Introduction to Neural Networks

Data Mining & Neural Networks

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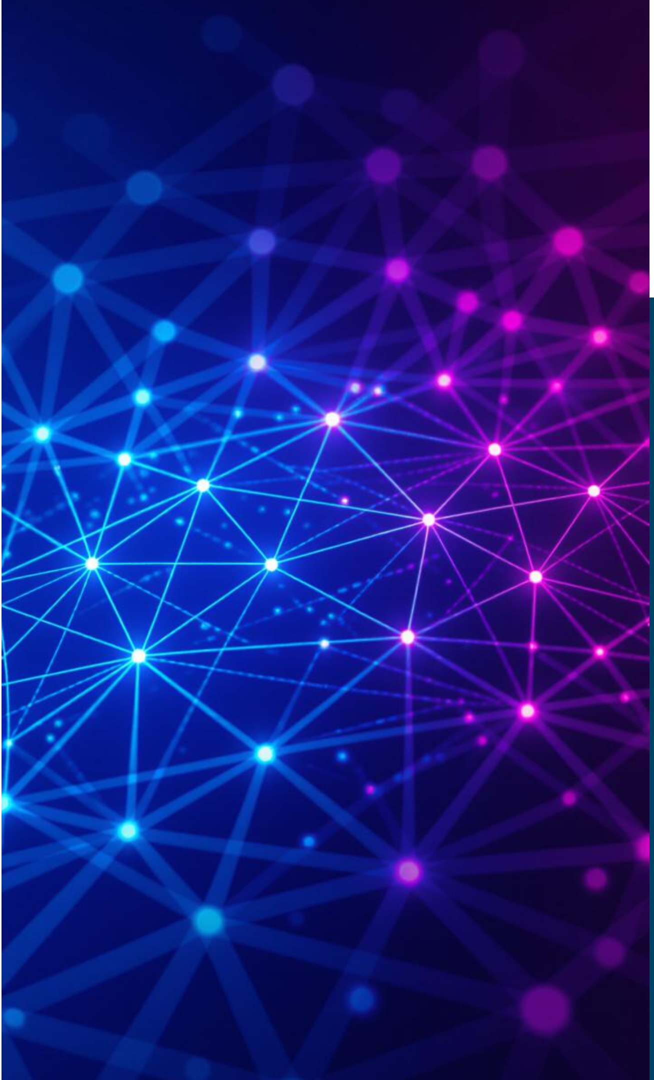

Introduction to Neural Networks

- We will explore the foundational **concepts of neural networks**, their biological inspiration, architecture, learning mechanisms, and real-world applications.
- Neural networks are a cornerstone of modern artificial intelligence and are widely used in data mining, computer vision, natural language processing, and more.

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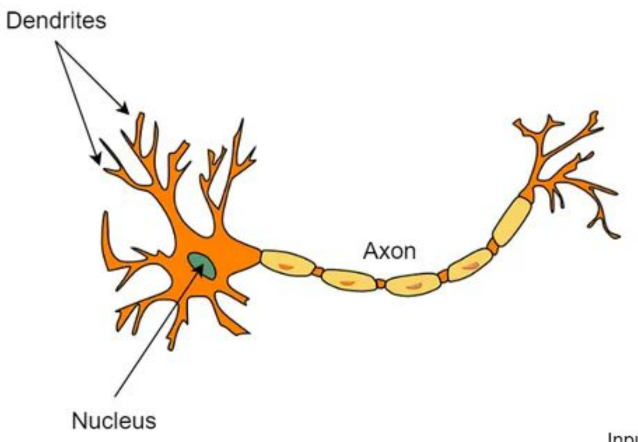
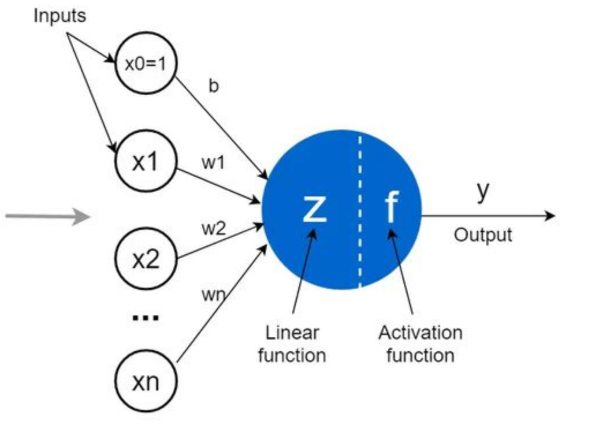
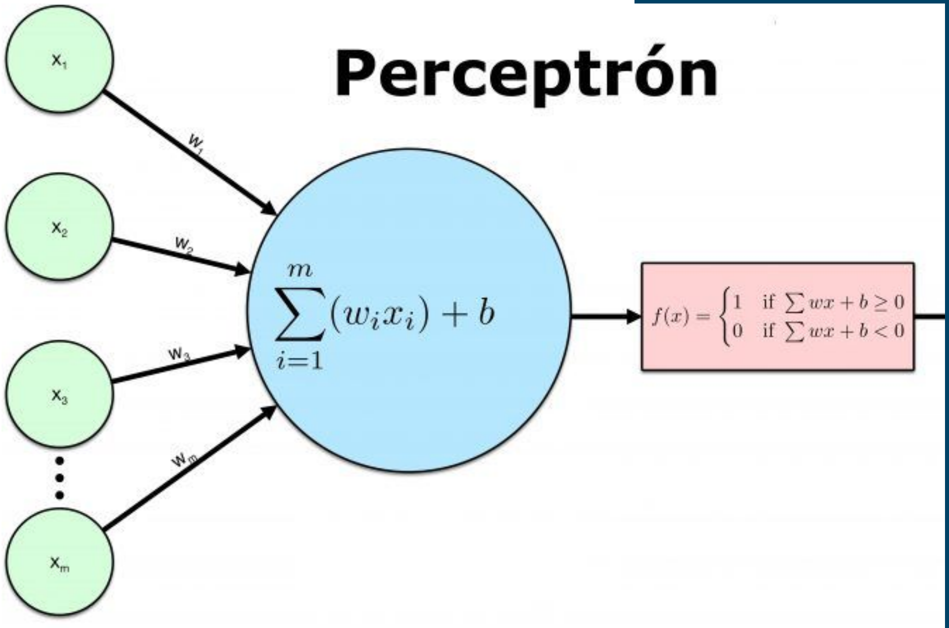


What is a Neural Network?

- NN is a computational model inspired by the structure and function of the **human brain**.
- It consists of layers of **interconnected nodes** (neurons)
- Process information by responding to inputs and transmitting signals.



What is a perceptron?



- The perceptron is the **simplest type of** ANN
- It models **single neuron** makes binary decisions
- Takes multiple **inputs (e.g., x_1, x_2, x_3)**, each with an associated **weight (w_1, w_2, w_3)**
- Computes a **weighted sum of the inputs**
- Passes the **result through an activation function**
- Outputs either **0 or 1** depending on the threshold

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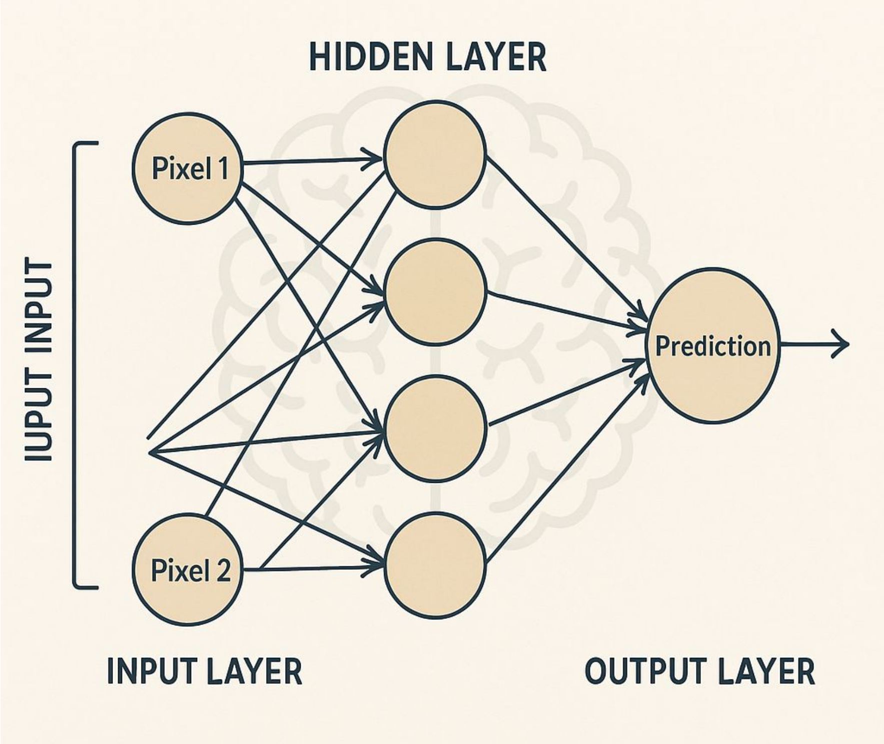
Architecture of a Neural Network



- Composed of layers of interconnected nodes called neurons
- **Input layer** receives raw data (e.g., pixels, features)
- **Hidden layers** process data through weighted connections and activation functions
- **Output layer** generates predictions or classifications
- Learns patterns from data through training (e.g., backpropagation)

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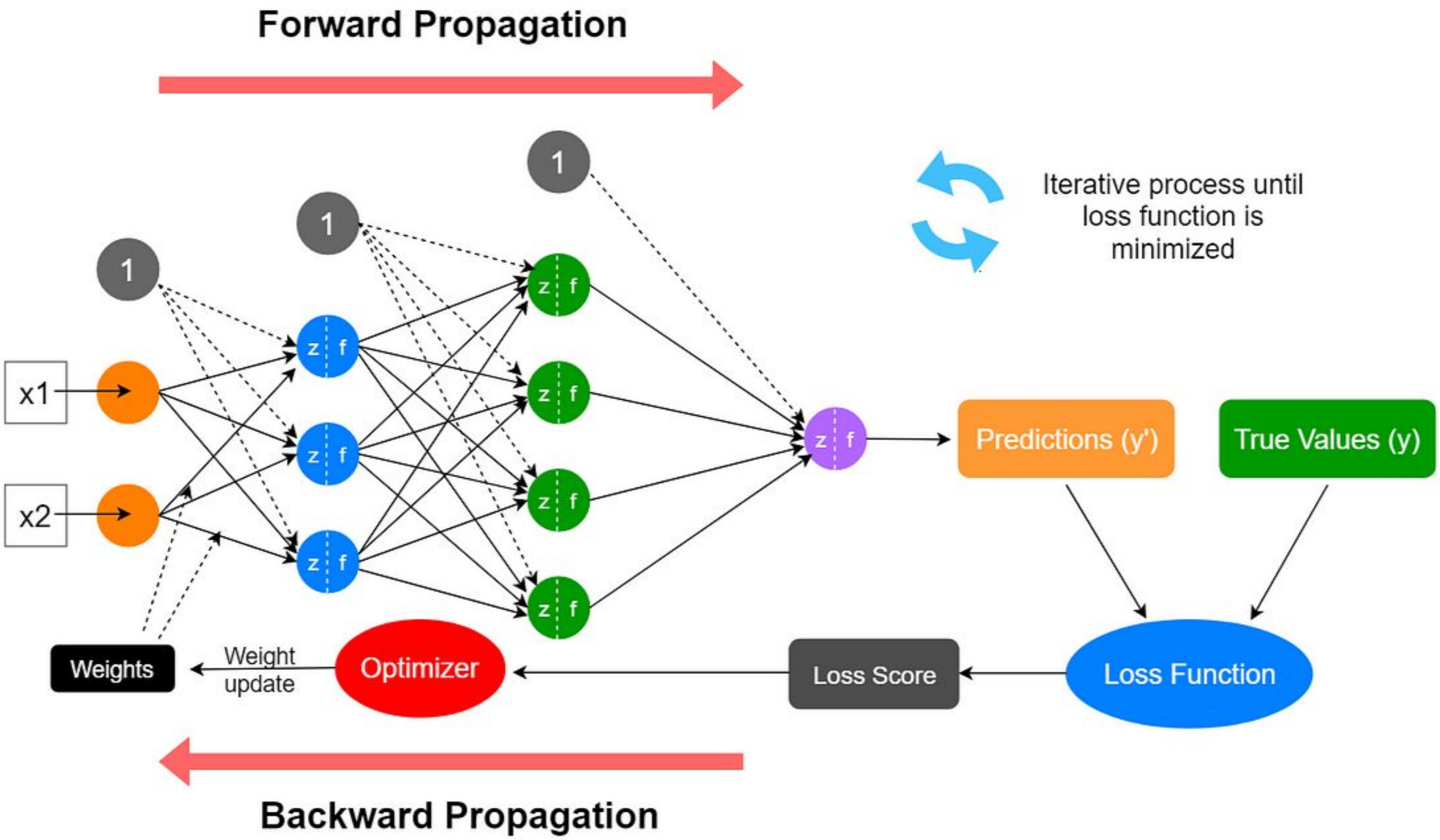
How Do Neural Networks Learn?



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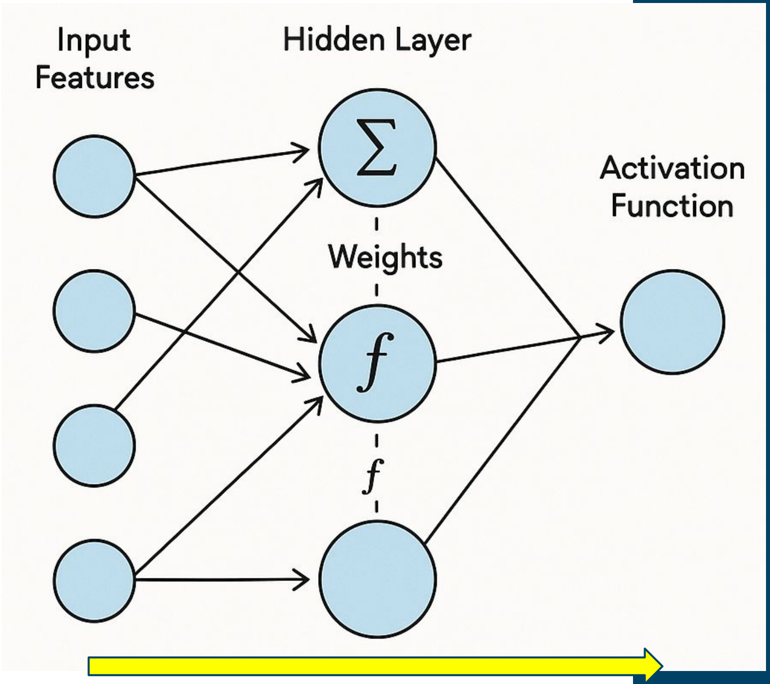
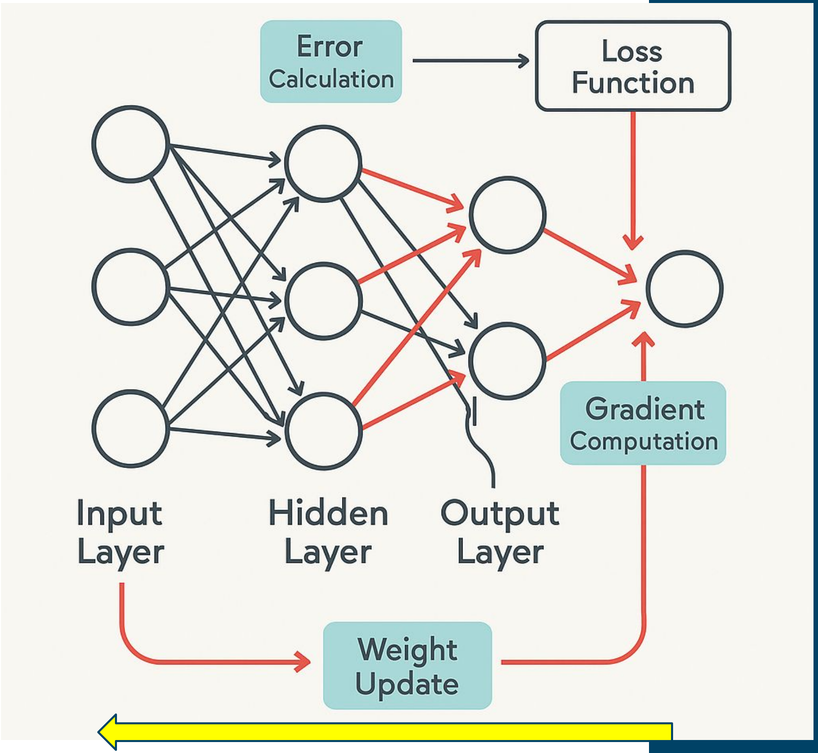
Forward Propagation



- Forward propagation is the process by which **input data** is passed **through the network** to **generate an output**.
- Each **neuron receives inputs**, multiplies them by weights, adds a bias, and applies an **activation function**.
- The result is passed to the next layer, continuing until the output layer.
- The **final output** is compared to the **true label** to compute the error (used later in **backpropagation**).
- **No learning happens here, just computation.**

Backward Propagation



- The process of **updating weights in a neural network** based on the error from the output
- Starts by calculating the **loss**, difference **between predicted and actual output**
- The error is propagated backward through the network
- **Gradients** are computed for each **weight** to determine how much they contributed to the error
- **Weights are updated using gradient descent to minimize the loss**
- This process is repeated over **many iterations (epochs) to improve accuracy**

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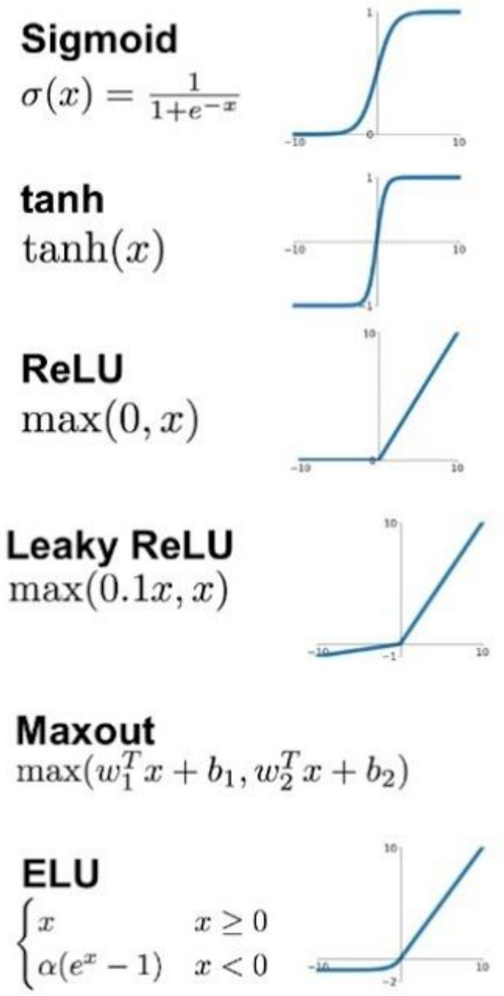

Activation Functions

AFs introduce non-linearity into the network, enabling it to learn complex relationships:

- **Sigmoid:** Outputs values between 0 and 1. Useful for binary classification.
- **Tanh:** Outputs values between -1 and 1. Zero-centered.
- **ReLU (Rectified Linear Unit):** Outputs 0 for negative inputs and the input itself for positive values.
- **Softmax:** Converts outputs into probabilities for multi-class classification.

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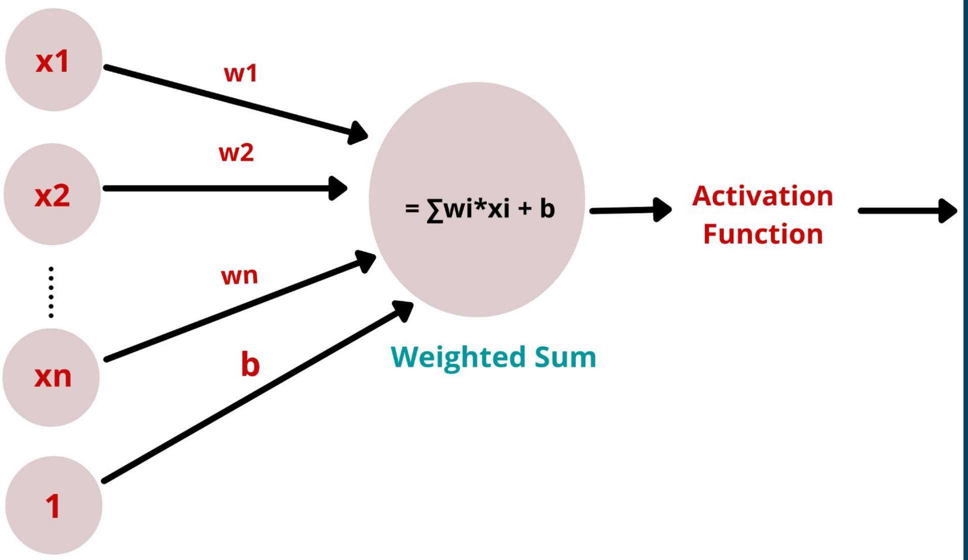
Activation Functions



- Each neuron receives multiple inputs **(x_1,x_2,...,x_n)**, each multiplied by a corresponding weight **(w_1,w_2,...,w_n)**.
- The neuron computes a weighted sum of these inputs plus a bias term:

$$z = w_1 x_1 + w_2 x_2 + \dots + w_n x_n + b$$

- This value ***z*** is passed through an ***AF(z)***, which transforms it into the neuron's output: ***a=AF(z)***
- This output ***a*** becomes the input for the next layer in the network

Real-World Applications

Neural networks are used in various domains:

- **Healthcare:** Disease diagnosis, medical imaging analysis.
- **Finance:** Fraud detection, credit scoring, algorithmic trading.
- **Retail:** Customer segmentation, recommendation systems.
- **Transportation:** Autonomous vehicles, traffic prediction.
- **Agriculture:** Crop disease detection, yield prediction.
- **Education:** Adaptive learning platforms, automated grading.
- **Cybersecurity:** Intrusion detection, malware classification.

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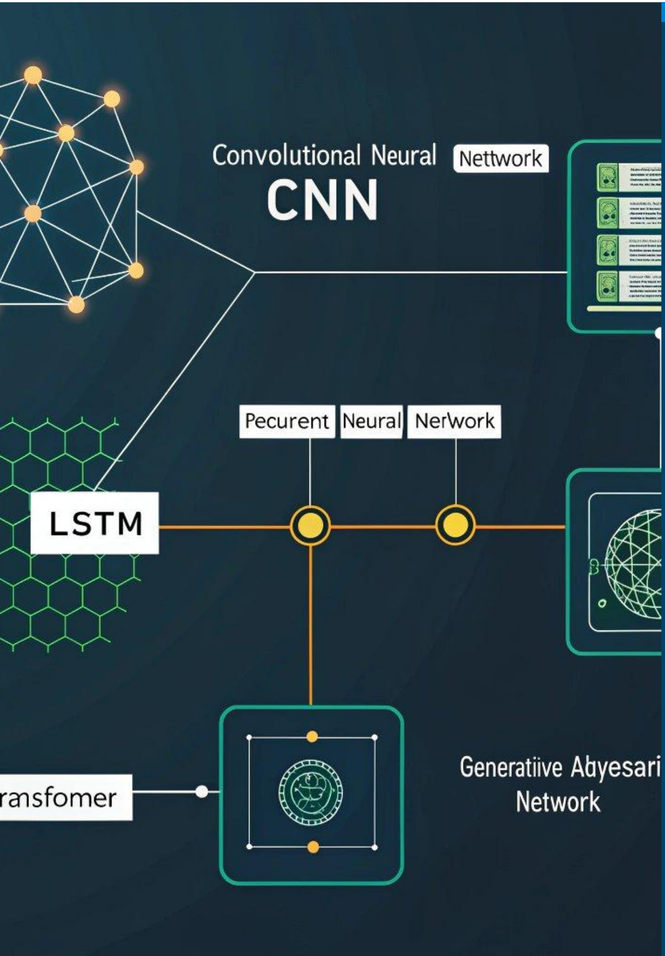

Advanced Architectures

- **Convolutional Neural Networks (CNNs):** Used for image and video processing.
- **Recurrent Neural Networks (RNNs):** Designed for sequential data like time series and text.
- **Long Short-Term Memory (LSTM):** A type of RNN that handles long-term dependencies.
- **Generative Adversarial Networks (GANs):** Used for generating realistic data.
- **Transformers:** State-of-the-art models for NLP tasks.

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Challenges and Limitations

Neural networks **have limitations**:

- Require **large amounts** of labeled data.
- **Computationally intensive** and require powerful hardware.
- Prone to overfitting if not properly regularized.
- **Lack interpretability – often considered "black boxes."**

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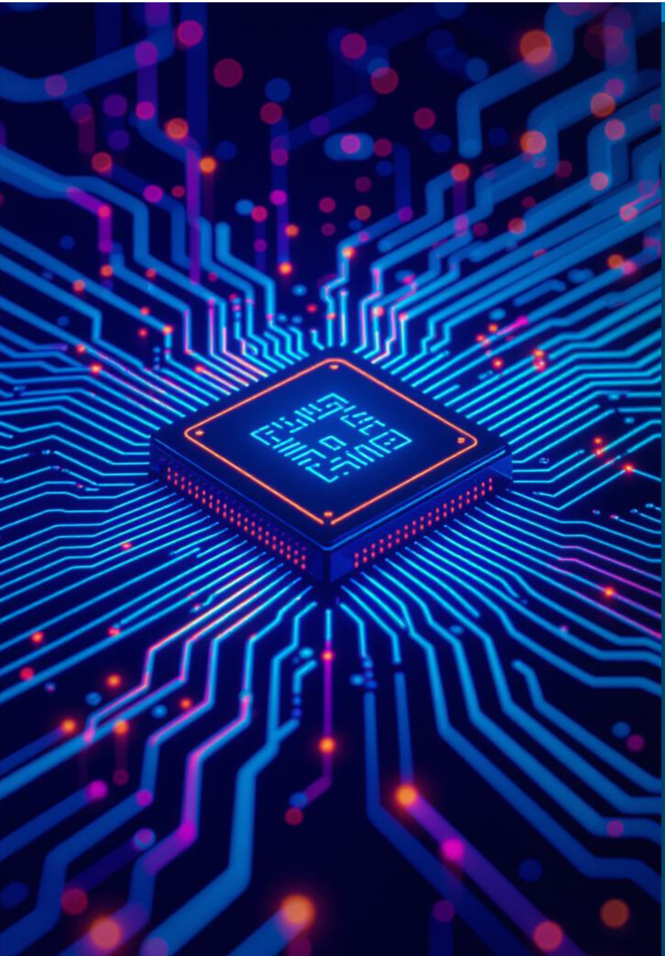

Tools and Frameworks

Popular tools for building neural networks include:

- **TensorFlow:** Developed by Google, supports deep learning and deployment.
- **PyTorch:** Developed by Facebook, known for flexibility and ease of use.
- **Keras:** High-level API for building and training models.
- **Scikit-learn:** Useful for simpler models and preprocessing.

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Case Study 1 - Voice Assistants

- Voice assistants like Siri, Alexa, and Google Assistant use **neural networks to understand and respond to user queries.**
- They process audio input using speech recognition models, interpret intent using **NLP models, and generate responses using language models.**
- These systems continuously learn from **user interactions to improve accuracy and personalization.**

Case Study 2 - Autonomous Vehicles

- Self-driving cars **rely on neural networks for perception, decision-making, and control.**
- CNNs are used to detect **objects like pedestrians and traffic signs.**
- RNNs help **predict the movement of other vehicles.**
- These systems are trained on massive datasets collected from real-world driving.

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Example - Handwritten Digit Recognition

- An example of ANN in action is the MNIST dataset, contains 70,000 images of handwritten digits (0–9).
- A neural network can be trained to recognize these digits with high accuracy.
- The input layer receives pixel values, hidden layers extract features like edges and curves, and the output layer predicts the digit.
- This application is widely used in postal services and banking.

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