Convolutional Neural Networks

Data Mining & Neural Networks

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2025

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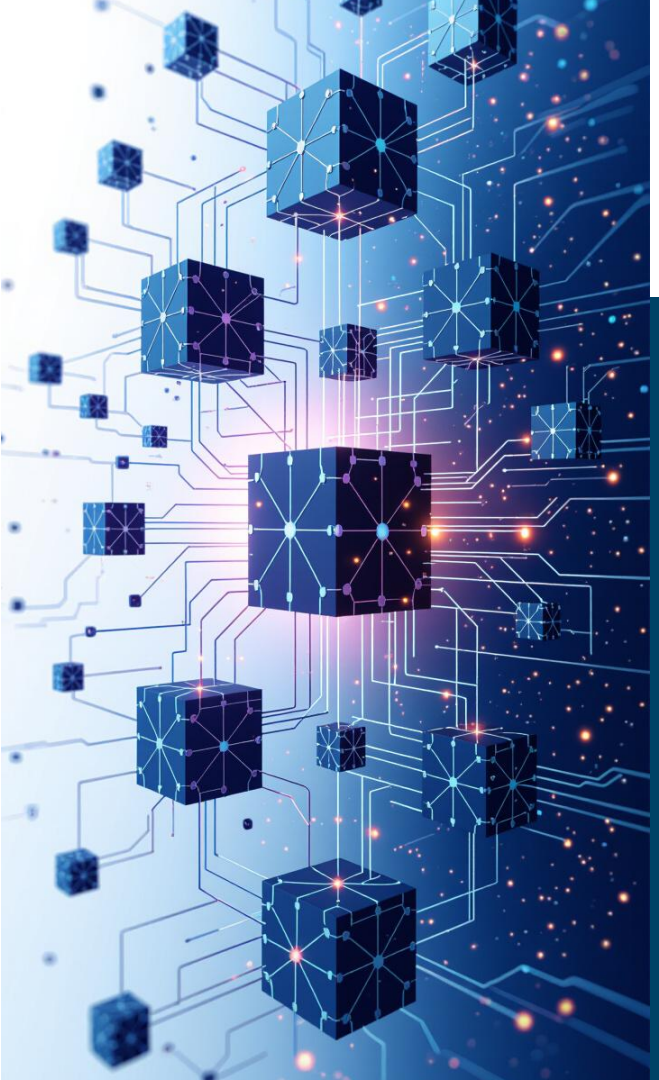
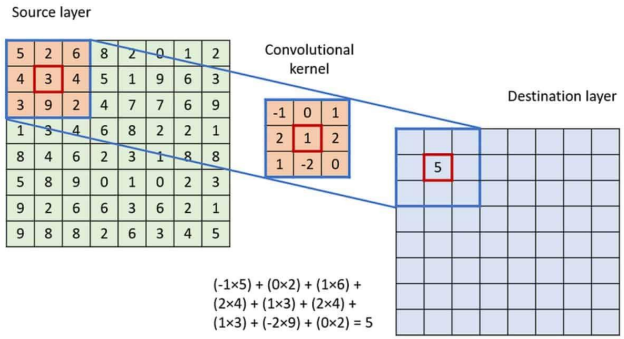


Convolutional Neural Networks (CNNs)

- CNNs are a powerful class of **DL algorithms used for tasks such as image recognition, classification, and computer vision**.
- We will explore the **architecture, key components, training process, and real-world applications of CNNs**.

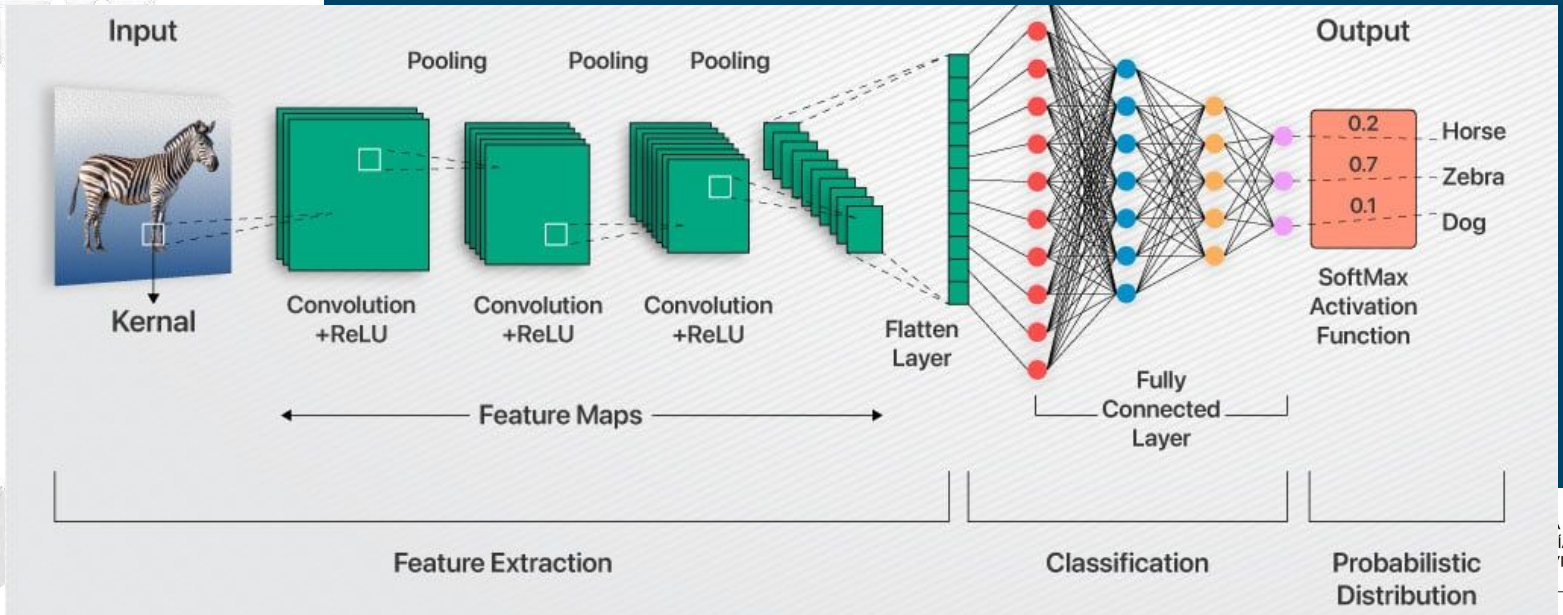
Definition and Purpose



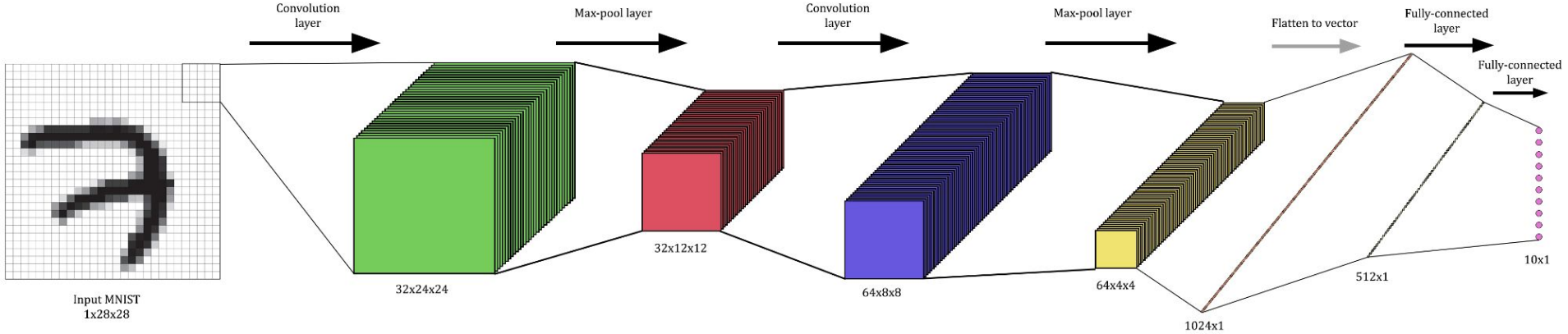
- **CNNs** are a type of **deep neural network** designed to **process data with a grid-like topology, such as images**.
- CNNs **automatically and adaptively learn spatial hierarchies of features** through backpropagation.
- They are widely used in **image classification, object detection, and even in natural language processing.**

Basic Structure of CNNs

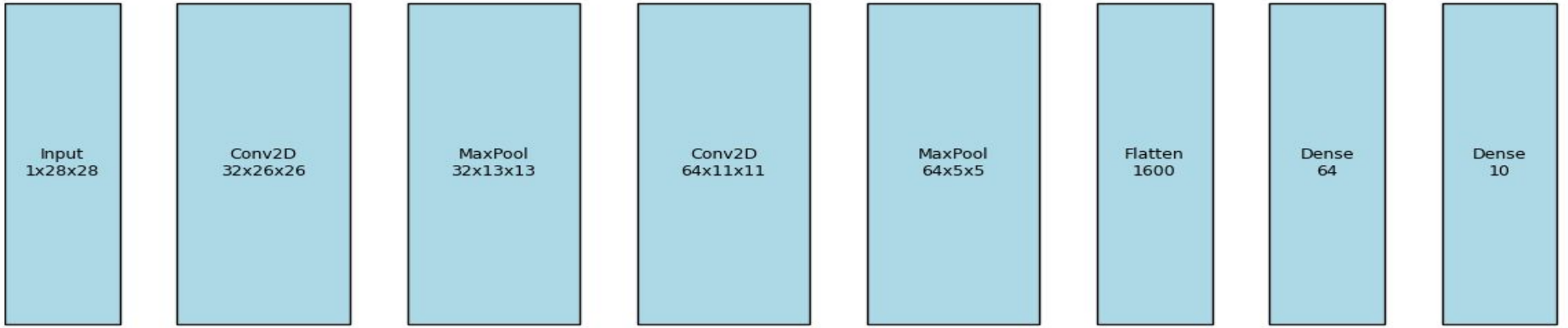
- CNN consists of three main types of layers: **convolutional layers, pooling layers, and fully connected layers.**

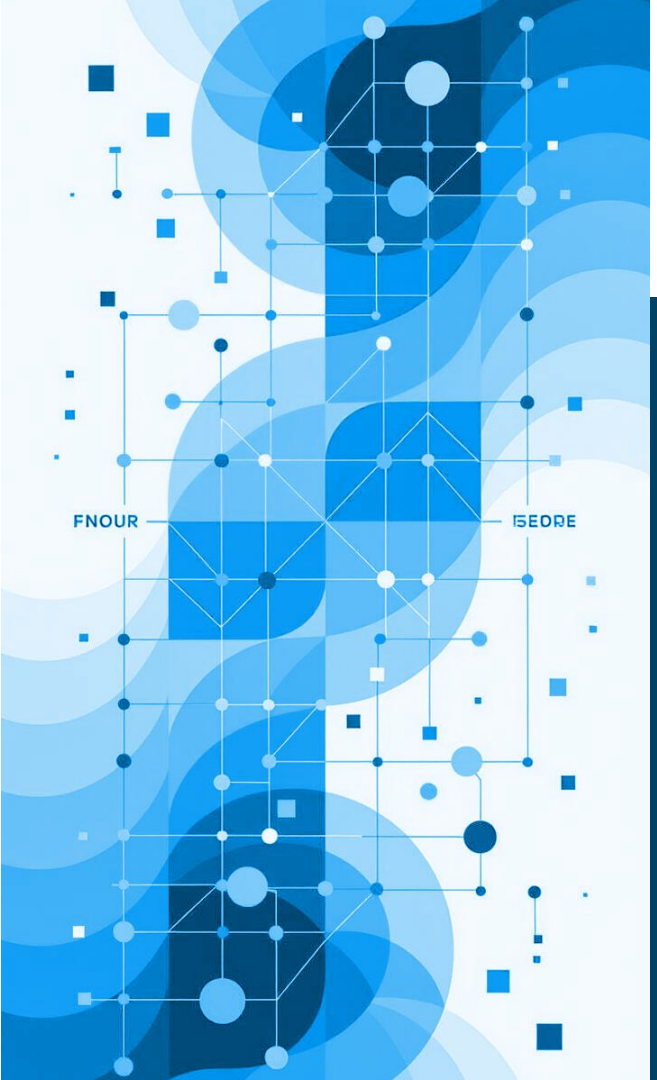


Example: Handwritten Digits



The CNN Model consists of 6 layers



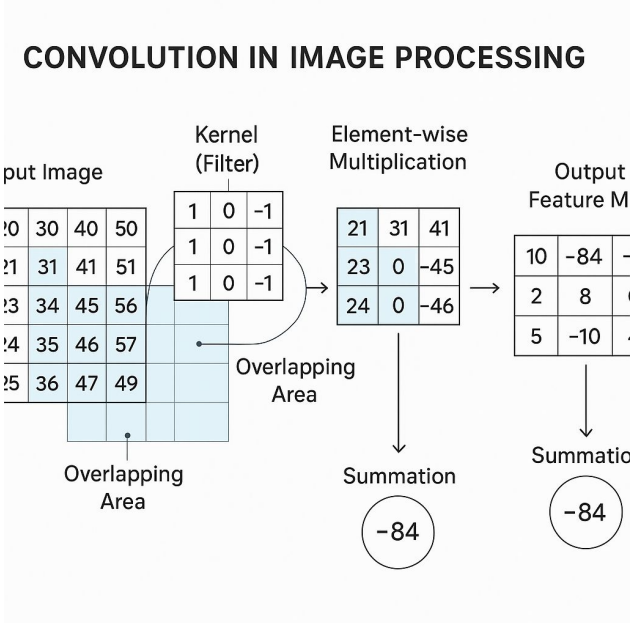


CNN Architecture

Typical CNN Architecture:

- **Input**: Raw pixel values from images (e.g., 28×28×1 or 224×224×3)
- **Convolutional** Layer: Applies filters to extract local features (edges, shapes)
- **Activation** (ReLU): Introduces non-linearity to learn complex patterns
- **Pooling Layer**: Reduces spatial size (e.g., MaxPooling) for dimensionality reduction
- **Fully Connected Layer**: Interprets high-level features
- **Output Layer**: Final prediction (e.g., softmax for classification)

How Convolution Works



- **A convolution is a mathematical operation that applies a filter to input data to extract local features such as edges or textures.**
- In CNN, a Convolution is an operation **in image processing**.
- Extract features like **edges, textures, and patterns** from images.

How does a CNN work?

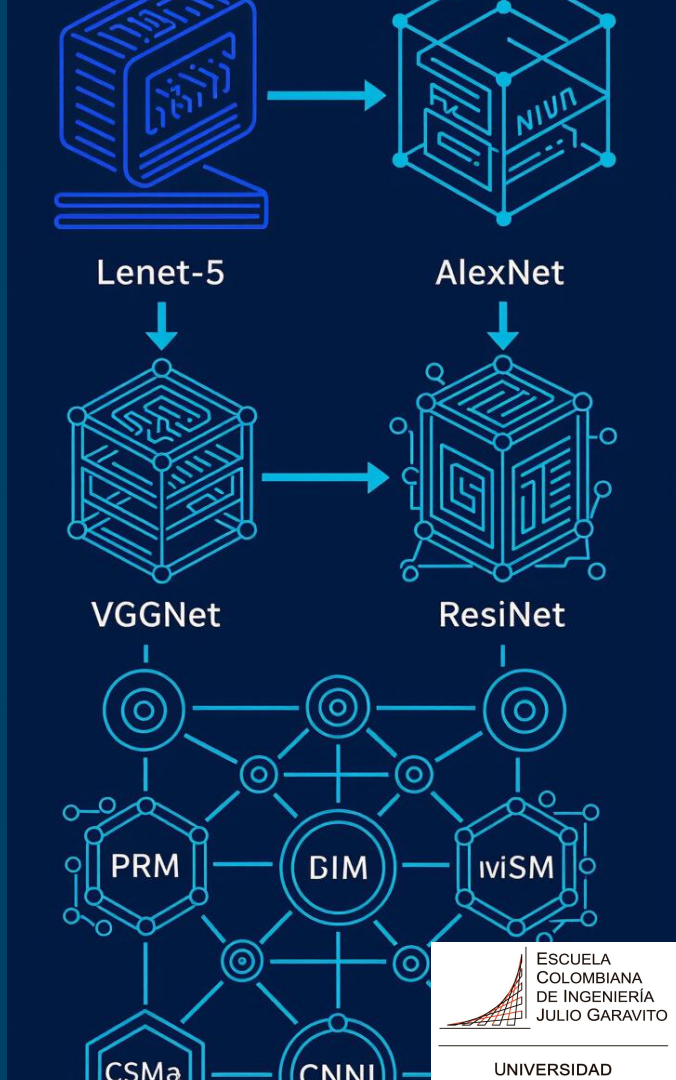
1. The **image passes through convolutional and pooling layers**.
2. Relevant **features are extracted**.
3. The **final layers classify the image**.
4. The **model learns by adjusting weights through backpropagation**.

Beyond Basic CNNs

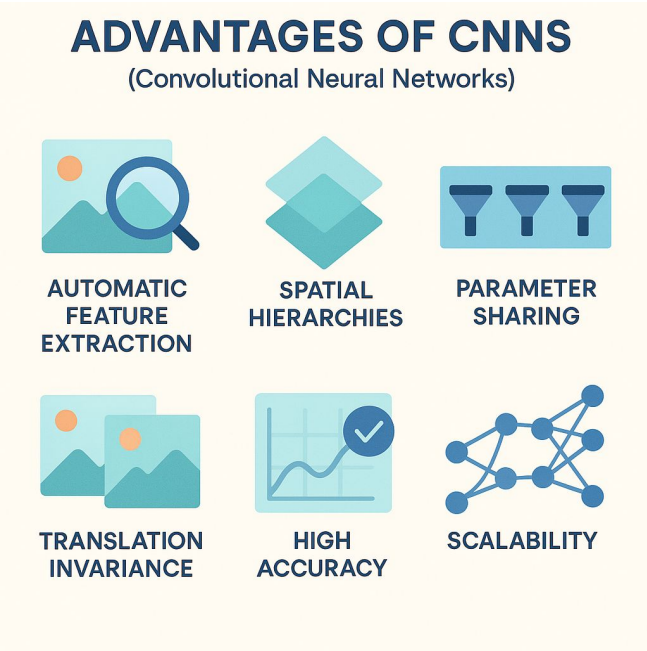
Modern CNNs include advanced architectures like:

- **LeNet-5** (early CNN for digit recognition)
- **AlexNet** (won ImageNet 2012, deeper and wider)
- **VGGNet** (uses small 3×3 filters, very deep)
- **ResNet** (introduces residual connections to train very deep networks)
- **Inception** (uses multi-scale convolutions in parallel)

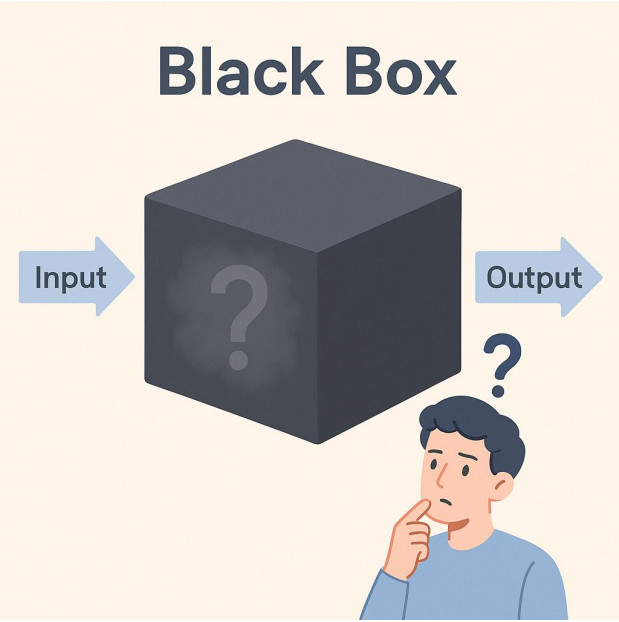
These models push the boundaries of accuracy and efficiency in computer vision tasks.



Advantages of CNNs



- **Automatic Feature Extraction**
  - Learn relevant patterns without manual engineering.
- **Parameter Efficiency**
  - Shared weights reduce the number of parameters.
- **Translation Invariance**
  - Detect patterns regardless of their position in the image.
- **Scalability**
  - Effective for high-dimensional inputs like images and videos.
- **Strong Performance**
- State-of-the-art results in computer vision tasks.



Disadvantages of CNNs

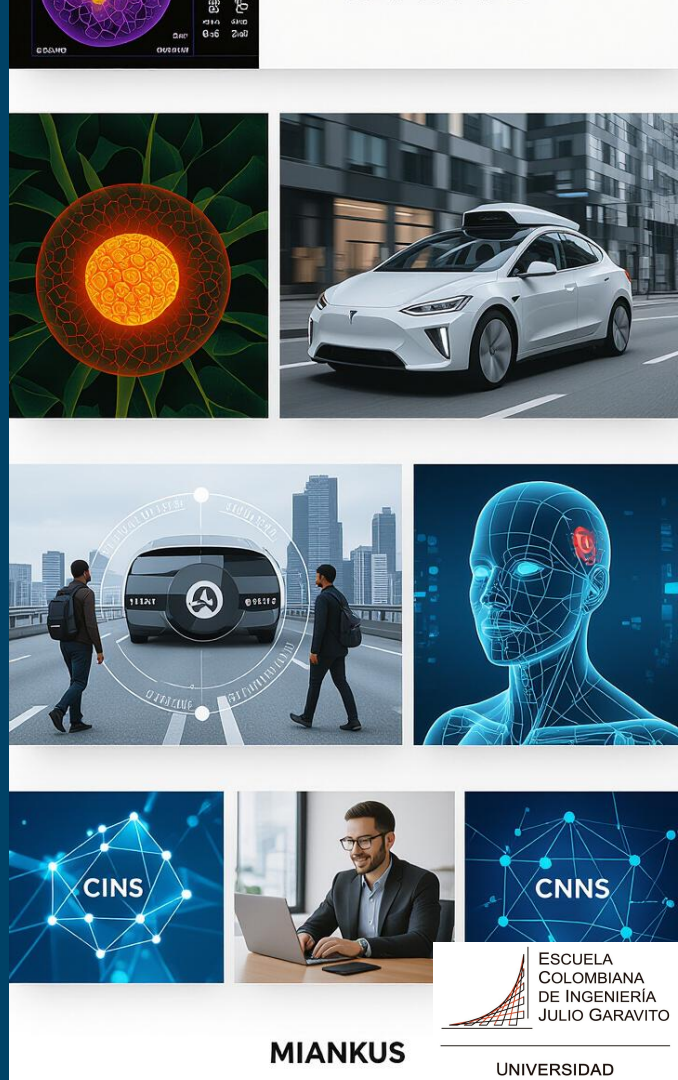
- **Require Large Amounts of Data**
  - Need extensive labeled datasets for good performance.
- **High Computational Cost**
  - Training can be slow and resource-intensive.
- **Limited to Grid-like Data**
  - Mainly designed for images or data with spatial structure.
- **Lack of Explainability**
  - Difficult to interpret how features are learned.
- **Overfitting Risk**
  - Can overfit when data is scarce or not diverse

Real-World Use Cases

CNNs are used in a wide range of applications:

- **Medical Imaging** (e.g., detecting tumors in MRI scans)
- **Autonomous Vehicles** (e.g., object detection, lane tracking)
- **Facial Recognition** (e.g., identity verification)
- **Art Generation** (e.g., style transfer and image synthesis)
- **Security** (e.g., surveillance and anomaly detection)

Their ability to learn from visual data makes them indispensable in modern AI systems.



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