

Neural Networks

Abstract

In the constantly evolving landscape of contemporary technology, neural networks remain at the forefront, helping to shape industries and transform traditional approaches to complex problems. The fundamentals of neural networks and their history are first explored, to provide contextualization for their pivotal role in modern applications. Components such as neurons, layers, and activation functions are examined to better dissect the inner mechanisms of these computational models. Following this is a discussion on the applications of neural networks, which offers a comprehensive survey of real-world implementations: spanning fields like image recognition, natural language processing, and finance. Through insightful examples the profound impact on modern technology is closely examined, establishing noticeable trends seen in this diverse field.

Delving into neural network training, the methodology behind the process is further explored, painting a clear portrait of common algorithms such as backpropagation. Discussion into data is explored as well, reflecting the importance of setup and processing. The results of this experiment highlight the effectiveness of neural networks, furthering the findings of successful applications. Finally, a general interpretation of these results ensues, drawing comparisons to existing studies, elucidating limitations, and proposing future directions for neural network research.

Introduction

Over the last few decades, unprecedented advancements in the field of artificial intelligence have occurred, directly originating from work on neural networks. Inspired by the intricate inner workings of the human brain, neural networks have demonstrated remarkable capabilities in various applications.

Neural networks, often referred to as artificial neural networks (ANNs), are computational models designed to mimic the neural connections found in biological systems. Analogous to neurons, these networks consist of interconnected nodes organized in layers. The strength of these connections is a critical component of these networks, often adjusted during the training process to learn patterns and make predictions. It is because of its pattern recognition and prediction ability that neural networks are applicable in numerous domains, ranging from autonomous driving to healthcare diagnostics. These advancements are a testament to the research being performed within this field, as it is able to refine processes and revolutionize industries in the pursuit of true artificial intelligence.

To delve deeper into neural networks, it is necessary to address the fundamentals of them, including the key components of neural networks as well as a deeper dive into their applications. A systematic exploration of architecture, training and proven implementations will provide a path to comprehending the inner workings as well as the practical significance of ANN's.

Neural Network Overview

The core of a neural network is often comprised of thousands and even millions of nodes, all of which provide the basis for a complex system of interconnected networks. Similar to the biological variant, the neurons of a neural network represent the basic units of computation in a system; receiving input, applying weights, and producing output in custom layers to form the structural foundation of the network. Each neural network has a custom number of layers

depending on the complexity needed, however they can be broken down into three main categories: the input layer, the hidden layer(s), and the output layer. Geoffrey Hinton, widely considered to be “The Godfather of AI” is responsible for this specific design of the neural network, which is inspired from the structure of the human brain (McCullum, 2020) [1]. To complete the equation, non-linear activation functions enable ANNs to learn complex patterns, with functions such as sigmoid, hyperbolic tangent and rectified linear unit (ReLU) being the most widely used.

Adding to the breadth of ANNs, different architectures have been tailored for specific tasks common in the industry. The four most widely used today are Feedforward Neural Networks (FNN), Recurrent Neural Networks (RNN), Convolutional Neural Networks (CNN), and Generative Adversarial Networks (GAN). Each architecture was created with a deliberate purpose, aiming to optimize the number of layers and functions used to create models with high efficacy. FNNs tend to specialize in image recognition tasks, due to their unidirectional paths, differing from CNNs which are optimized for processing grid-like-data. As a result, CNNs are highly efficient for image processing (Yamashita, Nishio, Do, & Togashi, 2018) [2]. RNNs are adept at processing sequential data and capturing temporal dependencies, making them excellent choices in natural language processing and time-series tasks. This is one of the key reasons ANNs like RNN play a key role in finance, due to the range of probabilistic models that can be created for financial markets (DiPietro & Hager, 2019) [3]. GANs are well versed in tasks such as image generation, due to their structure comprised of a generator and a discriminator.

Applications of neural networks

Logically, the diversity and wide range of applications encompassed within neural networks lead to many real-world utilizations. One of the primary reasons ANN’s are so versatile is because of their capacity to handle complex tasks and large datasets, making them the ideal solution for industry needs. Some of the most common use cases involve image recognition, natural language processing, algorithmic trading, disease detection, and manufacturing enhancements. With attributes such as adaptive learning and fault tolerance, investing in neural networks has helped companies fill roles that otherwise require niches skillsets (Ramos, 2018) [4].

These use cases have ushered in an era of enhanced decision-making, enabling the precedent of data-driven insights.

One prevalent subfield of neural networks is image recognition. The utilization of CNNs has been particularly successful, as its dominance in areas such as facial recognition, autonomous driving and automated tagging have all established it as a reliable mean to handle these tasks. Take Tesla for example, who developed the HydraNet system based on a structural foundation of CNNs. Essentially, the system switches between “branches” of CNNs to make final decisions based on obstacles (Barla, 2023) [5]. As expected, there are numerous ways of utilizing CNNs to fit custom needs, which makes them a popular choice for image-heavy tasks.

Another important application, natural language processing (NLP), is a constantly evolving subfield that aims to emulate the artificial understanding of naturally spoken language. This is especially coveted in conversational artificial intelligence as well as translation services. Corporations such as Google and Meta spend billions developing state of the art algorithms capable of improving NLP models and services. One reason why is due to cost saving measures, as language-based artificial intelligence, developed from research into NLP, can automate many tasks including those held by decision-makers. (Gruetzemacher, 2022) [6]. Not all tasks are in the process of being automated, however much of the ongoing research occurring is focused on this.

As for one industry that has benefitted immensely from the advancements in ANNs, the finance sector utilizes and develops these services for everything from algorithmic trading to fraud detection. Neural networks are part of the reason large financial institutions and high frequency trading firms are so profitable, as the predictive ability on these algorithms has only improved with time. In a volatile and emerging sector like cryptocurrency, for instance, algorithmic trading using Stochastic Neural Networks was able to provide a significant return on investment as opposed to a normal trader (Kalariya, et al., 2022) [7].

It is evident why ANNs have had such a profound impact on modern technology. The significance of their adoption has only skyrocketed advancements into the field and paved the way

for revolutionary new technologies to rise. First, enhanced decision making enables industries to lead with data-driven insights, allowing for trend analysis and improvement. Second, automation and efficiency have had an important impact, by eliminating redundant tasks as well as optimizing process'. Third, businesses and industries have leveraged these tools to gain a competitive edge amongst the market, showcasing adaptability in a rapidly evolving technological landscape. So long as their utilization is continued, the reach of ANNs will continue to expand and shape the future of technology.

Training Neural Networks

Having seen the power of neural networks and the implications of their applications, it is important to understand the methods used to train these ANNs and how layered the approach can be. While it is possible to start from scratch, training a neural network is a process than can be extremely lengthy, expensive, and redundant. It is often more efficient to employ proven algorithms to expedite the training process, allowing for faster turn around and more accurate results.

One such algorithm, Backpropagation, involves calculating the gradient of the loss function with respect to the model's parameters. This gradient is then used to update the weights and biases of the network in the opposite direction of the gradient, minimizing the loss incurred. Using this method, it is possible compute the necessary gradient more efficiently as opposed to individual weight computation (Hashemi-Pour) [8]. Some additional algorithms to enhance the training process include stochastic gradient descent, Adam, and RMSprop. Each algorithm has key advantages and disadvantages to be further explored, however, for the case of this research Backpropagation is sufficient.

Aside from choosing the appropriate algorithm, proper data plays a pivotal role in shaping a model's understanding and predictive capabilities. Through labeled datasets Backpropagation fine-tunes the parameters of a model, minimizing the gap between the predicted and actual outcomes. Errors that are calculated during the optimization process help drive the model, increasing accuracy and its ability to make predictions. Evidently, the importance of data cannot

be overstated, due to the impact it has on model evaluation, hyperparameter tuning and overall performance.

Conclusion

In conclusion, the evolution and advanced research of neural networks has propelled technology into new heights and proven indispensable in a wide range of applications. The real-world impact ANNs have had on the likes of autonomous driving and high frequency trading are proving to be quite significant. I believe the reliance on these networks will eventually reach a turning point, where many of the technologies we utilize daily will not be able to function without them. This will of course bring into play the ethical considerations surrounding technology like AI, which will be an important test for humanity and a turning point for the way we interact with technology. I have little doubt of the success ANN's will continue to receive, especially as training algorithms like Backpropagation continue to improve. The way to move forward with this technology will be to embrace it in all facets of life, setting up a new challenge of adaptability for so many of us.

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