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* Image Noise

- Image noise is unwanted signal.
- It is random variation of brightness or color informations in images.
- Degrades image quality and reduces accuracy in processing task

* Thresholding :

- Process of converting grayscale image into a binary image.
- If $I(x,y) > T$
  then
  white (1)
  else
  Black (0)

T is threshold Value
$I(x,y)$ - intensity at pixel (x,y)

* Dithering :

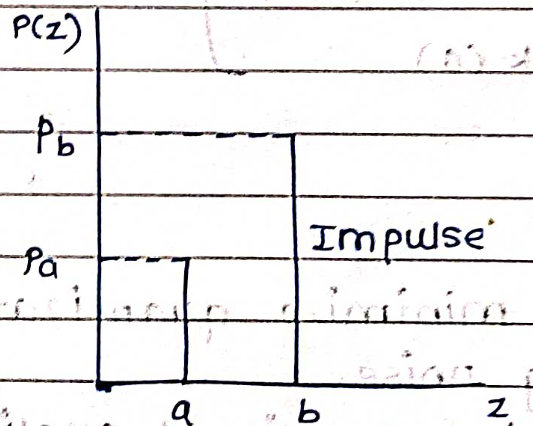
- Technique to minimize quantization artifacts by introducing noise.
- Goal is to improve visual quality.
- methods
  1. Error diffusion :
     - Distributes quantization error to neighboring pixels.
  2. Ordered dithering :
     - Applies predefined pattern to distribute errors.
     - representation : matrix

* Types: Image Noise

- There are 4 types of noise
  1] Salt and Pepper noise
  2] Gaussian noise
  3] Speckle noise
  4] Uniform noise

① Salt and Pepper noise (salt = white dots, pepper = Black dots)
- Also called as impulse noise
- Characterized by the presence of randomly occurring white & black pixels scattered throughout the image.
- Caused by sharp and sudden disturbance in the image signal.

Reasons



Here Pa, Pb are PDF (probability density fun)
p(z) is distribution of salt & pepper noise.

① Memory cell failure
② camera sensor's cell malfunction
③ Synchronization errors during image digitizing or transmission.

Filtering techniques

① Mean (Convolution filtering)
- → Computes average of pixel value within a defined neighbourhood.
- → It may blur edges
- → Not handle the salt & pepper noise well.

② Median filtering
- → Replaces each pixel value with median value of its neighbouring pixels.
- → Non linear in nature thus preserves edges
- → Effective for removing salt & pepper noise.

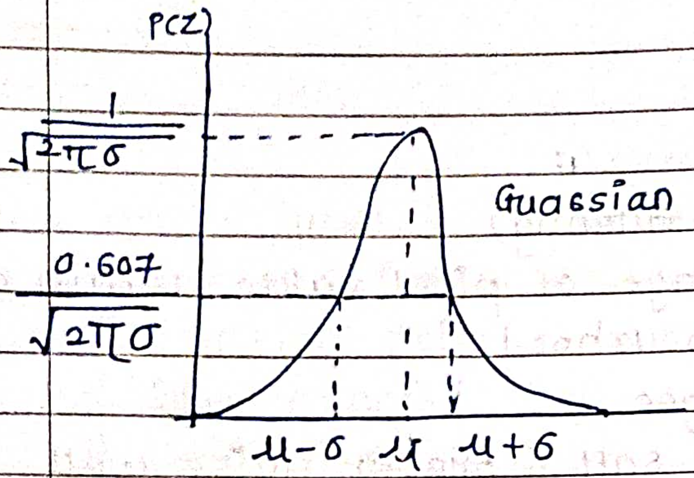
③ Gaussian filtering → Non linear
- → Uses a gaussian kernel to perform averaging of neighbouring pixels.
- → Preserves edges
- → Not effective like median filtering.

④ Deep CNN

② Gaussian noise :

- Random noise occurs due to random fluctuations in the signal.
- The noise has probability density function [PDF] of normal distribution.
- Grainy appearance.

Reasons



$$P(z) = \frac{1}{\sqrt{2\pi}\sigma} e^{-(z-\mu)^2/2\sigma^2}$$

① During image acquisition [image capturing] due to poor illumination or high temperature.
② During transmission.

Filtering techniques

- mean
- median
- Guassian

} same theory as previous (all are useful)

③ Speckle noise :

- Noise that can be modeled by random values multiplied by pixel values of an image.
- Increases mean gray level of local area.
-

Reasons

$$g(n,m) = f(n,m) * u(n,m) + \delta(n,m)$$

$g(n,m)$ observed image
$u(n,m)$ multiplicative component
$\delta(n,m)$ Additive component

1. Random fluctuations
2. Additive component
3. Multiplicative — " —

Filtering techinques

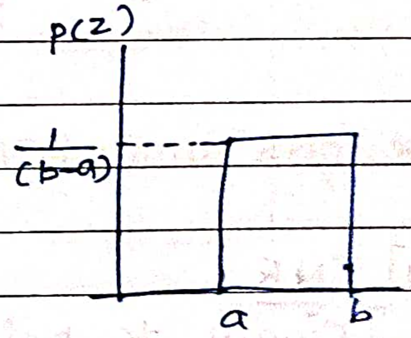
1] Mean
2] Median } (same theory)

4. Uniform noise

- Also called quantization noise.
- It is caused by quantizing the pixel of image to a no. of distinct levels

Reasons

$$P(z) = \begin{cases} 1/(b-a) & a \le z \le b \\ 0 & \text{otherwise} \end{cases}$$



* SNR and PSNR

1] SNR :

- signal to noise ratio
  - used to quantify level of signal compared to level of noise in signal / Image.

- SNR = signal power / Noise power

- where

  signal power = sum of squared pixel values.

  Noise power = mean squared difference betn original & filtered version of image.

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c] PSNR

- Peak signal to noise Ratio expressed in dB
- Used to evaluate quality of processed image compared to the original image
- PSNR = $10 \times \log_{10}\left(\frac{max_I^2}{MSE}\right)$

or

$$10 \times \log_{10}\left(\frac{max_I}{\sqrt{MSE}}\right)$$

where max_I is maximum possible pixel value (for 8-bit image it is 255)

MSE is Mean Squared Error calculated as avg of squared difference betn corresponding pixel in original & processed image.

i.e $MSE = \sum_{MN} \frac{[I_1(m-n) - I_2(m,n)]^2}{m*n}$

Numerical

① I/p = $\begin{bmatrix} 1 & 2 & 1 \\ 2 & 3 & 6 \\ 5 & 8 & 2 \end{bmatrix}$ o/p = $\begin{bmatrix} 1 & 3 & 1 \\ 2 & 3 & 5 \\ 5 & 8 & 1 \end{bmatrix}$

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

$m*n = 3 \times 3$

$Max_I = 255$

calculate MSE & PSNR ?

$$\Rightarrow MSE = \sum_{MN} \frac{[I_1(m,n) - I_2(m,n)]^2}{m*n}$$

$$= \frac{((1)^2 + (1)^2 + (-1)^2)}{3\times3}$$

$$= \frac{3}{9}$$

$MSE = 0.333\ldots$

$$PSNR = 10\log_{10}\left(\frac{(\cancel{max}_I)^2}{MSE}\right)$$

$$= 10\log_{10}\left(\frac{255^2}{0.333}\right)$$

$$= 52.9 \text{ dB}$$

② Same que I/p, o/p, $MSE = 0.333\ldots$

$R = 16$ find PSNR

$\rightarrow$

$Max_I = R - 1$

$\underline{\underline{Max_I = 15}}$

$$PSNR = 10\log_{10}\frac{(15)^2}{0.33}$$

$$= 28.3 \text{ dB}$$

* Spatial Filtering:
  - Operation performed directly on the pixels of an image
  - Operations are applied using convolution with a small matrix called as Kernel.
  - Types:
    1. Linear filter
       linear operations like bluring, edge detection, sharpening
       - Mean filter
       - Gaussian filter
       - Median filter.
    2. Non-linear filter : Operation edge preservation & noise reduction
       - median filter
       - max filter
       - min filter

* Frequency domain filtering
  - Involves transforming the image into frequency domain using techniques like Fourier transform, then filtering operations, etc.
  - Here we deal with rate at which the pixel values are changing in the spatial domain

(1) i/p img from spatial domain $F(x,y)$ → (2) Preprocess → (3) Fourier transform $\xrightarrow{F(u,v)}$ (4) Filter function

(filter operation)

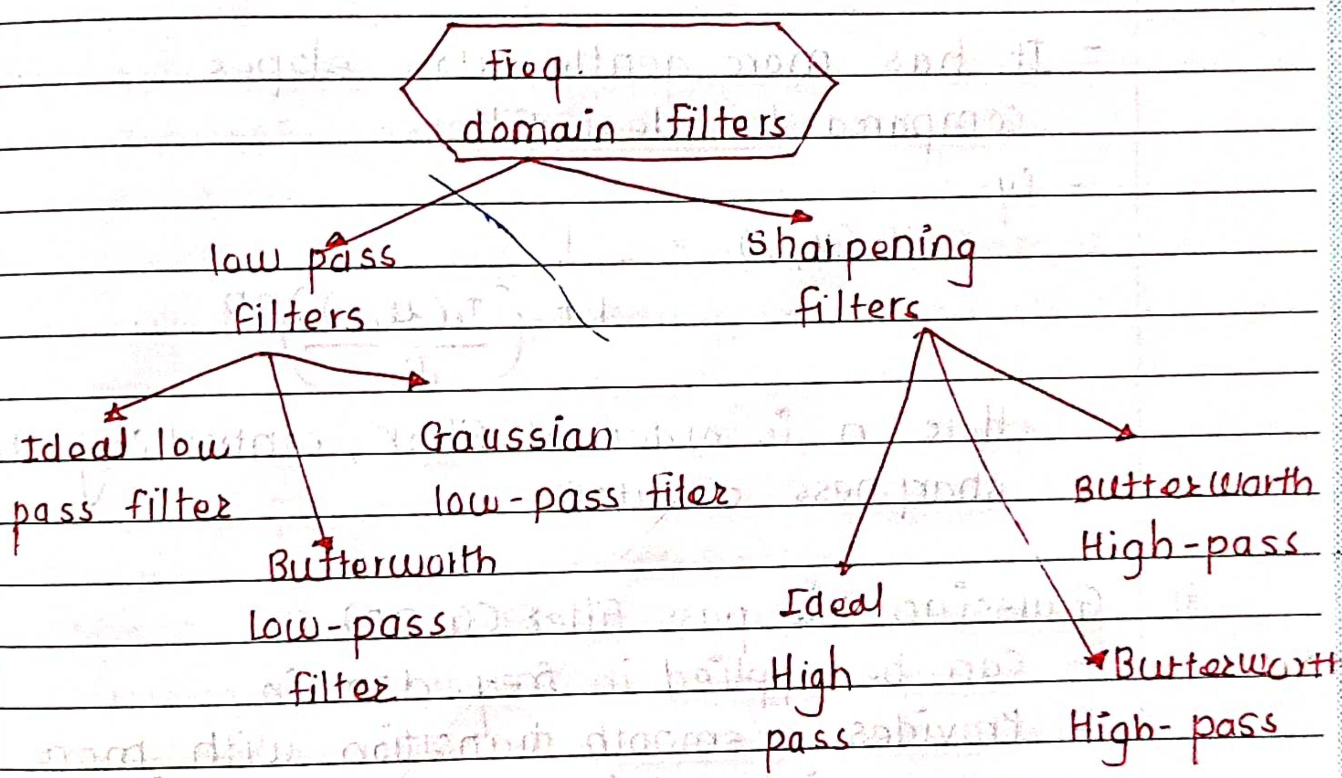
↓ $H(u,v) \cdot F(u,v)$

(5) Inverse of fourier transform → (6) Post process → (7) enhanced o/p img $g(x,y)$

why frequency domain filtering

- Makes faster computation
- Gives control over whole image inorder to enhance and supress the image characteristics.

Imp Classification of Filtering in Frequency domain



Low pass filters :-

① Ideal low pass filter (ILPF)

- Supress high freq. components
- Preserves low freq. components.
- After applying DFT, DC components & low-freq. components are towards center.
- Cutoff Frequency can be specified as a circle.
- eq.

$$H(u,v) = \begin{cases} 1 & D(u,v) \leq D_0 \\ 0 & \text{otherwise} \end{cases}$$

$D(u,v)$ = distance from origin

D_0 = limit (cutoff frequency)

- Here freq. closer to origin are preserved.

② Butterworth low pass filter (BLPF)

- It has parameter called the filter order
- for higher order values — Butterworth filter approaches the ideal filter.

  for lower order values — Butterworth filter approaches Guassian filter.

- It has more gentle cutoff slopes compared to ideal filters.
- Eq.

$$H(u,v) = \frac{1}{1 + \left(\frac{D(u,v)}{D_0}\right)^{2n}}$$

Here n is order of filter, controlling the sharpness of cutoff.

③ Gaussian low pass filter (GLPF)

- Can be applied in freq. domain
- Provides a smooth transition with more preservation of image details compared to ideal and Butterworth filters.
- Ensures no ringing effect.
- eqn

$$H(U,V) = e^{-D(u,v)^2/2D_0^2}$$

D_0 controls standard deviation of the gaussian function.

High pass filter

① Butterworth high pass filter (BHPF)
- Complementary to BLPF.
- Eliminates low freq. values while preserving high freq. components.
- Order of filter controls sharpness of the cutoff.

② Ideal high pass filter (IHPF)
- Eliminates low freq. components causing sharpening.
- Cutoff freq. affects the results, where a larger cutoff removes more information.
- eq.

$$H(u,v) = 1 - \text{Ideal low-pass filter.}$$

③ Guassian High pass filter (GHPF)
- Enhance edges while reducing noise.
- Provides smoother transition compared to ideal filter.

$$H(u,v) = 1 - \text{Guassian low-pass filter.}$$

* Additional concepts:

Freq. domain removal of periodic Noise:

① Notch filter:
- Set of Rows and Columns of the DFT corresponding to noise to zero.
- Remove much of periodic Noise.

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② Band Reject filter:

- Create a filter with 0's at the radius of the noise from the center.
- Apply the filter to the DFT to remove noise.

2D Transform Examples:
fourier

① Scaling : stretching an image cause the spectrum contract and vice versa

② Periodic pattern:
Repetitive periodic patterns appear as distinct peaks in the spectrum.

③ Rotation:
Rotating an image rotates the spectrum by the same angle /amoun

④ Oriented, Elongated structure:
Man-made elongated regular patterns dominate the spectrum.

⑤ Natural Images:
Repetition in natural scenes are less dominant in the spectrum compared to man-made patterns.

⑥ Printed patterns:
Regular diagonal patterns caused by printing are clearly visible/ removable in freq. spectrum.

Watermark attacks	effect in spatial domain	Effect in freq. domain
① Guassian smoothing attack	Reduce variation in image pixel values.	Acts as low pass filter.
② Guassian noise attack	Increase variation in image pixel values	Similar effect to a high pass filter.
③ Salt & pepper noise attack	Same as Guassian noise attack.	Same as guassian noise attack
④ Median filter attack	similar to Guassian smoothing attack.	Similar effect to a high pass filter
⑤ Histogram equalization attack	Reduces no. of unique grayscale values & make histogram more uniformly distributed.	Similar even though more moderate, effect as guassian smoothing attack
⑥ Sharpen attack.	Reduces overall image intensity & amplifies differences around edges.	Act as high pass filter
⑦ JPEG Compression attack.	Reduces variation in image pixel values & Creating block or uniform regions in image.	Similar effect to a high pass filter.

Questions :

① Which of following in an image can be removed by using a smoothing filter
ⓐ Sharp transition of brightness level
ⓑ —11— of gray level
ⓒ Smooth transition of —11—
ⓓ —11— of brightness level

② ______ is/are features of a high pass filter image.
ⓐ An overall sharper image
ⓑ Have less gray-level variation is smooth areas.
ⓒ Emphasized transitional gray-level details
ⓓ All

③ Which of the following comes under the application of image blurring
ⓐ Image segmentation
ⓑ Object motion
ⓒ Object detection
ⓓ Gross representation

Questions on affine transformation

① polygon $V = (10,10)\ (40,0)\ (40,40)\ (10,40)$.
polygon shifted 20 units upwards, 10 units left. find out transform object ?

→ $$\begin{bmatrix} 10 & 10 \\ 40 & 0 \\ 40 & 40 \\ 10 & 40 \end{bmatrix}$$

$\left.\begin{matrix} tx = -10 \\ ty = 20 \end{matrix}\right\}$ given matrix of translation $\begin{bmatrix} a=1 & b=0 \\ c=0 & d=1 \\ tx & ty \end{bmatrix}$

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ tx & ty & 1 \end{bmatrix}$$

We need matrix with 3 columns
so use homogenous co-ordinate (h)

$$\begin{array}{c} \begin{bmatrix} 10 & 10 & 1 \\ 40 & 0 & 1 \\ 40 & 40 & 1 \\ 10 & 40 & 1 \end{bmatrix} \\ \;\; x \quad\;\; y \quad\;\; h \end{array} \begin{array}{c} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ tx & ty & 1 \end{bmatrix} \\ (-10) \quad (+20) \end{array}$$

$$= \begin{bmatrix} 0 & 30 & 1 \\ 30 & 20 & 1 \\ 30 & 60 & 1 \\ 0 & 60 & 1 \end{bmatrix}$$

2) (2,2) (6,2) (3,6) (7,5) to be rotated
polygon (ABCD)
i) 90° clockwise
ii) 90° anticlockwise w.r.t point
hearer to the origin.

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Q3) ΔABC

A (1, 2)

B (2, 7)

C (-1, 3) Enlarge twice keeping point 'C' at fixed location

Q4) ΔABC

A (1, 2)

B (2, 7)

C (-1, 3) Reflect ΔABC through line $x=2$

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(B) * DCT :
Discrete Cosine Transform

* Transform coding :
- Transform coding is a fundamental technique in image and video processing.
- It's based on the premise that pixels in image or frames in a video
- It is loosless operation, ensuring perfect reconstruction of original data.

why ?
- Better image processing
  - considers long-range correlation in space
  - Provides conceptual insights into spatial-> freq. information.
- fast computation
- Alternative representation & sensing
- Efficient storage and transmission.
- Energy compaction.

* DCT VS DFT :
# DFT
- Discrete Fourier transform
- Computes the freq. components of signal or image.
- complex & computationally intensive
- Captures both imaginary and real components of the functions.

- Popular but poor energy compaction

\# DCT

- Discrete cosine transform
- Part of fourier transform family
- Converts data to freq. domain using summation of variable frequency cosine waves.
- Capture only real components of the function.
- Better energy compaction than DFT
- Exhibits less blocking artifacts & uses simpler H/w compared to DFT.

* Concept of DCT :

- mathematical operation to transform discrete sequence of pixels in digital image from

Spatial domain ⟶ freq. domain

- Converts data to freq. domain using summation of variable freq. cosine waves.

1] 1D DCT :

- Converts 1 dimensional sequence of data into freq. domain.

$$C(u) = \alpha(u) \sum_{x=0}^{N-1} f(x) \cos\left[\frac{\pi(2x+1)u}{2N}\right]$$

- 1D DCT calculates the cosine transform of i/p seq.

in eqn :-

$$\alpha(u) = \begin{cases} \sqrt{1/N} & \text{for } u=0 \\ \sqrt{2/N} & \text{for } u \neq 0 \end{cases}$$

here $C(u)$ = transform coefficient in freq. domain

$f(x)$ = i/p data in spatial domain

N = no. of data points in sequence

u = freq. index ranging from 0 to N-1

2] 2D DCT :

- extension of 1D DCT to two dimensional

$$\cancel{X(u,v) = \alpha(u)\,\alpha(v) \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x,y) \cos\left[\frac{\pi(2x+1)u}{2N}\right] \cos\left[\frac{\pi(2y+1)v}{2N}\right]}$$

$$\boxed{C(u,v) = \alpha(u)\,\alpha(v) \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x,y) \cos\left[\frac{\pi(2x+1)u}{2N}\right] \cos\left[\frac{\pi(2y+1)v}{2N}\right]}$$

Here data is 2 dimensional

Imp * Properties of DCT :

1. Decorrelation :
   - Reduces redundancy betn neighbouring pixels
   - By transforming image to freq. domain

DCT separates the correlated components of the image, making them easier to compress.

② Energy Compaction:

- DCT efficiently packs i/p data into few coefficients, facilitating compression without significant loss of visual quality
- achieves energy compaction by concentrating most of signal energy into small no. of low freq. coefficients.
- while highest frequency coefficients contains less energy.
- imp for image compression.

③ Separability:

- meaning it allows computation in two steps 1D operation on rows & column to get 2D DCT

$$f(x,y) \xrightarrow[\text{row transform}]{} C(u,v) \xrightarrow[\text{column transform}]{} C(u,v)$$

④ Symmetry:

- It means its basic function have even symmetry
- Simplifies computations & reduces no. of distinct basis functions required for image representation.

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⑤ Orthogonality:
- DCT basis functions are orthogonal to each other, meaning their inner products are 0.
- Simplifies reconstruction of original image from its DCT coefficients.

* Limitation of DCT :

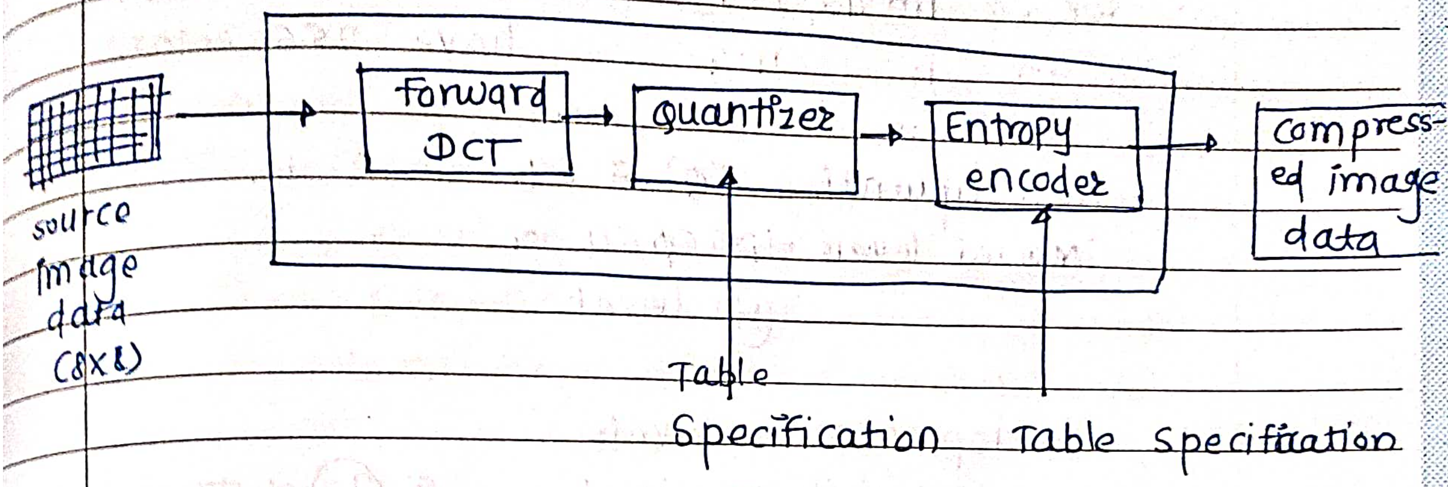
- Introduce the graininess in smooth portion of image
- Serious blocking artifacts are introduce at boundaries
- Truncation of higher spectral coefficients results in blurring of image.

* Application of DCT :
- Image processing (in JPEG compression)
- Audio processing (in MPEG audio coding)
- scientific computation (in HPC)

* Energy compaction

→ same theory as property of DCT (Energy compaction)

* Image Compression:



- Image compression involves reducing the amount of data required to represent an image while maintaining quality.
- compression technique involves.
  - Transform coding
  - quantization
  - entropy (lossless) coding.

(Imp) Benefits of compression :

1. Reduction in data size.
2. Improved efficiency
3. Bandwidth conservation
4. Faster transmission
5. Cost saving
6. Compatibility
7. Interoperability
8. Enhanced accessibility

Example of quantizer :

for x in [0, 255] we need 8 bits &
have 256 colors

when quantize (Q) = 64
No. of levels = 256/64
= 4 levels

To represent 4 levels
bits required = 2 bits

when q = 32
No. of levels = 256/32
= 8 levels

bits required = 3 bits

compression ratios
① for 64 = 8/2 = 4:1
② for 32 = 8/3 = 2.67 :1

(c) DWT :-
Discrete Wavelet Transform

- Concept of multi-resolution
- DWT Basic
- DCT vs DWT
- DWT properties
- DC component & compression.

Multiresolution :

- MRA (Multi-Resolution analysis) is fundamental concept in image compression and signal processing.
- In image processing, it enables the extraction of important features at different scales, facilitating tasks like edge detection, texture analyse & compression

+ Process

① Wavelet decomposition:
- an image is decomposed into different levels, each level of decomposition captures details at a specific scale, with higher levels representing finer details.

② Hierarchy of information:
- lower levels = coarse feature
- higher levels = finer details.

③ Scalibility
- allows reconstruction of image (original) at various resolutions.

DWT Basic:

- Useful for image compression and signal processing.
- It decomposes the signals into set of basic functions called as wavelets.
- Wavelets are obtain from prototype wavelet called as mother wavelet.

*+ 1D and 2D DWT are mathematical techniques used in image processing to decompose an image into its freq. components at different scales and orientations.

+ Based on concept of wavelets (wave-like function that capture localized information in a signal.
+ By manipulating wavelet coefficient, it is possible to enhance features of the image.

+ DWT is linear combination of finite duration "wavelets"

1D DWT equation :-

$$W_F(a,b) = \sum_n x(n) \, \psi_{a,b}(n)$$

Here,

$W_F(a,b)$ represents the DWT coefficient at scale a and translation b

$x(n)$ represents discrete signal at sample n

$\psi_{a,b}(n)$ in wavelet filter

- In two-dimensional DWT, it is the extension of 1D DWT.

* DCT VS DWT

① Orthogonality :-

DCT : Basic functions of DCT are orthogonal. (uncorrelated)

DWT : They are also orthogonal, providing MRA (multiresolution analysis) of the signal.

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② Time freq. localization:

DCT : doesn't offer good time frequency localization since it decomposes the signal into freq. components only.

DWT : Offers excellent time freq. localization as decompostion is into time & freq component.

③ Compression performance:

DCT : Widely used in image/ signal compression due to energy compaction property.

DWT : Better compression than DCT.

④ Boundary effects:

DCT : Suffers from boundary effect

DWT : Handles boundary effect

⑤ Computational complexity:

DCT : low

DWT : High

- DWT advantages, disadvantages

Disadvantages of DCT:

- Limited spatial correlation
- Boundary artifacts
- Fixed function
- Inefficiency for certain types of images

Advantages of DWT over DCT:

- Higher flexibility
- Avoidance of blocking artifacts
- Transformation of the whole image
- Performance: DWT offers higher compression ratios compared to DCT, with visually indistinguishable reconstructed images achieved at lower compression rates.

Implementation Complexity:

- DWT implementation complexity depends on the length of the wavelet filters. Methods like the lifting scheme enable efficient DWT computation using integer arithmetic. DWT can be implemented in hardware such as ASIC and FPGA.
- However, DWT may have higher computational costs compared to DCT, especially when using larger basis functions or wavelet filters, which can lead to blurring and ringing noise near edge regions in images or video frames.

- Compression

- **Principles of Compression:**
- **Spatial Correlation:** Refers to redundancy among neighboring pixels in an image.
- **Spectral Correlation:** Indicates redundancy among different color planes in an image.
- **Temporal Correlation:** Describes redundancy between adjacent frames in a sequence of images or video.

Classification of Compression:

- **Lossless vs. Lossy Compression:**
  - **Lossless:** Produces a compressed version of the image that is digitally identical to the original. Offers modest compression ratios.
  - **Lossy:** Discards redundant components of the signal, resulting in a changed signal from the input. Achieves much higher compression ratios, typically with no visible

loss perceived under normal viewing conditions (visually lossless).

- **Predictive vs. Transform Coding:**
    - **Predictive Coding:** Uses information already received to predict future values. Stores the difference between predicted and actual values. Easily implemented in the spatial (image) domain. Example: Differential Pulse Code Modulation (DPCM).
    - **Transform Coding:** Transforms the signal from the spatial domain to another space using a well-known transform. Encodes the signal in the new domain by storing coefficients. Generally offers higher compression but requires more computation due to quantization.
- **Subband Coding:**
    - **Subband Coding:** Involves splitting the frequency band of a signal into various subbands.
    - **Quadrature Mirror Filter (QMF):** Filters used in subband coding.
    - **Octave Tree Decomposition:** Technique used to decompose image data into various frequency subbands.
    - **Quantization and Encoding:** The output of each decimated subband is quantized and encoded separately.