Roadmap of Artificial Intelligence – Concepts to Reality and future

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Abstract. This paper reviews developments in Artificial Intelligence over the last 70 years. As such we begin with gestation of AI, and proceed to discuss early development, recent developments and future trends in AI. In doing so we point out background for emergence of the field of AI, gestation of AI with a particular emphasis on symbolic AI, which lead to knowledge modelling in the context of cognitive systems as a pragmatic approach to build intelligence programs such as expert systems, natural language processing, game playing, problem solvers and theorem provers. Background and implications of emergence of machine learning since early 2000 has also been discussed. The paper also highlights major AI programs including DART, Deep Blue, Pathfinder, Google self-driving car, AlphaGo and Watson, which made AI so attractive not only to researchers but also to general public. Finally, future trends of AI including man-machine coexistence, cyborgs, hybrid intelligence, mind uploading, and biological programming have been discussed by positioning AI within technological singularity.

Keywords: Artificial Intelligence, Machine Learning, Cognitive Systems, Singularity, Man-machine existence

1 Introduction

Undisputedly, AI is one of the most cited subject area in science and engineering in the 21st century. In 1956, at the landmark conference, at Dartmouth USA, John McCarthy, father of AI, coined the term Artificial Intelligence as science and engineering of building intelligent machines [1]. As such AI strives to understand natural intelligence of human and animals and build intelligence into machines. Roadmap of AI comprises of rise and falls together with rewards and criticisms. Seventy years of journey of AI has recorded an unprecedented development, which is not the case of any other subject area. More importantly, modern developments in many other areas such as architecture, medicine, engineering, science, business and entertainments have been accelerated by the developments in AI. In academia, although AI started as set of subject modules in Computer Science and Computer Engineering degree programs, nowadays, AI has grown as a distinct degree area under the broad umbrella of computing. Industry recognition for AI has also exponentially grown over the last 70 years [2]. In the modern world AI has been so exciting, because AI has offered smart solutions for the complex problems, which could not be solved otherwise. For instance, AI has been the champion of modelling problems with nonalgorithmic, noisy, incomplete, unpredictable, and dynamic data. Modern world has been constantly generating huge volume of such data through limitless online transactions, social media networks, and research and developments in many fields. It should also be noted that AI is good in not only modeling such unstructured problems, but also modeling structured systems such as science, mathematics and engineering. As such, AI has shown its amazing power to solve all kinds of problems. This is not the case in any other subject area.

This paper attempts to build the correct mindset of the reader to understand the foundation of AI, to recognize and appreciate the importance of AI, and to prepare the reader well in advanced to comprehend the future trend in AI. Here the future trends such as man-machine coexistence, singularity, and biological programing would be rather exciting, yet they are no longer dreams. The paper is targeted for both novice AI researchers and the general readers in AI.

The rest of the paper is organized as follows. Section 2 presents the background of emergence of the field of Artificial Intelligence. Section 3 discusses early developments and breakthroughs in AI. Section 4 is about the recent developments of AI by showing background for such developments. Section 5 highlights the potential future directions of AI and some implications of such developments. Section 6 concludes the paper.

2 Gestation of AI

Probably abacus is the oldest machine which could do calculations which requires intelligence when it is done by humans. Subsequently, Leibniz and Pascal also constructed calculating machines. Nevertheless, such development never made a claim that calculating devices are intelligent [3]. However, after the World War II, naturally environment was set out so that people appreciated the value of the well-being of mankind. This results in thinking about new kind of machines, obviously intelligent machines. During this time many things happen in parallel. In 1943, McCulloch and Pitts introduced Artificial Neural Networks, which is considered as the first AI work [4]. In 1948, transistor was invented and gave the birth for the modern digital computer. Further, Donald Hebb developed the first neural network training algorithm [5]. During this time, Alan Turing also published the seminal article "Computing Machinery and Intelligence" [6]. Turing's article postulates the idea that intelligent machines can be developed by writing computer programs. In 1939, Allen Turing completed his PhD at Princeton and returned to Manchester UK. In early 1950s, both Minsky and McCarthy completed their PhDs in the Department of Mathematics at Princeton. After that they moved to MIT and Dartmouth respectively. From Dartmouth, McCarthy did groundwork for introducing a separate area for intelligent machines. At this point, it is a noteworthy fact that many pioneers in AI had come with a strong background in Mathematics.

3 Early Developments of AI

There are many ways to discuss the roadmap of AI. Here we consider period mid-1950 to late 1980s as the early developments. This is because, although this era has significantly contributed to early development of AI, such developments were not visible to the society, not appreciated by the industry and AI did not adopt the scientific method to discover theories in AI.

In 1956, at the famous workshop at Dartmouth USA, Artificial Intelligence was born as the discipline to build intelligent machines. Minsky from Princeton, McCarthy from Dartmouth, Allen Newell and Herbert Simon from Carnegie Tech (now known as Carnegie Mellon University), Arthur Samuel from IBM, and Ray Solomonoff and Oliver Selfridge from MIT were among the attendees **[7]**. At this workshop, John McCarthy coined the term Artificial Intelligence as the science and engineering of building intelligent machines. More importantly, this workshop concluded that Artificial Intelligence is necessary to become a distinct field despite it cuts across engineering, computer science, mathematics and statistics. Although Dartmouth is the birthplace for AI, in 1958, McCarthy moved to MIT. From Princeton, Minsky also moved to MIT. However, McCarthy was promoting logic-based reasoning, while Minsky is interested in anti-logical behavior of intelligence. During this time McCarthy established connections with Stanford from where he came to Dartmouth. After Dartmouth workshop, for next 20 years, development of AI was dominated by AI enthusiasts in MIT, Stanford, CMU and IBM. During this time Princeton and Dartmouth were rather silent about AI.

The above two views of Minsky and McCarthy have created opportunity identifying broad areas of AI. Such disagreements stimulated, Newell and Simon to postulate the tradition of symbolic AI, which is different from conventional programming that involves numeric computation. Subsequently, symbolic AI evolves as a broader area of AI, artificial cognitive systems, which talks of rules-based/logic-based analytical intelligence. In contrast, non-symbolic tradition, which has ethos of anti-logic, evolves as machine learning sometime later. It should be noted that those broad areas of AI, artificial cognitive systems and machine learning has a nice mapping with neuroscience of the brain. This is because neuroscience identifies two kinds of intelligence in the human brain: one is associated with analytical and logical reasoning, while the other is about intelligence coming through training. Realizing the mapping between the human brain and the broad areas of AI enables a person to comprehend the foundation of natural intelligence, hence the primary role of AI.

Early development in AI is predominantly dominated by the tradition of symbolic AI (cognitive systems). During this period, concept of *search* has been recognized as a major approach to model intelligence into machines. Having recognized the knowledge as the main ingredient of intelligence, researchers have subsequently identified the opportunity for building knowledge into machines to build the intelligent machines. As a result, in late 1970s, the concept of knowledge modelling emerged as a pragmatic approach to develop intelligence machines. Allen Newell's seminal paper, "The Knowledge Level" emphasized the need for knowledge level modelling for intelligent systems, before going to symbolic or programming level. Subsequently, may techniques have been developed to represent the knowledge. Among others, logic, rules and frames have been the most popular way to build the knowledge into machines. Minsky's knowledge representation technique is known as frames, and it has become the ancestor of object oriented concept in computing [8]. Many AI programs including expert systems, natural language processing systems, game players, theorem provers, and problem solvers use logic, rues or frame-based knowledge representation to build such intelligent systems. Search and Knowledge representation are considered as the cornerstones of many AI programs.

After 1956, there were some developments in machine learning research as well. More importantly, Frank Rosenblatt developed a neural network, what is called Perceptron [9]. However, in 1969, Minsky and Papert vehemently criticized the representation power of Perceptron [10]. In 1958, Friedberg laid the foundation for machine evolution by introducing genetic algorithms technology, which also becomes a distinct candidate under machine learning [11]. It should be noted that developments in machine learning was rather slow in early days of AI. There were three main reasons for this situation, namely, over emphasis on symbolic AI, emergence of knowledge modeling, and Minsky's criticism about neural networks.

Since the late 1960s many AI programs had been developed under the umbrella of symbolic AI. Among those, expert systems happen to be the champion. The first expert system, DENDRAL was developed at Stanford by Buchanan and his colleagues [12]. Following the success of DENDRAL, Buchanan, Feigenbaum, and Shortliffe developed expert system MYCIN to diagnose bacterially infected blood disease [13]. During this era, Winograd at MIT also developed the first natural language understanding program, SHRDLU [14]. Subsequently, Schank and his students at Yale developed a series of programs for natural language understanding.

4 Recent Developments

Until late 1980s, AI could not win the industry recognition. In 1982, McDermott and his team developed the first commercially recognized expert system, XCON for Digital Equipment Corporation. This was developed for configuring minicomputers, and recoded a saving of $40 million per year. Since then AI industry bloomed from million dollars to billon dollars. Nevertheless, in this period, many companies were failed in their ambitious expectations, and this results in some people to name this era as "AI Winter". However, such failures amount to pick the momentum in developing AI in pragmatic manner since 1990s. By 1980s, AI community has abandoned ANN, but some researchers such as Hopfield, David Rumelhart, Geoff Hinton had continued research in ANN. As a result, Rumelhart and McClelland came up with exciting reporting of backpropagation learning algorithm for training multi-layer neural networks [15]. According to literature, backpropagation learning algorithm was first found as a work of Bryson and Ho [16]. Since 1990s, both machine learning and analytical-based reasoning have been equally appreciated. Let discuss some major events and AI programs, which made AI so popular since 1990s.

4.1 AI Becomes a Science

Scientific method has been considered as the methodological status of most subject areas. In 1981, the famous book, *The Sciences of the Artificial*, Herb Simon first time advocated the methodological status of AI [17]. According to Simon, theories in AI can be developed by mathematically as well as scientifically. However, until 1990s, scientific method has not been adopted for AI. Having adopted the scientific method, now AI undergoes through building hypothesis, design of experiments, statistical analysis of data in developing theories and justification of solutions generated by the theories in AI. As a result, development in modern AI is necessarily powered by mathematics, statistics, and computer science. Being a science, now AI can claim for very high-level of trustworthiness in the solutions generated by AI techniques. This was not the case in AI before 1990s, and it resulted in not only respecting AI by scientists but also general public. Once AI becomes a science, progression of AI has been drastically accelerated.

4.2 Intelligent Agent

Concept of intelligent agent has emerged as a new paradigm for building intelligent systems. Among others, work of Allen Newell is considered as the best-examples for defining a complete agent architecture [18]. In simple terms, an Agent is defined as anything that can perceive the environment through sensors and acting upon that environment through actuators [7]. This concept can be understood by looking at the way how a travel agent like person executes the specific tasks assigned to the travel agent. Ants and bees in their colonies can also be considered as Agents who perform some tasks. Taking analogy from travel agent, ants or bees, we can recognize some features of Agents as autonomy, task-specificity, reactivity, proactivity, rationality, evolvability, communication, negotiation and coordination. A computer program that mimics the behavior of natural agents (e.g. bees, ants, travel agents, office assistant) is called a Software Agent. Future of building the intelligent machine would be dominated by the agent technology.

4.3 Driverless Vehicles

Driverless vehicles also known as autonomous vehicles, robotics vehicles, unmanned vehicles and self-driving vehicles are yet another area of AI, which made AI so popular in the recent past. Unmanned aerial vehicles (UAV) happened to be popular as a upcoming method for remote sensing and data acquisition through aerial images [19]. UAV have also been heavily used in military applications in 1990s. In 1989, unmanned land vehicles were first time reported by NAVLAB at CMU [20]. Among others, Google Self-driving car and Tesla driver less trucks are commonly cited as unmanned land vehicles. Driverless vehicles have shown their potential to do many things including reduction of road accidents, giving opportunity for drivers to relax while driving, and accessing locations that cannot be reached by human drivers [21].

4.4 Neural Machine Translation

Machine translation comes as a branch of natural language processing [22]. The area of machine translation is as old as AI and involves translating from one natural language to another. Traditionally, rule-based, example-based and statistical machine translations were popular. Such approaches come under cognitive system approach involving symbolic manipulation of rules of languages. In the recent past, Neural machine translation (NMT) emerged as an approach to use machine learning techniques, in particular, neural networks for machine translation [23]. However, at present NMT suffers from many limitations including training time, inference speed, and ineffectiveness in dealing with rare words [23]. Undisputedly, this approach should also work because people do natural language translation not only by knowing grammar rules of two languages, but also applying the experience of the previous translations.

4.5 Data Science

With the birth of Internet and related technologies, people have created huge volume of data in all fields. Such data happen to be very large, dynamic, unstructured, noisy and difficult to analyze by conventional mathematical and statistical techniques. As a result, subject of Data Science emerged as a multi-disciplinary field of scientific analysis and predictions in unstructured data [24]. AI as a discipline covers not only AI techniques, but also computer science, mathematics, and statistics that are required for Data Science as well. Nowadays, Deep Learning in AI has become an integral part of Data Science [25]. By its very nature, AI can model real world problems with structured and/or unstructured data. Exponential growth of unstructured data in the recent past has been a key factor for gigantic popularity for AI.

4.6 Popular AI Programs

After 1990s, AI becomes popular much faster than before due to various reasons. In particular, many AI programs have shown the power of AI. On the other hand, after 1990s, an exponential growth of Internet and related technologies have connected the world than ever before. This results in generating huge volume of data through online transactions, social media, and numerous R&D work across the globe. Therefore, very high demand came for technologies that can model unstructured data. Below are some AI programs which made AI popular since 1990.

In 1991, AI program, Dynamic Analysis and Replanning Tool (DART) has recorded mazing results during the Persian Gulf war [26]. It has done automated logistic planning concerning 50,000 people, vehicles and cargos at a time. DARPA has announced that this single AI program itself has recovered more than the 30 years of investment on AI by the US government. In 1997, IBM's Deep Blue, chess computer program, first time defeated the world chess champion Garry Kasparov [27]. Kasparov has said that he felt a new kind of intelligence across the board. This event resulted in increase of values of IBM's stock by $18 billion. NASA's, Pathfinder, remote agent program is the first on-board autonomous planning and scheduling program to execute from million miles away from the earth [28]. Subsequently, many Mass exploration rovers have also been launched.

IBM Watson is a natural language-based open-domain Questions Answering (QA) systems [29]. The QA technology applied in Watson is called DeepQA, which offers a powerful new architecture for structuring and reasoning on unstructured natural language contents. Highest ranked players in a two-game Jeopardy! were defeated by Watson. This program is an example for the use of both analytical-based intelligence and machine learning. As such Watson goes beyond the conventional expert systems. Google's Deep Mind AlphaGo is yet another influential AI program in the recent past. It has beaten Lee Sedol, the grand master of Chinese Go game [30]. AlphaGo is a classic example of the applicability of deep learning, a branch of machine learning, techniques for the games, where we have very large state-spaces. In developing AlphaGo, information from 30 million played Go games have been studied. It should be noted that state-space of chess happen to be smaller, so rule-based symbolic AI approach was adequate for building IBM Deep Blue.

5 Future Trends in AI

Exciting recent developments in AI have made the people curious about the future of AI. Researchers and scholars have used different experiences and taken various approaches to predict the future of AI. Some scholars say that AI ends human race. Many people argue that AI would dominate the technological singularity at which machines surpass the mankind. In contrast, many AI researchers predict that future of AI would be dedicated to well-being of mankind.

At this venture, we should recall that every technology has a good side as well as a bad side. As such, issue is not with the technology, but how the technology is used by humans. For instance, Einstein's atomic theory can produce bombs for killing people, and also generate electricity for well-being of people. Here nobody would say that Einstein finds fault with discovery of nuclear energy. The same logic applies to AI as well. Therefore, here we discuss future of AI with a positive viewpoint, but without hiding any potential danger if there is any.

5.1 Man-machine Coexistence

Undisputedly, future machines will be smarter than humans. In such environments, researchers talk of man-machine coexistence where machines and humans work together. Nowadays, there are artificial legs and arms which are intelligent enough to learn to perform as a natural arm or a leg. Recall that the science fiction iRobot demonstrated an intelligent robot arm fixed to a policeman. The robot arm appears to be so active and risk taking when policeman meet with hazardous situation. Science fiction, Terminator has also demonstrated the use of biological brain within a robot. It is no longer a science fiction, and a robot has already been built with a biological brain of a rat [31]. Implanting AI chips in the brain and other organs has already been started at the therapeutic level. Thus man-machine coexistence will be an inevitable reality in the future.

5.2 Bionic and Cyborgs

Discoveries in neuroscience have already made a big impact on Artificial Intelligence. For instance, neuroscientist have discovered electrical signals generated by functional neurons in brains and muscles. Technologies such as EEG and fMRI technology have already been developed to capture electrical activity of the brain in noninvasive manner [32]. Such developments have postulated brain-machine interfacing, where people can use their brain waves to communicate with machines.

The field of biologically inspired engineering, known as Bionics, has taken new shape due to the recent advancements in neuroscience. Further developments in AI influences bionics to build cyborgs, who are humans with extended capabilities, both physical and intellectual, through AI-based devices. Person with an AI-based robot arm is an example for a cyborg. The AI-based device of a cyborg is generally controlled by EEG signals coming from the brain. The connectivity between brain and the AI-based device is normally developed through Bluetooth technology. Tesla founder Elon Musk says that human need to be cyborgs to survive in the future.

5.3 Hybrid Intelligence

According to Ray Kurzweil, probably, Arthur Clark of AI talks of what is called hybrid intelligence as a future trend of AI. The hybrid intelligence comes from a brain containing a biological brain and an AI chip. At a given time, one of biological brain or the AI chip works. This is analogous to a hybrid vehicle in which one of the battery or the engine works at a given time. Since implanting AI chips in the brain has already taken place, hybrid intelligence will be able to achieve by programming. This technology gives an exciting opportunity for humans and animals to extend their cognitive features. More importantly, hybrid intelligence can be used for therapeutic purposes in multiple ways including, relaxation, psychological treatments, regaining memory, addressing sleeping disorders, and so on. Further, hybrid intelligence may also be a new dimension for building cyborgs.

5.4 Mind Uploading

Many people would be happy to take a digital copy of their brains. This area is called mind uploading. When such technology is available, we never lose our previous knowledge. More importantly this technology enables us to preserve brains of genius and use the digital brains even after their death. Of course, technologies for mind uploading is already with us. This is because, if we capture EEG waves of a functioning brain, at least for a selected task, it is already possible for us to train an Artificial Neural Network (ANN) for EEG signals. The trained ANN become a digital copy of the brain related to certain cognitive task of a person. This ANN can be used for various purposes. For instance, we could execute the ANN to generate corresponding electrical signals and apply them to another brain. Technically, this process should stimulate the neurons in the second brain. This could result in wakening up inactive neurons in the second brain and develop potential to be good at the task for which the ANN was trained.

One may be rather skeptical about stimulating a second brain from a trained ANN. However, long time ago, electrical signals have been applied to the brains of psychiatric patents as a treatment. As such application of electrical signals to a certain part of the brain, could make a difference in the relevant neurons. It should be noted that scientists have already uploaded the mind of a worm into computer, then noticed that virtual worm (digital worm) has the ability to learn novel behavior on its own [33]. Conversely, the digital worm (program) can be used to change the behavior of the original worm.

5.5 Biological Programming

Ray Kurzweil also says that in the future, we will be able to program living cells as we program computers. This is in fact not a prediction, and researches have already programmed biological systems [34]. The biological programming happens at lower levels such as cells or DNA. In simple terms, such programming modifies the instructions in genes so that certain behavior of a person will change. On the same token, biological programming could be a new means of treatment for diseases such as cancers. Soon, programing living cells may be as common as programming computers. Researchers at MIT have already developed tools to design DNA circuits for living cells [35]. As such, there are already evidence to believe that biological programming will revolutionize the future of mankind. It should be noted that developments in Genetics and Neuroscience would necessarily revolutionize the future of AI.

6 Conclusions

This paper discussed the development of AI from its gestation to the recent developments. Wide spectrum of possible future development of AI have also been discussed in the paper. In doing so, we pointed out pioneering work by McCulloch & Pitts, Donald Hebb, John McCarthy, Allen Turing, Marvin Minsky, Herbert Simon and Allen Newell during 1940s to1980s. The paper also described how symbolic AI and non-symbolic AI have contributed for the early developments and the recent developments in AI. Importance of the concept of knowledge modelling and effect of AI becoming a science, and background for emergence of machine learning in the recent past have also been discussed. Further, we reported about AI programs such as DART, Pathfinder, Deep Blue, AlphaGo, Watson, Google self-driving car, which made AI so popular among AI enthusiasts and general public. Finally, future trends of AI were discussed covering man-machine coexistence, Bionics/cyborgs, hybrid intelligence, mind uploading, and biological programming. Undisputedly, AI would be the champion of technological singularity by ensuring well-being of mankind.

References

1. N. Nilsson, "Artificial Intelligence: A New Synthesis - 1st Edition," 1998. [Online]. Available: https://www.elsevier.com/books/artificial-intelligence-a-new-synthesis/nilsson/978-1-55860-535-0. [Accessed: 22-Sep-2019].
2. "Top Artificial Intelligence (AI) Software Companies in the USA and Internationally." [Online]. Available: https://www.thomasnet.com/articles/top-suppliers/ai-software-companies. [Accessed: 22-Sep-2019].
3. B. G. Buchanan, "A (Very) Brief History of Artificial Intelligence," p. 8.
4. W. S. McCllouch and W., "A Logical calculus of the idea immanent in nervous activity," *Bull. Math. Biophys.*, vol. 5, pp. 115–137, 1943.
5. D. O. Hebb, *The Organization of Behavior: A Neuropsychological Theory*. New York: Wiley & Sons, 1949.
6. A. M. Turing, "Computing Machinery and Intelligence," *Mind*, vol. 49, pp. 433–460.
7. S. Russell and P. Norvig, *Artificial Intelligence: A Modern Approach*, 3 edition. Upper Saddle River: Prentice Hall, 2010.
8. "The Society of Mind: Marvin Minsky: 9780671657130: Amazon.com: Books." [Online]. Available: https://www.amazon.com/Society-Mind-Marvin-Minsky/dp/0671657135. [Accessed: 22-Sep-2019].
9. F. Rosenblatt, "Principles of Neurodynamics: Perceptrons and the Theory of Brain Mechanisms," *Spartan Book Washinton DC*, 1962.
10. M. L. Minsky and S. Papert, "Perceptrons: An Introduction to Computational Geometry," 1969.
11. R. M. Friedberg, "A Learning Machine: Part I," *IBM J Res Dev*, vol. 2, no. 1, pp. 2–13, Jan. 1958.
12. B. G. Buchanan and G. L. Sutherland, "HEURISTIC DENDRAL: A PROGRAM FOR GENERATING

EXPLANATORY HYPOTHESES IN ORGANIC CHEMISTRY," 1968.
13. B. G. Buchanan and E. H. Shortliffe, Eds., *Rule-based expert systems: the MYCIN experiments of the Stanford Heuristic Programming Project*. Reading, Mass: Addison-Wesley, 1984.
14. T. Winograd, "Understanding natural language," *Cognit. Psychol.*, vol. 3, no. 1, pp. 1–191, Jan. 1972.
15. D. E. Rumelhart, and J. L. (Eds) McClelland, *Parallel Distributed Processing*. MIT Press, 1986.
16. A. E. Bryson and Y. C. Ho, "Applied optimal control," *Blaisdell*, 1969.
17. H. A. Simon, *The Sciences of the Artificial - 3rd Edition*, 3rd edition. Cambridge, Mass: MIT Press, 1996.
18. A. Newell, *Unified Theories of Cognition*. Cambridge, MA, USA: Harvard University Press, 1990.
19. K. Alkaabi and A. Abuelgasim, "Applications of Unmanned Aerial Vehicle (UAV) Technology for Research and Education in UAE," *Int. J. Soc. Sci. Arts Humanit.*, vol. 5, pp. 2321–4147, Sep. 2017.
20. A. J. Hawkins, "Meet ALVINN, the self-driving car from 1989," *The Verge*, 27-Nov-2016. [Online]. Available:

https://www.theverge.com/2016/11/27/13752344/alvinn-self-driving-car-1989-cmu-navlab. [Accessed: 28-Sep-2019].
21. Q. Memon, M. Ahmed, S. Ali, A. R. Memon, and W. Shah, "Self-driving and driver relaxing vehicle," in *2016 2nd International Conference on Robotics and Artificial Intelligence (ICRAI)*, 2016, pp. 170–174.
22. B. Hettige and A. Karunananda, "Existing systems and Approaches for Machine Translation: A Review," 2011.
23. Y. Wu *et al.*, "Google's Neural Machine Translation System: Bridging the Gap between Human and Machine Translation," *ArXiv160908144 Cs*, Sep. 2016.
24. V. Dhar, "Data Science and Prediction." [Online]. Available: https://cacm.acm.org/magazines/2013/12/169933-data-science-and prediction/abstract. [Accessed: 28-Sep-2019].
25. M. Najafabadi, F. Villanustre, T. Khoshgoftaar, N. Seliya, R. Wald, and E. Muharemagic, "Deep learning applications and challenges in big data analytics," *J. Big Data*, vol. 2, Dec. 2015.
26. S. E. Cross and E. Walker, *DART: Applying knowledge based planning and scheduling to crisis action planning.* In Zweben, M. and Fox, M. S. (Eds.), Intelligent Scheduling pp. 711–729. Morgan Kaufmann, 1994.
27. D. Goodman and R. Keene, "Man Versus Machine: Kasparov Versus Deep Blue," *ICGA J.*, vol. 20, no. 3, pp. 186–187, Jan. 1997.
28. A. K. Jonsson, P. H. Morris, N. Muscettola, and K. Rajan, "Planning in Interplanetary Space: Theory and Practice," p. 10, 2000.
29. D. Ferrucci, A. Levas, S. Bagchi, D. Gondek, and E. T. Mueller, "Watson: Beyond Jeopardy!," *Artif. Intell.*, vol. 199–200, pp. 93–105, Jun. 2013.
30. hermesauto, "Google's AlphaGo gets 'divine' Go ranking," *The Straits Times*, 15-Mar-2016. [Online]. Available: https://www.straitstimes.com/asia/east-asia/googles-alphago-gets-divine-go-ranking. [Accessed: 27-Sep-2019].
31. K. Warwick, "Implications and consequences of robots with biological brains," *Ethics Inf. Technol.*, vol. 12, no. 3, pp. 223–234, Sep. 2010.
32. M. Teplan, "FUNDAMENTALS OF EEG MEASUREMENT," *Meas. Sci. Rev.*, vol. 2, p. 11, 2002.
33. "Scientists Upload the Mind of a Worm Into Computer and Teach It Tricks | Mysterious Universe." [Online]. Available: https://mysteriousuniverse.org/2018/02/scientists-upload-the-mind-of-a-worm-into-computer-and-teach-it-tricks/. [Accessed: 28-Sep-2019].
34. C. Adami, "Biological programming," *Nature*, vol. 446, no. 7133, pp. 263–264, Mar. 2007.
35. A. A. K. Nielsen *et al.*, "Genetic circuit design automation," *Science*, vol. 352, no. 6281, p. aac7341, Apr. 2016.