📌 What is Convolution?

➤ Convolution in CNN:

- **Convolution** is a mathematical operation used in CNNs to extract **features** from an image using a **filter (kernel)**.
- The operation involves **sliding the filter** over the image and computing the **dot product** at each position.
- Resulting in a **feature map** (also called convolved output or activation map).

🖼️ Image Representation:

- Pixel values range from **0 to 255**.
- **Grayscale images** have **1 channel**, values from **0 (white)** to **255 (black)**.
    - In simplified CNNs, grayscale is often normalized: **0 (white)** to **1 (black)**.
- **RGB images** have **3 channels**: Red, Green, Blue.
    - Each channel is a separate 2D matrix.

☐ Convolution Example in the Image:

1. **Input Image**: 6×6 matrix.
2. **Filter (Kernel)**: 3×3 matrix.
3. **Operation**:
    - Slide the 3×3 filter over the 6×6 image.
    - Compute dot product at each position.
4. **Output Feature Map**: 4×4 matrix (after valid convolution, no padding).
5. **Visualization**: The teacher shows how convolution works with **step-by-step multiplication**.

🔧 Filters (Kernels) in CNN

Filters are used to **extract features** such as:

1. Edge Detection Filter:

- Highlights edges (changes in intensity).
- Example:

```
[ 1,  0, -1 ]
[ 2,  0, -2 ]
[ 1,  0, -1 ]
```

- Result: Detects **vertical edges**.

2. Sharpening Filter:

- Emphasizes fine details.

```
[ 0, -1,  0 ]
[-1,  5, -1 ]
[ 0, -1,  0 ]
```

3. Blurring Filter:

- Smoothens the image.

```
[1/9, 1/9, 1/9 ]
[1/9, 1/9, 1/9 ]
[1/9, 1/9, 1/9 ]
```

✅ **Purpose of Filters:**

- Different filters **learn different features** such as edges, textures, corners, etc.
- **Early layers** detect simple features; **deeper layers** detect complex patterns (e.g., eyes, faces in face detection).

Why Padding?

- Padding is used to **preserve spatial dimensions** of the input after convolution.
- Without padding, the output size **shrinks**.

Types of Padding:

1. **Zero Padding**: Add rows/columns of zeros around the border.

2. **Edge Padding**: Repeat **nearest values** at the border.

Padding Formula:

To compute **output size**:

Output size = (n + 2p - f) + 1

Where:

- n = input size (e.g., 6),
- p = padding (e.g., 1),
- f = filter size (e.g., 3)

Example in image:

6 + 2×1 - 3 + 1 = 6

→ Output size is 6 (same as input) → **Same padding**.

➡️ Stride

What is Stride?

- Stride is the **step size** with which the filter moves over the input.
- **Stride = 1**: Filter moves **one pixel at a time**.
- **Stride = 2**: Filter jumps **two pixels**, reducing output size.

Effect of Stride:

- Larger stride → **smaller output**.
- Formula with stride (s):

Output size = ⌊ (n + 2p - f) / s ⌋ + 1

🧠 Key Points Summary:

Term	Definition/Function
Convolution	Extracts features from images using filters.
Filter/Kernel	Small matrix applied on input to compute feature maps.

Term	Definition/Function
Padding	Preserves size or controls shrinking of output matrix.
Stride	Controls how far filter moves; affects output size.
Feature Map	Resultant matrix after convolution operation.

💡 **Additional Notes:**

- **Multiple filters** can be applied in one layer → each produces its own feature map.
- Output from one convolutional layer becomes **input to the next** layer.
- In CNN, filters are **learned during training** via backpropagation.