Handbook of Mathematical and Digital Engineering Foundations for Artificial Intelligence: A Systems Methodology

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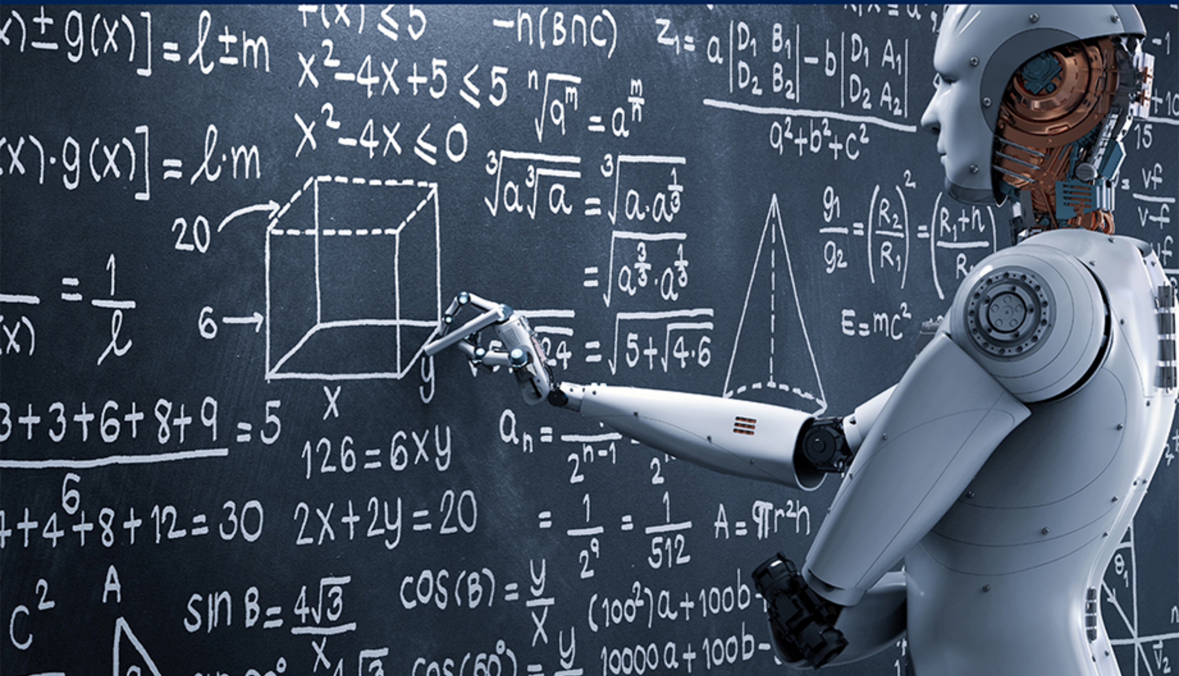

HANDBOOK OF MATHEMATICAL AND DIGITAL ENGINEERING FOUNDATIONS FOR ARTIFICIAL INTELLIGENCE

A Systems Methodology

Adedeji B. Badiru
Olumuyiwa Asaolu

CRC Press
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Handbook of Mathematical and Digital Engineering Foundations for Artificial Intelligence

Artificial intelligence (AI) and digital engineering have become prevalent in business, industry, government, and academia. However, the workforce still has a lot to learn on how to leverage them. This handbook presents the preparatory and operational foundations for the efficacy, applicability, risk, and how to take advantage of these tools and techniques.

Handbook of Mathematical and Digital Engineering Foundations for Artificial Intelligence: A Systems Methodology provides a guide for using digital engineering platforms for advancing AI applications. The book discusses an interface of education and research in the pursuit of AI developments and highlights the facilitation of advanced education through AI and digital engineering systems. It presents an integration of soft and hard skills in developing and using AI and offers a rigorous systems approach to understanding and using AI.

This handbook will be the go-to resource for practitioners and students on applying systems methodology to the body of knowledge of understanding, embracing, and using digital engineering tools and techniques.

The recent developments and emergence of Chatbots (AI tools) all have mathematical foundations for their efficacy. Such AI tools include ChatGPT, GPT-4, Bard, Tidio Support Bot, Kuki AI Companion, Meena, BlenderBot, Rose AI Chatbot, Replika: AI Friend, Eviebot, and Tay. This handbook highlights the importance of mathematical and digital foundations for AI developments. The handbook will enhance the understanding and appreciation of readers about the prevailing wave of artificial intelligence products, and, thereby, fitting the current market needs.

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Dedication

Dedicated to the memory of late Professor Oyewusi Ibidapo-Obe, whose unquenchable thirst for mathematical-based innovation and artificial intelligence motivated our interest in writing this book. He left a mathematical legacy that we must continue to carry forward.

Contents

Preface

The rapid growth of new technological tools has created new opportunities for operational efficiency, effectiveness, and productivity improvement. Artificial intelligence (AI) has emerged with new technological tools to provide new opportunities for how we live and work. From an operational perspective, the digital era consists primarily of digital-based science, technology, engineering, and mathematics (STEM) that have enabled new AI capabilities and expanded application opportunities. Learning to use the new developments requires rigorous and adaptive understanding of the mathematical foundations for AI. The present wave of interest in AI is facilitated by the rapid growth in computational tools, represented by powerful software and hardware resources. This book presents a collection of mathematical roots, digital techniques, and statistical tools that are essential for developing AI-based applications. This is done from a systems perspective, whereby cooperating and diverse tools and techniques come together to facilitate building powerful new AI products.

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We thank everyone around us, at home, work, and play, for the support and inspiration to write this monumental contemporary book on the widely spreading topic of artificial intelligence. We particularly thank Mr. Abubakar Ademola Raji and Mrs. Iswat Badiru for their painstaking help in typing and formatting many of the ugly-complicated equations in this book.

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1 Artificial Intelligence within Industrial and Systems Engineering Framework

1.1 INTRODUCTION

Everything around us is a system. Embracing a systems-thinking approach is the first order of possibilities for Artificial Intelligence (AI). Nothing brings this fact to the fore more than the robust discipline of Industrial and Systems Engineering (ISE). The traditional discipline of industrial engineering uses a foundation of systems thinking to facilitate process improvement, efficiency, effectiveness, and productivity in both technical and non-technical areas. The forward-looking approach of industrial engineering makes the embrace of AI natural for industrial engineers. Over the decades, industrial engineering has been at the forefront of the application of new and emerging techniques and technologies. This is evidenced in the early development and utilization of mathematical operations research in the military and the operational leveraging of electronic spreadsheets and computational tools in business and industry in the early days of the emergence of microcomputers (Badiru and Bauer, 1985; Badiru, 1985, 1988; Badiru and Whitehouse, 1989; Badiru and Whitehouse 1986; Badiru et al., 1987).

AI is all about fast computation, approximation, estimation, and prediction (See Badiru et al., 1987). In mimicking the human brain, an AI tool must quickly calculate outputs on the order of millions of combinations and permutations. Such a feat is only possible through mathematical foundations, both simple and complex. Every part of the vast expanse of the entire field of mathematics has something to offer to how AI works. One reference is estimation tricks to arrive at a quick answer, similar to using mental math strategies (Balch et al., 1993). Johann Carl Friedrich Gauss (1777–1855), of the Gaussian fame, is reputed to have demonstrated amazingly fast math calculation techniques. Gauss was a German mathematician and physicist who made significant contributions to many fields in mathematics and science. Gauss had an exceptional influence in many fields of mathematics and science, and he is ranked among history's most influential mathematicians. He is reported to have impressed his teacher at the age 10 with his ability to quickly mentally calculate answers to calculation questions. A story goes that when the teacher asked students to find the sum of the numbers from 1 through 100, young Gauss amazed his teacher and the class by writing the answer immediately. Gauss used a mental math strategy to find the sum. One mental math strategy is compensation. In compensation, you change a

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problem so that it is easy to solve mentally. Then, you make an adjustment to compensate for the change you made. There are many ways to compensate in finding an answer. In many AI techniques, estimation and compensation strategies are used. AI is not just one modeling or computational approach. The diverse applications of AI call for diverse mathematical formulations. This chapter and the chapters that follow present a potpourri of mathematical representations that are directly applicable to AI modeling, programming, and applications. The expectation is that the collection will motivate additional advancements in the area of mathematical foundations for AI in multidisciplinary fields of application. See Badiru (2022), Badiru and Ibidapo-Obe (2008), Badiru, et al. (2012), Doran, et al. (2022), Ibidapo-Obe, et al. (1995), and Ibidapo-Obe et al. (2001).

1.2 QUANTUM POTENTIAL FOR AI

Artificial intelligence is becoming more pervasive in our modern society. The interest in AI has heightened in recent years, particularly because of the availability of more powerful hardware and software tools. The emerging field of Quantum Computing bodes well for more robust AI developments in the future. A quantum computer is a computer which makes use of the quantum states of subatomic particles to store information. The better we can store and retrieve data, the more achievable our AI goals can be.

Quantum computing is the processing of information that's represented by special quantum states. The process taps into quantum phenomena like "superposition" and "entanglement," thereby creating a fundamentally different way of handling information. When practical quantum computing finally arrives, we will see dramatic improvement in the operations of computers, laptops, smartphones, and others. Quantum computers can tackle complex problems involving humongous numbers of variables and potential outputs. Simulations and optimization modeling in industrial engineering applications will become faster and more effective. Although quantum computing is not yet where advocates are touting it to be, there are rapid advancements happening almost daily. Quantum now is where AI used to be some 20 years ago. We now see what AI can do in the present research and development landscape. We expect quantum to approach a similar level of growth and practical applications in just a few years more.

1.3 OLD AND NEW AI ACHIEVEMENTS

What was hypothesized as being with the realm of possibilities several decades ago are now being realized. Although the capabilities have not yet peaked, we can already see applications in the home, at work, in leisure pursuits, in sports, in technical undertakings, and so on. Consider the days of physical peep holes on wooden front doors compared to today's digital front-door ring cameras. Our society has come a long way in a short period of time. There is a strong wave of interest in AI in every corner of business, industry, government, academia, and military in our society. Sadiku et al. (2022) present several practical AI applications in smart cities, smart electrical grids, healthcare, engineering, education, business, industries, manufacturing, agriculture, vehicle autonomy, social media, and the military. The premise of this book is to focus on selected mathematical framework and foundation for developing sustainable AI tools, techniques, and processes. This is to emphasize that a technology that is based on a mathematical foundation will have a basis for sustainment, very much in the same way that mathematical formulations can stand the test of time.

For years, detractors have derided the prospects for AI as a serious and sustainable tool. But AI can no longer be ignored as more and more realistic AI-based products are developed. AI is not yet where it could be, but it is getting there, albeit slowly.

AI is actually not new. It actually originated as a research curiosity in the 1950s. As far back as 1992, Badiru (1992) highlighted the potential applications of AI in manufacturing, with an explicit emphasis on Expert Systems, the legacy software component of AI. It has taken this long to get to where we are today with AI. Adedeji Badiru developed, directed, and ran a rudimentary AI laboratory at the University of Oklahoma, School of Industrial Engineering, as far back as 1986. It was the first such ambitious university-based technical pursuit in the State of Oklahoma at that time. New AI-based courses were developed, and thesis and dissertation products emanated from the AI efforts of those days. The prediction then was that AI would someday emerge from the laboratory to become a viable asset for the society. We are now beginning to realize that prediction. Some of the scholarly AI products that the authors have been involved in over the past decades are summarized below:

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- 1993: Oliver, Gaugarin E., and A. B. Badiru, “An Expert System Model for Supplier Development Program in a Manufacturing Firm,” Proceedings of the 7th Oklahoma Symposium on Artificial Intelligence, Stillwater, Oklahoma, November 18–19, 1993, pp. 135–141.
- 1993: Rogers, Steve, “Fuzzy Inferencing Approach to Modeling and Simulation,” Ph.D. Dissertation, University of Oklahoma, 1993. Senior Artificial Intelligence Engineering, Seagate Technologies, Oklahoma City.
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- 2008: Olunloyo, V. O. S.; Abayomi Ajofoyinbo; and A. Badiru, "An Alternative Approach for Computing the Union and Intersection of Fuzzy Sets: A Basis for Design of Robust Fuzzy Controller," in Proceedings of 7th WSEAS International Conference on Artificial Intelligence, Knowledge Engineering and Data Bases (AIKED '08), Cambridge, UK, February 23–25, 2008. Note: This paper won best student paper at the conference.
- 2012: Badiru, A. B.; Oye Ibidapo-Obe; and B. J. Ayeni (2012), Industrial Control Systems: Mathematical and Statistical Models and Techniques, Taylor & Francis Group / CRC Press, Boca Raton, FL.
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- 2022: Badiru, A. B. (2022), Artificial Intelligence and Digital Systems Engineering, Taylor & Francis Group / CRC Press, Boca Raton, FL.

- 2022: Doran, Eric, Sharon Bommer, and Adedeji Badiru, "Integration of Human Factors, Cognitive Ergonomics, and Artificial Intelligence in the Human-Machine Interface for Additive Manufacturing," International Journal of Quality Engineering and Technology, International Journal of Mechatronics and Manufacturing Systems, Vol. 15, No. 4, 2022, pp. 310–330.

Some of these intellectual products culminated in seminal AI-themed textbooks (Badiru and Cheung, 2002; Badiru, 1992). So, why is AI now bursting into the limelight in light of its long tenure in the dark recesses of many university laboratories? This renewed emergence is due to the emergence of new powerful computational tools and techniques. Below of its process orientation, the discipline of industrial engineering actually had many early influences on the development of AI then and now. Those who know AI inside and out know how much mathematical programming affects optimization of AI products. In fact, there is a noticeable application of industrial engineering and operations research techniques of non-linear programming to machine learning and artificial neural networks. Further, the people orientation of industrial engineering paves the way for the consideration of social science and humanities in the practical uses of AI products by people. Nowadays, we are more sensitized to how people use AI products, from a humanistic standpoint rather than from mechanical standpoint. Similarly, the emergence of more powerful data manipulation techniques created additional inroads into predictive analytics, data envelopment, data quality control, decision science, process efficiency, and path optimization. All of these have foundational linkages to industrial engineering.

An interesting example of recent AI application is its adoption by FIFA for decision-making in the 2022 Football World Cup in Qatar. AI is deployed to ascertain when the ball has crossed the goal line, and also for detection of "offside" via usage of sensors and intelligent image/video processing. The Virtual Assistant Referee (VAR) help obviate controversies such as England's 1966 cross-bar related goal in the final as well as Maradona's (in)famous "hand of God" goal in 1986.

1.4 INDUSTRIAL ENGINEERING LINKAGE

So, what does industrial engineering have to do with the surge and resurgence of AI? The answer can be seen in the very definition of industrial engineering, as presented below:

> Industrial engineering is concerned with the design, installation, and improvement of integrated systems of people, materials, information, equipment, and energy by drawing upon specialized knowledge and skills in the mathematical, physical, and social sciences, together with the principles and methods of engineering analysis and design to specify, predict, and evaluate the results to be obtained from such systems.

The above definition demonstrates the versatility and diversity of industrial engineering to enmesh with AI. For the purpose of this book, we are focusing on the "mathematical" angle of industrial engineering. The fact that the most fruitful applications of AI can be found in "industry" further solidifies the linkage of the discipline of industrial engineering to the field of AI.

Artificial intelligence is not just one single thing. It is a conglomerate of various elements, involving software, hardware, data platform, policy, procedures, specifications, rules, and people intuition. How we leverage such a multifaceted system to do seemingly intelligent things, typical of how humans think and work, is a matter of systems implementation. This is why the premise of this book centers on a systems methodology. In spite of the recent boost in the visibility and hype of AI, it has actually been around and toyed with for decades. What has brought AI more to the forefront nowadays is the availability and prevalence of high-powered computing tools that have enabled the data-intensive processing required by AI systems. The resurgence of AI has been driven by the following developments:

- Emergence of new computational techniques and more powerful computers
- Machine learning techniques
- Autonomous systems
- New/Innovative applications
- Specialized techniques: Intelligent Computational Search Technique Using Cantor Set Sectioning
- Human-in-the-loop requirements
- Systems integration aspects

As long ago as the mid-1980s, the author has led many research and development projects that embedded AI software and hardware into conventional human decision processes. AI has revolutionized and will continue to revolutionize many things we see and use around us. So, we need to pay attention to the emerging developments.

The comprehensive definition of industrial engineering epitomizes what AI is expected to accomplish.

1.5 HISTORICAL BACKGROUND OF AI

The background of AI has been characterized by controversial opinions and diverse approaches. The controversies have ranged from the basic definition of intelligence to questions about the moral and ethical aspects of pursuing AI. However, despite the unsettled controversies, the technology continues to generate practical results. With increasing efforts in AI research, many of the prevailing arguments are being resolved with proven technical approaches.

"Artificial intelligence" is a controversial name for a technology that promises much potential for improving human productivity. The phrase seems to challenge human pride in being the sole creation capable of possessing real intelligence. All kinds of anecdotal jokes about AI have been offered by casual observers. A speaker once recounted his wife's response when he told her that he was venturing into the new technology of AI. "Thank God, you are finally realizing how dumb I have been saying you were all these years," was alleged to have been the wife's words of encouragement. One whimsical definition of AI refers to it as the "Artificial Insemination of knowledge into a machine." Despite the deriding remarks, serious embracers of AI may yet have the last laugh. It is being shown again and again that AI may hold the key to improving operational effectiveness in many areas of application. Some observers have suggested changing the term "Artificial Intelligence" to a less controversial one such as "Intelligent Applications (IA)." This refers more to the way that computers and software are used innovatively to solve complex decision problems.

Natural Intelligence involves the capability of humans to acquire knowledge, reason with the knowledge, and use it to solve problems effectively. It also refers to the ability to develop new knowledge based on existing knowledge. By contrast, *Artificial Intelligence* is defined as the ability of a machine to use simulated knowledge in solving problems.

1.6 ORIGIN OF ARTIFICIAL INTELLIGENCE

The definition of intelligence had been sought by many ancient philosophers and mathematicians, including Aristotle, Plato, Copernicus, and Galileo. These great philosophers attempted to explain the process of thought and understanding. The real key that started the quest for the simulation of intelligence did not occur, however, until the English philosopher Thomas Hobbes put forth an interesting concept in the 1650s. Hobbes believed that thinking consists of symbolic operations and that everything in life can be represented mathematically. These beliefs directly led to the notion that a machine capable of carrying out mathematical operations on symbols could imitate human thinking. This is the basic driving force behind the Al effort. For that reason, Hobbes is sometimes referred to as the grandfather of AI.

While the term "Artificial Intelligence" was coined by John McCarthy relatively recently, the idea had been considered centuries before. As early as 1637, Rene Descartes was conceptually exploring the ability of a machine to have intelligence when he said:

> For we can well imagine a machine so made that it utters words and even, in a few cases, words pertaining specifically to some actions that affect it physically. However, no such machine could ever arrange its words in various different ways so as to respond to the sense of whatever is said in its presence—as even the dullest people can do.

Descartes believed that the mind and the physical world are on parallel planes that cannot be equated. They are of different substances following entirely different rules and can, thus, not be successfully compared. The physical world (i.e., machines) cannot imitate the mind because there is no common reference point.

Hobbes proposed the idea that thinking could be reduced to mathematical operations. On the other hand, Descartes had the insight into functions that machines might someday be able to perform. But he had reservations about the concept that thinking could be simply a mathematical process.

The 1800s was an era that saw some advancement in the conceptualization of the computer. Charles Babbage, a British mathematician, laid the foundation for the construction of the computer, a machine defined as being capable of performing mathematical computations. In 1833, Babbage introduced an Analytical Engine. This computational machine incorporated two unprecedented ideas that were to become crucial elements in the modern computer. First, it had operations that were fully programmable, and second, the engine could contain conditional branches. Without these two abilities, the power of today's computers would be inconceivable. Babbage was never able to realize his dream of building the analytic engine due to a lack of financial support. However, his dream was revived through the efforts of later researchers. Babbage's basic concepts could be observed in the way that most computers operate today.

Another British mathematician, George Boole, worked on issues that were to become equally important. Boole formulated the "laws of thought" that set up rules of logic for representing thought. The rules contained only two-valued variables. By this, any variable in a logical operation could be in one of only two states: yes or no, true or false, all or nothing, 0 or 1, on or off, and so on. This was the birth of digital logic, a key component of the AI effort.

In the early 1900s, Alfred North Whitehead and Bertrand Russell extended Boole's logic to include mathematical operations. This not only led to the formulation of digital computers but also made possible one of the first ties between computers and thought process.

However, there was still a lack of an acceptable way to construct such a computer. In 1938, Claude Shannon published "A Symbolic Analysis of Relay and Switching Circuits." This work demonstrated that Boolean logic consisting of only two-variable states (e.g., on-off switching of circuits) can be used to perform logic operations. Based on this premise, the ENIAC (Electronic Numerical Integrator and Computer) was built in 1946 at the University of Pennsylvania. The ENIAC was a large-scale fully operational electronic computer that signaled thebeginning of the first generation of computers. It could perform calculations 1000 times faster than its electromechanical predecessors. It weighed 30 tons, stood two stories high, and occupied 1500 square feet of floor space. Unlike today's computers that operate in binary codes (0s and Is), the ENIAC operated in decimal (0, 1, 2,…, 9) and it required 10 vacuum tubes to represent one decimal digit. With over 18,000 vacuum tubes, the ENIAC needed a great amount of electrical power, so much that it was said that it dimmed the lights in Philadelphia whenever it operated.

1.7 HUMAN INTELLIGENCE VERSUS MACHINE INTELLIGENCE

Two of the leading mathematicians and computer enthusiasts during the 1900 to 1950 timeframe were Alan Turing and John Von Neumann. In 1945, Von Neumann insisted that computers should not be built as glorified adding machines, with all their operations specified in advance. Rather, he suggested that computers should be built as general-purpose logic machines capable of executing a wide variety of programs. Such machines, Von Neumann proclaimed, would be highly flexible and capable of being readily shifted from one task to another. They could react intelligently to the results of their calculations, could choose among alternatives, and could even play checkers or chess. This represented something unheard of at that time: a machine with built-in intelligence, able to operate on internal instructions.

Prior to Von Neumann's concept, even the most complex mechanical devices had always been controlled from the outside, for example, by setting dials and knobs. Von Neumann did not invent the computer, but what he introduced was equally significant: computing by use of computer programs, the way it is done today. His work paved the way for what would later be called AI in computers.

Alan Turing also made major contributions to the conceptualization of a machine that can be universally used for all problems based only on variable instructions fed into it. Turing's universal machine concept, along with Von Neumann's concept of a storage area containing multiple instructions that can be accessed in any sequence, solidified the ideas needed to develop the programmable computer. Thus, a machine was developed that could perform logical operations and could do them in varying orders by changing the set of instructions that were executed.

Due to the fact that operational machines were now being realized, questions about the "intelligence" of the machines began to surface. Turing's other contribution to the world of Al came in the area of defining what constitutes intelligence. In 1950, he designed the Turing test for determining the intelligence of a system. The test utilized the conversational interaction between three players to try and verify computer intelligence.

The test is conducted by having a person (the interrogator) in a room that contains only a computer terminal. In an adjoining room, hidden from view, a man (Person A) and a woman (Person B) are located with another computer terminal. The interrogator communicates with the couple in the other room by typing questions on the keyboard. The questions appear on the couple's computer screen and they respond by typing on their own keyboard. The interrogator can direct questions to either Person A or Person B, but without knowing which is the man and which is the woman.

The purpose of the test is to distinguish between the man and the woman merely by analyzing their responses. In the test, only one of the people is obligated to give truthful responses. The other person deliberately attempts to fool and confuse the interrogator by giving responses that may lead to an incorrect guess. The second stage of the test is to substitute a computer for one of the two persons in the other room. Now, the human is obligated to give truthful responses to the interrogator, while the computer tries to fool the interrogator into thinking that it is human. Turing's contention is that if the interrogator's success rate in the human/computer version of the game is not better than his success rate in the man/woman version, then the computer can be said to be "thinking." That is, the computer possesses "intelligence." Turing's test has served as a classical example for AI proponents for many years.

By 1952, computer hardware had advanced far enough that actual experiments in writing programs to imitate thought processes could be conducted. The team of Herbert Simon, Allen Newell, and Cliff Shaw organized to conduct such an experiment. They set out to establish what kinds of problems a computer could solve with the right programming. Proving theorems in symbolic logic such as those set forth by Whitehead and Russell in the early 1900s fit the concept of what they felt an intelligent computer should be able to handle.

It quickly became apparent that there was a need for a new, higher level computer language than was currently available. First, they needed a language that was more user-friendly and could take program instructions that are easily understood by a human programmer and automatically convert them into machine language that could be understood by the computer. Second, they needed a programming language that changed the way in which computer memory was allocated. All previous languages would pre-assign memory at the start of a program. The team found that the type of programs they were writing would require large amounts of memory and would function unpredictably.

To solve the problem, they developed a list processing language. This type of language would label each area of memory and then maintain a list of all available memory. As memory became available, it would update the list, and when more memory was needed, it would allocate the amount necessary. This type of programming also allowed the programmer to be able to structure his or her data so that any information that was to be used for a particular problem could be easily accessed.

The end result of their effort was a program called Logic Theorist. This program had rules consisting of axioms already proved. When it was given a new logical expression, it would search through all of the possible operations in an effort to discover a proof of the new expression. Instead of using a brute force search method, they pioneered the use of heuristics in the search method.

The Logic Theorist that they developed in 1955 was capable of solving 38 of 52 theorems that Whitehead and Russell had devised. It was not only capable of the proofs but also did them very quickly. What took a Logic Theorist a matter of minutes to prove would have taken years to do if it had been done by simple brute force on a computer. By comparing the steps which it went through to arrive at a proof to those that human subjects went through, it was also found that it had a remarkable imitation of the human thought process.

1.8 NATURAL LANGUAGE DICHOTOMIES

Despite the various successful experiments, many observers still believe that AI does not have much potential for practical applications. There is a popular joke in the AI community that points out the deficiency of AI in natural language applications. It is said that a computer was asked to translate the following English statement into Russian and back to English: *The spirit is willing but the flesh is weak*. The reverse translation from Russian to English yielded: *The vodka is good but the meat is rotten*.

From my own author perspective, AI systems are not capable of thinking in the human sense. They are great in mimicking based on the massive amounts of data structures and linkages available. For example, consider the following natural language interpretations of the following ordinary statements:

"No salt is sodium free."

A human being can quickly infer the correct interpretation and meaning based on the prevailing context of the conversation. However, an "intelligent" machine may see the same statement in different ways, as enumerated below:

"No (salt) is sodium free," which negates the property of the object, salt. This means that there is no type of salt that is sodium free. In other words, all salts contain sodium.

Alternately, the statement can be seen as follows:

"(No-salt) is sodium free," which is a popular advertisement slogan for the commercial kitchen ingredient named (No-salt). In this case, the interpretation is that this product, named No-salt does not contain sodium.

Here is another one:

"No news is good news."

This is a common saying that humans can easily understand regardless of the context. In AI reasoning, it could be subject to the following interpretations:

"(No news) is good news," which agrees with the normal understanding that the state of having no new implies the absence of bad news, which is good (i.e., desirable). In this case, (No-news), as a compound word, is the object.

Or, an AI system could see it as:

"No (news) is good news," which is a contradiction of the normal interpretation. In this case, the AI system could interpret it as a case where all pieces of news are bad (i.e., not good). This implies that the object is the (news).

Here is another one from the political arena:

"The British parliament wants no deal off the table."

The AI interpretations could see the objects as follow:

(No deal), as a condition of negotiation, is off the table.

Alternately, it could be seen, in the negation sense, as all deals are acceptable to be on the table.

Pattern recognition is another interesting example that distinguishes human intelligence from machine intelligence. For example, when I park my vehicle in a large shopping center parking lot, with many similarly colored and shaped vehicles, I can always identify my vehicle from a far distance by simply seeing a tiny segment of the body of the vehicle. This could be by seeing half of the headlight jotting out from among several vehicles. It could be by seeing a portion of the tail light. It could even be by seeing the luggage carriage on top of the vehicle barely visible above other vehicles around mine. For an AI system to use pattern recognition to correctly identify my vehicle, it would have to use a tremendous amount data collection, data manipulation, interpolation, extrapolation, and other complex mathematical algorithms to consider the options to provide a probable match. Considering example such as the above, it can be seen that human intelligence and natural perception still trump machine's simulated intelligence. In spite of this deficiency, machine intelligence, under the banner of AI, can be useful to supplement human intelligence to arrive at a more efficient and effective decision processes. Consequently, AI is a useful and desirable ally in human operations. This belief was what drove the early efforts in defining and advancing the science, technology, engineering, and mathematics foundations for AI.

1.9 THE FIRST CONFERENCE ON ARTIFICIAL INTELLIGENCE

The summer of 1956 signified the first attempt to establish the field of machine intelligence into an organized effort. The Dartmouth Summer Conference, organized by John McCarthy, Marvin Minsky, Nathaniel Rochester, and Claude Shannon, brought together people whose work and interest formally founded the field of AI. The conference, held at Dartmouth College in New Hampshire, was funded by a grant from the Rockefeller foundation. It was at that conference that John McCarthy coined the term "artificial intelligence." It was the same John McCarthy who developed the LISP programming language that has become a standard tool for Al development. In attendance at the meeting, in addition to the organizers, were Herbert Simon, Allen Newell, Arthur Samuel, Trenchard More, Oliver Selfridge, and Ray Solomon off.

The Logic Theorist (LT), developed by Newell, Shaw, and Simon, was discussed at the conference. The system, considered the first Al program, used heuristic search to solve mathematical problems in *Principia Mathematica*, written by Whitehead and Russell (Newell and Simon 1972). Newell and Simon were far ahead of others in actually implementing Al ideas with their Logic Theorist. The Dartmouth meeting served mostly as an avenue for the exchange of information and, more importantly, as a turning point in the main emphasis of work in the Al endeavor. Instead of concentrating so much on the hardware to imitate intelligence, the meeting set the course for examining the structure of the data being processed by computers, the use of computers to process symbols, the need for new languages, and the role of computers for testing theories.

1.10 EVOLUTION OF SMART PROGRAMS

The next major step in software technology came from Newell, Shaw, and Simon in 1959. The program they introduced was called General Problem Solver (GPS). GPS was intended to be a program that could solve many types of problems. It was capable of solving theorems, playing chess, or doing various complex puzzles. GPS was a significant step forward in AI. It incorporates several new ideas to facilitate problem solving. The nucleus of the system was the use of means-end analysis. Means-end analysis involves comparing a present state with a goal state. The difference between the two states is determined and a search is done to find a method to reduce this difference. This process is continued until there is no difference between the current state and the goal state.

In order to further improve the search, GPS contained two other features. The first is that, if while trying to reduce the deviation from the goal state, it finds that it has actually complicated the search process, it was capable of backtracking to an earlier state and exploring alternate solution paths. The second is that it was capable of defining sub-goal states that, if satisfied, would permit the solution process to continue. In formulating GPS, Newell and Simon had done extensive work studying human subjects and the way they solved problems. They felt that GPS did a good job of imitating the human subjects. They commented on the effort by saying (Newell and Simon 1961):

> The fragmentary evidence we have obtained to date encourages us to think that the General Problem Solver provides a rather good first approximation to an information processing theory of certain kinds of thinking and problem-solving behavior. The processes of 'thinking' can no longer be regarded as completely mysterious.

GPS was not without critics. One of the criticisms was that the only way the program obtained any information was to get it from human input. The way and order in which the problems were presented was controlled by humans, thus, the program was doing only what it was told to do. Newell and Simon argued that the fact that the program was not just repeating steps and sequences but was actually applying rules to solve problems it had not previously encountered, is indicative of intelligent behavior.

There were other criticisms also. Humans are able to devise new shortcuts and improvise. GPS would always go down the same path to solve the same problem, making the same mistakes as before. It could not learn. Another problem was that GPS was good when given a certain area or a specific search space to solve. The problem with this limitation was that in the solution of problems, it was difficult to determine what search space to use. Sometimes solving the problem is trivial compared to finding the search space. The problems posed to GPS were all of a specific nature. They were all puzzles or logical challenges: problems that could easily be expressed in a symbolic form and operated on in a pseudo-mathematical approach. There are many problems that humans face that are not so easily expressed in a symbolic form.

Also during the year 1959, John McCarthy came out with a tool that was to greatly improve the ability of researchers to develop Al programs. He developed a new computer programming language called LISP (list processing). It was to become one of the most widely used languages in the field.

LISP is distinctive in two areas: memory organization and control structure. The memory organization is done in a tree fashion with interconnections between memory groups. Thus, it permits a programmer to keep track of complex structural relationships. The other distinction is the way the control of the program is done. Instead of working from the prerequisites to a goal, it starts with the goal and works backwards to determine what prerequisites are required to achieve the goal.

In 1960, Frank Rosenblatt did some work in the area of pattern recognition. He introduced a device called PERCEPTRON that was supposed to be capable of recognizing letters and other patterns. It consisted of a grid of 400 photo cells connected with wires to a response unit that would produce a signal only if the light coming off the subject to be recognized crossed a certain threshold.

During the latter part of the 1960s, there were two efforts in another area of simulating human reasoning. Kenneth Colby at Stanford University and Joseph Weizenbaum at MIT wrote separate programs that were capable of interacting in a two-way conversation. Weizenbaum's program was called ELIZA. The programs were able to sustain very realistic conversations by using very clever techniques. For example, ELIZA used a pattern matching method that would scan for keywords like "I," "you," "like," and so on. If one of these words was found, it would execute rules associated with it. If there was no match found, the program would respond with a request for more information or with some noncommittal response.

It was also during the 1960s that Marvin Minsky and his students at MIT made significant contributions toward the progress of AI. One student, T. G. Evans, wrote a program that could perform visual analogies. The program was shown two figures that had some relationship with each other and was then asked to find another set of figures from a set that matched the same relationship. The input to the computer was not done by a visual sensor (like the one worked on by Rosenblatt), but instead the figures were described to the system.

In 1968, another student of Minsky's, Daniel Bobrow, introduced a linguistic problem solver called STUDENT. It was designed to solve problems that were presented to it in a word problem format. The key to the program was the assumption that every sentence was an equation. It would take certain words and turn them into mathematical operations. For example, it would convert "is" into "=" and "per" into "/ ".

Even though STUDENTS responded very much the same way that a real student would, there was a major difference in depth of understanding. While the program was capable of calculating the time two trains would collide given the starting points and speeds of both, it had no real understanding or even cared what a "train" or "time" was. Expressions like "per chance" and "this is it" could mean totally different things than what the program would assume. A human student would be able to discern the intended meaning from the context in which the terms were used.

In an attempt to answer the criticisms about understanding, another student at MIT, Terry Winograd, developed a significant program named SHRDLU. In setting up his program, he utilized what was referred to as a micro-world or blocks-world. This limited the scope of the world that the program had to try to understand. The program communicated in what appeared to be natural language.

The operation of SHRDLU consisted of a set of blocks of varying shapes (cubes, pyramids, etc.), sizes, and colors. These blocks were all set on an imaginary table. Upon request, SHRDLU would rearrange the blocks to any requested configuration. The program was capable of knowing when a request was unclear or impossible. For instance, if it was requested to put a block on top of the pyramid, it would request that the user specify more clearly what block and what pyramid. It could also recognize that the block would not sit on top of the pyramid.

Two other approaches that the program took that were new to programs were the ability to make assumptions and the ability to learn. If asked to pick up a larger block, it would assume a larger block than the one it was currently working on. If asked to build a figure that it did not know, it would ask for an explanation of what it was and, thereafter, it would recognize the object. One major sophistication that SHRDLU added to the science of AI programming was its use of a series of expert modules or specialists. There was one segment of the program that specialized in segmenting sentences into meaningful word groups, a sentence specialist to determine the relationship between nouns and verbs, and a scenario specialist that understood how individual scenes related to one another. This sophistication added much enhancement to the method in which instructions were analyzed.

As sophisticated as SHRDLU was at that time, it did not escape criticism. Other scholars were quick to point out its deficiencies. One of the shortcomings was that

SHRDLU only responded to requests; it could not initiate conversations. It also had no sense of conversational flow. It would jump from performing one type of task to a totally different one if so requested. While SHRDLU had an understanding of the tasks it was to perform and the physical world in which it operated, it still could not understand very abstract concepts. Some of the latest developments in the evolution of AI systems is the emergence of ChatBots, which are AI-based chat tools. The most popular tool in this genre is ChatGPT (Generative Pre-trained Transformer), which has been hailed as a very astute ChatBot. It uses deep learning to produce human-like text. Given an initial text as a prompt, it will produce text that continues the prompt. More developments in this regard will further transform human-AI interfaces.

1.11 BRANCHES OF ARTIFICIAL INTELLIGENCE

The various attempts to formally define the use of machines to simulate human intelligence led to the development of several branches of Al. Current sub-specialties of AI include:

(1) *Natural language processing:* This deals with various areas of research such as database inquiry systems, story understanders, automatic text indexing, grammar and style analysis of text, automatic text generation, machine translation, speech analysis, and speech synthesis.
(2) *Computer vision:* This deals with research efforts involving scene analysis, image understanding, and motion derivation.
(3) *Robotics:* This involves the control of effectors on robots to manipulate or grasp objects, locomotion of independent machines, and use of sensory input to guide actions.
(4) *Problem solving and planning:* This involves applications such as refinement of high-level goals into lower-level ones, determination of actions needed to achieve goals, revision of plans based on intermediate results, and focused search of important goals.
(5) *Learning:* This area of Al deals with research into various forms of learning, including rote learning, learning through advice, learning by example, learning by task performance, and learning by following concepts.
(6) *Expert systems:* This deals with the processing of knowledge as opposed to the processing of data. It involves the development of computer software to solve complex decision problems.

1.12 NEURAL NETWORKS

Neural networks, sometimes called connectionist systems, represent networks of simple processing elements or nodes capable of processing information in response to external inputs. Neural networks were originally presented as being models of the human nervous system. Just after World War II, scientists found out that the physiology of the brain was similar to the electronic processing mode used by computers. In both cases, large amounts of data are manipulated. In the case of computers, the elementary unit of processing is the bit, which is in either an "on" or "off' state. In the case of the brain, *neurons* perform the basic data processing. Neurons are tiny cells that follow a binary principle of being either in a state of firing (on) or not firing (off). When a neuron is on, it fires a signal to other neurons across a network of synapses.

In the late 1940s, Donald Hebb, a researcher, hypothesized that biological memory results when two neurons are active simultaneously. The synaptic connection of synchronous neurons is reinforced and given preference over connections made by neurons that are not active simultaneously. The level of preference is measured as a weighted value. Pattern recognition, a major strength of human intelligence, is based on the weighted strengths of the reinforced connections between various pairs of simultaneously active neurons.

The idea presented by Hebb was to develop a computer model based on the way in which neurons form connections in the human brain. But the idea was considered to be preposterous at that time since the human brain contains 100 billion neurons and each neuron is connected to 10,000 others by a synapse. Even by today's computing capability, it is still difficult to duplicate the activities of neurons. In 1969, Marvin Minsky and Seymour Pappert wrote the book entitled *Perceptrons*, in which they criticized existing neural network research as being worthless. It has been claimed that the pessimistic views presented by the book discouraged further funding for neural network research for several years. Funding was, instead, diverted to further research of expert systems, which Minsky and Pappert favored. It is only recently that neural networks are beginning to make a strong comeback.

Because neural networks are modeled after the operations of the brain, they hold considerable promise as building blocks for achieving the ultimate aim of AI. The present generation of neural networks use artificial neurons. Each neuron is connected to at least one other neuron in a synapse-like fashion. The networks are based on some form of learning model. Neural networks learn by evaluating changes in input. Learning can be either supervised or unsupervised. In supervised learning, each response is guided by given parameters. The computer is instructed to compare any inputs to ideal responses, and any discrepancy between the new inputs and ideal responses is recorded. The system then uses this databank to guess how much the newly gathered data is similar to or different from the ideal responses. That is, how closely the pattern matches. Supervised learning networks are now commercially used for control systems and for handwriting and speech recognition.

In unsupervised learning, input is evaluated independently and stored as patterns. The system evaluates a range of patterns and identifies similarities and dissimilarities among them. However, the system cannot derive any meaning from the information without human assignment of values to the patterns. Comparisons are relative to other results, rather than to an ideal result. Unsupervised learning networks are used to discover patterns where a particular outcome is not known in advance, such as in physics research and the analysis of financial data. Several commercial neural network products are now available. An example is NeuroShell from Ward Systems Group. The software is expensive, but it is relatively easy to use. It interfaces well with other software such as Lotus 1-2-3 and dBASE, as well as with C, Pascal, FORTRAN, and BASIC programming languages.

Despite the proven potential of neural networks, they drastically oversimplify the operations of the brain. The existing systems can undertake only elementary pattern-recognition tasks, and are weak at deductive reasoning, math calculations, and other computations that are easily handled by conventional computer processing. The difficulty in achieving the promise of neural networks lies in our limited understanding of how the human brain functions. Undoubtedly, to accurately model the brain, we must know more about it. But a complete knowledge of the brain is still many years away.

Google's ANN-based "deepmind" is arguably one of the strongest AI engines available at the moment: it has been used to tackle numerous problems in Mathematics, Chess, etc.

1.13 EMERGENCE OF EXPERT SYSTEMS

In the late 1960s to early 1970s, a special branch of Al began to emerge. The branch, known as expert systems, has grown dramatically in the past few years and it represents the most successful demonstration of the capabilities of Al. Expert systems are the first truly commercial application of work done in the Al field and as such have received considerable publicity. Due to the potential benefits, there is currently a major concentration in the research and development of expert systems compared to other efforts in Al.

Not driven by the desire to develop general problem-solving techniques that had characterized Al before, expert systems address problems that are focused. When Edward Feigenbaum developed the first successful expert system, DENDRAL, he had a specific type of problem that he wanted to be able to solve. The problem involved determining which organic compound was being analyzed in a mass spectrograph. The program was intended to simulate the work that an expert chemist would do in analyzing the data. This led to the term expert system.

The period of time from 1970 to 1980 saw the introduction of numerous expert systems to handle several functions from diagnosing diseases to analyzing geological exploration information. Of course, expert systems have not escaped the critics. Given the nature of the system, critics argue that it does not fit the true structure of AI. Because of the use of only specific knowledge and the ability to solve only specific problems, some critics are apprehensive about referring to an expert system as being intelligent. Proponents argue that if the system produces the desired results, it is of little concern whether it is intelligent or not.

A controversy of interest surfaced in 1972 with a book published by Hubert Dreyfus called *What Computers Can't Do: A Critique of Artificial Reason*. Views similar to those contained in the book were presented in 1976 by Joseph Weizenbaum. The issues that both authors raised touched on some of the basic questions that prevailed way back in the days of Descartes. One of Weizenbaum's reservations concerned what should ethically and morally be handed over to machines. He maintained that the path that Al was pursuing was headed in a dangerous direction. There are some aspects of human experience, such as love and morality, that could not adequately be imitated by machines.

While the debates were going on over how much Al could do, the work on getting Al to do more continued. In 1972, Roger Shrank introduced the notion of script; the set of familiar events that can be expected from an often encountered setting. This enables a program to quickly assimilate facts. In 1975, Marvin Minsky presented the idea of frames. Even though both concepts did not drastically advance the theory of Al, they did help expedite research in the field.

In 1979, Minsky suggested a method that could lead to a better simulation of intelligence. He presented the “society of minds” view, in which the execution of knowledge is performed by several programs working in conjunction simultaneously. This concept helped to encourage interesting developments such as present-day parallel processing.

As time proceeded through the 1980s, Al gained significant exposure and interest. AI, once a phrase restricted to the domain of esoteric research, has now become a practical tool for solving real problems. While Al is enjoying its most prosperous period, it is still plagued with disagreements and criticisms. The emergence of commercial expert systems on the market has created both enthusiasm and skepticism. There is no doubt that more research and successful applications developments will help prove the potential of expert systems. It should be recalled that new technologies sometimes fail to convince all initial observers. IBM, which later became a giant in the personal computer business, hesitated for several years before getting into the market because the company never thought that those little *boxes* called personal computers would ever have any significant impact on the society. How wrong they were!

The effort in Al is a worthwhile endeavor as long as it increases the understanding that we have of intelligence and as long as it enables us to do things that we previously could not do. Due to the discoveries made in Al research, computers are now capable of doing things that were once beyond imagination.

Embedded Expert Systems: More expert systems are beginning to show up, not as stand-alone systems, but as software applications in large software systems. This trend is bound to continue as systems integration takes hold in many software applications. Many conventional commercial packages such as statistical analysis systems, data management systems, information management systems, project management systems, and data analysis systems now contain embedded heuristics that constitute expert systems components of the packages. Even some computer operating systems now contain embedded expert systems designed to provide real-time systems monitoring and troubleshooting. With the success of embedded expert systems, the long-awaited payoffs from the technology are now beginning to be realized.

Because the technology behind expert systems has changed little over the past decade, the issue is not whether the technology is useful, but how to implement it. This is why the integrated approach of this book is very useful. The book focuses not only on the technology of expert systems, but also on how to implement and manage the technology. Combining neural network technology with expert systems, for example, will become more prevalent. In combination, the neural network might be implemented as a tool for scanning and selecting data, while the expert system would evaluate the data and present recommendations.

While AI technology is good and amenable to organizational objectives, we must temper it with human intelligence. The best hybrid is when machine intelligence is integrated with human intelligence. The human can handle the intuition part, while the machine, as AI, handles the data-intensive and number-crunching parts.

Over the past several years, expert systems have proven their potential for solving important problems in engineering and manufacturing environments. Expert systems are helping major companies to diagnose processes in real time, schedule operations, troubleshoot equipment, maintain machinery, and design service and production facilities. With the implementation of expert systems in industrial environments, companies are finding that real-world problems are best solved by an integrated strategy involving the management of personnel, software, and hardware systems.

Solutions to most engineering and manufacturing problems involve not only heuristics, but also mathematical calculations, large data manipulations, statistical analysis, real-time information management, system optimization, and man machine interfaces. These issues and other related topics are addressed in detail in this book. In addition to the basic concepts of expert systems, guidelines are presented on various items ranging from problem selection, data analysis, knowledge acquisition, and system development to verification, validation, integration, implementation, and maintenance.

Can artificial intelligence systems and products live up to the hype?

In general, the expectations for all products, systems, and processes of AI include effectiveness, efficiency, ease of use, elegance, safety, security, sustainability, and satisfaction. A systems view can, indeed, bring us closer to realizing these expectations. In terms of a practical and readily seen example of AI, look no further than your mobile phone. The present generation of smart phones is readily a common example of an AI system. So, AI is already all around us on a daily basis. Figure 1.1 illustrates a comprehensive view of IE and DE for AI. It can be seen that every element within the definition of industrial engineering fits within the wide scope of AI. Liebowitz (2021) presents a wide coverage of the digital platforms using data analytics to enable AI applications in diverse fields. Some of the topics include autonomy, machine intelligence, managerial decision-making, deep learning, natural language

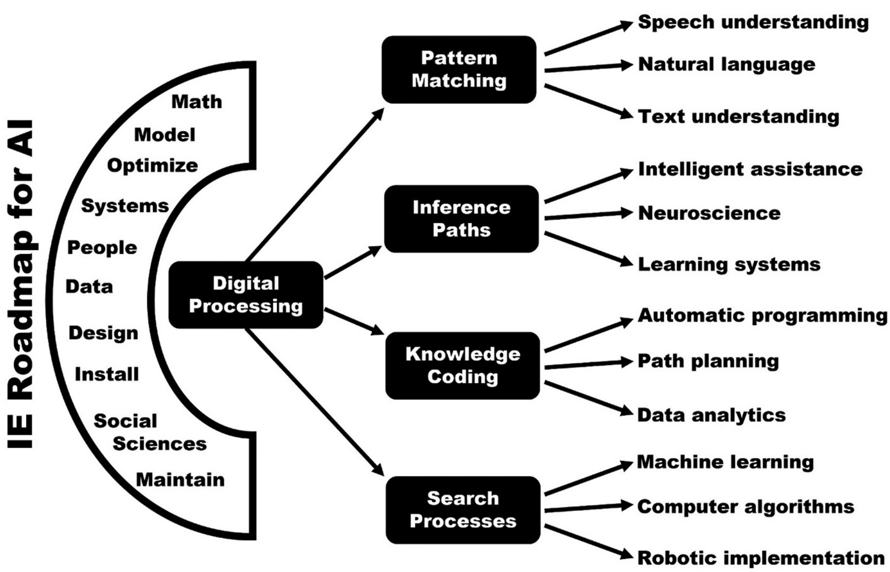

FIGURE 1.1 Industrial engineering and digital engineering roadmap for artificial intelligence.

processing, smart materials, predicting, and cognitive neuroimaging. Lohr (2022) describes how one entrepreneur, David Ferrucii, is fusing common sense into AI applications. It is recalled that common sense applications and implications are among the bastions of industrial engineering.

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