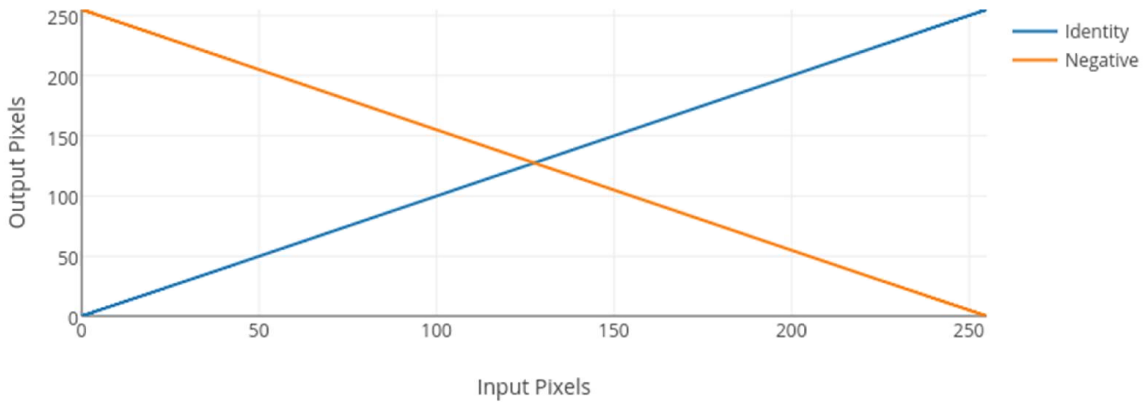
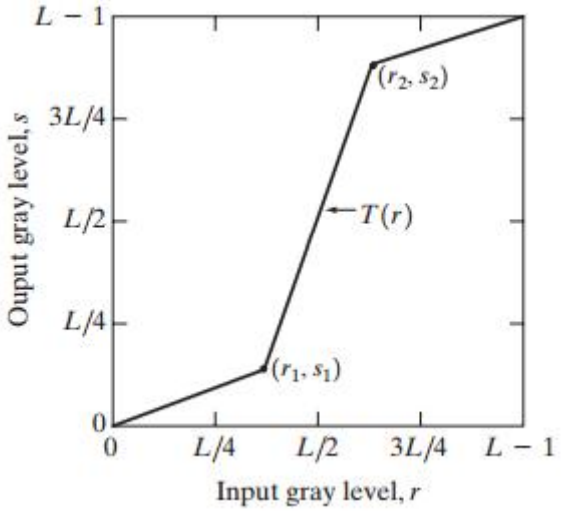
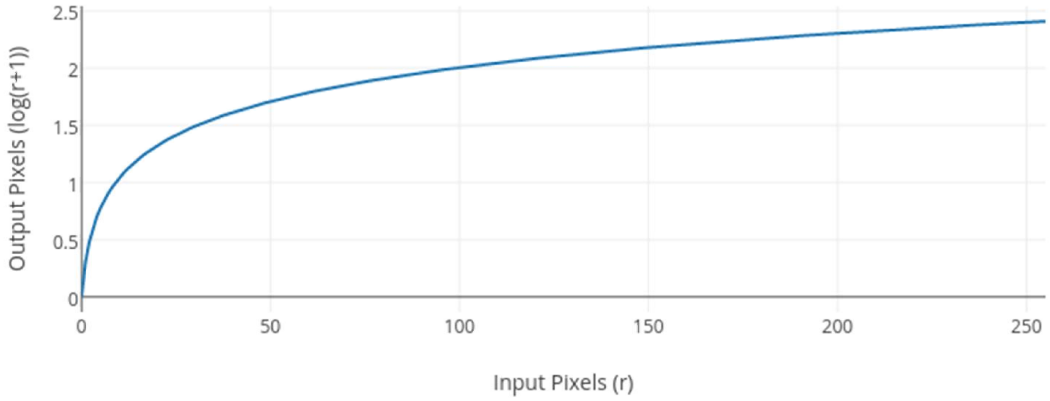
Chapter 1: Laying the Foundation

But the camera sees this:

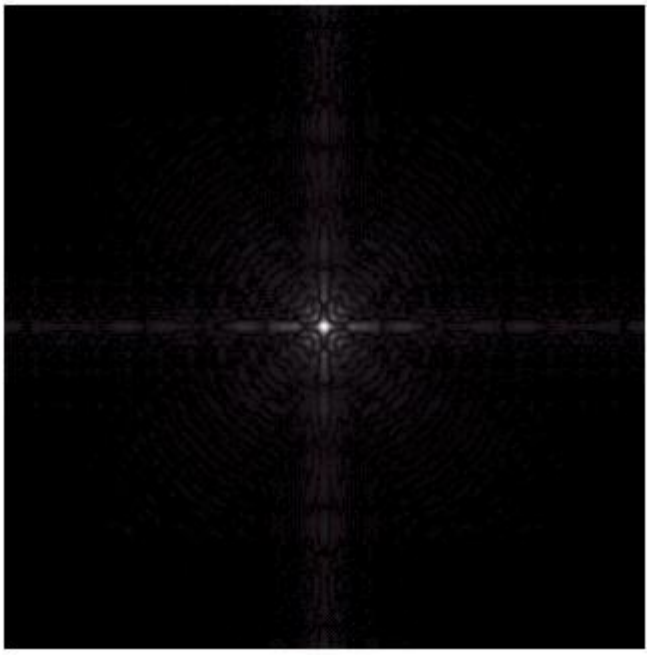
194	210	201	212	199	213	215	195	178	158	182	209
180	189	190	221	209	205	191	167	147	115	129	163
114	126	140	188	176	165	152	140	170	106	78	88
87	103	115	154	143	142	149	153	173	101	57	57
102	112	106	131	122	138	152	147	128	84	58	66
94	95	79	104	105	124	129	113	107	87	69	67
68	71	69	98	89	92	98	95	89	88	76	67
41	56	68	99	63	45	60	82	58	76	74	65
20	41	69	75	56	41	51	73	55	70	63	44
50	50	57	69	75	75	73	74	53	68	59	37
72	59	53	66	84	92	84	74	57	72	63	42
67	61	58	65	75	78	76	73	59	75	69	50

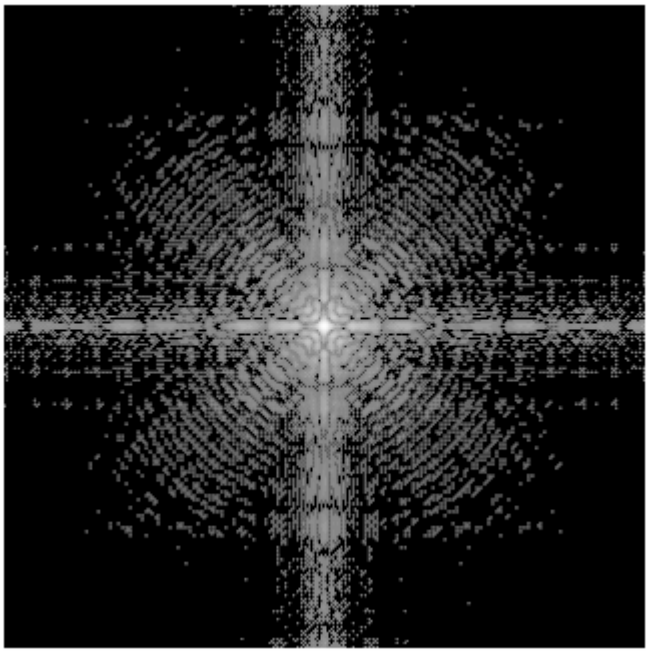

Identity
Negative
Output Pixels
Input Pixels
0
50
100
150
200
250


L − 1
3L/4
L/2
L/4
0
(r2, s2)
T(r)
(r1, s1)
Ouput gray level, s
Input gray level, r

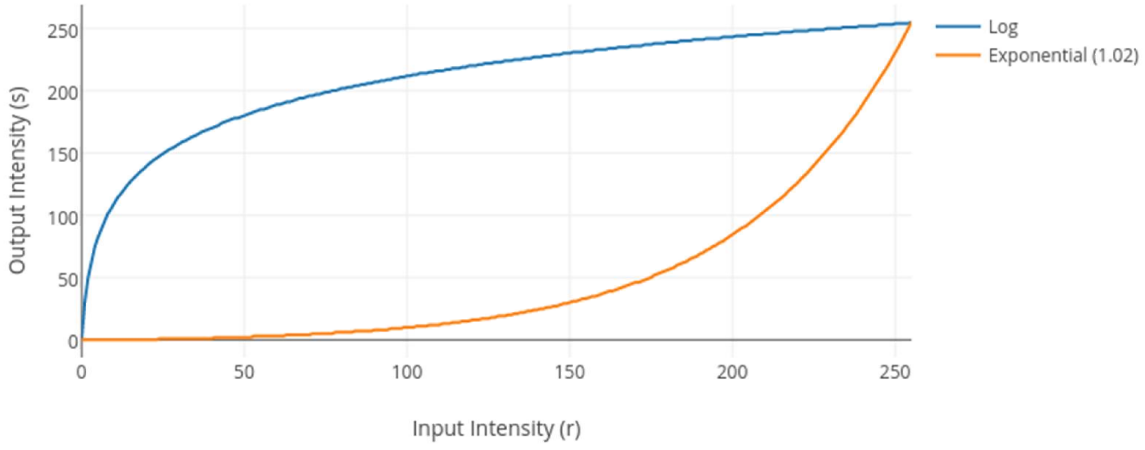


$$255 = c\log\left(r_{max} + 1\right)$$

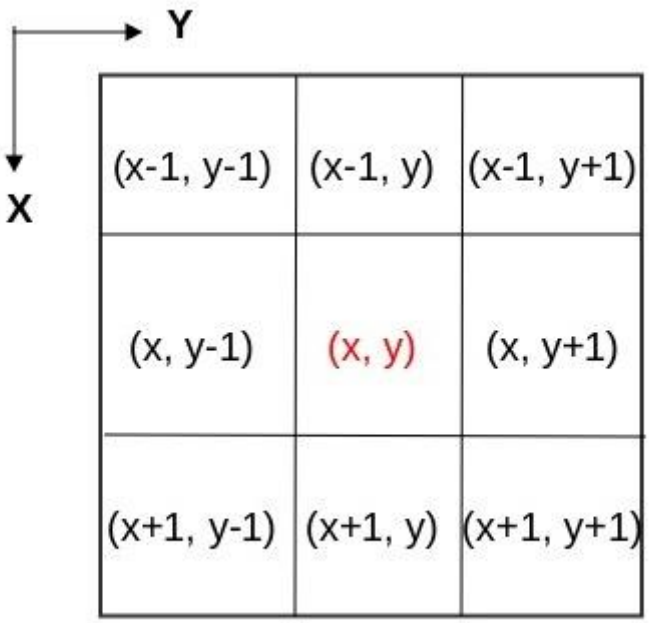




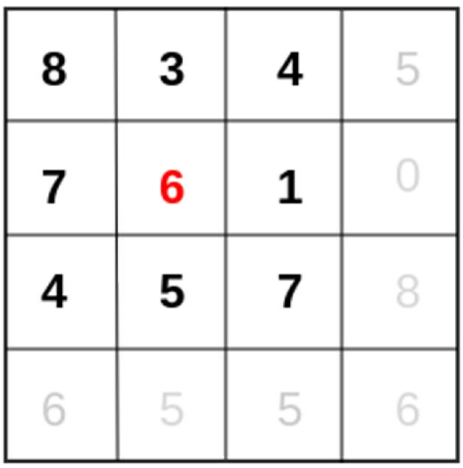
$$s = T(r) = c\left(b^{r} - 1\right)$$

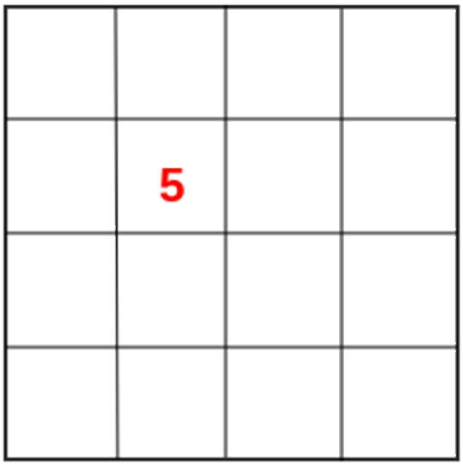


Chapter 2: Image Filtering



$$\frac{1}{9}(8+3+4+7+6+1+4+5+7) = 45/9 = 5$$





$$J(x,y)=\frac{1}{9}\left(I(x-1,y-1)+I(x-1,y)+\cdots+I(x+1,y-1)+I(x,y-1)\right)$$

$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$
$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$
$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$

8	**3**	**4**	5
7	**6**	**1**	0
4	**5**	**7**	8
6	5	5	6

	8	3	4	5	
	7	6	1	0	
	4	5	7	8	
	6	5	5	6	

8	3	4	5
7	6	1	0
4	5	7	8
6	5	5	6

8	8	3	4	5	5
8	8	3	4	5	5
7	7	6	1	0	0
4	4	5	7	8	8
6	6	5	5	6	6
6	6	5	5	6	6

$$K=\alpha\begin{bmatrix}1 & 1 & 1 & \cdots & 1 & 1\\ 1 & 1 & 1 & \cdots & 1 & 1\\ & & \cdots & \cdots & & \\ 1 & 1 & 1 & \cdots & 1 & 1\end{bmatrix}$$

$$\alpha = \begin{cases} \dfrac{1}{width * height} & if\ normalize = true \\ 1 & if\ otherwise \end{cases}$$

$$K = \frac{1}{width * height}\begin{bmatrix} 1 & 1 & 1 & \cdots & 1 & 1 \\ 1 & 1 & 1 & \cdots & 1 & 1 \\ & & \cdots & \cdots & & \\ 1 & 1 & 1 & \cdots & 1 & 1 \end{bmatrix}$$

$$\overline{x} = \frac{w_1 x_1 + w_2 x_2 + \cdots + w_n x_n}{w_1 + w_2 + \cdots + w_n} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}$$

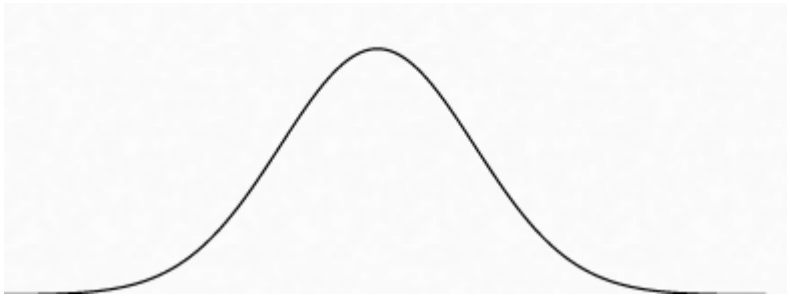
$$\overline{x} = w_1 x_1 + w_2 x_2 + \cdots + w_n x_n = \sum_{i=1}^{n} w_i x_i$$

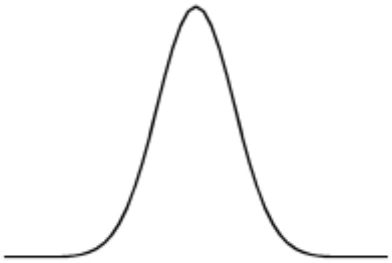
8	3	4	5
7	6	1	0
4	5	7	8
6	5	5	6

4	5	2	7	0	6	**8**	**4**	**3**	0	5	2	1	4	4	9	3	2	4	6	2	5	4	0	1

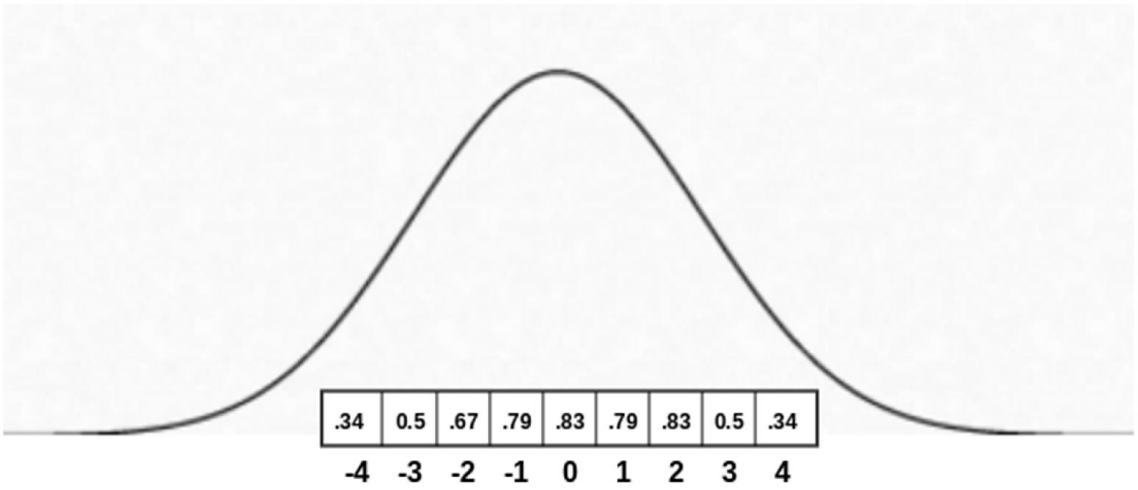
$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$

$$G(x) = \frac{1}{\sigma\sqrt{2x}} e^{\frac{x^2}{2\sigma^2}}$$



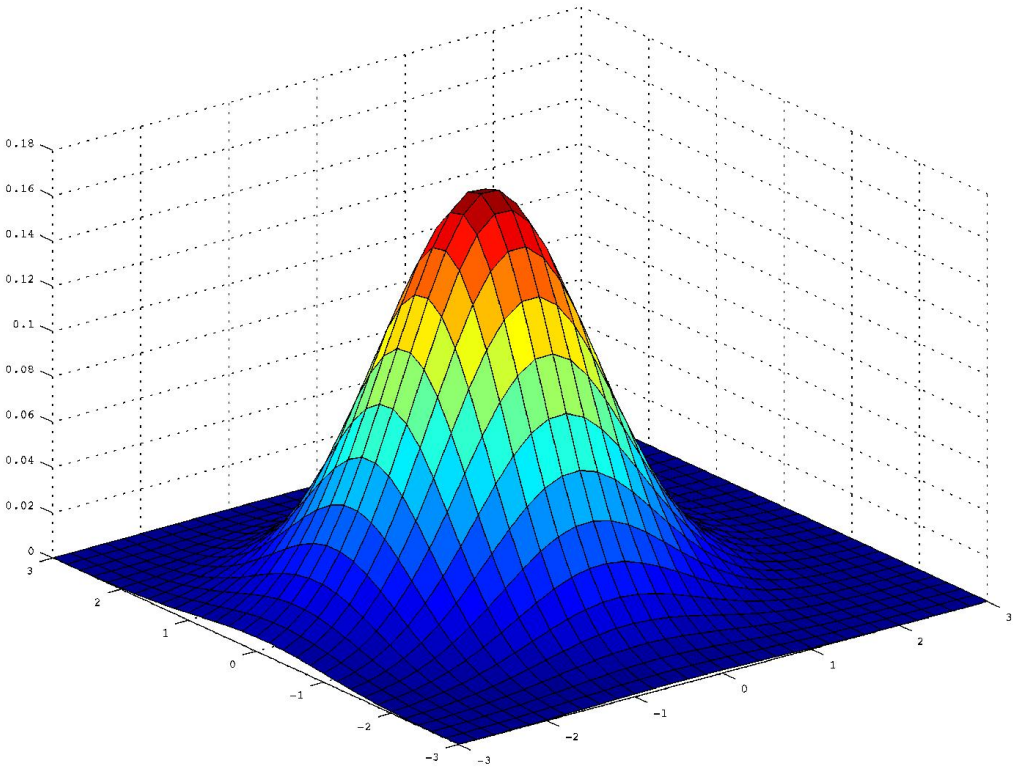


-4	-3	-2	-1	0	1	2	3	4

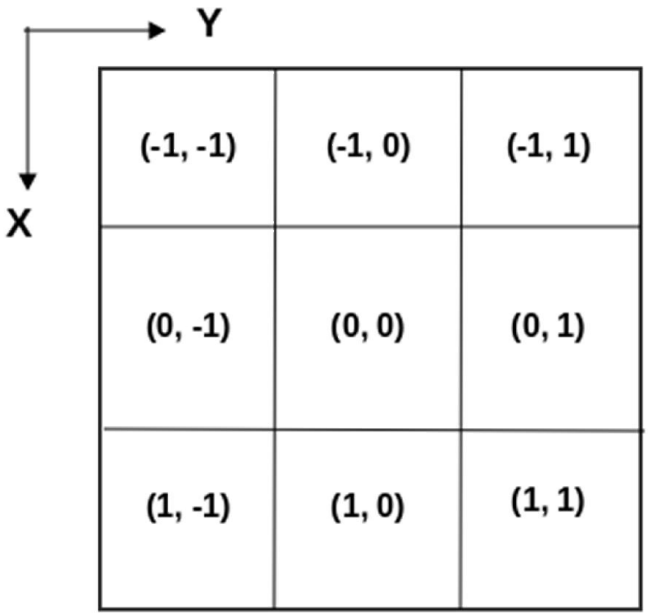


$$F(i) = \frac{G(i)}{\sum_{k=-N}^{N} G(k)} \; where \; G(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}}$$

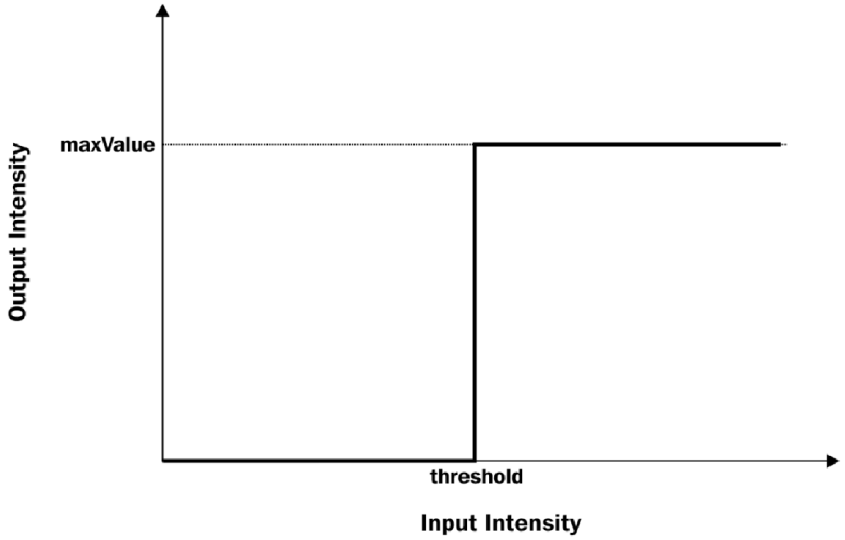
$$G(x,y) = \frac{1}{2\pi\sigma_x\sigma_y} e^{-\frac{1}{2}\left(\frac{x^2}{\sigma_x^2}+\frac{y^2}{\sigma_y^2}\right)}$$

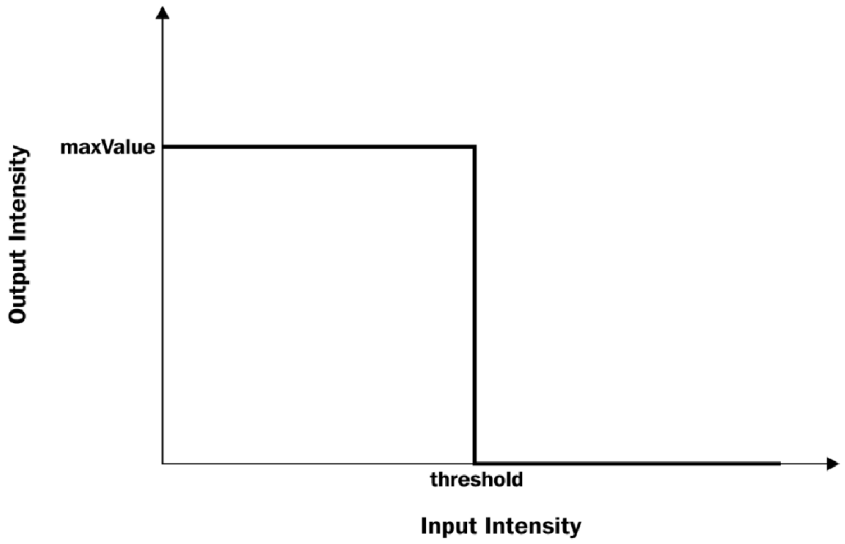


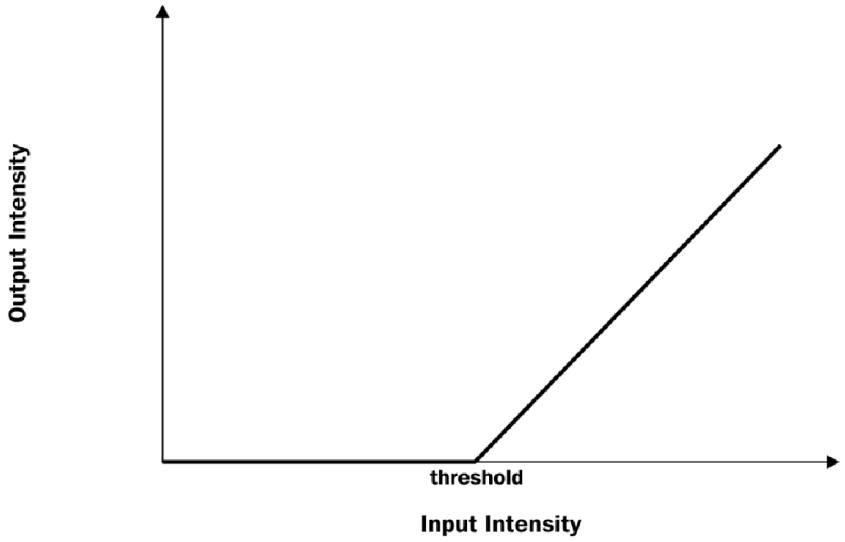
$$G(x,y) = \frac{1}{\sigma_x\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma_x^2}} \cdot \frac{1}{\sigma_y\sqrt{2\pi}} e^{-\frac{y^2}{2\sigma_y^2}}$$

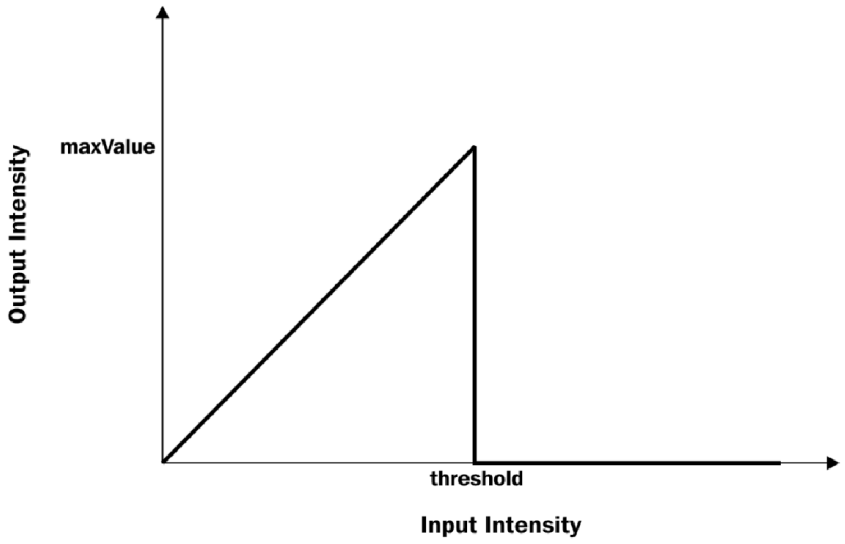

Y
X
(-1, -1)
(-1, 0)
(-1, 1)
(0, -1)
(0, 0)
(0, 1)
(1, -1)
(1, 0)
(1, 1)

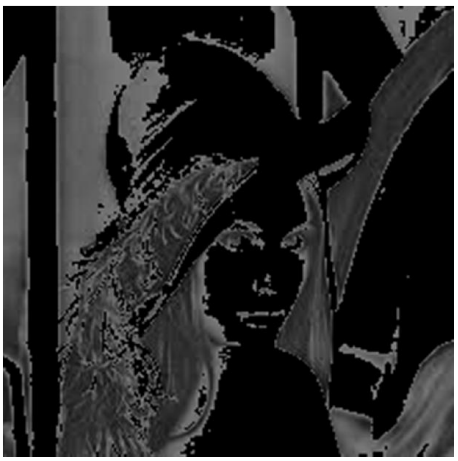
Chapter 3: Image Thresholding




maxValue
Output Intensity
threshold
Input Intensity


Output Intensity
threshold
Input Intensity

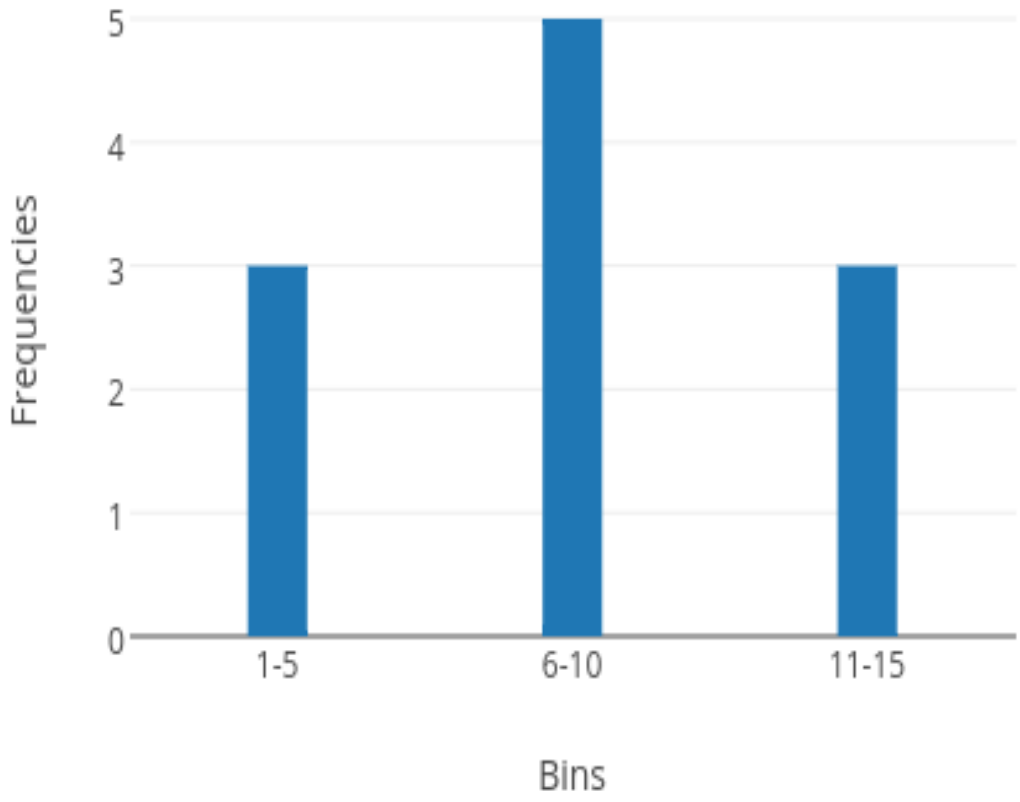

Output Intensity
maxValue
threshold
Input Intensity

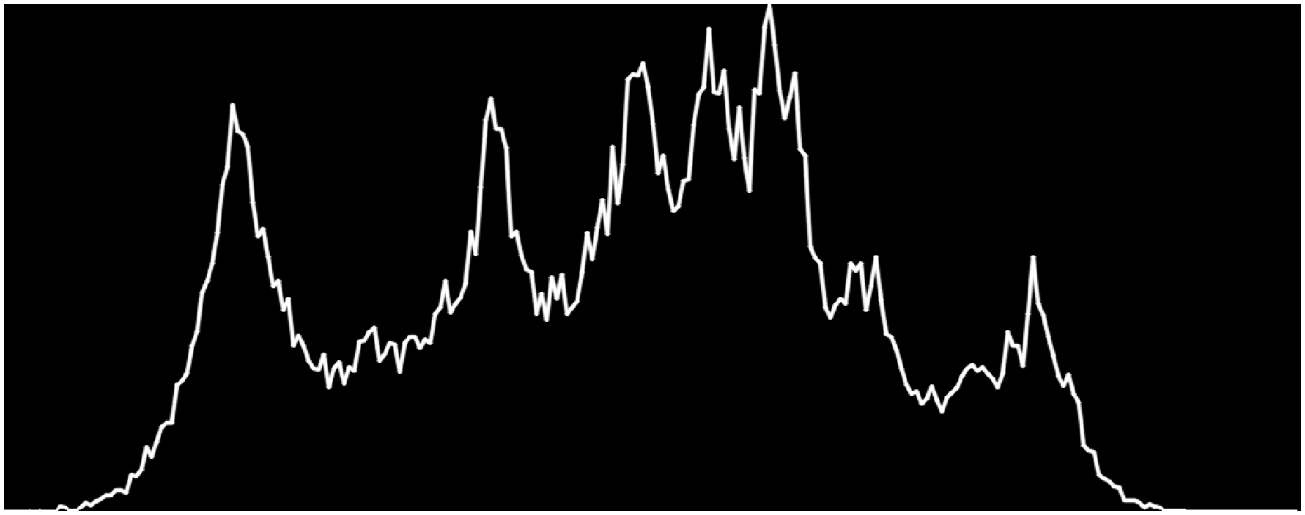


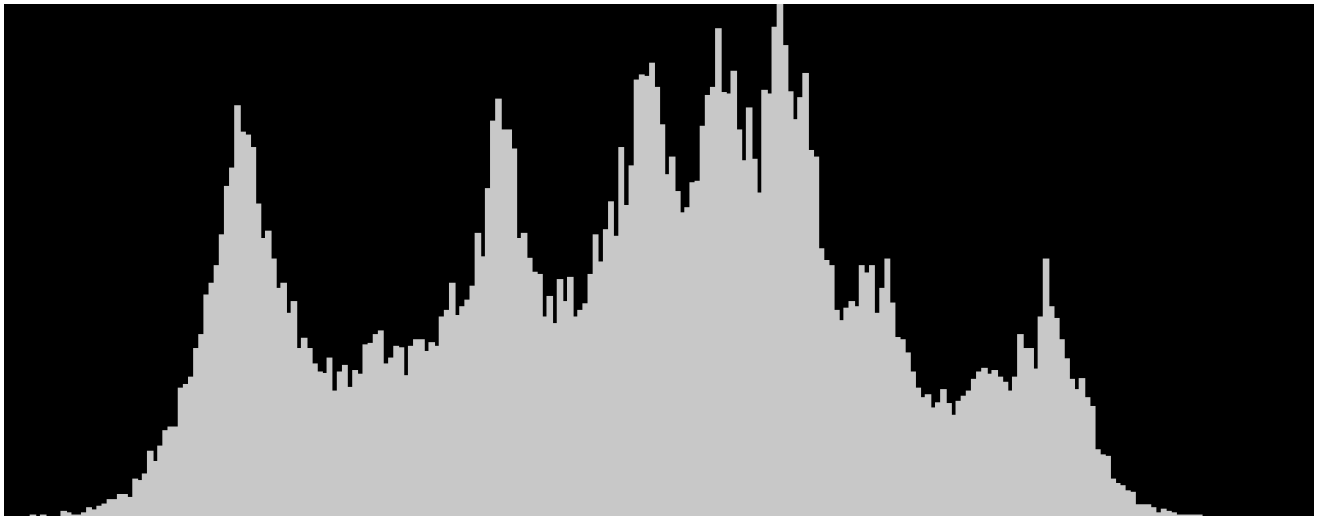
i

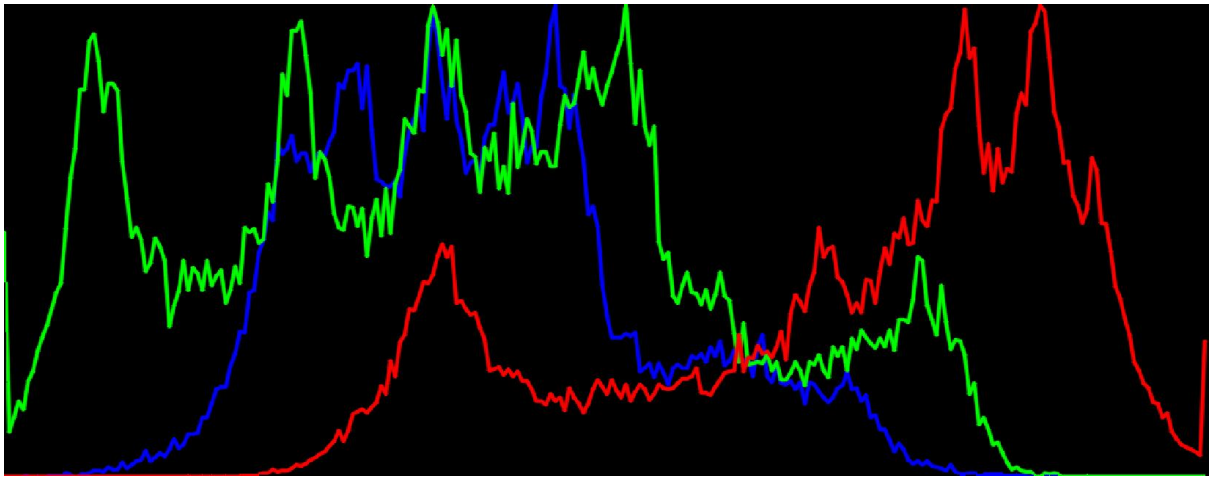
i i

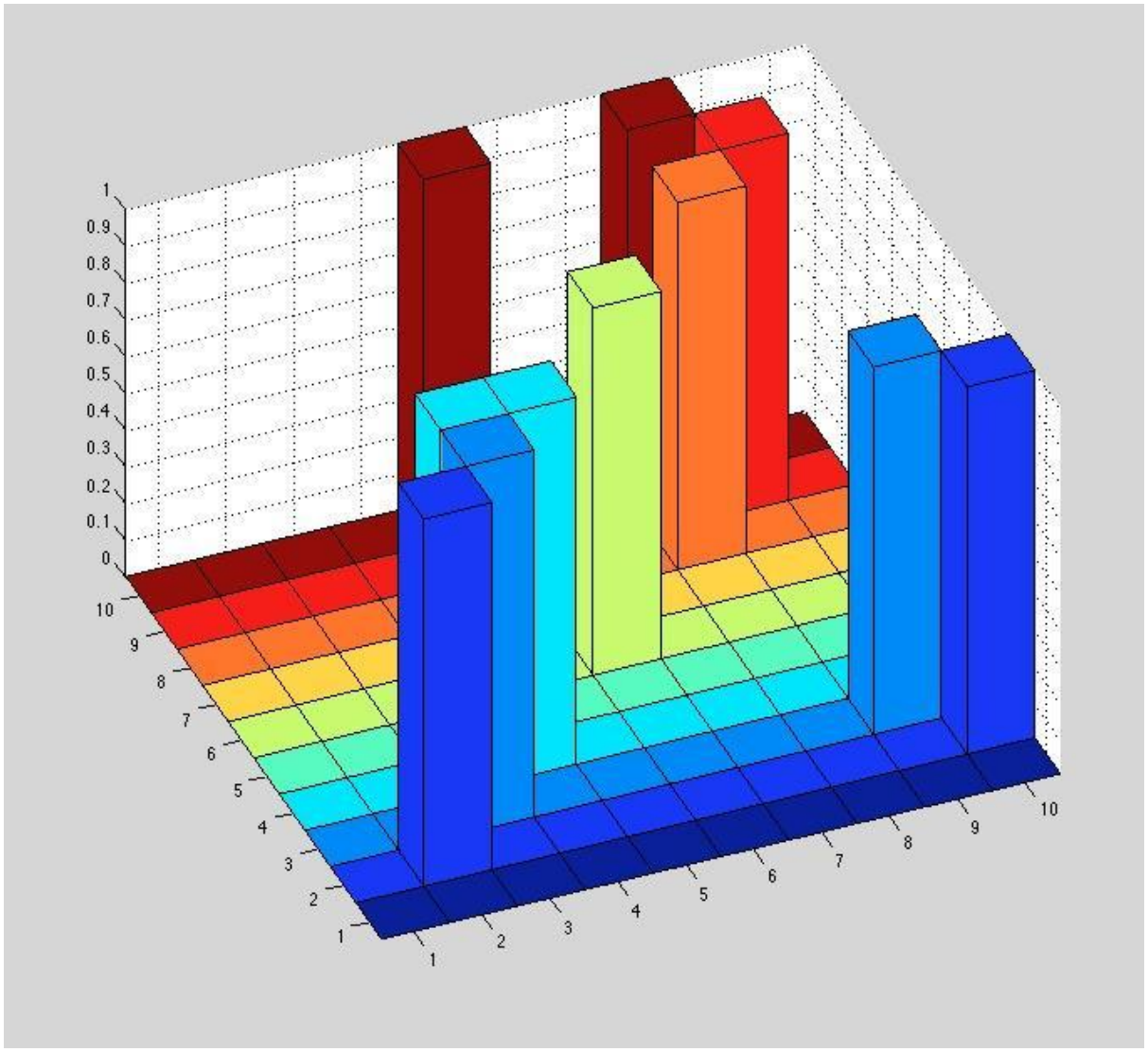
Chapter 4: Image Histograms

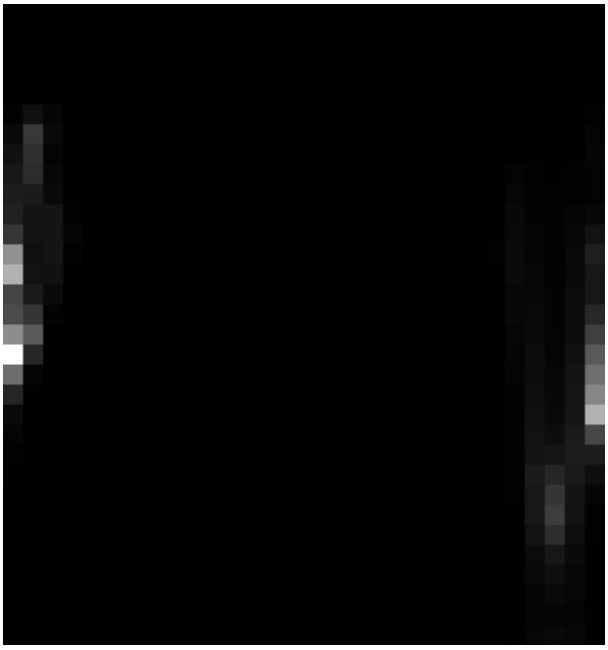









1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10



Chapter 5: Image Derivatives and Edge Detection

$$\frac{d}{dx} f(x)|_{x'} = \lim_{h \to 0} \frac{f(x+h) - f(x)}{h}$$

4	5	2	7	0	6	8	4	3	0	5	2	1	4	4	9	3	2	4	6	2	5	4	0	1

-1	3	-5	7	-6	-2	4	1	3	-5	3	1	-3	0	-5	6	1	-2	-2	4	-3	1	4	-1	

$$f'[x]|_{x=x'} = f[x'] - f[x'+1]$$

$$f'[x]|_{x=x'} = f[x'] - f[x'-1]$$

$$f'[x]|_{x=x'} = \frac{1}{2}\left(f[x'+1] - f[x'-1]\right)$$

1	-1

-1	1

-1/2	0	1/2

0	1	-1

(a) Forward Difference

-1	1	0

(b) Backward Difference

-1/2	0	1/2

(c) Central Difference

$\frac{1}{3}$

-1	0	1
-1	0	1
-1	0	1

$$\frac{1}{3}$$

-1	-1	-1
0	0	0
1	1	1

$$\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$

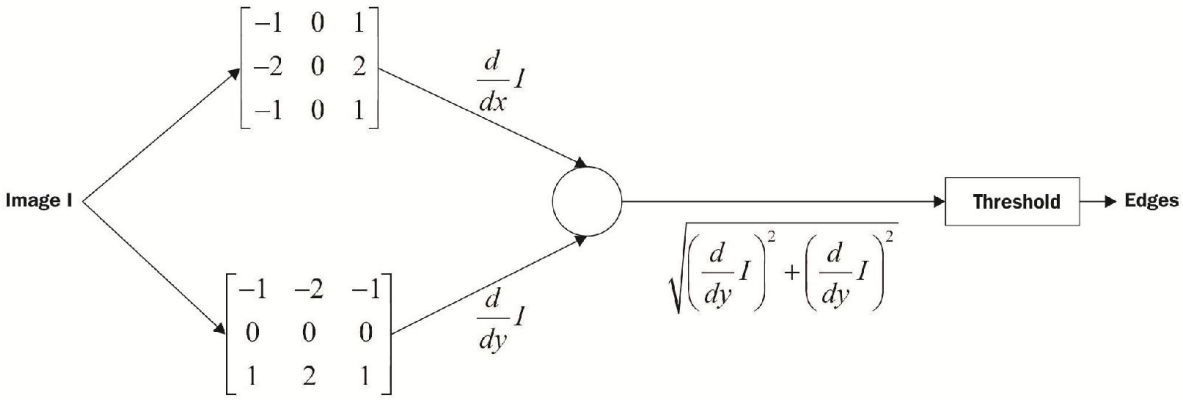
$$\begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

$$\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 1 \end{bmatrix}$$

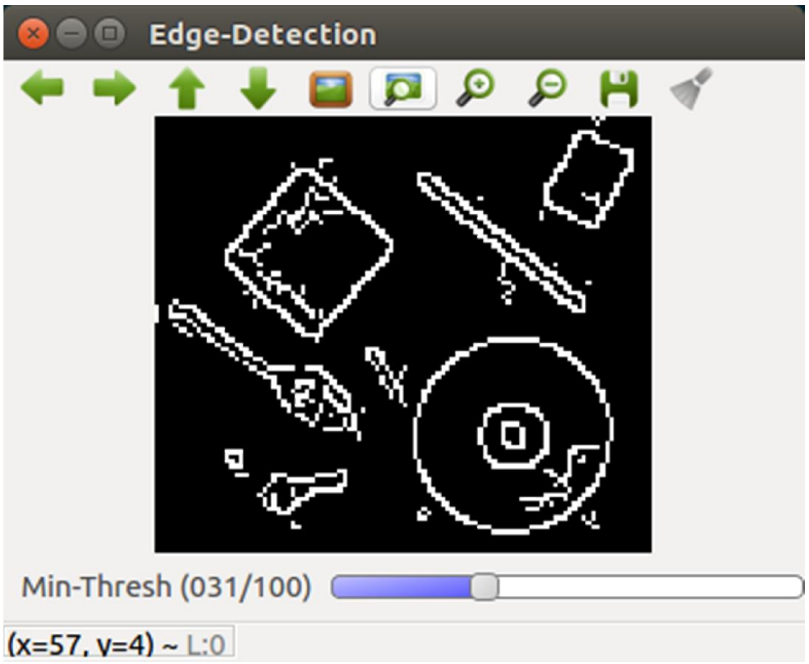
$$\begin{bmatrix} -3 & 0 & 3 \\ -10 & 0 & 10 \\ -3 & 0 & 3 \end{bmatrix}$$

$$G = \sqrt{G_x^2 + G_y^2}\ G_x\ G_y$$

$$\theta = \tan^{-1}\left(\frac{G_y}{G_x}\right)$$



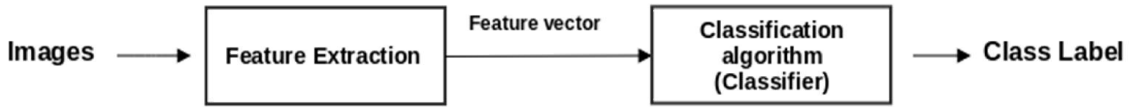
$$G = |G_x| + |G_y|$$

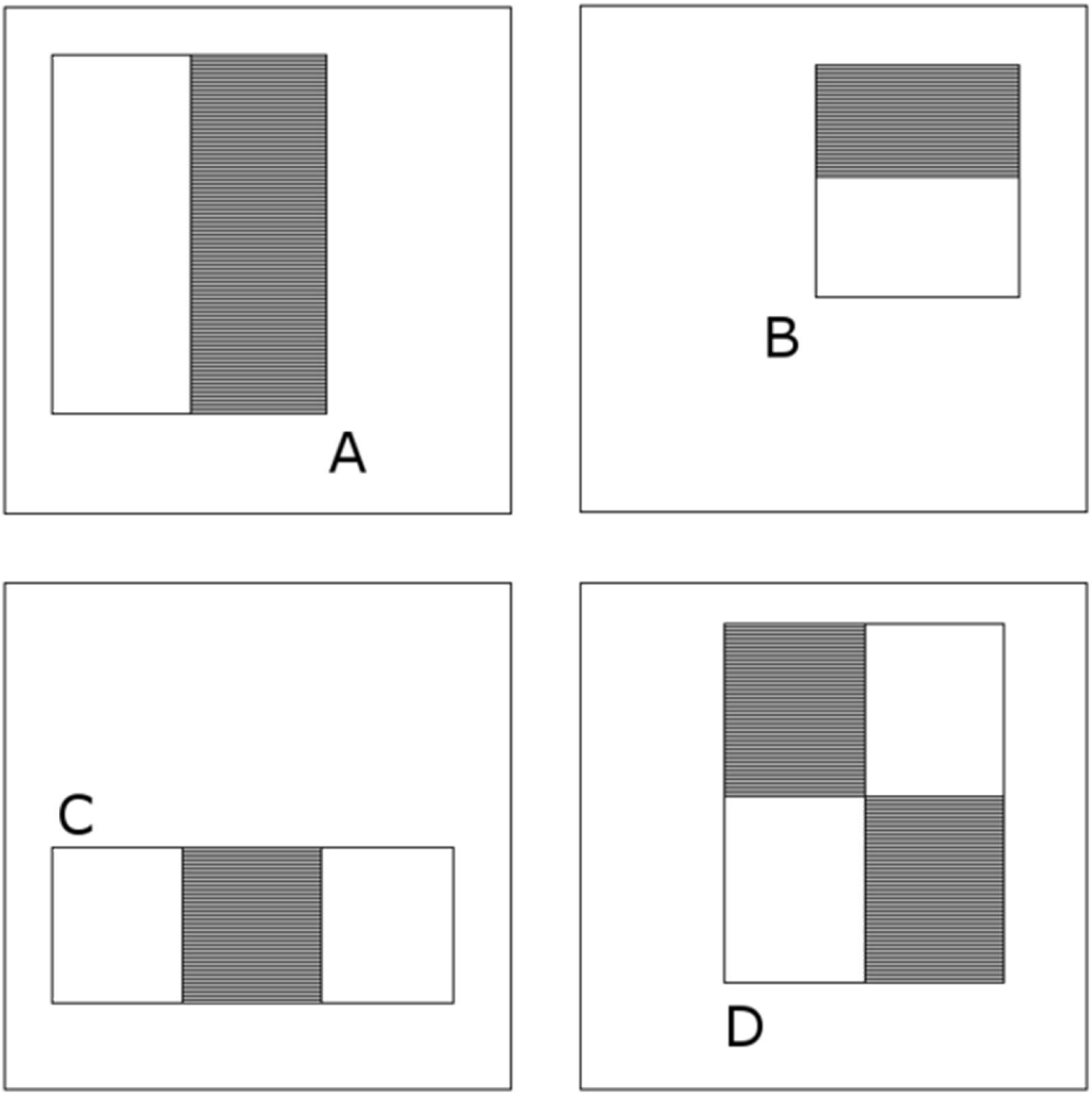

Edge-Detection
Min-Thresh (031/100)
(x=57, y=4) ~ L:0

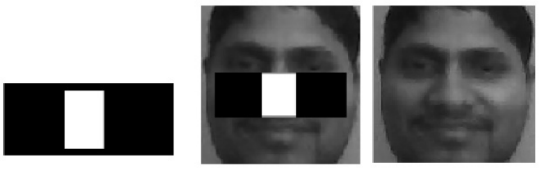
$$dst = \frac{d^2 src}{dx^2} + \frac{d^2 src}{dy^2}$$

$$\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

Chapter 6: Face Detection Using OpenCV







8	8	3	4	5	5
8	8	3	4	5	5
7	7	6	1	0	0
4	4	5	7	8	8
6	6	5	5	6	6
6	6	5	5	6	6

8	8	3	4	5	5
8	8	3	4	5	5
7	7	6	1	0	0
4	4	5	7	8	8
6	6	5	5	6	6
6	6	5	5	6	6

8	8	3	4	5	5
8	8	3	4	5	5
7	7	6	1	0	0
4	4	5	7	8	8
6	6	5	5	6	6
6	6	5	5	6	6

$$I(x,y) = \sum_{\substack{x' \le x \\ y' \le y}} i(x',y')$$

1	2	2	4	1
3	4	1	5	2
2	3	3	2	4
4	1	5	4	6
6	3	2	1	3

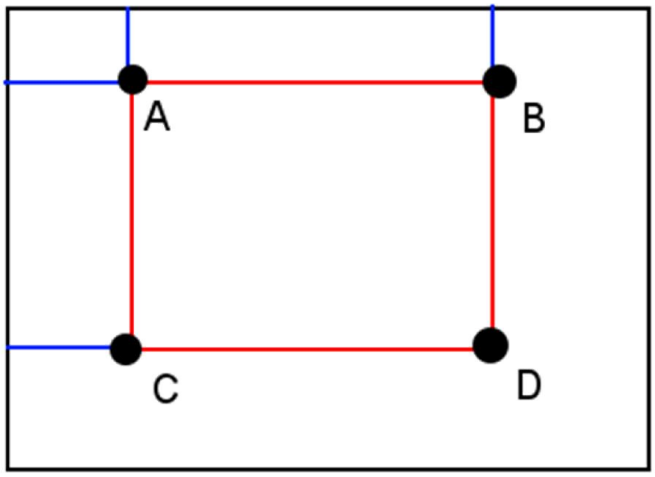
input image

0	0	0	0	0	0
0	1	3	5	9	10
0	4	10	13	22	25
0	6	15	21	32	39
0	10	20	31	46	59
0	16	29	42	58	74

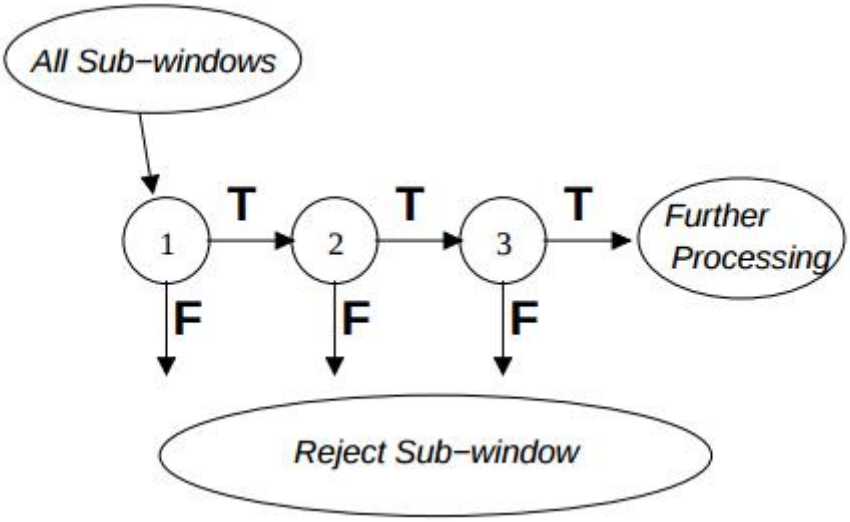
integral image

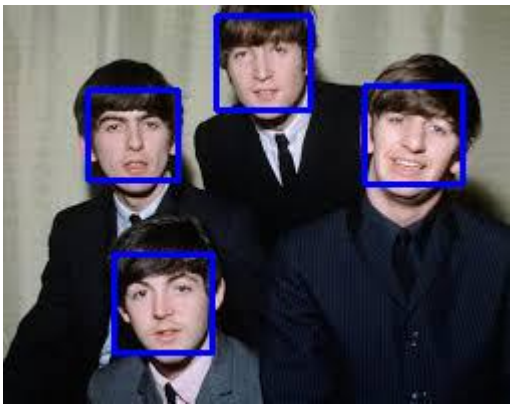
i (0, 0)	i (0, 1)	i (0, 2)	i (0, 3)	i (0, 4)	i (0, 5)
i (1, 0)	i (1, 1)	i (1, 2)	i (1, 3)	i (1, 4)	i (1, 5)
i (2, 0)	i (2, 1)	i (2, 2)	i (2, 3)	i (2, 4)	i (2, 5)
i (3, 0)	i (3, 1)	i (3, 2)	i (3, 3)	i (3, 4)	i (3, 5)
i (4, 0)	i (4, 1)	i (4, 2)	i (4, 3)	i (4, 4)	i (4, 5)
i (05, 0)	i (4, 1)	i (5, 2)	i (5, 3)	i (5, 4)	i (5, 5)

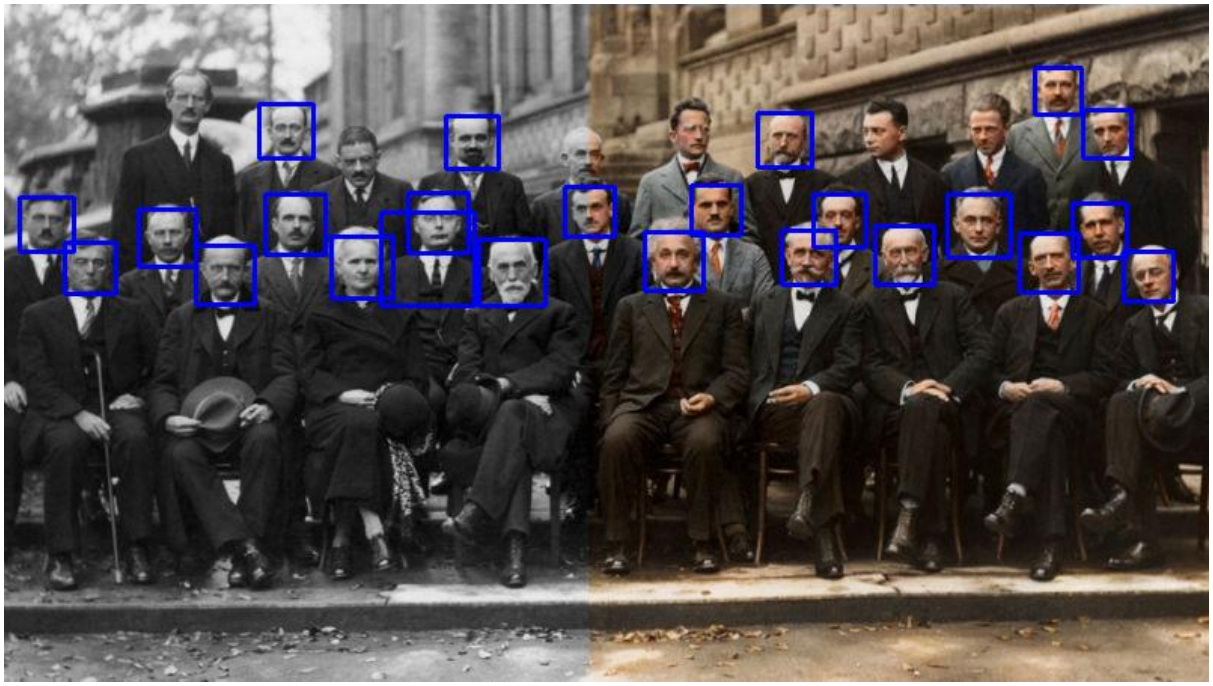
$$S(1,2,2,4) = I(2,4) - I(0,4) - I(2,1) + I(0,1)$$

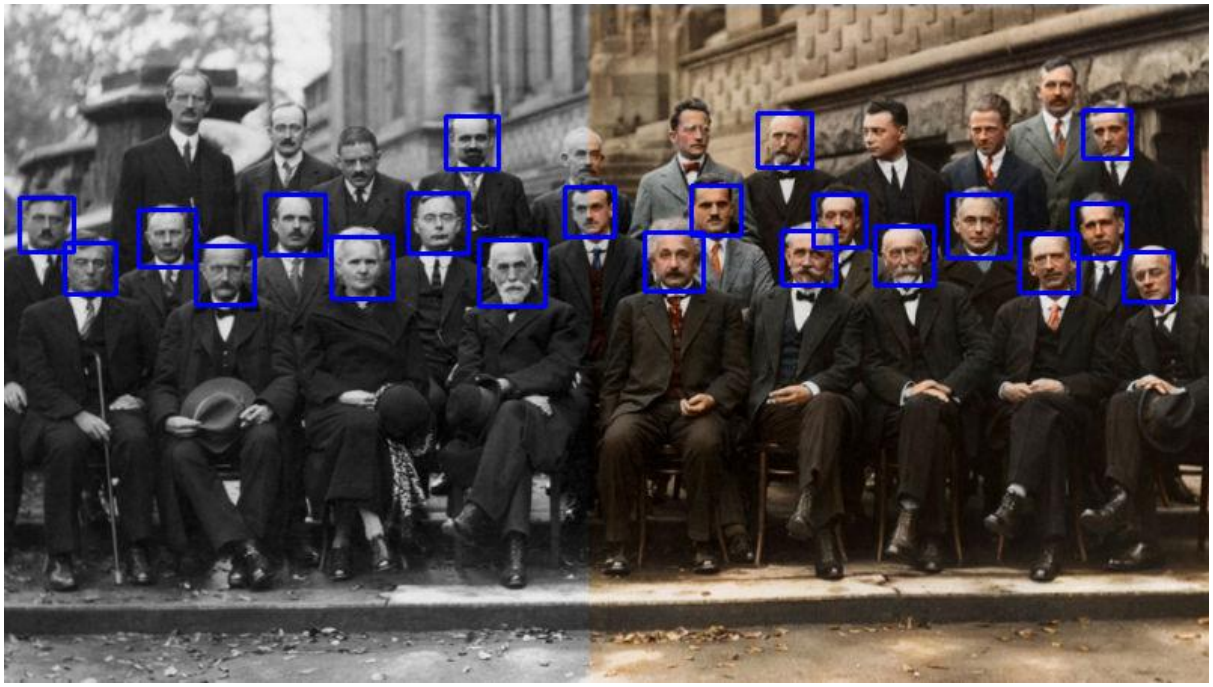


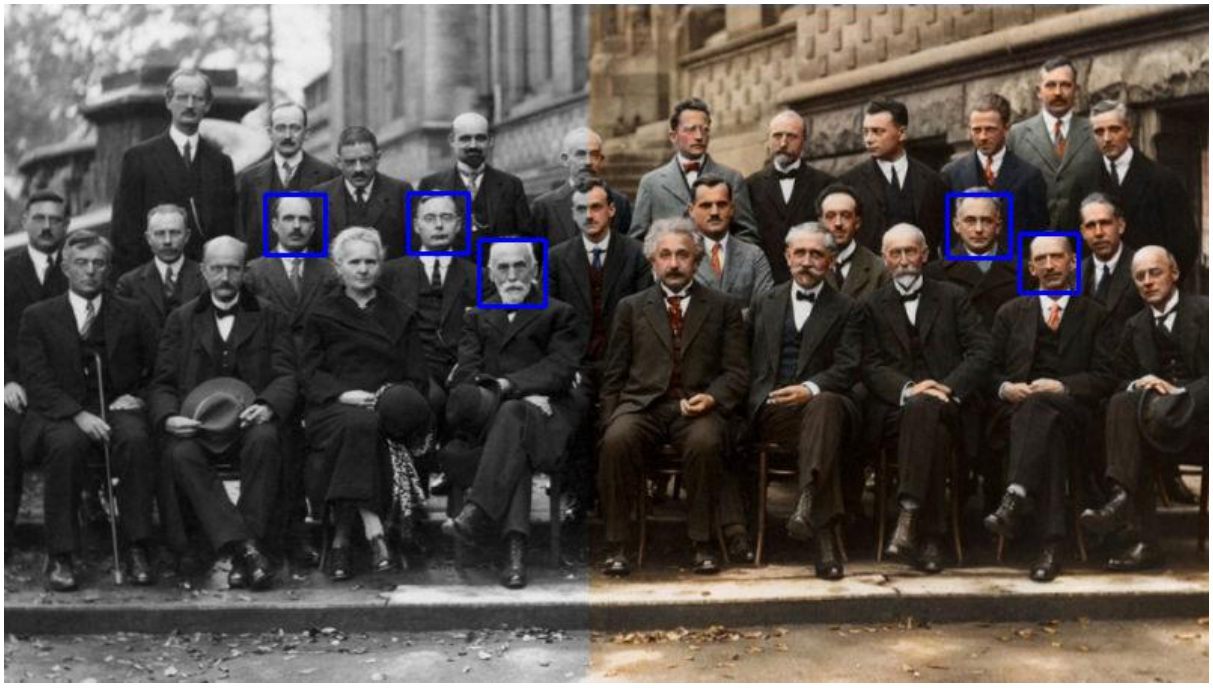
Sum = D - B - C + A


All Sub−windows
1
2
3
T
T
T
F
F
F
Further
Processing
Reject Sub−window





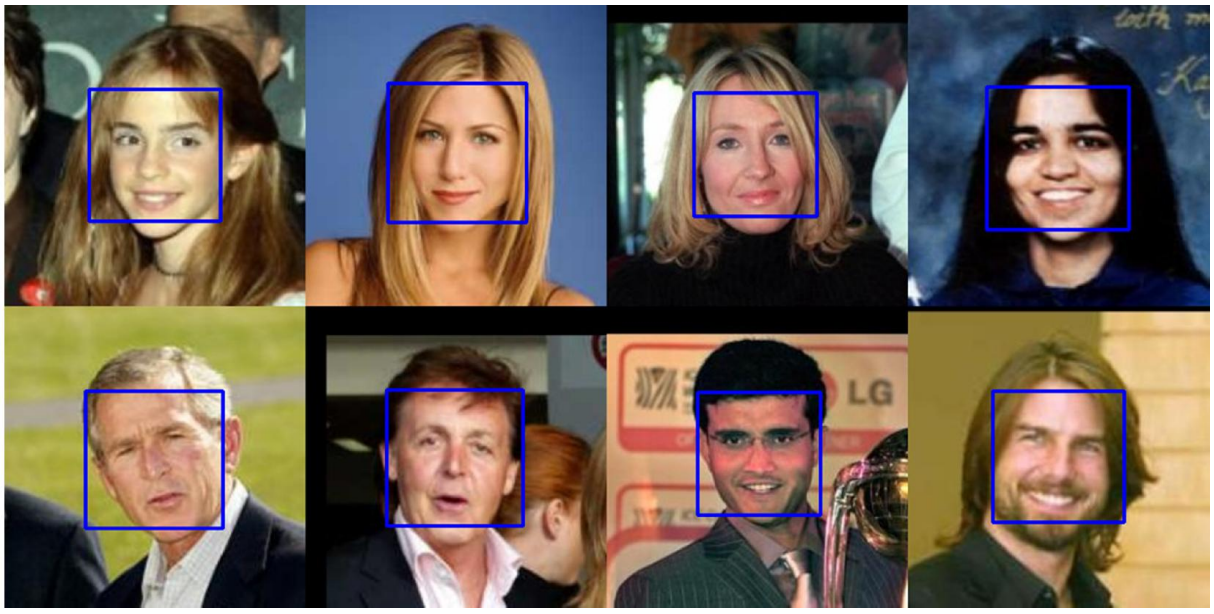


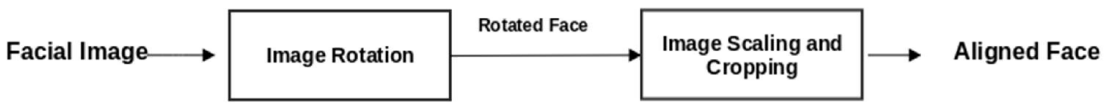


Male

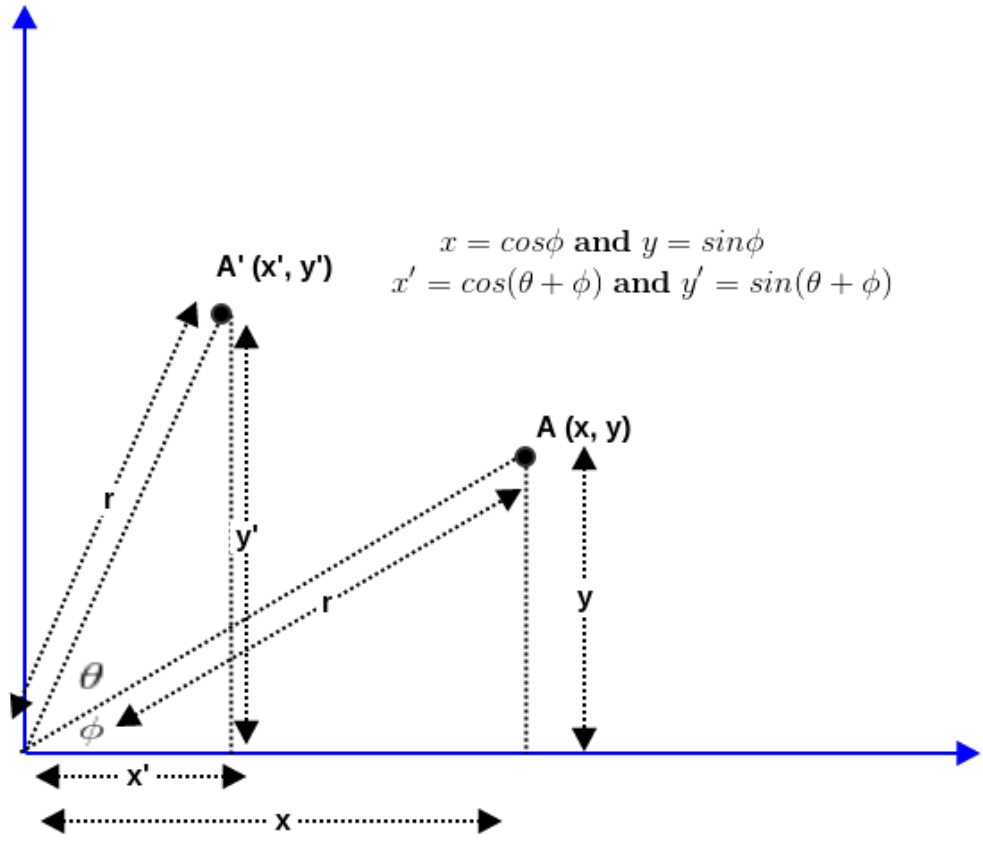
Female

Chapter 7: Affine Transformations and Face Alignment



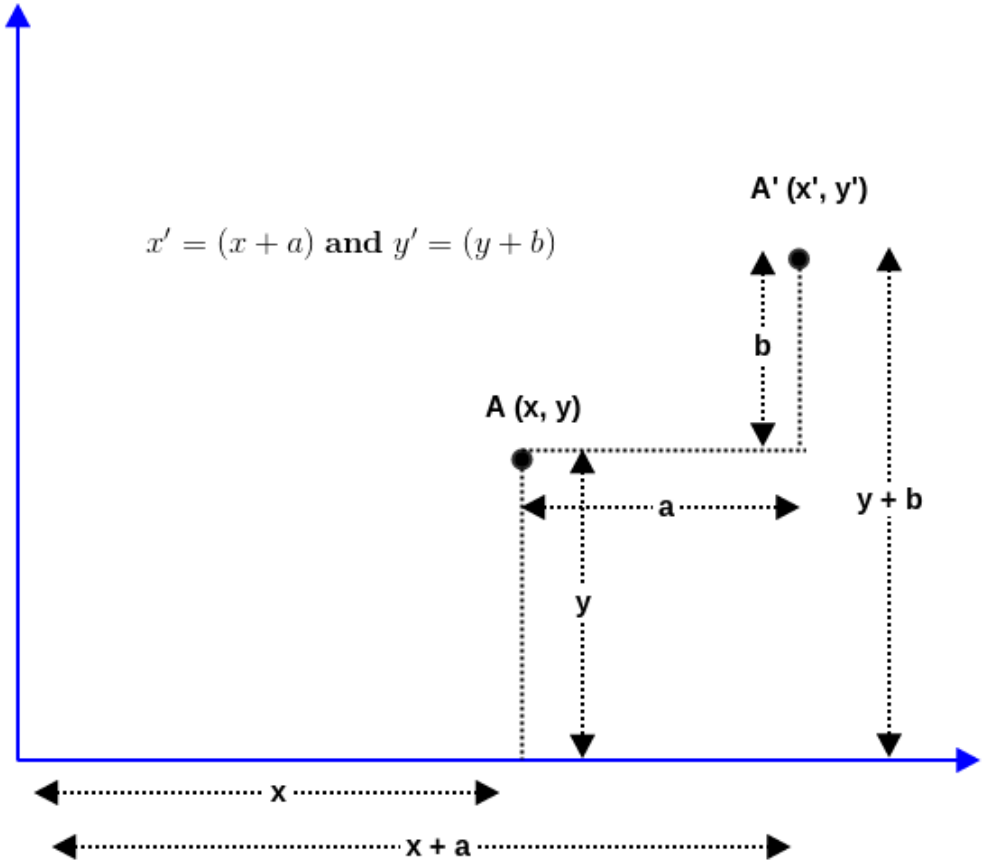


$$\theta = tan^{-1}(\frac{y_{right} - y_{left}}{x_{right} - x_{left}})$$

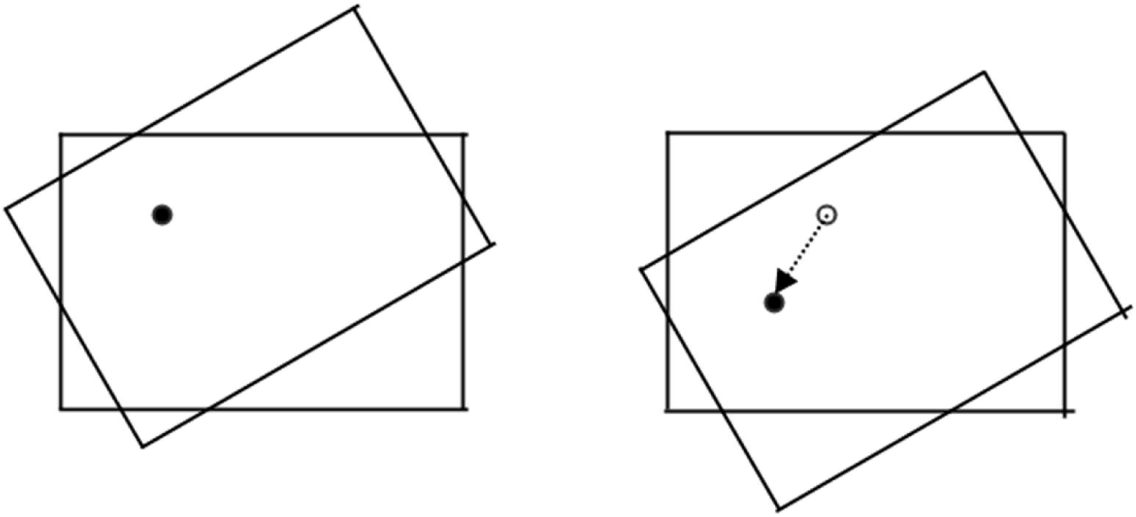


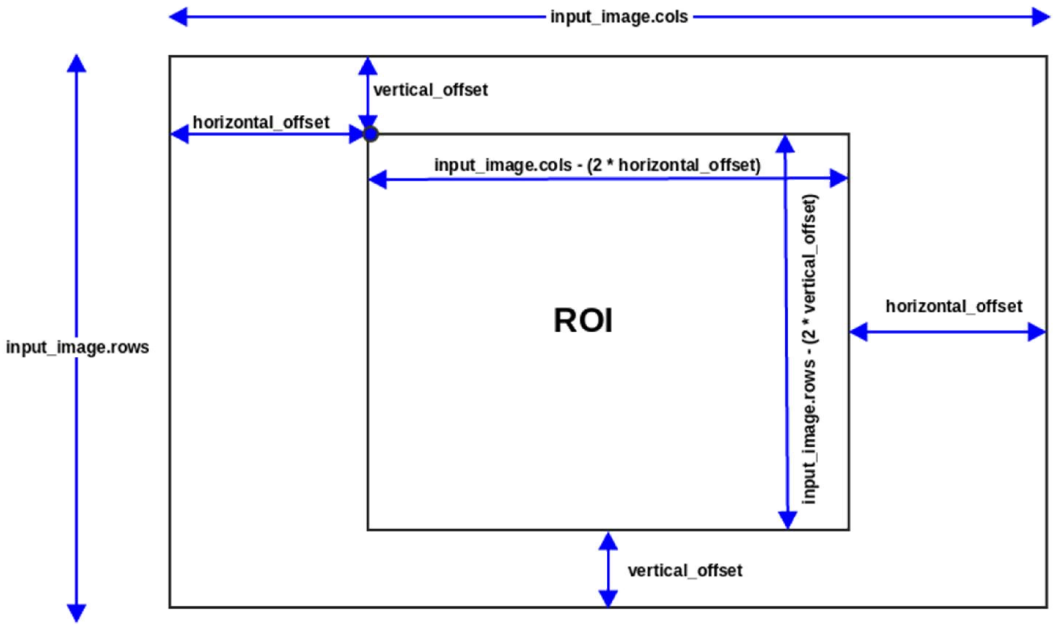
$$x = cos\phi \text{ and } y = sin\phi$$
$$x' = cos(\theta + \phi) \text{ and } y' = sin(\theta + \phi)$$

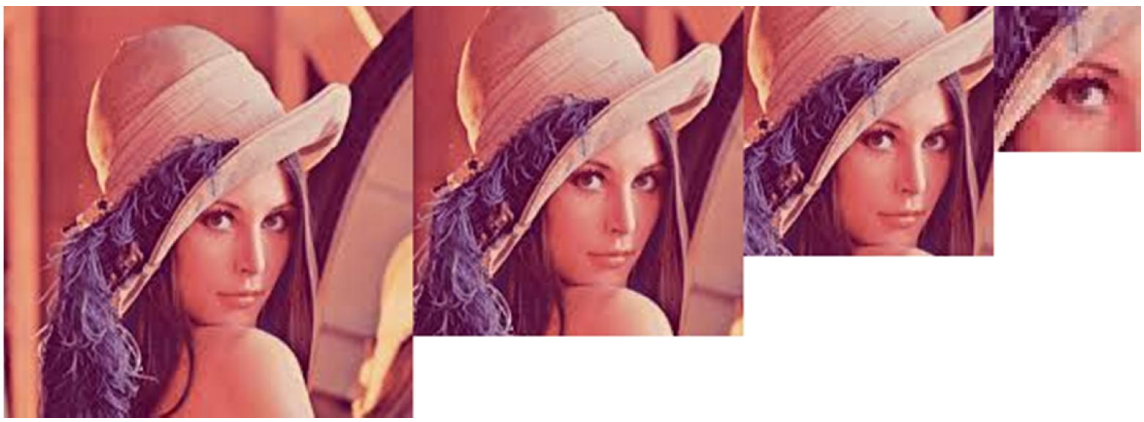
$$x' = cos(\theta + \phi) \textbf{ and } y' = sin(\theta + \phi)$$
$$\Rightarrow x' = cos\theta cos\phi - sin\theta sin\phi \textbf{ and } y' = sin\theta cos\phi + cos\theta sin\phi$$
$$\Rightarrow x' = xcos\theta - ysin\theta \textbf{ and } y' = xsin\theta + ycos\theta]$$
$$\Rightarrow \begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

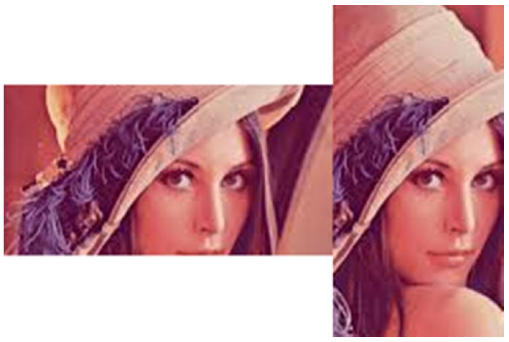


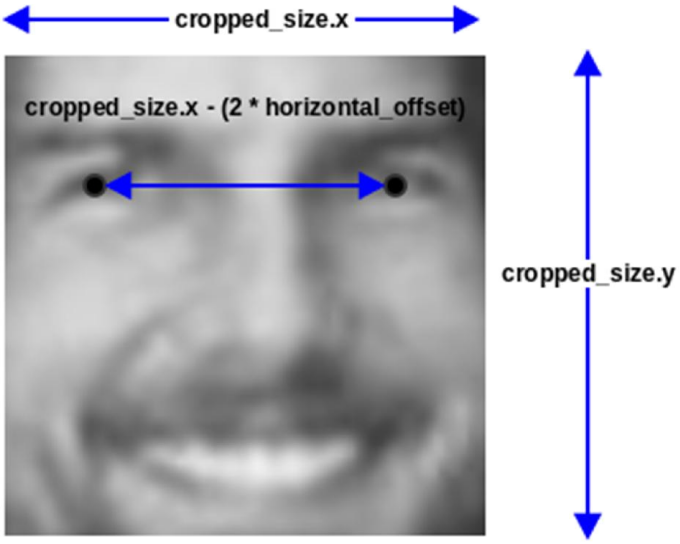
$$\begin{matrix} \\ \theta \end{matrix} \begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} cos\theta & -sin\theta & a \\ sin\theta & cos\theta & b \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$



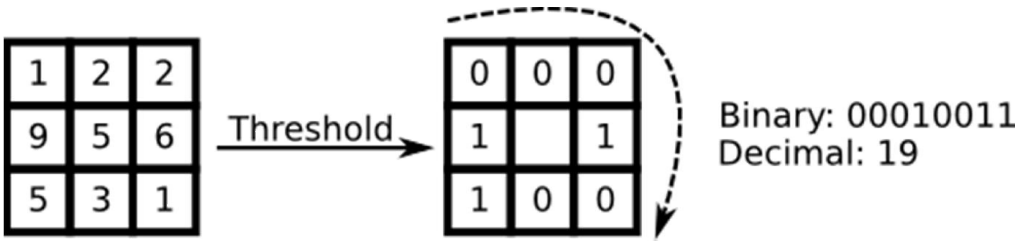

input_image.cols
vertical_offset
horizontal_offset
input_image.cols - (2 * horizontal_offset)
input_image.rows - (2 * vertical_offset)
ROI
horizontal_offset
input_image.rows
vertical_offset

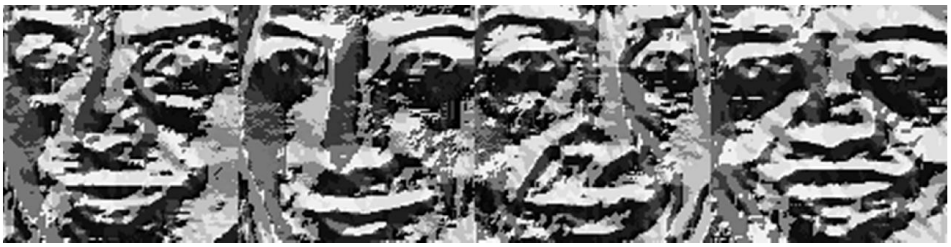


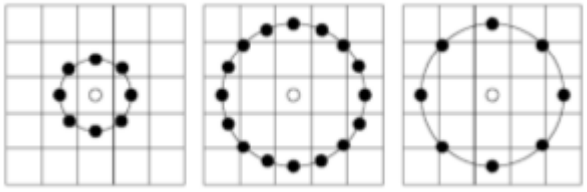


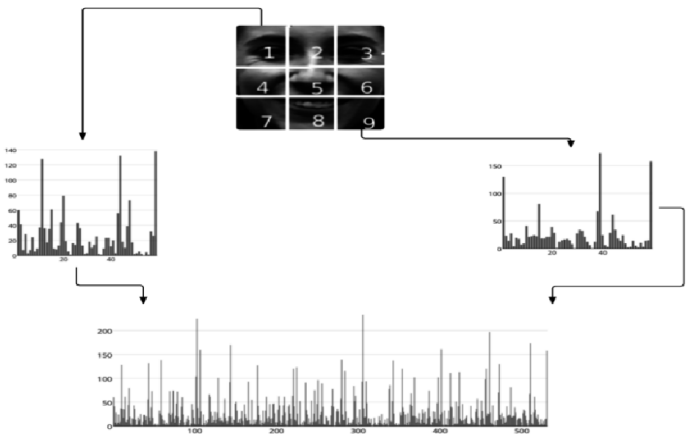

cropped_size.x
cropped_size.x - (2 * horizontal_offset)
cropped_size.y

Chapter 8: Feature Descriptors in OpenCV

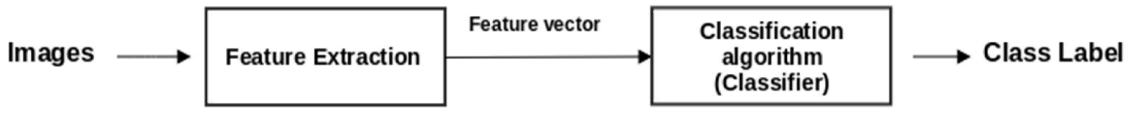


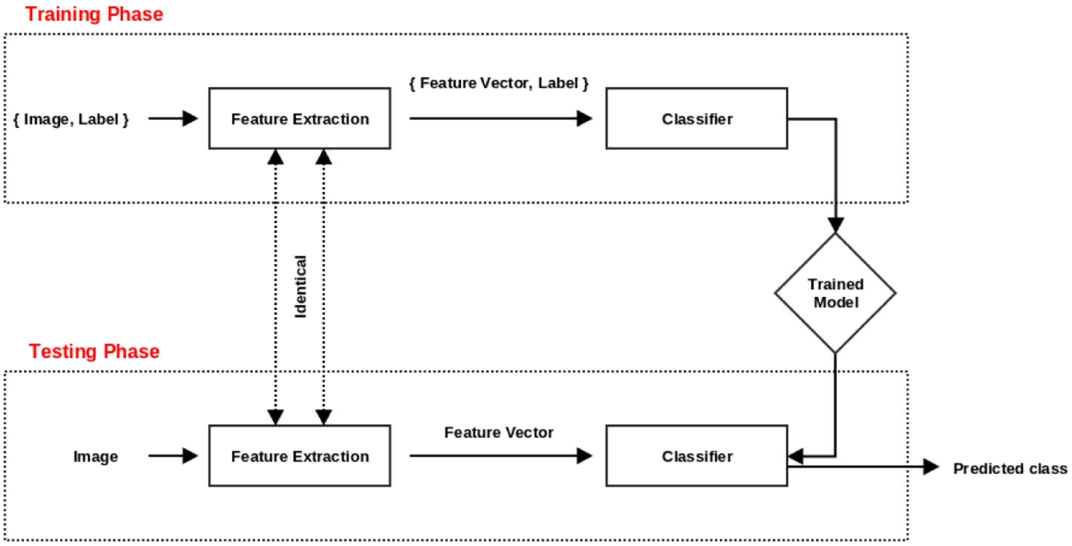


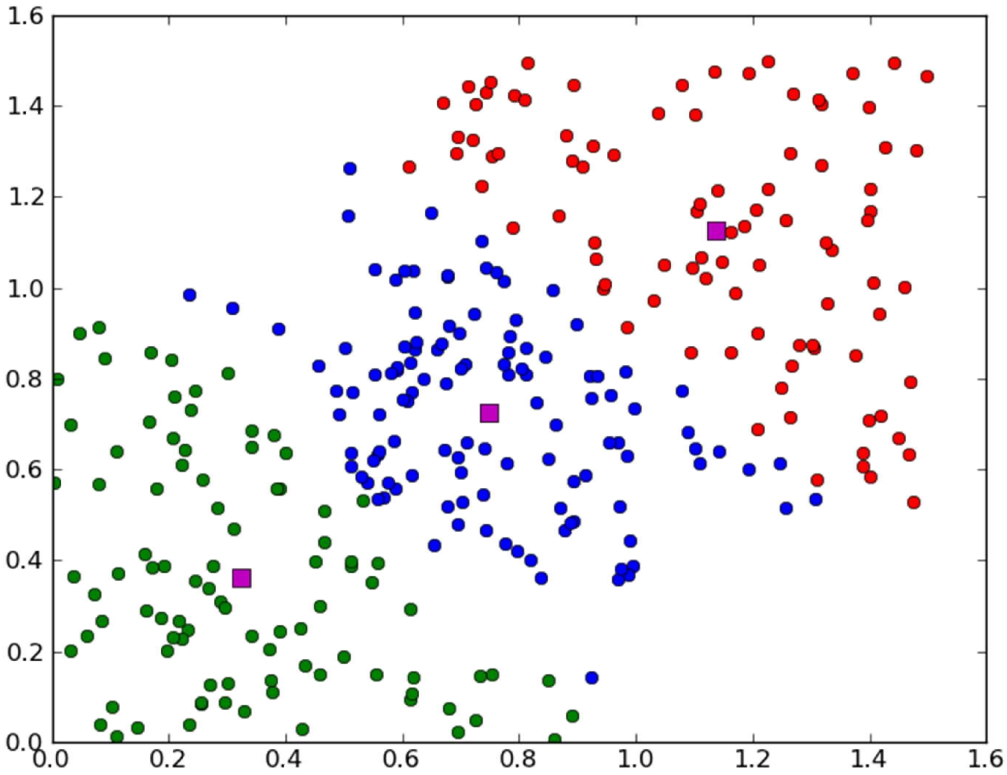


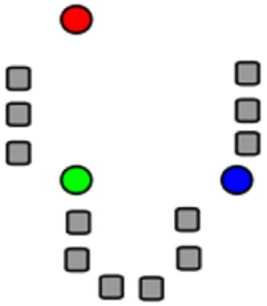

1
2
3
4
5
6
7
8
9

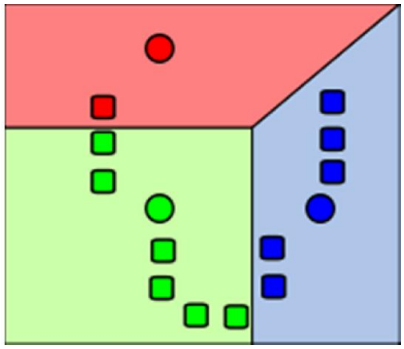
Chapter 9: Machine Learning with OpenCV

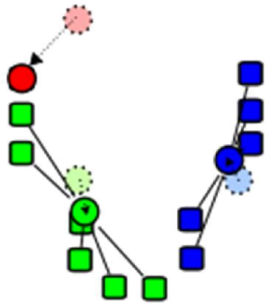


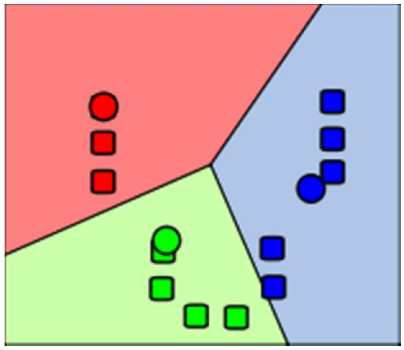


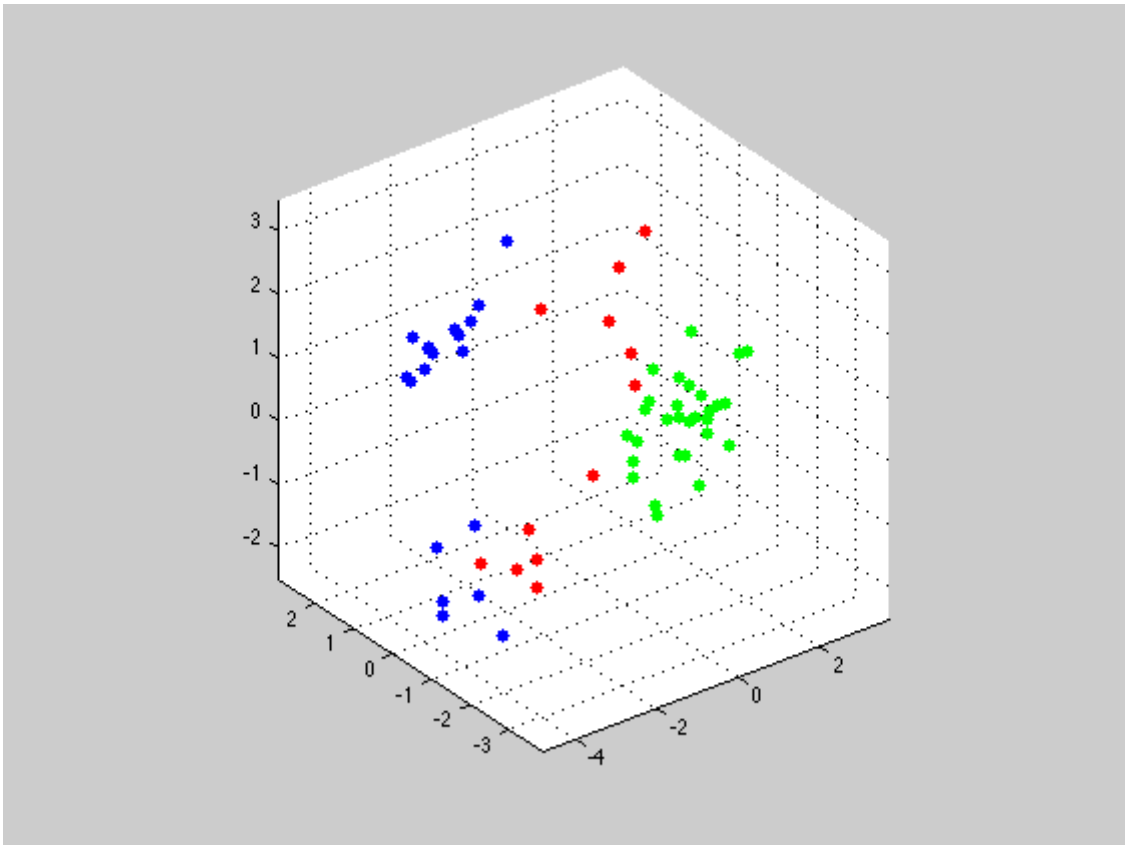

1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

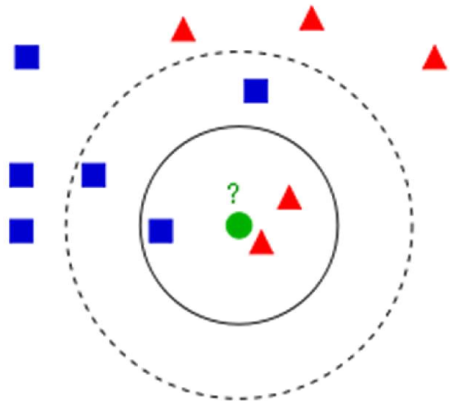


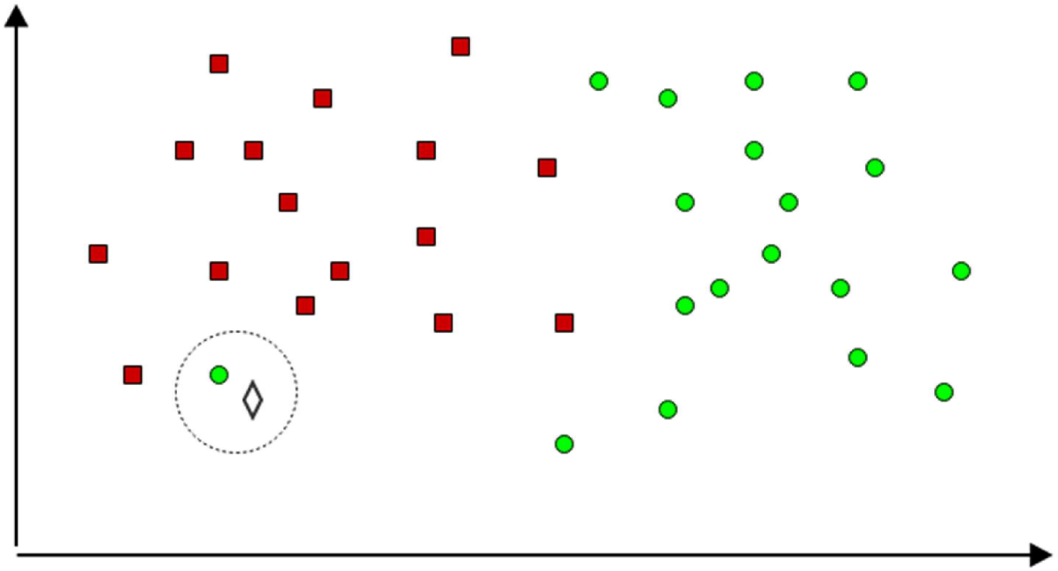


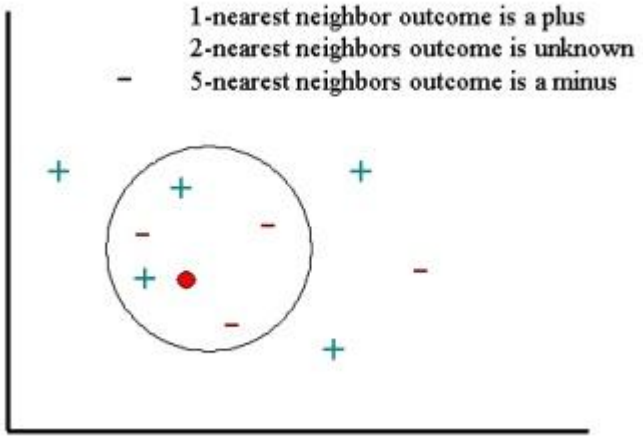





3
2
1
0
-1
-2
2
1
0
-1
-2
-3
-4
-2
0
2


?

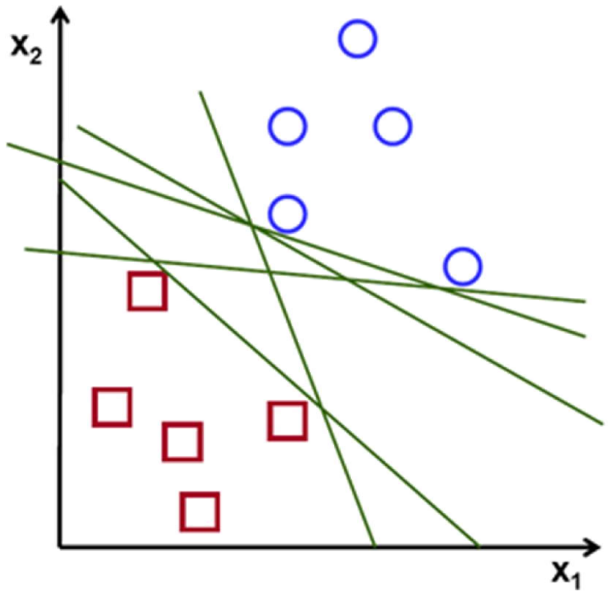


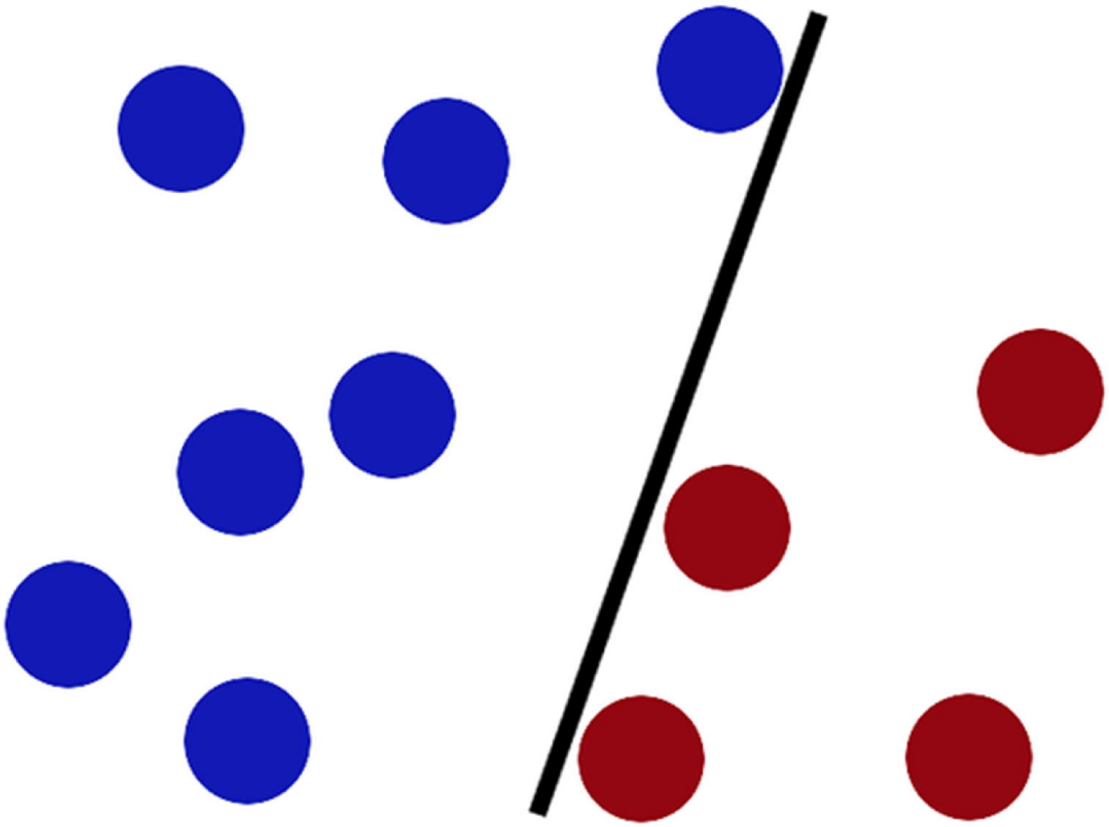


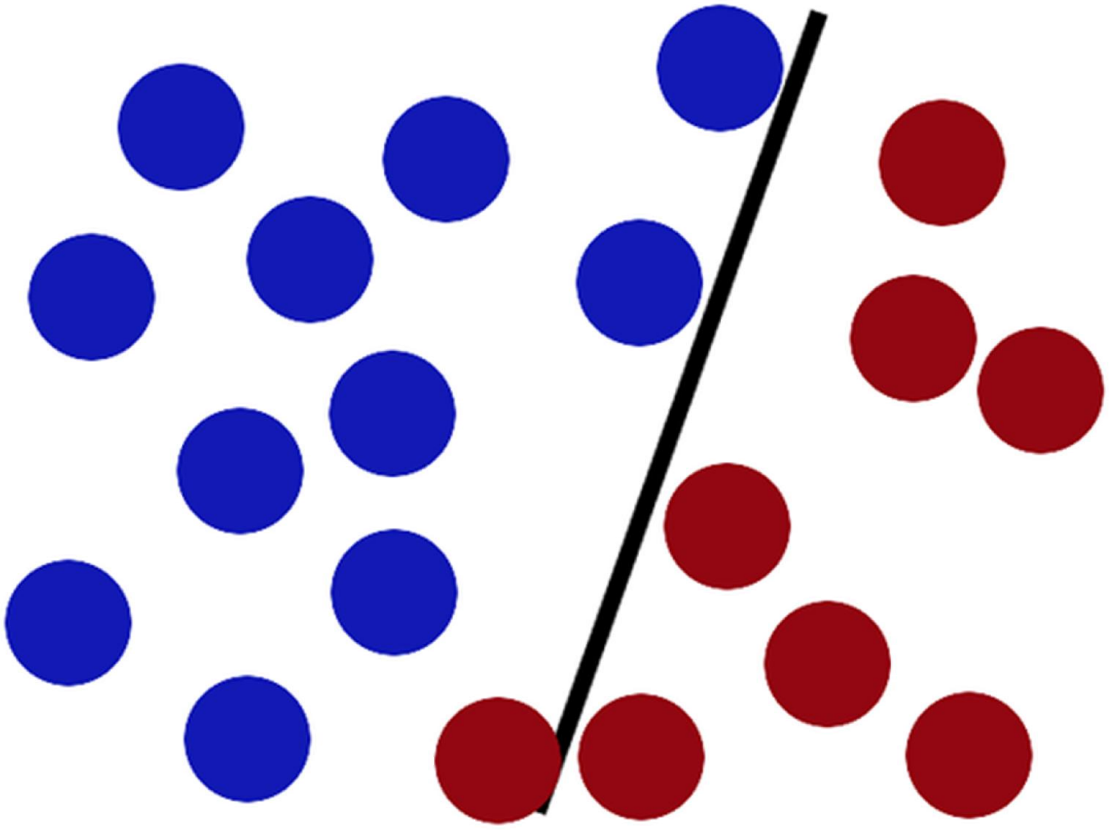
$$d(x, y) = \sqrt{\sum_{i=1}^{d} (x_i - y_i)^2}$$ L_p L_p

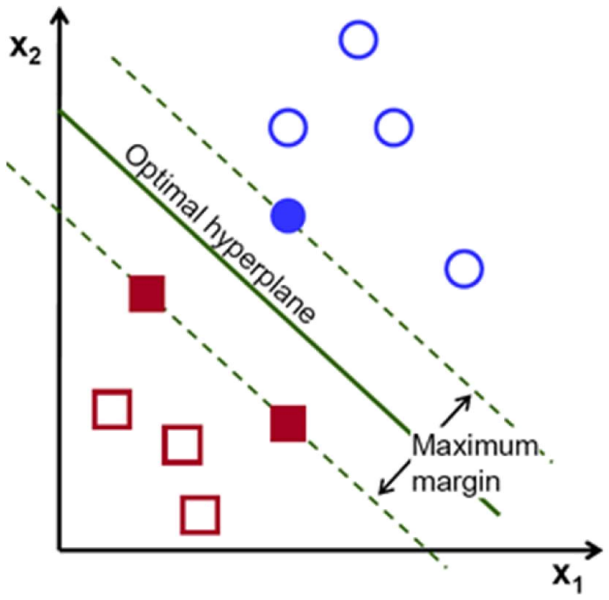
$$L_p(x, y) = (\sum_{i=1}^{d} |x_i - y_i|^p)^{\frac{1}{p}}$$

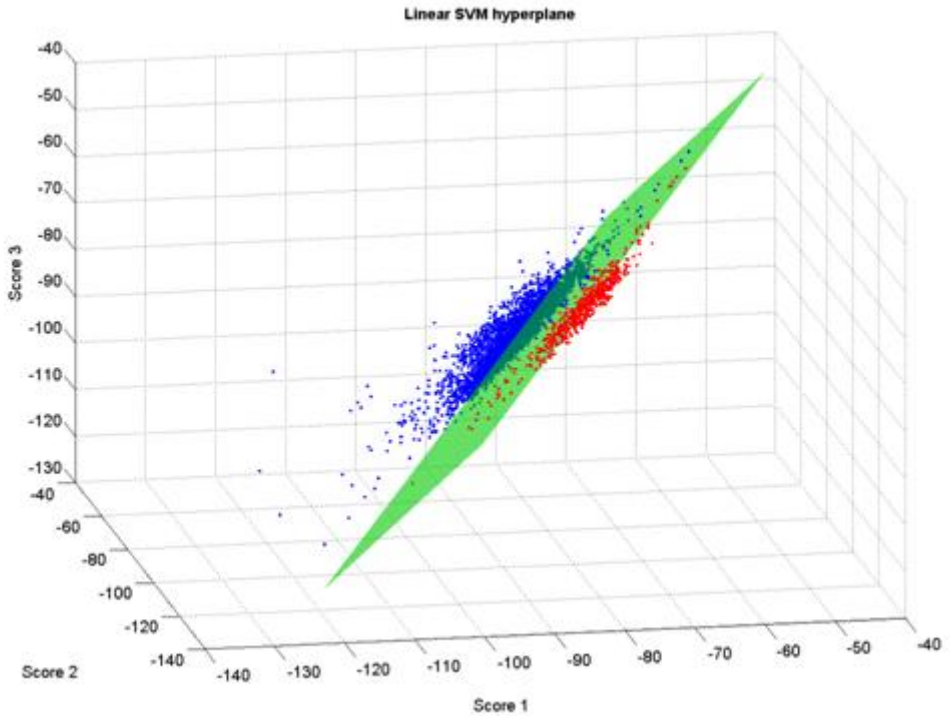
$$L_1(x, y) = \sum_{i=1}^{d} |x_i - y_i|)$$

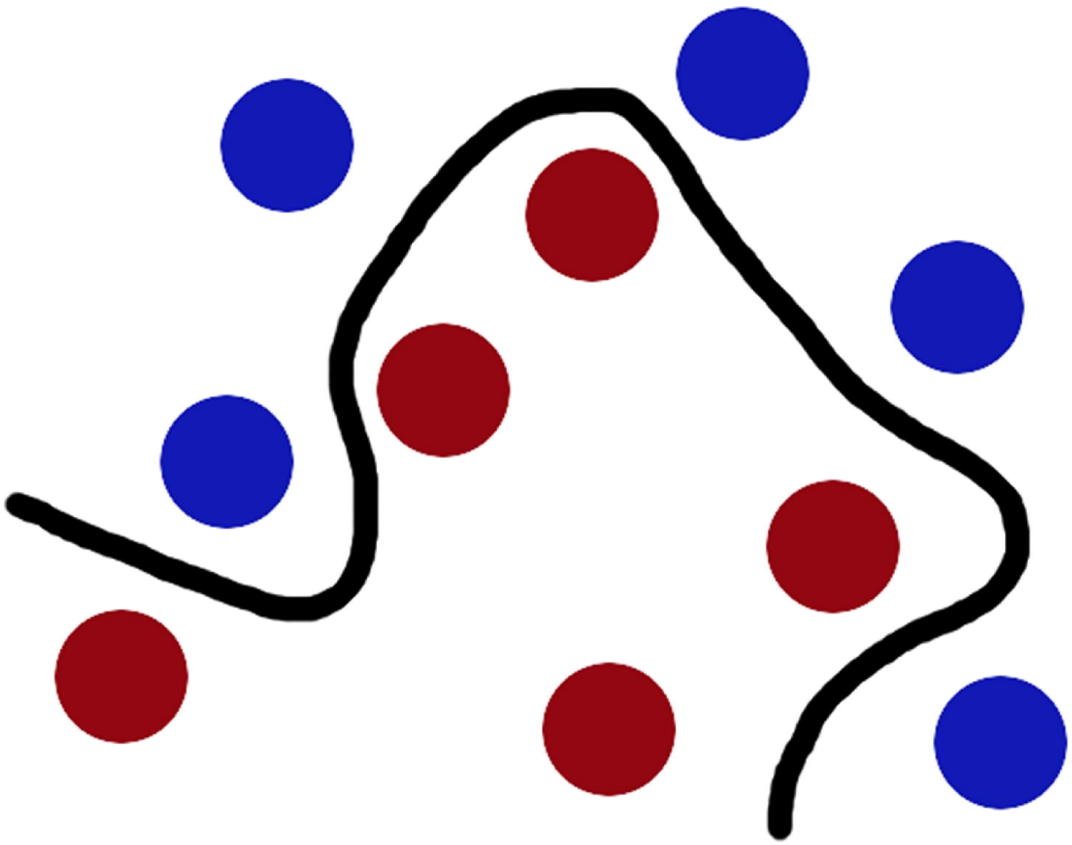


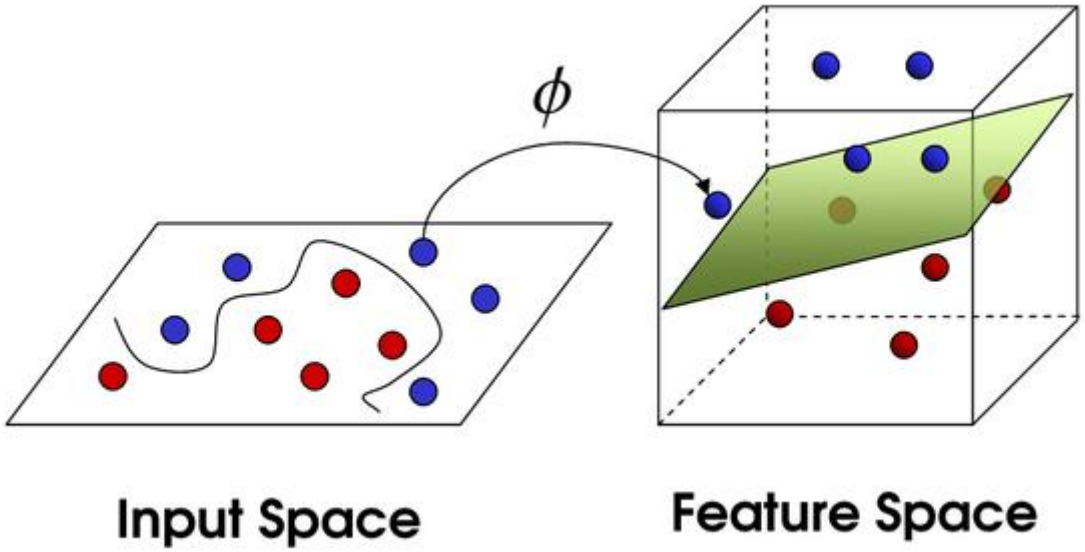


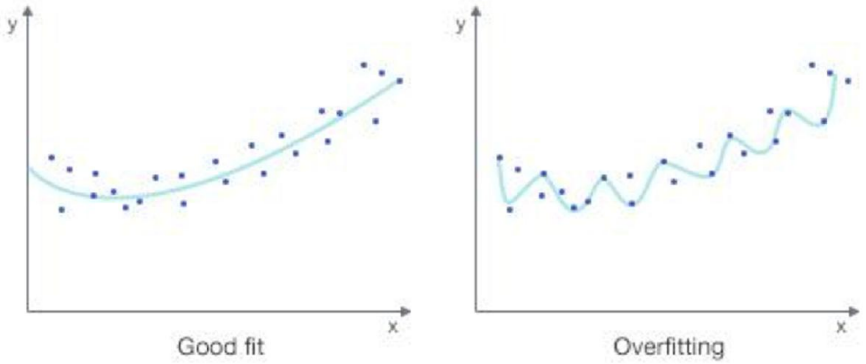


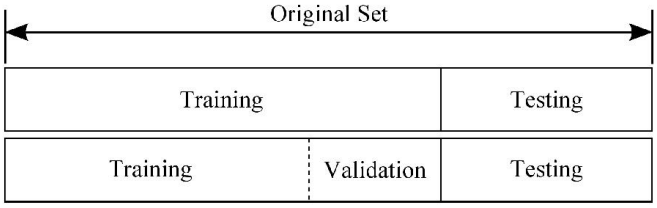

x2
Optimal hyperplane
Maximum
margin
x1

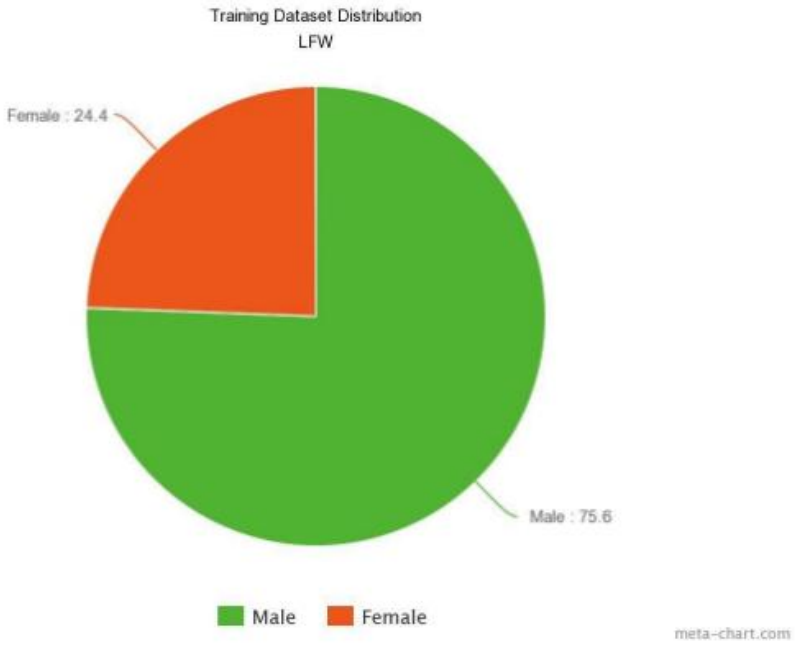

Linear SVM hyperplane
Score 3
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
Score 2
-40
-60
-80
-100
-120
-140
Score 1
-140
-130
-120
-110
-100
-90
-80
-70
-60
-50
-40



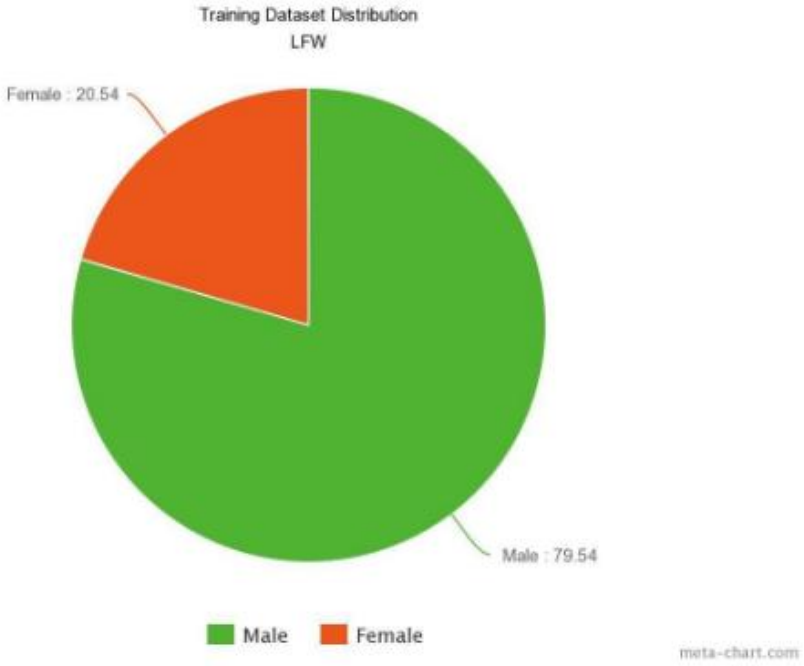

ϕ
Input Space
Feature Space


y
x
Good fit
y
x
Overfitting


Original Set
Training
Testing
Training
Validation
Testing



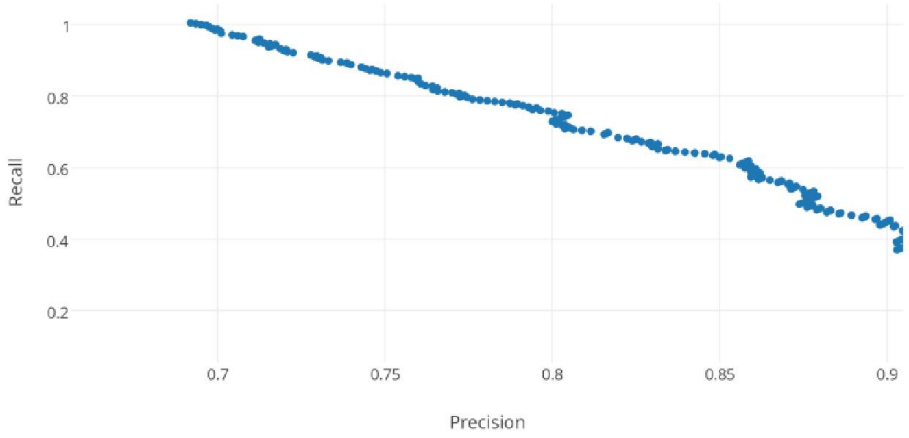
Training dataset distribution



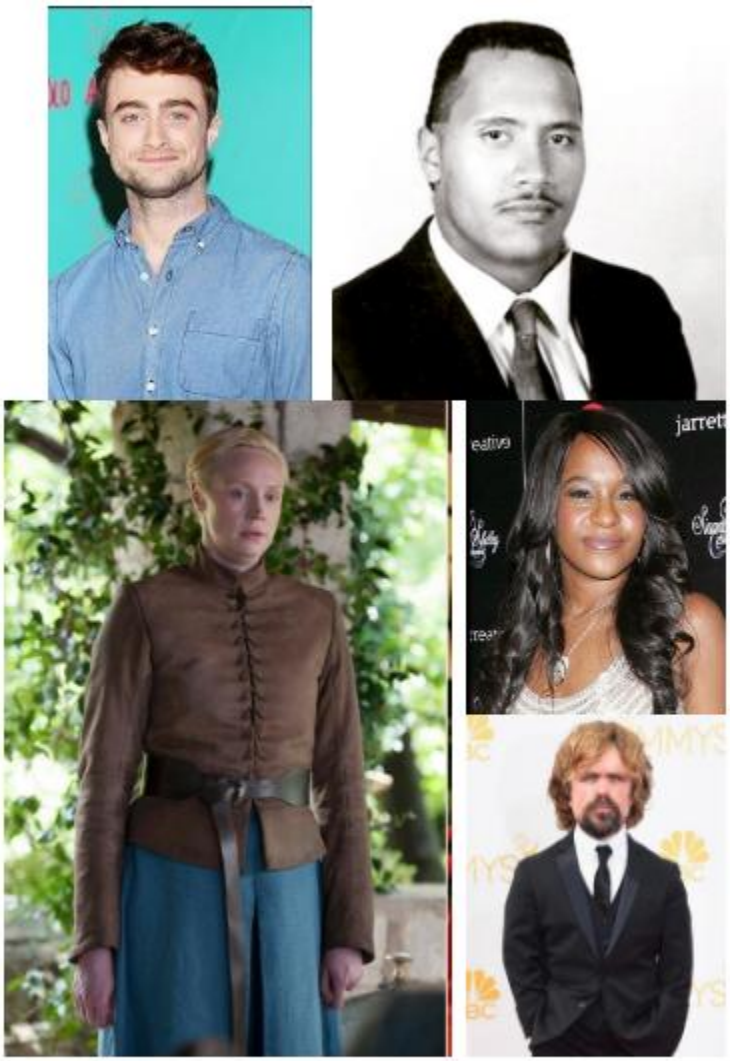
Test dataset distribution

		Actual	
		0	**1**
Predicted	0	True Negative	False Negative
	1	False Positive	True Positive

Precision-Recall (P-R Curve)



Female Predictions



Male Predictions

Appendix: Command-line Arguments in C++