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Book Review

The prophet who foretold our future

REBEL GENIUS: WARREN MCCULLOCH'S TRANSDISCIPLINARY LIFE IN SCIENCE
By *Tara H. Abraham* 2016
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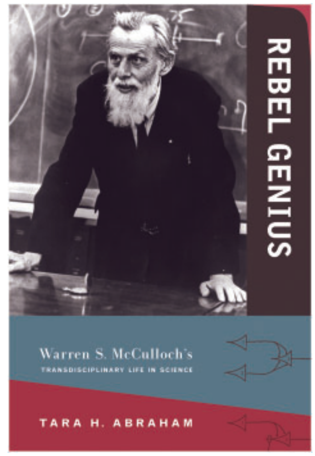

Staring out from the cover of Tara Abraham's book, *Rebel Genius*, Warren McCulloch strikes one as a biblical prophet, someone who has the power to foresee the future. He was a remarkable individual at the dawn of a new age in the science of the mind-brain, whose reach extended from psychiatry to mathematics, and who had a talent for bringing together thought leaders from diverse fields of science and the humanities. Many early concepts in brain function, some of which persist today, can be traced back to McCulloch and others in his circle who were inspired by him. This book tells the remarkable story of how these pioneers came together in the first half of the 20th century and laid the foundation for recent advances in neural computation and machine learning that are transforming the 21st century.

McCulloch was trained in psychiatry, and began his career at the Illinois Neuropsychiatric Institute, where he collaborated with Percival Bailey, Gerhardt von Bonin and Horace Magoun on exploring the cortical organization of chimps and monkeys. It was in Chicago that he met Jerome Lettvin and Walter Pitts, who would become lifelong colleagues and friends. They were both just starting their careers and were mentored by McCulloch, who had an unusual ability to treat others as equals, including children. Everyone was struck by his piercing eyes and ability to listen carefully and help them clarify what they were trying to say.

The golden period for McCulloch started when Jerome Wiesner, soon to become head of the Research Laboratory of Electronics at MIT, and eventually the president of MIT, invited McCulloch and his Chicago group to join his lab. It was at MIT, surrounded by exceptionally talented colleagues, including neurophysiologists Patrick Wall and Jerome Lettvin, that McCulloch became a sage. He influenced the lives of many young investigators, among them Marvin Minsky, who would become a founder of artificial intelligence (p. 170): 'And he had a grand view of this, the importance of cybernetics, which was correct, so, otherwise you would have said he was delusional…but I must have spent the most part of a year just hanging around him and trying to understand how he could see such importance in ordinary things'.

Many other lives were similarly influenced by McCulloch during this period, including a generation of budding brain theorists that included Michael Arbib (2018), Jack Cowan, and Manuel Blum. McCulloch's group flourished at MIT, with Lettvin carrying out experiments on the frog retina that would influence a generation of neurophysiologists, and with Walter Pitts, a mathematical genius, pioneering studies that would influence the early days of computer science (Lettvin, 1998). McCulloch became his guardian as well as collaborator when Pitts tragically succumbed to depression and died prematurely (Gefter, 2015). McCulloch's collected papers from that era reflect the broad range of his interests and many collaborators (McCulloch, 1965).

McCulloch was central to a series of 10 focused meetings spanning 1942 to 1953 sponsored by the Josiah Macy Foundation, which brought together John von Neumann, Norbert Wiener, Margaret Mead, Karl Lashley, Ross Ashby, Claude Shannon, Heinz von Foerster, Rafael Lorente de Nó, R. Karl Pribram, Duncan Luce, Donald M. MacKay, Gregory Bateson, Ralph Girard and many others (Macy Conferences, Wikipedia). This was a mid-20th century dream team. The overall theme was cybernetics, a new approach at the time to understanding the

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complexities of animal behaviour. The transcripts of the discussions at these meetings were published and had a strong influence on me when I began as a graduate student of physics at Princeton University in the 1970s. McCulloch's role in these meetings was to translate concepts between fields. He was a mesmerizing expositor and used technical terms like feedback metaphorically, so that even an anthropologist without mathematical skills could relate to them. He was also a good listener, a rare combination of skills. As I read each of the volumes from the Josiah Macy meetings, I felt as if I were present in the room, overhearing the deliberations. There was an inevitable let down at the end of the volumes—what was the next chapter and what was the impact of these meetings?

What I discovered was that the meetings had fertilized several new fields, each going off in a different direction. Wiener's cybernetics (1948) was the seed that would become control theory, a branch of engineering that more or less ignored brains, which were Wiener's inspiration. John von Neumann, inspired by McCulloch and Pitts' paper on how neurons could perform logical operations and were capable of universal computation (McCulloch and Pitts, 1943), went on to build one of the first digital computers at the Institute for Advanced Study at Princeton, New Jersey. But to my disappointment, the field that McCulloch had advocated, a mathematical approach to understanding how brains compute, was stillborn. It did not take off the way that control theory and computer science did. Why? In retrospect, not enough was known about the mechanisms underlying brain function in the 1940s. The seminal advances by Hodgkin and Huxley on the ionic basis of the action potential and by Bernard Katz on synapses were yet to come in the 1950s.

What McCulloch and his colleagues managed to accomplish was a foreshadowing of concepts that would emerge in subsequent decades. His paper with Lettvin on 'What the frog's eye tells the frog's brain' (Lettvin *et al.*, 1959) foreshadowed the great advances by Hubel and Wiesel in uncovering the response properties of single neurons in the visual cortex. His paper on 'Universals' with Pitts (Pitts and McCulloch, 1947) foreshadowed the invariance transformations that have now made it possible for deep learning networks to recognize objects in images (Sejnowski, 2018) (Fig. 1). In a similar way, Donald Hebb's book (Hebb, 1949) from the same era foreshadowed the great advances in our present day understanding of synaptic plasticity, which is how brains learn complex concepts. Interestingly, one of the few figures in Hebb's book was a simpler version of the neural network in Pitts and McCulloch (1947) (Fig. 1).

By 1958, Minsky had abandoned brain modelling and had adopted an approach to artificial intelligence that was based on logic, rules and computer programming. Computer science was establishing itself as a new branch of engineering and the world was turning away from McCulloch's mesmerizing vision based on intuitions inspired by brains. It took half a

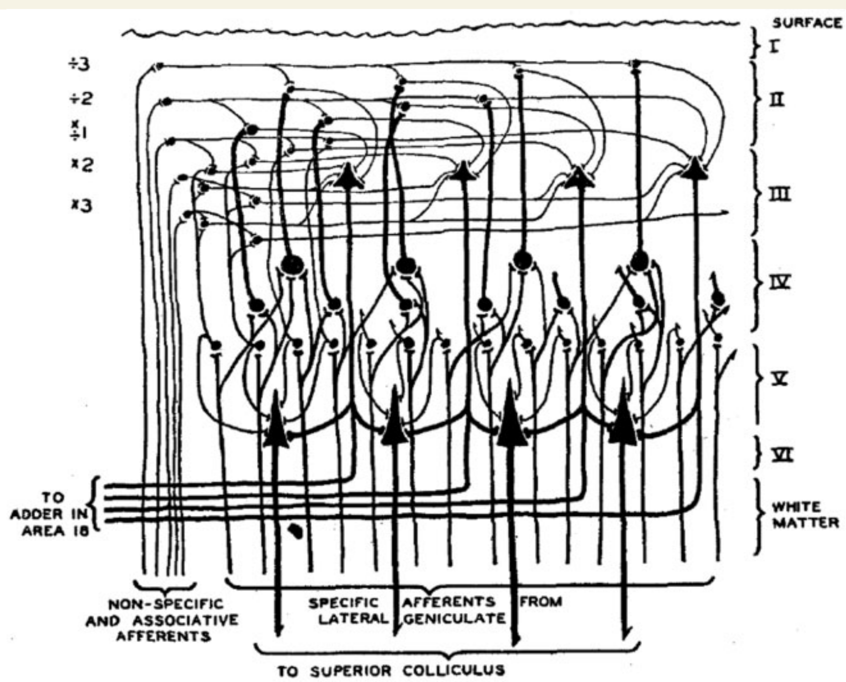

Figure 1 Drawing from Figure 3 in Pitts and McCulloch (1947) on 'How we know universals' depicting some of the principal neurons and circuits in the six-layered primary visual cortex of primates. This illustrated their theory for how we are able to perceive objects at different locations on the retina and with different sizes and positions, called invariances. The key architectural motif is the repeated pattern of neural connections across the cortex, also a key feature of convolutional neural networks (CNN). A convolution is a mathematical operation that is applied with varying offsets across the array of inputs. CNNs trained by deep learning have solved the problem of invariant object recognition and can classify images of objects from thousands of categories (Sejnowski, 2018).

century for his vision to be realized by a new generation of researchers who revolutionized artificial intelligence based on deep learning networks, not unlike the ones that he had imagined (Sejnowski, 2018). Computational neuroscience, the descendent of his pioneering work in brain theory, is now an integral part of neuroscience. The convergence of these two fields may be a defining event for science and engineering in the 21st century. McCulloch was playing the long game.

Abraham's biography of McCulloch brings to life a fascinating group of individuals and the era in which they lived. McCulloch and his wife Rook created a vibrant intellectual environment where talented youth could flourish. McCulloch had evolved from a background in medicine to embracing the computational complexity of the brain, and he expected others to evolve with him. His broad conceptual framework was based on computational principles at a time when neuroscience was focused on biological mechanisms. When he died at 70 in 1969, Warren McCulloch was already a legendary figure. His vision lived on in the scientists and engineers he influenced, and in those who today are creating the future that he foresaw.

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