1. **Introduction to Neural Networks**

According to (Kevin Gurney 1997) A neural network is an interconnected assembly of simple processing elements, units or nodes, whose functionality is loosely based on the animal neuron. The processing ability of the network is stored in the interunit connection strengths, or weights, obtained by a process of adaptation to, or learning from, a set of training patterns.

* + **Brief history and background**

| Stage | Development |
| --- | --- |
| Early Development | Neural networks were first proposed in the 1940s as models of artificial neurons. |
| Perceptron | The Perceptron, an early learning neural network, was introduced in the late 1950s. |
| Limitations and Frustration | In the 1960s, challenges and limitations of single-layer perceptrons were highlighted, leading to a decline in interest. |
| Renewed Interest | In the 1980s, contributions by researchers like Kohonen and Hopfield reignited interest in neural networks. |
| Backpropagation Algorithm | In the 1980s, the rediscovery of the backpropagation algorithm revolutionized neural network training. |
| Modern Advancements | In recent years, neural networks have made significant progress, attracting attention and funding for further research. |

* + **Why Neural Networks ?**

= Historical Motivations: Neural networks have two historical roots:

1. Understanding the Brain:

Researchers have been driven by a desire to comprehend the principles underlying the human brain.

2. Overcoming Computational Limitations:

There is a need for machines that can perform complex tasks beyond the capabilities of sequential, programmable computers.

3. Focus on Complex Tasks:

The recent surge of interest in neural networks and "neural computing" is primarily driven by the desire to build machines capable of tackling complex tasks.

4. Advantages over Traditional Computers:

Neural networks offer advantages in handling tasks that are not well-suited for traditional programmable computers, as conceived by Babbage and von Neumann.

* + **Basic concepts of artificial neurons and neural networks :**

Historical Development:

A wave of interest in neural networks emerged after the introduction of simplified neurons by McCulloch and Pitts in 1943.

Artificial Neurons:

Artificial neurons, also known as nodes, are the fundamental processing elements of neural networks. They are computational models inspired by natural neurons.

Neural Signal Processing:

Artificial neurons receive input signals through synapses, similar to natural neurons receiving signals through dendrites or membranes.

Activation Threshold:

If the input signals surpass a certain threshold, the artificial neuron is activated and emits an output signal through its axon.

Signal Transmission:

The output signal from one artificial neuron can be transmitted to other neurons through synapses, simulating the interconnected nature of natural neural networks.

1. **Neural Network Architectures**
   * **Feedforward Neural Networks (Multilayer Perceptron)**

= Feedforward Artificial Neural Network(FANN) is an information processing technique that can provide meaningful answers even when the data to be processed include errors or are incomplete, and can process information extremely rapidly when applied to solve real world problems.

* + **Recurrent Neural Networks (RNNs)**

**=** Recurrent networks are the state of the art in nonlinear time series prediction, system identification, and temporal pattern classification. A simple recurrent neural network could be constructed by a modification of the multilayered feed-forward network with the addition of a ‘context layer’. The context layer is added to the structure, which retains information between observations.

* + **Convolutional Neural Networks (CNNs)**

**= Convolutional Neural Networks (CNN)**are used for **facial recognition and image processing.** Large number of pictures are fed into the database for training a neural network. The collected images are further processed for training. Sampling layers in CNN are used for proper evaluations. Models are optimized for accurate recognition results.

* + **Generative Adversarial Networks (GANs)**

**=** Generative adversarial networks (GANs) provide a way to learn deep representations without extensively annotated training data. They achieve this by deriving backpropagation signals through a competitive process involving a pair of networks. The representations that can be learned by GANs may be used in a variety of applications, including image synthesis, semantic image editing, style transfer, image superresolution, and classification

* + **Radial Basis Function Networks (RBFNs)**

**=** The Radial Basis Function (RBF) network is a three-layer feed-forward network that uses a linear transfer function for the output units and a nonlinear transfer function (normally the Gaussian) for the hidden layer neurons (Chen, Cowan and Grant, 1991)

1. **Training and Neural Networks Learning Algorithms**
   * **Backpropagation Learning**

= In neural networks, the backpropagation algorithm is a crucial learning algorithm. By computing the partial derivatives of the error with respect to each weight, it requires modifying the network's weights. The error lowers toward a local minimum by weighting the negative of these derivatives.

* + **Hebbian Learning**

= Hebbian Learning, which modifies synaptic connections between neurons based on their activation patterns, is a key idea in connectionism. According to Hebb's 1949 theory of Hebbian Learning, the connection between presynaptic and postsynaptic neurons gets stronger when they are stimulated repeatedly.

* + **Perceptron Learning**

= The perceptron is a single layer neural network whose weights and biases could be trained to produce a correct target vector when presented with the corresponding input vector. The training technique used is called the perceptronlearning rule. Perceptrons are especially suited for simple problems in pattern classification.

TRAINING :

* + **Choosing the number of neurons:**= The number of hidden neurons affects how well the network is able to separate the data. A large number of hidden neurons will ensure correct learning, and the network is able to correctly predict the data it has been trained on, but its performance on new data, its ability to generalize, is compromised.
  + **Regularization methods (dropout, weight decay)**

**=** The learning algorithm uses a steepest descent technique, which rolls straight downhill in weight space until the first valley is reached. This makes the choice of initial starting point in the multidimensional weight space critical. However, there are no recommended rules for this selection except trying several different starting weight values to see if the network results are improved.

* + **Learning rate and convergence considerations**

**=** Learning rate effectively controls the size of the step that is taken in multidimensional weight space when each weight is modified. If the selected learning rate is too large, then the local minimum may be overstepped constantly, resulting in oscillations and slow convergence to the lower error state. If the learning rate is too low, the number of iterations required may be too large, resulting in slow performance.

1. **Deep Learning**
   * **Deep neural networks and their advantages**

= Deep learning is a subset of machine learning that uses artificial neural networks (ANNs) to model and solve complex problems. It is based on the idea of building artificial neural networks with multiple layers, called deep neural networks, that can learn hierarchical representations of the data.

Advantages :

a) Automatic feature learning:

Deep learning algorithms can learn features automatically from data, eliminating the need for manual feature engineering. This is particularly beneficial in tasks like image recognition where defining features is challenging.

b) Handling large and complex data:

Deep learning algorithms can handle large and complex datasets that would be difficult for traditional machine learning algorithms to process. This makes it a useful tool for extracting insights from big data.

c) Improved performance:

Deep learning algorithms have been shown to achieve state-of-the-art performance on a wide range of problems, including image and speech recognition, natural language processing, and computer vision.

d) Handling non-linear relationships:

Deep learning can uncover non-linear relationships in data that would be difficult to detect through traditional methods.

e) Handling structured and unstructured data:

Deep learning algorithms can handle both structured and unstructured data such as images, text, and audio.

f) Predictive modeling:

Deep learning can be used to make predictions about future events or trends, which can help organizations plan for the future and make strategic decisions.

* + **Deep learning architectures**

= 1) Deep belief networks :

The DBN is a typical network architecture, but includes a novel training algorithm. The DBN is a multilayer network (typically deep and including many hidden layers) in which each pair of connected layers is an RBM(restricted Boltzmann machine).

Note : A restricted Boltzmann machine (RBM) is a [generative](https://en.wikipedia.org/wiki/Generative_model) [artificial neural network](https://en.wikipedia.org/wiki/Artificial_neural_network) that can learn a [probability distribution](https://en.wikipedia.org/wiki/Probability_distribution) over its set of inputs.

2) Autoencoders :  
 Autoencoders (AEs) are common deep models in unsupervised learning [4]. They aim to represent high-dimensional data through the low-dimensional latent layer, a.k.a. bottleneck vector or code.

* + **Transfer learning and pre-trained models**

= Transfer learning is proposed to learn knowledge from a completed model, while improving the training of new models for different tasks. Based on existing knowledge, transfer learning speeds up the development of the new models even when their domains or learning tasks are different.

* + **Deep reinforcement learning**

= Deep reinforcement learning is poised to revolutionise the field of AI and represents a step towards building autonomous systems with a higher level understanding of the visual world. Currently, deep learning is enabling reinforcement learning to scale to problems that were previously intractable, such as learning to play video games directly from pixels. Deep reinforcement learning algorithms are also applied to robotics, allowing control policies for robots to be learned directly from camera inputs in the real world.

* + **Applications of deep learning**

= Computer vision :

Most artificial intelligence applications have been developed on the shoulders of computer vision, and deep learning has made significant advancements in computer vision, including object detection, image classification, and image segmentation.  
= Cybersecurity :

Cybersecurity also uses deep learning to improve threat detection and response. Cybersecurity threats are becoming increasingly sophisticated, and traditional rule-based approaches are insufficient to detect and prevent attacks. Deep learning algorithms can analyze large volumes of data to identify patterns and anomalies that may indicate a security breach or attack.

= Natural language processing :

Natural language processing (NLP) is the field of study that focuses on the interaction between human language and computers. Deep learning has transformed the field of NLP, enabling computers to interpret and respond to human language. One of the key applications of deep learning in NLP is machine translation. Deep learning models can be trained on large datasets of human language to translate text from one language to another accurately. This technology has a wide range of applications, including website localization, document translation, and language learning tools.

1. **Applications of Neural Networks**

**Recommendation Systems :**

=These systems seek to provide recommendations on content to present to users, who are often acting in the role of consumers. This enables automatic personalization of the recommended content, product or services to a large number of users.

**Facial Recognition:**

= Neural networks are used for robust facial recognition systems in surveillance, authentication, and selective entries. Convolutional Neural Networks (CNN) process large datasets for accurate recognition results.

**Stock Market Prediction:**

= Neural networks, specifically Multilayer Perceptron (MLP), are employed for real-time stock market predictions. MLP models analyze past performances, annual returns, and ratios to make successful predictions.

**Social Media Analysis:**

= Artificial Neural Networks (ANN) study social media user behaviors for competitive analysis and mining data. MLP models forecast social media trends based on factors like user preferences and bookmarked choices.

**Aerospace Applications:**

= Neural networks, including Time Delay Neural Networks (TNN), are used for fault diagnosis, auto piloting, securing control systems, and dynamic simulations in aerospace engineering.

**Defense Systems:**

= Artificial neural networks shape defense operations, including logistics, armed attack analysis, object location, air patrols, maritime patrols, and controlling automated drones. Convolutional Neural Networks (CNN) detect underwater mines and aid image processing.

1. **Challenges and Future Directions**
   * **Overfitting and underfitting**

**=** Machine learning model is said to have **Underfitting**when it cannot capture the underlying trend of the data.**Underfitting** usually happens when we train the Machine learning model with very less data than required to build an accurate model.

= Machine learning model is said to have **OverFitting**when it does not capture the underlying trend of unseen data, and has learnt from noise.**Overfitting**usually happens when we train the machine learning model with a lot of data (including noise in Data)

* + **Data availability and quality**

**=** One of the main challenges of neural networks and deep learning is the need for large amounts of data and computational resources. Neural networks learn from data by adjusting their parameters to minimize a loss function, which measures how well they fit the data. However, to achieve high accuracy and generalization, they often require millions or billions of data points, which may not be available or accessible for some tasks or domains.

## **Interpretability and explainability**

**=** Another challenge of neural networks and deep learning is the lack of interpretability and explainability of their outputs and decisions. Neural networks are often considered as black boxes, as it is hard to understand how they process the input data and what features they learn and use. This can pose problems for applications that require transparency, accountability, and trust, such as healthcare, finance, or law.

* + **Advances in neural network research**

**=** Attention Mechanisms:

Attention mechanisms enable models to concentrate on relevant parts of the input data and enhance efficiency in tasks like machine translation, image captioning, and natural language processing.

= Models of the Transformer:

The mechanism of the Transformer architecture has enabled it to perform at the cutting edge in activities like text production and language translation. By allowing parallel processing and more successfully capturing long-range dependencies, transformers have been able to get around RNNs' constraints.

= Graph Neural Networks (GNNs):

Graph neural networks have become an effective tool for processing data with complex relational structures. GNNs can be used to process graph-structured data, including social networks and molecular graphs, and they can also capture complex connections between nodes. ­---

* + **Potential future applications and impact of neural networks**

= Integration:

Neural networks can be integrated with complementary technologies, such as symbolic functions, to address their weaknesses and achieve better results.

= Scaling up complexity:

Technological advancements allow for the scalability of neural networks. Cheaper and faster CPUs and GPUs enable the development of larger and more efficient algorithms. Neural networks can process more data and learn from fewer examples, pushing the boundaries of their capabilities.

= New applications:

Neural networks have the potential to revolutionize diverse industries. They can enhance operational efficiency, target new audiences, facilitate product development, and improve consumer safety. However, the widespread adoption and creative implementation of neural networks across industries are still underutilized.

= Potential obsolescence:

While neural networks have seen remarkable progress, their limitations and weaknesses may lead to the emergence of alternative approaches in the future. As technology evolves, developers and consumers may gravitate towards new solutions that offer superior capabilities and potential for solving complex problems.

1. **CONCLUSION :**

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