Module 4

Image Processing

Image

An image is defined as a two-dimensional function, $F(x, y)$ where x and y are spatial coordinates, and the amplitude of F at any pair of coordinates (x, y) is called the intensity of that image at that point.

Images can be represented in many forms, generally they are represented as a matrix with the indices specifying the spatial coordinate and the value being the intensity of the pixel at that point. Usually each point in the image is called a `pixel`

Some ways of representing images:

- **Binary Image**: The values of the pixels range from 0 to 1.
- **8 Bit Color Format (Gray Image):** The values of pixels range from 0 to 255, also sometimes referred to as PGM (Portable Gray Map).
- **16 Bit Color Format**: It is a color image format, with 65,536 different colors in it.

Application of Image Processing

Image processing is a very important field of study and has implication in a lot of fields, like:

Gamma Ray Imaging
In nuclear medicine injecting a patient with a radioactive isotope emits gamma rays as its decays. Images of this sort are used to locate sites of bone pathology such as infections or tumors

Astronomical Observations
The output images from satellites and observatories need further processing to extract details and also image processing is needed to visualize data from IR imaging, heatmap data and many more.

X-ray Imaging
This is used in processes like medical diagnostics, Computerized axial Tomography (CT scan) and also in a magnitude of Industrial applications.

Ultraviolet Imaging
Ultraviolet imaging is used in lithography, industrial inspection, microscopy, lasers, biological imaging, and astronomical observations.

Visible and Infrared band Imaging
Imaging in the visible and infrared bands is utilized in light microscopy, astronomy, remote sensing, industry, and law enforcement (biometrics).

Note

There are more application and use cases for image processing, like **Forensics & Investigation**, **Machine Learning**, **Entertainment**

Fundamental Steps of Image Processing

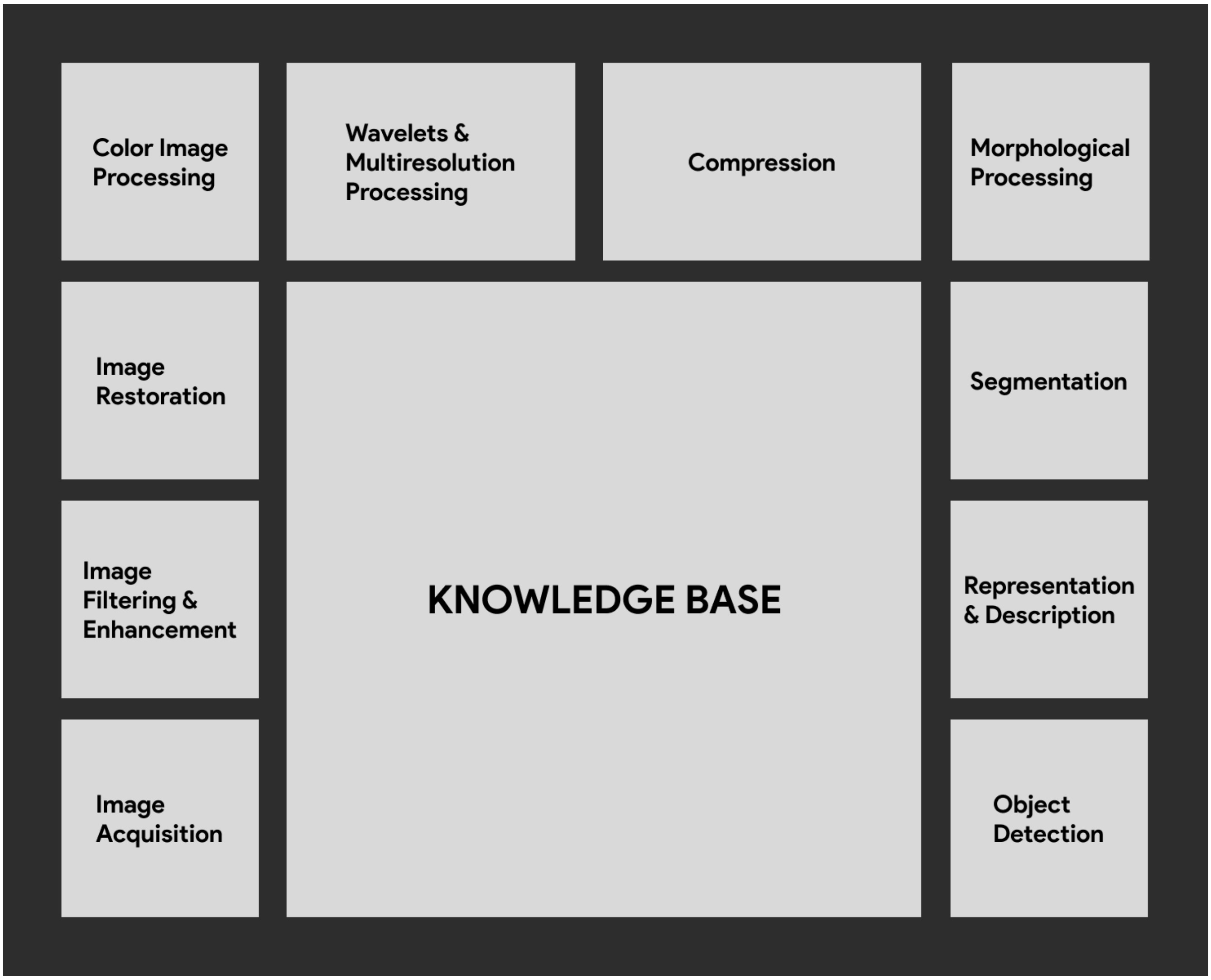


Image Acquisition

This is the first step of the fundamental steps of image processing. In this stage, an image is given in digital form. Generally, in this stage, pre-processing such as scaling is done.

Image Enhancement

This is the process of manipulating an image so that the result is more suitable than the original for a specific application. Interesting features of an image is highlighted such as brightness, contrast, removal of noise, sharpening of an image etc. Subjective in nature – vary from application to application.

Image Restoration

This is the stage in which the appearance of an image is improved. Recovering an image that has been degraded.

Color Image Processing

Color image processing is a famous area because it has increased the use of digital images on the internet. This includes color modeling, processing in a digital domain, etc.

Wavelets and Multi-Resolution Processing

Wavelets facilitate wavelet transforms, providing time and frequency information of an image and enabling multi-resolution processing where the image is represented at various degrees of resolution.

Compression

Compression is a crucial technique for reducing the storage requirements of an image, especially important for efficient data transmission over the internet.

Morphological Processing

Morphological processing in image processing involves a set of non-linear operations that analyze and manipulate image structures based on their shapes, primarily applied to binary images but also extendable to grayscale images.

Segmentation

Segmentation is one of the most challenging tasks in digital image processing, requiring significant time to successfully identify and isolate individual objects within an image. Ref Module 5 for more info.

Representation and Description

Converting raw pixel data representing the regions or their boundaries. Representation and description stages are crucial for transforming this raw data into a suitable form for computer processing, facilitating further analysis and interpretation.

Object Detection

In this stage, the label is assigned to the object, which is based on descriptors.

Points

- Acquisition
- Enhancement
- Restoration
- Color Processing
- Wavelets and Multi-Resolution Processing
- Compression
- Morphological Processing
- Segmentation
- Representation
- Object Detection

Components of An image processing System

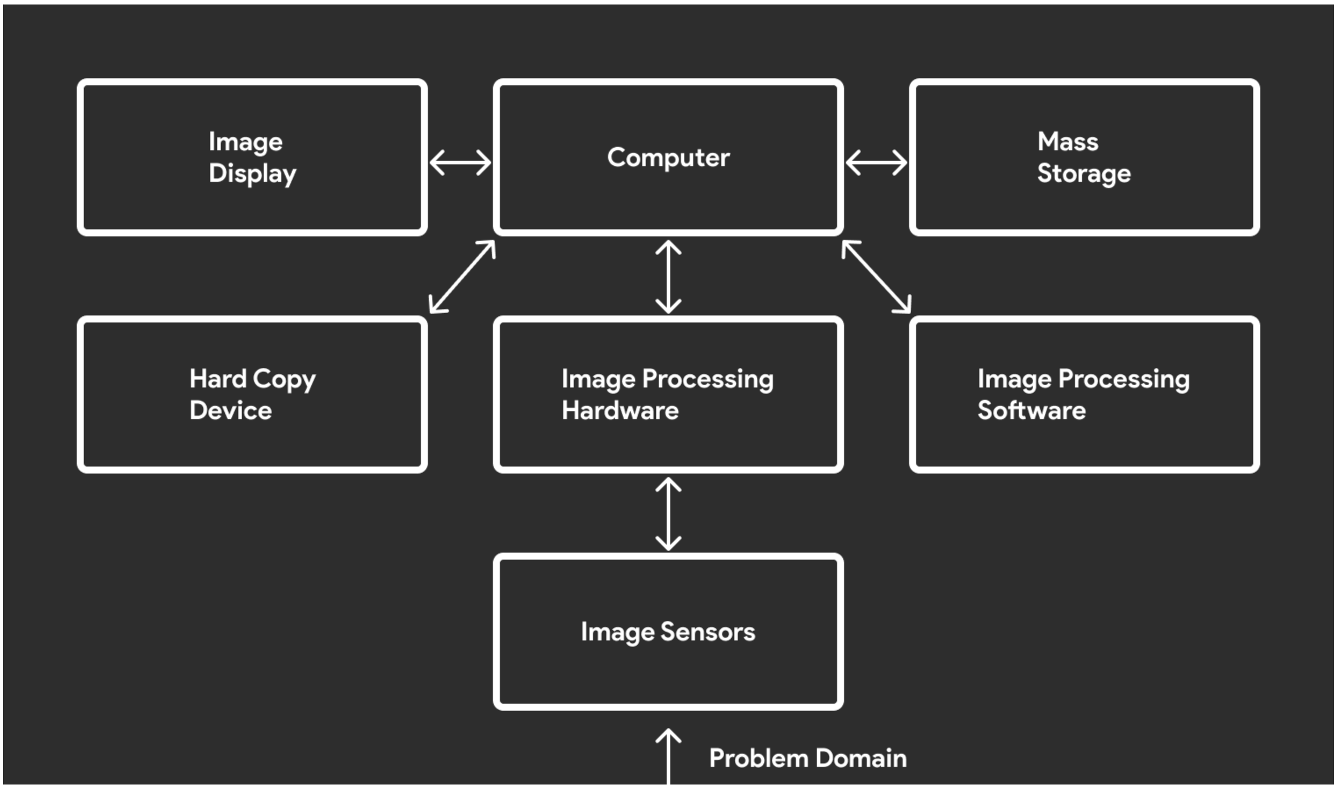


Image Sensors

To acquire digital images, two components are essential: a physical sensor sensitive to the energy emitted by the object being imaged and a digitizer, which converts the sensor's output into digital data.

Image Processing Hardware

Specialized image processing hardware includes the digitizer along with additional hardware capable of performing primitive operations such as arithmetic and logic functions in parallel on entire images, enhancing processing efficiency. (A good example would be dedicated chips on smartphones to enhance images).

Computer

The computer utilized in an image processing system can be a general-purpose one commonly used in daily life, ranging from personal computers to supercomputers. Occasionally, custom computers are employed to attain specific performance levels as needed.

Image Processing Software

Image processing software encompasses all mechanisms and algorithms utilized within an image processing system to manipulate and analyze images.

Mass Storage

Mass storage in image processing systems, which accommodates the pixels of images during processing and after processing, this is done by providing sufficient capacity for images depending on the some parameters like quality, file size, with digital storage typically categorized into short-term storage for processing, online storage for quick retrieval, and archival storage for less frequent access, all with different formats such as `png`, `jpg` etc.

Image Display

Image display in image processing systems primarily utilizes color TVs, monitors, mobile phone displays occasionally incorporating stereo displays, which can be in the form of headgear or normal desktop monitors.

Physical Copy Devices

After processing, the image is transferred to a hard copy device, which could be a pen drive or any external ROM device, utilizing laser printers, film cameras, as well as optical and CD-ROM disks for storage.

Sampling and Quantization

Sampling and Quantization are the processes used in converting analog signals of the light that we can see into digital representations which can than be used for image processing

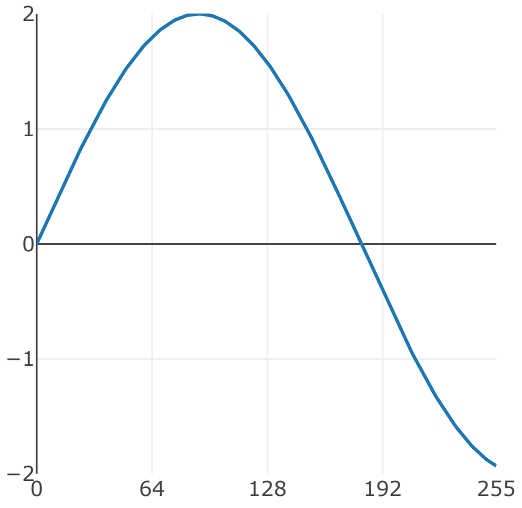
> Quantization is a lossy compression technique in image processing that reduces the amount of data in an image by compressing a range of values into a single discrete value

> Sampling is the process of converting an analog signal into discrete values, or pixels, at regular intervals of time.

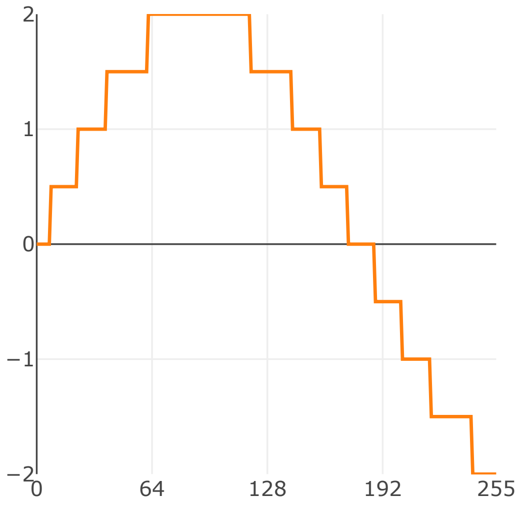
Simply Put

- Quantization is dividing the analog in the `y-axis` into specific levels rather than continuous
- Sampling is dividing the analog input in the `x-axis` the analog signal into specific time intervals (this doesn't have a big visual difference on the graph)

Normal Analog Image Input



Digitized Image



Usually the number of quantas (levels) is equal to the number of gray levels in the image.

Spatial and Gray Level Resolution

Spatial Resolution

Spatial resolution can be defined as the number of independent pixels values per inch.

Some spatial resolution measurements are:

Dots Per Inch
DPI measures image clarity and detail in printing, digital displays, and scanning, with higher DPI yielding sharper prints, more vibrant screen images, and higher quality scans.

Lines Per Inch
LPI is a printing resolution measurement used in commercial offset printing, indicating how closely spaced the lines in a halftone grid of ink dots are, with a higher LPI signifying greater detail and sharpness.

Pixels Per Inch
Pixels per inch (PPI) measures the number of pixels in a digital image or on a screen, indicating the resolution of digital images, videos, displays, and the resolution capacity of cameras and scanners.

Gray Level Resolution

Gray level resolution refers to the predictable or deterministic change in the shades or levels of gray in an image.

Gray level resolution is usual represented as L which can be calculated by

$$L = 2^k$$

where k is the number of **Bits Per Pixel** (BPP).

Sample problem

Q: The spatial resolution of an image is given by 128 X 128. What is its storage requirements if it is represented by 64 gray levels?

A: $64 = 2^6$ 6-bit representation for each grey level.
Image size = $128x128$
ie Storage requirements = $128x128x6$ bits

Relationship Between Pixels

The basic relationship between pixels are - neighborhood, adjacency, connectivity

Neighbors of a Pixel

A pixel p at coordinates (x, y) has four horizontal and vertical neighbors whose coordinates are given by: $(x + 1, y)$, $(x - 1, y)$, $(x, y + 1)$, $(x, y - 1)$. This set is called the 4-neighbors of P, is denoted by $N_4(P)$.

For the set of coordinates: $(x + 1, y + 1)$, $(x - 1, y + 1)$, $(x + 1, y - 1)$, $(x - 1, y - 1)$, these are called the four diagonal neighbors of P usually denoted as $N_D(P)$.

N_4 and N_D together are called 8-neighbour of P denoted as $N_8(P)$

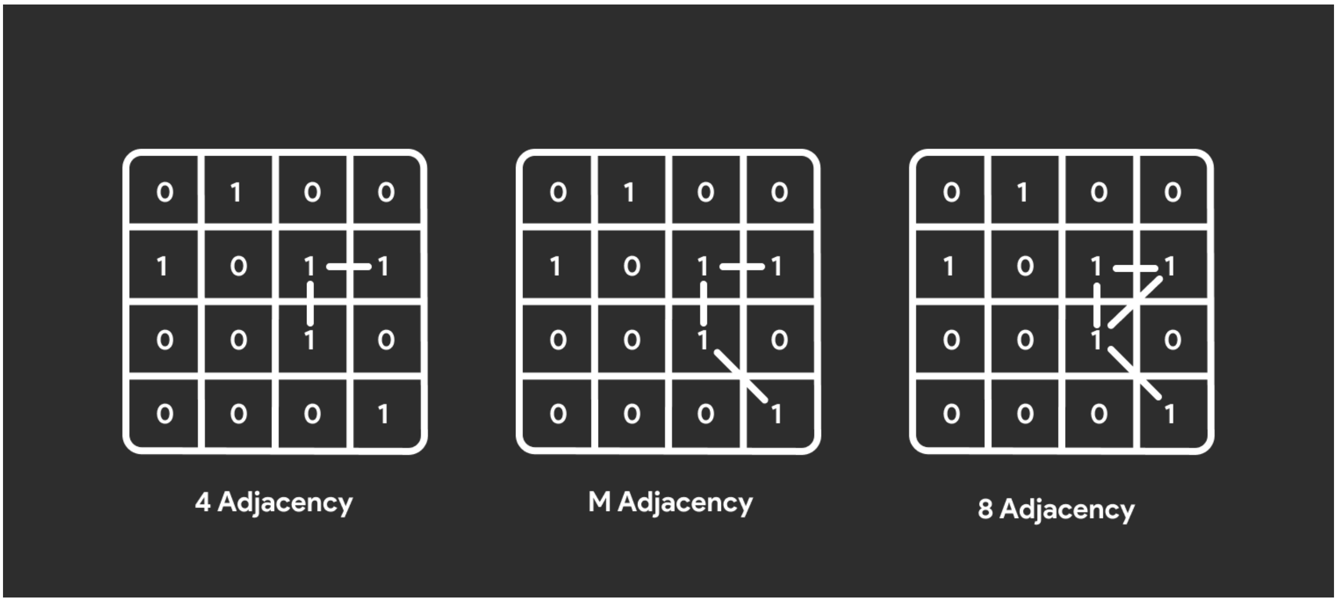
$$N_8 N_4 \cup N_D$$

Adjacency

Two pixels are connected if they are neighbors, and their gray levels satisfy some specified criterion of similarity.
Types of adjacency/connectivity

1. **4-adjacency**: Two pixels p and q with values from v are 4-adjacent if q is in the set $N_4(p)$.
2. **8-adjacency**: Two pixels p and q with values from v are 8-adjacent if q is in the set $N_8(p)$.
3. **M-adjacency (mixed):** Two pixels p and q with values from V are m-adjacent if q is in $N_4(p)$ or q is in $N_D(p)$ and the set $N_4(p) \cap N_4(q)$ has no pixel whose values are from V.

V is the set of all the possible values that can form a connection if they are adjacent



> Here $V = \{1\}$

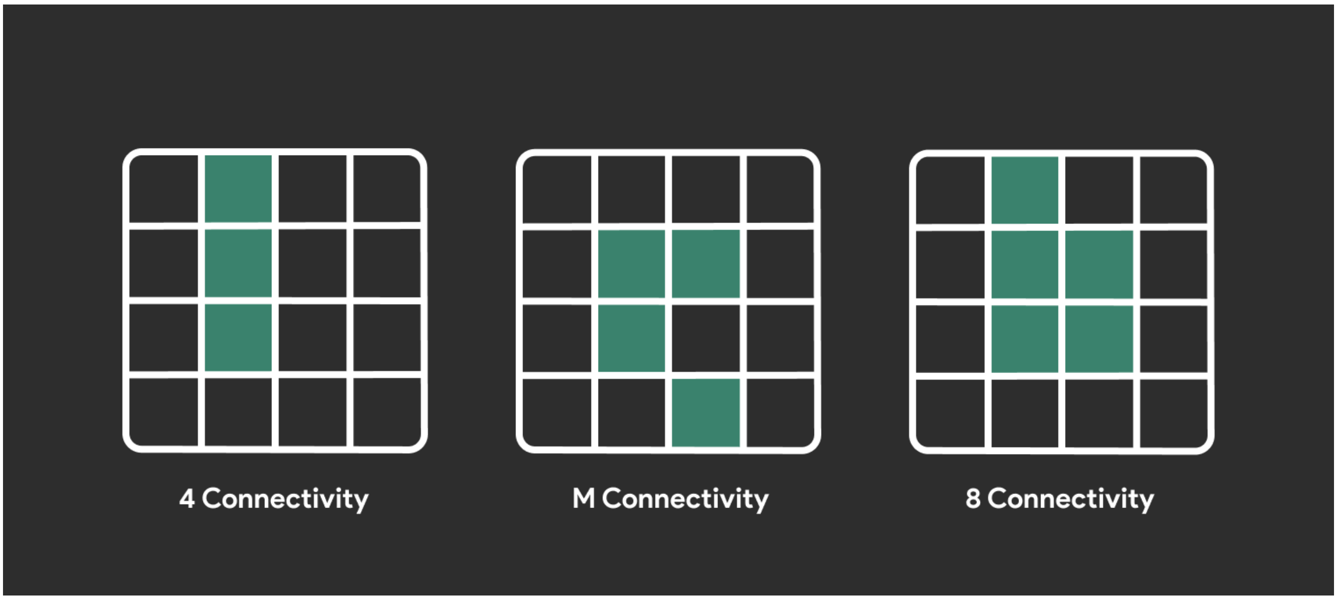
Mixed adjacency is a modification of 8-adjacency is introduced to eliminate the ambiguities that often arise when 8-adjacency is used. (eliminate multiple path connection)

Connectivity

A subset (S) of pixels in an image forms a connected set if it comprises only one connected component. Two pixels (p) and (q) in (S) are considered connected if there is a path between them consisting entirely of pixels in (S). The set of all pixels connected to a pixel (p) in (S) is called a connected component of (S).

Types of connectivity based on adjacency:

1. **4-connectivity**: Two or more pixels are 4-connected if they are 4-adjacent to each other.
2. **8-connectivity**: Two or more pixels are 8-connected if they are 8-adjacent to each other.
3. **m-connectivity**: Two or more pixels are m-connected if they are m-adjacent to each other.



Region

Let R to be a subset of pixels in an image, we call R a region of the image. If R is a connected set. Two regions R_i, R_j are said to be adjacent if their union forms a connected set. Regions that are not adjacent are said to be disjoint. Two regions (of 1s) in the figure, are adjacent only if 8-adjacency is used.

Boundary

The boundary of a region is defined as the set of pixels within the region that have one or more neighbors outside the region. Consider an image with K distinct regions, denoted as R_k where $k = 1, 2, 3, \ldots, K$. None of these regions touch the image border. Let (R_u) represent the union of all (K) regions, and let $(R_u)^c$ denote the complement of (R_u) (the complement of a set (S) is the set of points that are not in (S).

We define all the points in (R_u) as the foreground and all the points in $(R_u)^c$ as the background of the image. The boundary of a region (R) consists of the pixels in (R) that have at least one neighbor in the background.

> **Basically..**
>
> The Region and Boundary defined here are very similar to the general senses of those words, and can be written in your own words, just remember to keep the key points.

> **Spatial Filtering is explained in a bit more detail in Module 5, so explanation skipped here.**

Spatial Domain Operations

Correlation and Convolution
These are functions of displacement.

- Correlation: the process of moving a filter mask over the image and computing the sum of products at each location.
- Convolution: the same process as correlation, except that the filter is first rotated by 180 degrees.
  For example a filter could be:

  $$[w_1, w_2, w_3]$$

  Correlation and convolution with images with a filter of size m · n, we pad the image with a minimum of m-1 rows of 0s at the top and the bottom, and n-1 columns of 0s on the left and right.

  > **If the filter mask is symmetric, correlation and convolution yield the same result.**

> **Prob**
>
> Consider the filter: $[1, 2, 3]$
> This can then be applied on a image say: $[0, 1, 0, 0, 1, 1, 0]$
>
> We initially pad the matrix to make it work properly with the filter $[0, 0, 1, 0, 0, 1, 1, 0, 0]$
> Now we start applying the filter like:
>
> $[0, 0, 1, 0, 0, 1, 1, 0, 0]$
> $[1, 2, 3]$
>
> We perform the operations $0 * 1 + 2 * 0 + 3 * 0$ and the save the value at the position of the first element in the image
>
> Next the filter is shifted to the right by one element and the operations are repeated
> $[0, 0, 1, 0, 0, 1, 1, 0, 0]$
> $[1, 2, 3]$
> ...
> After all the operations are complete we get the result as:
>
> - **Convolution Output:** $[1, 2, 3, 1, 3, 5, 3, 1, 2, 3, 1, 3, 5, 3]$
> - **Correlation Output:** $[3, 2, 1, 3, 5, 3, 1, 3, 2, 1, 3, 5, 3, 1]$