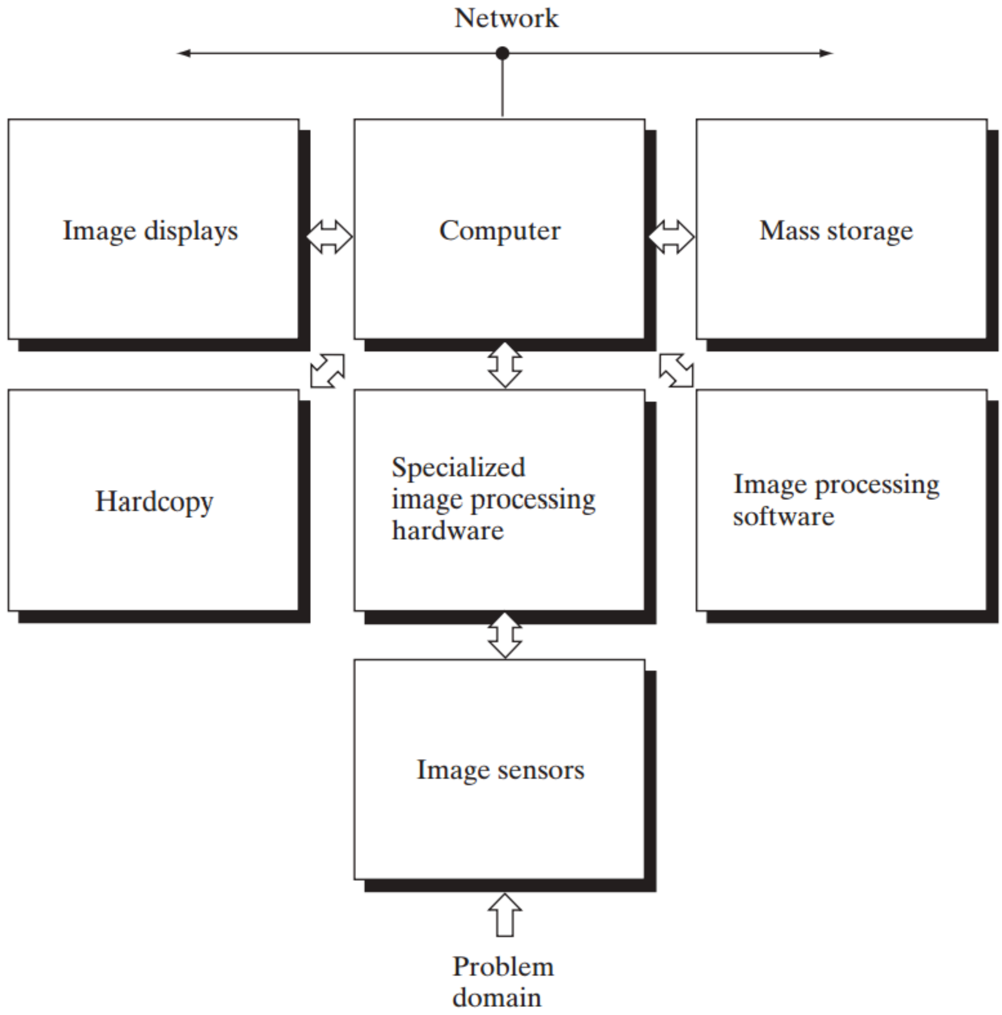
DIP IA1

M1Q1) Explain the components of an Image Processing System.



1. **Image Sensors**: These capture the image using devices that are sensitive to the energy emitted by the object. A digitizer then converts this data into digital form.
2. **Specialized Image Processing Hardware**: This includes components like Arithmetic Logic Units (ALUs) which perform operations like image averaging, primarily for noise reduction and real-time processing.
3. **Computer**: A general-purpose computer handles the main processing tasks. It can range from personal computers to supercomputers depending

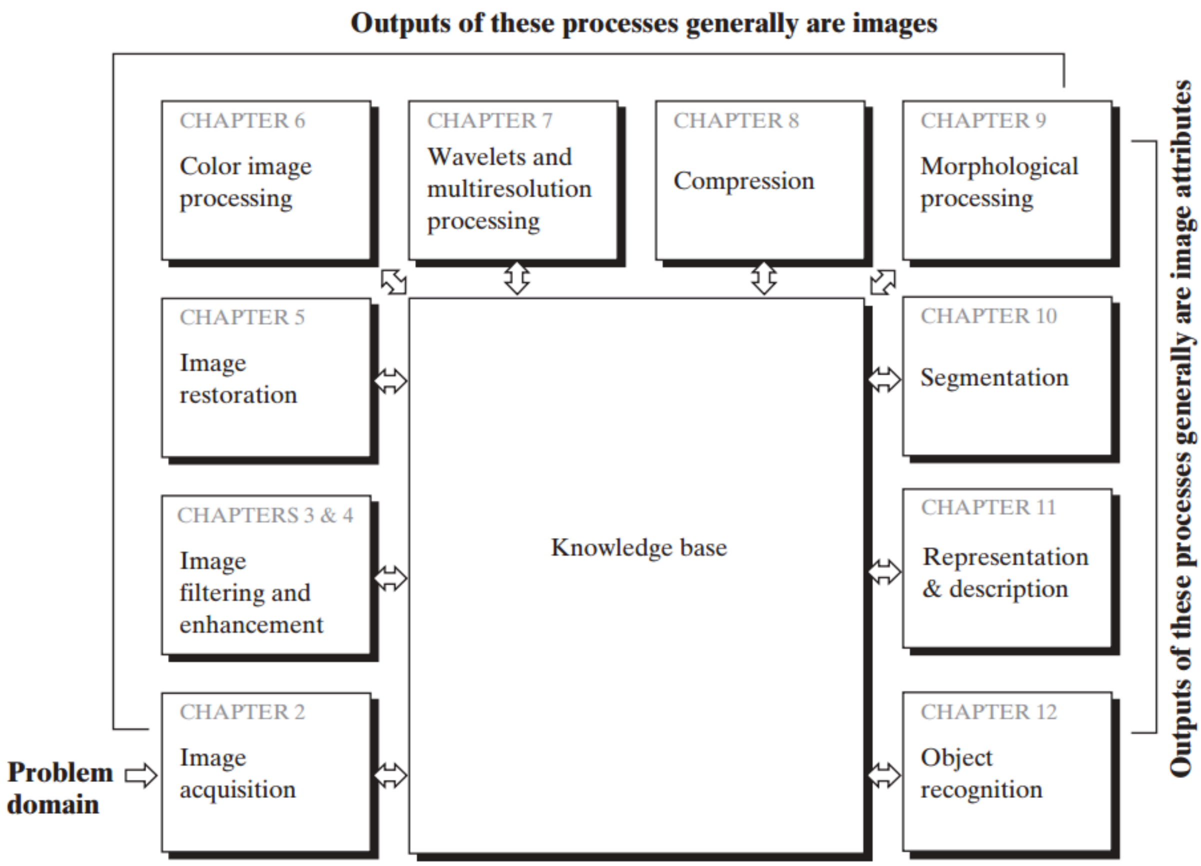
on the application.

4. **Image Processing Software**: These are specialized software modules used for performing various image processing tasks. Some software packages also allow users to write custom code.
5. **Mass Storage**: Storage devices are required for storing image data. This can be short-term storage for ongoing tasks, online storage for easy access, or archival storage for long-term retention.
6. **Image Displays**: Monitors or display units, typically color flat-screen TVs, are used for viewing the processed images.
7. **Hardcopy Devices**: Devices like laser printers, inkjet printers, and film cameras are used to create physical copies of images.
8. **Networking**: Networking capabilities allow image data to be transmitted to remote locations for further analysis or storage.

M1Q2) Explain the fundamental steps in Digital Image Processing.

1. **Image Acquisition**: It involves capturing an image using a sensor and converting it into a manageable digital format. This may also include preprocessing steps like scaling and noise reduction.
2. **Image Enhancement**: This step is used to improve the visual quality of an image, making it more suitable for further analysis or display. Enhancement techniques are subjective and application-specific.
3. **Image Restoration**: Unlike enhancement, restoration uses mathematical models to recover an image that has been degraded. It is objective and often applied in applications like medical imaging or satellite imagery.
4. **Color Image Processing**: Focuses on color spaces and manipulations, applying techniques for color correction, enhancement, and segmentation.
5. **Wavelets and Multiresolution Processing**: This involves the application of wavelet transforms for analyzing images at multiple resolutions, often used in image compression.
6. **Compression**: Reducing the size of an image for storage or transmission using techniques like JPEG or PNG.

7. **Morphological Processing**: Extracts image components useful in shape representation and description using techniques like dilation, erosion, and skeletonization.
8. **Segmentation**: This step partitions an image into meaningful regions or objects, which is often a crucial part of object recognition tasks.
9. **Representation and Description**: After segmentation, the shape and structure of the objects are described using boundary or region-based descriptors.
10. **Object Recognition**: Finally, recognition algorithms classify objects into categories based on their descriptors.



M1Q3) Explain formation of image in human eye with example.

The human eye works similarly to a camera, forming images using a lens and projecting them onto a light-sensitive surface called the **retina**. The key components involved in the image formation process are:

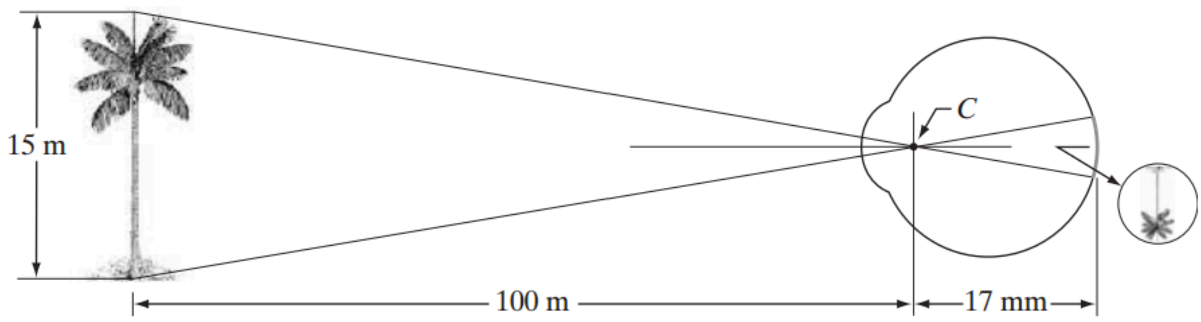
1. **Cornea and Lens**:
    - Light enters the eye through the **cornea**, which provides most of the focusing power.
    - The light then passes through the **aqueous humor** and reaches the **lens**, which further adjusts its shape to focus the light correctly onto the retina.
2. **Iris and Pupil**:
    - The **iris** controls the size of the **pupil**, regulating the amount of light entering the eye.
    - In bright light, the pupil contracts, and in dim light, it expands.
3. **Retina and Photoreceptors**:
    - The retina contains millions of **photoreceptor cells** called **rods** and **cones**.
    - **Rods** are highly sensitive to light and are responsible for **night vision**.
    - **Cones** detect **color** and are concentrated in the central region called the **fovea**, providing sharp and detailed vision.
4. **Optic Nerve and Visual Perception**:
    - The signals from the photoreceptors are converted into electrical impulses and sent to the brain via the **optic nerve**.
    - The brain processes these signals to form the image we perceive.

Example of Image Formation

If a person looks at a **tree 15 meters high** from a distance of **100 meters**, the eye's lens focuses the light onto the retina. Using geometric optics, the height of the image formed on the retina can be calculated using the ratio of distances:

$$\frac{\text{Image Height}}{\text{Retinal Distance (17 mm)}} = \frac{15\text{ m}}{100\text{ m}}$$

$$\text{Image Height} = \frac{15\text{ m} \times 17\text{ mm}}{100\text{ m}} = 2.55\text{ mm}$$



M1Q4) Consider the two images subsets S1 and S2 shown in the figure. For V={1}, determine whether the two subsets are:
a) 4-adjacent
b) 8-adjacent

Coordinates of S1 and S2 Pixels

- S_1 includes the block of pixels from the left part.
- S_2 includes the block of pixels from the right part.

a) 4-Adjacency Check

- In **4-adjacency**, two pixels are adjacent if they share a side (left, right, top, bottom).
- Examining the borders of S_1 and S_2, no pixel from S_1 directly touches a pixel from S_2.
- **Hence, they are not 4-adjacent.**

b) 8-Adjacency Check

- In **8-adjacency**, two pixels are adjacent if they share a side or a corner (diagonal).
- There are instances where pixels from S_1 and S_2 touch diagonally. Like the **(2,5)** pixel from S_1 and the **(2,6)** pixel from S_2.
- **Therefore, S_1 and S_2 are 8-adjacent.**

Representative Diagram

Below is an approximate text representation of the adjacency check:

```
    S1         S2

  ______________
0|0 0 0 0|0 0 1 1|0
1|0 0 1 0|0 1 0 0|1
1|0 0 1 0|1 1 0 0|0
0|0 1 1 1|0 0 0 0|0
 |_____________|
0  0 1 1 1|0 0 1 1  1
```

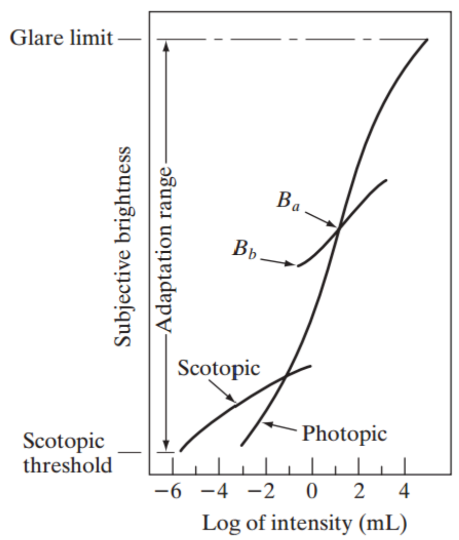
- The **vertical bar** `|` separates S_1 and S_2.
- No direct side connection → **Not 4-adjacent**.
- Some diagonal connections exist → **8-adjacent**.

This confirms that S_1 and S_2 satisfy **8-adjacency but not 4-adjacency**.

M1Q5) Explain the importance of brightness adaptation and discrimination in image processing.

Brightness Adaptation

- The human visual system can adapt to a broad range of light intensities, approximately from 10^{-6} to 10^{6} millilamberts (mL).
- However, it cannot operate over this entire range simultaneously. Instead, the eye adjusts its sensitivity through **brightness adaptation**.
- **Adaptation Level:** At any given time, the eye adapts to a specific brightness level, called the adaptation level. This determines the range of intensities the eye can effectively perceive.



Range of subjective brightness sensations showing a particular adaptation level.

- Figure 2.4 in the textbook shows the adaptation curve, illustrating how the visual system transitions from **scotopic** (low-light) to **photopic** (bright-light) vision.

Brightness Discrimination

- **Brightness discrimination** refers to the eye's ability to detect small differences in light intensity.
- The **Weber Ratio** is used to measure discrimination and is defined as:

  $\text{Weber Ratio} = \frac{\Delta I}{I}$

  Where:
  - I = Background illumination
  - ΔI = Minimum detectable intensity difference
- A small Weber ratio implies good discrimination, while a large ratio indicates poor discrimination. The eye is more sensitive to changes in intensity at higher illumination levels.

M2Q1) Explain the 2D DFT Properties.

1. **Symmetric and Unitary**

   The 2D DFT is symmetric and unitary, meaning it preserves energy. In matrix notation:

   $$\mathcal{F}^{-1} = \mathcal{F}^* = F^* \otimes F^*$$

   Where:
   - $\mathcal{F}$ is the DFT matrix
   - $\mathcal{F}^{-1}$ is its inverse
   - F^* denotes the conjugate transpose of the 1D DFT matrix
   - $\otimes$ denotes the Kronecker product.
2. **Periodic Extensions**

Both the image and its transform are treated as periodic functions:

$$v(k+N, l+N) = v(k,l) \qquad \text{all } k, l$$

$$u(m+N, n+N) = u(m,n) \qquad \text{all } m, n$$

3. **Sampled Fourier Spectrum**

   The 2D DFT samples the continuous Fourier transform of the image:

   $$V(k,l) = \mathrm{DFT}\{u(m,n)\} = v(k,l)$$

   Where $V(k,l)$ is the sampled transform at discrete frequencies.

4. **Fast Transform**

   The separability of the 2D DFT allows it to be efficiently computed using the Fast Fourier Transform (FFT):

   $$\text{Total Operations} = O(N^2 \log_2 N)$$

   This is done using two 1D FFTs applied row-wise and then column-wise.

5. **Conjugate Symmetry**

   For real images, the 2D DFT exhibits conjugate symmetry:

   $$v(k,l) = v^*(N-k, N-l), \quad 0 \le k, l \le N-1$$

   This reduces the storage requirement to half of the transform coefficients.

M2Q2) State and explain properties unitary transforms.

1. **Energy Conservation and Rotation**
   - A unitary transformation preserves the energy of the signal or the length of the vector in the N-dimensional space.
   - Mathematically:

     $$||v||^2 = ||u||^2 \qquad \sum_{k=0}^{N-1} |v(k)|^2 = \sum_{n=0}^{N-1} |u(n)|^2$$

   - This implies that a unitary transform is a rotation in the vector space.

2. **Energy Compaction and Variance of Transform Coefficients**

- Most unitary transforms tend to pack a significant fraction of the image's energy into a few transform coefficients.
- Given the mean μ_u and covariance R_u of a vector u, the corresponding mean and covariance for the transformed vector v are:

  $\mu_v = A\mu_u$

  $R_v = AR_uA^*$
- Variance of transform coefficients:

  $\sigma_v^2(k) = [R_v]_{k,k} = [AR_uA^*]_{k,k}$

3. **Decorrelation**
   - When input vector elements are correlated, the transform coefficients tend to become uncorrelated.
   - The off-diagonal elements of the covariance matrix R_v become small, making the matrix nearly diagonal.
   - The Karhunen-Loève Transform (KLT) is optimal in this regard.
4. **Other Properties**
   - **Determinant and Eigenvalues**: The magnitude of the determinant of a unitary matrix is unity. All eigenvalues also have a magnitude of one.

     $\det(A)| = 1$
   - **Entropy Preservation**: The entropy of a random vector is preserved under a unitary transform, meaning no information is lost.

M2Q3) Define and explain Image Transforms.

An **image transform** refers to a mathematical operation that converts an image from its spatial domain to a different domain, often the frequency domain, to facilitate further processing such as compression, enhancement, and analysis.

Explanation:

1. **Basis Images and Series Representation**
   - Similar to representing one-dimensional signals using orthogonal series expansions, images can be expanded using a discrete set of basis images.

- Mathematically, a unitary transformation for a 1D sequence $u(n)$ of size N is given by:

> 🪧 $v(k) = \sum_{n=0}^{N-1} a(k,n)u(n)$

  where $a(k,n)$ are the transform coefficients.

- The inverse transform is expressed as:

> 🪧 $u(n) = \sum_{k=0}^{N-1} v(k)a^*(k,n)$

  Here, $a^*(k,n)$ represents the complex conjugate of the matrix.

2. **Two-Dimensional Image Transforms**
   - For a 2D image $u(m,n)$ of size $N \times N$, the transform and inverse transform are given by:

$$v(k,l) = \sum_{m=0}^{N-1} \sum_{n=0}^{N-1} u(m,n)a(k,l,m,n)$$

$$u(m,n) = \sum_{k=0}^{N-1} \sum_{l=0}^{N-1} v(k,l)a^*(k,l,m,n)$$

   - The basis functions $a(k,l,m,n)$ form a complete orthonormal set that can represent any image.
3. **Applications of Image Transforms**
   - **Filtering:** Unwanted noise or features can be removed by manipulating the transform coefficients.
   - **Compression:** Transforms like the Discrete Cosine Transform (DCT) are widely used in image compression algorithms such as JPEG.
   - **Feature Extraction:** Key image features can be extracted using transforms like the Fourier Transform.

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