Gray Level Co-occurrence Matrix (GLCM)

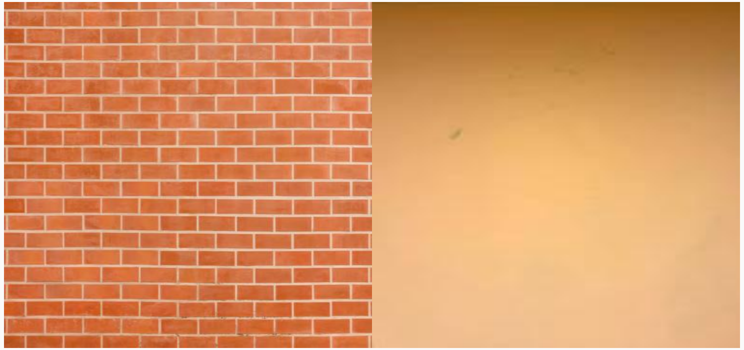
CSE523 – Digital Image Processing

Gray Level Co-occurrence (GLCM)

Texture:

- ❑ Texture in an image means how a surface looks and feels visually – whether it appears smooth, rough, bumpy, or patterned.

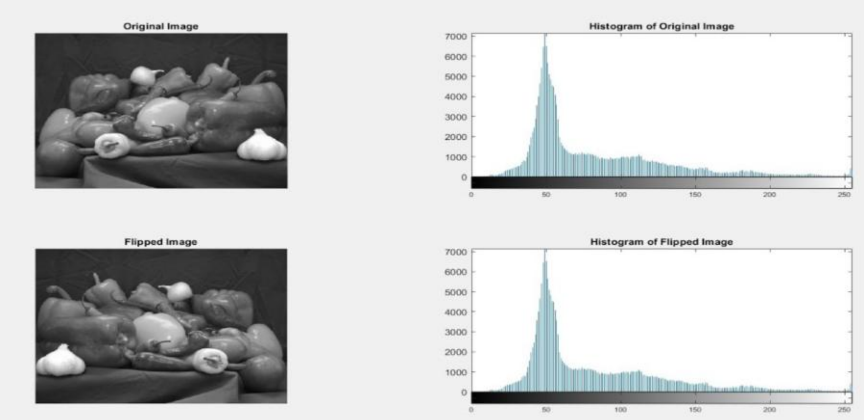
- ❑ Texture comes from how pixel values change and repeat in a small area of the image.



Gray Level Co-occurrence (GLCM)

Background:

- ❑ An image histogram only counts how many times an intensity occurs, but not where it occurs.
- ❑ Many textures have similar histograms but different spatial patterns.



Keynote:
Texture is determined not only by intensities but by their relationship.

Gray Level Co-occurrence (GLCM)

Background :

- By studying texture, a computer can understand what kind of surface is in an image.
- This helps in tasks like finding objects, separating regions, or identifying diseases in medical images.
- Methods like GLCM and LBP help computers measure these texture patterns automatically.

Gray Level Co-occurrence (GLCM)

GLCM:

- ❑ GLCM (Gray Level Co-occurrence Matrix) captures how often pairs of gray levels occur next to each other in a specific direction and distance.
- ❑ It encodes spatial relationships between pixels → good for texture analysis.
- ❑ It is simple and interpretable:
    - ❖ the matrix itself is just co-occurrence counts;
    - ❖ from it we derive well-known features (contrast, energy, homogeneity, correlation, etc.).

Main Mechanism of GLCM

01 Quantize gray levels

02 Choose offset (distance + direction)

03 Build the GLCM $P(i,j)$

04 Symmetrization

05 Normalize to get probabilities

06 Derive texture features

Main mechanism of GLCM

Consider a grayscale image $I(x,y)$ with gray levels 0, 1 ,..., $L - 1$.

Step 1: Quantize gray levels

- For an 8-bit image (0–255), we might reduce it to, say, $L = 16$ or $L = 8$ levels to keep the matrix size manageable.
- After quantization, every pixel has value in $\{0, 1, \ldots, L - 1\}$.
- Quantization formula: *new_pixel* = $\dfrac{old\_pixel}{Current\ range \div New\ range}$

$$I = \begin{bmatrix} 10 & 10 & 80 & 90 \\ 15 & 200 & 210 & 85 \\ 20 & 205 & 215 & 95 \\ 25 & 30 & 100 & 110 \end{bmatrix}$$

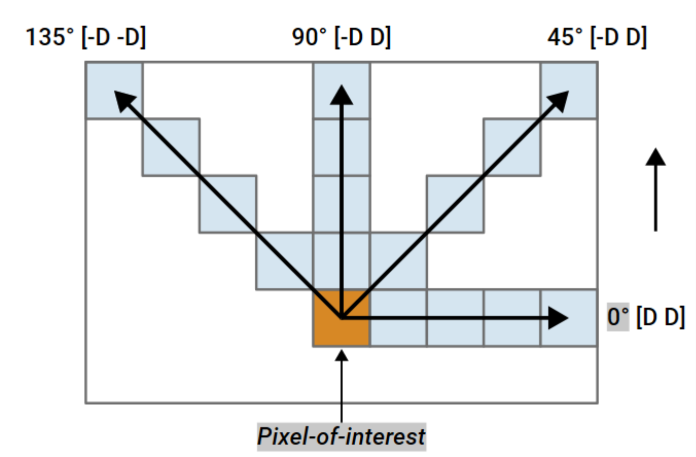
$$I_q = \begin{bmatrix} 0 & 0 & 1 & 1 \\ 0 & 3 & 3 & 1 \\ 0 & 3 & 3 & 1 \\ 0 & 0 & 1 & 1 \end{bmatrix}$$

L = 8 bit to L = 4 bit

Main mechanism of GLCM

Step 2: Choose offset (distance + direction)

- ❑ Choose a distance d (e.g., 1 pixel, 2 pixels).
- ❑ Choose a direction θ :



Main mechanism of GLCM

Step 3: Build the GLCM $P(i,j)$

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

GLCM

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

Main mechanism of GLCM

Step 4: Symmetrization

- Sometimes we count both directions:
- If we also count pairs (j, i) reverse direction, we might define a symmetric GLCM:

$$Psym(i,j) = P(i,j) + P(j,i)$$

Step 5: Normalize to get probabilities

- To derive features, we often normalize:

$$p(i,j) = \frac{P(i,j)}{\sum_{i,j} P(i,j)}$$

- so that $\sum_{i,j} p(i,j) = 1$.

Main mechanism of GLCM

Step 6: Derive texture features

From the normalized GLCM $p(i, j)$, classic features include:

- ❑ **Contrast**: measures local intensity variation

$$Contrast = \sum (i-j)^2 p(i,j)$$

- ❑ **Energy** (Angular Second Moment):

$$\text{Energy} = \sum_{i,j} p(i,j)^2$$

- ❑ **Homogeneity** (Inverse Difference Moment):

$$\text{Homogeneity} = \sum_{i,j} \frac{p(i,j)}{1 + |i-j|}$$

- ❑ **Correlation**: measures how correlated neighboring gray levels are.

Example

We are given the 4×4 image,

- distance d = 1 pixel.
- Direction $\theta = 0^{\circ}$ (right side)

0	0	1	1
0	0	1	1
0	2	2	2
2	2	3	3

P(i,j)	0	1	2	3
0	(0,0)	(0,1)	(0,2)	(0,3)
1	(1,0)	(1,1)	(1,2)	(1,3)
2	(2,0)	(2,1)	(2,2)	(2,3)
3	(3,0)	(3,1)	(3,2)	(3,3)

Example

Build the GLCM $P(i,j)$

0	0	1	1
0	0	1	1
0	2	2	2
2	2	3	3

For 0,0 →

P(i,j)	0	1	2	3
0	2			
1				
2				
3				

Example

Build the GLCM $P(i,j)$

0	0	1	1
0	0	1	1
0	2	2	2
2	2	3	3

For 0,1 →

P(i,j)	0	1	2	3
0	2	2		
1				
2				
3				

Example

Build the GLCM $P(i,j)$

0	0	1	1
0	0	1	1
0	2	2	2
2	2	3	3

For 0,2 →

P(i,j)	0	1	2	3
0	2	2	1	
1				
2				
3				

Example

Build the GLCM $P(i,j)$

0	0	1	1
0	0	1	1
0	2	2	2
2	2	3	3

For 0,3 →

P(i,j)	0	1	2	3
0	2	2	1	0
1				
2				
3				

Example

Build the GLCM $P(i,j)$

0	0	1	1
0	0	1	1
0	2	2	2
2	2	3	3

For 1,0 →

P(i,j)	0	1	2	3
0	2	2	1	0
1	0			
2				
3				

Example

Build the GLCM $P(i,j)$

0	0	1	1
0	0	1	1
0	2	2	2
2	2	3	3

For 1,1 →

P(i,j)	0	1	2	3
0	2	2	1	0
1	0	2		
2				
3				

Example

Build the GLCM $P(i,j)$

0	0	1	1
0	0	1	1
0	2	2	2
2	2	3	3

For 1,2 →

P(i,j)	0	1	2	3
0	2	2	1	0
1	0	2	0	
2				
3				

Example

Build the GLCM $P(i,j)$

0	0	1	1
0	0	1	1
0	2	2	2
2	2	3	3

For 1,3 →

P(i,j)	0	1	2	3
0	2	2	1	0
1	0	2	0	0
2				
3				

Example

Build the GLCM $P(i,j)$

0	0	1	1
0	0	1	1
0	2	2	2
2	2	3	3

→

P(i,j)	0	1	2	3
0	2	2	1	0
1	0	2	0	0
2	0	0	3	1
3	0	0	0	1

Example

Symmetrization

2	2	1	0
0	2	0	0
0	0	3	1
0	0	0	1

CM of the image

+

2	0	0	0
2	2	0	0
1	0	3	0
0	0	1	1

Transpose CM of the image

=

4	2	1	0
2	4	0	0
1	0	6	1
0	0	1	2

Symmetric GLCM

Example

Normalization

Sum of all elements = 24

4	2	1	0
2	4	0	0
1	0	6	1
0	0	1	2

Symmetric GLCM

→

0.167	0.083	0.0416	0
0.083	0.167	0	0
0.0416	0	0.25	0.0416
0	0	0.0416	0.083

Normalized GLCM

Example

Contrast

P(i,j)	0	1	2	3
0	0	1	4	9
1	1	0	1	4
2	4	1	0	1
3	9	4	1	0

$| I - J |^2$

×

0.167	0.083	0.0416	0
0.083	0.167	0	0
0.0416	0	0.25	0.0416
0	0	0.0416	0.083

Normalized GLCM p (i,j)

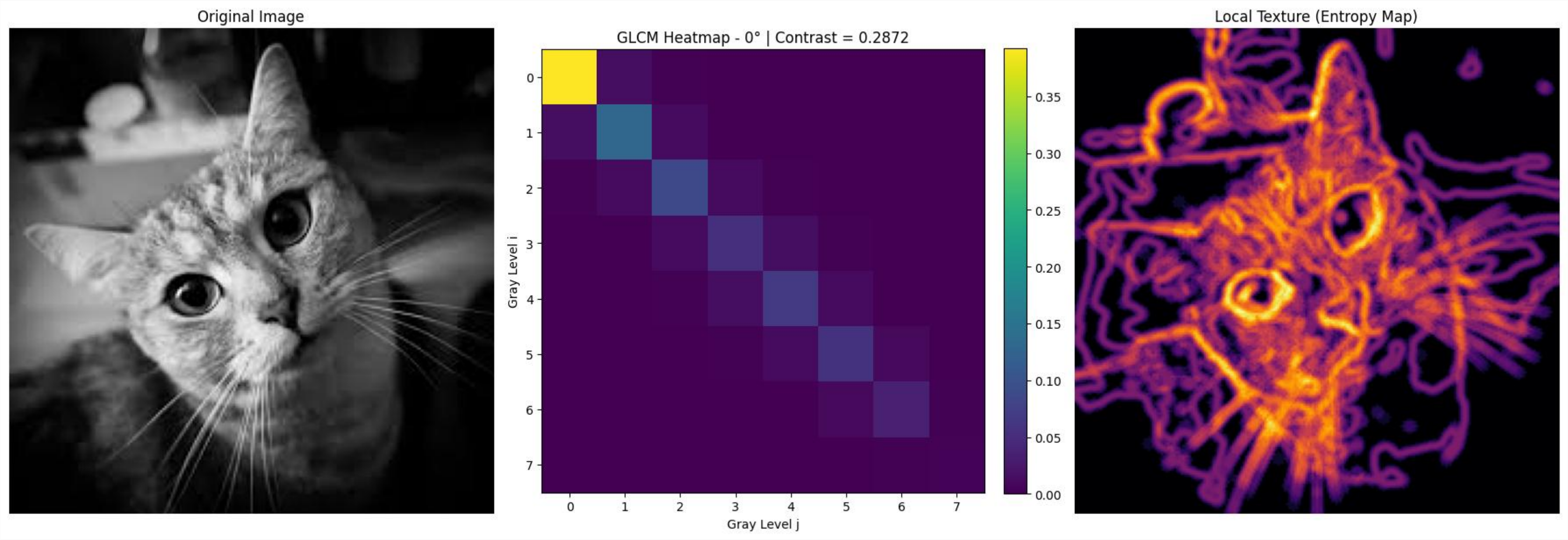
=

Contrast = 0.582

0	0.083	0.1664	0
0.083	0	0	0
0.1664	0	0	0.0416
0	0	0.0416	0

$| I - J |^2 \times p(i, j)$

Example


Original Image
GLCM Heatmap - 0° | Contrast = 0.2872
Gray Level i
Gray Level j
0
1
2
3
4
5
6
7
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Local Texture (Entropy Map)

Advantages of GLCM

- **Captures texture, not just intensity**
  - Considers pairs of pixels → encodes spatial structure, helpful for distinguishing textures with similar histograms.

- **Flexible**
  - You can choose different directions and distances to capture anisotropic textures (e.g., vertical stripes vs horizontal stripes).

- **Interpretable features**
  - Features like contrast, energy, and homogeneity have intuitive meanings (rough vs smooth, homogeneous vs heterogeneous).

Limitations of GLCM

- **Parameter sensitivity**
  - Results depend on:
    - Number of gray levels L (quantization),
    - Choice of distance d,
    - Choice of directions (0°, 45°, 90°, 135°, etc.).
- **High dimensionality for many gray levels**
  - For an 8-bit image with 256 gray levels, GLCM is 256×256 → 65,536 entries per direction and distance → heavy in memory and computation.
- **Not inherently rotation/scale invariant**
  - Changing the rotation of the image changes the GLCM unless you average over multiple directions.

Limitations of GLCM

- **Sensitive to noise and illumination changes**
  - Small changes in intensities (noise, illumination) can affect co-occurrence counts.

- **Global unless localized**
  - A single GLCM for the whole image may miss local variations; often people compute GLCM over moving windows, which increases computation.

Applications of GLCM

- **Medical Imaging**
  - Tumor vs normal tissue classification in CT, MRI, ultrasound, histopathology, etc. GLCM features often help characterize tissue heterogeneity.
- **Remote Sensing and Land Cover Classification**
  - Distinguish forests, urban areas, water bodies based on texture in satellite images.
- **Industrial Inspection**
  - Detect surface defects (scratches, cracks, fabric defects, paper quality, etc.) from textures.
- **Object Detection & Pattern Recognition**
  - Use GLCM features as inputs to machine learning models for object detection, texture classification, etc.

Local Binary Pattern (LBP)

CSE523 – Digital Image Processing

Local Binary Pattern (LBP)

LBP:

- ❑ Examine a pixel relative to its neighborhood:
    - ❖ Compare neighbor values to center pixel
    - ❖ Form binary pattern indicating structure

- ❑ It tells - are neighbors brighter or darker than the center?

- ❑ This effectively captures: Edges, Corners, Spots, Flat regions, Micro-texture.

Main mechanism of LBP

Consider a grayscale image $I(x,y)$

Step 1: Neighborhood (3×3 window)

P_0	P_1	P_2
P_7	P_c	P_3
P_6	P_5	P_4

Main mechanism of LBP

Step 2: $s(p_k - p_c)$

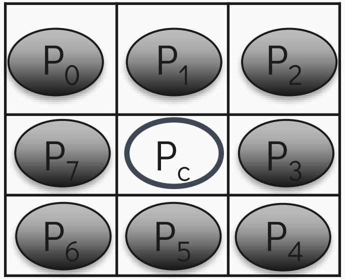
P_0	P_1	P_2
P_7	P_c	P_3
P_6	P_5	P_4

Step 3: Binary decision

$$s(x) = \begin{cases} 0, & x < 0 \\ 1, & x \geq 0 \end{cases}$$

Main mechanism of LBP

Step 2: $s(p_k - p_c)$



Step 3: Binary decision

$$s(x) = \begin{cases} 0, & x < 0 \\ 1, & x \geq 0 \end{cases}$$

Main mechanism of LBP

Step 4: 2^k matrix

2^0	2^1	2^2
2^7	P_c	2^3
2^6	2^5	2^4

$\Longrightarrow$

1	2	4
128	Pc	8
64	32	16

Step 5: LBP encoding

$$LBP(pc) = \sum_{k=0}^{k=7} s(p_{kc} - p_c) \cdot 2^k$$

Example

Consider a grayscale image $I(x,y)$

Step 1: Neighborhood (3×3 window)

P_c

3	7	2
8	4	1
2	3	5

Example

Step 2: $s(p_k - p_c)$

$$s(x) = \begin{cases} 0, & x < 0 \\ 1, & x \geq 0 \end{cases}$$

P_k

3	7	2
8	4	1
2	3	5

P_c

$\Longrightarrow$

0		
	P_c	

Binary Matrix

Example

Step 2: $s(p_k - p_c)$

$$s(x) = \begin{cases} 0, & x < 0 \\ 1, & x \geq 0 \end{cases}$$

P_k

3	7	2
8	4	1
2	3	5

P_c

$\Longrightarrow$

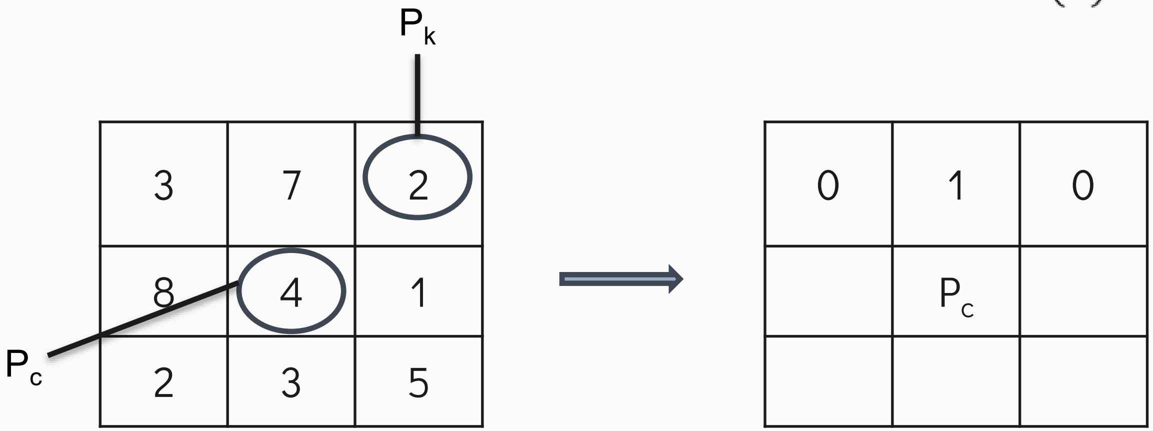
0	1	
	P_c	

Binary Matrix

Example

Step 2: $s(p_k - p_c)$

$$s(x) = \begin{cases} 0, & x < 0 \\ 1, & x \geq 0 \end{cases}$$



Binary Matrix

Example

Step 2: $s(p_k - p_c)$

$$s(x) = \begin{cases} 0, & x < 0 \\ 1, & x \geq 0 \end{cases}$$

3	7	2
8	4	1
2	3	5

P_c P_k

$\Longrightarrow$

0	1	0
	P_c	0

Binary Matrix

Example

Step 2: $s(p_k - p_c)$

$$s(x) = \begin{cases} 0, & x < 0 \\ 1, & x \geq 0 \end{cases}$$

3	7	2
8	4	1
2	3	5

P_c

P_k

$\Longrightarrow$

0	1	0
	P_c	0
		1

Binary Matrix

Example

Step 2: $s(p_k - p_c)$

$$s(x) = \begin{cases} 0, & x < 0 \\ 1, & x \geq 0 \end{cases}$$

3	7	2
8	4	1
2	3	5

P_c

P_k

0	1	0
	P_c	0
	0	1

Binary Matrix

Example

Step 2: $s(p_k - p_c)$

$$s(x) = \begin{cases} 0, & x < 0 \\ 1, & x \geq 0 \end{cases}$$

3	7	2
8	4	1
2	3	5

P_c

P_k

0	1	0
	P_c	0
0	0	1

Binary Matrix

Example

Step 2: $s(p_k - p_c)$

$$s(x) = \begin{cases} 0, & x < 0 \\ 1, & x \geq 0 \end{cases}$$

P_c

P_k

3	7	2
8	4	1
2	3	5

$\Longrightarrow$

0	1	0
1	P_c	0
0	0	1

Binary Matrix

Example

Step 2: $s(p_k - p_c)$

3	7	2
8	4	1
2	3	5

0	1	0
1	P_c	0
0	0	1

Binary Matrix

Example

Step 3: LBP encoding

0	1	0
1	P_c	0
0	0	1

Binary Matrix

$\times$

1	2	4
128	Pc	8
64	32	16

2^k matrix

$\Longrightarrow$

0	2	0
128	P_c	0
0	0	16

LBP

Example

Step 3: LBP encoding

$$\sum_{i=0}^{n} 2 + 128 + 16 = 146$$

0	1	0
1	P_c	0
0	0	1

Binary Matrix

×

1	2	4
128	Pc	8
64	32	16

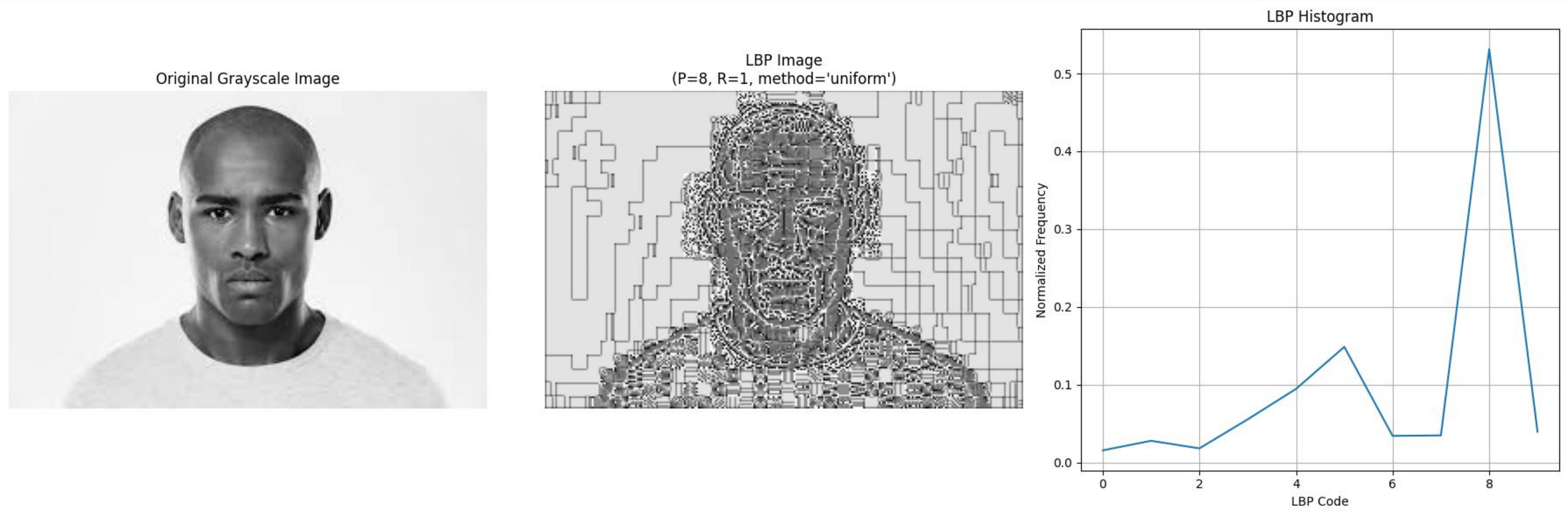
2^k matrix

$\Longrightarrow$

0	2	0
128	P_c	0
0	0	16

LBP

Example


Original Grayscale Image
LBP Image
(P=8, R=1, method='uniform')
LBP Histogram
Normalized Frequency
0.0
0.1
0.2
0.3
0.4
0.5
0
2
4
6
8
LBP Code

Local Feature → Global Representation

- ❑ After computing LBP for every pixel, we obtain a texture map.
- ❑ We extract a histogram of LBP values
- ❑ Histogram becomes the final feature vector used for:
  - ❖ Classification
  - ❖ Segmentation
  - ❖ Recognition
  - ❖ Anomaly detection

Advantages of LBP

- Very fast and simple to compute.
- Works well even when lighting changes (brightness/contrast changes).
- Captures local texture patterns like edges, corners, and spots.
- Produces features that are easy to use in machine learning.
- Low memory usage → suitable for real-time systems

Limitations of LBP

- Sensitive to noise, especially in flat or low-contrast areas.
- Only captures local information → misses global or large-scale patterns.
- Standard LBP is not rotation-invariant unless improved versions are used.
- Binary thresholding (≥ or <) may lose fine intensity differences.
- Histogram features can become large if many neighborhoods are used

Applications of LBP

- **Face recognition** (LBPH algorithm).
- **Medical image analysis** – detecting tumors or abnormal tissue textures.
- **Industrial inspection** – detecting cracks, scratches, or surface defects.
- **Surveillance** – human and object detection.
- **Remote sensing** – land-use and vegetation texture classification.
- **Document analysis** – paper texture and print quality recognition.
- **Agricultural imaging** – plant disease texture detection

Comparison

- LBP vs GLCM Features

Feature Type	LBP	GLCM
Complexity	Low	Medium
Uses Local Info?	✓	✓
Histogram size	Small-medium	Depends on L, D, angles
Dataset size required	Small	Small
Explainability	High	Medium

Thanks!