Chapter 6
Rudolf Carnap–The Grandfather of Artificial Neural Networks: The Influence of Carnap's Philosophy on Walter Pitts

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Abstract The importance and relevance of philosophy for the development of the AI is often neglected. By revealing the influence of Rudolf Carnap on Warren McCulloch's and especially Walter Pitts' work on artificial neural networks, this influence could be reexposed to the scientific community. It is possible to establish a firm connection between Rudolf Carnap and Walter Pitts by pointing out to a personal relationship but also to a more internal structure of that influence as evidenced by Pitts' usage of Carnap's logical formalism. By referring to Carnap's work, Pitts was able to abide Kantian notion of unknowable and undescribable and to lay foundation of the world as a completely describable structure. It also meant that it could be possible to construct machines that use neural networks just as the biological entities do. Thus, Carnap could be regarded as the grandfather of artificial neural networks and logic, divided by the unfortunate historical development, could become united again as a single discipline that keeps both it's mathematical and philosophical side.

Keywords Carnap · Pitts · Artificial neural networks · Connectionism · Neurocomputational formalism

Artificial intelligence (AI) is a propulsive modern and contemporary field connected to many different research and scientific areas, including both science and humanities. As such, it presents a field of major interest to philosophers, mathematicians, engineers, computer programmers, etc. In common and maybe even most accepted views today, connection between AI and different scientific fields is most often regarded as a completely plausible and almost a natural one. Yet, its connection to philosophy and especially the fact that one can justifiably claim that AI originates from philosophy is more often than not perceived as a vague effort undertaken by those who want to appropriate this propulsive field for themselves while having no true merit

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for it. Thus, the main goal of this chapter will be to show that philosophy has every right to claim its relevance for the development of the AI (the question of importance of philosophy for the development of the AI not only as a part of its history but as a relevant discipline in its current development will be put aside for now) and this task will be done by showing the influence of one of the famous philosophers, that is Rudolf Carnap's influence, on Walter Pitts' development of artificial neural networks.

The importance of philosophy could be stressed even more as some of the "core formalisms and techniques used in AI come out of, and are indeed still much used and refined in, philosophy" [6], although extensive tracking of philosophical roots in AI development can go all the way back to Descartes and even Aristotle [25]. AI is usually described as a field which is concerned with constructing artificial creatures that act in an intelligent way and may those creatures be regarded as artificial animals or even as artificial persons, it represents, as such, a field of a major interest to philosophers. Answering the question whether these creatures, in different contexts, are artificial animals or even artificial persons may be well worth on its own but do not represent an important insight into our topic. However, a deeper insight into Carnap's influence on Walter Pitts' work might reveal a continuous relation between philosophy and AI and this relation might prove to be a missing link which connects science and humanities within the development of AI.

When considering the history and early development of AI, it is impossible not to mention famous conference of summer 1956 at Dartmouth College, in Hanover, New Hampshire. The conference was sponsored by DARPA (Defense Advanced Research Project Agency) and was attended by "John McCarthy (who was working at Dartmouth in 1956), Claude Shannon, Marvin Minsky, Arthur Samuel, Trenchard Moore (apparently the lone notetaker at the original conference), Ray Solomonoff, Oliver Selfridge, Allen Newell, and Herbert Simon" [6]. Among other notable conclusions, the conference remains well known as the birthday and the birthplace of the term AI. However, it would be hard to defend the claim that nothing of the field of AI, besides the of the field name itself, did not exist before 1956 and the aforementioned conference. Maybe the two best-known examples of development of the rich AI field before the term was even coined are works of Alan Turing and Walter Pitts (together with Warren McCulloch) which greatly improved our understanding of machine learning and problem-solving. In other words, their work led to the development of the AI field which was trying to build a machine that could actually think and learn. Turing [29] was interested in giving a systematical analysis of algorithms which function as mechanical instructions for each phase of machine problem-solving.[1] Known as the development of the Turing machine, this famous analysis was just one step along the way of understanding machine learning. The next step was to consider the possibility of existence of machines that could actually think. The discussion whether machines (or later, computers) can really replicate or just mimic human thought was, in a way, anticipated by Turing. In his famous paper published in Mind [30], he suggested

[1]For informal description of Turing machines see Rescorla [24] and for its rigorous mathematical model see De Mol [11].

the imitation game , a mind experiment which is known today as the Turing test (TT),[2] which will, in a way, force us to replace the question "Can a machine think?" with a more precise one that can actually produce some meaningful results—"Can a machine be linguistically indistinguishable from a human?" [6]. By switching our focus from the definitions of words *"machine"* and *"think"*, we avoid the statistical nature of the possible answer to the stated question "Can a machine think?" due to different common language usage of those terms [30].

The TT can also be interpreted as Turing's suggestion and attempt to overthrow a demand for building machines that have the full mental capacities of humans and to replace it with machines that only appear to have them [26]. In this way, Turing again anticipated the dispute over "strong" and "weak" AI arguments. Computer science today, although differing somewhat from the Turing's simplified model, is based on Turing's work and is making a rapid progress in developing more complex computing systems. However, what is very interesting for us is that Turing in in TT also suggested how to construct such machines:

> He suggests that "child machines" be built, and that these machines could then gradually grow up on their own to learn to communicate in natural language at the level of adult humans. This suggestion has arguably been followed by Rodney Brooks and the philosopher Daniel Dennett (1994) in the Cog Project. In addition, the Spielberg and Kubrick movie A.I. is at least in part a cinematic exploration of Turing's suggestion. [6]

Machines gradually growing up and learning how to communicate is what brings us to the work of Walter Pitts, especially his work on artificial neural networks. This brings us to the end of short review of AI, machine learning and neurocomputing and their relation.

Throughout history, artificial neural networks were known by various names. Some of those names are cybernetics, nerve nets, perceptrons, connectionism, parallel distributed processing, optimization networks, deep learning and, of course, artificial neural networks (ANN). The latter will be used in this chapter. ANN is connectionist[3] and as such part of computing[4] systems inspired by and interpreted as biological neural networks. It is important to emphasize that ANN are not identical to biological neural networks that constitute animal (including human) brains, but there is a strong resemblance between them. Although the goal of using ANN was to develop neural network system that could approach and solve general and complex problems in a way similar to the way a human brain does, it was dealing with specific tasks that proved to be a more realistic approach and offered better results which could be applied in different areas such as video games, medical diagnosis, speech recognition, and even painting.

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[2]For objections to the TT see Block [4] and for more detailed overview of the TT see Oppy and Dowe [17].

[3]Connectionism is part of cognitive science that explains intellectual abilities and learning using artificial neural networks. For further reading on connectionism see Buckner and Garson [7].

[4]Computational theory of mind holds that the mind itself is a computational system or a thinking machine. For further reading on computational theory of mind see Rescorla [24].

From the very onset and first attempts toward the grand original goal, all neural network models diverged from biology and the biological brain. Nevertheless, ANN retained strong resemblance to biological brain in terms of connecting units that work as biological neurons and that can, as the synapses in a biological brain, transmit and receive signals and then process and "inform" other neurons connected to it by signaling them. This new form of non-logicist formalism treated the brain as a computational system or, more precisely, it tried to explain intelligence as non-symbolic processing like the one that can be found at some level (at least at the cellular level) in the brain. Having that in mind, it is safe to say that it was a new paradigm in understanding and creating AI that triggered the race between the symbolicist and connectionist approach to AI. Connectionist paradigm developed the following neurophysiology rather than logic and has greatly influenced later development of computer science. The pioneer work, as it is often emphasized, was done by Warren S. McCulloch and Walter Pitts [16] in their famous paper[5] *A Logical Calculus of the Ideas Immanent in Nervous Activity* where they "first suggested that something resembling the Turing machine might provide a good model for the mind" [24], although their proposal of artificial neural networks differed significantly from the Turing machines.

However, there are views that, despite its significance, McCulloch's and Pitts' paper work remained relatively underrated both historically and philosophically. That seems strange enough by itself and becomes even more strange considering there were already biophysicists that were engaged in mathematical investigations of (biological) neural networks at that time as [19] notes.

Furthermore, there was no similar theory developed at the time and instead of producing seminal results in neurobiology, McCulloch's and Pitts' work influenced far more the field that will later be known as AI [15]. So, what was the contribution of McCulloch's and Pitts' work regarding what was discussed earlier and the process of machines' learning? Let us here quote the opening passage from their famous paper:

> Because of the "all-or-none" character of nervous activity, neural events and the relations among them can be treated by means of propositional logic. It is found that the behavior of every net can be described in these terms, with the addition of more complicated logical means for nets containing circles; and that for any logical expression satisfying certain conditions, one can find a net behaving in the fashion it describes. It is shown that many particular choices among possible neuropsychological assumptions are equivalent, in the sense that for every net behaving under one assumption, there exists another net which behaves under the other and gives the same results, although perhaps not in the same time. Various applications of the calculus are discussed. [16, p. 99]

Given the quoted passage, it can be asserted along the lines of [19] that their major contribution should be divided into four parts: (1) constructing a formalistic approach which eventually led to the notion of "finite automata",[6] (2) an early technique of

[5]Just as illustration of the influence of their paper, the interested reader can consult the excellent handbook edited by Michael A. Arbib The Handbook of Brain Theory and Neural Networks [2]—it is almost impossible to find any article that is not referring to McCulloch's and Pitts' paper.

[6]A finite automaton is an abstract machine constructed through a mathematical model of computation that can be in exactly one finite state at a time and this state can change depending on external

logic design, (3) the first use of computation for resolving some mind–body problems, and (4) the first modern theory of mind and brain.

However, here we can summarize their contribution as a development of a non-logistic, connectionist, and neurocomputational formalism that enhanced machine learning and developed a brain-like organization of AI as much as the *brain-as-a-computer* paradigm. According to McCulloch and Pitts [16], it should be added to the fact that all our theories or ideas, as well as sensations, are realized by the activity of our brains, and that the same network determines epistemic relations of our theories to our observations and from these to the facts of the world. Thus mental illness such as delusions, hallucinations, and confusions represent alterations to the network and empiric confirmation that if our networks are undetermined, our facts are also undetermined and there is no observation, sensation, or theory that we can get hold of. The final consequence of this, as they put it, is a somewhat Kantian sentence and the final dismissal of the metaphysical residue of our knowledge:

> With determination of the net, the unknowable object of knowledge, the "thing in itself," ceases to be unknowable. [16, p. 113]

When he was asked about neural modeling (cf. [1]), Jack D. Cowan saw computer technology as being a driving force in applying theory to real-world problems. He saw development of artificial neural networks as crucial to this application, even when there were obvious problems of neural network approaches to language. His view on McCulloch's and Pitts' work is of great significance:

> It's very like the content of the McCulloch-Pitts paper itself. The late Donald Mackay, whom I knew very well, characterized their theorem as follows: if you are arguing with someone about what a machine can or cannot do, and you can specify exactly what it is the machine cannot do, then their theorem guarantees that there exists at least one machine that can do exactly what you said it cannot do. If you can specify in enough detail what it is that you say a machine can't do, you've produced a solution. So the real question is, "Is everything out there describable?" [1, p. 125]

It is now distinctly possible to say that McCulloch and Pitts considered neural networks to be able to teach machines to perform every action describable or, to use their own words, every action that is defined, that is, every action that is determined by defining our net the brain. To define it, we need to describe what it does and, even when dealing with a psychic unit *psychon*, we can reduce its actions to activity of a single neuron which is inherently propositional. Hence, all psychic events have intentional or "semiotic character" and "in psychology, introspective, behavioristic or physiological, the fundamental relations are those of two-valued logic" [16, p. 114]. So, how is all of this related to Rudolf Carnap's work?

In their famous paper, McCulloch and Pitts referred only to three works of other authors and those are Hilbert's and Ackermann's *Grundüge der Theoretischen Logik*

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inputs or conditions that have been met. It is similar to the Turing machine, although it has less computational power because of the limited number of finite states and, consequently, limited memory. Some of the most known and simple finite automata examples are vending machines, elevators, and traffic lights.

[14], Whitehead's and Russell's *Principia Mathematica* [32] and Carnap's *The Logical Syntax of Language* [9]. And while Hilbert's and Ackermann's and Russell's and Whitehead's work was already famous, and thus might have been expected to be referred to by McCulloch and Pitts, Carnap's work was not quite there yet and inclusion of his book came as a bit of surprise. That fact alone says enough about Carnap's influence on development of ANN (as the authors perceived it) but let us go one step further in explaining this influence.

Let us start by shortly sketching the characters of McCulloch and Pitts.[7] As pointed out in several testimonials by their friends and colleagues in Anderson's and Rosenfeld's [1] noteworthy book which, by interviewing some of the scientists involved, describes more closely the beginnings of development of AI and ANN, the atmosphere and relations among most prominent names of the field, Warren McCulloch is often characterized as a generous and outgoing person who had taken care of his younger colleagues and had even housed Pitts and Lettvin during their early days. He was mostly recognized as a creative and imaginative force among the members of his neurophysiology group. His creativity and imagination went so far that he was considered by Jack D. Cowan as the most eccentric one among Pitts, Lettvin, and Wall. Turing, who at least once met McCulloch, even thought of him as a charlatan. The imaginative driving force of McCulloch had its opposite in the character of Walter Pitts. Pitts was in a way, as Lettvin, McCulloch's protégé but was also closely connected to Norbert Wiener for whom he started to work in 1943 and of whom he actually thought of as a father figure which he never really had. That is the reason why he felt being left in the middle between McCulloch and Wiener, had a nervous breakdown from which he never recovered and started to destroy his own work. Especially traumatic was the nervous breakdown Pitts had after McCulloch's and Wiener's dispute. This was devastating since Pitts was, as witnessed by Cowan, considered to be the brain of McCulloch's group:

> I was very much impressed with Pitts and his insights. Walter was really the intelligence behind Lettvin and McCulloch. I think it was Walter who was the real driving intelligence there. Since 1921 Warren had had an idea of somehow writing down the logic of transitive verbs in a way that would connect with what might be going on in the nervous system, but he couldn't do it by himself. In 1942, he was introduced to Pitts, who was then about seventeen years old. Within a few months Walter had solved the problem of how to do it, using the Russell-Whitehead formalism of logic, which is not a transparently clear formalism. Nonetheless, they had actually solved an important problem and introduced a new notion, the notion of a finite-state automaton. So here was this eccentric but imaginative Warren and this clever young Walter doing this stuff together. [1, p. 104]

What is really interesting and is often told about Pitts is his path that led him to McCulloch. Lettvin, who was considered Pitts' best and inseparable friend, is the most reliable source to document Pitts' life. According to him Lettvin (cf. [1, pp. 2–12]), Pitts was an autodidact who taught himself mathematics, logic and a fair number of languages and ran away from home when he was 15. Maybe the most frequently mentioned episode of his early life includes Whitehead's and Russell's *Principia*

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[7] The best references about their life and work are Anderson and Rosenfeld [1] for both of them, Arbib [3] for McCulloch and Smalheiser [27] for Pitts.

Mathematica. After being chased by bullies, he hid himself in a public library where he found it and read it in a three-day period after which he sent a letter to Russell, pointing out some problems in the book he considered to be serious. Russell invited him to go and study in England but Pitts refused and went to the University of Chicago where he attended some lectures but never registered as a student. There, in 1938, he read Carnap's new book The Logical Syntax of Language and did almost the same thing as with Principia Mathematica. Without even introducing himself, he walked into Carnap's office and once again pointed at some problems and flaws in the book and left without saying a word about himself.[8]

Of course, Carnap have had tough time finding him, but succeeded in the end and managed to persuade University of Chicago to give Pitts a menial job.[9] At the time, Pitts was considered to be Carnap's protégé.[10]

This is where we find proof about Carnap's influence on Pitts. It is for sure beyond any doubt that Pitts knew about Carnap's work very well since his early days at the University of Chicago. Furthermore, as confirmed by his colleagues, he was later attending Carnap's and Russell's lectures in logic and there he got to know their work to details. In combination with Pitts' intelligence and influences as evidenced, it is safe to say that McCulloch's and Pitts' work[11] on ANN is influenced by Carnap. And that influence is, surely, most notable in their usage of

> "the uncommon logical formalism of Carnap (1938) and Hilbert and Ackermann (1927) for the presentation of their results" [18, pp. 230]

which was, undoubtedly, acquired by Pitts. So, the next logical step would be to discover and describe properties of Carnap's logical formalism that can be found in McCulloch's and Pitts' work on ANN. However, let us first see why logic played such important role for Pitts in modeling ANN.

While studying with Carnap, Pitts wrote three papers on neuron network modeling[12] that preceded the famous paper written with McCulloch. What is usually considered to have been a trigger for this paper was discovery of inhibitory synapses

[8] Rudolf Carnap confirmed that this event actually happened and had explicitly said that after Pitts made his objections some parts of his own book were unclear even to him [5].

[9] Another interesting insight into Pitts' life and career development from homeless young boy to one of the masterminds of early AI development is Smalheiser's paper on Walter Pitts [27].

[10] As a note on Pitts' life, it is interesting to read how McCulloch later on was informing Carnap about Pitts' progress and achievements: *"He is the most omniverous of scientists and scholars. He has become an excellent dye chemist, a good mammalogist, he knows the sedges, mushrooms and the birds of New England. He knows neuroanatomy and neurophysiology from their original sources in Greek, Latin, Italian, Spanish, Portuguese, and German for he learns any language he needs as soon as he needs it. Things like electrical circuit theory and the practical soldering in of power, lighting, and radio circuits he does himself. In my long life, I have never seen a man so erudite or so really practical."* [13, p. 60].

[11] It has to be said that it applies not only to "The Logical Calculus of the Ideas Immanent in Nervous Activity" but also to their second paper "How we know universals" [23].

[12] These papers are "Some observations on the simple neuron circuit" [21], "The linear theory of neuron networks: The static problem" [20] and "The linear theory of neuron networks: The dynamic problem" [22].

that, together with Pitts' knowledge of propositional logic and McCulloch's knowledge of neurophysiology, led to development of the McCulloch–Pitts neuron model [27, p. 219]. Although, as witnessed by Pitts' best friend Lettvin [1, p. 3], McCulloch and Pitts got together on "The Logical Calculus of the Ideas Immanent in Nervous Activity" in the evening on the same day they moved in with McCulloch and his family, it would not be strange to say that Pitts, back then an 18-year-old boy, had a major influence on developing new approach to neuron modeling. The most obvious reason to think so is, as already expressed in Donald Mackay's words about McCulloch's and Pitts' theorem, Leibniz influence on Pitts and his view that a logical machine could do anything that can be completely described:

> Walter at that time was, if I remember correctly, about eighteen, something like that. Walter had read Leibniz, who had shown that and task which can be described completely and unambiguously in a finite number of words can be done by a logical machine. Leibniz had developed the concept of computer almost three centuries back and had even developed a concept of how to program them. I didn't realize that at the time. All I knew was that Walter had dredged this idea out of Leibniz, and then he and Warren sat down and asked whether or not you could consider the nervous system such a device. So they hammered out the essay at the end of 42. [1, p. 3]

The notion of completely describable tasks, taken from Leibniz, was supported by McCulloch–Pitts neurons model which "receive[s] a set of monosynaptic excitatory and inhibitory inputs and that fire whenever the net sum exceeds a threshold" [27, p. 219] or otherwise do not fire. This led Pitts to believe that, by mastering logic, neural nets became completely determined.

In turn, this could get hold of our innate structure and transfer it to the artificial level. Thus, as already mentioned as a Kantian sentence in McCulloch's and Pitts' paper, the world stops being indescribable and therefore unknowable. This view is supported by Cowan's understanding of McCulloch's group:

> All through the McCulloch group was this idea that there was an innate structure there. They believed in the Kantian notions of synthetic a priori. That's the kind of thinking that led Lettvin and Pitts to come up with "What the Frog's Eye Tells the Frog's Brain". [1, p. 108]

However, this is where Pitts' certainty about logic as being the key to the world ends:

> See, up to that time, Walter had the belief that if you could master logic, and really master it, the world in fact would become more and more transparent. In some sense or another logic was literally the key to understanding the world. It was apparent to him after we had done the frog's eye that even if logic played a part, it didn't play the important or central part that one would have expected. And so, while he accepted the work enthusiastically at the same time it disappointed him. [1, p. 10]

So, where does Rudolf Carnap fit in? Besides being Pitts' professor at the University of Chicago, besides being a target of Pitts' criticism and a man who helped Pitts stay at the University of Chicago, it has already been pointed out that Carnap's book was one of the three books referred to by McCulloch and Pitts in their famous paper. It has also been pointed out and shown that Carnap most surely influenced Pitts more than McCulloch. Pitts attended Carnap's lectures and was determined to show that by mastering logic one would be able to completely understand the world. In fact, this understanding had to come from Carnap's work considering that "Pitts immediately saw how one might apply Carnap's formalism to McCulloch's ideas about the logic of the nervous system" [3, p. 197] and that "the use of logical formalism by McCulloch and Pitts is a clear consequence of their conviction that in physiology the fundamental relations are those of two-valued binary logics" [18, p. 230].

As McCulloch's group did, Carnap also starts with a Kantian question: how is mathematics, both pure and applied, really possible [12]? He avoids both pure reason and naive empiricism and establishes logical empiricism in which mathematics and logics are not a part of empiricism nor a part of pure intuition. For Carnap [9], it is crucial to form *analytic* a priori sentences that are true only by virtue of their constituent terms and that require no empirical evidence whatsoever. On the other hand, scientific sentences are *synthetic* a posteriori and prove to be true or false depending on the state of objects in the real world.

For Carnap, this offers a satisfactory methodological analysis of science and bypasses Gödel's incompleteness theorems, leaving its results intact and not trying to prove the contrary. These *synthetic* a posteriori sentences, dependent on empirical evidence, can be expressed in any natural language and, by the principle of tolerance, *analytic* a priori sentences of mathematics and logic can be formulated in any way that can prove them to be true or false by aforementioned virtue of their constituent terms. This way, Carnap's (conventional) formalism[13] leaves the possibility of reducing all of the complexity of arithmetic to logic in a Russell–Whitehead manner and not being shaken by Gödel's results. By managing that, Carnap secures a satisfactory methodological analysis of science and holds that logic, as metalanguage, and natural language that we use to communicate our empirically gathered results form a logical syntactic order in which propositions secure the truth of scientific sentences about our real world.

This model rejects every kind of dogmatic claims, namely, those of metaphysics, and provide a safe progress of our knowledge. It is here where we find the true influence of Rudolf Carnap on Walter Pitts[14] if we get firm hold of the truth of our propositions analytically and a priori and "manage to map them in the brain" [3, p. 4], as well as secure the truth of our a posteriori sentences by submitting them to rigorous analysis of our propositions, no matter how we construct them to work as long as they are able to perform their function, we should be able to say that ANN can do everything that human neural net can do. In other words, everything that Walter Pitts was hoping for would be possible.

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[13]The development of this term can be tracked in two general articles written by Creath [10] and Uebel [31].

[14]Maybe it is farfetched, but let us here try to speculate over one more thing. In his paper "Meaning and synonymy in natural languages" [8], Carnap engages the problem of linguistic meaning and the way robots could maybe use it in the future. Although at the time being only a thought experiment, Carnap claimed that knowing their internal structure would help us develop an empirical approach to semantics. In a way, this is similar to Pitts' attempts to completely determine the state of neural networks which would result in possibility to completely describe their behavior.

Remember Leibniz' anticipation of computers, Kant's unknowable thing by itself and the theorem that says there would always exist at least one machine that could do exactly what you say machines cannot do if you were able to completely describe what it is they cannot do? Well, let us use here a common computer phrase that seems suitable yes to all! By mastering logic and by adhering to the rules of logical syntax of language, we would be able to cover both our deductively and inductively gathered knowledge, know the world up to the smallest bits and pieces and precisely and completely describe each action we want. In other words, we would have complete propositional and scientific knowledge needed for describing the world. In this way, we would be able to produce many simple or few complex algorithms that would cover all of our knowledge, leaving nothing unknowable and therefore indescribable. Finally, it would mean every action we can perform would be describable and transferable to ANN, which would now be fully determined as Pitts wanted it to be, opening the possibility of advanced machine learning that would completely correspond to human behavior and learning models. It is safe to say that Carnap influenced Pitts by providing rigorous logical formalism and language syntax offering a way to make the world describable through propositions and scientific, empirical, evidence and, thus, providing an answer to the question that left after the description theorem under which McCulloch's and Pitts' worked. If we consider Turing as paving the way for the development of the research in cognitive frameworks for artificial intelligence in general and (machine) learning in particular, then we can consider McCulloch and Pitts as providing provide a formalization of the physiological part, which grants different insights into the common problem.

In conclusion, let us explicitly state what we hope this chapter could be expected to achieve. Development in different aspects of logic caused the mathematical and philosophical subspecialties to emerge and cause friction between scientists. One would hope to expect to see this friction on the same side of a rift so that it evolves into a fruitful discussion. But alas, the rift occurred in the wrong place—what happened in the last century is not a desirable state of the field:

> In the final analysis, logic deals with reasoning—and relatively little of the reasoning we do is mathematical, while almost all of the mathematical reasoning that nonmathematicians do is mere calculation. To have both rigor and scope, logic needs to keep its mathematical and its philosophical side united in a single discipline. In recent years, neither the mathematical nor the philosophical professions—and this is especially true in the United States—have done a great deal to promote this unity. [28]

It is not a small thing to ask for, but let us hope this chapter is a small step to desired unification, especially with all of philosophical relevance and implications shown in a subject matter that is usually considered to belong to mathematics and computer science.

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