SOME INSIGHTS FROM ALAN TURING'S ARTIFICIAL COGNITION RESEARCH

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ABSTRACT

As one examines the research by Alan Turing, one realizes a discrepancy between his early and late works. At the beginning of his career, his sole focus was mathematical logic, computability of numbers, mechanistic description of mathematical operations, and so on. However, in his late research, one of the most fascinating articles on biology and chemistry is found -his examination of the chemical basis of morphogenesis. The question is how his research on morphogenesis relates to his earlier research. In this article, it is argued that Turing's desire to develop 'artificial cognition' and the cybernetics-friendly atmosphere of the late 1940s are the links connecting his two research periods.

KEYWORDS

Artificial Intelligence, Philosophy of Mind, British Cybernetics, Ratio Club.

1. TURING'S POSTWAR RESEARCH

Alan Mathison Turing was a British logician, mathematician, engineer, and cryptanalyst who lived from 1912 to 1954. He is regarded as one of the founding fathers of modern computational theory due to his 1936 article (Turing, 1936) which he defined the limits of computability and introduced the conceptual machine (now called the Turing Machine) capable of mechanically imitating the calculating powers of a human mathematician who uses a pen and paper. He is also considered a war hero of WWII due to his contributions to decrypting the German Enigma and Lorenz ciphers based on the techniques developed by the Polish mathematicians -Rejewski, Zygalski, and Różycki. (Rejewski, 1981; Christensen, 2015)

After the war ended, Turing started working at the National Physical Laboratory. One of their goals during this period was to develop Britain's first commercial computer. During these years, Turing wrote a significant article on what he called "artificial cognition" as part of his job, but this article has not published until 1968. In this article, Turing identified some shortcomings in the machine he developed in 1936 and made technical suggestions to improve them. In the later period, it is observed that Turing's work has changed in the direction of solving the problems mentioned in this article. After 1949, he regularly met with British cyberneticists who were interested in similar topics such as sensory information, the structure of nervous tissue, and the possibility of reasoning machines. He was an essential part of the discussions, especially on the computational properties of nerve tissue. Identifying the self-regulating principle of neural tissue became Turing's top priority during these years. Turing's views were transformed considerably during this period, and his focus shifted from machines to organic forms, patterns, and their emergence.

This article aims to show that between 1946 and 1954, Turing's primary focus was designing artificial cognition. This ambition eventually led him to the study of organic forms and morphogenesis. Along the way, he identified and tried to solve some principal problems of machine intelligence. Some of those problems are still debated, and Turing's answers are still relevant.

2. THE LIMITS OF THE TURING MACHINE

Today, even the best chess players do not have any chance of winning even a single game against the best chess engines. However, less than a century ago, playing a game of chess was still an open problem for machines. In the 1940s, some algorithms could solve mate-in-two or similar problems, but there were not any algorithms that could play a game from start to finish. The idea of reasoning machines has been debated for centuries, and already in the 19^{th} century, some machines could prove logical theorems with few variables. (Peirce, 1887) But the game of chess, with its strategies, tactics, and theories for openings and endgames, seemed too human for machines to perform.

Playing chess mechanically was one of the first projects that Turing directed his attention to after the war. It might be argued that he selected this problem due to its limited representational requirements and well-defined operators such as the moves of pieces. With his economist friend, David Champernowne (1912–2000), they designed an algorithm that takes a chess position as input and returns a move suggestion as output. In 1947, the algorithm was already developed, but there was one problem. They did not have a computer to code their algorithm and see the results. Yet, that did not stop them. They decided to give it a shot by calculating each step of the algorithm with pen and paper to see if the machine was able to complete a game of chess. The algorithm is called *TuroChamp*, and it was re-created in 2012 and evaluated by the former chess world champion, Garry Kasparov. (Kasparov & Friedel, 2017)

Intelligent Machinery - 1948

The development of TuroChamp was a significant point in Turing's research on artificial cognition not only because they were able to solve a centuries-old problem of automata tradition, but also because the project showed the capabilities and limitations of algorithms that can be computed by Turing machines. Following this project, Turing wrote arguably one of the most insightful articles on the subject of machine intelligence which was, unfortunately, not published due to the dislike of his boss Charles Galton Darwin who thought that it was "a schoolboy essay." (Copeland & Proudfoot, 1999)

In the article "Intelligent Machinery" (1948), Turing investigates the development of the infant cortex into adulthood in his peculiar fashion and draws parallels to the concept of machinery that can learn as babies do. He argues that the primary goal of artificial cognition should not be mimicking the adult behavior but an infant's ability to acquire that behavior. In infancy, the cortex is almost completely unorganized so is the behavior. However, as they grow older the cortex organizes itself through experience and congruous behavior is formed. Turing believes this ability should be achieved by mechanical means to have artificial cognition. He opens the article by listing five main objections against machine intelligence which can be summarized as:

"(A) An unwillingness to admit the possibility that mankind can have any rivals in intellectual power. […] (B) A religious belief that any attempt to construct such machines is a sort of Promethean irreverence. […] (C) The very limited character of the machinery which has been used until recent times (e.g. up to 1940). […] (D) Recently the theorem of [Kurt] Gödel and related results have shown that if one tries to use machines for such purposes as determining the truth or falsity of mathematical theorems and one is not willing to tolerate an occasional wrong result, then any given machine will in some cases be unable to give an answer at all. […] (E) In so far as a machine can show intelligence this is to be regarded as nothing but a reflection of the intelligence of its creator."

Turing instantly dismisses the first two objections for being "emotional" and not scientific. The third one, according to Turing, is not a significant objection since it depends on the current state of the technology that, by definition, changes and improves over time. However, he takes the last two (D & E) objections seriously and views them as genuine obstacles in front of human-like reasoning machines. In the rest of the article, he directly attacks them.

Influenced by their chess algorithm, Turing identifies one more problem. In the case of chess, the machine only needs a limited representation and input-output coupling. However, only a tiny amount of real-life problems are of this sort. He introduces the dichotomy between *open* and *close* problems to capture this dual nature. According to this dichotomy, chess, cryptography, and solving logical theorems are close problems since they require almost no interaction with the world. He posits animal cognition and language acquisition as open problems since they require constant interaction with the environment. In between these two ends, he places linguistic translation and mathematics. Turing argues that "the possession of a human cortex would be virtually useless if no attempt was made to organize it. Thus if a wolf by a mutation acquired a human cortex there is little reason to believe that he would have any selective advantage." (1948) So, the cortex alone is meaningless without the sensory and locomotor structures that would enable the organization of the necessary nervous structures.

Turing also introduces a division between two types of machinery: *organized* and *unorganized*. According to this dichotomy, the Turing machine as introduced in 1936 (TM36) is organized since all its circuitry and program are determined by the architect, thus making its behavior solely a product of its designer (objection E). On the other hand, the cortex of an infant is almost entirely unorganized. By experience alone, it gets organized towards adulthood.

To overcome these problems, he introduces some improvements to TM36 and presents a new design -which will be called TM48 for brevity. There are three fundamental differences. First, some of the circuits have internal states that regulate their behavior. These internal states are physically realized by some electric circuitry as well. Just as flip-flop circuits, these internal states act as some form of memory that represents the history of the circuitry. Second, the machine's initial configuration is not entirely determined by the designer, but rather by some randomization technique. Third, some circuits have sensory counterparts that affect their internal states and, as a result, their behavior. With these improvements, Turing aimed to achieve the sensory openness and self-organization abilities of the animal cortex that went beyond the capabilities of TM36. Some researchers consider this design as one of the earliest neural network architectures. (Teuscher, 2002)

3. THE PROBLEM OF SELF-ORGANIZATION

With the introduction of TM48, Turing solved the two fundamental problems of TM36, at least on an abstract level. However, these abstract ideas had to be carried out physically as well. There was not much that Turing could do for the sensory openness problem other than following the relevant technological developments in sensor systems. On the other hand, self-organization was something that could be accomplished with the extant electric circuitry -or, at least, Turing thought so. The solution he offered in the 1948 article was not sufficient and Turing knew that.

As Turing was working on these problems, the concept of *self-organization* was re-introduced to the domains of biology and psychology, especially with the research by the British psychiatrist Ross Ashby. (Ashby, 1947) According to Ashby, to investigate and understand the complex structures observed in nature, such as animal morphology and human behavior, we need to posit self-organization as a fundamental principle of biology. This conclusion was what Turing had in mind while introducing TM48.

Ashby and Turing were not the only ones who shared this vein of thinking. Meanwhile, across the Atlantic, another group of thinkers had similar ideas. In 1948, Norbert Wiener (1948) coined (or, more correctly, reintroduced) the term *cybernetics* and crystalized this way of thinking into a research agenda. In the US, there were many brilliant minds such as Shannon, Weaver, Rosenblueth, McCulloch, Pitts, and Bigelow who focused their research on the cybernetics conceptions such as systems theory, negative feedback, self-regulation, and homeostasis.

British Cybernetics

The physical war was over, but the intellectual war was in full swing. Wartime allies, the British and Americans, were the biggest competitors in producing the first commercial computers in peacetime. The British response to the rise of the American cybernetic tradition under the guidance of Wiener was prompt. Many people had similar ideas around that time, and the British neurologist John Bates was determined to gather at least some of those people under the same root to discuss and study the problems of machine intelligence. Thus, he founded the Ratio Club to bring together "those who had Wiener's ideas before Wiener's book appeared." (Husbands & Holland, 2008)

The group was around 20 people and were predominantly biologists and mathematicians who mostly had wartime experience with sensory and electrical systems and machinery. The discussions revolved around the same cybernetics concepts (mentioned above) and the possibility of building intelligent machinery. After the first meeting, they invited Turing to the club at the request of Ashby, who had known him well for years.

In this new intellectual environment, Turing had the chance to meet biology-oriented people who had similar ideas and insights about designing machines that can reason or behave as humans or animals do. During this period, Turing's ideas and research got more and more focused on the biological restrictions and structures that consist of the physical substratum of so-called self-organization. It can be argued that his desire for artificial cognition turned into his search for the basis of natural cognition. What he aimed to capture with the electric circuitry was already realized with the organic nerves. If he could understand the workings of the neurons, he could imitate the process via artificial means.

4. The Problem of Form

The British cyberneticist Gregory Bateson (1972) distinguishes two types of problems:

"I have often been impatient with colleagues who seemed unable to discern the difference between the *trivial* and the *profound*. But when students have asked me to define that difference, I have been struck dumb. I have said vaguely that any study which throws light upon the nature of 'order' or 'pattern' in the universe is surely *nontrivial*." (emphases added)

In this sense of the term, Turing was getting more and more interested in profound questions of cognition. He was not only trying to understand the functional and abstract aspects of the subject as many others did, but he was also trying to comprehend how such features can be achieved through organic forms and growth patterns. One can argue that this tendency towards the organic forms was the discriminating feature of British cybernetics that was almost absent in the American tradition.

Although not a member of the Ratio Club, renowned British neuroscientist John Zachary Young was one of the researchers who closely followed the community's meetings. Turing and Young had met through Ashby a few years earlier, just after the end of the war. Ashby thought that these two thinkers had common scientific interests and that they could be beneficial to each other's work. During the Ratio Club meetings, the intellectual partnership between Turing and Young expanded.

In 1949 and later, both thinkers focused on the same subject: the formal properties and organizational skills of the nerves. In their correspondences, many insights are found regarding animal cognition and the architecture of the nervous system, both from physiological and computational points of view. What they communicated will not be examined in detail here. Just to show how Turing’s studies on morphogenesis are related to his search for the organizing principle of the nervous tissue, one excerpt proves quite noteworthy. Turing, in his letter to Young in February 1951, mentions the morphogenetic phenomena he is trying to model and explains the reasons why: (1951)

“At present I am not working on the problem at all, but on my mathematical theory of embryology... This is yielding to treatment, and it will so far as I can see, give satisfactory explanations of-

i) Gastrulation.
ii) Polyogonally symmetrical structures, e.g., starfish, flowers.
iii) Leaf arrangement, in particular the way the Fibonacci series (0, 1, 1, 2, 3, 5, 8, 13,...) comes to be involved.
iv) Colour patterns on animals, e.g., stripes, spots and dappling.
v) Patterns on nearly spherical structures such as some Radiolaria, but this is more difficult and doubtful.

[…] I think it is not altogether unconnected with the other problem. The brain structure has to be one which can be achieved by the genetical embryological mechanism, and I hope that this theory that I am now working on may make clearer what restrictions this really implies.”

Morphogenesis

TM48 was a significant improvement on TM36. However, it still had problems with its internal design. Although the mathematical properties of the connections between circuits could change, their numbers and structures were predetermined by the designer. In the case of nervous tissue, the organization and the number of connections are dynamic and self-regulating. Moreover, the self-organization principle of TM48 was too complex to be realized locally by the physicochemical characteristics of the neurons.

With these shortcomings in mind, Turing’s 1952 article on morphogenesis attempted to explain complex natural forms based on simple local processes such as chemical reactions and physical diffusion of the molecules. He demonstrated that such simple procedures were sufficient to create the natural patterns he mentioned in his letter to Young.

However, with Turing's untimely and tragic death in 1954, this study ended before the results could be generalized to nerve cells. Cajal (1917) in the late 19^{th} century and Hebb (1949) in the 1940s researched the same self-organizing principle of the nerve cells. However, to the knowledge of the author, there is no scientific work yet that can explain the characteristics of nerve tissue with this embryological model developed by Turing.

5. CONCLUSION AND DISCUSSION

As an admirer of Alan Turing's research, I have always had trouble understanding how and why his early research on computability, electrical circuitry, cryptoanalysis, and similar subjects transformed into one of the most curious articles in biology, where he investigates the emergence, self-organization, and growth patterns of organic forms. As it has been argued in this article, the missing link in the chain was his quest for artificial cognition.

In his pursuit, first, he realized the insufficiency of his earlier design. TM36 had two main problems: i) it was closed, and ii) its circuitry; hence its behavior was entirely organized and determined by its designer. To tackle these two problems, Turing introduced TM48 as a novel circuit design. The TM48 circuitry had sensory connections, so it was open. Moreover, instead of being entirely determined by its designer, TM48 could organize some parts of its circuitry based on its experience. So, the problem of artificial cognition turned into the problem of finding the organizing principle that regulates the harmony between the sensory and the inner circuitry.

Turing knew that, although it was a huge step compared to TM36, TM48 was neither satisfactory nor complete for mimicking animal cognition. His attention shifted to understanding how the nervous tissue and organic forms solve the self-organization problem. As a result of Ratio club meetings and communication with the esteemed neuroscientists such as Young, Turing became well aware that the organization problem of nerve tissue is essentially a problem of morphogenesis. Of course, it is undeniable that D'arcy Thompson's On Growth and Form (1917), which he read before the war, also contributed to this awareness. As a result, Turing focused his research on organic growth and pattern formation. He taught that those were the keys to understanding nervous phenomena and animal cognition.

Three fundamental claims that resulted from and shaped the artificial cognition research by Turing can be identified:

1- TM36 is insufficient for capturing animal behavior due to its closed and completely determined nature.
2- The main issue of artificial cognition is not developing the proper algorithm to solve the problem but discovering the self-organization principle that would enable the machinery to learn from experience just like animals do.
3- Self-organization of the nervous tissue should be explicable in terms of cellular morphogenesis and organic pattern formation.

It can be argued that these same problems Turing identified and tried to solve have occupied the artificial intelligence research that was mainly derived from the US cybernetics tradition that centralized the abstract concepts such as function and overlooked the problem of form almost completely. A more comprehensive look into Turing’s postwar research will prove more than useful for our ambition of building intelligent machines and understanding the fundamental obstacles in front of us.

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REFERENCES

[1] Ashby, W. Ross (1947), "Principles of the Self-Organizing Dynamic System", *The Journal of General Psychology*. 37 (2): 125–28.
[2] Bateson, Gregory (1972), "The science of mind and order", *Steps to an Ecology of Mind*. Chandlers Publishing Company.
[3] Cajal, S. Ramon y (1917), *Recuerdos de mi vida*, Library of Nicolas Moya Publishing.
[4] Christensen, C. (2015). "Review of IEEE Milestone Award to the Polish Cipher Bureau for 'The first breaking of enigma code'", *Cryptologia,* 39(2), 178-193.
[5] Copeland, B. J., & Proudfoot, D. (1999), "Alan Turing's forgotten ideas in computer science", *Scientific American*, 280(4), 98-103.
[6] Hebb, D. (1949), *The organization of behavior: a neuropsychological theory,* Wiley Press.
[7] Husbands, P., & Holland, O. (2008), "The ratio club: a hub of British cybernetics", *The mechanical mind in history*, 91-148.
[8] Kasparov, G. & Friedel, F. (2017), "Reconstructing Turing's 'paper machine'", *EasyChair Preprint,* (3).
[9] Peirce, C. S. (1887), "Logical machines"
[10] Rejewski, M. (1981). "How Polish mathematicians deciphered the Enigma", *Annals of the History of Computing*, 3(3), 213-234.
[11] Thompson, D'arcy. W. (1917). *On growth and form,* Cambridge University Press.
[12] Teuscher, C. (2002). *Turing's connectionism: an investigation of neural network architectures,* Springer Science & Business Media
[13] Turing, Alan M. (1936). "On computable numbers, with an application to the Entscheidungsproblem", *Journal of Math*, 58(345-363), 5.
[14] Turing, Alan M. (1948), "Intelligent machinery"
[15] Turing, Alan M. (1951, 8 February), "Alan Turing to J. Zachary Young, 8 February, 1951" [Letter].
[16] Turing, Alan M. (1990) "The chemical basis of morphogenesis", *Bulletin of mathematical biology*, 52(1), 153-197.
[17] Wiener, Norbert (1948) *Cybernetics or Control and Communication in the Animal and the Machine,* Technology Press.
[18] Young, John Z. (1964) *A Model of the Brain,* Clarendon Press.

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