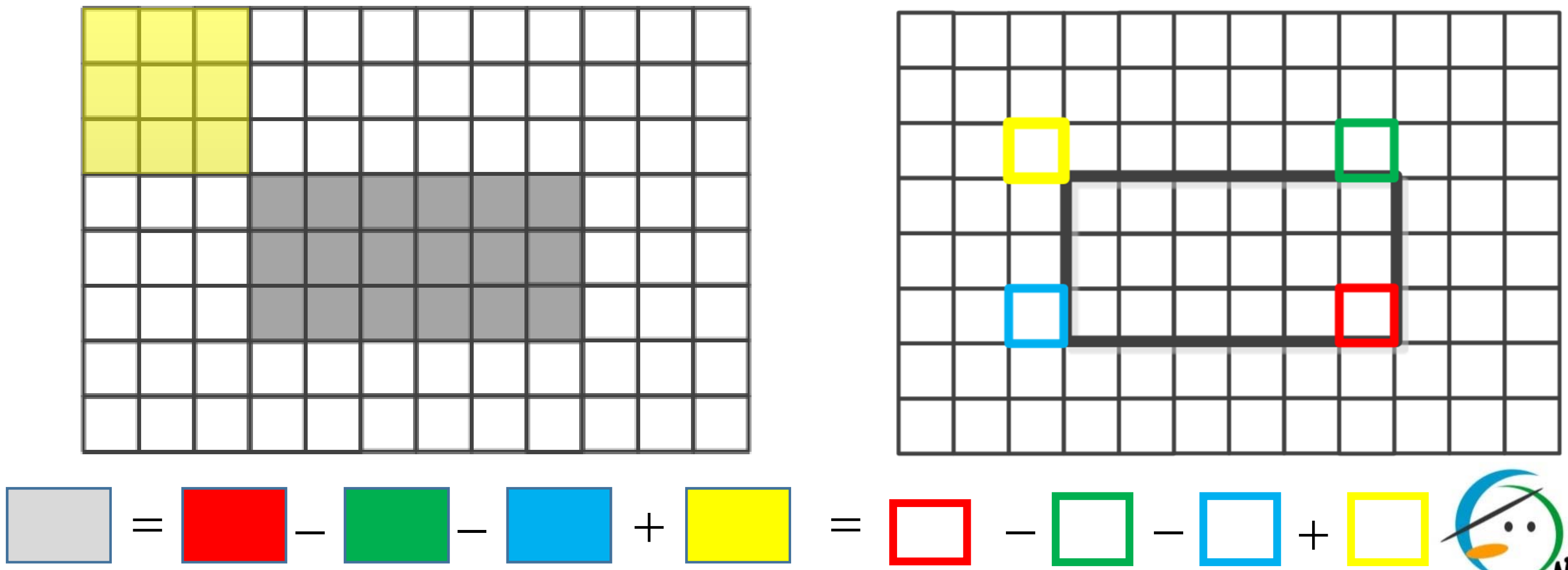
$II(2,3)$

II: integral image

Fast Computation

- Speed-Up Strategy
  - We can compute sum of points in a rectangle in constant time using $II(.)$

I: image II: integral image



Fast Computation

- Speed-Up Strategy: Example

y \ x	0	1	2	3	4	5
0	4	2	1	3	4	5
1	3	2	3	4	3	2
2	2	1	2	3	4	2
3	1	2	5	6	7	2
4	6	3	4	6	7	1
5	3	1	5	2	1	3

I: image

$$\sum_{(x,y)\in R^{(w)}} I(x,y)$$

$= \square$ (red) $- \square$ (green) $- \square$ (blue) $+ \square$ (yellow)

$$= 30 - 10 - 9 + 4$$

$$= 15$$

y \ x	0	1	2	3	4	5
0	4	6	7	10	14	19
1	7	11	15	22	29	36
2	9	14	20	30	41	50
3	10	17	28	44	62	73
4	16	26	41	63	88	100
5	19	30	50	74	100	115

II: integral image

Fast Computation

- Speed-Up Strategy: Example

y \ x	0	1	2	3	4	5
0	4	2	1	3	4	5
1	3	2	3	4	3	2
2	2	1	2	3	4	2
3	1	2	5	6	7	2
4	6	3	4	6	7	1
5	3	1	5	2	1	3

I: image

$$\sum_{(x,y)\in R^{(b)}} I(x,y)$$

$= \square - \square - \square + \square$

$= 63 - 30 - 16 + 9$

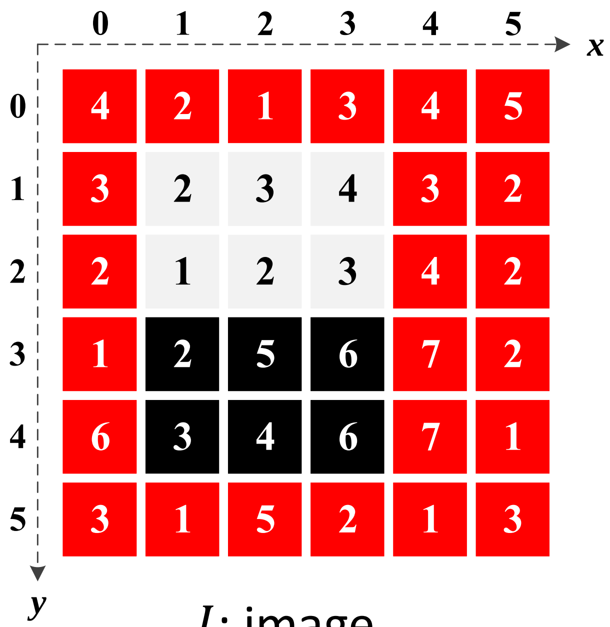
$= 26$

y \ x	0	1	2	3	4	5
0	4	6	7	10	14	19
1	7	11	15	22	29	36
2	9	14	20	30	41	50
3	10	17	28	44	62	73
4	16	26	41	63	88	100
5	19	30	50	74	100	115

II: integral image

Fast Computation

- Speed-Up Strategy: Example



I: image

$$\phi_t(I,\theta) = \sum_{(x,y)\in R^{(w)}} I(x,y) \quad = 15$$

Constant Time

$$- \sum_{(x,y)\in R^{(b)}} I(x,y) \quad = 26$$

Constant Time

$$\phi_t(I,\theta) = 15 - 26 = -11$$

Constant Time


thank you
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