## Grey Level Co-occurrence Matrix for Texture Description

For building the grey level co-occurrence matrix (GLCM) associated to an image we must first specify a displacement vector ***d=(dx,dy)***. An element ***P(i,j)*** of the GLCM is the number of all pairs of pixels ***($p_1$, $p_2$)*** separated by ***d*** having grey levels ***(i,j).***

$$p_1 = (x, y, i) \quad , \quad p_2 = (x + dx, y + dy, j)$$

$$P(i,j) = |\{(p_1, p_2);\ p_1 = (x, y, i),\ p_2 = (x + dx, y + dy, j)\}|.$$

Assume we have an ***5x5*** image with only 4 grey levels ***{0,1,2,3}***:

$$I = \begin{pmatrix} 0 & 1 & 2 & 3 & 3 \\ 1 & 2 & 1 & 0 & 2 \\ 2 & 1 & 3 & 3 & 0 \\ 0 & 0 & 2 & 2 & 1 \\ 1 & 1 & 2 & 0 & 2 \end{pmatrix} \quad , \quad d = (1,1)\ , \ P = \begin{pmatrix} 1 & 1 & 2 & 0 \\ 0 & 2 & 1 & 1 \\ 3 & 0 & 1 & 1 \\ 0 & 1 & 2 & 0 \end{pmatrix} \ (\text{or } P = \frac{1}{16} P)\ .$$

For an image with 256 grey levels of intensity the GLCM is of size ***256x256***. Usually the elements of the GLCM are normalized by dividing it to the total number of pixel pairs.

The following descriptors are used for GLCM characterization:

1. Maximum probability

$$\max\{P(i,j);\quad i,j = 1,...,L\}\ ;$$

2. Correlation

$$\sum_{i=1}^{L}\sum_{j=1}^{L} \frac{(i - m_r)(j - m_c)P(i,j)}{\sigma_r \sigma_c} \quad (\text{if } \sigma_r \sigma_c \neq 0)$$

$$m_r = \sum_{i=1}^{L} i \sum_{j=1}^{L} P(i,j)$$

$$m_c = \sum_{j=1}^{L} j \sum_{i=1}^{L} P(i,j)$$

$$\sigma_r^2 = \sum_{i=1}^{L} (i - m_r)^2 \sum_{j=1}^{L} P(i,j)$$

$$\sigma_c^2 = \sum_{j=1}^{L} (j - m_c)^2 \sum_{i=1}^{L} P(i,j)\ ;$$

3. Contrast

$$\sum_{i=1}^{L}\sum_{j=1}^{L}(i-j)^2 P(i,j);$$

4. Uniformity (energy)

$$\sum_{i=1}^{L}\sum_{j=1}^{L}P(i,j)^2;$$

5. Homogeneity

$$\sum_{i=1}^{L}\sum_{j=1}^{L}\frac{P(i,j)}{1+|i-j|};$$

6. Entropy

$$-\sum_{i=1}^{L}\sum_{j=1}^{L}P(i,j)\log_2 P(i,j);$$

7. Dissimilarity

$$\sum_{i=1}^{L}\sum_{j=1}^{L}|i-j|P(i,j).$$

Use GLCM and their descriptors in order to build feature vectors for face recognition. Test these features using 1-NN.