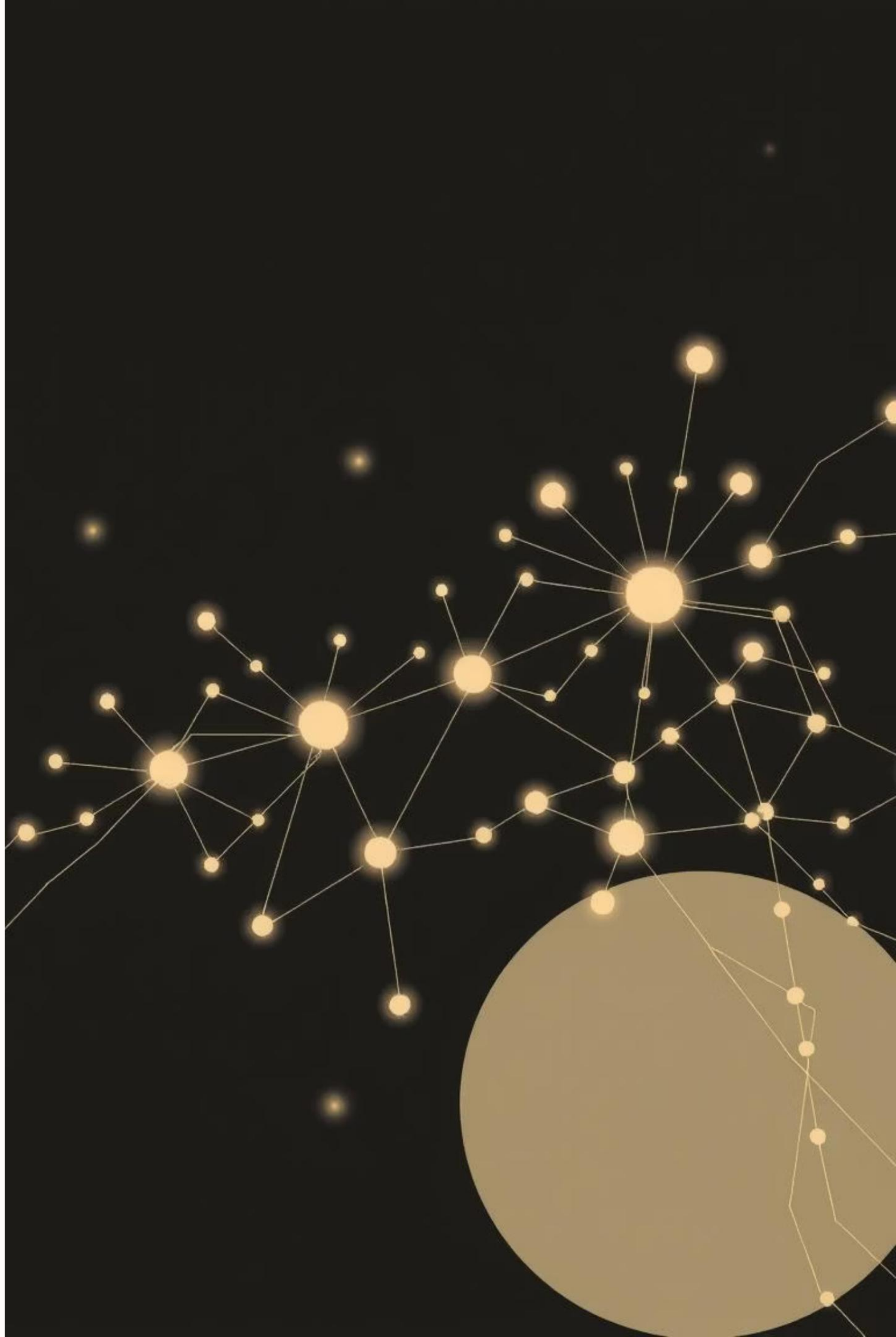
Chapter 6

Understanding Neural Networks

Explore the fascinating world of neural networks, from their biological inspiration to their powerful applications in AI.



Key Concepts:

1. Parts of a neural network.

2. Components of a neural network.

3. Working of a neural network.

4. Types of neural networks, such as feedforward, convolutional, and recurrent.

5. Impact of neural network on society.

What is a Neural Network?

A neural network is an AI model mimicking the human brain's decision-making process. It adapts to changing inputs, automatically extracts data features, and generates optimal outcomes.

Human Brain Inspiration

"Neural" comes from neurons, the brain's basic units for processing and transmitting information.

AI Adaptation

AI embeds similar neuron behavior into Artificial Neural Networks (ANNs) for adaptive learning.

Neural Network Architecture

Every neural network consists of interconnected layers: an input layer, hidden layer(s), and an output layer.

- **Input Layer:** Units representing input fields/features.
- **Hidden Layers:** One or more layers between input and output, processing data with weighted connections.
- **Output Layer:** Units representing target fields, generating final predictions.

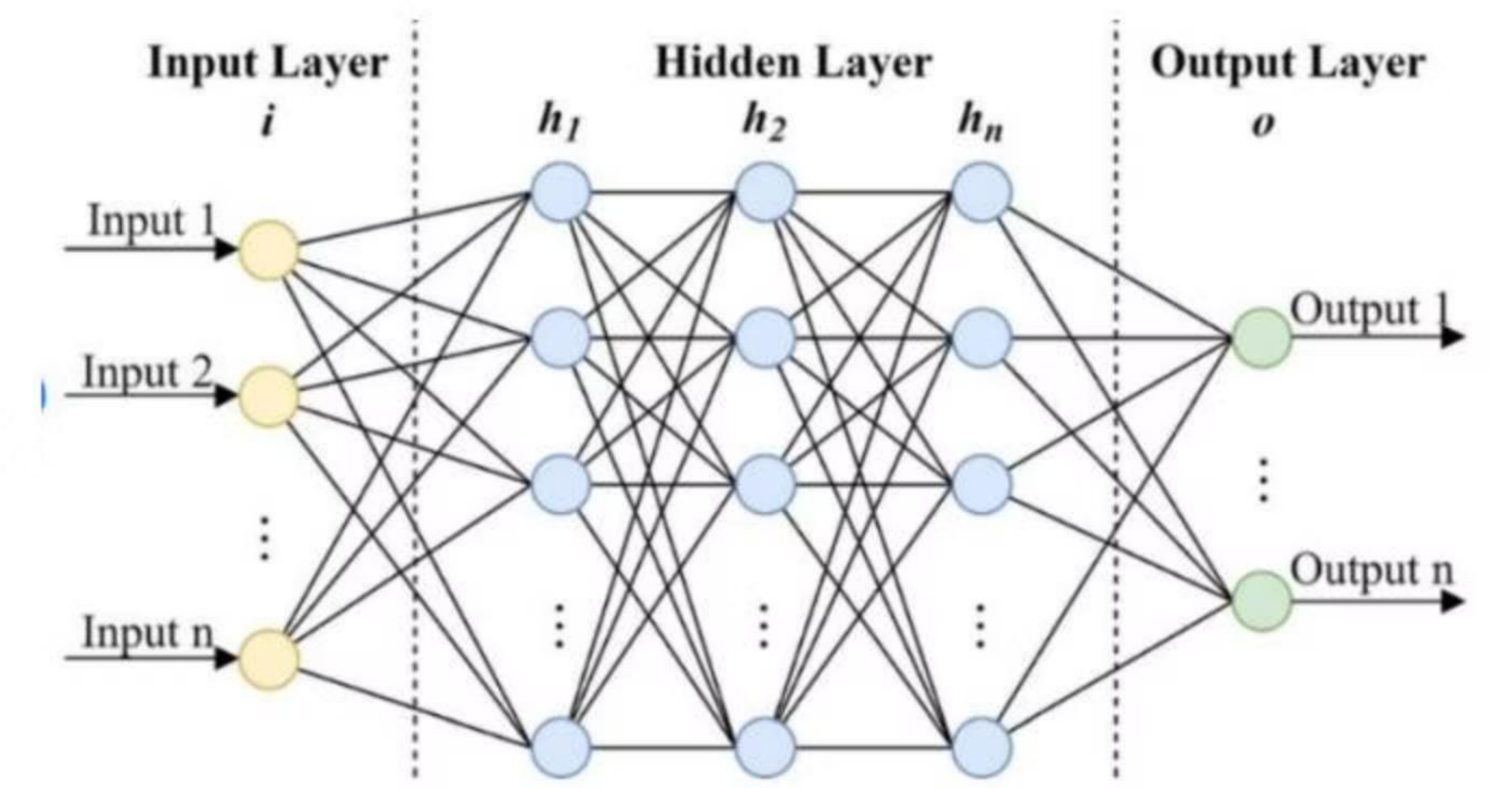


Fig 6.1 Layers of Neural Network

Key Components of a Neural Network

Neurons

Fundamental building blocks that process inputs and produce outputs.

Weights

Represent connection strength between neurons, learned during training.

Activation Functions

Decide if a neuron activates, adding non-linearity for complex pattern learning.

Bias

Constants added to weighted sums, shifting activation functions.

Connections

Synapses between neurons with associated weights and biases.

Learning Rule

Specifies how weights and biases are adjusted during training.

How Neural Networks Learn

Neural networks learn by adjusting weights and biases through propagation functions.

1

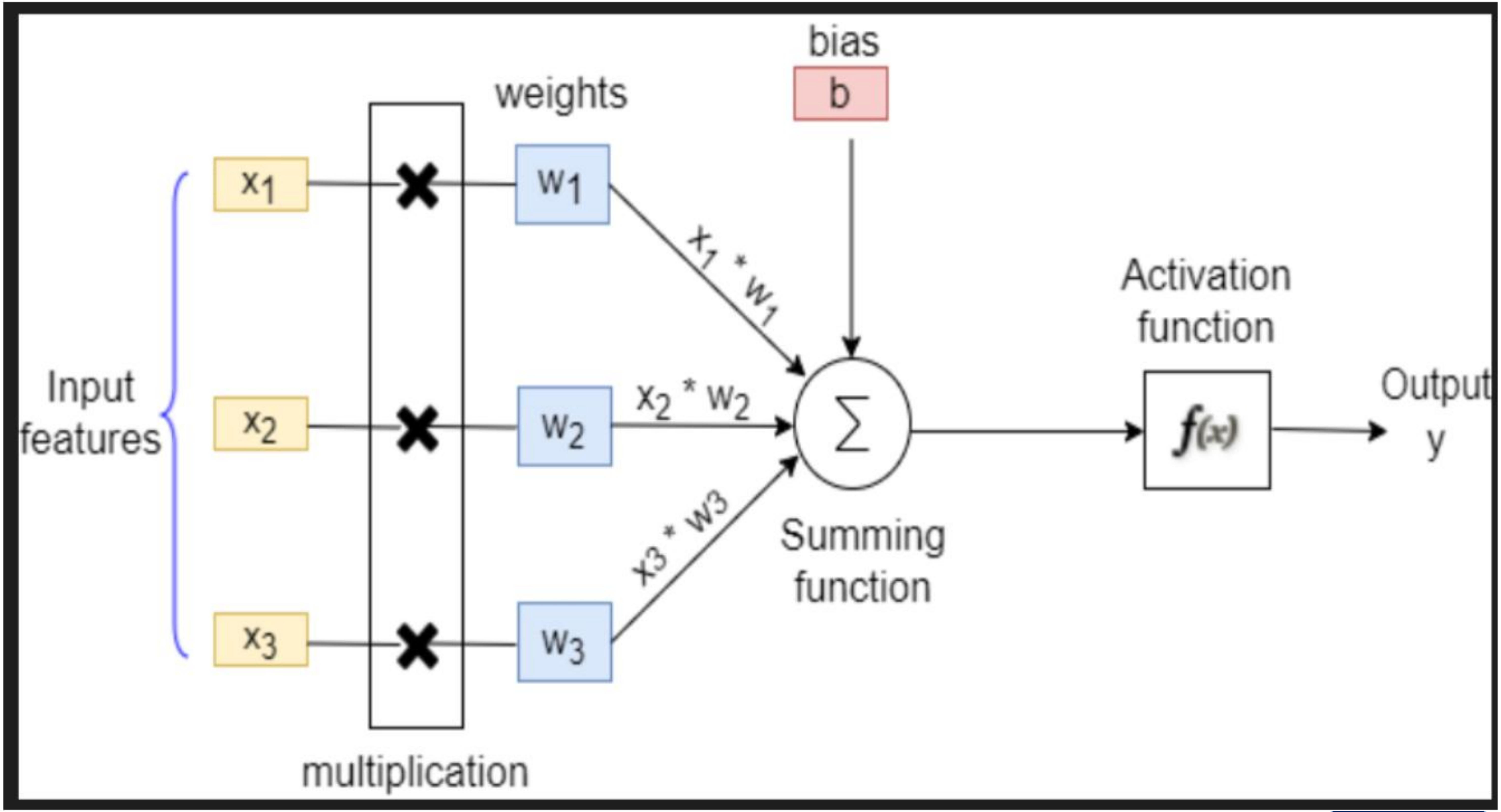
Forward Propagation

Input data flows through layers, activations are computed, and predicted output is compared to actual target, resulting in an error.

2

Backpropagation

Adjusts network weights based on the error rate from the previous iteration, improving prediction accuracy over time.


bias
b
weights
x1
x2
x3
w1
w2
w3
x1 * w1
x2 * w2
x3 * w3
Input
features
Activation
function
f(x)
Output
y
Summing
function
multiplication

$$\boxed{\sum wixi + bias = w1x1 + w2x2 + w3x3 + bias}$$

$$\text{output} \rightarrow \begin{cases} f(x) = 1, & \text{if } \sum w1x1 + b >= 0; \\ f(x) = 0, & \text{if } \sum w1x1 + b < 0 \end{cases}$$

Let us see a simple problem.
CASE I: Let the features be represented as $x1$, $x2$ and $x3$.
Input Layer:
Feature 1, $x1 = 2$
Feature 2, $x2 = 3$
Feature 3, $x3 = 1$
Hidden Layer: Weight 1, $w1 = 0.4$ Weight 2, $w2 = 0.2$ Weight 3, $w3 = 0.6$ bias = 0.1 threshold = 3.0

Output: Using the formula:
$\sum wixi + bias = w1x1 + w2x2 + w3x3 + bias = (0.4*2) + (0.2*3) + (0.6*1) + 0.1$
$= 0.8 + 0.6 + 0.6 + 0.1 = 2.1$

Now, we apply the threshold value: If output > threshold, then output = 1 (active)
If output < threshold, then output = 0 (inactive) In this case:
Output (2.1) < threshold (3.0)
So, the output of the hidden layer is: Output = 0
This means that the neuron in the hidden layer is inactive.

CASE II

Let's say we have another neuron in the output layer with the following weights and bias:

w1 = 0.7 w2 = 0.3 bias = 0.2

The output of the hidden layer (0) is passed as input to the output layer:

Output = w1_x1 + w2_x2 + bias

= 0.7_0 + 0.3_0 + 0.2

= 0.2

Let's assume the threshold value for the output layer is 0.1: Output (0.2) > threshold (0.1)

So, the final output of the neural network is:

Output = 1

We can now apply this concept to a more tangible example: -

*Imagine you are standing on the shore, contemplating whether to go for surfing or not. You glance out at the ocean, assessing the conditions. Are the waves big and inviting? Is the line-up crowded with fellow surfers? And perhaps most importantly, has there been any recent shark activity? Using Neural Network concept decide **"Whether you should go for surfing or not"***
Note: The decision to go or not to go is our predicted outcome, ŷ or y-hat. (The estimated or predicted values in a regression or other predictive model are termed the ŷ.)
If Output is 1, then Yes (go for surfing), else 0 implies No (do not go for surfing)

Solution:

1. Let us assume that there are three factors influencing your decision-making:
- Are the waves good? (Yes: 1, No: 0)
- Is the line-up empty? (Yes: 1, No: 0)
- Has there been a recent shark attack? (Yes: 0, No: 1)

2. Then, let us assume the following, giving us the following inputs:
- X1 = 1, since the waves are pumping
- X2 = 0, since the crowds are out
- X3 = 1, since there has not been a recent shark attack

3. Now, we need to assign some weights to determine importance. Larger weights signify that particular variables are of greater importance to the decision or outcome.
- W1 = 5, since large swells do not come often
- W2 = 2, since you are used to the crowds
- W3 = 4, since you have a fear of sharks

Factor	Input	Weight
Wave Quality	1	5
Lineup Congestion	0	2
Any Shark Activity	1	4

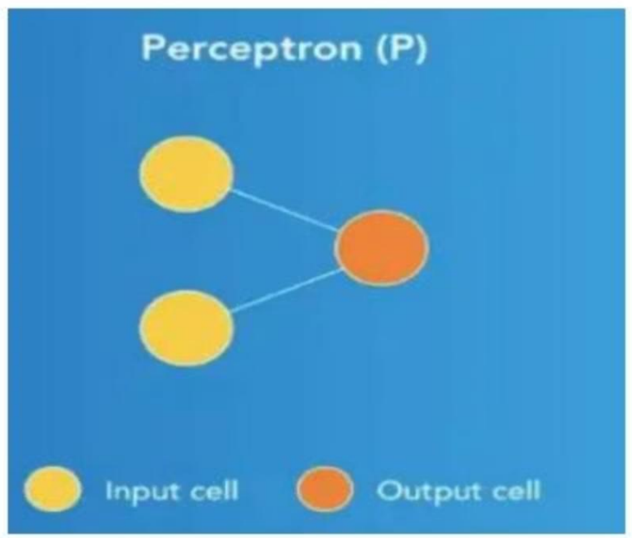
4. Finally, we will assume a threshold value of 3, which would translate to a bias value of –3. With all the various inputs, we can start to plug in values into the formula to get the desired output.

$$\hat{y} = (1*5) + (0*2) + (1*4) - 3 = 6$$

If $\hat{y}$ > threshold, then output = 1
If $\hat{y}$ < threshold, then output = 0
Since 6 is greater than 3, we can determine that the output of this node would be 1.
In this instance, you would go surfing.
If we adjust the weights or the threshold, we can achieve different outcomes from the model.

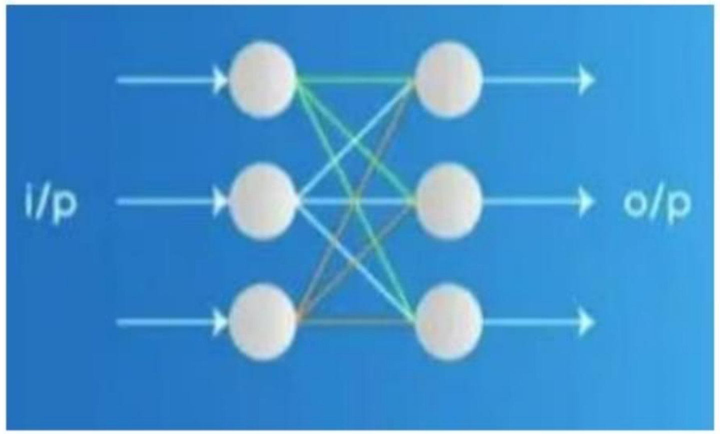
Types of Neural Networks

Perceptron



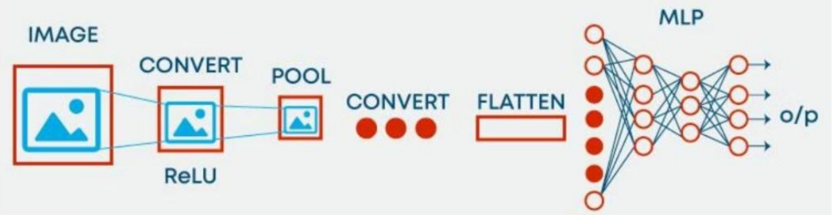
Simple, single-layer network for binary classification.

Feed Forward Neural Network (FFNN)



Multi-layer perceptrons with data flowing in one direction.

Convolutional Neural Network (CNN)

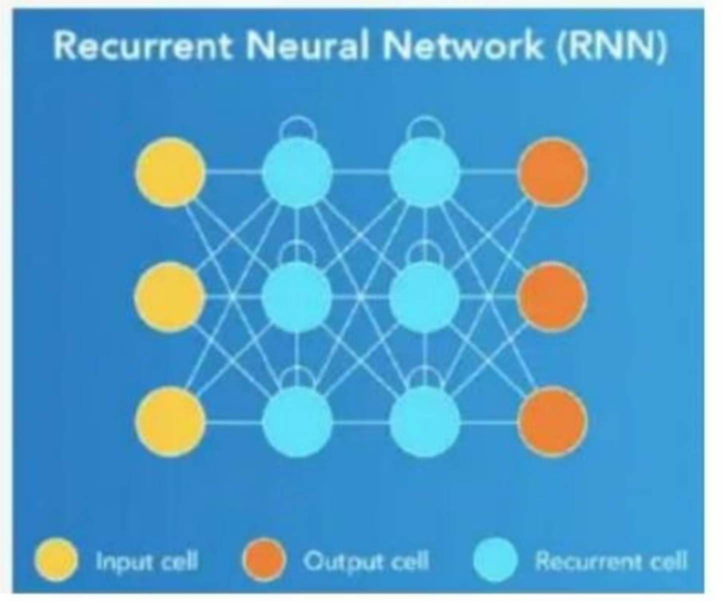


Uses filters to extract features from images for robust recognition.

Application: Dominant in computer vision for tasks such as object detection, image recognition, style transfer, and medical imaging.
[To see the working of a CNN, you may watch the video on https://www.youtube.com/watch?v=K_BHmztRTpA&t=1s]

Advanced Neural Network Types

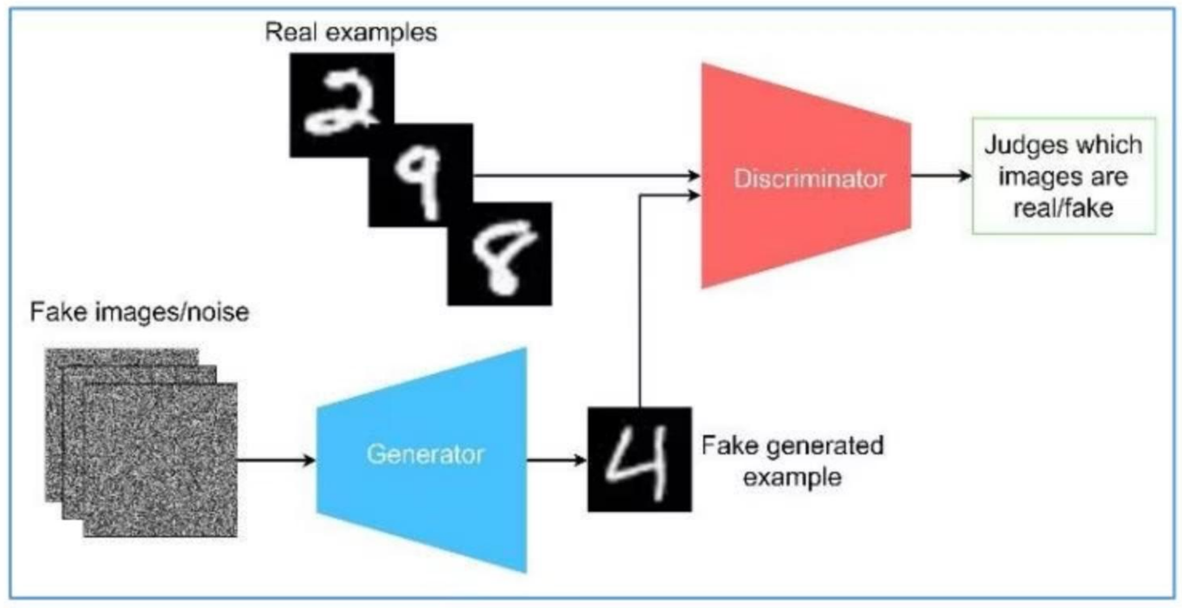
Recurrent Neural Network (RNN)



Designed for sequential data with feedback loops for information persistence.

Application: Used in NLP for language modeling, machine translation, chatbots, as well as in speech recognition, time series prediction, and sentiment analysis.

Generative Adversarial Network (GAN)

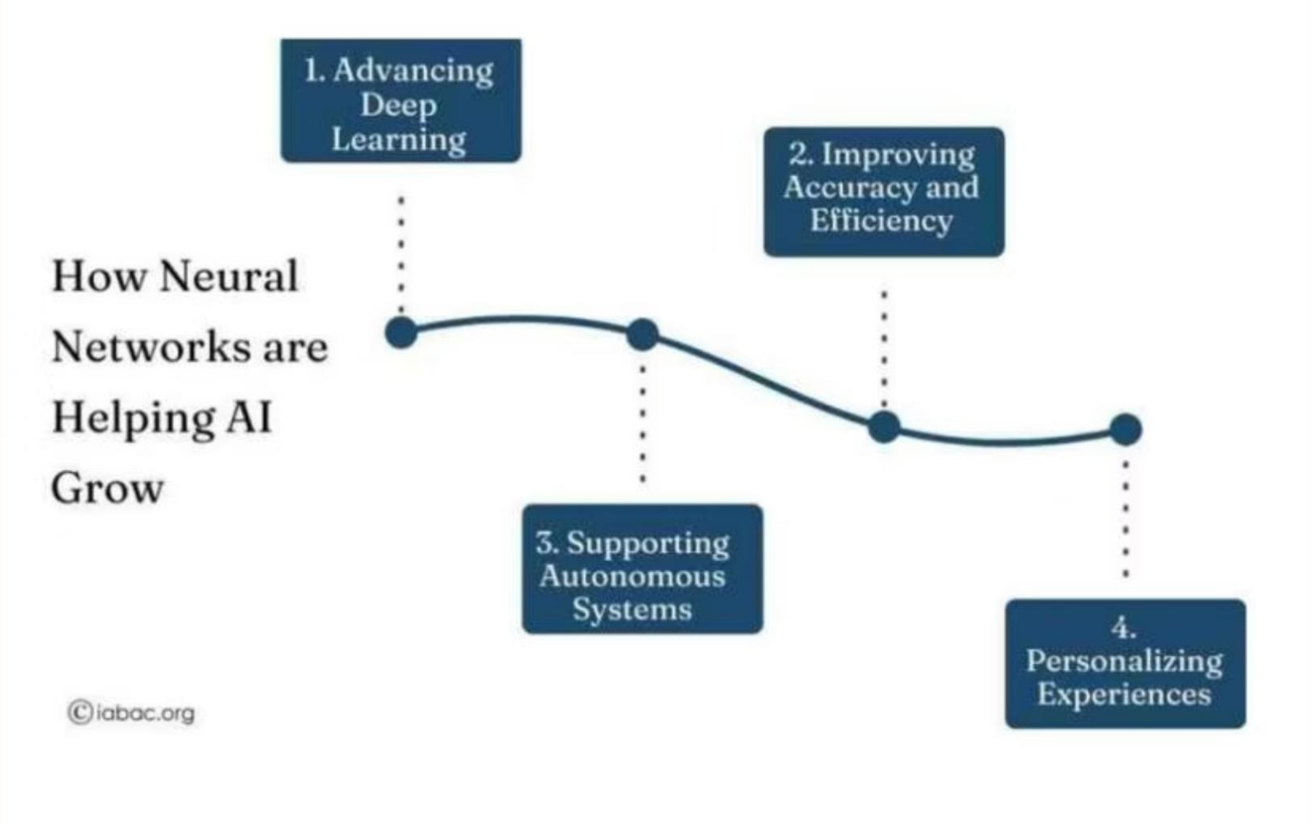


Two networks (generator, discriminator) trained simultaneously to create realistic data.

Application: Widely employed in generating synthetic data for various tasks like image generation, style transfer, and data augmentation.

Future & Impact of Neural Networks

Neural networks are revolutionizing society by enhancing efficiency, personalizing services, and driving economic growth.



- **Enhanced Efficiency:** Automating tasks and optimizing resource allocation.
- **Personalized Services:** Tailored recommendations based on data analysis.
- **Economic Growth:** Spurring innovation and creating new job opportunities.
- **Ethical Concerns:** Addressing data privacy, algorithmic bias, and job displacement.