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ON W.S. McCULLOCH

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Two recent scientific developments have necessitated a revision of the traditional modern conception of the relation between introspectively known ideas and human behavior in the public world of mathematically designated, indirectly verified space-time. These two developments are: (1) Warren S. McCulloch and Walter Pitts' indirectly confirmed theory of neurologically "trapped universals" and (2) Arturo Rosenblueth, Norbert Wiener and Julian Bigelow's distinction between nonteleological and teleological mechanisms, together with the demonstration that all human nervous systems are mechanisms of the latter type.

I met McCulloch first in the fall of 1923. I had come to Yale as an instructor in philosophy to teach mathematical physics in the graduate seminar of Professor Frank Pike on the theory of the nervous system. Pike's seminar was held in the old medical building of Columbia University's College of Physicians and Surgeons, just off 57th Street and Broadway. In one of these seminars Warren walked in. This, I believe, is the first time we met.

McCulloch, then 24 years old, was in his last year of P&S, the medical school of Columbia University in New York. He knew even then that the only way to understand mind, "the logic of psyche", is by way of the nervous system: both he and Pike realized that very little was known about this at that time. By 1919 McCulloch had read Whitehead and Russell's Principia Mathematica and had learned his math-physics from Boltwood, Yale's Professor of Physical Chemistry.

It was McCulloch's recognition that any scientifically clear theory of the public person must be an imageless, formally constructed concept by postulation, that is a concept by intellection, which caused him, a few years later, to collaborate with the symbolic logician Walter Pitts in the statement of their theory of "trapped universals". McCulloch's contribution consisted in discovering the theory and bringing forth evidence from experimental neural physiology in its support.

Similarly, it was McCulloch's acceptance of the epistemology required to distinguish and correctly relate the different types of concepts of the experimentally verified theories of both common-sense knowledge and mathematical physics which made him aware from the outset that his and Pitts' expression "trapped universals" is elliptical. It is a shorthand for a much more complex expression.

That such is the case becomes evident when one notes that, if taken literally as non-elliptical, the expression "trapped universals" is nonsensical. As will be shown in a moment, the word "trapped" refers to a physical impulse which is passed continuously around a circle of nerve cells. The word "universal", on the other hand, refers to an idea or meaning the content of which (though not the truth or falsity) is introspected, and hence is a concept by intuition, whereas the concept "trapped" refers to an unobservable, theoretically designated entity in the indirectly confirmed public world of natural science and is, therefore, a concept by postulation which is a concept by intellection. Whenever a concept by postulation referring to the public world of discourse is predicated on an entity denoted by a concept by intuition the directly sensed or introspected radically empirical world of discourse, or conversely, nonsense results. Examples are "Physical power causes legal obligation", "That electromagnetic wave is yellow", "Photons are particle-like", "Meanings are spatially extended", "Facts are true" and "The idea of a universal is in the brain". As McCulloch was well aware from the beginning, the expression "trapped universals" would be similarly nonsensical were it not an elliptical shorthand symbol for a much more epistemologically complex expression. To understand what this complex expression is, it will be wise for us to begin with the

empirical considerations in introspective and behavioristic psychology and in neural physiology which led McCulloch and others to the theory of trapped universals.

McCulloch began his postgraduate work in the eclecticism of the traditional introspective, behavioristic and analytic psychology and turned later to medicine to specialize in experimental research on the neuronc firings of the motor area of the cortex under electrical stimulation recorded by pickup through implanted electrodes. He came to realize early, as did von Neumann in the building of calculating machines, that were the relation between input stimulus and output behavioristic motor response in the human system merely the mechanical linear transmission of the stimulating cause to the motor effect, there would be no such thing as "memory" in either a human being or a calculating machine. Neither could it possess or recall the data fed into it inductively as stimulus or "information". Nor could any person or calculating machine be "programmed" to deduce consequences, i.e., calculated in a specified way from the "information" fed into it.

Since it is an indubitable fact of introspective and psychoanalytic psychology that people do remember and "forget", and recall in many cases what they have temporarily forgotten, McCulloch's task as a neurological psychologist became that of discovering and confirming a speculatively introduced theory of neurophysiological epistemic correlates of remembered ideas.

We can most easily understand the McCulloch-Pitts theory of trapped universals if we approach it by way of the route which McCulloch actually traveled in its discovery. As a student who took considerable philosophy as well as psychology, mathematics, and mathematical physics in Yale College, the young McCulloch became intimately acquainted with the major systems of modern epistemology, psychology and philosophy. Upon receiving his B.A. he pursued graduate studies in psychology. There he encountered the eclecticism of the psychology of that time, an eclecticism composed of introspective, psychoanalytic and behavioristic components, all of them tending to fight one another. This eclecticism convinced him that one should not pursue psychology

further without the most thoroughgoing knowledge of the human nervous system and its brain. He noted, as did Norbert Wiener, that what behavioristic psychology did was to treat the human body as a box, the internal contents of which in its brain is disregarded or assumed to remain a constant. Then the behavioristic psychologist attempts to find laws connecting a stimulus introduced on the sensory neuron side of this box to the box's motor neuron response on its other side. This was thoroughly scientific as far as it went. It seemed unreasonable, however, to suppose that any adequate or complete theory of the public self could be obtained without also looking inside the box to learn what were the entities, neural connections, and events that occurred there.

Consequently, McCulloch decided to enter medical school. Even then he did not believe that he had even the beginnings of enough knowledge to construct a neurological and behavioristic psychological theory of the public self. He decided, therefore, to do two things; (1) acquaint himself with neurological disorders by pursuing a neurological internship in residence in Bellevue Hospital, and (2) when this was completed get the tools for the theoretical concept-by-postulation side of his problem by studying mathematical physics at New York University. When these two things were accomplished, he then went to Rockland State Hospital for two years to acquaint himself, as one of the hospital's physicians, with the more extreme forms of neurological and mental disorders. There he found himself associated with one of the outstanding diagnosticians of schizophrenia, Dr. Eilhard von Domarus, who took his M.D. in Germany and who had written a thesis under the direction of the writer on *The Logical Structure of the Mind* for which he received the Ph.D. in Philosophy at Yale University in 1930. Through von Domarus McCulloch became acquainted for the first time with the writer's epistemological theory of radical empiricism in epistemic correlation with logical realism.

With all these symbolic logical, mathematically theoretical, neurologically clinical and epistemological distinctions and materials in hand, McCulloch then localized his problem in research work, concentrating on experimental study of the relation between neuron firings in the cortical neurons and in

the motor areas of animal cortex. To this end he shifted to the Yale Medical School, carrying on his research in the laboratory of the Dutch neurologist, Dusser de Barenne, who had been trained under Rudolf Magnus, famous for his theory of the *physiological a priori*, i.e., the theory that the person does not come as a Lockean blank tablet to the data given to him by way of his senses, but instead brings a certain relational structure within his nervous system to the interpretation which he puts on sensuous data. The analogy with the epistemology of Kant's Critique of Pure Reason is obvious and was not overlooked by Dusser de Barenne. It was while carrying on his experiments that McCulloch, together with Clark Hull, H.S. Burr, Mark A. May, John Dollard, Leonard Doob, Henry Morgenau and Frederic B. Fitch, decided to launch a research scientists' seminar in the analysis of the theories and methods of mathematical physics which they asked the writer to guide. In this period McCulloch came again upon the writer's theory of epistemic correlations for escaping the pseudo-body-mind problem and bringing the data of neurological behavioristic, introspective and psychoanalytic psychology into an epistemologically meaningful relation to one another. This also is the reason why, when Doctors Frank Fremont-Smith and McCulloch organized the later Macy Foundation conferences, the writer was made a continuous member from the outset.

One evening, at a meeting of this Yale scientific research group, the symbolic logician, Frederic B. Fitch, gave a descriptive report of the primitive concepts and postulates of the theory of deduction and mathematical calculation in Whitehead and Russell's Principia Mathematica. McCulloch, as early as 1923, had begun to envisage the ordering of nerve cells and the neural firings in any animal's cortex as ordered in ways that possess the logical relations of Principia Mathematica. If so, the neurological reason becomes evidence why human beings can carry through calculations and logical deductions when their brains are healthy, and cannot do so if the neural connections in those brains are destroyed by cancer, a lesion, or from any other cause. Immediately therefore, upon the presentation by Fitch to the Yale research group in the 1930's, McCulloch urged Fitch to work on the symbolic logical formulation of neural nets, and attended advanced lectures by Fitch on certain logical operators.

McCulloch learned also from Fitch how to think with formal logical rigor about discontinuous and continuous processes. Only later did Fitch carry through McCulloch's suggestion. Hence the earliest formulation of the formal logical structure of neural nets was by McCulloch and Pitts.

Meantime, McCulloch intensified his thinking of the firings which he induced or picked up with electrodes in the cortex of a monkey or cat from the standpoint of the formal properties of the logical relatedness of these events and the logical relatedness of the neural nets within which the experimentally confirmable events occurred.

Note what he had now: an epistemic rule of correspondence exists between the introspected primitive ideas and postulates of symbolic logic, Boolean algebra, or Principia Mathematica, and the logical relatedness of nerve cells and events in the human nervous system, especially in its cortex.

One key problem, however, remained unsolved. The concept by postulation theory, with its epistemic rules of correspondence, provided no neurological and physiological epistemic correlate for consciously introspected memory. What is this correlate? If it can be found, then calculating machines built with mechanical units and their events that are related by a relation with the same formal properties as that of this neurological factor in human nervous systems will have the capacity to retain the information fed into them. In short, it will be possible, to use von Neumann's language, to build "memories" into calculating machines. It is such considerations that brought together experimental neurologists and the designers of calculation machines in the Macy conferences, as von Neumann's posthumous book, The Computer and the Brain confirms.

The clue, as far as McCulloch and the psychoanalytic psychiatrist Dr. Lawrence Kubie were concerned, came when they noted that the Spanish experimental neurologist, Lorente de Nó, gave anatomical experimental reasons for believing that the nerve cells in cortical neural nets are ordered in circles as well as throughways. It was McCulloch's and Pitts' genius to have realized that

this neural possibility permitted one to have the neural physiological public epistemic correlate of a privately introspected and remembered idea.

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