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Deep Learning, Theory and Foundation: A Brief Review

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Abstract:- The concept of deep learning is becoming more and more popular and is becoming extensively used in many research areas and industries as well. One sector where deep learning has been used heavily is the Healthcare industry, where medical researchers are employing the use of deep learning algorithms to detect various cancer cells and using it in different imaging techniques. The aim of this article is to review the literature on deep learning, the basic foundation of deep learning, as well as, understand the various models available that pertains to deep learning. This study employed the use of published research papers to evaluate the various concepts and models pertaining to deep learning as well as the origin of deep learning and its main concept. This paper also discusses the various applications of deep learning and how they are employed currently. With technological improvements, both in terms of hardware and software, deep learning algorithms will be able to perform more efficiently and accurately.

Keywords:- *Deep Learning, Machine Learning, Artificial Intelligence, Deep Belief Network, Convolutional Neural Network, Recurrent Neural Network, Artificial Neural Networks.*

I. INTRODUCTION

The concept of deep learning emerged from the field of artificial intelligence, when researchers and scientists tried to mimic how the the human brain function in terms of cognitive ability and the processing of data (Du, Cai, Wang & Zhang, 2016). Deep learning has been a great success in many fields and this includes the fields pertinent to machine learning, image processing as well as artificial intelligence (El-Amir & Hamdy, 2019). It is important to note that, Deep learning is a subset of Machine Learning and is concerned with the development of various algorithms that allow researchers and scientists to mimic the cognitive ability of the human brain (Kawaguchi, 2016). This concept can also be termed as Artificial Neural Networks (ANNs) (Özkural, 2018). Furthermore, the development of deep learning algorithms pertain to the development of many layers of codes, employing the use of different algorithms in order to understand, compute and display the intended results (Ketkar, 2017). To further enhance the complexity of a deep learning algorithm to produce more accurate and complex results, the number of layers within the network is increased and the codes are further broken down into specific functions that compute the results more accurately (Lin, Zhang, Luo & Zuo, 2020). Consider the following example: to identify the patterns within an image, the image first needs to be converted to pixels by the deep learning algorithm, and in a step-by-step process, the values of the pixels is computed at different complexity levels to ensure that the algorithm is performing as intended and outputs the results denoting patterns within an image (Affonso, Rossi, Vieira & de Leon Ferreira, 2017).

The aim of this research article is to review the literature on deep learning, the basic foundation of deep learning, and also, understand the various models available that pertain to deep learning.

- To study the concepts of deep learning from a theoretical perspective
- To understand the foundation of deep learning, as well as deep learning models
- To appraise the applications of deep learning

II. LITERATURE REVIEW

A. The Concept of Deep Learning

The initial notion of deep learning was established back in the year 2006 and since its establishment, it is becoming more and more developed and being employed in many different research areas (Lin et al., 2019; Mahmud, Kaiser, Hussain & Vassanelli, 2018). Since the inception of deep learning, organisations such as Google and Facebook have done an extensive research and have applied the concepts within various organisational operations (Malhotra, 2018). One of Google's deep learning software is known as 'DeepDream', through which the company is able not to only classify images, but also is able to generate artificial paintings based on the information gathered in its knowledge base (O'shea & Hoydis, 2017). The concept of deep learning, although being late in its inception, is one area of technology which was developed at a very rapid pace (Özkural, 2018). Various models of deep learning as well as specific institutes have been developed which solely focus on the development of deep learning mechanisms (Schmidhuber, 2015). The overall structure of a deep learning model pertains to a hierarchical structure which consist of several layers between the input and the output of the program (Liu, Wang, Liu, Zeng, Liu & Alsaadi, 2017). The number of layers within a deep learning network depicts the complexity of the network and increases the accuracy of the results obtained (Li, Kawale & Fu, 2015). However, the study of Najafabadi *et al.* (2015) describes that, in order to develop a deep learning network, there must be a minimum of two hidden layers, between the input and output layer. It is equally important to note that, deep learning models are able to convert low-level data into data which consists of high-level abstract features.

B. Deep learning vs Machine Learning

Machine learning (ML) and deep learning are two segments that fall under the field of artificial intelligence (Bisong,2019). Machine learning can be defined as the subset of artificial intelligence which deals with the formulation of

algorithms that are able to modify themselves after each iterative step and do not require the intervention of a user (Chauhan, & Singh, 2018). Furthermore, input data of machine learning must pertain to a structured form of data in order to ensure that the model is able to automatically improve itself (Eskofier et al., 2016). To define deep learning in simpler terms, it is similar to machine learning and also a subset of ML, however, during the formulation of algorithms of deep learning, several layers of neurons must be constructed and adjusted according to the dataset being analysed to ensure the desired output of analysis (Hung, Song & Lan, 2019). It is important to note that both deep learning and machine learning have different mechanisms to solve problems or analyse data sets. For machine learning, it is important to input structured set of data which is labelled for the algorithm to easily understand and define the features of the data set (Iba, 2018). On the other hand, for deep learning algorithms, one of the strength of employment of such algorithm is that input data does not need to be structured and that the artificial neural network pertaining to deep learning algorithm itself categorises the data, by sending it to multiple layers of neurons to define the patterns and features present within the dataset (Ng, 2019). The working mechanism of a deep learning algorithm is similar to the processing method of the human brain in the sense that it logically and hierarchically processes data in order to identify patterns and features. Additionally, another difference to note between deep learning and machine learning is that each of them require different levels of data sets and the application of deep learning is based on a much deeper and larger scale (Zhang, Tan, Han & Zhu, 2017; Kamilaris & Prenafeta, 2018).

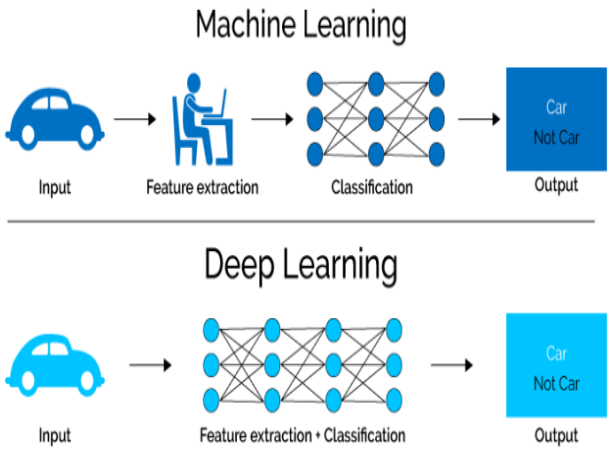

Fig 1. *Machine learning vs Deep learning. Source: (*Saha, 2018*)*

C. The Foundation of Deep Learning

The foundation of deep learning was first originated back in 1943 by Walter Pitts and Warren McCulloch when they worked together to develop a computer that consisted of neural networks that would allow them to mimic the functioning of the human brain (Hung et al., 2019). The aforementioned developers developed the computer with a combination algorithms and arithmetical formulas and termed them as 'threshold logic' to mimic the cognitive ability of the brain (Lin et al., 2019, Litjens et al., 2017). Since its inception in 1943, the field of deep learning has been growing steadily, with many models and theories being developed and employed in various fields of research and organisation (Özkural, 2018). One of the first algorithm that was developed for deep learning was made possible by two specialists known as Alexey Grigoryevich Ivakhnenko and Valentin Grigor'evich Lapa in the year 1965 (Lin et al., 2019; LeCun, Bengio & Hinton, 2015). The development of their deep learning algorithm pertained to complex polynomial equations to activate different functions of the algorithm and then input various data sets to analyse them statistically. Additionally, from each layer, the best feature was statistically selected and forwarded to the next layer within the deep learning algorithm (Ketkar, 2017; Ker, Wang, Rao & Lim, 2017).

D. Deep Learning Models

Some of the typical models of deep learning include, "Autoencoder", "Deep Belief Network (DBN)", "Convolutional Neural Network (CNN)" and "Recurrent Neural Network (RNN)".

➢ *Autoencoder*

The main purpose of an autoencoder deep learning model is to compute and process complex data which includes high-dimensions. The main aim of this model is to learn the process of dimensionality reduction of data and then represent the outputs for easier understanding (Bao, Yue & Rao, 2017). With the employment of autoencoder deep learning model, researchers have been able to improve structures such as "Denoising Autoencoder" and "Sparse Autoencoder" (Schmidhuber, 2015). For the former autoencoder, it employs the use of data sets which includes random noises and use these random noises to calibrate the weight of deep learning network. This ensures that the output of the features extracted is more robust (Wolff, 2016). For the latter autoencoder, apart from the increasing number of neurons and hidden layers, it limits the activation of hidden nodes to some extent and then produce the output for the data (Kawaguchi, 2016).

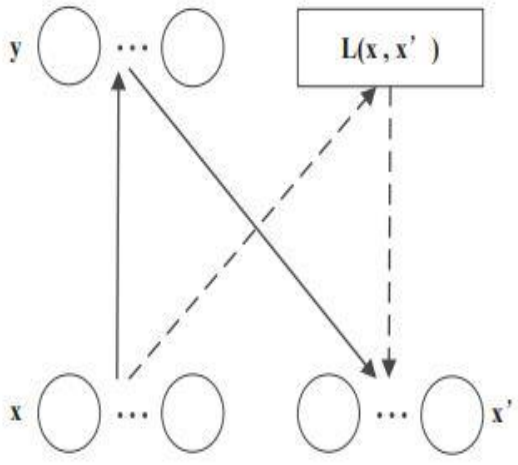

Fig. 2 *The basic principle of autoencoder: x is the input, while y is the output. L (x, x') is the error function. Source: (Ketkar, 2017)*

➢ *Deep Belief Network (DBN)*

The DBN is a type of deep learning model that is developed by many stacked Restricted Boltzmann Machines (RBMs). This model is a generative stochastic model, which is developed from Boltzmann machine (Chen, Zhao & Jia, 2017). Furthermore, within RBM there is no connection between the neurons present in the same layer and have simple connection between neurons in other hidden layers and if the neurons in the hidden layer are increased, an in-depth version of the Boltzmann machine is achieved (Ghasemi, Mehridehnavi, Fassi & Pérez-Sánchez, 2018). Additionally, this model is trained through the concept of greedy unsupervised learning method of weight adjustment, whereby, the training begins one-layer at a time and the output of the lower layer is then fed to the input of the higher layer, training and adjusting the weights of the neurons accordingly (Jiang, Liang, Feng, Fan, Pei, Xue & Guan, 2018). After each layer of neurons is trained and adjusted, a back-propagation model is applied to the whole model in order to fine-tune the whole network (Wang, Ma, Zhang, Gao & Wu, 2018).

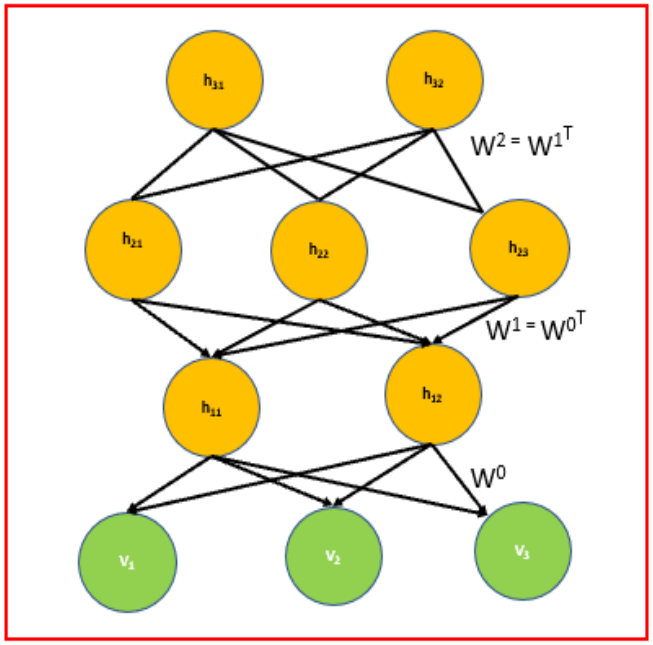

Fig 3. *A basic architecture of DBN. Source: (*Khandelwal, 2018*)*

➢ *Convolutional Neural Network (CNN)*

The CNN deep learning model is one of the most efficient models used in representing the output of data entered and has had a lot of attention over the past few years (Qian, Dong Wang & Tan, 2015). There are many structures within the CNN and some of them include, "LeNet", "AlexNet" and "GoogleNet", along with many others. CNN can be modified into various types according to intention and specification of research being carried out, and enhance the complexity of the network as well as improve the rate of accuracy of outputs obtained (Rawat & Wang, 2017). The CNN is mostly employed by researchers to identify and differentiate between images in the same way as the human brain identifies and differentiates images (Yamashita & Togashi, 2018). Additionally, the overall architecture of CNN was inspired by the organisation of the Visual Cortex and pertains to the analogous connectivity of the brain.

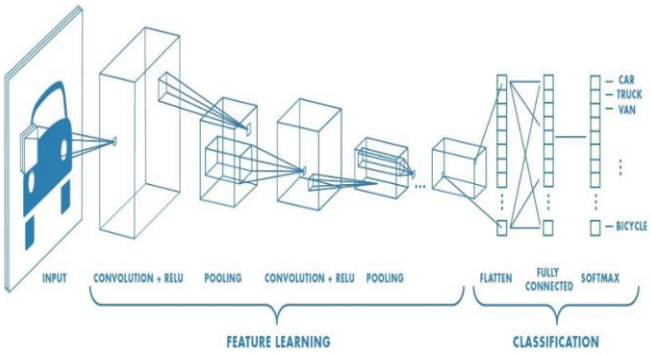

Fig 4. *A basic concept of CNN. Source: (*Saha, 2018*)*

➢ *Recurrent Neural Network (RNN)*

RNN is deep learning model which is much similar to an artificial neural network in the sense that it consists of feedforward neural network structure, but becomes unique when directed cycles are incorporated within RNN (Choi, Schuetz, Stewart & Sun, 2017). The structure of RNN allows to circulate the data inputs within the network in order to ensure that the output recieved is not only similar to the input, but also similar in terms of input values for each prior timestamp (Kim, Kim, Thu & Kim, 2016). It is important to highlight that although this model deals with data that incorporates time series, one of the drawbacks of this model is gradient vanishing during the process of back propagation (Mou, Ghamisi & Zhu, 2017). Thus, RNN is mostly employed in cases of short-term memory and for scientists and researchers to solve the issue of gradient vanishing and also be able to use it for long-term memory, they have introduced an improved structure known as Long Short-Term Memory (LSTM) (Yin, Zhu, Fei & He, 2017)

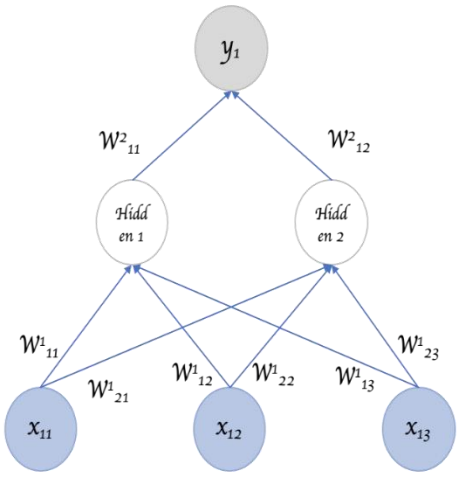

Fig 5. *RNN representation with an input size of 3 and two hidden layers and output layer. Source: (*Venkatachalam, 2019*)*

E. Applications of Deep Learning

There are various applications of deep learning that is being currently used in various fields and organisations, some of the applications include, image classification and image classification with localisation, object detection and image colorisation, alongside many other applications available.

Image Classification: Affonso *et al.* (2017) and Mou *et al.* (2017) describes that this application of deep learning pertains to the classification of image based on the recognising the patterns within the image.

Image classification with localisation: The deep learning algorithms involved in this classification pertains to identifying the object that is present in the image and identifying its location as well (Rawat & Wang, 2017). This relates to the display of a 'bounding box' that allows the users to evaluate whether the DL algorithm has identified the correct object and location or not (Ren, Girshick & Sun, 2017).

Object Detection: This application is similar to image classification with localisation in the sense that the main purpose of such algorithm is to identify the objects that is present within the image (Girshick, Donahue, Darrell & Malik, 2014; Zhao, Zheng, Xu & Wu, 2019). This is also done through the representation of a bounding box along with the name of the object identified (Han, Zhang, Cheng, Liu & Xu, 2018; Ren et al., 2017).

Image Colorisation: This application of deep learning pertains to the conversion of a grayscale image into a colour image. This mechanism is considered as a type of photo transformation rather than image or object identification (Hung et al., 2019).

III. METHOD

The method selected for this article pertained to secondary qualitative method, whereby the researchers reviewed various articles, research papers and journals of different authors in order to collect data for the purpose of this study. The authors ensured to collect data from authentic sources and use of any unpublished data, case studies and any unauthentic article or website was avoided by the researchers to maintain high quality of this research.

IV. DISCUSSION

These days the number of scientists and researchers researching for new technological innovations in the application of deep learning concept and models has increased astronomically. One field in society that has been targeted most is the healthcare industry.(Zhang et al., 2017). The study of Litjens *et al.* (2019) discuss in their article that the applications of deep learning is being employed in all phases of cardiovascular imaging. This pertains to employing deep learning models in echocardiography to intraoperative fluoroscopy (Litjens et al., 2019). As such, the applications of deep learning is not only limited to the field of healthcare, but is also being widely used for detection of images and evaluating patterns and features of the image (zhao et al., 2019). Deep learning algorithms are being employed for computer vision, which allows the user to classify images based on live image feeding or live video recording (Cheng, Yang & Sheng, 2015). Such algorithms are being mostly used for licence plate detection, vehicle identification system, and facial recognition, in conjunction with many other computer vision applications of deep learning (He, Zhang, Ren & Sun, 2016). Another practical application of deep learning algorithm is in the area of self-driving cars, where heavy computation of data is needed and this data needs to be processed in real time and precisely in order to ensure the safety of the driver and other pedestrians and cars nearby (Zhong, Wang, Ling & Dong, 2016). Some of the organisations that are employing the use of deep learning algorithms for self-driving cars include, Tesla, Google, Waymo and Uber, alongside many other car manufacturers who are researching in this field (Zhong et al., 2016).

Another popular employment of deep learning algorithms relates to voice search and voice activated assistants (Hauswald et al., 2015). Voice search and voice activated assistants allow users to operate their smartphone and computers with the help of a virtual assistant, through which, vocal commands sent by the user is recognised and the computer is able to take appropriate action (Wolff, 2016). Some of the common voice activated assistant include, Siri which was developed by Apple in 2011, Google Now, developed by Google is the voice assistant for android, and one of the latest voice activated assistant includes Cortana, which was developed by Microsoft (Thikshaja & Paul, 2020; Wang, Ma, Zhang, Gao & Wu, 2018).

Deep learning neural networks are being increasingly employed for the detection of Brain Cancer (Zhanget al., 2017). This is due to the fact that many researchers and brain surgeons found difficulties in identifying invasive brain cancer cells during the process of surgery (Kim, 2014). Thus, the combination of deep learning algorithm and Raman spectroscopy during the process of surgery, allows surgeons to easily detect cancerous cells and decrease the number of residual cancer after operation (Ghasemi et al., 2017).

One of the key benefits of employing the use of deep learning within different sectors is because of the accuracy of results and self-analysis and also self-categorisation of results (Wolff, 2016). For deep learning, large amounts of data is fed into the neural network and the network itself, with the aid of the many hidden layers, is able to classify the data and extract its features. This is not possible with machine learning due to the fact that the user has to manually extract the features of the data set and then feed it into the machine learning algorithms to receive appropriate outputs (Eskofier et al., 2016). Furthermore, another aspect where deep learning algorithms are more beneficial as compared to machine learning algorithms, is their technique of problem solving (Verhelst & Moons, 2020). In deep learning, the problems are solved through an end to end method, while in machine learning, all problems need to be broken in steps or stages and each stage is solved separately first and then the final result is combined at the output stage (Severyn & Moschitti, 2015).

Although there are many uses of deep learning algorithms and models, it also has its drawbacks, and some of which are; for deep learning algorithms and models to perform efficiently, it is necessary to input large amounts of datasets (Rawat, & Wang, 2017). Furthermore, due to use of large data sets, the training of these models is complex and requires the use of technologically advanced GPUs and many machines in order to ensure the efficiency of the system and the accuracy of the results (Sawat & Hegadi, 2016). Thus, this increases the cost incurred to the user or organisation. Moreover, the use of deep learning models requires skilled programmers, developers, and researchers, as it requires extensive knowledge of topology, parameters to be employed and various methods of training (Yin et al., 2017)

V. CONCLUSION

It is important to note that the introduction of the concept of deep learning, has aided many researchers, organisations and scientists in easing the process of computation and at the same time be able to compute arithmetically complex formulas and obtain efficient and accurate results. The inception of deep learning has had a big impact in major fields of research as well as industry and users should be knowledgeable of the fact that deep learning is not a solution to each question. With the amount of research being done and new algorithms that are being introduced in the field of deep learning, researchers and scientists have been able to create algorithms that are able to reach human-level performance and are able to perform tasks that a human can perform. As such, considering the many applications of deep learning, the area of computer vision heavily employs the use of deep algorithms as, large amounts of data needs to be computed quickly and accurately. With further advancements in technology in terms of both software and hardware, these applications of deep learning will be further improved and be able to compute results more quickly and effectively.

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