Abstract

This is where the abstract will go. I guess I'll mention a thing or two about the contents, what I plan to discuss and what my analysis shows.

Cognitive Science and Artificial Intelligence: An Interwoven Approach

Supervisor: Francesco Bianchini

Paolo Marzolo

June 19, 2021

1 Introduction

This is Paolo Marzolo's bachelor thesis, written as part of the three-year program in computer science at University of Bologna. The stated objective of this document is to analyze the history of Cognitive Science and Artificial Intelligence and identify how influences among the two disciplines and others led to a partially shared evolution in the overarching research topics throughout their lifespans. Other similarities will be pointed out, and some of the algorithms and concepts contained throughout the sections will be explained in detail, in order to give the reader a more complete understanding.

The structure of the document will be as follows: after this introduction, a brief glossary will introduce some of the terms that will be used in this document with a short definition; this has been included to avoid having "foundational" terms be constrained by a specific philosophy or line of research. Then, the rest of the document will develop parallel to the history of the disciplines. In the final section, a bird's-eye-view will provide additional insight, and **MAYBE** a brief discussion of the roles of symbols will conclude the contents.

2 Terms and Definitions

Before definining our glossary, it is important to understand the reasoning behind why we chose to include it: when discussing researchers' understanding of human thought, it is nearly impossible to avoid using terms that have a strong past history. As an example, "thought" could already be considered too far from a behaviorist point of view. A further example is a recent discussion that took place after a somewhat controversial paper by Nunez was published [15], questioning the multidisciplinarity of Cognitive Science as a discipline (and journal) and declaring "The prospect launched by the cognitive revolution of a unified and coherent interdisciplinary seamless cognitive science did not materialize".

Cognitive Science. As we will see in following sections, saying "definitions of Cognitive Science have evolved throughout the years" would be a massive understatement. ("Thinking can best be understood in terms of representational structures in the mind and computational procedures that operate on those structures"). Its multidisciplinary nature is uncontested from what the International Encyclopedia of Social & Behavioral Sciences [8] reports ' may have been the first published use of the term cognitive science':

> 'The concerted efforts of a number of people from ... linguistics, artificial intelligence, and psychology may be creating a new field: cognitive science'

. Even the "essential original features" identified by Gardner in 1987 [6] (summarized here as (1) necessity to speak about mental representation as a separate layer of analysis from the biological, (2) faith that the computer is central to the understanding of the human mind and (3) de-emphasizing factors such as emotions or cultural factors) would be completely or partially thrown out by contemporary scholars.

In a more recent publication[2], Cognitive Science is characterized as

> The field would be better defined as the study of 'mind as machine' ... More precisely, cognitive science is the interdisciplinary study of mind, informed by theoretical concepts drawn from computer science and control theory.

.

Not only was its definition cloudy and unstable ("cognitive science is ... a perspective, rather than a discipline in any conventional sense" [19]), but as Nunez points out its disciplines have varied wildly in which ones they are and how represented they are in the Cognitive Science enterprise. Because of the reasons outlined here, far removed form the subject of this document, we will avoid using the term "Cognitive Science", and prefer the acronym "DCS".

Descriptive Cognitive Sciences (DCS). As we mentioned, the disciplines which make up Cognitive Science are not only multiple, but subject to interpretation as well. Since the nature of this work is to compare it to the history of Artificial Intelligence, we will from this point on use the acronym "DCS", for Descriptive Cognitive Sciences, as an alternate approach to the Constructive one taken by Artificial Intelligence researchers. This is not to say that a psychologist cannot take a constructive approach to the explanation of consciousness: the only reason we chose this is because we found it to be an intuitive use of the term.

Mind. Once again, although we take notice of the history of the term, we have to select a few terms to use in our language. Hereafter, we consider the mind as the non-physical correlate of human brains: "the complex of faculties involved in perceiving, remembering, considering, evaluating, and deciding. Mind is in some sense reflected in such occurrences as sensations, perceptions, emotions, memory, desires, various types of reasoning, motives, choices, traits of personality, and the unconscious."[12].

whatever else will come up

3 A History of Influences

As mentioned in the introduction, our approach will follow the historical sequence of events, although some references or explanations may be anachronistic for clarity. In order to give a general view, we split the histories of these disciplines into broad periods: one for (more or less) every substantial shift in approach and views. Generally, every time period will mention two sides of the story: one of them will focus on DCS, and the other on AI and Computer Science.

3.1 Landscape before 1950

Although the official birth of the "Cognitive Science" institutions is in the late 1970s, reasoning about thought has been a staple in philosophical research for centuries. Because of the scope of this document, we will focus on a few important concepts, and use them to set the stage for the first large shift of ideas.

3.1.1 Mathematics and Computer Science

Some of the most relevant contributions to the "reasoning as a process" come from Mathematics and what would later become Theoretical Computer Science. We will outline some of them here, while we trace part of the history of conceiving of thought as computation, first, and computers as devices for computation, second. In this respect, the following step is to be expected: can we use devices for the computation that thoughts "work" with?

Boole's Laws of Thought and Boolean Algebra. To avoid going too deep in mathematical concepts for our purposes, we can think of Boolean algebra as the branch of algebra where the variables can be either true or false (1 and 0), and the main operations on its variables are conjuction (and, $\wedge$), disjunction (or, $\vee$), negation (not, $\neg$). Through these, logical operations can be described. In "An Investigation of the Laws of Thought on Which are Founded the Mathematical Theories of Logic and Probabilities", one of the author's two monographs on algebraic logic, George Boole, then mathematics professor in Ireland, introduces Boole's algebra as an extension to Aristotle's logic. In it, Boole provides Aristotle's algebra with mathematical foundations, and expands it from two-term to any-term. Boole's algebra differs from modern Boolean algebra (in Boole's algebra *uninterpretable* terms exist) and cannot be intepredted as set operations; still, its introduction marks a step towards the formalization of laws of thought and a possible bridge between mathematical research and thinking processes (even the title of the book it was introduced in gives a very clear direction). Boolean algebra would instead be developed by Boole's successors (Jevons, Peirce, Schroder and Huntington in particular); this work allows boolean algebra to now be defined by the Stanford Encyclopedia as

> the algebra of two-valued logic with only sentential connectives, or equivalently of algebras of sets under union and complementation.

KEY CONCEPTS: laws of thought can be modeled in mathematics, using algebra.

Automata theory. The study of how automatic calculators (more properly, abstract machines **TODO: mi sbaglio?** or automata) can be used to compute and solve problems is a part of theoretical computer science research. The history of Automata Theory is especially interesting, as it will let us meet some important researchers: it features two neurophysiologists, Warren McCulloch and Walter Pitts, and is thus born from the desire of modeling human thought itself. The first model was proposed in 1943 [10], in a seminal paper that also introduced other research themes we will come back to later. A little over twelve years later, two computer scientists, Mealy and Moore, generalized the theory to more powerful machines, "Finite-State machines". The general idea behind them is this: starting from an input and a set of states, a "transition function" maps the current state and an input to an output together with the next state. They do not have any memory, and as such can only "solve" simpler problems: if used to recognize languages, they can only recognize regular ones.

More powerful abstract machines had already been proposed: Turing had introduced "Turing machines" in 1937 [25], as part of his proof of the Entscheidungsproblem. The relationship between automata "expressive power" and language complexity will be explained in later chapters. **TODO: undecidability problem already puts a stop to modeling thought as maths?**

KEY CONCEPTS: Modeling algebra, so thought, is possible through some computational structure

Cybernetics. Although in recent years the term "cybernetic" has been used to mean futuristic/sci-fi technology, Cybernetics is a transdisciplinary discipline that studies regulatory systems. The core of the discipline are feedback loops (or circular causality), where the result of action is taken as input for (choosing) future actions. Cybernetics isn't bound to any particular application, so its applications include biology, sociology, computer science, robotics and many others. Its flexible approach led to many different definitions: two early ones are the one used in Macy cybernetics conferences, "the study of circular causal and feedback mechanisms in biological and social systems"[22], and the definition by Norbert Wiener, considered the originator of cybernetics, "the scientific study of control and communication in the animal and the machine"[29]. Although the word itself was used by Plato to signify the governance of people, our interest resides in contemporary cybernetics, born in the 1940s. Before the aforementioned paper by McCulloch and Pitts, the study of feedback was considered by Anokhin in 1935 [1] (physiologist). In the same year as the McCulloch-Pitts paper was published, Wiener, together with Rosenblueth and Bigelow, published "Behavior, Purpose and Teleology" [17]: these three researchers, together with McCulloch, Turing, Grey Walter and Ross Ashby, would go on to establish the discipline of cybernetics. Wiener coined the term to denote "teleological mechanisms".

An important addition to the field would be the Von Neumann cellular automata: these are yet another model of computation part of automata theory. A cellular automata is a grid of cells (of any dimensions, but for clarity, consider a 2-dimensional one first), of which each has a finite number of states it can be in; the cellular automata evolves by moving from generation zero ($t = 0$) to the next generation ($t = 1$) following mathematical rules: the state of every cell is determined by its past state and the surrounding cells. Without going into the specific rules Von Neumann determined, this is relevant to us because it introduces the concept of self replication, soon adopted by cybernetics as a core concept. Another important contribution from cybernetics is the creation of Artificial Neural Networks, introduced in the same McCulloch-Pitts paper we mentioned earlier.

KEY CONCEPTS: Study of feedback is subject-agnostic, self replication, artificial neural networks.

Information theory and technical advances. As we have seen, theoretical advances were many and varied, but the technical advances were what drove the ability to put those in practice. Among those, we have to mention the move from electromechanical devices to vacuum tube-based computers, which gave birth to a device for controlling the connections between telephone exchanges, thanks to Flowers, in 1934. The record for the first general-purpose stored-program (as in, controlled by wires, the opposite of a stored-program computer) went to Konrad Zuse, with the Z3 machine. This machine also used a binary system, but it was not a universal computer. In 1944, the Bletchley Park cryptanalysts started using Colossus. The first Turing-complete (i.e. with the same computing ability as the Turing machine) computer was completed in 1945. It used over 18.000 vacuum tubes. The first stored-program computer, built as a testbed for new technology and design, was the Manchester Baby, ran in June 1948[4].

As part of the advances of this period, we must mention the birth and development of Information Theory. Information Theory encompasses the study of quantification, storage and communication of information, in digital form. After being introduced by Nyquist and Ralph [16], the field was firmly established by Shannon's "A Mathematical Theory of Communication" in 1948. Without going into mathematical details, its main influences include the bit as a unit of informationa and the necessity of redundancy of a source when using unreliable communication channels.

Lastly, we note that neuroscience had new tools at his disposal: electrophysiological techniques, such as brain stimulation, single cell recording and EEG recording [8] were instrumental to the research into localization studies (like deficits derived from brain lesions) approached by Geschwind in the 1950s.

3.1.2 DCS

The DCS landscape around 1950 was strongly rooted in Behaviorism, with hints of the revolution that was soon to come. Some of the larger influences from the Computer Science side, such as the McCullough Pitts artificial neural network we mentioned, would in fact be ignored and re-discovered at the following shift.

Behaviorism. Behaviorism emerged as the dominant school in Western psychology as a reaction to depth psychology and other forms of psychology that did not fit well with scientific experimental verification. That is not to say it was unprecedented: Thorndike presented the law of effect (using consequences to strengthen or weaken behaviour) in 1898. Still, behaviorism was introduced as "methodological behaviorism" by a 1924 publication by John Watson [27], and then further expanded by many researchers, of which we must mention B. F. Skinner.

Behaviorism, more than a way to impose empirical constraints on studying psychology, is a doctrine of how to do behavioral science itself. The Stanford

Encyclopedia identifies three claims as the roots of behaviorism (as a doctrine):

- Psychology is the science of behavior. Psychology is not the science of the inner mind – as something other or different from behavior.
- Behavior can be described and explained without making ultimate reference to mental events or to internal psychological processes. The sources of behavior are external (in the environment), not internal (in the mind, in the head).
- In the course of theory development in psychology, if, somehow, mental terms or concepts are deployed in describing or explaining behavior, then either (a) these terms or concepts should be eliminated and replaced by behavioral terms or (b) they can and should be translated or paraphrased into behavioral concepts.

These fundamental truths identify three of the various flavours behaviorism is studied in. Skinner, mentioned above, was the first to suggest that covert behavior, such as cognition and emotions, is governed by the same controlling variables as observable behavior: although focused on the third "truth", his philosophy combines all three mentioned pillars, and is described as *radical behaviorism* by skinner himself [20].

One can easily see how the philosophy itself forced the practitioners into a state of absolute experimental dependency, which constrained the concept explored to the scientific realm. At the same time, its complete rejection of mental processes (or at least their relevance to scientific study) is the complete opposite of the assumptions that were made on the "CS" side of comprehension. Other behaviorists, though, were less radical: Clark Hull was willing to put drive inbetween stimulus and response, but only to create a corresponding theory that explained it in terms of behavior[7]; Edward Tolman, instead, proposed rats navigate a maze following a mental map[24].

Cognitive signs. Just like Tolman, other cognitive-leaning psychologists proposed ideas that did not fit with the behavioral narrative. Among them, we mention some relevant ones. Gestalt psychology: refusing the behavioristic assumption that conscious experience could be considered by reducing it to the sum of it parts, proposed the principle of totality; it also proposed the principle of psychophysical isomorphism, which meant the cerebral activity was correlated to conscious activity [26]. Vygotsky and Luria pioneered "cultural-historical psychology", which noted the role of culture and language in the development of higher pschological functions; Luria, alone, also published research on individuals' thought processes as his doctoral dissertation.

Lastly, we mention Miller, who was just a trainee at Stevens's Psychoacoustic Laboratory at Harvard: he will soon become relevant, as part of the 1956 cognitive revolution.

In our exploration of the state of disciplines around 1950, it is clear that Computer Science was firmly en route to a first attempt at thought modeling though mathematical "symbols": if, as they suspected, thought was to be considered a use of (or better yet, possible to model with) algebra, then once physical computers were capable enough they would be capable of thought. On the other side of the fence, DCS was still firmly rooted in behaviorism: in their view, the entire discussion would be based on false premises which were in turn based on wrongful research; the roots of human behavior were to be found in human behavior itself, and assuming otherwise was not only useless but unscientific, as it would lead to unprovable theories and impossible experiments. At the same time, cognitive suggestions were starting to appear, challenging the general (or at the very least American) current view.

3.2 1956: A Pivotal Year

As we have mentioned in the previous section, there were various lines of research into thought modeling: automata theory was focused on what problems were possible to model, cybernetics took (analog and biology-based) feedback and self replication as founding pillars, while information theory dedicated itself to information storage and transmission. Instead, DCS was still mostly led by behaviorist views, but cognitive-oriented proposal started to pop up. This trend would continue in 1956, and spike in 1957 with a publication by Noam Chomsky that would rattle the field.

3.2.1 CS

The most relevant event of 1956 (and quite possibly of the history of AI research) is the Darmouth College Workshop, a sort of convention that connected researchers from diverse fields interested on similar topics. This is also the context in which the term "Artificial Intelligence" was attached to the field.

Dartmouth College Workshop. As we said, at the start of the 1950s thinking machines were being inspected by a few different disciplines; in 1955 John McCarthy, an Assistant Professor at Dartmouth, proposed a conference to organize and fertilize such disciplines. He proposed the name "Artificial Intelligence" because, unlike today, it was still neutral; Wikipedia reports that avoiding cybernetics was partly due to 'him potentially having to accept the assertive Norbert Wiener as guru or having to argue with him'. The project was formally proposed in September, by four of those who would become (if they weren't already) prominent researchers in the field: McCarthy himself, Marvin Minsky, Nathaniel Rochester and Claude Shannon. Among the extraordinary attendees we mention: Minsky (who will become very relevant in the next section), Bigelow (co-author of the seminal paper "Behavior, Purpose and Teleology." on cybernetics), Solomonoff (inventor of algorithmic probability), Holland (pioneer of genetic algorithms, was invited but did not end up attending), Ross Ashby (psychiatrist and cybernetics pioneer), McCulloch (who we've already mentioned), Nash (prolific mathematician, also known for his work on game theory), Samuel (creator of what is considered the first AI program, a checkers program) and finally Allen Newell and Paul Simon, who presented their recently completed "Logic Theorist". Although the discussions were not directed, many of the topics would have a long-lasting impact on the field, like the rise of symbolic methods and limiting domains (which would lead to expert systems).

Logic Theorist. The Logic Theorist was created in 1955 by Newell and Simon, helped by the systems programmer John Shaw. In order to prove a theorem, the simplest strategy is to start from the theory's postulates and create new theorems by combining them; then continue by combining every theorem with every postulate and every theorem again, exploring the entire truth spectrum. Although this may seem obvious, this is part of the first important concept introduced by the Logic Theorist: seeing the truth space as a tree, that started with the hypothesis and aimed at the proposition to prove; envisioning *reasoning as search*. Of course, exploring the entire tree is impractical, because of the time it takes to explore the entire truth space (as it grows exponentially); when considered from the point of view of "modeling the human thought process", this solution would not be useful even if it was practical, because this is not how human theorem-provers work. In order to solve this problem, the Logic Theorist introduced the second important factor: employing *heuristics* to ignore branches that were unlikely to lead to the goal. The last important factor is technical: in order to implement the Logic Theorist, the authors implemented IPL, a programming language that used symbolic *list processing* in the same way as the following, fundamental, Lisp.

3.2.2 DCS

In this section, we'll talk about some of the important findings that seemed difficult to integrate behaviorism and the important figures behind them.

Miller. George Miller, before becoming one of the founders of cognitive psychology, was of the behaviorist school (although he later wrote of one of his works on language 'By Skinner's standards, my book had little or nothing to do with behavior'[11]). After slowly moving to the cognitive side, driven by similar thinkers ('Peter Wason, Nelson Goodman and Noam Chomsky had the most influence on my thinking at that time'). In 1956 he published a paper that had a sizable impact: "The magical number seven, plus or minus two". In it, he observed tht various experimental findings revealed that, on average, human can hold seven items in short-term capacity. We note that it is not the finding that goes against behavioral philosophy and psychology, but the framework in which it is put in general: such attention to mental processes would be irrational, when seen from a behavioral point of view, hence disregarding mental processes as a whole. **TODO: is this right? check with mom**.

Bruner, Goodnow, Austin, and the basis of cognitive science. Another important book published in 1956 is "A Study of Thinking", by Bruner, Goodnow and Austin. The book is focused on using categories for concept formation, or how human beings group the world of particulars into classes, together with the results of relevant experiments. Before such experiment on cognition, Bruner had dedicated himself to the study of perception: two relevant studies we report are the one on estimating the sizes of coins or similarly sized wooden sticks (the first were significantly overestimated), and another one on slowing reaction times while playing cards in connection with revered suit symbols. These two experiments are relevant because of the focus on the internal interpretation of external stimuli. Other foundational ideas of cognitive science, developed in the years following the Miller publication, include the application of the scientific method to human cognition (if anything was to come after behaviorism, it could not avoid its history of scientific "rigor"), the interest towards information processing and storage, and as we will see in the next paragraph, a degree of possible innateness.

Chomsky and the final departure. In this last section, we move further than 1956. Nonetheless, it is extremely relevant to the subject discussed, and represents the strongest blow (in purely historical terms; this document has no psychological authority to express an evaluation of *any* theory) to behaviorism. In 1957, Skinner published "Verbal Behavior". In it, he describes the controlling elements of verbal behavior, and attempts to form a hypothesis about the behavioral framework with which verbal behavior is to be understood. In it, he uses specific terminology for his analysis, using both existing words and neologisms; in his own words: 'The emphasis [in Verbal Behavior] is upon an orderly arrangement of well-known facts, in accordance with a formulation of behavior derived from an experimental analysis of a more rigorous sort. The present extension to verbal behavior is thus an exercise in interpretation rather than a quantitative extrapolation of rigorous experimental results'[21].

In the same year, Chomsky proposed a different model for understanding language; in "Syntactic Structures" he argued two important points that would have a large impact on the field of linguistics:

1. **Syntax vs semantics.** The first point he makes is the clear distinction between syntax and semantics: '...such semantic notions as reference, significance, and synonymity played no role in the discussion.'

2. **Generative grammars.** His approach to syntax was formal, and followed both his teacher's (Zellig Harris) and notions advanced by Danish linguist Louis Hjelmslev: language was to be understood as a generative grammar, which bound by "phrase structure rules" (producing new sentences) and "transformations" (modifying exising sentences).

This seminal paper would soon be interpreted as an argument for a mentalistic, *innate* view of language production, but this intepretation was not originally put forth in the book itself: '[Chomsky's generative system of rules] was more powerful that anything ... psycholinguists had heretofore had at their disposal. [It] was of special interest to these theorists. Many psychologists were quick to attribute generative systems to the minds of speakers and quick to abandon ... Behaviorism'[23].

Two years later, Chomsky published a scathing (this time both in historical terms and considering the tone of the paper) review [3] of the book which had a widespread effect of the decline of behaviorism's influence. In it, one of the points he argued was that children are not taught the rules of language, and the amount of input they receive is not sufficient to derive them. This argument would later be called the "Poverty of the Stimulus" argument, and to this day represent a very controversial issue of linguistics and language acquisition.

In the words of Newmeyer:

> Chomsky's review has come to be regarded as one of the foundational documents of the discipline of cognitive psychology, and even after the passage of twenty-five years it is considered the most important refutation of behaviorism. Of all his writings, it was the Skinner review which contributed most to spreading his reputation beyond the small circle of professional linguists.

[14]. The review has been criticized by other writers, such as MacCorquodale [9], but its effect cannot be ignored.

As we have explored in this section, 1956 was both the culmination and start of a cognitively-inspired revolution across the DCS. As behaviorism grew less popular, cognitive findings and research drew more interest. At the same time, one of the very first AI programs was presented, and it tackled a purely symbolical problem with a purely symbolical approach: the trend was clear, and it was pushing towards a cognitive approach.

3.3 1960-1970: Great Promise

The years after 1956 are considered by many the "golden years" of AI research: thanks to considerable successes and a general wave of optimism, money was poured into the field, which thankfully generated more results and increased the hopes again. Although some interest was generated towards neural networks, this was completely shut down by a Minsky critique in 1969 (analogous to the Chomsky critique of "Verbal Behavior"). Psychology saw the rise of research into representations, categories and memory, as we will briefly overview in this section.

3.3.1 Computer Science and Artificial Intelligence

For what concern Computer Science and Artificial Intelligence, this period saw various directions, inspired by some of the previous research we've touched on in the previous sections. Most of them were focused on symbolic AI; at the same time, the "perceptron" proposal from McCulloch and Pitts saw some interest, before being shut down for more than ten years.

Reasoning and the General Problem Solver. As we mentioned, an important paradigm was introduced with the Logic Theorist: seeing reasoning as search. Newell and Simon, in 1959, developed what they hoped could become a general version of the LT, the General Problem Solver. Although the paradigm of reasoning as search was maintained, the GPS did not prune paths that were unlikely to lead to the goal, but used *means-ends analysis* to limit search. When following MEA, a system chooses, given a current state, an action that reduces the difference between the current state and the goal state. By focusing on the difference between current and goal state, MEA improves on brute-forcing all possible choices. In addition, if knowledge about the relative importance of differences is available, the goal-seeking system can follow the path which decreases the difference most, further pruning the possible choices. The correspondance difference-action, also called operator, must be given as an input, and represents "a priori knowledge" of the problem. This separation between problem-specific knowledge and strategy of how to solve it is a relevant feature of the project, and an important point when compared with the following paradigm, expert systems.

Symbols and successes. Following the GPS, other symbol and knowledge-based systems led to great successes. In 1958, the same year in which he invented Lisp, McCarthy published "Programs with Common Sense"; in it, he described a hypothetical program that used general knowledge to search for solutions to problems (such as generating a plan to drive to the airport). Called the Advice Taker, it also allowed for additional knowledge (axioms) to be introduced during the course of operation. As such, it embodied the a simple principle of knowledge representation: manipulating a formal representation of the world and its workings as a mean to solving problems. For later purposes, we mention the Shakey project at Stanford, which used subgoals (like GPS) and logic to control a robot. Minsky, who moved to MIT in 1958, started supervising students who tackled limited problems that seemed to require intelligence to solve: these would become known as microworlds. Two of these were Daniel Bobrow's STUDENT (1967), which could solve high school algebra word problems and Tom Evans's ANALOGY (1968), that solved geometric analogy problems from IQ tests. The most famous microworld was the block world, a set of blocks on a tabletop (real or virtual), which had to be rearranged, one block at a time, according to instructions. The success of this microworld derived from the cooperation of many different researchers, as "Artificial Intelligence: a Modern Approach" reports:

> The blocks world was home to the vision project of David Huffman (1971), the vision and constraint-propagation work of David Waltz (1975), the learning theory of Patrick Winston (1970), the natural-language-understanding program of Terry Winograd (1972), and the planner of Scott Fahlman (1974).

[18] As a fitting consequence for such successes, in 1976 Newell and Simon formulated the Physical Symbol System Hyposthesis [13]. It states that "a physical symbol system has the necessary and sufficient means for general intelligent action"; which means that any system possessing intelligence must operate by manipulating symbols. This statement would later be challenged by many researchers.

Genetic algorithms and perceptrons. Between the late 1950s and early 1960s [5], Friedberg started researching machine evolution (later called genetic algorithms), with scarce success. The basic idea was to make a series of small modifications to a program, then select the best-performing variant and repeat the process until the result was good enough. Unfortunately, due to how immature representation research and because of computing power constraints, these showed very limited success and the program was dropped.

Following the work of McCulloch and Pitts, research on neural networks picked up. Bernie Widrow researched his adalines[28], while Rosenblatt researched perceptrons. In addition, in 1962 Block showed, with the perceptron convergence theorem, that if a pattern of connection strenghts that matches a certain input data exists, then the learning algorithm can adjust the strengths correctly[18].

3.3.2 DCS

3.4 1970-1985: Ashes and Embers

3.5 1987-1993: Bodies as the Key to Minds

3.6 1993-2000: Agents and Cooperation

3.7 2000-now: Hybrid Systems: New Perspectives

3.7.1 gianandrea

4 Perception shifts

Should I merge these two?

4.1 Symbolism and Connectionism

4.2 Symbols and Subsymbols: Collect or Extract

5 Conclusion

References

[1] P. K. Anokhin. “Problems of centre and periphery in the physiology of nervous activity”. In: *Gorki, Gozizdat* (1935).

[2] Margaret A. Boden. *Mind as Machine: A History of Cognitive Science*. en. Google-Books-ID: yRyETy43AdQC. Clarendon Press, June 2008. ISBN: 978-0-19-954316-8.

[3] Noam Chomsky. *4. A Review of BF Skinner's Verbal Behavior*. Harvard University Press, 2013.

[4] *Computer Resurrection Issue 20*. Jan. 2012. URL: https://web.archive.org/web/20120109142655/http://www.cs.man.ac.uk/CCS/res/res20.htm#d#d (visited on 06/17/2021).

[5] R. M. Friedberg. “A Learning Machine: Part I”. In: *IBM Journal of Research and Development* 2.1 (Jan. 1958). Conference Name: IBM Journal of Research and Development, pp. 2–13. ISSN: 0018-8646. DOI: 10.1147/rd.21.0002.

[6] Howard E. Gardner. *The Mind’s New Science: A History of the Cognitive Revolution*. June 1987.

[7] C. L. Hull. “Goal attraction and directing ideas conceived as habit phenomena”. In: *Psychological Review* 38.6 (1931). Place: US Publisher: Psychological Review Company, pp. 487–506. ISSN: 1939-1471(Electronic),0033-295X(Print). DOI: 10.1037/h0071442.

[8] *International Encyclopedia of Social & Behavioral Sciences - 1st Edition*. URL: https://www.elsevier.com/books/international-encyclopedia-of-social-and-behavioral-sciences/smelser/978-0-08-043076-8 (visited on 06/14/2021).

[9] Kenneth MacCorquodale. “On Chomsky’s review of Skinner’s Verbal behavior”. In: *Journal of the experimental analysis of behavior* 13.1 (1970). Publisher: Society for the Experimental Analysis of Behavior, p. 83.

[10] Warren S. McCulloch and Walter Pitts. “A logical calculus of the ideas immanent in nervous activity”. en. In: *The bulletin of mathematical biophysics* 5.4 (Dec. 1943). Company: Springer Distributor: Springer Institution: Springer Label: Springer Number: 4 Publisher: Kluwer Academic Publishers, pp. 115–133. ISSN: 1522-9602. DOI: 10.1007/BF02478259. URL: https://link.springer.com/article/10.1007/BF02478259 (visited on 06/16/2021).

[11] George A Miller. “The cognitive revolution: a historical perspective”. en. In: *Trends in Cognitive Sciences* 7.3 (Mar. 2003), pp. 141–144. ISSN: 13646613. DOI: 10.1016/S1364-6613(03)00029-9. URL: https://linkinghub.elsevier.com/retrieve/pii/S1364661303000299 (visited on 06/18/2021).

[12] *Mind*. en. URL: https://www.britannica.com/topic/mind (visited on 06/14/2021).

[13] Allen Newell and Herbert A. Simon. “Computer science as empirical inquiry: symbols and search”. In: *Communications of the ACM* 19.3 (Mar. 1976), pp. 113–126. ISSN: 0001-0782. DOI: 10.1145/360018.360022. URL: https://doi.org/10.1145/360018.360022 (visited on 06/19/2021).

[14] Frederick J. Newmeyer. *The politics of linguistics*. eng. 1986. ISBN: 978-0-226-57720-3. URL: https://dialnet.unirioja.es/servlet/libro?codigo=605873 (visited on 06/18/2021).

[15] Rafael Núñez et al. “What happened to cognitive science?” en. In: *Nature Human Behaviour* 3.8 (Aug. 2019). Number: 8 Publisher: Nature Publishing Group, pp. 782–791. ISSN: 2397-3374. DOI: 10.1038/s41562-019-0626-2. URL: https://www.nature.com/articles/s41562-019-0626-2 (visited on 06/13/2021).

[16] H. Nyquist. “Certain Topics in Telegraph Transmission Theory”. In: *Transactions of the American Institute of Electrical Engineers* 47.2 (Apr. 1928). Conference Name: Transactions of the American Institute of Electrical Engineers, pp. 617–644. ISSN: 2330-9431. DOI: 10.1109/T-AIEE.1928.5055024.

[17] Arturo Rosenblueth, Norbert Wiener, and Julian Bigelow. “Behavior, Purpose and Teleology”. In: *Philosophy of Science* 10.1 (Jan. 1943). Publisher: The University of Chicago Press, pp. 18–24. ISSN: 0031-8248. DOI: 10.1086/286788. URL: https://www.journals.uchicago.edu/doi/abs/10.1086/286788 (visited on 06/16/2021).

[18] Stuart Russell and Peter Norvig. “Artificial intelligence: a modern approach”. In: (2002).

[19] Noel Sheehy and Antony J. Chapman. *Cognitive Science*. Sept. 1995.

[20] B. F. Skinner. *About behaviorism*. About behaviorism. Pages: 256. Oxford, England: Alfred A. Knopf, 1974. ISBN: 978-0-394-49201-8.

[21] Burrhus Frederic Skinner. *Verbal behavior*. New York: Appleton-Century-Crofts, 1957.

[22] M. D. Steer. “Cybernetics: Circular Causal and Feedback Mechanisms in Biological and Social Systems. Transactions of the Seventh Conference, March 23-24, 1950, New York. Heinz von Foerster, Ed. New York: Josiah Macy, Jr. Foundation, 1951. 251 pp. $3.50”. en. In: *Science* 115.2978 (Jan. 1952). Publisher: American Association for the Advancement of Science Section: Book Reviews, pp. 100–100. ISSN: 0036-8075, 1095-9203. DOI: 10.1126/science.115.2978.100. URL: https://science.sciencemag.org/content/115/2978/100.1 (visited on 06/16/2021).

[23] Danny D. Steinberg, Hiroshi Nagata, and David P. Aline. *Psycholinguistics: Language, Mind and World*. en. Google-Books-ID: EfK1AQAAQBAJ. Routledge, Oct. 2013. ISBN: 978-1-317-90056-6.

[24] Edward C. Tolman. “Cognitive maps in rats and men”. In: *Psychological Review* 55.4 (1948). Place: US Publisher: American Psychological Association, pp. 189–208. ISSN: 1939-1471(Electronic),0033-295X(Print). DOI: 10.1037/h0061626.

[25] A. M. Turing. “On Computable Numbers, with an Application to the Entscheidungsproblem”. en. In: *Proceedings of the London Mathematical Society* s2-42.1 (1937). _eprint: https://londmathsoc.onlinelibrary.wiley.com/doi/pdf/10.1112/plms/s2-42.1.230, pp. 230–265. ISSN: 1460-244X. DOI: 10.1112/plms/s2-42.1.230. URL: https://londmathsoc.onlinelibrary.wiley.com/doi/abs/10.1112/plms/s2-42.1.230 (visited on 06/16/2021).

[26] Johan Wagemans et al. “A Century of Gestalt Psychology in Visual Perception I. Perceptual Grouping and Figure-Ground Organization”. In: *Psychological bulletin* 138.6 (Nov. 2012), pp. 1172–1217. ISSN: 0033-2909. DOI: 10.1037/a0029333. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3482144/ (visited on 06/17/2021).

[27] J. B. Watson. "The Unverbalized in Human Behavior". In: *Psychological Review* 31.4 (1924). Place: US Publisher: Psychological Review Company, pp. 273–280. ISSN: 1939-1471(Electronic),0033-295X(Print). DOI: 10.1037/h0071569.

[28] Bernard Widrow and Marcian E. Hoff. "Associative Storage and Retrieval of Digital Information in Networks of Adaptive "Neurons"". en. In: *Biological Prototypes and Synthetic Systems: Volume 1 Proceedings of the Second Annual Bionics Symposium sponsored by Cornell University and the General Electric Company, Advanced Electronics Center, held at Cornell University, August 30–September 1, 1961*. Ed. by Eugene E. Bernard and Morley R. Kare. Boston, MA: Springer US, 1962, pp. 160–160. ISBN: 978-1-4684-1716-6. DOI: 10.1007/978-1-4684-1716-6_25. URL: https://doi.org/10.1007/978-1-4684-1716-6_25 (visited on 06/19/2021).

[29] Norbert Wiener. "Cybernetics : Control and Communication in the Animal and the Machine –2nd. ed". In: *212 p. Cambridge, Mass.: The MIT press, 1961. includes index*. CUMINCAD, 1961. URL: http://cumincad.scix.net/cgi-bin/works/Show&_id=caadria2010_000&sort=DEFAULT&search=series:caadria/Show?_id=4e2e&sort=DEFAULT&search=%2Fseries%3A%22CADline%22&hits=808 (visited on 06/16/2021).