# III. Artificial Intelligence

Artificial Intelligence (AI) is one of the newest fields in science and engineering and currently covers a huge variety of subfields, from the more general, as learning and perception, to the specific, such as playing chess, proving mathematical theorems, driving a car and diagnosing disease. AI is truly a universal field that aims not just to understand but also to build intelligent entities [9].

1. Brief history

The beginnings of AI can be traced to philosophy and fiction, while early inventions in electronics, engineering and many other disciplines have greatly influenced the path of AI. Some early milestones include work in problem solving, including basic work in learning, knowledge representation and inference as well as programs in language understanding, translation, theorem proving, associative memory and knowledge-based systems [10].

AI sits at the intersection of a number of important disciplines, listed in Table III.1 below, each of them contributing in some way to the development of this field. In its formative years, AI was influenced by ideas from many fields of study. These came from people working in engineering(such as Wiener’s work in cybernetics), biology(Ashby, McCulloch and Pitt’s work on neural networks in simple organisms), experimental psychology, communication theory, game theory(notably by von Neumann and Morgenstern), mathematics and statistics, logic and philosophy(for example, Church and Hempel) and linguistics(such as Chomsky’s work in grammar) [10].

**Table III.1.** The disciplines and the personalities that lead to the development of AI

by finding answers to important questions [9]

|  |  |  |
| --- | --- | --- |
| Discipline | Questions | Personalities |
| Philosophy | * Can formal rules be used to draw valid conclusions? * How does the mind arise from a physical brain? * Where does knowledge come from? | Aristotle  Leonardo da Vinci  Wilhelm Leibniz  René Descartes  Rudolf Carnap |
| Mathematics | * What are the formal rules to draw valid conclusions? * What can be computed? * How do we reason with uncertain information? | George Boole  Kurt Gödel  Alan Turing  Steven Cook  Thomas Bayes |
| Economics | * How should we make decisions so as to maximize payoff? * How should we do this when the payoff may be far in the future? | Adam Smith  John von Neumann  Richard Bellman  Herbert Simon |
| Neuroscience | * How do brains process information? | Hans Berger, Camillo Golgi, Santiago Ramon y Cajal |
| Psychology | * How do humans and animals think and act? | H. Helmholtz, F. Bartlett, K. Craik, N. Chomsky |
| Computer Engineering | * How can we build an efficient computer? | J. Eckert, C. Babbage, J.M. Jacquard |
| Control theory and cybernetics | * How can artifacts operate under their own control? | N. Wiener, W.R. Ashby |
| Linguistics | * How does language relate the thought? | B.F. Skinner, N. Chomsky |

These areas made their mark and continue to influence this field of study, but after having assimilated much, AI has grown beyond them and has, in turn, occasionally influenced them back [10]. Only in the last half century computational devices and programming languages have become sufficiently powerful to build experimental tests of ideas about what intelligence is.

The first work that is now seen as belonging to AI was done by McCulloch and Pitt in 1943 and proposed a model of artificial neurons, drawing knowledge from three different sources: the basic function and physiology of neurons in the brain, a formal analysis of propositional logic and Turing‘s theory of computation. Their network of connected neurons was able to compute any computable function and could also implement all the logical connectives [9].

But the birth of AI is considered to have taken place in **1956** at the Dartmouth College in Hanover, where a two-month workshop gathered 10 scientists interested in the automata theory, neural nets and the study of intelligence from all over the US, in an attempt “to find how to make machines use language, form abstractions and concepts, solve kinds of problems now reserved for humans and improve themselves” [9].

Although the workshop itself did not lead to any new breakthroughs, it succeeded in introducing all the major figures involved in the discipline to each other. For the next 20 years, the field would be dominated by these people and their students and colleagues at major universities and study groups in the US [9].

The early years (**1952-1969**) of AI were full of successes, even though in a limited way. Taking into account the primitive computers and programming tools of the time, whenever a computer did something even remotely clever it was considered astonishing. Some accomplishments from this period are:

* the General Problem Solver (GPS) of Newell and Simon, probably the first program to incorporate the “thinking humanly” approach and could handle a limited class of puzzles
* the Geometry Theorem Prover of Gelernter, which was able to prove theorems that were considered tricky by many mathematics students
* the definition of the high-level language Lisp by McCarthy, which would become the dominant AI programming language for the next 30 years
* perceptrons and flourishing work on neural networks

Although these years where full of successes and enthusiasm was high, the period between **1966 and 1973** [9] was marked by a dose of reality. The predictions stated by many scientists did come true, but it took 40 years for this to happen, rather than 10. This overconfidence came from the fact that the early AI systems showed promising performance, but failed to take into account three major difficulties:

* The programs succeeded only by means of simple syntactic manipulations and knew nothing of their subject matter. An example of a failed project because of this aspect would be the efforts of early machine translation, when it was thought that simple syntactic transformations and word replacements would suffice to preserve the meaning of a sentence.
* The combinatorial explosion. It was thought at the time, before the theory of computational complexity was developed, that scaling up to more difficult tasks would be a matter of faster hardware and larger memories, but this assumption was soon proven wrong, when researchers failed to prove theorems involving more than a few dozen facts.
* The basic structures used to generate intelligent behavior had some fundamental limitations. For example, the perceptrons, although they were shown to be capable to learn anything that they could represent, they in fact could represent very little.

Until 1969, the problem solving techniques employed were using a general-purpose search mechanism attempting to put together elementary reasoning steps to find complete solutions, and they weren’t able to scale up to larger or more difficult problems. The alternative was to build more powerful, domain-specific knowledge that would allow larger reasoning steps and could easily handle typically occurring cases in narrow areas of expertise. The **decade after 1969** [9] was marked by the emergence of projects that did just that, such as:

* DENDRAL – it was the first successful knowledge-intensive system and was used to solve the problem of inferring molecular structure from the information provided by a mass spectrometer. The first naïve version generated all possible structures for the given formula, predicted the spectrum that would be observed for each one and then compared these results with the actual spectrum of the molecule, but couldn’t manage even moderate-sized molecules. So the researchers consulted analytical chemists and all the relevant theoretical knowledge gathered from them was mapped into rules that helped in restricting the search space.
* HPP – the Heuristic Programming Project was developed to investigate the extent to which the new methodology of expert systems could be applied to other areas of human expertise.
* MYCIN – was developed to aid in the diagnosis of blood infections. It had 450 rules acquired from extensive interviewing of medical experts, took into account the uncertainty associated with medical knowledge and was able to perform as well as some specialists.
* SHRDLU – a system for understanding natural language which was able to overcome ambiguity and understand pronoun references.
* Prolog – logic based reasoning language widely used in Europe at the time.

Since **1980** [9], AI has become an industry, with the first successful commercial expert system, R1, being employed at the Digital Equipment Corporation to help configure orders for new computer systems and saved the company an estimated $40 million a year. Also, in the mid 1980s, the back-propagation learning algorithm gained the spotlight and was applied to many learning problems in computer science and psychology. The content and methodology of work in AI has seen a revolution in recent years and is more common to build on existing theories than to propose new ones, to base claims on rigorous theorems or experimental evidence rather than on intuition and to show relevance to real-world applications.

Up until the years **2000s** [9], the emphasis in computer science has been on the algorithm, but recent work in AI suggests that for many problems, it is better to focus in the data and be less meticulous about what algorithm to apply, also taking into consideration the increasing availability of very large data sources. This suggests that the problem of how to express all the knowledge that a system needs may be solved by learning methods, rather than hard coded rules, provided that the learning algorithms have sufficient data to work with.

1. Domains of application

The multidisciplinary trait of AI can also be observed in the number of fields to which AI has contributed to, not only in the ones from which it originated. Although initially the research was much narrower, considering the multitude of areas in which AI has been proven useful until now, AI has been able to gain popularity thanks to its very efficient and general techniques. They allowed the methods to be easily adapted to different data and representations, from the financial field, to healthcare and robotics.

Some of the most notable examples of projects that incorporate AI method currently in use today are listed in Table III.2, along with their corresponding domain. Some projects include not just only one technique, but make use of AI for a multitude of tasks, such as the humanoid robot Sophia, created by Hanson Robotics. Sophia uses facial and speech recognition, imitates human gestures and facial expressions and is able to maintain a conversation [11].

**Table III.2.** Some of the more prominent domains in which AI is currently being applied in

and a few corresponding examples of AI projects [9, 12-14]

|  |  |
| --- | --- |
| Domains | Examples |
| Automotive | STANLEY, a driverless robotic car equipped with cameras, radar, sensors and an onboard software to command the steering, braking and acceleration won the DARPA Grand Challenge in 2005. Today there are more than 30 companies using AI to develop driverless cars. |
| Games | Deep Blue became the first computer program to defeat the world champion in a chess match in 1997. Also, AI is used in video games to produce bots that play the game alongside humans. |
| Military | Although many AI researchers seek to distance themselves from military applications, AI is currently used to develop military drones capable of autonomous actions and unmanned combat aerial vehicles. |
| Healthcare | AI has been successfully used to extract information on treatment patterns and diagnoses from large digital databases. Furthermore, robotic surgeries are being developed and performed, with the first unassisted surgery taking place in 2006 on a patient having heart arrhythmia. |
| Finance and economics | Systems to detect unauthorized use of debit cards have been in use since 1987 and AI also has an impact in online trading, stock investment decisions and preventing financial fraud. |
| Robotics | The iRobot Corporation has sold over two million Roomba robotic vacuum cleaners for home use. In addition to this, robotic manipulators are often used in industrial workflows, where repetitive actions are needed or precision is required. |
| Speech and image recognition | Image recognition methods are used in the analysis of medical imaging results and the subsequent diagnosis of disease, but also in day to day objects, such as cameras with face recognition or surveillance systems. Speech recognition has been proven very useful in the development of online assistants, such as Siri. |
| Aviation | Airlines use expert systems in planes to monitor the atmospheric conditions and system status, enabling planes to be put in autopilot. Also, the use of artificial intelligence in building simulators and analyze the data gathered by using them is proving to be very beneficial to the industry. |
| Education | Intelligent tutoring systems have been used to teach Air Force technicians to diagnose electrical problems in aircrafts and to train Navy recruits in technical skills in a shorter amount of time. |
| Marketing | AI techniques are used to back up marketing decisions by analyzing trends, providing forecasts, reducing information overload and allowing for up-to-date information. |

1. Applications of AI in bioinformatics and life sciences

Bioinformatics is an interdisciplinary field that develops methods and software tools for understanding biological data. The technical advances in the last years have increased the amount of data that biologists can record about different aspects of an organism at the genomic, transcriptomic and proteomic levels, and the discipline of bioinformatics has allowed scientists to exploit the advances in computer science and computational statistics in analyzing this data. But as the volume of data grows, the techniques used must cater for large-scale data [15].

Such an approach is ideal because of the ease with which computers can handle large quantities of data and probe the complex dynamics observed in nature [16]. But this merger of disciplines is not as surprising considering that life itself is an information technology. An organism’s physiology is largely determined by its genes, which at its most basic can be considered as digital information.

Bioinformatics tackles three main topics of handling biological data [16], particularly data regarding macromolecules such as DNA, RNA and proteins, and those are: organizing data in a way that makes it easily accessible for researchers, building specially developed tools and using those tools to analyze the data and interpret the results in a biologically meaningful manner. AI has a role in developing and applying particular methods that use biological data, such as DNA sequences or amino acid chains, to help understand different physiological functions or pathological processes within an organism.

**DENDRAL** was the first rule-based system applied to a “real-world” problem. Its development began at Stanford University in 1965 under the guidance of E. Feigenbaum, B. Buchanan, J. Lederberg and C. Djerassi and it spanned approximately half the history of AI research. It was used by chemists to determine the molecular structure of different organic compounds by analysis of certain physical spectra of the molecules. It was one of the first large-scale programs to incorporate the strategy of using detailed, task-specific knowledge about the problem domain as a source of heuristics and to seek generality through automating the acquisition of such knowledge. It used a substantial amount of knowledge of chemistry and thus managed to reach a high level of performance.

DENDRAL was a knowledge driven program and one of the first to conceptually separate the knowledge base that could be edited or redefined for new problems, from the code that would remain the same for interpreting and using that knowledge. Perhaps most significant is that this research was an extensive empirical exploration of heuristic programming techniques that highlighted the strengths and weaknesses of these techniques [17, 18].

**DNA sequence analysis** is another [19] topic that has attracted computer scientists to use AI techniques because of the availability of digital information. But there are also some challenges related to this area, such as:

* Parsing a genome in order to find the segments of DNA with various biological roles (sequences that encode proteins or that control when and where proteins are expressed).
* Aligning the sequences of DNA in order to check for similarities between them.

Sequencing by Hybridization (SBH) [19], also called “sequencing by k-tuple composition” is a method to determine the order in which nucleotides appear in a strand of DNA. It uses a matrix, or chip, with a fixed number of features and each one can accommodate one probe, consisting of smaller sequences of k nucleotides, to be searched in the DNA strand. This leads to a combinatorial constraint that limits the use of classical algorithms to piece together the entire sequence of the DNA strand of interest. Usually k is between 8 and 10, so a chip with k=8 will have 48 = 65 536 probes on it that will allow researchers to reconstruct only 200 nucleotides long sequences.

In SBH, an appropriate length probe must be used to unambiguously determine a target sequence of length N. When the sequence is larger than 40 nucleotides, a probe of length k=4 cannot be used to reconstruct the target with a high probability of success. As N increases, the probability of redundancy in the target increases, making unambiguous reconstruction difficult. Hence the AI methods are well suited to solve the DNA sequencing problem and obtain a near optimal solution. DIMANTS [19] is a multi-casts ant system that uses a heuristic approach based on social insects’ organization. Also, evolutionary programming has been applied for DNA sequencing with very good results after numerous simulations. A hybrid genetic algorithm that had a greedy improvement managed to have over 95% optimal results when tested on sequences to up to 500 nucleotides and probes of length 10 [19].

A summary of some of the most important applications of AI in bioinformatics is given in Table III.3, grouped by the techniques employed to analyze the data.

**Table III.3.** Some important applications of AI in the field of bioinformatics [15]

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| --- | --- |
| Technique | Bioinformatics applications |
| Nearest neighbor and clustering approaches | Both algorithms could provide good solutions where implementation and computation time are a priority. They can be used to determine useful information from high-dimensional data, but also as a method for pre-processing data for use by other algorithms. |
| Decision trees | * HIV and Hepatitis C protease cleavage prediction: See5 was developed to determine whether there was a pattern of amino acids in the substrate that could help determine whether the viral protease did or did not cleave, for the design of possible future protease inhibitors. * Classification of cancer by using diagnosis data: using a committee of decision trees to decide the outcome of the classification task (deciding if the data corresponds to ovarian cancer or not). Performs better than See5, but may require significant extra computation. |
| Neural Networks | * Gene expression analysis: using neural networks or perceptrons to attempt to distinguish between diseased and normal individuals, or to distinguish between two types of a disease by solely using the expression values of genes taken from those individuals. * Identifying protein subcellular location: using a Kohonen neural network to predict where a protein was located, based on its amino acid make-up, because it can provide important clues as to its function in the cell. |
| Genetic Algorithms | * Reverse engineering of regulatory networks: taking snapshots of a system at different times, consisting of the gene expression data and constructing a graph representing the regulatory network of the system. * Multiple sequence alignment: matching two or more DNA or amino acid sequences in order to find similarity between genes or proteins that may lead to similarity also in function. |
| Cellular Automata | CA allows the behavior of molecules to be investigated in highly complex environments where there might be many hundreds of molecules interacting at once.   * Simulation of an apoptosis(cellular death) network * Cellular automata model for enzyme kinetics |

**Medicine** seems particularly amenable to AI solutions [20] and has been the focus of much interest in thriving technological economies. The impact of AI can be grouped in two main topics: extracting meaning from large amounts of medical data in the search domain and aiding clinicians in delivering care to patients. Data-driven predictions of drug effects and interactions, identification of type 2 diabetes subgroups and the discovery of comorbidity clusters in autism spectrum disorders are just some of the successful results of using AI to extract information from large databases of Electronic Health Records. In the United States, machine learning approaches have been used to create a decision support system for physicians treating cancer patients, with the intention of improving diagnostic accuracy and reducing costs using large volumes of patient cases and scholarly articles.

As both the number of imaging studies and the number of images per study grows, the incorporation of computer-aided detection systems into the diagnostic process could improve the performance of image interpretation by providing quantitative support for clinical decision making, particularly the differentiation of malignant and benign tumors.

Another topic of major interest at the crossroads of molecular biology, chemistry and artificial intelligence is the prediction of protein structure from the amino acid sequence. This is also the focus of this paper and will be discussed in depth in the next chapter, classifying the different techniques based on algorithm, exterior knowledge used or the structure type that is being predicted.

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