1) Contrast Stretching:

Contrast stretching is a linear transformation technique used to enhance the contrast of an image by expanding the range of intensity values.

Purpose: Improves visibility of details in image with low contrast by stretching the range of pixel intensities to utilize the full dynamic range. (e.g 0 to 255 for 8 bit)

Equation:

$$s = \left(\frac{r - r_{min}}{r_{max} - r_{min}}\right) \times (s_{max} - s_{min}) + s_{min}$$

r = original pixel intensity , s = transformed intensity.

Algorithm:

1. Find r_{min} & r_{max} for the input image
2. Lineally mapping these to a desired output range (e.g. [0, 255])

Advantage: * simple & computationally fast

* Enhances visibility in under or over exposed image.

Issues: * Doesn't adapt to local image characteristics due to sensitive to outliers

* Fails if original histogram is already white.

2) Histogram Equalization:

A nonlinear method to redistribute pixel intensities to achieve a uniform histogram, improving global contrast.

Purpose: Enhances global contrast by flattening the histogram of the image.

Equation: $S_K = T(r_K) = (L-1) \sum_{i=0}^{K} P_r(r_i)$

$P_r(r_i)$ = probability of intensity r_i.

L = Number of gray levels [256]

Algorithm: 1) Compute histogram & CDF of image

2) Remap pixel values using CDF as transformation

Advantages: 1) Effective for global contrast enhancement.

2) Fully automated and computationally straightforward

Issues: 1) Over amplifies noise in homogenous regions.

2) Ignores local details, leading to information loss in some regions.

3) May produce unnatural artifacts.

Differences Between HE, AHE, CLAHE:

Histogram Equalization (HE)	Adaptive HE (AHE)	Contrast Limited AHE (CLAHE)
1) Global contrast enhancement via uniform histogram redistribution.	1) Divides image into tiles and applies HE locally	1) Local contrast enhancement with histogram clipping to limit amplification.
2) Works on entire image	2) Enahances local small region or tiles.	2) Enhances small regions/tiles (local)
3) Uses single CDF	3) Computes CDF per tiles, interpolates boundaries.	3) Clips histogram per tiles, redistributes excess, then applies AHE
4) May amplify noise globally	4) Oftenamplifies noise locally	4) Reduces noise amplification by clipping.
5) ~~Igones~~ Ignores local details, overenhances noise	5) Noise amplification in flat regions.	5) Requires parameter tuning, (clip limit, tile size).
6) Used for basic image enhancement. (photography, under exposed image etc.)	6) Texture analysis (eg. satellite image) Enhancing fine details in unevenly lit scenes.	6) Medical imaging (Xrays, MRI) for clear tissue contrast.

3) Log Transformation:

A non linear technique used to compress dynamic range of an image.

<u>Purpose:</u> Enhances details in dark regions while compressing bright regions. often used for images with a wide range of intensities. (eg. Fourier spectra)

<u>Equation:</u> $s = c \cdot \log(1 + r)$

c: Scaling constant, r = Input intensity (normalized to [0, 1])

<u>Advantages:</u>

1) Effective for visualizing HDR images
2) Emphasizes low-intensity details

<u>Issues:</u>

1) May suppress details in bright regions due to compression.
2) Requires careful selection of c to avoid unnatural results.

4) Power Law Transformation:

Adjusts intensity values using an exponential function to correct brightness/contrast.

Purpose: 1) correct gamma distortion in camera/screens

2) Enhances specific intensity ranges (e.g dark or bright regions)

Equation:

$$S = c \cdot r^{\gamma}$$

γ: Gamma value ($\gamma < 1$ brightens dark areas, $\gamma > 1$ darkens bright areas)

Applications: Display calibration, MRI/CT scan enhancement.

Advantages: Flexible control over brightness/contrast.

Issues: 1) Requires trial and error to choose optimal γ.

2) Can introduce artifacts in extreme cases.

5) Gray level Slicing:

Highlights a specific range of gray levels in an image while suppressing or preserving others.

Purpose: Emphasizes specific intensity ranges (eg for feature extraction/visualization).

Mathematical Approach:

1) Binary slicing: $s = \begin{cases} A & \text{if } a \le r \le b \\ 0 & \text{otherwise} \end{cases}$

* Highlights the range [a,b] as intensity A.

2) Preservation slicing: $s = \begin{cases} A & \text{if } a \le r \le b \\ r & \text{otherwise} \end{cases}$

* Preserves background while highligting [a,b].

Advantages: 1) Useful for isolating features. (eg. tumors in medical image)
2) Simple to implement.

Issues: 1) loss of information outside the selected range.
2) Binary output may oversimplify complex images.

6) Gaussian filtering:

A linear smoothing technique using a Gaussian kernel to reduce noise and blur details.

Purpose:
1) Noise reduction
2) Preprocessing step for edge detection/segmentation

Mathematical Equation:

2D Gaussian function: $$G(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

where σ = standard deviation controlling spread of kernel.

Output image is obtained by convalving:

$$g(x,y) = f(x,y) * G(x,y)$$

Advantages:
i) Smooths noise effectively without introducing sharp artifacts.
ii) Rotationally symmetric, preserving image structure.

Disadvantages:
1) Blurs edges, which may be undesirable for edge detection if implemented incorrectly.
2) Computationally expensive for large kernels.