EMERGING TECHNOLOGIES IN COMPUTING

Theory, Practice, and Advances

Edited by
Pramod Kumar
Anuradha Tomar
R. Sharmila

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CHAPTER 1

Introduction to Emerging Technologies in Computer Science and Its Applications

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CONTENTS

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1.1 INTRODUCTION

The extensive and exhaustive research carried out in the field of Artificial Intelligence (AI) is a confirmation that it finds its applications in every field of life now-a-days. Researchers and scientists are making every possible effort to help the world by using AI, in turn making machines which think and maybe act like humans. We are aware that AI is like an umbrella that shelters numerous technologies under it and hence it is perceived as an interdisciplinary field with several approaches. AI is an eclectic branch of Computer Science that aims to respond to Turing's question in assenting and is responsible for developing smart machines capable of executing tasks that require human intelligence and is responsible for a visible paradigm shift in every sector of the technological world and thereby giving birth to new concepts and technologies on the way. Machine Learning is an application of AI, which aims at offering the machines or systems the capability to learn on its own and improve its experiences at every turn without human intervention. In order to make the machines learn, we need to provide them with ample amount of data so that machines can analyze some pattern in the data (if any) and make better decisions based on observing the data, working on the patterns of the data and then training the algorithms using that data [1,2]. Learning process is initiated by observing the data as mentioned above, and learning techniques can be as follows: supervised, unsupervised, semi-supervised, or reinforced based on the data to be trained and the application to be addressed. Hence, the main aim of Machine Learning is to allow the machines to learn on their own in the absence of human assistance and adjust their output or actions accordingly [3]. AI has given birth to many new technologies and Machine Learning is one of the ways to achieve AI. We will now be discussing some recent technologies which have been researched the most these days and are finding their way in every aspect of business, education, health, commercial, and other fields of life.

1.1.1 Computer Vision

Computer vision is such a type of AI which we all have naturally experienced in our lives in multiple ways without even realizing it. Such is the power of human brain and senses. Computer vision aims to replicate this power of human brain and senses using machines. Humans can (i) describe the content of the image or video they have seen, (ii) summarize an image or video they have seen, and (iii) recognize a face or an object that they have seen [4]. Hence, a machine can take advantage of human's capability of remembering things and people they have seen and make their machines learn the same capability using algorithms dedicated for this process. We all are aware that taking and uploading a picture or video on internet has become extremely easy; all we need is a smartphone and some social media platform. According to recent articles, around hundreds of videos are uploaded per minute on YouTube social platform; and the same is the case with other social platforms such as Facebook, Instagram, and Twitter. Around 3 billion images alone are shared online each day, maybe more. These images and videos can be easily recognized and summarized by humans but to train the machine for the same capability, we first need the machine to be able to index the content and then be able to search the content in that video or photograph. The Machine Learning algorithms will need to (i) find what the image or video contains and (ii) utilize the metadata descriptions provided by the person who has uploaded that image or video.

In simple terms, computer vision can be defined as a field of study focused on the problem of helping computers to see [5]. The goal of computer vision is to use the observed image data to infer something about the world [6]. Computer vision is an interdisciplinary technological field which deals with replicating and observing the human vision and brain processing system and facilitating the machines to identify and process items in images and videos in a similar manner as humans are capable of. Due to the advancements in AI, Neural Networks (NNs), and Deep Learning, computer vision has taken great leaps in recent years and is still a hot field among researchers [7]. Computer vision is also clearly a subfield of AI, Machine Learning, and Deep Learning, as it deals with overly complex data identification and interpretation. Due to recent advancements, computer vision has been able to successfully outdo humans in tasks of identifying, indexing, and labeling objects in the images or videos. This must have been experienced by many users while tagging people in images using social media platforms such as Facebook. The algorithms are trained in such an extensive manner that now they can perform better than humans in identifying and tagging items or people [8]. Another factor which is responsible for the better working of machines to achieve computer vision is that over the past few years, ample amount of data is being generated these days. Large amount of data generated is being used for training of Machine Learning algorithms which, in turn, leads to better results. The concept and aim of computer vision can be understood by referring to Figure 1.1.

Research and experiments on computer vision can be traced back to 1950s. But it was used commercially in 1970s to distinguish between handwritten text and typed text. Back then, there was not as much abundance of data as is the case now. Today, the applications have also increased as there is a huge amount of data, better trained algorithms and hardware. The data is so huge that these days data scientists are being hired to just analyze and work upon the data. It is the job of the data scientists to filter the data and select the data sets to be used for training of the algorithms. The computer vision market is expected to reach $48.6 billion by early 2022 [5].

Another topic of discussion is how does computer vision work? This question is not simple to answer as computer vision is inspired by the human brain. Since it is still not clear how human brain and eyes work to interpret the objects, it is difficult to approximate the same concept in algorithms. All we can say is that computer vision mimics the way human brain works. However, it is difficult to comment on how well the developed algorithms will be able to copy the human brain and implement it

FIGURE 1.1 Object detection and classification. (From Jarvis, R.A., *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 122–139, 1983. With permission.) [5].

on machines. Current algorithms are heavily using Pattern Recognition approach to achieve computer vision. Hence, to make the computer understand and to train the algorithm, the approach used is to feed the system with a lot of data (i.e. images of the objects to be identified). Larger the data set, better labeling would be achieved. Then, these labeled images or objects would be subjected to various algorithms or software to identify the patterns with the objects and thereby in classification (Figure 1.1). When a large data set of images is fed to the machine, the algorithms analyze the angles, shapes, colors, and borders of the objects and the distance between various objects. After this analysis, the machine would match these unlabeled images with the labeled images and put them in the respective image set of objects (single object image or multiple object image). The basic working of computer vision algorithm is divided into (i) classification, (ii) localization, (iii) object detection, and (iv) instance segmentation. Algorithms train better when the input image data set is big, even though large image data set means larger memory requirements, but in the end, we get a better trained algorithm.

In recent years, Machine Learning and Deep Learning technology produce better results as compared to previous efforts where the working of machines was extremely limited. Earlier, a set manual approach was used where first a database was created in which all captured images were stored that needed analysis. Second, all images had to be annotated, i.e. many key points were added to the images for labeling them, and manually rules were coded for each object in the image. Third, new images were captured, and the entire process had to be repeated. When Machine Learning came into the picture, the manual rule coding was eliminated and feature extraction using various Machine Learning algorithms such as Support Vector Machine (SVM) and linear regression were used to identify patterns and classify further. However, in recent years, Deep Learning has given a new approach to apply Machine Learning to the data set by using NNs. The detailed working of Deep Learning for computer vision is out of the scope of this chapter.

Computer vision finds many applications today and users are making use of computer vision knowingly or unknowingly. The applications of computer vision include (i) computer vision in facial recognition, (ii) computer vision in self-driving cars, (iii) computer vision in healthcare, and (iv) computer vision in augmented reality (AR).

1.1.2 Deep Learning

Deep Learning is a subset of Machine Learning that aims to further automate the functions of a human being.

It is a branch based on the building algorithms that learn and re-learn by mimicking the functions of a human brain.

Just like the NN helps humans learn from their experiences, artificial neural networks (ANNs) help an algorithm learn and execute the task.

ANNs, also generally called NNs, are computing systems vaguely inspired by the biological NNs that constitute animal brains.

An ANN comprises multiple artificial neurons (or nodes) arranged in a network of multiple layers, which loosely models the NN of the biological brain (Figure 1.2).

Each connection, like the synapses in a biological brain, can transmit a signal to other neurons.

The "signal" comprises input data (in real numbers) and then processes it before sending it further down the chain. Every neuron processes the data before transmitting it further.

Different layers of the neurons perform different transformations on their inputs. Signals travel from the first layer (the input layer) to the last layer (the output layer), possibly after traversing the layers multiple times.

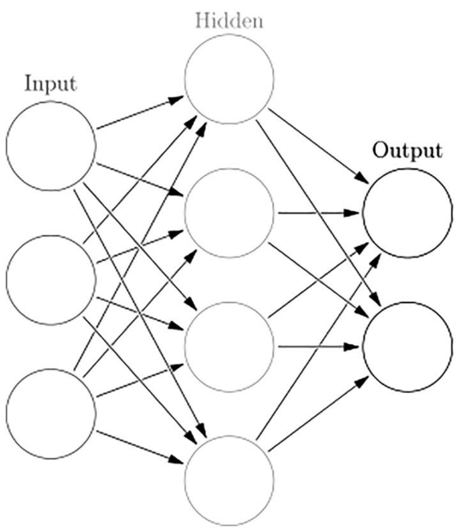

FIGURE 1.2 Artificial neural network layers.

There are a few different types of ANNs designed to execute different tasks. The major ones are listed below.

- Multilayer Perceptron Networks.
- Convolutional NNs.
- Long Short-Term Memory or Recurrent NNs.

Once the data is prepared for processing, it is fed to the NN in the first layer, also known as the input layer.

Now the neurons process this data and send it further down to the next layer. Each layer is designed to perform a specific task. The middle layers are also called the hidden layers.

Once the data is sequentially processed by each hidden layer, the model transmits the processed data to the output layer (the last layer).

In the output layer, the data is further processed finally as designed and gives out the final model. This one pass of the data through the network is called an epoch.

This output is then tested for accuracy; most often than not, the output of the first epoch is far from being correct. Therefore, this information is passed back to the network in reverse order so that the network can learn from its mistakes. This is called back-propagation.

The network then tweaks its parameters further and processes the data in a similar fashion. This process is continued for several epochs until the model starts producing acceptably accurate results.

The theory, model, and the data existed earlier as well, though it is only the advancements in the technology that have empowered this vision into reality.

Today we have access to sophisticated data management architectures and the computational power to process this massive data. This has made the access to these technologies fairly simple.

The most prominent technologies on this front are TensorFlow, Keras, and Pytorch that have enabled everyone to access the state-of-art technology of Deep Learning.

There are not many differences between Machine Learning and Deep Learning. Here are a few.

While Machine Learning is based on pre-defined models or algorithms, Deep Learning is built on NN architecture. It further removes the need for human intervention for feature selection in the data.

Since Deep Learning is state-of-the-art, it requires high computational power to be processed, which is now possible with the advanced GPUs.

Deep Learning finds its applications in several industries. Some of the major applications of Deep Learning are as follows:

- Self-driving cars
- News aggregation and fraud news detection
- Natural language processing
- Virtual assistants
- Recommender systems
- Visual recognition
- Credit fraud detection
- Healthcare and diagnostics

There are many more. The possibilities are endless (Figure 1.3).

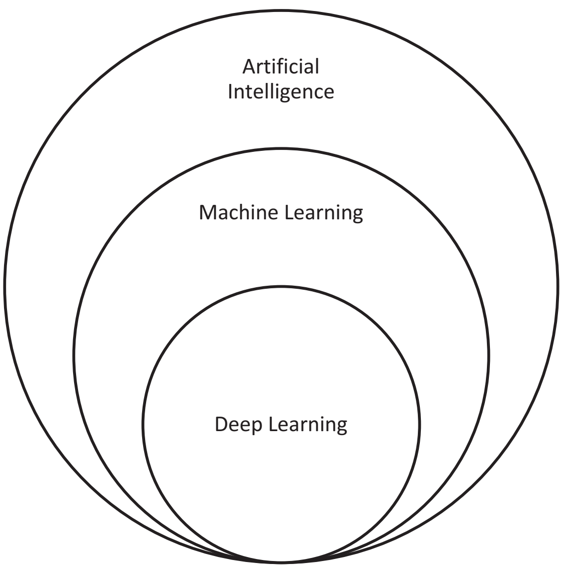

FIGURE 1.3 Relationship between artificial intelligence, machine learning, and deep learning.

1.1.3 Internet of Things (IoT)

Researchers describe Internet of Things (IoT) as a wide network of physical devices or objects connected with each other over the internet for the purpose of exchanging data and communication with each other, as depicted in Figure 1.4. These devices can also be called as smart devices as they require minimum or no human intervention for their processing. These physical devices are embedded with sensors and technologies for establishing connection with other devices. Today such devices range from basic household devices to much sophisticated engineering devices. As predicted by experts, the number of connected IoT devices is expected to increase from current 8 billion to 45 billion by 2025 or maybe more [9]. Examples of such devices range from a smart coffee maker, smart lightbulb, smart toy, baby monitor, and driverless vehicle to a smart city. A device being controlled by a smartphone or a controlled environment fall under the category of IoT or smart devices. IoT has become one of the most sought after technologies of recent times to provide effortless and continuous communication between people and things (devices) [10]. This has made every possible device connect to other devices over the internet via embedded devices. These devices cooperate by making the physical world meet the digital world [11].

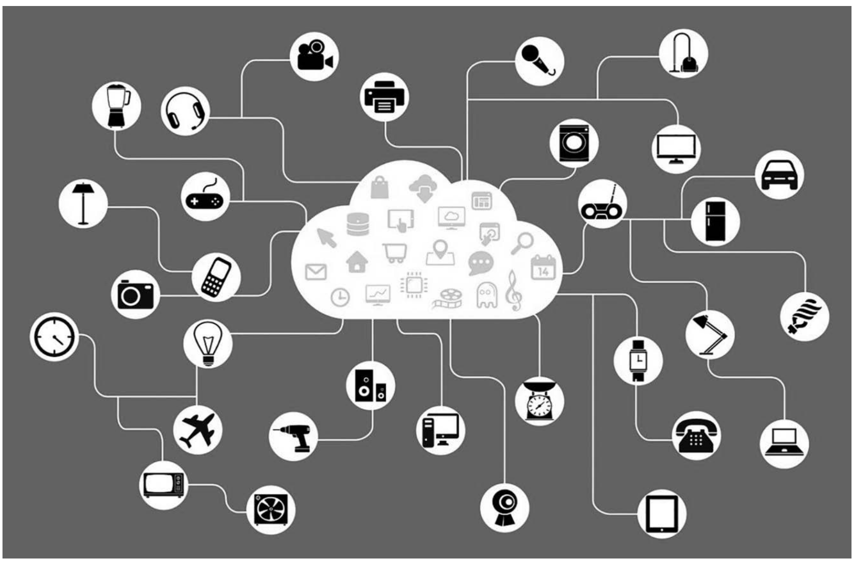

FIGURE 1.4 Device connectivity over the internet.

The connection of a large number of embedded devices over the internet has been possible due to the availability of mobile technologies, low-power sensor technologies, low-cost computing capabilities, cloud connectivity, Machine Learning and big data analytics, and AI. These devices communicate, share, and collect data with other embedded devices with minimum human intervention; hence, the demand of IoT devices is increasing gradually. IoT has large business scope due to its benefits in marketplace. Benefits include: (i) new IoT-based business models, (ii) increased productivity due to smart connectivity, (iii) efficient business operations, (iv) better revenue modes, and (v) smooth connection between physical business world and digital world [12]. Due to these benefits, IoT has become widespread in the industrial world and there is a new classification of IoT: Industrial Internet of Things (IIoT). IIoT refers to the merging of the IoT technology in industrial environments. To integrate IoT in industrial settings, industries have used cloud, analytics, Machine Learning and machine-to-machine (M2M) communication for wireless automation and control among connected devices.

This integration of IoT in industries has led to a large number of application areas such as smart homes, smart cities, smart logistics, smart manufacturing, smart power grids, smart digital supply chains, and predictive logistics and maintenance, among others.

Devices have been able to connect digitally over the internet low-power chips and cloud technologies, and the device connectivity will keep on increasing as discussed above. However, this device connectivity is highly vulnerable to security threats as these devices collect and communicate almost all of the user's sensitive data over the internet. Until now, security has been the biggest area of concern and the most researched area of IoT. Researchers are continuously working on to make the devices self-capable in order to find the patches of the detected faults in security. These software faults are regularly discovered and hence their patches are of utmost requirement, but many devices lack the capability to remove the risk factors of these faults, thereby keeping the devices and users at permanent risk, ultimately making the user vulnerable to hackers. Hackers can hack the sensors of the device and control the entire environment by manipulating the sensors without the user's knowledge, and this threat can be minor or catastrophic. One example of such security vulnerability in users wearing a smartwatch is hackers being able to eavesdrop the user's conversations even when the microphone is switched off or track the user's location all the time even when internet is disabled. And such security threats put all users at risks in using small household devices and business or industrial devices. As discussed above, IoT connects physical devices with digital devices; hence, the real world between the two is always at risk. Hence, the current area of research in IoT these days revolves mostly around security concerns.

As security is a major concern in IoT, so is privacy. By always being connected over the internet using embedded devices, privacy takes a back seat in the entire process and hence the security lapse. IoT models have user's data which can be manipulated to achieve some cause or worse it can be sold to companies or can be made available over the dark web. Hence, it becomes equally important for the users to be aware about the bargain they make while using these smart devices. Apart from security and privacy, other IoT concerns can be cost, connectivity, user's acceptance, and device standards.

IoT has given rise to big data analytics as IoT generates vast amount of data on a daily basis and hence has given companies vast data sets to analyze and work upon. This data can be in many different forms such as images, videos, audios, pressure or temperature readings or heartbeat, or other sensor readings. This vast amount of data has given rise to metadata, which contains data about data. This huge data cannot be stored in the company's data warehouse or other resources, but on the cloud. Hence, IoT, in turn, has given rise to the need for cloud services with every company aiming to achieve the IoT business model. These days, from small organizations and institutes to large multinational companies, all are making use of cloud services to better manage the data. With better connectivity (3G, 4G, 5G, CDMA, GSM, and LTE networks) and new technologies, the IoT market will continue to evolve even with security and privacy issues.

1.1.4 Quantum Computing

Current generation computers are based on classical physics and therefore on classical computing. In theory, i.e. Turing machines and in practice, i.e. PCs, laptops, smartphones, tablets all are current generation computers and work on the principle of classical computing and are called classical computers. These classical computers can only be in one state at a particular time and their operations can only have local effects, i.e. they are limited by locality [13]. As we are aware, the fundamental principle behind the computer systems is the ability to store, fetch, and manipulate information. This information is stored in the form of bits, i.e. binary 0 and 1 states, and all the manipulation is carried out by using these binary 0 and 1 states only [14]. These two bits are used in all classical computers. However, we have shifted from classical physics to quantum physics, as the real world behaves quite randomly and this behavior is not fixed; and to capture this random behavior of world using the machines, we cannot always use classical computers, or computers using classical computing as they remain in a single state at a particular time as discussed above, hence the shift from classical computers to quantum computers. A quantum computer can be in different states at the same time and the different states can be superimposed upon each other, and hence interference among different states can be achieved during processing. This superimposition of states can be achieved by using quantum bits, also called as qubits [14]. Hence, quantum computers manipulate the information stored by applying quantum mechanical principle using qubits instead of bits. A cluster of these quantum computers [15] can be either locally placed or spatially distributed but, in any case, they can achieve the non-local effects due to state superimposition.

As discussed above, quantum computing uses the principles of quantum mechanics and examines the processing power and related properties of computers. The main aim of quantum computing is to develop quantum algorithms to be used in quantum computers which would be faster and better than classical algorithms being used in classical computers [15]. Quantum computing is aimed to speed up the computation and to solve computationally hard problems which are not only difficult but next to impossible to solve using classical computers.

The field of quantum computing started with the use of analog quantum computers in the early 1980s by Yuri Manin [16], Richard Feynman [17,18], and Paul Benioff [19]. Although the work in this field has not been progressing at an extremely fast pace, the first noted algorithms in this field were developed later by Deutsch [20] and Simon [21]. The work on quantum complexity theory was initiated by Bernstein and Vazirani [14]. The work pace and interest in the field caught up fast in 1994 when Peter Shor discovered the efficient quantum algorithms for integer factorization and discrete logarithms problems [20].

Quantum mechanical phenomena use three basic quantum properties: (i) superposition: it is a condition where two or more independent states are combined to yield a new state. An example of such superposition would be the combination of two or more music notes, and the final music that we hear would be the super positioned note; (ii) Entanglement: it is a counter-intuitive quantum behavior which is not visible in the classical environment. Here, the object particles are entangled with each other and form a new model or environment. This new model behaves in entirely new ways which is not possible in the classical world and also cannot be explained using classical computing logic; and (iii) Interference: interference of quantum states occurs due to the logic of phase. Due to the phenomenon of phase, the states undergo interference. This logic of state interference is similar to the logic of wave interference. In wave interference, the wave amplitudes add when they are in phase, else their amplitudes cancel each other. To develop a fault-tolerant quantum system and to enhance the computational capabilities of a quantum computer, researchers are working toward improving the (i) qubit count: the aim to create more qubit states; more the qubit states, more the options of manipulation and processing of states; and (ii) low error rates: the aim is to eliminate the possible noise and errors encountered while working on multiple qubit states. Low error rates are required to manage qubit states in an efficient manner and to perform all sequential or parallel operations. Volume is considered to be a useful metric for analyzing quantum computer capability [14]. Volume measures the correlation between the quality and number of qubits, the error rates of qubit processing, and the quantum computer circuit connectivity. Hence, the aim is to develop quantum computers with large quantum volume for solving computational hard problems [22,23].

The basic motivation to research in the field of quantum computing is that the classical computers themselves have become so powerful and cheap due to miniaturization that they have almost already reached micro levels where quantum processing and effects are said to occur. The chip makers have led to such a level of miniaturization that instead of suppressing the quantum effects in classical computers, researchers might try to work with them, leading to further miniaturization and hence more quantum effects. It is too soon to comment on the pressing question “to what extent will quantum computers be built?” The first 2-qubit quantum computer was developed in 1997, and then a 5-qubit quantum computer was built in 2001 to find the factor of number 15 [21]. The largest quantum computer up until now has only few dozen qubits. Hence, the work on quantum computers has been rather slow but at a steady pace.

1.1.5 Edge Computing

With the rise in IoT-connected devices, edge computing has also come into the picture and is transmuting the manner in which data is being processed, managed, stored, and distributed to the users by millions and millions of connected devices around the globe. As discussed in Section 1.1.3, in IoT, the connected devices generate tremendous amount of data which is stored and retrieved from either a centralized storage location or cloud-based storage location. And this data is expected to continue to grow at an unprecedented growth. Hence, more time is being spent in storing and retrieving the generated data. IoT, real-time computing power, and faster networking medium and technologies like 5G (wireless) have aided edge computing with a large number of opportunities in business industries.

As per the definition given by celebrated researcher Gartner, edge computing is a part of a distributed computing topology in which information processing is located closer to the edge, also called as edge nodes (Figure 1.5), where things and people produce or consume that information [24]. It is understood that edge computing gets the data storage and its processing closer to where the data is being generated. Hence, edge computing is a decentralized distributed computing framework bringing the enterprise data closer to data sources [25].

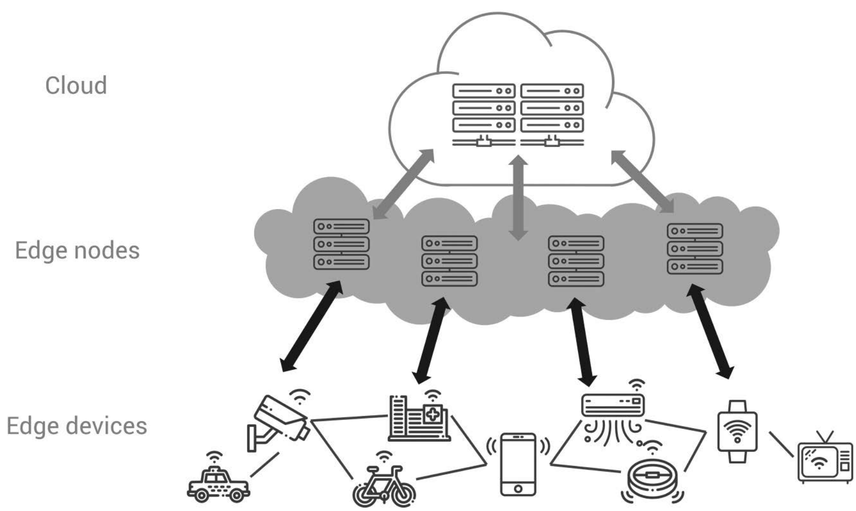

FIGURE 1.5 Edge nodes and edge devices.