DEEP LEARNING: A REVIEW

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Abstract. Deep learning is an emerging area of machine learning (ML) research. It comprises multiple hidden layers of artificial neural networks. The deep learning methodology applies nonlinear transformations and model abstractions of high level in large databases. The recent advancements in deep learning architectures within numerous fields have already provided significant contributions in artificial intelligence. This article presents a state of the art survey on the contributions and the novel applications of deep learning. The following review chronologically presents how and in what major applications deep learning algorithms have been utilized. Furthermore, the superior and beneficial of the deep learning methodology and its hierarchy in layers and nonlinear operations are presented and compared with the more conventional algorithms in the common applications. The state of the art survey further provides a general overview on the novel concept and the ever-increasing advantages and popularity of deep learning.

Keywords: Deep learning, Machine Learning, Applied Deep Learning.

1 Introduction

Artificial intelligence (AI) as an intelligence exhibited by machines has been an effective approach to human learning and reasoning [1]. In 1950, "The Turing Test" was proposed as a satisfactory explanation of how a computer could perform a human cognitive reasoning [2]. As a research field, AI is divided in more specific research subfields. For example: Natural Language Processing (NLP) [3] can enhance the writing experience in various applications [4,17]. The most classic subdivision within NLP is machine translation, which is understood as the translation between languages. Machine translation algorithms have resulted in various applications that consider grammar structure as well as spelling mistakes. Moreover, a set of words and vocabulary related to the main topic is automatically used as the main source when the computer is suggesting changes to writer or editor [5]. Fig. 1 shows in detail how AI covers seven subfields of computer sciences.

Recently, machine learning and data mining have become the center of attention and the most popular topics among research community. These combined fields of study

analyze multiple possibilities of characterization of databases [9]. Through the years, databases have been collected with statistical purposes. Statistical curves can describe past, and present in order to predict future behaviors. Nevertheless, during the last decades only classic techniques and algorithms have been used to process this data, whereas an optimization of those algorithms could lead on an effective self–learning [19]. A better decision making can be implemented based on existing values, multiple criteria and statistics advanced methods. Thus, one of the most important application of this optimization is medicine, where symptoms, causes and medical solutions generate big databases that can be used to predict better treatments [11].
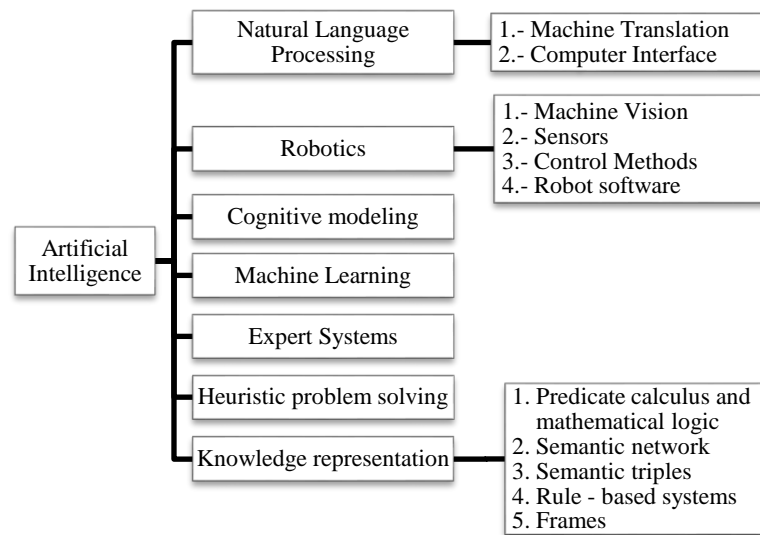
Fig. 1. Research in artificial intelligence (AI) Source: [1].

Since ML covers a wide range of research, many approaches have been established. Clustering, Bayesian Network, Deep Learning and Decision Tree Learning are only part of the approaches. The following review mainly focuses on deep learning, its basic concepts, past and nowadays applications in different fields. Additionally, it presents several figures portraying the rapid development of deep learning research through publications over the recent years in scientific databases.

2   Background

The Deep Learning (DL) concept appeared for the first time in 2006 as a new field of research within machine learning. It was first known as hierarchical learning at the [2],

and it usually involved many research fields related to pattern recognition. Deep learning mainly considers two key factors: nonlinear processing in multiple layers or stages and supervised or unsupervised learning [4]. Nonlinear processing in multiple layers refers to an algorithm where the current layer takes the output of the previous layer as an input. Hierarchy is established among layers to organize the importance of the data to be considered as useful or not. On the other hand, supervised and unsupervised learning is related with the class target label, its availability means a supervised system, whereas its absence means an unsupervised system.

3   Applications

Deep learning implies an abstract layer analysis and hierarchical methods. However, it can be utilized in numerous real life applications. As an example, within digital image processing; gray scale image coloring from a picture used to be done manually by users who had to choose each color based on their own judgment. Applying a deep learning algorithm, coloring can be performed automatically by a computer [10]. Similarly, sound can be added into a mute drumming video by using Recurrent Neural Networks (RNN) as part of the deep learning methods [18].

Deep learning can be understood as a method to improve results and optimize processing times in several computing processes. In the field of natural language processing, deep learning methods have been applied for image caption generation [20], and handwriting generation [6]. The following applications are categorized in pure digital image processing, medicine and biometrics.

3.1   Image Processing

Before deep learning officially appeared as a new research approach, some applications had been carried out within the concept of pattern recognition through layer processing. In 2003, an interesting example was developed by applying particle filtering and Bayesian − belief propagation. The main concept of this application proposes that a human can recognize the face of a person by watching only a half − cropped face picture [14], therefore a computer could be able to reconstruct the image of a face from a cropped one.

Later in 2006, greed algorithm and hierarchy were combined into an application capable to process handwritten digits [7]. Recent researches have applied deep learning as the main tool for digital image processing. For instance, applying a Convolutional Neural Networks (CNN) for Iris Recognition can be more effective than using conventional iris sensors. CNN effectiveness can reach up to 99.35 % of accuracy [16].

Mobile location recognition nowadays allows the user to know a determined address based on a picture. A Supervised Semantics − Preserving Deep Hashing (SSPDH) algorithm has proved a considerable improvement in comparison with Visual Hash Bit

(VHB) and Space – Saliency Fingerprint Selection (SSFS). The accuracy of SSPDH is even 70% more efficient [15].

Finally, another remarkable application in digital image processing, using deep learning method, is facial recognition. Google, Facebook and Microsoft have unique deep learning face recognition models [8]. Lately, identification based on a facial picture has changed to an automatic recognition by establishing age and gender as initial parameters. Sighthound Inc. for instance tested a deep convolutional neural network algorithm capable to recognize not only age and gender, but even emotions [3]. Furthermore, a robust system was developed to accurately determine the age and gender of a person from a single image by the application of a deep multi-task learning architecture [21].

3.2   Medicine

Digital image processing is undeniably an important part of the research fields where a deep learning method can be applied. Thus, clinical applications have been recently tested. For instance, a comparison between shallow learning and deep learning in neural networks leaded to a better performance on disease prediction. An image taken from a Magnetic Resonance Imaging (MRI) [22] from a human brain was processed in order to predict a possible Alzheimer disease [3]. Although the early success of this procedure, some issues should be considered for future applications. Training and dependency on high quality are some of the limitations. Volume, quality and complexity of data are challenging aspects, however the integration of heterogeneous data types is a potential aspect of deep learning architecture [17, 23].

Optical Coherence Tomography (OCT) is another example where deep learning methods are showing valuable results. Conventionally, images are treated by a manual development of convolutional matrices [12]. Unfortunately, the lack of training sets, limits the deep learning method. Nevertheless within a few years, the introduction of better training sets will effectively predict retinal pathologies and decrease OCT technology costs [24].

3.3   Biometrics

In 2009, an automatic speech recognition application was carried out to decrease the Phone Error Rate (PER) by using two different architectures of deep belief networks [18]. In 2012, CNN [25] method was applied within the framework of a Hybrid Neural Network - Hidden Markov Model (NN – HMM). As a result, a PER of 20.07 % was achieved. The PER obtained is better in comparison with a $3 -$ layer neural network baseline method previously applied [26]. Smartphones and their camera resolution have been tested on iris recognition. Using mobile phones developed by different companies the iris recognition accuracy can reach up to 87% of effectiveness [22,28].

In terms of security, especially access control; deep learning is used in conjunction with biometric characteristics. DL was employed to speed up the developing and optimization of FaceSentinel face recognition devices. According to this manufacturer, their devices could expand their identification process from one–to–one to one–to–many in nine months [27]. This engine advancement could have taken 10 man years without DL introduction. It accelerated the production and launch of the equipment. These devices are used in Heathrow airport in London and have the potential to be used for time and attendance and in the banking sector [3, 29].

4 Overview

Table 1 summarizes several applications carried out throughout previous years regarding deep learning. Mostly, speech recognition and image processing are mentioned. This review only considers a few from the large list of applications.

Table 1. Deep Learning Applications, 2003 - 2017.

Author	Application	Method/algorithm	Year
Tai Sing Lee, David Mumford	Hierarchical Bayesian inference in the visual cortex	Particle filtering and Bayesian - belief propagation	2003
Hinton, Geoffrey E., Simon Osindero, Yee-WhyeTeh.	Digit Classification	Complementary Priors on Belief networks	2006
Mohamed, Abdel-rahman, George Dahl, Geoffrey Hinton	Deep Belief Networks for phone recognition	Back propagation and associative memory architecture	2009
Abdel-Hamid Ossama, Mohamed Abdel-rahman,Jiang Hui, Penn Gerald	Multi-speaker speech recognition	Local filtering and max-pooling infrequency domain	2012
Kiran B. Raja, R. Raghavendra, Vinay Krishna Vemuri, Christoph Busch	Iris Recognition by using smartphones' cameras	Deep sparse filtering	2015
Silver David, et al	Mastering the Game of Go with Deep Neural Networks and Tree Search	Supervised learning and reinforcement learning	2016
Francesco Marra, Giovanni Poggi, Carlo Sansone,	Iris sensor model identification	Convolutional neural networks	2017

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## 4.1 Publication analysis per year

Fig. 1 details the number of deep learning publications from ScienceDirect database per year from 2006 till June 2017. Clearly, there is a progressive increment of publications that could describe an exponential growth.

Fig. 2 presents the total number of Springer's deep learning publications per year from Jan 2006 till Jun 2017. In 2016, there is a sudden increment of publications, reaching up to 706 publications, which proves that deep learning is truly a contemporaneous area of interest for researchers.

Fig. 3 shows the IEEE Digital Library's number of conference publications and journals & magazines from Jan 2006 till the Jun 2017. It is noticeable that since 2015 the number of publications has dramatically increased. The difference between 2016 and 2015 is even more than 200% of increment.
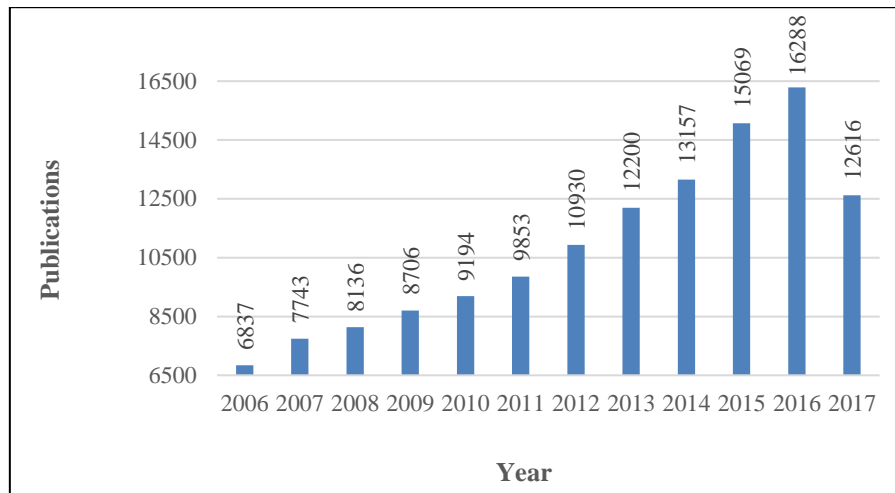
Fig. 1. Growth of the number of publications in Deep Learning, Sciencedirect database *(Jan 2006-Jun 2017)*
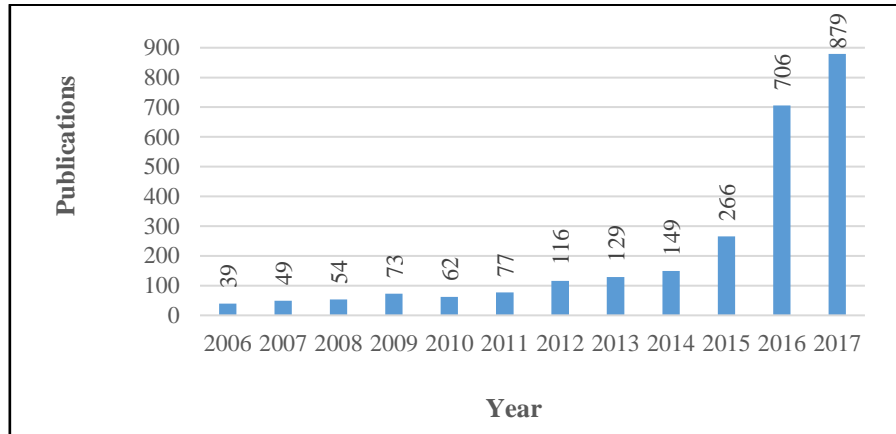
Fig. 2. Growth of the number of publications in Deep Learning from Springer database. *(Jan 2006-Jun 2017)*
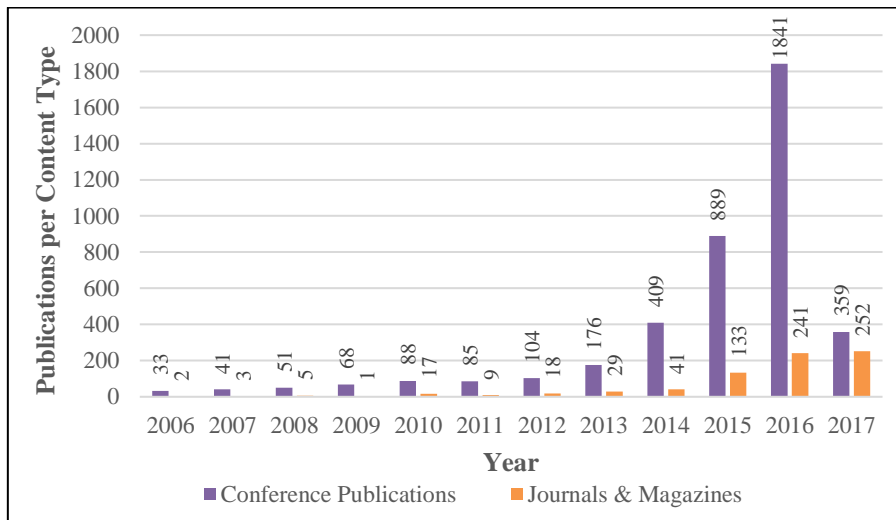
Fig. 3. Growth of publications in Deep Learning from IEEE database. *(Jan 2006-Jun 2017)*

5   Conclusions

Deep learning is indeed a fast growing application of machine learning. The numerous applications described above prove its rapid development in just few years. The usage of these algorithms in different fields shows its versatility. The publication analysis

performed in this study clearly demonstrates the relevance of this technology and gives a clearly illustrates the growth of deep learning and the tendency regarding for future research in this field.

Additionally, it is important to note that hierarchy of layers and the supervision in learning are key factors to develop a successful application regarding deep learning. Hierarchy is essential for appropriate data classification, whereas supervision considers the importance of the database itself to be part of the process. The main value of deep learning relies on the optimization of existing applications in machine learning, due to its innovativeness on hierarchical layer processing. Deep learning can deliver effective results on digital image processing and speech recognition. The reduction on error percentage (10 to 20 %) clearly corroborates the improvement compared with existing and tested methods.

During the current era and in a future, deep learning can result into a useful security tool due to the facial recognition and speech recognition combined. Besides this, digital image processing is a research field that can be applied in multiple areas. For this reason and having proved a true optimization, deep learning is a contemporary and exciting subject of advancement in artificial intelligence.

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