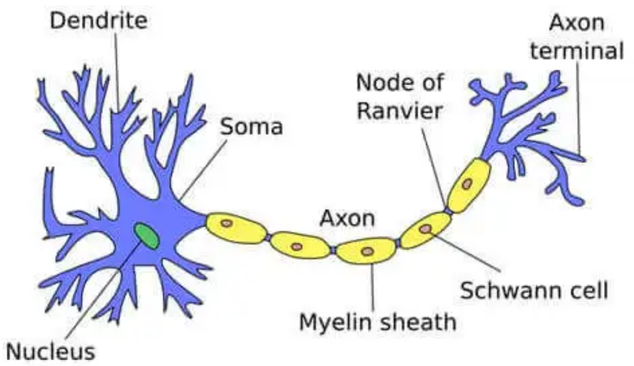
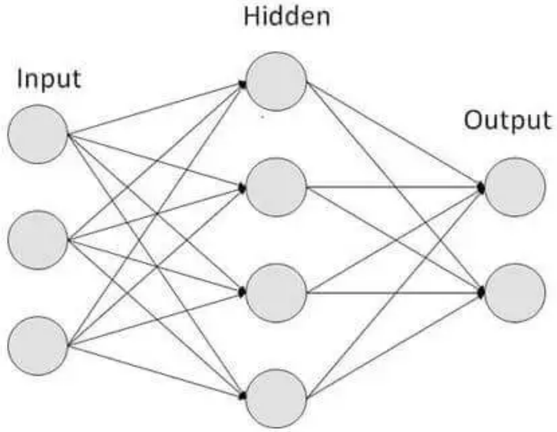
Convolutional Neural Networks (CNN)





Sharing Session - @SoramitsuKhmer

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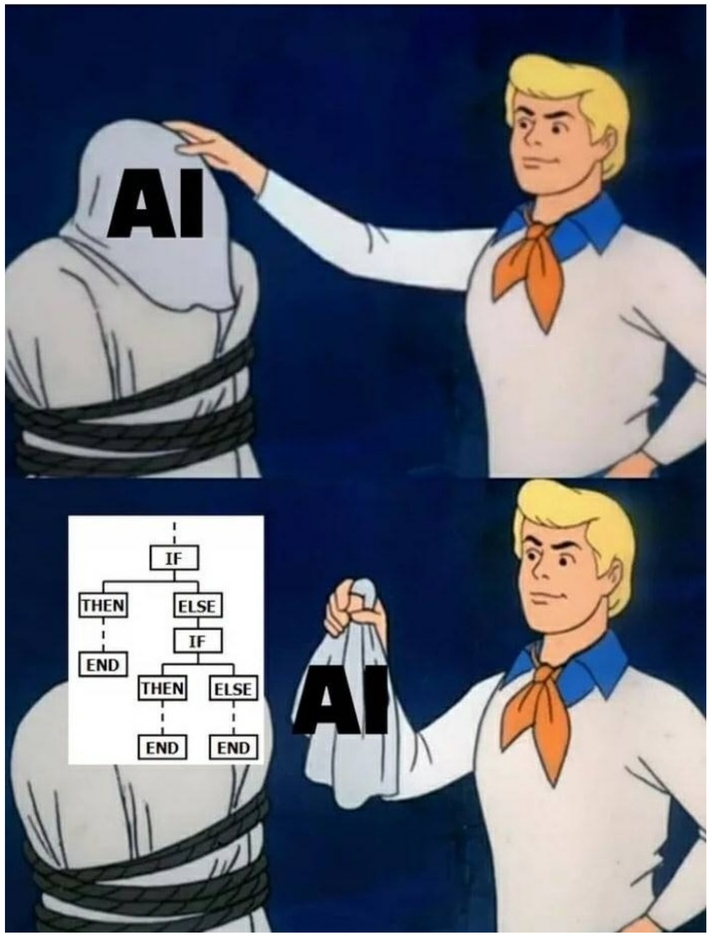
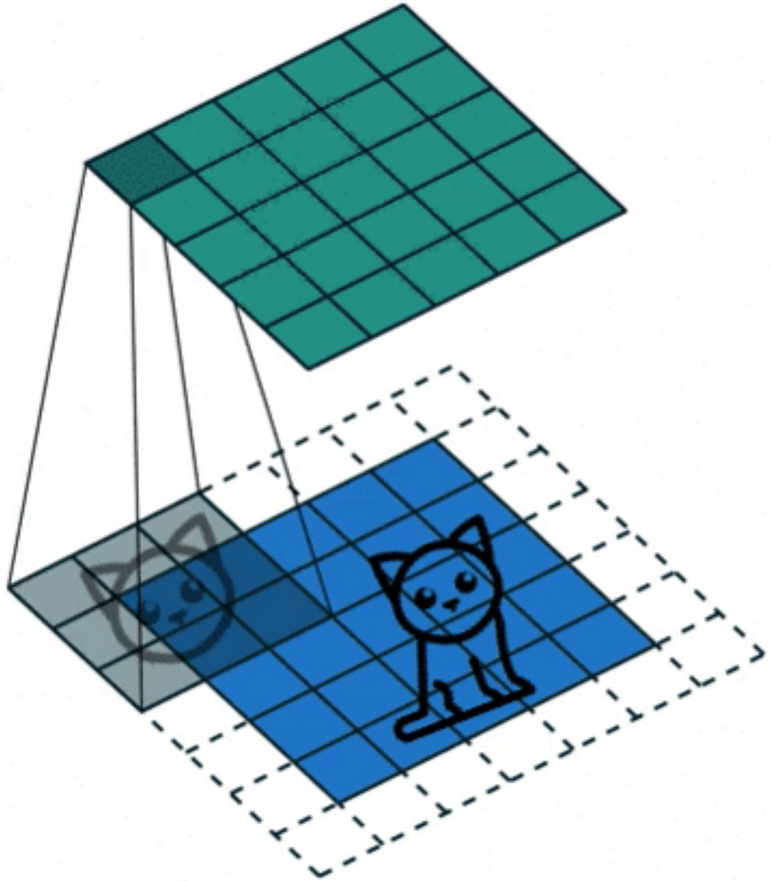
Goals

- Familiar with CNN terminology (know the keywords)
- Learn CNN without diving deep into the math
- Be able to implement basic CNN model



Agenda

1. Background
2. What is Neural Network?
3. What is CNN?
4. CNN Components
5. Coding Session



Background

Origins of Neural Networks

- **1958**: The **Perceptron**, developed by **Frank Rosenblatt**, was an early neural network model capable of learning simple binary classifiers. Due to its limited capacity to learn complex patterns and its inability to handle non-linearly separable data, led to the decline of research on perceptrons in the 1960s and 1970s.

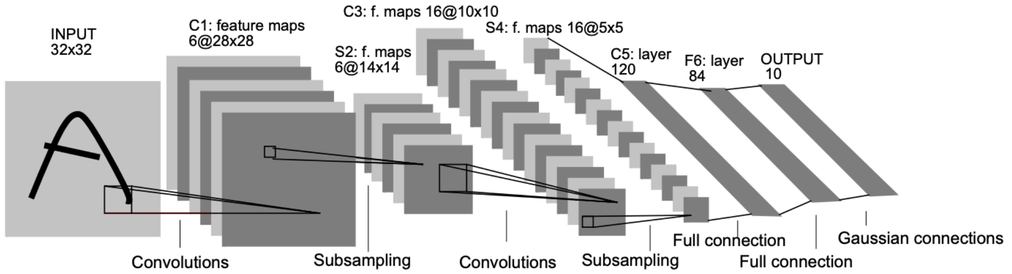
- **1986**: **Backpropagation** was popularized by **Rumelhart**, **Hinton**, and **Williams**, enabling multi-layer perceptrons (MLPs) to be trained more effectively. MLPs renewed interest in artificial neural networks and sparked a new era of research and innovation in machine learning.

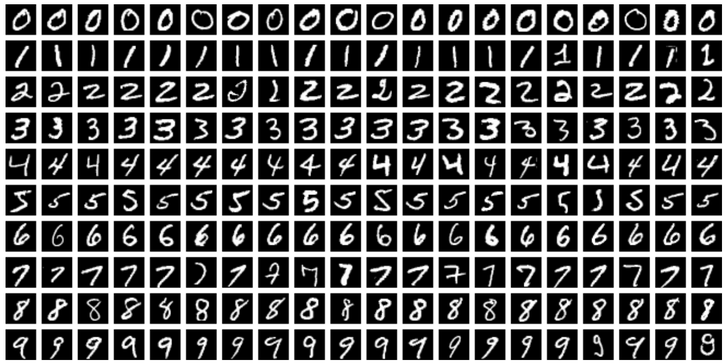
https://www.simplilearn.com/tutorials/deep-learning-tutorial/perceptron

Background

Birth of CNNs: LeNet-5

- In the late 1980s and 1990s, **Yann LeCun** introduced **LeNet-5**, one of the first convolutional neural networks.
- Used by the US Postal Service to read handwritten ZIP codes.
- Introduced weight sharing and local receptive fields, drastically reducing model complexity for image inputs.





http://vision.stanford.edu/cs598_spring07/papers/Lecun98.pdf

Background

Key Milestone: AlexNet (2012)

- **AlexNet** created by **Alex Krizhevsky**, with **Ilya Sutskever** and **Geoffrey Hinton** at the University of Toronto.
- Trained on **ImageNet** — a massive dataset with 1.2 million labeled images across 1000 categories.
- Utilized GPUs (**NVIDIA GTX 580**) to massively accelerate training.
- Introduced **ReLU**, **Dropout**, and **Data Augmentation** in a deep CNN architecture.
- Published as "**ImageNet Classification with Deep Convolutional Neural Networks**".
- **AlexNet** wasn't the first CNN, but it was the first to show deep CNNs can scale to real-world, large datasets and crush traditional methods. It marked the start of the **deep learning** era we're in today.

https://papers.nips.cc/paper_files/paper/2012/file/c399862d3b9d6b76c8436e924a68c45b-Paper.pdf

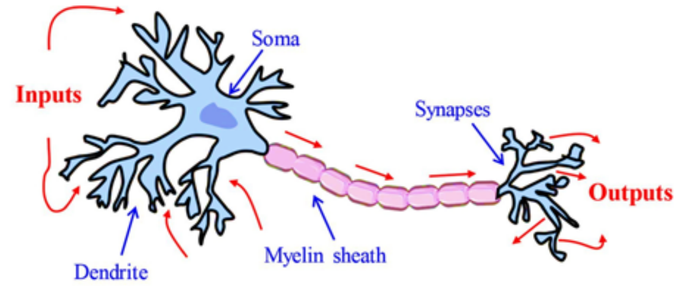
Background

Summary Timeline

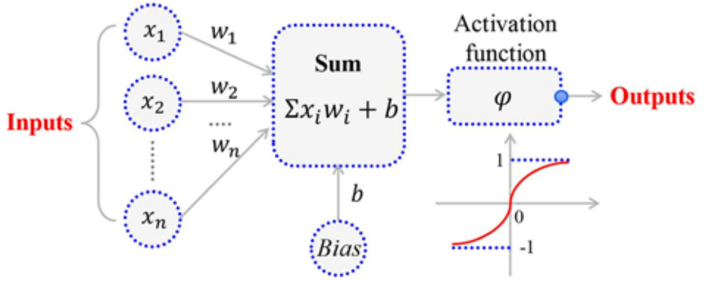
Year	Milestone	Contribution
1958	Perceptron	First artificial neuron model
1986	Backpropagation	Multi-layer training becomes feasible
1998	LeNet-5	First CNN for image classification
2012	AlexNet	CNN breakthrough on large-scale datasets

What is Neural Network?

- A neural network is a type of machine learning model inspired by the way the human brain works.
- **Neurons**: These are like tiny processors that receive input, do some math (like summing and applying an activation function), and pass the result to the next layer.
- **Input Layer**: Takes in the raw data (like pixels in an image).
- **Hidden Layers**: Do the heavy lifting—extracting patterns, features, and relationships.
- **Output Layer**: Produces the final result (like predicting a number or a category).
- **Weights & Biases**: Each connection between neurons has a weight (importance), and each neuron has a bias (a tweak factor). These are adjusted during training to improve accuracy.



(a) Biological neuron.

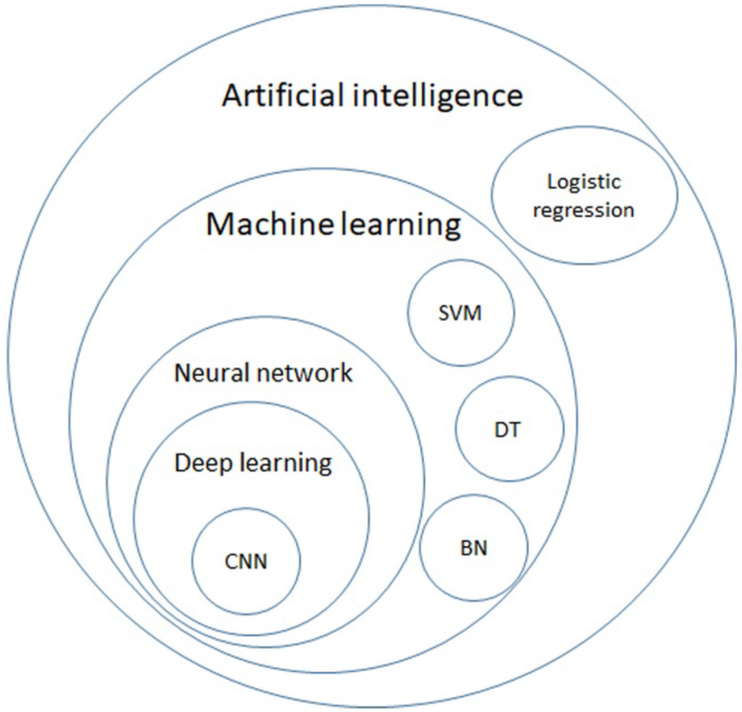


(b) Artificial neuron.

- Neural networks learn by adjusting weights and biases based on how wrong they are, using a process called **backpropagation** with **gradient descent**.

What is CNN?

- A **CNN** is a type of deep learning algorithm used primarily for image recognition, video analysis, natural language processing, and more.
- It's designed to automatically and adaptively learn patterns in data using layers like:
  - **Convolutional layers** – for detecting features like edges, textures, shapes.
  - **Pooling layers** – for reducing dimensionality and keeping important information.
  - **Fully connected layers** – for making final predictions or classifications.



Why Use CNNs for Images?

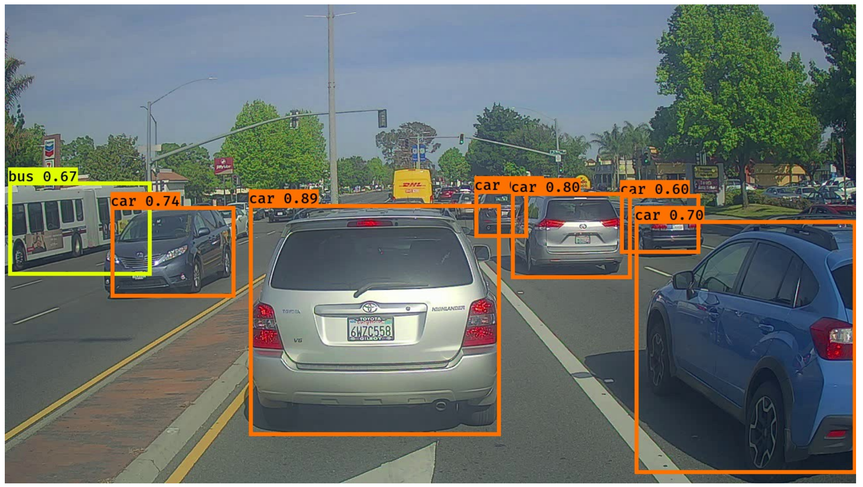
- **Regular Neural Networks (NNs)**:
  - Work fine for small data
  - Struggle with large images (millions of pixels)
  - Treat every pixel separately => Too many parameters
- **CNNs (Convolutional Neural Networks)**:
  - Look at small areas of the image (like scanning)
  - Use same filter across the image (Weight sharing)
  - Understand spatial patterns (e.g., edges, shapes)
  - Need far fewer parameters than NNs

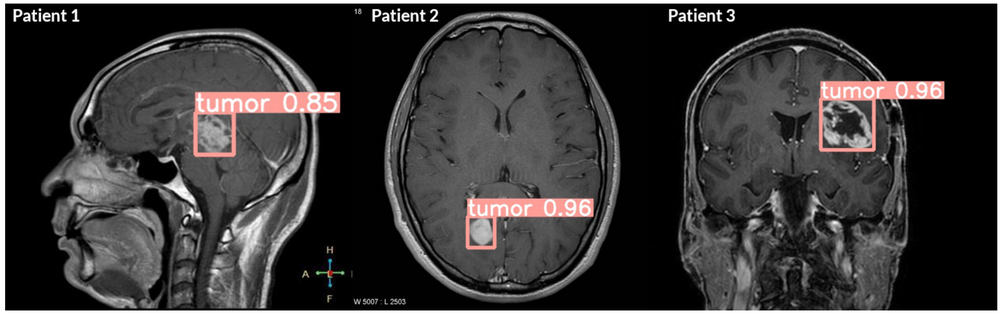
CNNs vs Regular Neural Networks (NNs)

🔍 Feature	🧠 Regular NNs	📷 CNNs (Convolutional NNs)
How they see images	Looks at all pixels separately	Looks at small parts at a time
Use of image structure	Doesn’t know nearby pixels are related	Understands nearby pixels go together
Number of connections	A lot (millions!)	Much fewer (shared weights)
Learning speed	Slow	Faster
Best for	Simple data (numbers, text)	Images, faces, objects, etc.

CNNs in the Real World

- Medical imaging (tumor detection)
- Autonomous driving (object/lane recognition)
- Face recognition
- Image search and recommendation
- Social media (auto-tagging, moderation)

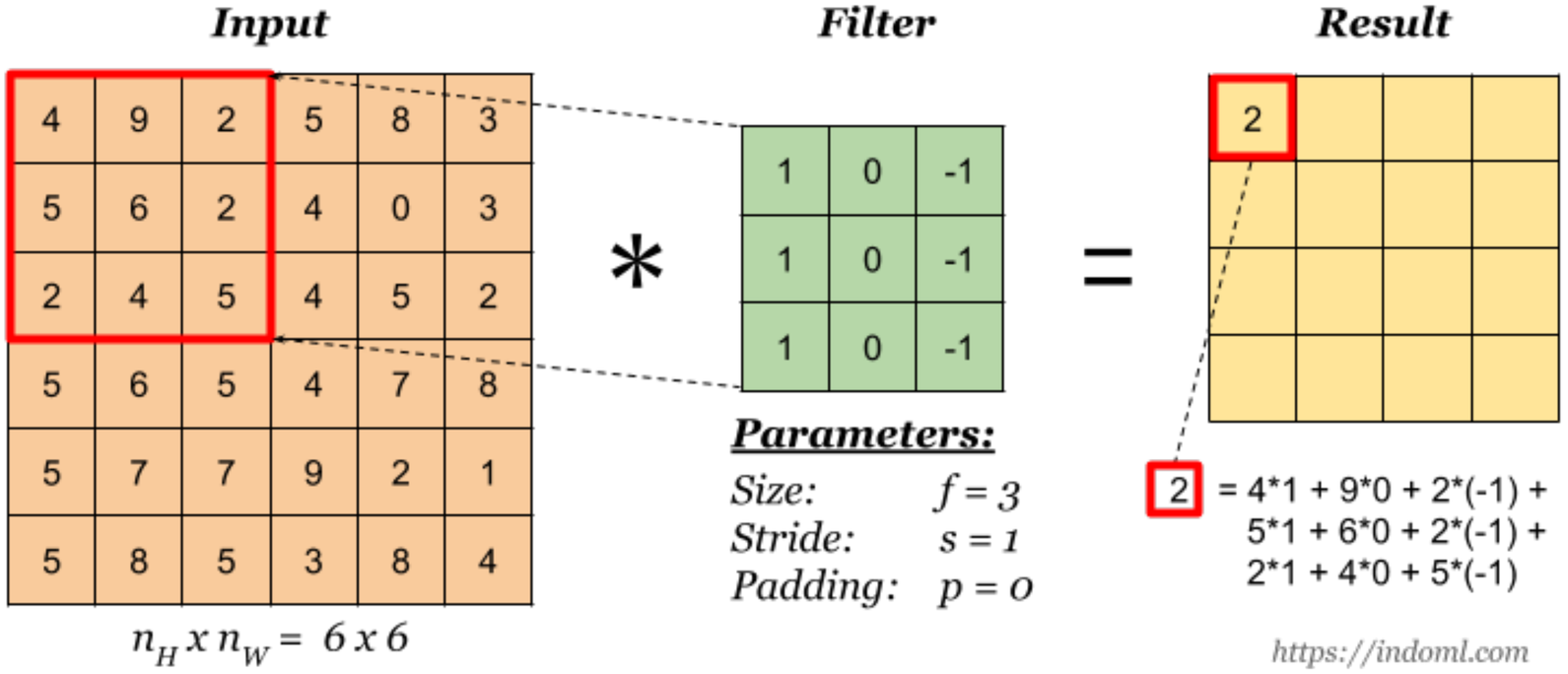




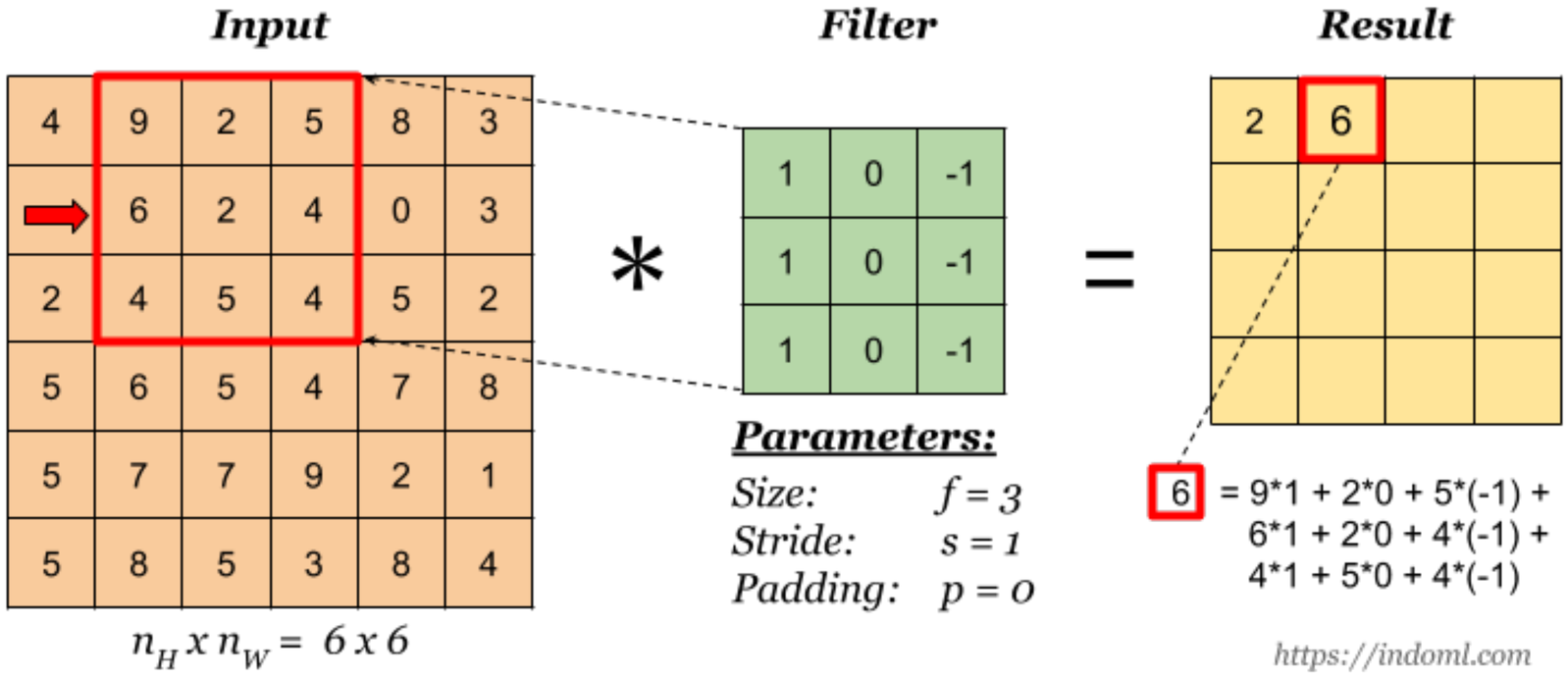
CNN Components

1. **Convolution Layer**
    - Applies filters to detect patterns (edges, textures)
2. **ReLU Activation**
    - Introduces non-linearity: ReLU(x) = max(0, x)
3. **Pooling Layer**
    - Downsamples input (typically with Max Pooling)
    - Reduces size, keeps essential features
4. **Fully Connected Layer**
    - Final classification layer using dense neurons

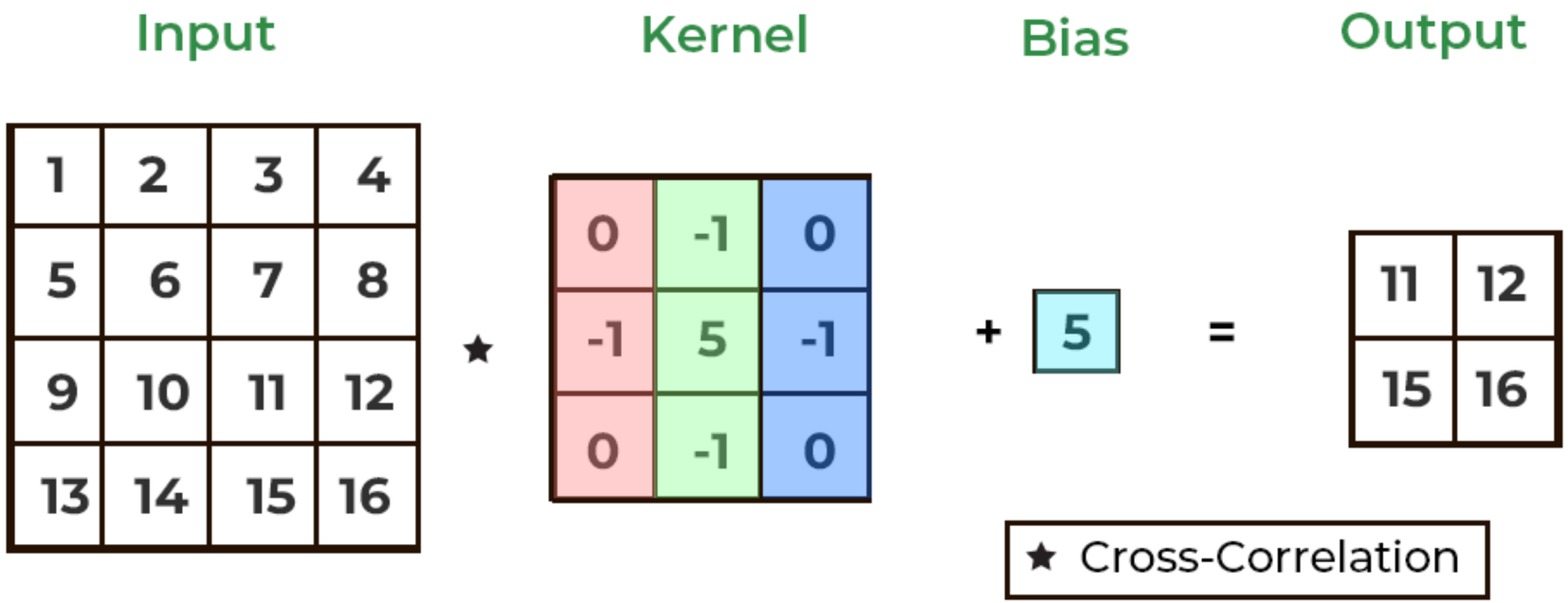
Convolution Operation



Convolution Operation



A Convolution Operation

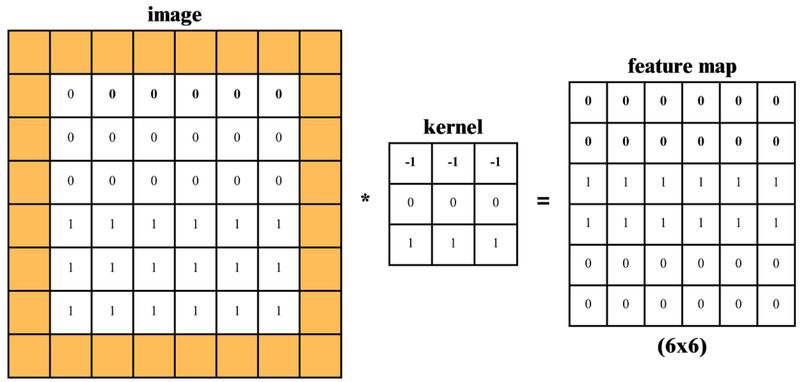


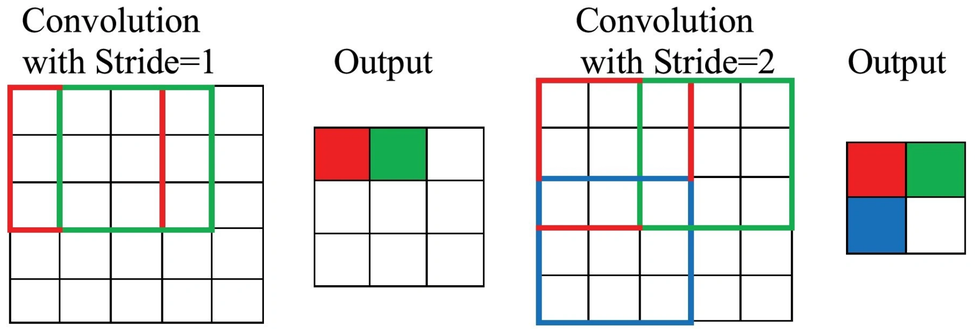
Padding and Strides in CNN

- In Convolutional Neural Networks (CNNs), **padding** and **strides** are important concepts that determine how the convolution operation is applied to an input, affecting the output size and how features are extracted.

- **Padding** refers to the process of adding extra pixels (usually zeros) around the border of the input image.

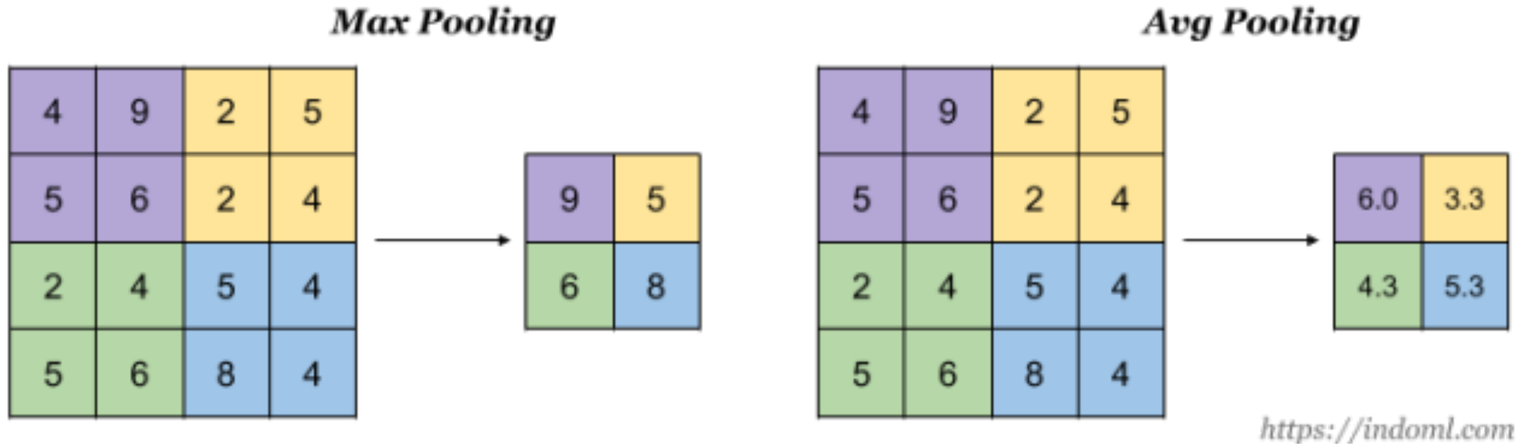
- **Strides** refer to the number of pixels by which the filter (or kernel) moves or slides across the input image.





Pooling Layer

- **Pooling layer** is used to reduce the size of the representations and to speed up calculations, as well as to make some of the features it detects a bit more robust.

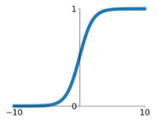


Activation Functions

- An activation function is a mathematical function applied to the output of a neuron. It introduces non-linearity into the model.
- Without activation functions, CNNs would be like a bunch of multiplication steps with no real "decision-making" ability.
- Activation functions help CNNs:
  - Detect non-linear patterns
  - Separate different classes better
  - Learn hierarchical features (edges, textures, shapes, objects)

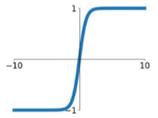
Sigmoid

$\sigma(x) = \frac{1}{1+e^{-x}}$



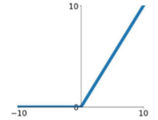
tanh

$\tanh(x)$



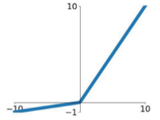
ReLU

$\max(0, x)$



Leaky ReLU

$\max(0.1x, x)$

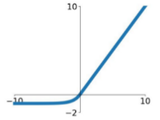


Maxout

$\max(w_1^T x + b_1, w_2^T x + b_2)$

ELU

$$\begin{cases} x & x \geq 0 \\ \alpha(e^x - 1) & x < 0 \end{cases}$$



Cost Function

- **Cost function** (also called a **loss function**) is a mathematical function that measures how well the CNN's predictions match the actual target values (i.e., the ground truth).

- It is used during training to guide the optimization process by providing feedback on how to adjust the model's parameters (weights and biases) to minimize errors.

- Purpose of the Cost Function
  - **Quantifies Error**: Tells us how far off the predictions are from the actual values.
  - **Optimization Target**: The goal of training is to minimize this cost.
  - **Backpropagation**: It's used to calculate gradients, which help update weights during backpropagation.

CNN as a Student

Activation Function = How the Student Thinks

- Think of the **activation function** as how the student **processes information** from a lesson.
  - A **linear** student just memorizes facts.
  - An **activated** student (using ReLU, sigmoid, etc.) can think critically, understand patterns, and make connections.

🧠 ***Why it's important:***

  - Without an activation function, the student can only learn in a straight line — simple input => simple output.
  - With it, they can handle complexity, like recognizing faces or reading emotions in photos.

CNN as a Student

Loss Function = The Student’s Grade

- The **loss function** is like the **score** the student gets on a test.
  - High loss? ❌ They made lots of mistakes.
  - Low loss? ✅ They're understanding the material.

🧠 ***Why it's important:***

  - The student needs feedback to know how well they’re doing. The loss function tells them exactly where and how much they went wrong.

CNN as a Student

Optimization = The Study Plan

- **Optimizer** is the **study strategy** or **tutor** that helps the student improve based on their grades (**loss**).
  - If they keep getting a question wrong, the tutor adjusts how they study it.
  - Strategies like SGD or Adam are different tutoring methods — some learn steadily, some adapt fast.

🧠 ***Why it's important:***

  - Without optimization, the student would just keep taking tests and failing without improving. Optimization makes learning happen.

Coding Session

https://github.com/ishinvin/cnn-demo

Thanks!

Q & !A