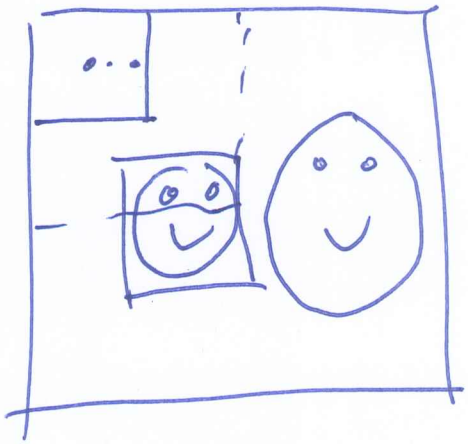
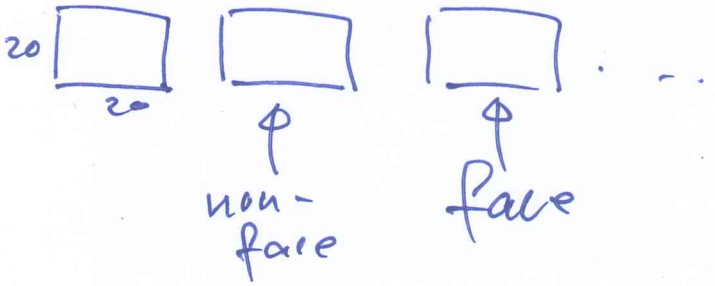
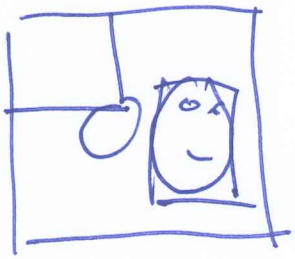
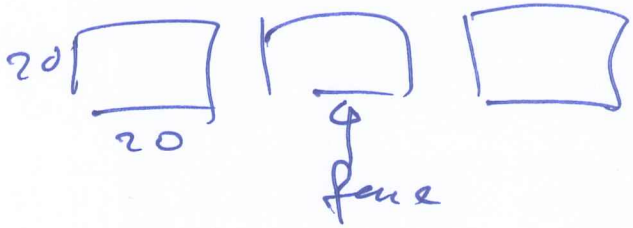
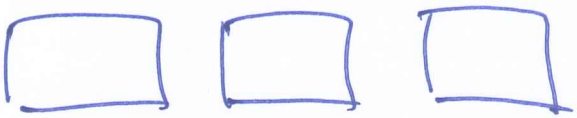
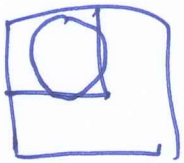


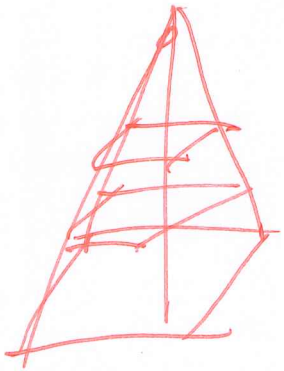










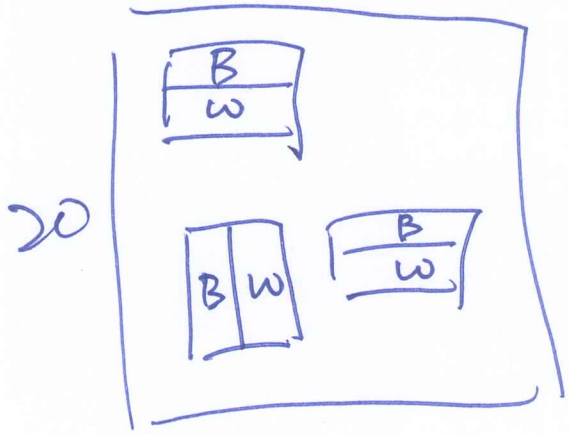


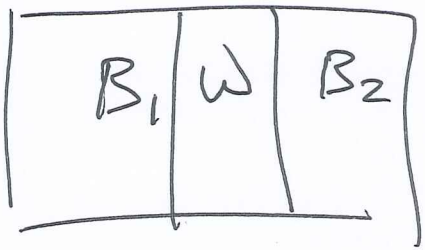
The same detector is applied to the original image, then to scaled-down versions of the image, to detect faces of different sizes.

Haar-like features

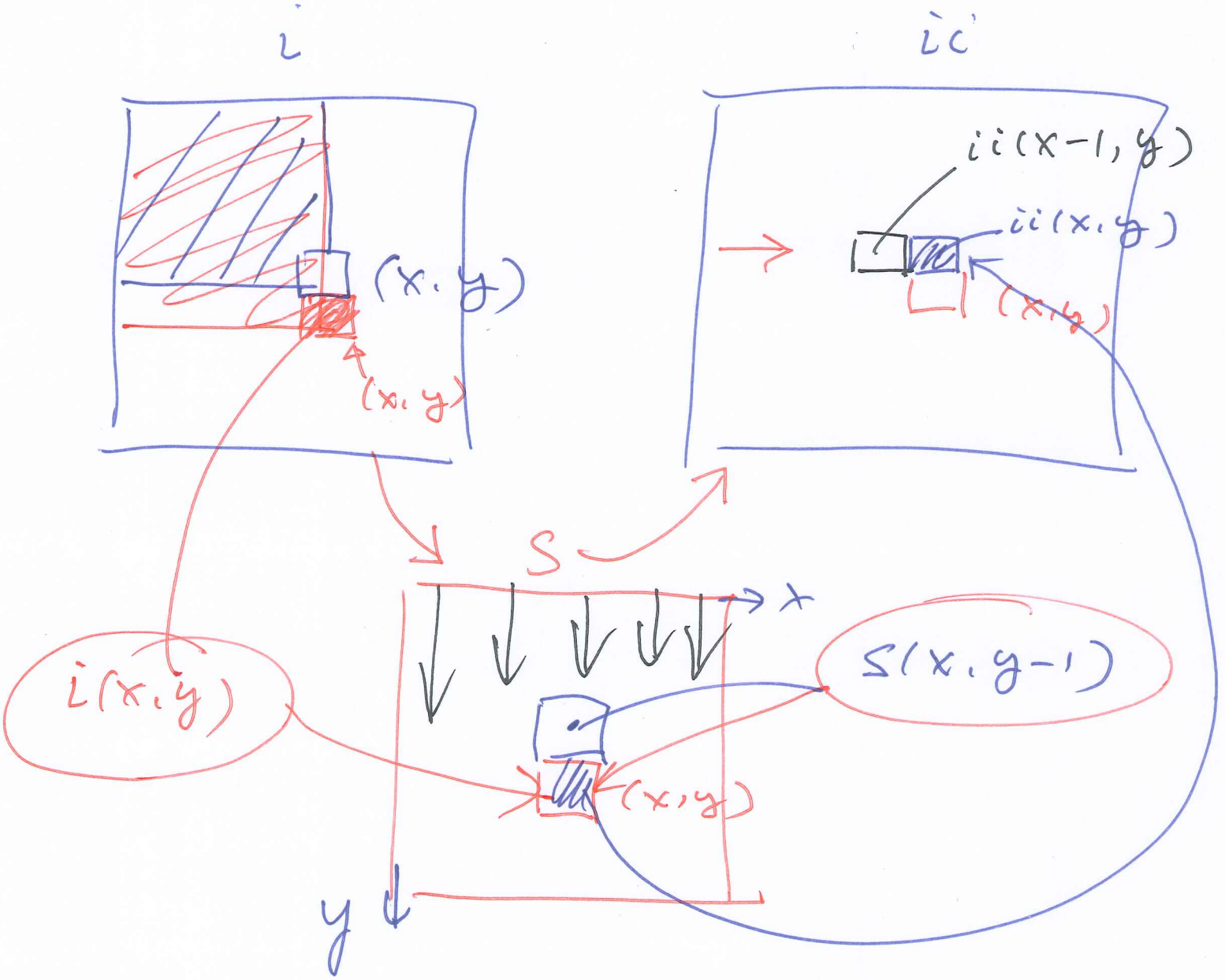
feature

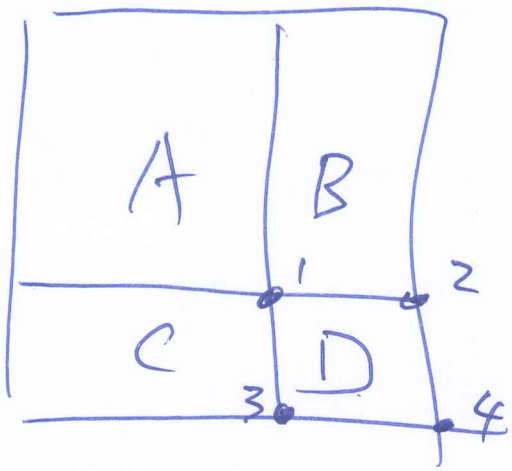
$f = \sum_W I - \sum_B I$





$$f = \sum_W I - \left(\sum_{B_1} I + \sum_{B_2} I \right)$$

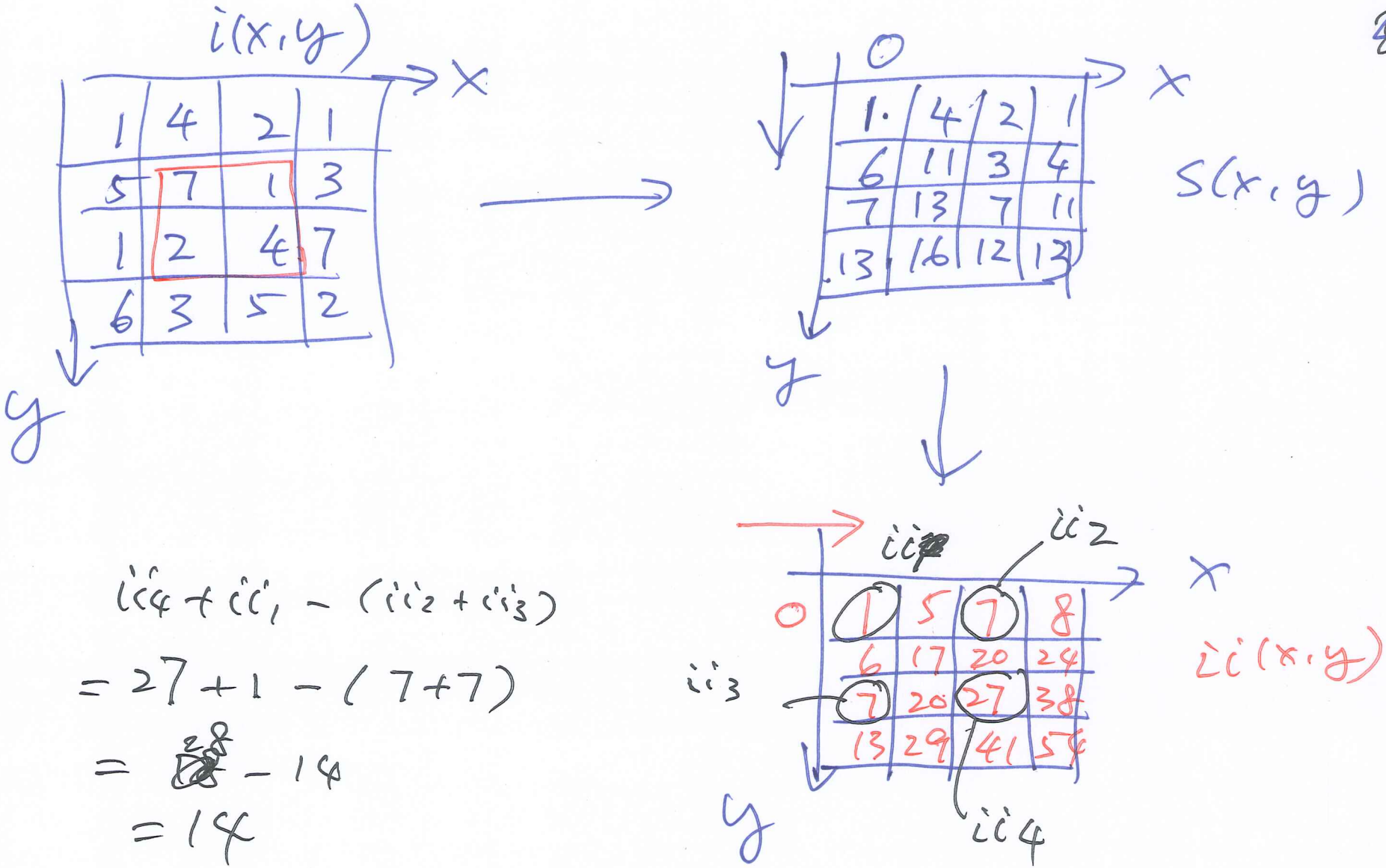

i
ic
ii(x-1, y)
ii(x, y)
(x, y)
(x, y)
S
x
i(x, y)
s(x, y-1)
(x, y)
y



$$\sum_{D} i = \sum_{AUBUCUD} i - \sum_{AUB} i - \sum_{C} i$$

$$= ii_4 - ii_2 - (ii_3 - ii_1)$$

$$= (ii_4 + ii_1) - (ii_2 + ii_3)$$

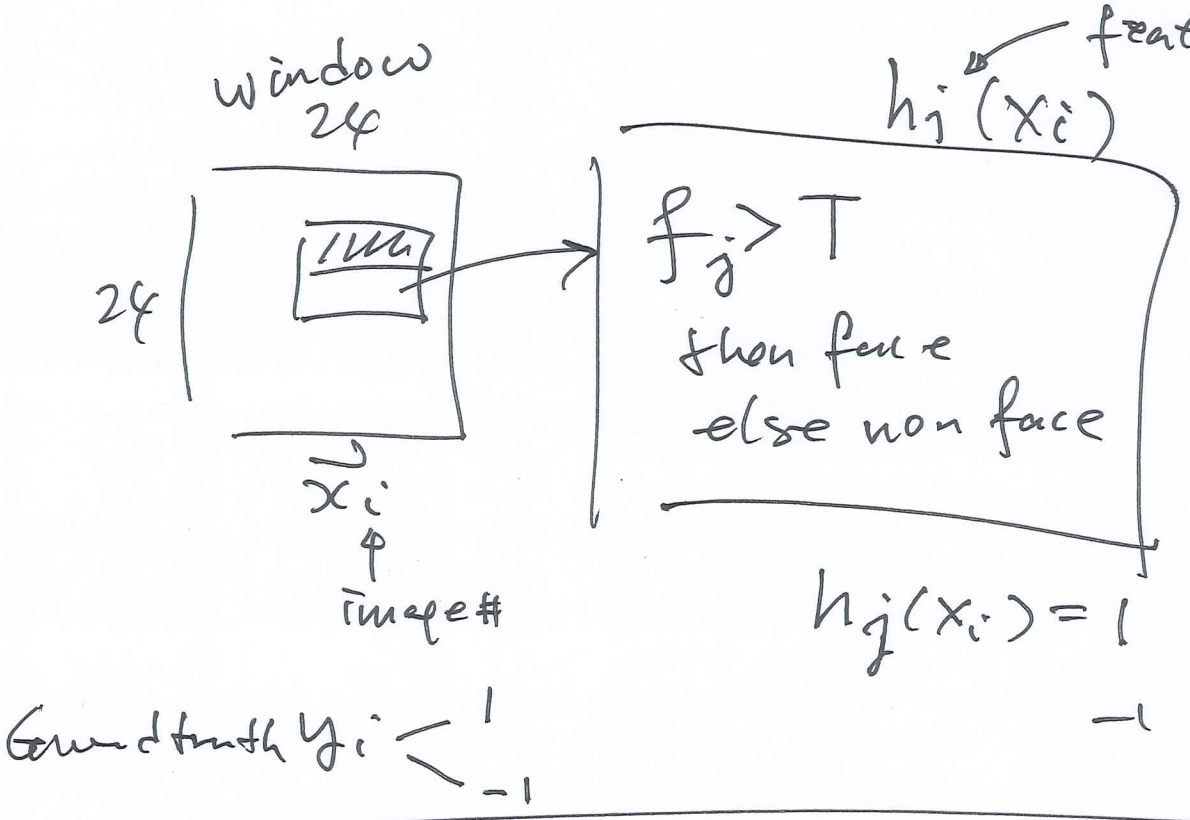


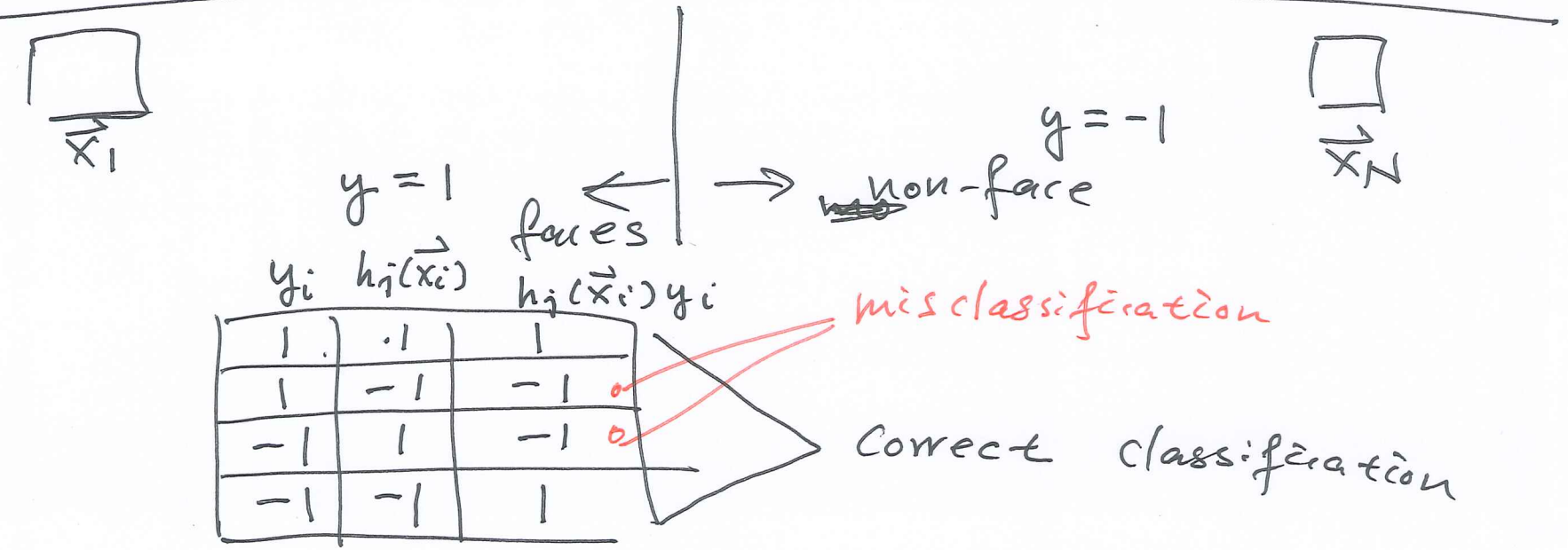
$ii_4 + ii_1 - (ii_2 + ii_3)$

$= 27 + 1 - (7+7)$

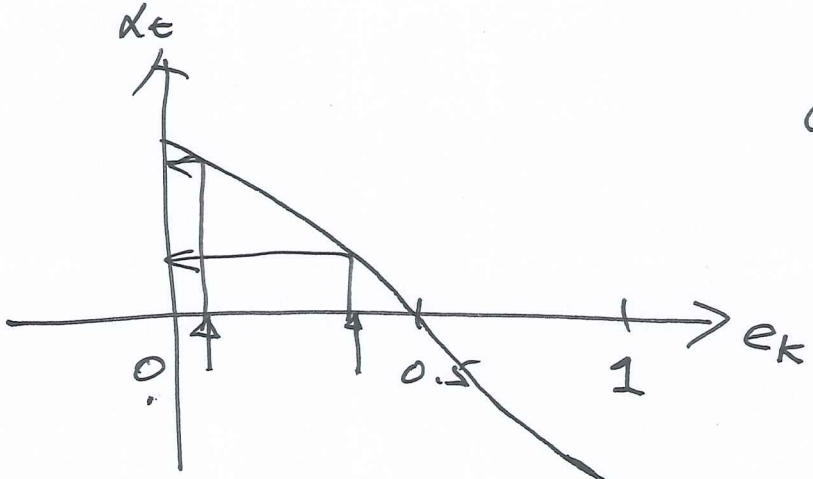
$= 28 - 14$

$= 14$





y_i	$h_j(\vec{x}_i)$	$h_j(\vec{x}_i)\, y_i$
1	1	1
1	−1	−1
−1	1	−1
−1	−1	1



$$\alpha_t = \frac{1}{2} \ln\left(\frac{1 - e_k}{e_k}\right)$$

$$w_i = w_i e^{-\alpha_t y_i h_j(\vec{x}_i)}$$

if $y_i \neq h_j(\vec{x}_i)$ then $w_i = w_i e^{\alpha_t}$

if $y_i = h_j(\vec{x}_i)$ then $w_i = w_i e^{-\alpha_t}$

face | → non-face

```
% training data
y = [1 1 1 1 -1 -1 -1 -1 -1] ;
% weak classifier responses on the training data
h = zeros(4,9) ;
h(1,:) = [1 1 -1 1 -1 -1 -1 1 1] ;
h(2,:) = [1 -1 1 1 -1 1 1 -1 -1] ;
h(3,:) = [1 1 1 -1 1 -1 -1 -1 -1] ;
h(4,:) = [-1 1 -1 1 -1 -1 1 -1 -1] ;
```

1st iteration

```
errors =
    0.3333    0.3333    0.2222    0.3333
bestError =
    0.2222
bestWC =
     3
weakClassifiers =
     3     0     0
alpha =
    0.6264         0         0
w =
    0.1111    0.1111    0.1111    0.1111    0.1111    0.1111    0.1111    0.1111    0.1111
w =
    0.0594    0.0594    0.0594    0.2079    0.2079    0.0594    0.0594    0.0594    0.0594
```

$= \frac{3}{9}$ $\quad 3/9 \quad 2/9 \quad 3/9$

select

$= h_3$

$$\alpha_1 = \frac{1}{2} \ln\left(\frac{1-0.2222}{0.2222}\right)$$

4th 5th

increase

2nd iteration

```
errors =
    0.2143    0.2143    0.5000    0.2143
bestError =
    0.2143
bestWC =
     1
weakClassifiers =
     3     1     0
alpha =
    0.6264    0.6496         0
w =
    0.0714    0.0714    0.0714    0.2500    0.2500    0.0714    0.0714    0.0714    0.0714
w =
    0.0373    0.0373    0.1368    0.1306    0.1306    0.0373    0.0373    0.1368    0.1368
```

$= h_1$

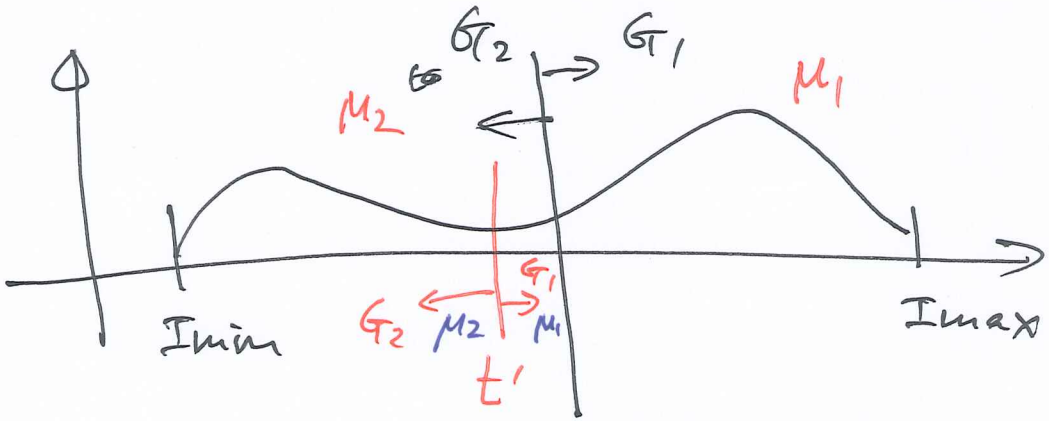
$$\alpha_2 = \frac{1}{2} \ln\left(\frac{1-0.2143}{0.2143}\right)$$

3rd iteration

```
errors =
    0.5000    0.1364    0.3182    0.2576
bestError =
    0.1364
bestWC =
     2
weakClassifiers =
     3     1     2
alpha =
    0.6264    0.6496    0.9229
w =
    0.0455    0.0455    0.1667    0.1591    0.1591    0.0455    0.0455    0.1667    0.1667
w =
    0.0181    0.1144    0.0662    0.0632    0.0632    0.1144    0.1144    0.0662    0.0662
```

$\alpha_1 \quad \alpha_2 \quad \alpha_3$

$$H(\vec{x}) = \mathrm{sgn}(\alpha_1 h_3 + \alpha_2 h_1 + \alpha_3 h_2)$$



$$t = \frac{I_{min} + I_{max}}{2}$$

$$t' = \frac{\mu_1 + \mu_2}{2}$$

$$t'' = \frac{\mu_1 + \mu_2}{2}$$