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Deep Learning

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***Abstract*—Deep Learning is a subfield of machine learning concerned with algorithms inspired by the structure and function of the brain called artificial neural networks. The core of deep learning is that we now have fast enough computers. Deep Learning models are vaguely inspired by information processing and communication patterns in biological nervous systems yet have various differences from the structural and functional properties of biological brains. The biggest limitation of deep learning models is that they learn observations.**

***Index Terms*—deep learning**

I. Introduction

Machine-learning technology powers many aspects of modern society: from web searches to content filtering on social net-works to recommendations on e-commerce websites, and it is increasingly present in consumer products such as cameras and smartphones. Machine-learning systems are used to identify objects in images, transcribe speech into text, match news items, posts or products with users' interests, and select relevant results of search. Increasingly, these applications make use of a class of techniques called deep learning.

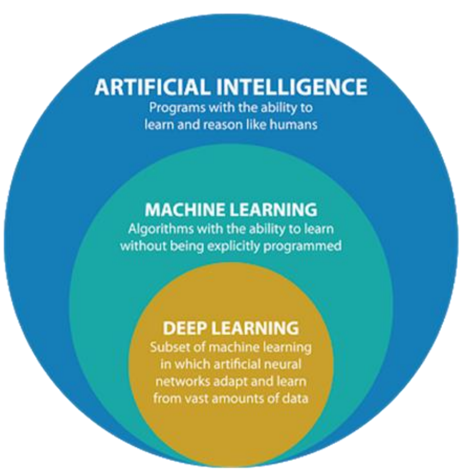

Fig. 1. Deep learning

Conventional machine-learning techniques were limited in their ability to process natural data in their raw form. For decades, con¬structing a pattern-recognition or machine-learning system required careful engineering and considerable domain expertise to design a fea¬ture extractor that transformed the raw data (such as the pixel values of an image) into a suitable internal representation or feature vector from which the learning subsystem, often a classifier, could detect or classify patterns in the input.

Representation learning is a set of methods that allows a machine to be fed with raw data and to automatically discover the representations needed for detection or classification. Deep-learning methods are representation-learning methods with multiple levels of representation, obtained by composing simple but non-linear modules that each transform the representation at one level (starting with the raw input) into a representation at a higher, slightly more abstract level. With the composition of enough such transformations, very complex functions can be learned. For classification tasks, higher layers of representation amplify aspects of the input that are important for discrimination and suppress irrelevant variations. An image, for example, comes in the form of an array of pixel values, and the learned features in the first layer of representation typically represent the presence or absence of edges at particular orientations and locations in the image. The second layer typically detects motifs by spotting particular arrangements of edges, regardless of small variations in the edge positions. The third layer may assemble motifs into larger combinations that correspond to parts of familiar objects, and subsequent layers would detect objects as combinations of these parts. The key aspect of deep learning is that these layers of features are not designed by human engineers: they are learned from data using a general-purpose learning procedure.

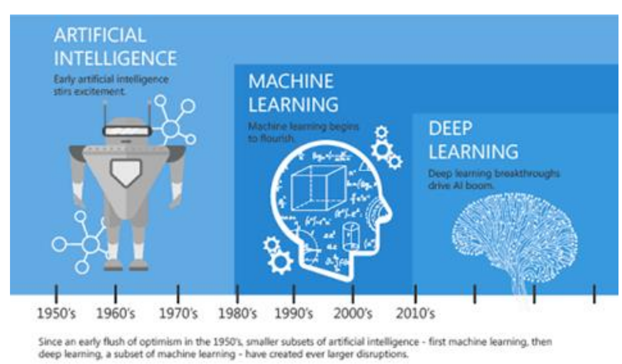

Fig. 2. Evolution of deep learning

Deep learning is making major advances in solving problems that have resisted the best attempts of the artificial intelligence community for many years. It has turned out to be very good at discovering intricate structures in high-dimensional data and is therefore applicable to many domains of science, business and government. In addition to beating records in image recognition and speech recognition, it has beaten other machine-learning

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techniques at predicting the activity of potential drug molecules, analyzing particle accelerator data, reconstructing brain circuits, and predicting the effects of mutations in non-coding DNA on gene expression and disease. Perhaps more surprisingly, deep learning has produced extremely promising results for various tasks in natural language understanding, particularly topic classification, sentiment analysis, question answering and language translation.

We think that deep learning will have many more successes in the near future because it requires very little engineering by hand, so it can easily take advantage of increases in the amount of available computation and data. New learning algorithms and architectures that are currently being developed for deep neural networks will only accelerate this progress.

A. *Some Historical Context of Deep Learning*

Until recently, most machine learning and signal processing techniques had exploited shallow-structured architectures. These architectures typically contain at most one or two layers of nonlinear feature transformations. Examples of the shallow architectures are Gaussian mixture models (GMMs), linear or nonlinear dynamical systems, conditional random fields (CRFs), maximum entropy (MaxEnt) models, support vector machines (SVMs), logistic regression, kernel regression, multilayer perceptron's (MLPs) with a single hidden layer including extreme learning machines (ELMs). For instance, SVMs use a shallow linear pattern separation model with one or zero feature transformation layer when the kernel trick is used or otherwise. (Notable exceptions are the recent kernel methods that have been inspired by and integrated with deep learning. Shallow architectures have been shown effective in solving many simple or well-constrained problems, but their limited modeling and representational power can cause difficulties when dealing with more complicated real-world applications involving natural signals such as human speech, natural sound and language, and natural image and visual scenes.

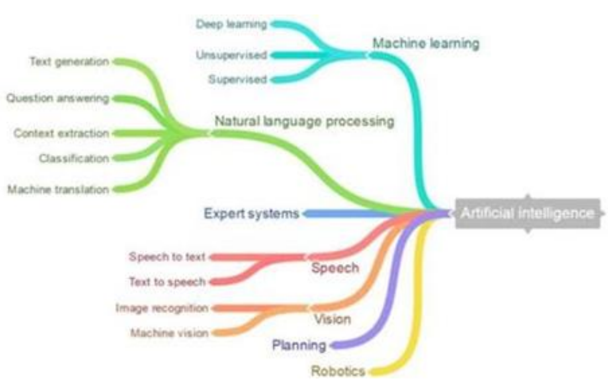

Fig. 3. Categorization of deep learning

B. *A Three-Way Categorization*

As described earlier, deep learning refers to a rather wide class of machine learning techniques and architectures, with the hallmark of using many layers of non-linear information processing that are hierarchical in nature. Depending on how the architectures and techniques are intended for use, e.g., synthesis/generation or recognition/ classification, one can broadly categorize most of the work in this area into three major classes:

1) *Deep networks for unsupervised or generative learning*

Which are intended to capture high-order correlation of the observed or visible data for pattern analysis or synthesis purposes when no information about target class labels is available. Unsupervised feature or representation learning in the literature refers to this category of the deep networks. When used in the generative mode, may also be intended to characterize joint statistical distributions of the visible data and their associated classes when available and being treated as part of the visible data. In the latter case, the use of Bayes rule can turn this type of generative networks into a discriminative one for learning.

2) *Deep networks for supervised learning*

Which are intended to directly provide discriminative power for pattern classification purposes, often by characterizing the posterior distributions of classes conditioned on the visible data. Target label data are always available in direct or indirect forms for such supervised learning. They are also called discriminative deep networks.

3) *Hybrid deep networks*

Where the goal is discrimination which is assisted, often in a significant way, with the outcomes of generative or unsupervised deep networks. This can be accomplished by better optimization or/and regularization of the deep networks in category. The goal can also be accomplished when discriminative criteria for supervised learning are used to estimate the parameters in any of the deep generative or unsupervised deep networks in category.

C. *Selected Applications in Language Modeling and Natural Language Processing*

Research in language, document, and text processing has seen increasing popularity recently in the signal processing community, and has been designated as one of the main focus areas by the IEEE Signal Processing Society's Speech and Language Processing Technical Committee. Applications of deep learning to this area started with language modeling (LM), where the goal is to provide a probability to any arbitrary sequence of words or other linguistic symbols (e.g., letters, characters, phones, etc.). Natural language processing (NLP) or computational linguistics also deals with sequences of words or other linguistic symbols, but the tasks are much more diverse (e.g., translation, parsing, text classification, etc.), not focusing on providing probabilities for linguistic symbols. The connection is that LM is often an important and very useful component of NLP systems. Applications to NLP is currently one of the most active areas in deep learning research, and deep learning is also considered as one promising direction by the

NLP research community. However, the intersection between the deep learning and NLP researchers is so far not nearly as large as that for the application areas of speech or vision. This is partly because the hard evidence for the superiority of deep learning over the current state of the art NLP methods has not been as strong as speech or visual object recognition.

II. 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; grayscale 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. Similarly, sound can be added into a mute drumming video by using Recurrent Neural Networks (RNN) as part of the deep learning methods. 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, and handwriting generation. The following applications are categorized in pure digital image processing, medicine and biometrics.

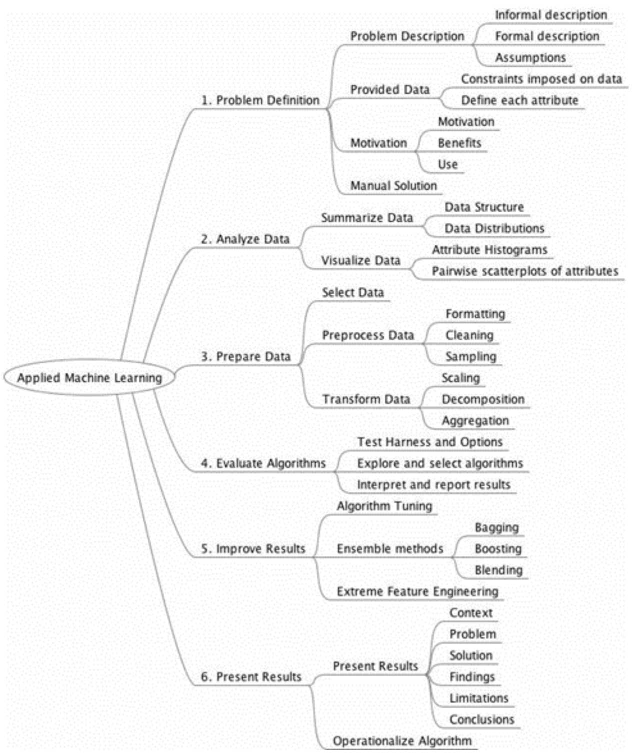

Fig. 4. Applied machine learning

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, 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. 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. 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.

2) *Medicine*

Deep learning methods have been tested for clinical applications. 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) from a human brain was processed in order to predict Alzheimer disease. 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.

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. In 2012, CNN 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. 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.

III. Conclusion

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 illustrates the growth of deep learning and the tendency regarding 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. As for future applications and research, it is essential to take into account that deep learning needs large datasets and computational power. Big enterprises such as Google or pharmaceutical companies offer computational capabilities to startups.

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