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A Study on Applications of Cognitive Computing in the Internet of Things

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***Abstract*—** The introduction of the Cognitive Approach of Computing would lead to a comprehensive and better decision-making system. This approach of cognitive computing on the Internet of Things is called Cognitive IoT or CIoT. This paper focuses on various different kinds of applications of Cognitive Computing in the field of IoT. The goal of Cognitive IoT is to make computers understand people by trying to recreate how the neocortex in our brain works to make them think like humans. These fields are interdependent as the computer requires numerous data points. With a collection of other devices performing the same task, their results can be used as information for the system to learn. The Internet of Things' concept of a "system of systems" helps Cognitive Computing's core plan to simulate the human brain move forward.

***Keywords*—** Cognitive Computing, Internet of Things, Artificial Intelligence, Machine Learning, Big Data Analysis

I. INTRODUCTION

The idea of Cognitive Computing goes back to the late 19th Century when George Boole, a Mathematician wrote a book called “The Laws of thought” [1] and when Charles Babbage, again a Mathematician also known as the Father of Computer proposed in creating a machine, which he termed as “Analytical Engine”, meaning it analyses or thinks.

The word AI (Artificial Intelligence) was later coined by John McCarthy in 1955 and was defined as “The Science and Engineering of Making Intelligent Machines” [1].

The world was excited to see when IBM’s Deep Blue beat Garry Kasparov, the current chess world champion in the year 1977 [1].

In the year 2005, the DARPA Grand Challenge was won by the Stanford built Robot [24].

In the year 2011, yet again, IBM’s Watson defeated the two of the greatest Jeopardy! Champions without Internet!

Ideas about thinking machines are from the ancient history with Greek mythologists imagining such artificial devices like the automatons of Hero of Alexandria, Hephaestus’ bronze robot Talos, and the carved ivory statue Galatea that came to life in Ovid’s retelling of Pygmalion [1]. Grand creations like these have been in the purview of human imagination for a very long time, but only in the past 30-40 years the reality of Cognitive Computing start to evident in our daily lives [1].

The goal of cognitive computing is to simulate human thought processes in a computerized model by the use of self-learning algorithms that use data mining, pattern recognition, natural language, and sentiment analysis processing to mimic the human brain. This procedure involves replicating the neocortex, the part in our brains that see, controls our bodies, understands languages and does the math. If we were to translate the neocortex to computer code, the result would be a computer that thinks like a person. Except it doesn't need to eat or sleep [1].

The major bottleneck of this idea is the data which is being generated at an exponential rate, but not being fully processed. Thus, we have Big Data Analytics to solve these problems. The current Big Data Algorithms that are processing the data that is being generated is better than how it was before. The information was gathered only from a basic input device like a keyboard or a mouse, but these days, the introduction of data from various sensors has led to the generation of large amounts of significant data which can be synthesized to make better decisions.

So, if this information is fed to a computer and the computer itself could coordinate and calibrate the sensors based on its own intelligence, we would have the best decision maker in our era of computing. In order to process and collect vast amounts of data, we needed a system that could obtain the results of various analysis from various different systems.

The Internet of Things accelerates this process, by connecting millions or even billions of devices to the internet. Related devices become interconnected with each other and it forms a system of systems. When this data is sent over the cloud and analyzed, it can transform our lives

and our world in countless ways. The mix of Cognitive Computing and IoT is Cognitive IoT. Here, we use the cognitive computing technologies in addition to the data generated by different connected devices. These systems must learn by being able to automatically derive new knowledge from data which is a key component. These computer systems must be able to understand at scale.

Cognitive computing is very significant to the Internet of Things for a few compelling reasons.

Applying machine learning is essential. The data generated can rapidly overwhelm the human ability to detect and analyze important patterns of learning.

Computing must move into the physical world. Currently, we need to move beyond current machine interface standards that require humans to learn the abstractions needed to interact with machines. As more people of various age groups and skill levels begin to interact with these systems, these systems must begin to understand people.

In the Internet of Things, many data sources exist that may provide information for better understanding and decision making. The ability to analyze, process and integrate different types of digital sensor data to identify patterns across these data types have very powerful capabilities. If the machine is able to understand the context and the intentions of its operators its knowledge can be greatly enhanced.

II. COGNITIVE INTERNET OF THINGS

In simple words, Cognitive IOT can be defined as the use of Cognitive Computing Technologies with a huge amount of data generated by billions of connected devices and the data and actions those devices can perform.

We probably know how the Internet of Things work and what we mean about sensors and actuators.

In respect to Cognitive Computing, how does it make sense with the Internet of Things?

Cognition does mean Thinking, and as computers are not able to think like humans, they can perform some of the same underlying functions that humans perceive as thinking. Cognition involves three main elements:

1. Understanding
2. Reasoning
3. Learning [3]

In a computer, *Understanding* means the ability to take in a large amount of Dark Data also known as unstructured data and structured data and derive a meaning out of it like establishing a model of concepts, entities, and relationships [3].

Reasoning means using the derived data models and solves related problems without having the answers and solutions specifically programmed [3].

Learning means the ability to automatically infer new knowledge from data, which is the key component in understanding at scale [3].

Building too complex data models of concepts and its relationships can be tiresome, time-consuming and costly. Furthermore, there are many relationships that are not known beforehand, so they are practically possible to look at only using a machine automatically analyze a large set of data and discover patterns in them.

III. THINKING THINGS

[3]

The approach of cognitive computing is essential for the Internet of Things for a few specific reasons.

- Rate and scale of data generation [3]: As there is a huge number of devices connected, there are an exponential amount of data being generated by these devices. The learning helps optimize systems or processes to make them more efficient by combining the sensor data with other contextual information available in the system. The data generated by these devices can quickly surprise the human ability to analyze for learning and detecting new important patterns.

- Computing's movement to the physical world [3]: We need to move towards more human-centric interface from the present machine interface paradigms so that the people from all ages and technical skills could interact with the Internet of Things systems. They should be able to naturally speak and interact with the Internet of Things and the systems need to start understanding people from the information provided. Author David Rose from MIT Media Lab coined the term "enchanted objects" to characterize the seemingly intelligent

behavior that we can interpret into connected devices through the Internet of Things and cognitive computing.

- Integration of multiple data sources and types [3]: For better understanding and decision making, there may be many data sources that provide related information or context. The systems should have powerful capabilities of digesting and analyzing different types of data, including digital sensor data, audio, video, unstructured, structured, location data, and so on. The decision making and reasoning can be improved by the help of integration of multiple different data sources. For example, correlating sensor data with acoustic data.

According to John E. Kelly, "Cognitive Computing refers to systems that learn at scale, reason with purpose and interact with humans naturally. Rather than being explicitly programmed, they learn and reason from their interactions with us and from their experiences with their environment." [2]

Cognitive Internet of Things enables us to learn from, and infuse intelligence to the physical world to transform businesses like B2B and B2C and enhance the human experience.

By this, we can infer that this system basically works by, observing the surroundings, evaluating the patterns, interpreting the patterns evaluated and finally making the right decision.

Technically, it works by, defining the field of Knowledge obtained by the sensors, defining the corpus of knowledge, curating the content defined, ingesting it with indexes, metadata and knowledge graphs, training (via Machine Learning), building a reasoning model, further training and fine-tuning by human interaction and we finally have a Cognitive IOT System [2].

In the future IoT and big-data management, large scale industrial automation applications will bring out the importance of the internet increasing day by day. Many technologies such as computational intelligence, machine type communication, big-data, and sensor technology can be incorporated together to improve the data management and knowledge discovery efficiency of large-scale automation applications [22].

The knowledge organization from IoT and big-data always need a database and a knowledge base to give the cognitive outputs like plans and decisions for monitoring time-dependent automation applications [22].

Using various methods of collecting data (statistical analysis) now and in the future, IoT big-data management and knowledge discovery perspective, many sensors, RFID devices, wearable intelligent devices, and various other smart technologies can be used to develop a large-scale in-depth knowledge base [22].

IV. CASE STUDY: OPEN COGNITIVE INTERFACE WITH HARMAN [2]

The WAV files from the Internet of Things Foundation are sent to Speech to Text Conversion through MQTT.
In the Speech to Text conversion, the question is taken as a string such as "Will the storm hit Job #123 tomorrow?"

This string is passed on to the Natural Language Classifier where the Question's class is noted down such as for example temperature, rain, snow, wind, etc. In this particular example taken, it classifies Class as weather and Class as Snow.

Then the information is passed on to the Relationship Extractor where the relationship between the class, location and time is retrieved. In this particular example, it is 'Tomorrow'.

Then this information is stored in a database as in this particular example it is 'Job Site #123 is in Rajankunte, Bangalore'

Then this information is sent to the Insights for the weather where weather data for the location and time is obtained. In this particular example, it gives 'Chances of stormy weather in Rajankunte tomorrow is 30%'.

The final text is sent to the text to speech converter where the result obtained is converted to a WAV file back.

This file is sent back to the device through the Internet of Things Foundation over MQTT [2].

V. APPLICATIONS OF COGNITIVE INTERNET OF THINGS

1. WORLD WIDE WEB:

We all know that the World Wide Web or WWW refers to the Web or information space where documents and other web resources are identified by Uniform Resource Locator also known as URL [6]. The usage of webpages or websites by the Internet of Things to control the devices are huge. The number of devices a person use also cannot be limited to one device. Then, we would have a limitation of the addressability of the device. Now, as we have the IPv6 addresses, we can give almost a hundred addresses to an atom in this universe. That is almost like giving a hundred different names to an atom. Likewise, we do not have any limitation on the number of devices that we can connect together and use at a time. Managing these devices on

different platforms or webpages can be tiresome [5]. Collaborating one speech, to do many tasks together can be achieved by using platforms like 'If This Then That' also known as IFTTT. Likewise, if we can inculcate all the devices under one webpage and let the cognitive system understand the readings given by these sensors or devices, we can have an automated decision maker for the devices to act accordingly. Let's say, an IOT surveillance system [4] has been set up to monitor thefts and a cognitive system is watching over the different activities going around in the surroundings and identify whether a person is trying to either have a look at the item or is the person trying to steal that article. Similarly, we could use the Cognitive IOT approach in the Web Applications of the financial sector to decide whether a person can pay back a certain amount or not according to his/her monthly expenditure.

2. ENVIRONMENT MODELLING:

When an environmental change is predicted to be made either natural or man-made, the response of the change can also be predicted by mathematic modeling also known as Environment Modelling. It can also be used to reduce pollution in a certain place by knowing the climate and rate of change in climate due to various reasons in the place. There are many sensors to detect any kind of pollution, majorly air pollution, water pollution, and noise pollution. Combining these sensors and obtaining the geographical data of the place and analyzing the result of the place according to the change in climate can be made possible by combining the Internet of Things which connects the sensors and merges different set of data and Cognitive Computing to analyze the previous set of data, analyze and predict the future changes that can happen at a place in respect to time. This type of application can also be applied to reduce road accidents by inculcating different sensors communicating with each other and use cognitive system of approach to decide whether an accident could happen or not according to various aspects like the presence of potholes in the road or over speeding vehicles in range and number of accidents that had happened before in the same place and the reason and data for such accidents. This can not only help in reducing accidents, but it can also help in increasing awareness of humans regarding these activities. The use of Environment Modelling, IOT and Cognitive Computing can be a very good decision maker in many ways like auto applying of brakes, automatically parking a vehicle and calling emergency contacts when a driver dozes off, and so on. [4]

3. SMART CITIES

The cities where many devices are automatically controlled by different sensors' data collected are known as the smart cities. These data include data collected from sensors, citizens traffic and transportation systems, power plants, water supply network, waste management, law enforcement, schools, libraries and so on. The devices in these domains are connected together using the Internet of Things where the data collected from these devices are used to monitor the evolution of the city. It can be used to enhance quality, performance, and interactivity of urban services to its citizens. It can also reduce costs and consumption of resources accordingly. The bridge between the citizens and the government can be made stronger. The application of IOT in this scenario is available for a very long time. The cognitive computing of the data procured from these sensors and devices can be very helpful in producing an exponential growth in the city and also reducing the costs and consumption of resources. The cognitive computing can be applied to the architecture of these smart cities thereby fulfilling the needs of the citizens. The requests from the citizens and corporate bodies can be taken as a set of data and can be analyzed and acted upon. If IOT is the central nervous system of a smart city, then Cognitive Computing is the brain which gives insights to the decision makers of the cities. Cognitive Computing can gather, integrate and analyze data from the systems and processes that make a city function. Building a smart city, the decision makers could use the data from the sensors already available and use Big Data for good.

4. HEALTH CARE

The field of Internet of Technologies has made essential services such as Smart Healthcare in a smart city environment. The advancements in the Internet of Technologies, cloud technologies have resulted in a huge demand for real-time, intelligent and remote health care services under smart cities. The availability of specific doctors, hospital and so on is difficult in emergency situations. Thus, we can connect different health devices such as smartwatches and so on which could send health data of a person to a cloud service. The data could be analyzed by a cognitive system by analyzing the patient's previous health records. A framework where the emergency services, doctors, hospitals, ambulances and so on can be made to give a quick response to a critical health issue. The cognitive system could give insights regarding the patient's health records thereby giving them the decision for what to do and what not. The success rate of operation could be drastically improved using this technique of combining different devices such as weight monitoring device, ECG [7], smartwatch et al. with the Internet of Things, Cloud Computing, Big Data Analytics, and Cognitive Computing. This cognitive IOT framework requires devices used by the patient to cooperate to sense his/her body signals, movements, voice or monitored signals, such as EEG and ECG [7] and deduce the state of the patient. The cognitive healthcare framework is sufficiently intelligent to make the corresponding decision to make the patient comfortable and decide the future course of activities by involving different stakeholders of the smart city.

5. INSURANCE

Since the beginning of the insurance companies, the insurance business has been fueled by science and maths; initially, a financier could ascertain solid risk rates and offer adequate payouts that would not close down the insurance agency. With the help of Artificial Intelligence [8], it is conceivable to utilize it to repeatable operations that depend on rationale and mathematics at a higher authenticity quality rate than that done by people [8]. By the help of cognitive computing and IoT, we could give customized offerings [9], prevent frauds [9] from happening and have a premium pricing [9]. Most of the leading agencies are using their data analytics algorithms with the best AI's innovation to enhance the precision of risk calculations. This is because they need a huge amount of information to enhance their appreciation of customer hazard. The cognitive computing technologies will turn into the standard methodology for processing huge and complex data that will be created by active insurance products attached to a person's conduct and activities. With expanded commercialization of these innovations, agencies will approach models that are always learning and adapting to their general surroundings which empower new engagement techniques and product classifications while checking to fundamental risks in real time. By connecting the sensors and IoT gadgets, policies may change in real time by adapting to enrollee's risk profile. It is stupid to disregard the impacts that cognitive computing will have on the insurance business. They will be very like automation in the car industry. Numerous parts of insurance will never again be done by people. As this progress unfurls with cognitive computing and connectivity prompting to autonomous vehicles at some point during the 2020s, the insurance business and numerous others will be compelled to advance and adjust to new realities, for example, fewer mishaps and even better approaches for deciding who is at fault.

6. BANKING

The use of wearables in the modern century is rapidly increasing. So, is banking on wearables. When it comes to an IoT approach in the Banking sector, the wearables are not the only thing. We have Pumping up payments, branching out to connected cars, Blockchain based smart contracts, Smarter branches, Banking at Home, Chatbots, et al [11]. The use of cognitive computing on these devices has the potential to manage large numbers of banking transactions in a much more sophisticated manner, allowing banks to fulfill the promise competing on analytics [10]. It can use evidence and context-based information to provide tailored products and services to its customers. Self-service for bank customers can be improved through enhanced automation of investment and banking products. Cognitive computing can also examine significantly more data, from more sources, because it looks wider than traditional analytics, it helps the bank to have a better picture of potential risks and therefore predict the risk more accurately [10]. This is a key improvement in the digitalization of financial sector [12]. It also leads to the generation of job changes in the financial sector. Using cognitive computing and the expenditure pattern from the IoT devices a person uses, several implications can be made for the call center and banking staff. This also helps in better customer satisfaction when he/she interacts with his bank officials.

7. EDUCATION

The introduction of IoT in the education field has been a very good success in bringing up the thinking capabilities in a student. It can make a student think and learn about different things and how they work [13]. Introduction of cognitive computing with this IoT will bring about many new products and services in the education sector. This will include the personal cognitive assistant for students, support teams and teachers. The delivery of online learning, compiling and assessment materials to students, the automation of routine tasks and activities such as the production of student's report card and so on [13]. Design and though of cognitive services will help schools, college and universities to deliver enhanced services that will benefit the students and communities they serve [13]. It is the process of adapting how a human learns. Humans access knowledge from a series of actions like storing, retrieving, understanding, using and organizing the information acquired by the senses [14]. The cognitive system helps discover relations between a huge amount of information it has access to, in a very short time. Combination of cognitive IoT can make life easier for students within their educational environment. The scope of this approach is very broad, with cases like students who seek counselors based on their studies or international students seeking assistance in language or even wizards to student life in the city they are, to inform them about all kind of activities.

8. CLIMATE CHANGE

What rate is climate change happening? How is human affecting the environment? These are just a few questions that scientists are attempting to answer using powerful high-performance tools and massive amounts of climate data [15]. Climate change is one of the grand challenges currently facing humanity. Addressing it is dependent on the ability to quickly discover patterns in huge amounts and data and get insights that will help save lives and property. The way of addressing it is using Cognitive IoT. As we already have many sensors to detect different kinds of pollutions around us, we have different data from different sensors which are unstructured or not well used. The introduction of cognitive computing is showing great promise to solve complex data heavy and multi-layered problems. In the climate and weather industry, researchers are incorporating these techniques to train a new generation of computers to automatically discover new weather patterns, predict

extreme weather conditions and help us how climate change evolve. Using Cognitive IoT, a government can now pinpoint on the source of pollution more precisely [15]. This helps the governing body take better actions that will directly help their citizens too. Prediction models to forecast things like pollution, drought, weather already exist. With machine learning, we can understand which model will perform better when, where and under what circumstances. This will also, help us minimize track urbanization, deforestation and make a better understanding of the ecosystems.

9. SUSTAINABILITY

We might not think the Internet of Things like clean tech, but we must consider bringing the greater connectivity to the environment we live and work will drive down unnecessary costs and save huge amounts of resources. Addressing the sustainable development goals [18], we can introduce smart grids, smart street lights, water monitoring, air quality trackers, connected transport and so on [19]. In the oil and gas industries, cognitive IoT has its potential to outperform and transform the industry [17]. A new report from the IBM Institute for Business Value, "A New Natural Resource: Your Cognitive Future in the Oil and Gas Industry," [16] found that leaders are ready to invest in cognitive capabilities for a digital future in oil and gas. These companies need to enhance their ability to digest a vast amount of unstructured and structured data to navigate complexity, identify new avenues and implement new ideas at a higher velocity with quantitative risk levels. Cognitive IoT can help build knowledge and learn, reason, interact and understand natural language with human beings than traditional programs. Companies like TruValue Labs based in San Francisco have developed tools that aggregate a wide range of sustainability-related information, extract useful signals and meaningful patterns and serve up interpretations and conclusion to business users. With the help of Cognitive IoT not only companies will get real-time insights, but they will also be able to track the success of their sustainability efforts more effectively.

10. FOOD SCIENCE AND AGRICULTURE

Cognitive cooking provides a great potential to provide commercial kitchens, food scientists and chefs in the industry the ability to quickly determine ingredient substitution in recipes and still maintain the flavor of the original recipe [20]. This helps in preparing foods which do not alter the consumer's taste but can have nutritional supplements [20]. The Internet of Things devices in the agricultural sector is predicted to increase to 75 million by 2020 [20]. With such a huge amount of dark or unstructured data being produced, it is only useful if it can be usable, insightful. This can be done using Cognitive IoT by checking the previous patterns of data generated and so on. Many collaborators with NITI Aayog like IBM are providing insights to farmers on how to improve their crop productivity, soil yield et al [20]. Introduction of Climate aware cognitive farming techniques will help the crops to get adequate water and so on. There are many sensors to collect information such as temperature, humidity, soil texture, pH value of the water, et al [20]. Cognitive IoT can help in moving normal farming to precision farming. Cognitive IoT probes more into turning data into valuable information thereby providing an advantage for our operation [21]. The data being generated by these devices can be sent to be analyzed by Big Data Analytics. It can collaborate with the Cognitive IoT system and provide detailed and real-time insights into operational and financial activities. Farmers can use this information to calculate harvest yields, fertilizer demand, cost savings and even to identify strategies for future crops. IBM's AgroPad [20] provides a solution which is a prototype for real-time, on-location, chemical analysis of water and soil using AI built by a team of physicists, engineers and computer scientists in Brazil: "IBM AgroPad is a paper-based water and soil testing strip that uses visual recognition capabilities and machine learning algorithms to determine exact amounts of chemicals in the sample." [20] While this focuses on the use of Cognitive IoT to enhance yield, preservation of crops from diseases is also equally important. Globally, an estimated 40% of all potential food production each year is destroyed by insects, plant pathogens and weed pests.[20] One of the most devastating diseases in agriculture is a late blight and is traditionally combated by spraying fungicide, even on crops where the disease might not be visibly present. [20] To reduce the harm done to the environment and cost, IBM has helped scientists to develop a "decision-support system that combines visual and near-infrared image analysis with climate data." [20] This system is able to predict how likely it is that late blight will strike through images captured are analyzed by Watson Image Recognition via the cloud. The use of Climate aware cognitive computing system can be used extensively in many areas to reduce the loss of crops due to insufficient water supply or excess of water due to heavy rain et al. Overall, the application of Cognitive IoT in the field of agriculture is developing at a very faster rate. This will not only help the farmers gain more insights, but it will also start the era of 100% organic farming by knowing which crop to grow in which soil based on the history of crop grown in that soil.

VI. CONCLUSION AND FUTURE WORK

To sum up, the amount of data being produced by many sensors in the Internet of Things around the world is massive. This data, should not become a bottleneck for our computing. Rather, cognitive computing techniques should be applied to make sense of these data and convert them into valuable information or insights. The ability of cognitive computing to make the accurate decision can be improved

by introducing various algorithms and analytics such as Big Data et al Cognitive Computing in all of the above applications urges to act, think and behave like a human in order to achieve maximum synergy from a human-machine interaction. The development of Cognitive IoT and its application is increasing rapidly. We predict the use of Cognitive Computing and IoT would be a mandatory type of approach for any kind of analytics in the near future. To conclude, this learning system using IoT and Cognitive computing is not only becoming a major industry trend but also has a significant impact on media. This scenario is extremely challenging and in a few more years, these devices will significantly change the way we live our lives. Every day we're taking an evolutionary approach towards a future where we close the gap between real and virtual worlds by providing customizable cyber-physical services [23] that will change the way we work and live.

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