Two Weeks Short-term Training Program

On

Ethical AI/ML for Innovation: Exploring Technologies and Applications

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Organized by

Department of Artificial Intelligence
SVNIT, Surat

Deep Learning and Its Applications

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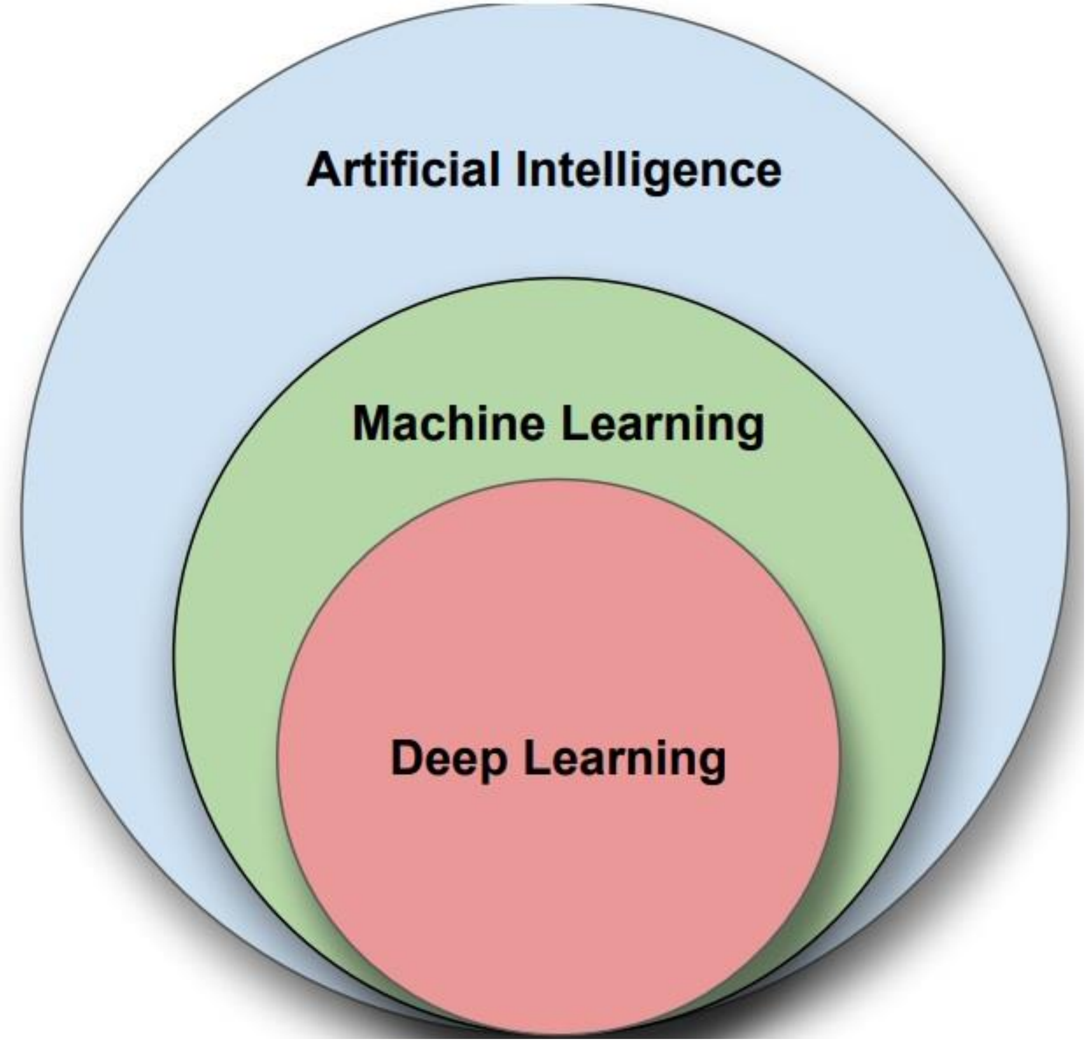
Deep Learning

- **Artificial Intelligence (AI)**
- AI is intelligence demonstrated by machines, as opposed to natural intelligence.
- **Machine Learning (ML)**
- ML is the study of computer algorithms that can improve automatically through experience and using data.
- **Deep Learning (DL)**
- DL is part of a wider family of machine learning methods based on artificial neural networks.

Deep Learning



Types of Learning

- **Supervised**
  - (x, y) available training data set
  - For a new data x (input), predict the label of y (output)
  - This is applicable for labeled data
- **Unsupervised**
  - x is only given
  - Cluster the data based on x
  - This is applicable for unlabeled data
- **Reinforcement**
  - Learning made by rewards or penalty

Deep Learning

- Deep learning uses artificial neural networks to perform complex computations on large amount of data.
- This is also called intensed learning
- **Alternative definition:**
  - a type of machine learning based on artificial neural networks in which multiple layers of processing are used to extract progressively higher level features from data.

Key features

- Uses artificial neural networks.
- Learns from large datasets with minimal human intervention.
- Excels in complex tasks like image recognition, speech processing, and natural language understanding.

Deep Learning Algorithms

- Convolutional Neural Networks
- Recurrent Neural Networks
- Generative Adversarial Network
- Autoencoder
- Transformer

History

- 1943: Warren McCulloch and mathematician Walter Pitts created a model using neural networks for an electrical circuit.
- 1958: Frank Rosenblatt designed the first artificial neural network, called Perceptron.
- 1982: John Hopfield suggested creating a network which had bidirectional lines, similar to how neurons actually work.
- 1986: Neural networks use back propagation.

History

- 2006: Computer scientist Geoffrey Hinton has given a new name to neural net research as "**deep learning**".

- GoogleBrain (2012) - a deep neural network created by Jeff Dean, which focused on pattern detection in images and videos.

- AlexNet (2012): AlexNet won the ImageNet competition by a large margin in 2012.

History

- DeepFace (2014):
  - A DNN created by Facebook
  - Claimed it can recognize people with the same precision as a human can.

- DeepMind (2014):
  - it managed to beat a professional at the game Go.

- Generative Adversarial Neural Network (GAN) was introduced in 2014

- OpenAI (2015):
  - This is a non-profit organisation created by Elon Musk and others.

History

- ResNet (2015) - This was a major advancement in CNNs.

- U-net (2015)- a CNN architecture specialized in biomedical image segmentation.

- 2016: AlphaGo beat the world's number second player at Go game, beat the number one player in 2017.

- BERT (Bidirectional Encoder Representations from Transformers):
  - In 2017, Google's BERT model transformed NLP, pre-trained models to understand context in language better;
  - applications in sentiment analysis and question answering.

History

- 2018: GPT (Generative Pretrained Transformer):
  - OpenAI released GPT, a language model capable of generating coherent and contextually relevant text.

- GPT-2 (2019):
  - OpenAI released GPT-2, a more powerful version of its predecessor,
  - capable of generating human-like text across a variety of domains.

- GPT-3 (2020):
  - OpenAI introduced GPT-3, very powerful language model, with 175 billion parameters
  - prompting new advancements in conversational AI and creative writing tools.

History

- 2021: CLIP (Contrastive Language-Image Pretraining):
  - OpenAI introduced CLIP, which linked text and images.

- 2022: Multimodal Models:
  - Increasing focus on multimodal models that combine text, images, and even video to improve performance across different types of data.

- 2023: GPT-4 (1.76 trillion parameters) and other advanced language models (Gemini, Llama, BERT, Meta, XAI, Claude, MistralAI etc.) further improved text generation, understanding, and reasoning capabilities.

History

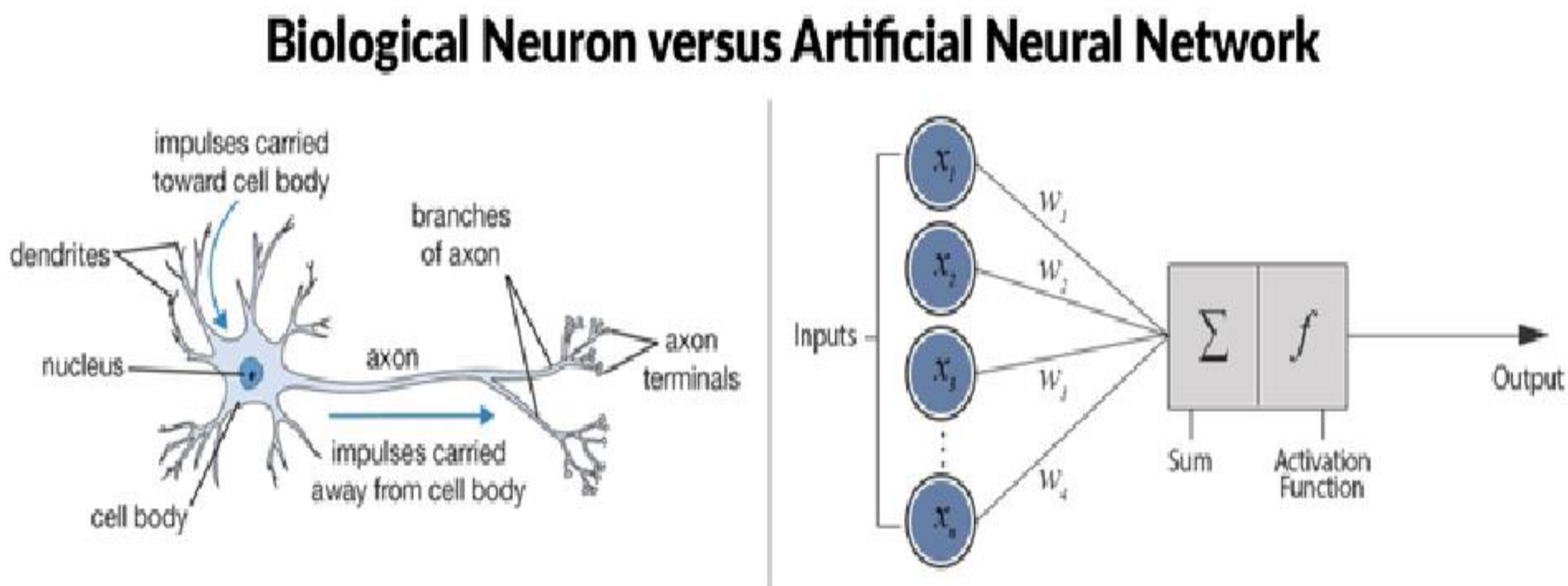
- 2023: AI Ethics and Bias: A growing focus on responsible AI, addressing ethical concerns, bias, fairness, and transparency in deep learning systems.

- 2024: Transformer-Based Models in Multilingual NLP: Deep learning continues to improve multilingual understanding with models capable of handling multiple languages.

- 2024: AI in Creativity and Art: The integration of deep learning into various creative fields—such as AI-generated art, music, and even video creation

Neural Networks

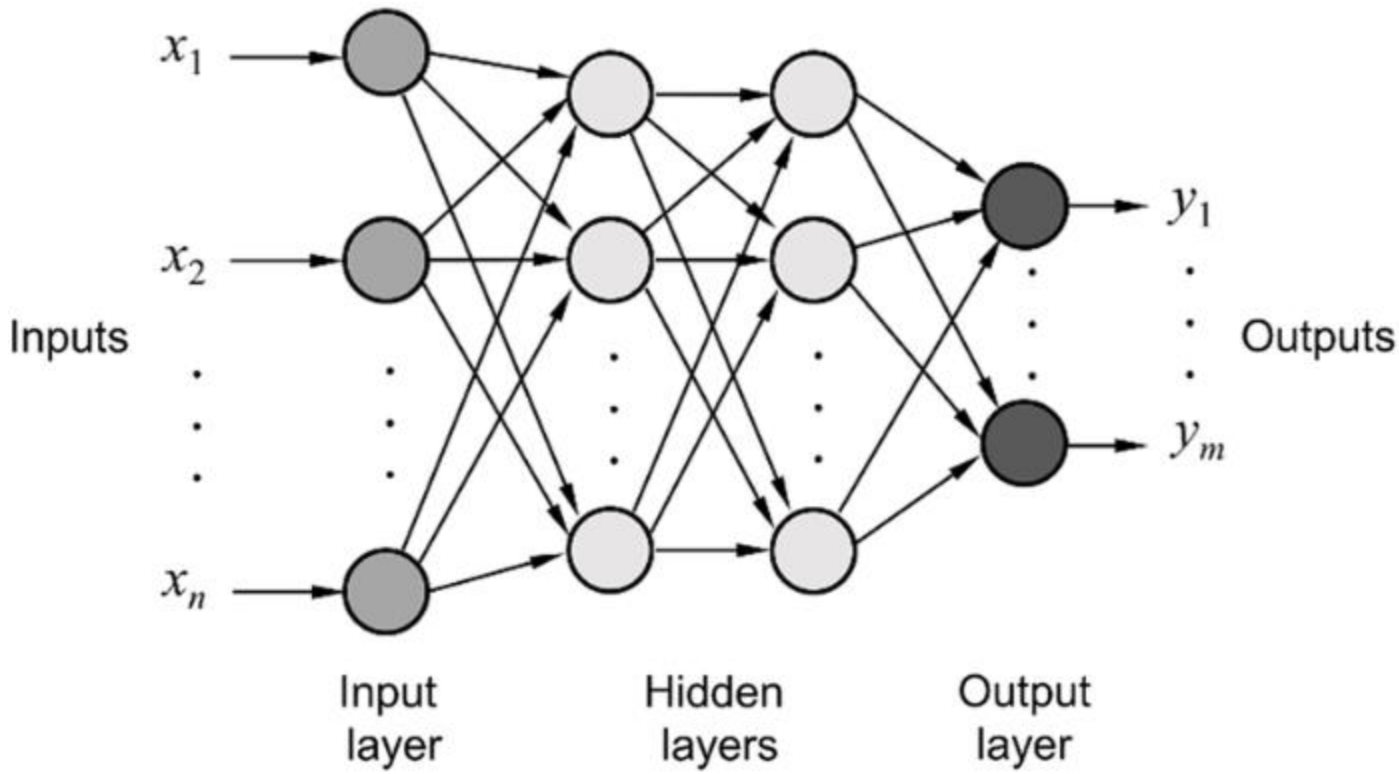
- 10 billions of neurons in human brains
- Massive parallelism
- Connectionism
- Distributed associative memory



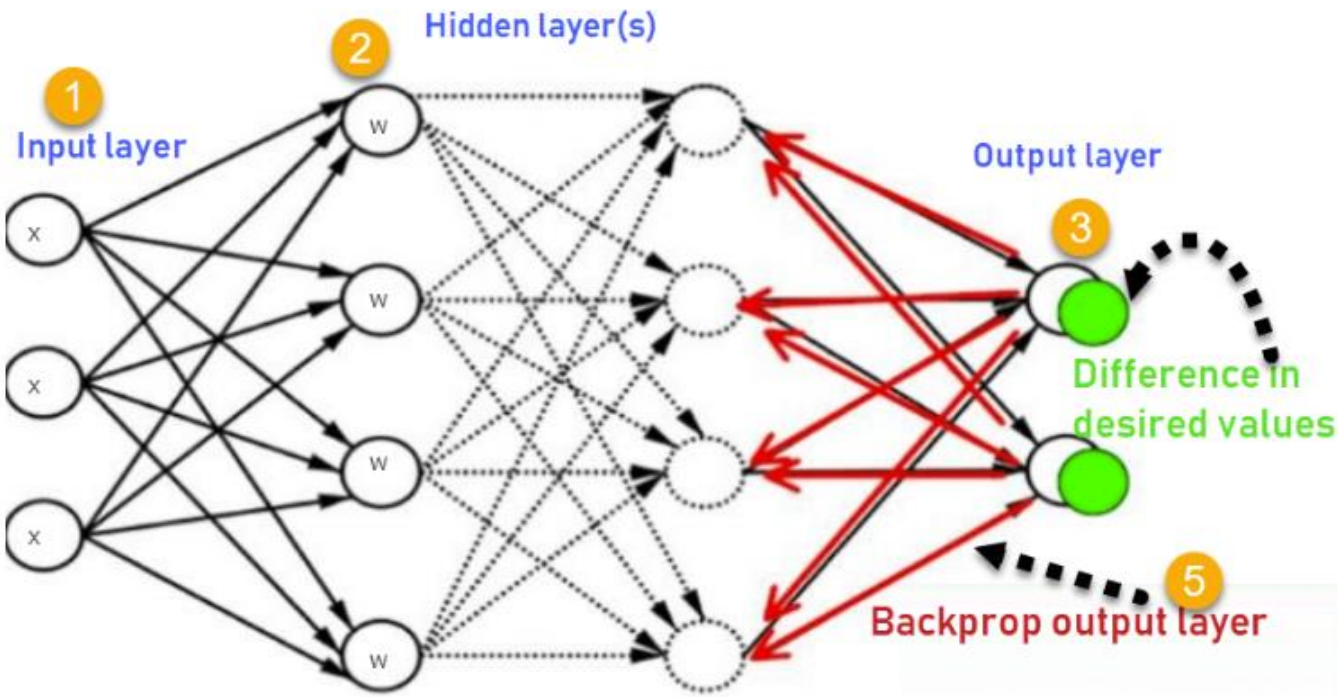
How neural network works?

- **Forward Propagation**:
  - Data moves through the network (input to output) to generate predictions.
- **Backpropagation**:
  - The error (loss) is propagated back through the network to update weights and minimize the error using optimization algorithms (e.g., gradient descent).
- **Learning Rate**:
  - Controls how much the weights are updated during training.

Multilayer Neural Networks

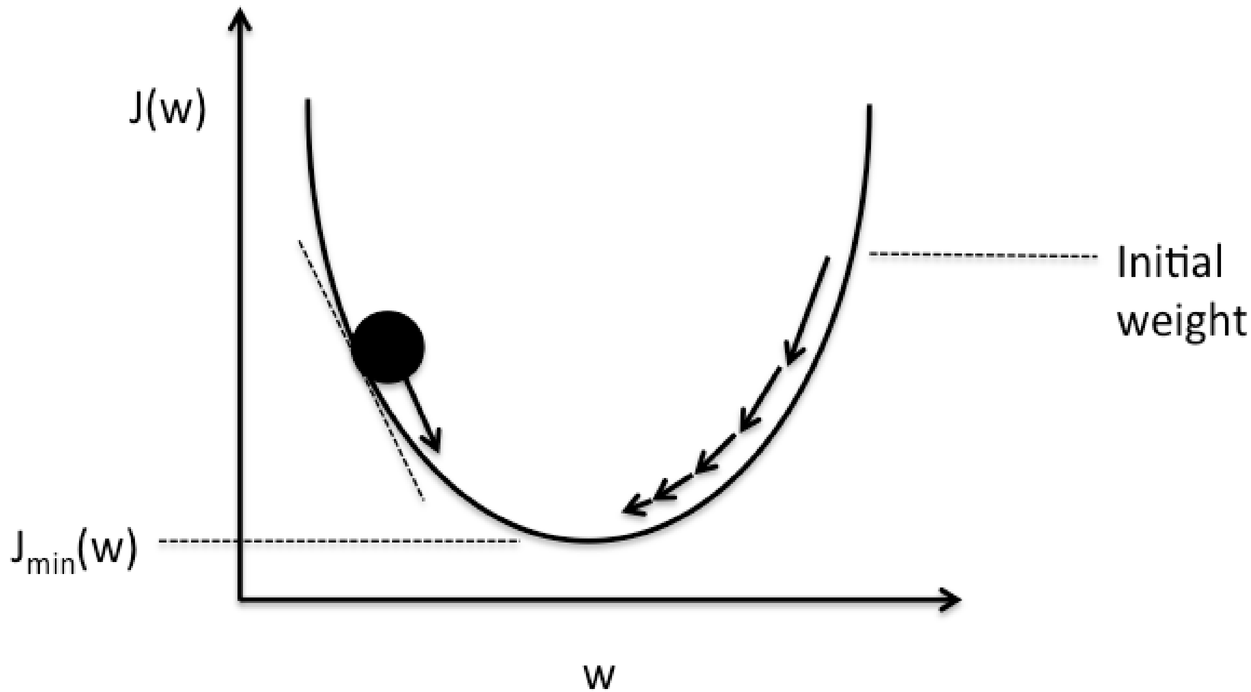


Multilayer Backpropagation Neural Networks



How Backpropagation Works

Gradient descent Algorithm



Convolutional Neural Networks

- A convolutional neural network can have tens or hundreds of layers that each learn to detect different features of an image.
- Filters are applied to each training image at different resolutions, and the output of each convolved image is used as the input to the next layer.
- The filters can start as very simple features, such as brightness and edges, and increase in complexity to features that uniquely define the object.

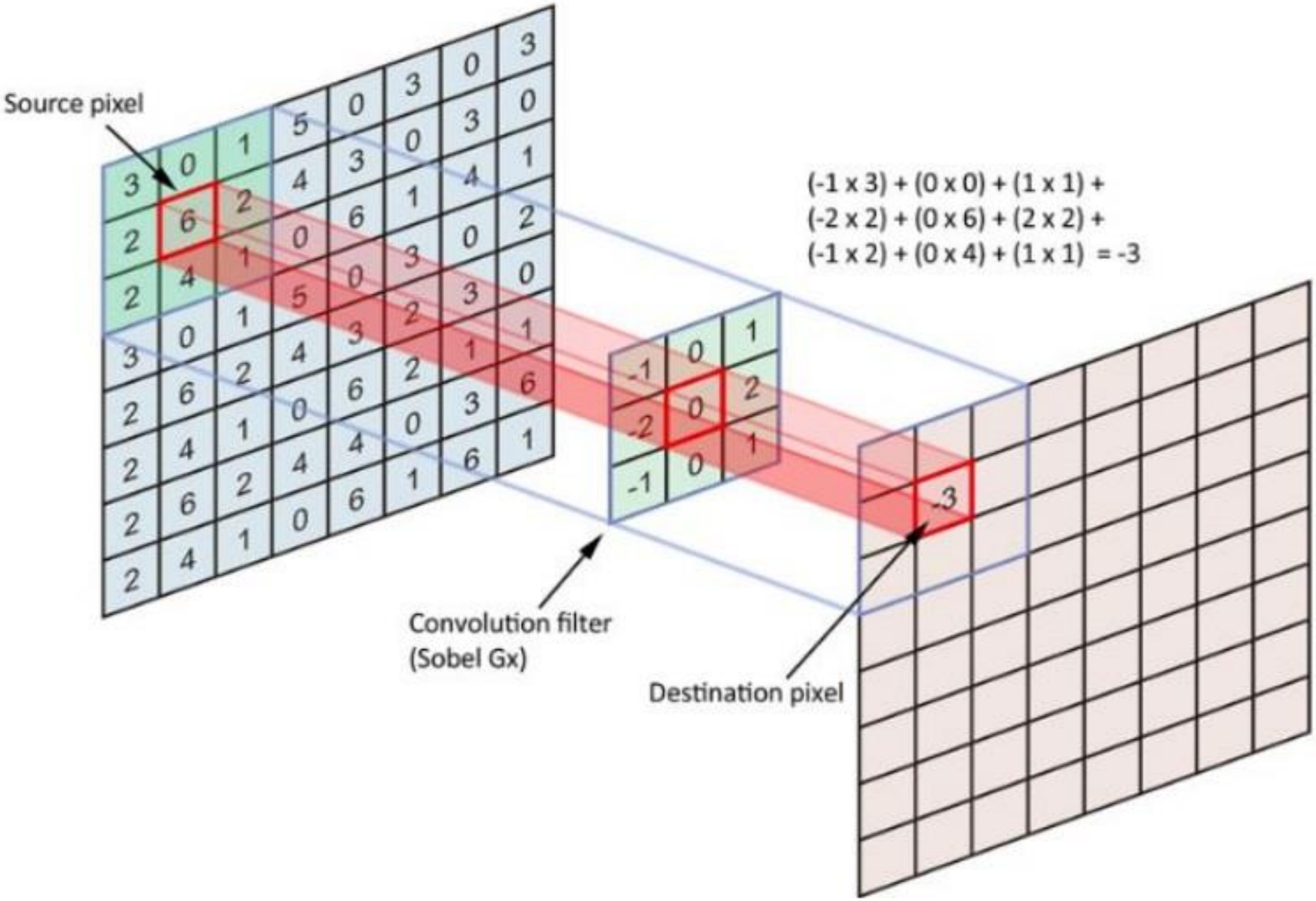
Convolutional Neural Networks

- **Methodology:**
  - It consists of layers that perform convolution operations, where small filters or kernels slide over the input data (like an image) to detect local patterns such as edges, textures, and shapes.
  - These convolutional layers are followed by pooling layers that downsample the feature maps, reducing their dimensionality and computational complexity while retaining the most important features.

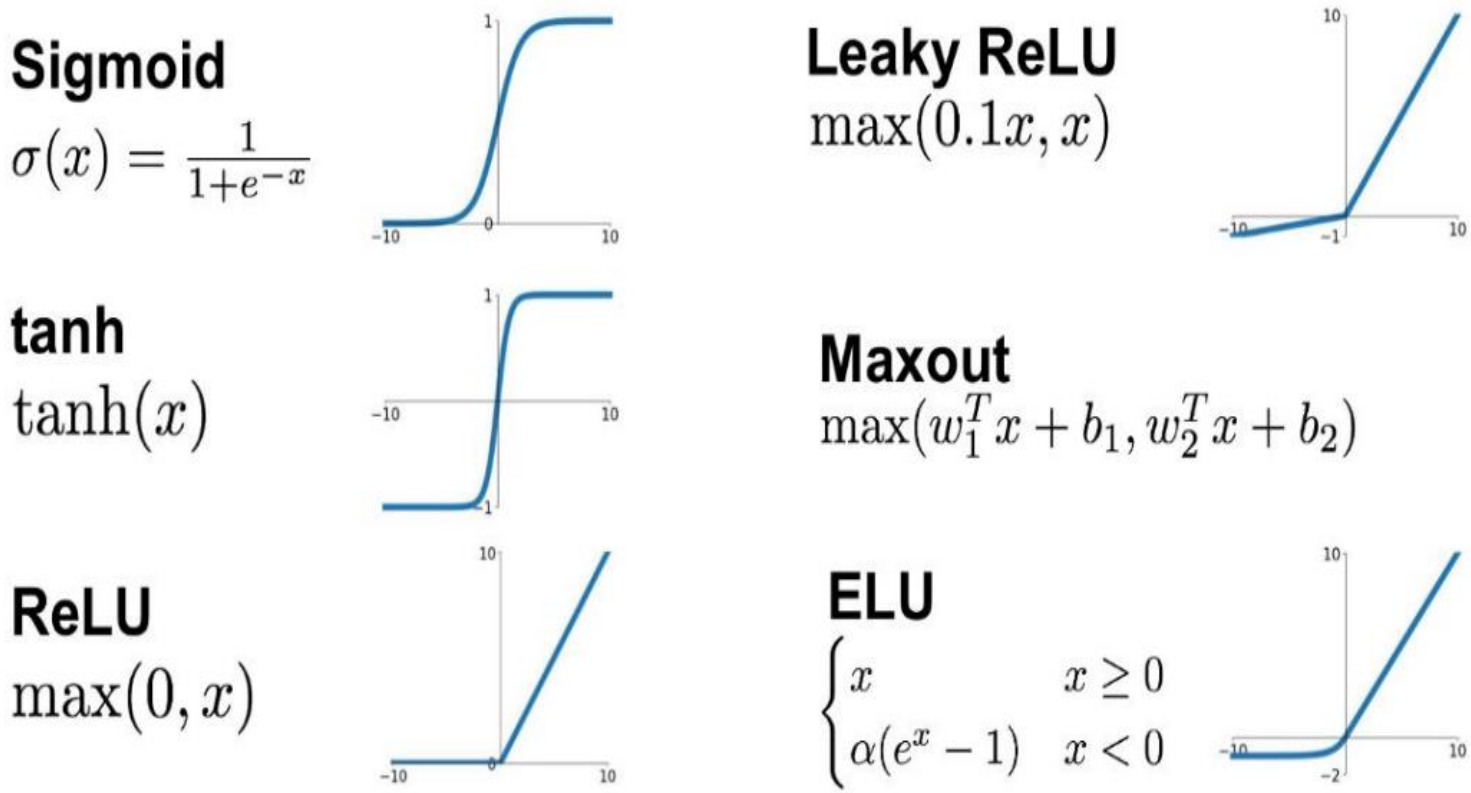
Convolutional Neural Networks

- **Methodology:**
  - After several convolution and pooling layers, the network typically includes fully connected layers to make final predictions or classifications.

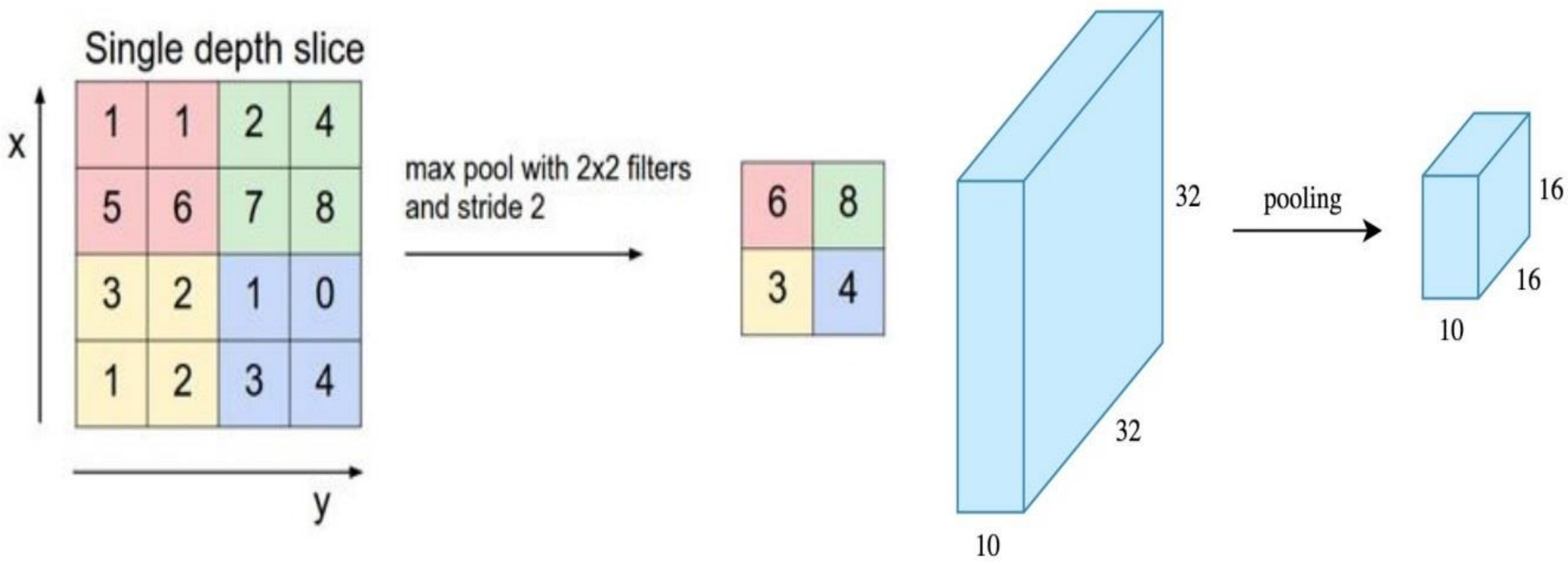
Convolution in 2D



Activation Function

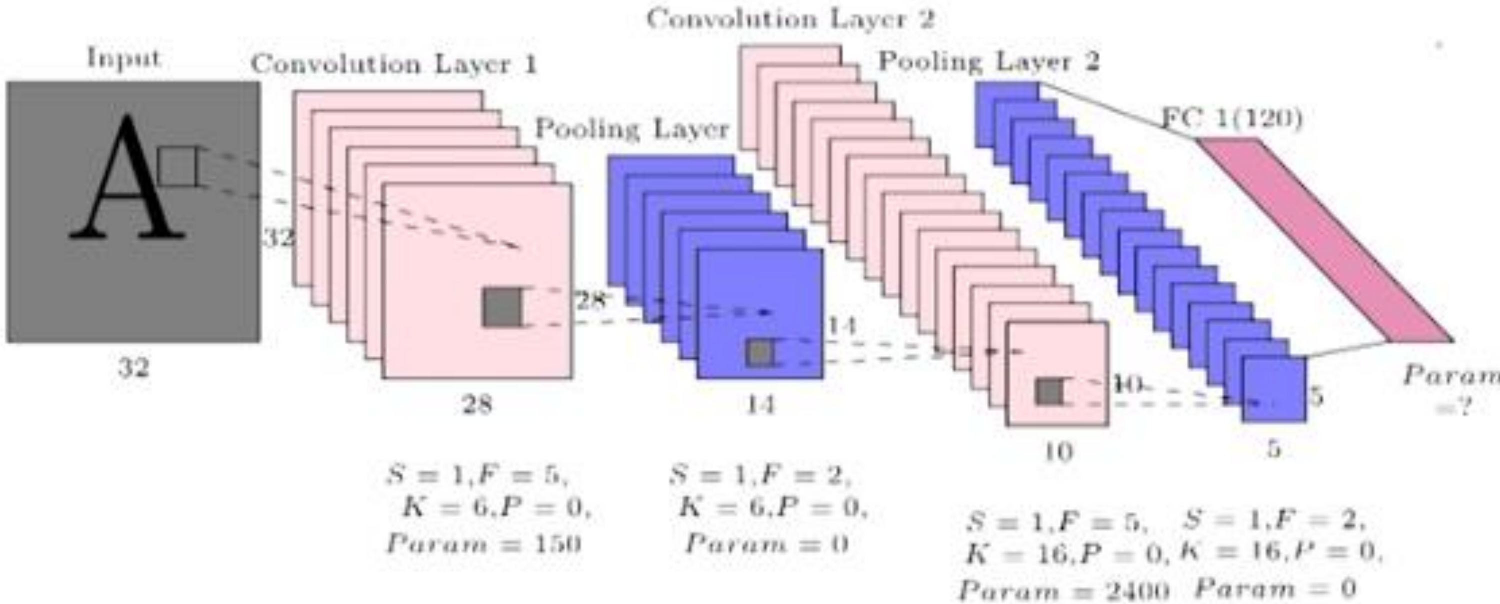


Max Pooling

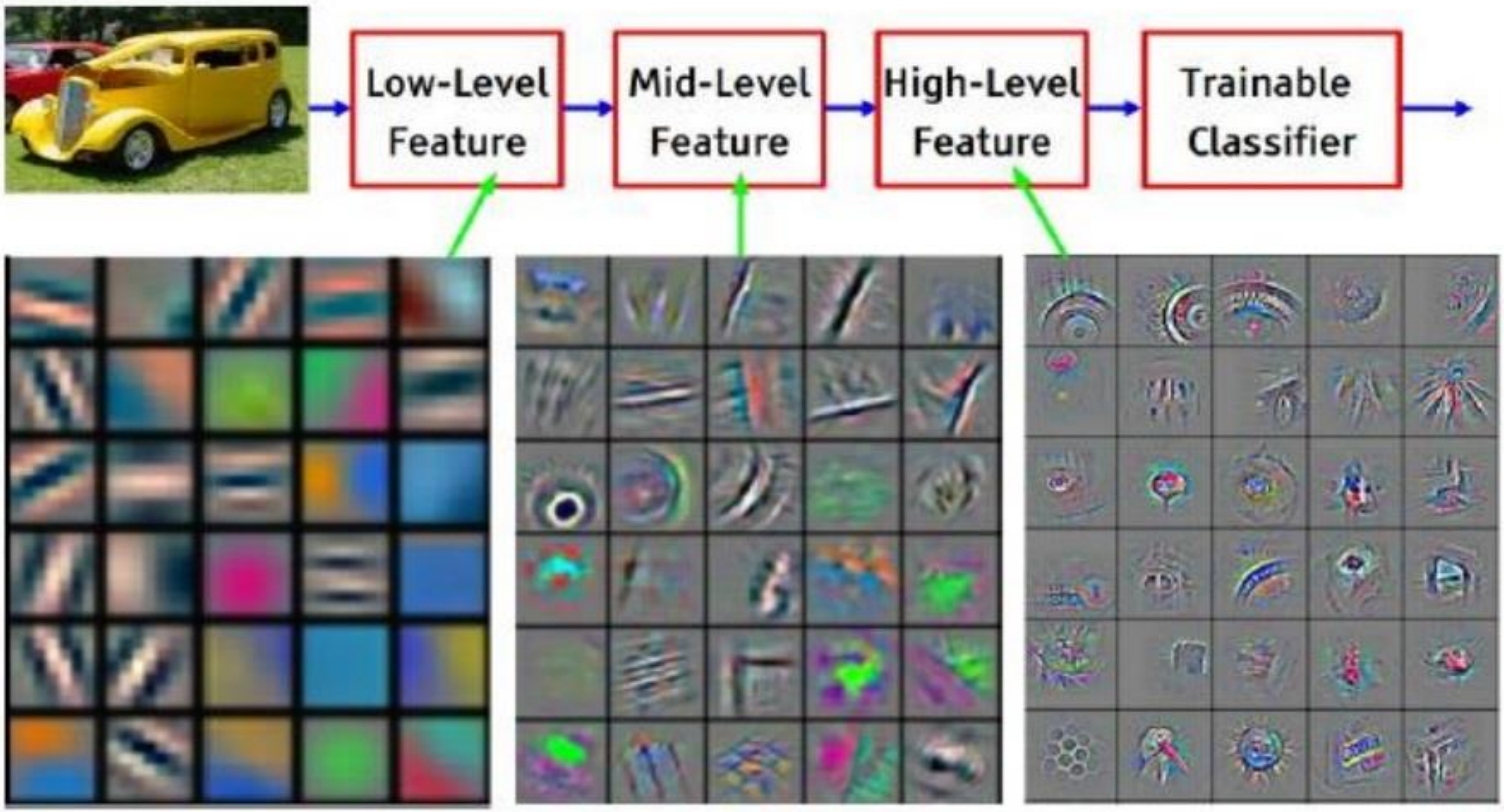


Single depth slice
x
y
1 1 2 4
5 6 7 8
3 2 1 0
1 2 3 4
max pool with 2x2 filters
and stride 2
6 8
3 4
32
32
10
pooling
16
16
10

Convolutional Neural Networks

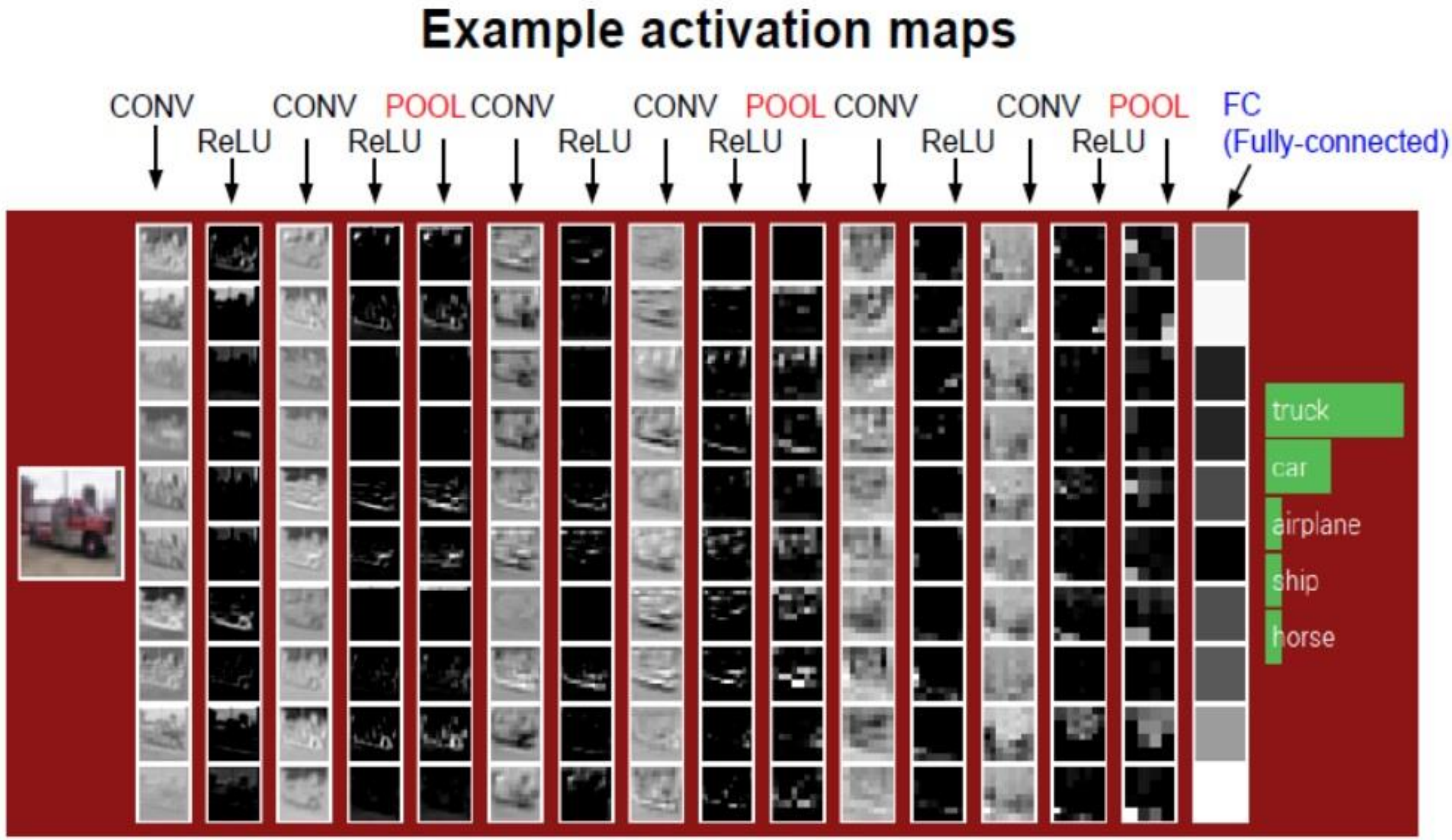


What do the neurons learn?

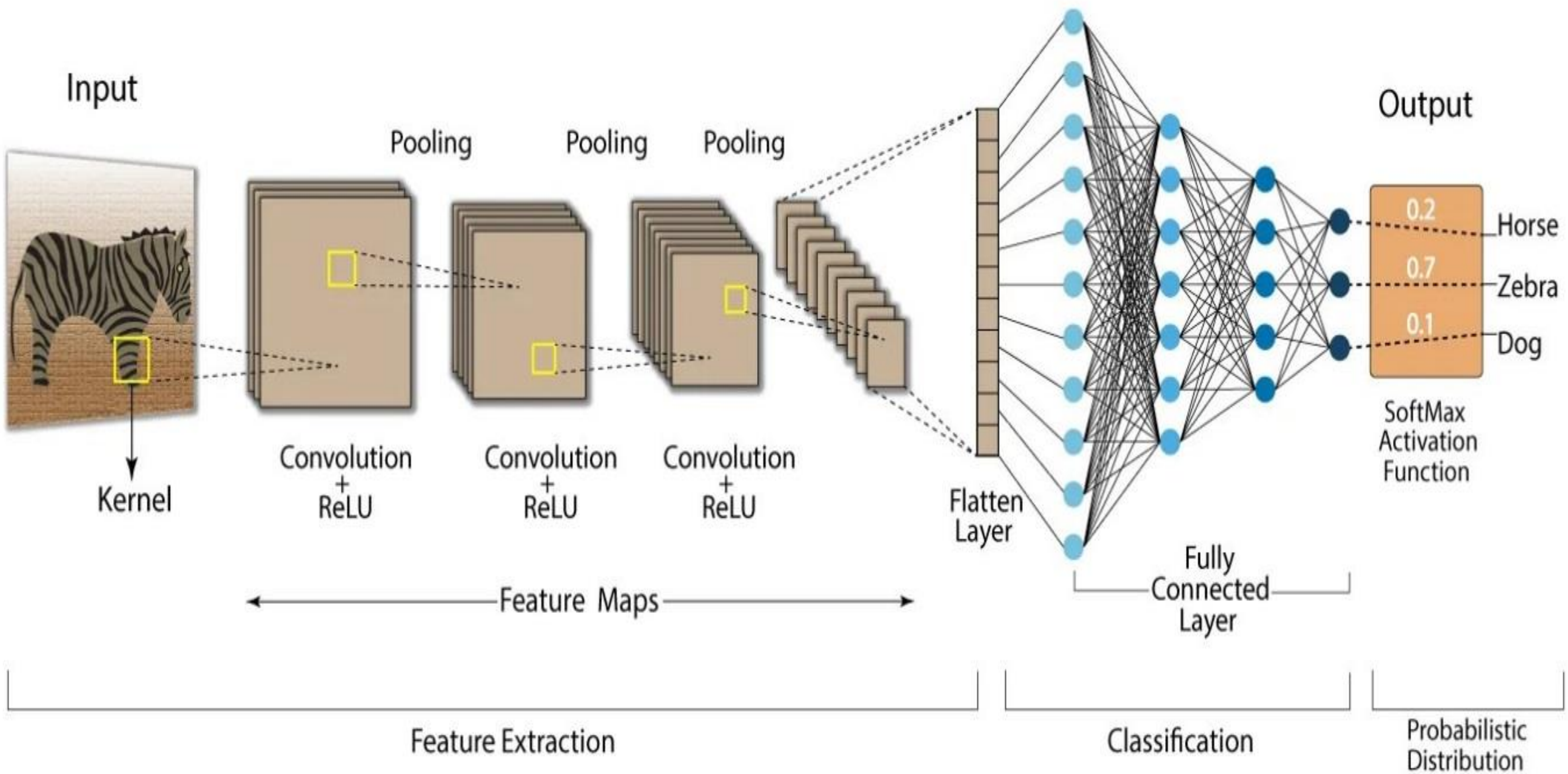


Feature visualization of convolutional net trained on ImageNet from [Zeiler & Fergus 2013]

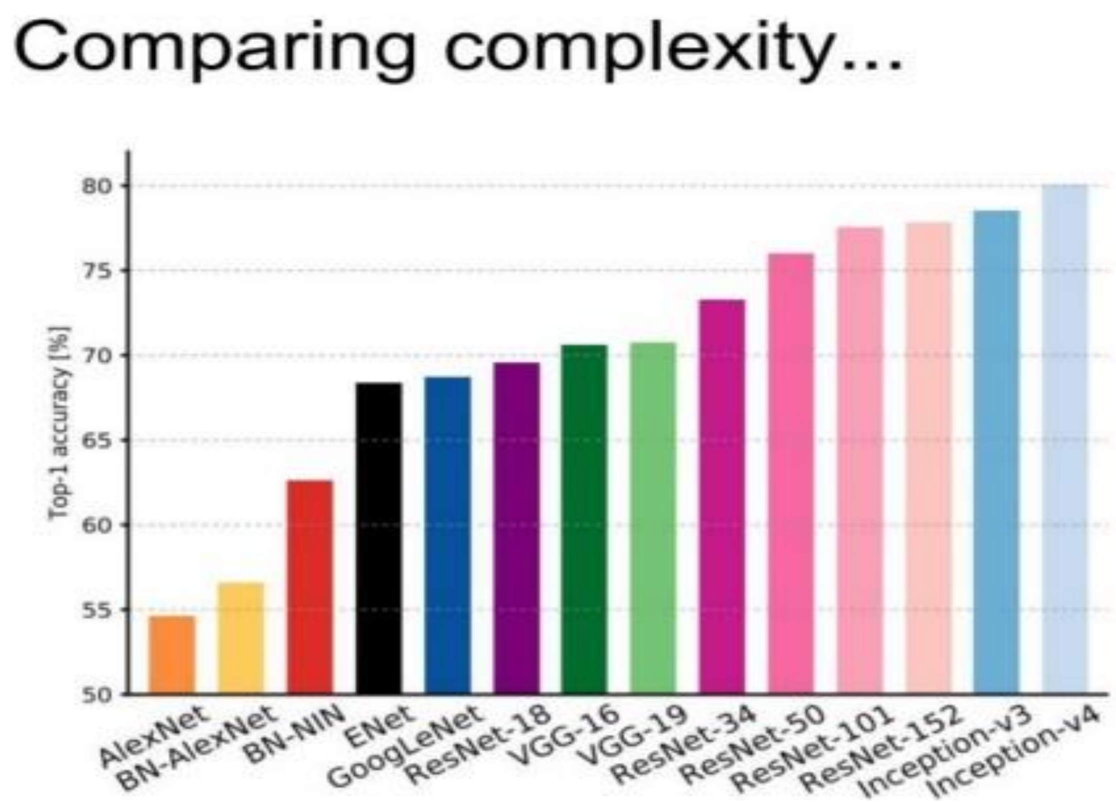
Example activation maps



Representation



Computational Complexity



Key Takeaways

- **Use Cases**: Image classification, object detection, facial recognition.
- **How It Works**:
  - Convolutional layers apply filters to detect patterns.
  - Pooling layers reduce dimensionality.
  - Fully connected layers for final prediction.
- **Example**: ImageNet classification (e.g., AlexNet, ResNet).

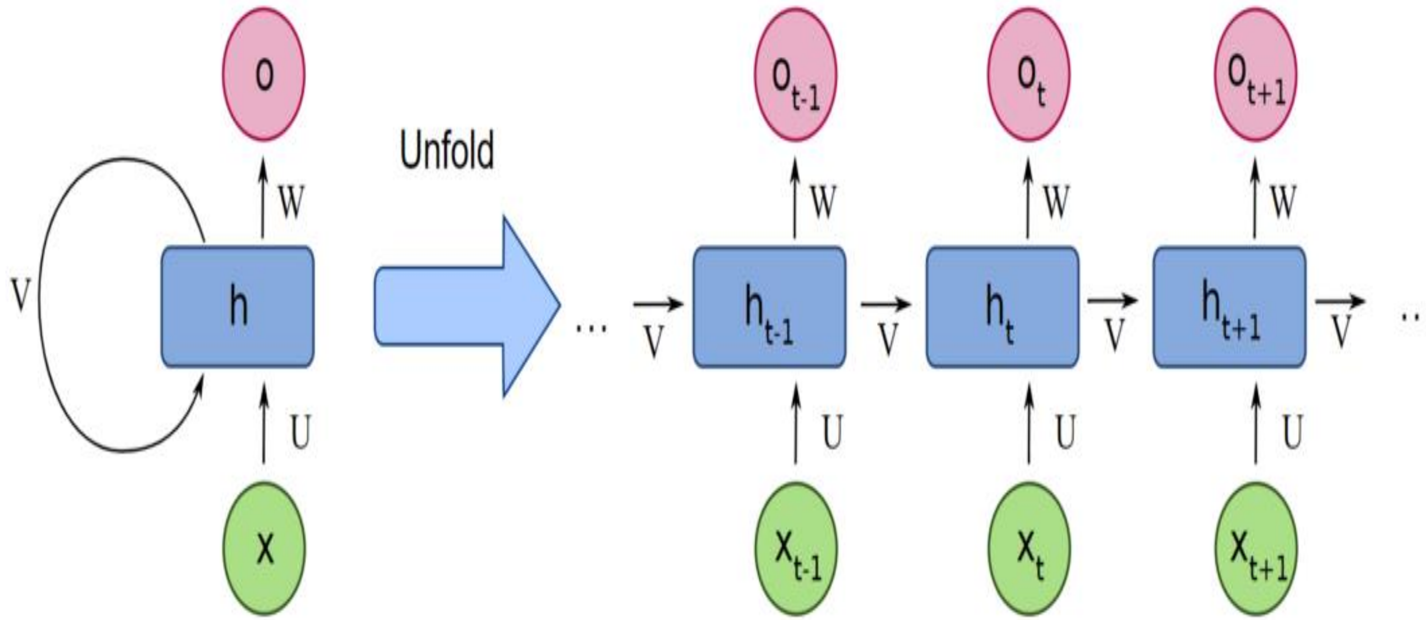
Recurrent Neural Network

- A recurrent neural network (RNN) is a type of artificial neural network which uses sequential data or time series data.
- These deep learning algorithms are commonly used for ordinal or temporal problems, such as language translation, natural language processing (NLP), speech recognition, and image captioning

Recurrent Neural Network

- RNNs have hidden states that are updated at each time step based on the current input and the previous hidden state, effectively creating a form of memory.
- However, traditional RNNs can struggle with long-term dependencies due to issues like vanishing gradients, which is why advanced variants such as Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU) networks are often used to improve performance.

Recurrent Neural Network



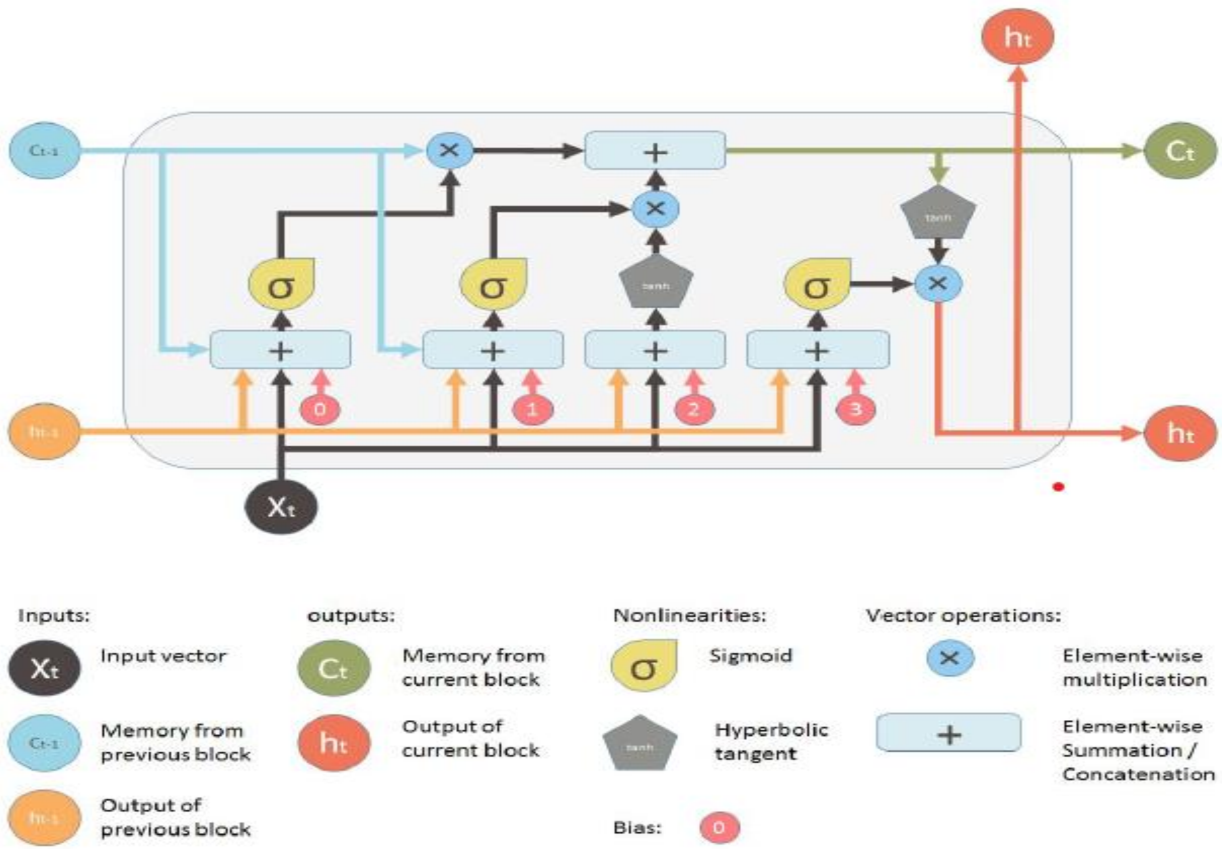
Key Takeaways

- **Use Cases**: Sequence data, speech recognition, text generation.
- **How It Works**:
  - RNNs have loops allowing information to persist.
  - They are good at handling temporal dependencies in data.
- **Variants**: Long Short-Term Memory (LSTM), Gated Recurrent Units (GRU).

Long Short Term Memory

- It is special kind of recurrent neural network that is capable of learning long term dependencies in data.
- LSTMs are predominantly used to learn, process, and classify sequential data because these networks can learn long-term dependencies between time steps of data.
- Common LSTM applications include sentiment analysis, language modeling, speech recognition, and video analysis.

Long Short Term Memory



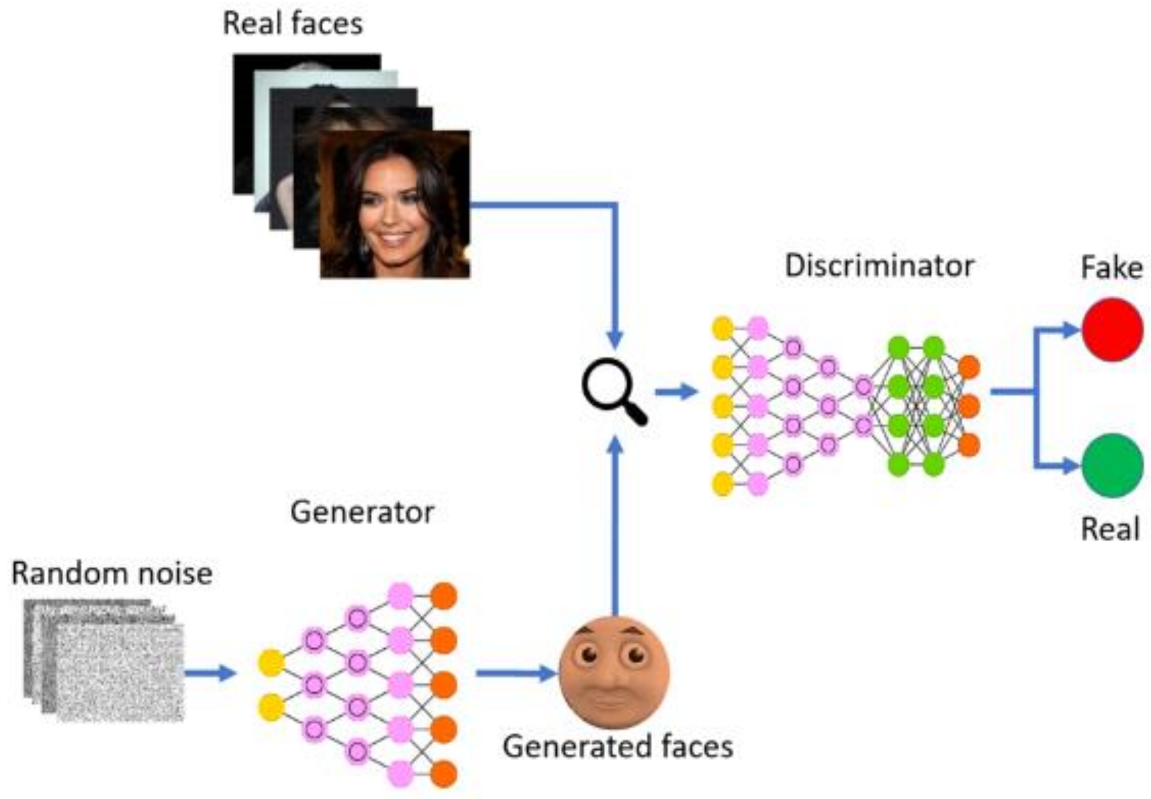
Generative Adversarial Network

- A generative adversarial network (GAN) is a deep learning architecture.
- It trains two neural networks (discriminator and generator) to compete against each other to generate more authentic new data from a given training dataset.
- During training, the generator improves its ability to create more convincing data, while the discriminator becomes better at identifying fake data.

Generative Adversarial Network

- This adversarial process continues until the generator produces data that is nearly indistinguishable from real data, and the discriminator is unable to tell the difference.
- For instance, we can generate new images from an existing image database or original music from a database of songs.

Generative Adversarial Network



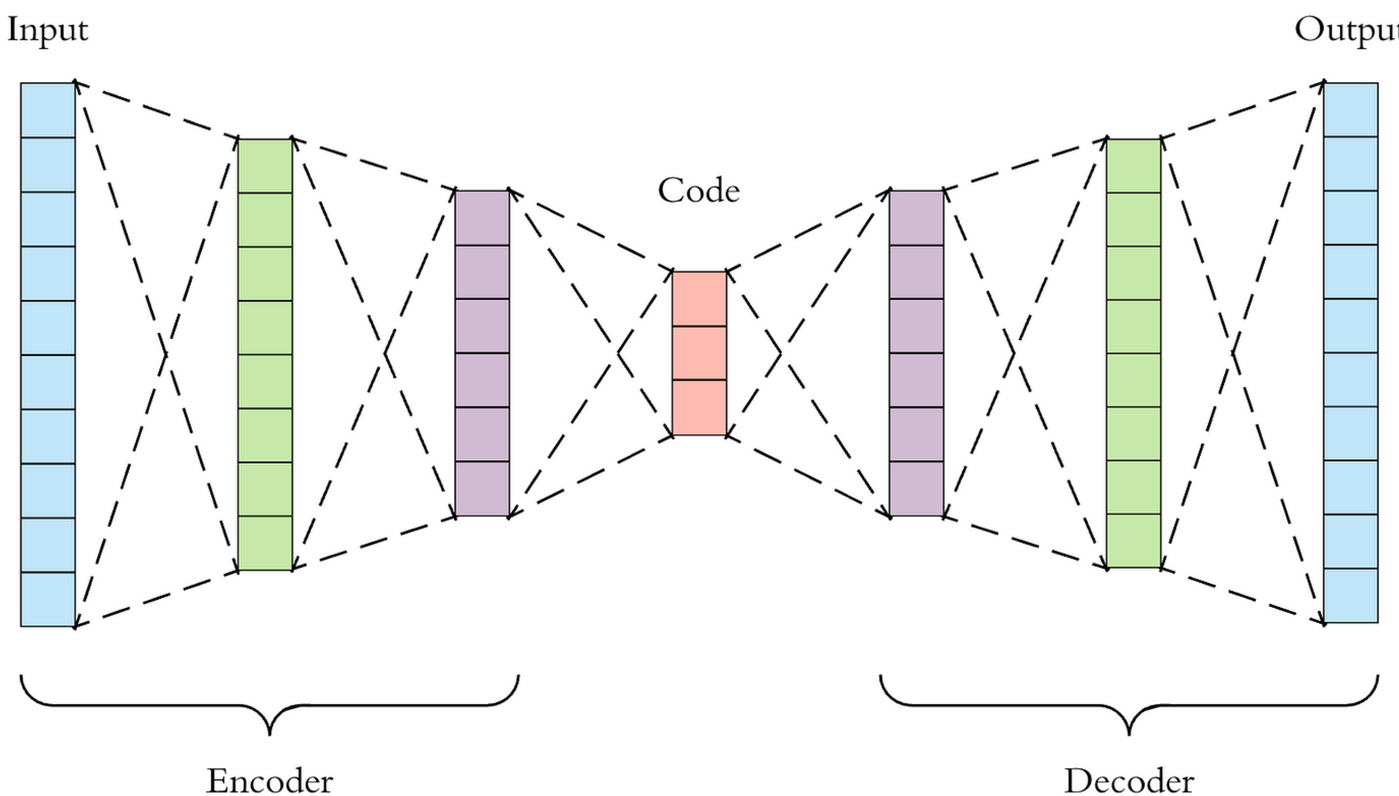
Key Takeaways

- **What is a GAN?**: A type of neural network architecture where two networks (Generator and Discriminator) compete against each other.
- **Use Cases**: Image generation, style transfer, data augmentation.
- **How it Works**:
  - Generator creates fake data.
  - Discriminator evaluates if the data is real or fake.
  - Both networks improve through adversarial training.

Autoencoder

- Autoencoders are neural network models primarily used for unsupervised learning tasks such as dimensionality reduction, data compression, and feature extraction.
- They learn to reconstruct the input data and capture its essential patterns, making them useful for anomaly detection and image-denoising tasks
- An autoencoder learns two functions: an encoding function that transforms the input data, and a decoding function that recreates the input data from the encoded representation.

Autoencoder



Transformer

- Self-Attention:
  - Allows the model to weigh the importance of each word in a sequence relative to others; capture long-range dependencies.
- Multi-Head Attention:
  - Uses multiple attention mechanisms in parallel to capture different aspects of relationships within the input.
- Position Encoding:
  - Adds information about the order of tokens since the Transformer doesn't inherently process sequences step by step like RNNs.

Transformer

- Feed-Forward Networks:
  - Each token's representation is passed through a simple fully connected network.

- Encoder-Decoder Structure:
  - Encoder processes the input sequence.
  - Decoder generates the output sequence.

- Parallelization:
  - Unlike RNNs, Transformers process all tokens in a sequence simultaneously, making training faster.

Transformer

Applications:

- NLP: Models like BERT, GPT etc.
- Computer Vision: Vision Transformer (ViT).
- Speech Processing: Speech-to-text, language modeling.

DL Models for Various Problems

- Computer Vision – GANs and CNN
- Natural Language Processing – BERT, Attention, Memory networks, RNN, LSTM, GRU and CNN
- Adversary Attacks Detection – GAN
- Object Detection – YOLO models

DL Models for Various Problems

- Semantic Segmentation – Mask RCNN
- Image Classification – CNNs
- Sequence Problem Prediction – RNN, LSTM, GRU
- Linear Problems Modeling and Analysis – ANN

Research on Deep Learning

- To detect and classify
  - objects in images
  - objects in videos
  - emotions in images
  - emotions in audio
- To generate
  - new images from a given set of images.
  - new audio from a given set of audio

Research on Deep Learning

- To detect and classify
  - emotions in text
  - objects in medical images
  - objects in satellite images
  - objects in speech recognition
  - objects in gesture recognition
  - objects in sentiment analysis

Research on Deep Learning

- To detect and classify
  - objects in time series analysis
  - objects in anomaly detection
  - objects in medical diagnosis
  - objects in fraud detection

Current research trends in DL

- **Transfer Learning**: Fine-tuning pre-trained models for specific tasks.
- **Explainability**: Making deep learning models interpretable to humans (e.g., SHAP, LIME).
- **Self-Supervised Learning**: Leveraging unlabeled data to pre-train models.
- **AI Ethics and Bias**: Addressing fairness and reducing bias in AI models.
- **Edge AI**: Deploying deep learning models on edge devices (e.g., smartphones, IoT).

Future Directions

- Meta-Learning: Training approaches used for small-scale instances
- fault-tolerant deep learning models for small training data
- Deep learning model execution over mobile devices
- Use of DL in neuroscience
- Applications of deep learning in game theory
- Extracting complete information from partial information using DL
- Deep learning in quantum environment
- GenAI, XAI

Challenges

- Time-consuming process
- Using small-scale data leads to overfitting issue
- Observation-based learning
- Use large-scale data for processing
- Training / Processing of large data is costly
- Hardware constraints and cost

References

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Thank You