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SOME HISTORICAL PERSPECTIVES ON EARLY PULSE CODED NEURAL NETWORK CIRCUITS

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PERSPECTIVES

From the beginnings of mankind the means of brain activity must have fascinated man. And although Galvani had shown in the late 1700s that muscles were excited by electrical activity of the nerves [Galvani 1791, Brazier 61] it was not known through most of the 1800's what was the basis for activity of the brain - indeed it is still unknown how a person thinks. In any event the publication by the Polish neurophysiologist Adolf Beck in the *Centralblatt für Physiologie* [Beck 1890], concerning his measurements of electrical activity in the brain [Beck 1888], caused considerable controversy as to whom was the first one to achieve such an accomplishment. After almost all sides were heard from, the controversy was settled by a further letter to the *Centralblatt* by Richard Caton calling attention to the measurements he had reported to the August 24, 1875, meeting of the British Medical Association and recorded in the report of the meeting [Caton 1875]. Among statements in Caton's original report is the following: "When any part of the grey matter is in a state of functional activity, its electric current usually exhibits negative variation" [Brazier 61] where by "negative variation" at the time was meant action potentials. Thus, we see that measurements were made on the pulse coded electrical activity in the brain as early as 1875.

Nevertheless it was well into the 1930's before really significant measurements were begun. Once such measurements were initiated more and more sophisticated measurements were needed and for them more elaborate electronic circuits were developed for that purpose. Among those making such measurements in the 1930's was Dr. Otto H. Schmitt, who devised a means of solving the equations proposed in theories of biological impulse propagation via vacuum tube circuits [Schmitt 37a].

From my search of the literature it appears that Dr. Schmitt should be given the credit for the first electronic circuit specifically designed as a pulse coded neural circuit. This occurs in his April 1937 paper "An Electrical Theory of Nerve Impulse Propagation" [Schmitt 37b] for which only the abstract survives in the open literature. From the two abstracts, [Schmitt 37a, Schmitt 37b], it is clear that an electrical circuit was built to test the theory of "impulse propagation" as the following is stated in [Schmitt 37b]: "The validity of the theory is tested by comparing the behavior of this artificial "nerve" with that of real nerve." It is also clear that Dr. Schmitt had in mind the use of such circuits for the simulation of live neuron behavior since the above quote continues: "If the theory is valid and the electrical model is a suitable equivalent, then certain of the unmeasurable electrical characteristics of nerve can be evaluated in terms of the constants in the electrical "nerve" required to make its performance duplicate that of real nerve." This viewpoint is further strengthened by private correspondence of Dr. Schmitt to the author (dated June 9, 1993) in which he states that his 1937 Ph.D. was "in Physics, Mathematics and Zoology with the topic of simulating the nerve axon with computer available components." Finally it is also clear that the purposes of these circuits was to better study neural function, rather than to make better computers or controllers, since the abstract closes with: "The way would then be open for a study of the mechanisms of the effects of abnormal agents such as drugs, ion imbalances, and the like."

Dr. Otto H. Schmitt's position is borne out further by the following quote from the 1979 article of Pellionisz [Pellionisz 79] for which it should be noted that [Schmitt 37a] follows [Schmitt 37b] on the original printed page and that [Schmitt 37a] is an abstract for a demonstration of the working circuits: "The third approach was the physical representation of highly simplified neurons by small electrical circuits (so called neuromeme: see Harmon, 1959; McGrogan, 1961; Jenik, 1962; Lewis, 1964). Although this approach received a great impetus from the widespread acceptance of the McCulloch-Pitts concept, it is actually rooted in an idea of Schmitt (1937), who created the binary-output electrical circuit that realizes threshold function (the Schmitt trigger)." These references are [Harmon 59], [McGrogan 61], [Jenik 62], [Lewis 64], and

[Schmitt 37a] for Schmitt. It should be noted that it is after Dr. Schmitt that the Schmitt trigger is named, this being the regenerative comparator which gives hysteresis familiar to almost all undergraduate students studying electronics [Millman 79, p. 623]. And, although the Schmitt trigger was published as a circuit in its own right [Schmitt 38], it is clear that the work on pulsing in neural circuits had a considerable influence on its development, if not being the primary reason for its existence.

As we can see from the references of Pellionisz cited above, there was a gap of roughly 15 years before further serious work on electronic circuits occurred after that cited of Schmitt. In the meantime the fundamental paper of Hodgkin and Huxley [Hodgkin 52] was published. Having given a mathematical treatment for the generation and processing of action potentials, this paper [Hodgkin 52] spawned a large number of circuits for simulating these equations and, as a consequence, stimulated the development of many aspects in the modeling of neural behavior [Eccles 57]. A typical circuit of the era used a large number of bipolar transistors, both npn and pnp, incorporated relays and many transistors and capacitors, see for example Figure 11 of [Jenik 64]. The references cited by Pellionisz give other representative circuits with the book of MacGregor and Lewis [MacGregor 77] somewhat giving the state of the art of the ideas surrounding circuits for neural modeling in the mid 1970's. However, to anyone versed in present day VLSI technology it is clear that it would not be practical to build VLSI circuits of any size using the neurons of most of the circuits published into the early 1970s.

With this last comment in mind it is worth noting that in the early and mid 1960s another philosophy emerged. This was the idea that rather than simulating the actual behavior of neurons, as set up in equations like those of Hodgkin and Huxley it might be expedient to mimic their behavior through more concise abstractions. Although a move in this direction can be seen in the work of the Applied Research Department team at RCA, [Putzrath 61, Martin 61, McGrogan 61], and of Harmon [Harmon 59] at Bell Laboratories, in my mind the most significant idea of the 1960s toward this philosophy is contained in the "neuristor" introduced by H. Crane in his 1960 doctoral dissertation at Stanford [Crane 60]. This was published two years later in the *Proceedings of the IRE* [Crane 62] where in the same issue appeared a very interesting circuit by Nagumo, et all [Nagumo 62], for mimicking nerve axon propagation, in essence giving a circuit realization of the neuristor, albeit quite impractical for VLSI due to its use of tunnel diodes (a similar type of circuit was actually given earlier by Cote [Cote 61] but the paper by Nagumo, et al, has received more recognition, probably due to its rather elegant mathematical development of axon mimicking equations). The idea of the neuristor was to abstract the four key axon properties of threshold of excitation, refractory period, attenuationless and uniform speed of propagation from which new classes of computers could be conceived following upon the structure of neural systems. Although in some sense impractical for circuit realizations due to the need for lines and circulation of pulses upon the lines, the idea of abstracting the neural system properties into ones that are tractable for electronic realization is one that appears to be paying off. In any event the neuristor and its derivatives led to a large number of circuits being proposed for neural system realizations in the mid 1960s through the mid 1970s, in Europe, Japan and the US. Many of the pertinent references to that era are listed in [Newcomb 79], a paper appearing originally in Spanish out of friendship for a Latin American colleague interested in the ideas.

Although there were a number of isolated studies throughout the world at the time, one of the most interesting group undertakings was the Polish-USA neural-type microsystems studies funded in the early 1970s by the US National Science Foundation (under grants 42178 and 75-03227) using Polish wheat purchase debt funds to finance the Polish side of the research. This program had as its goal the development of bipolar and MOS circuits suitable for integrated circuit construction that would mimic the behavior of neural systems, and, hence, called "neural-type," a word coined by Professor N. DeClaris. On the Polish side this was directed by Dr. M. Bialko of Politecnica Gdansk, with involvement of C. Czarnul, B. Wilamowski, and J. Zurada, among others, and on the US side was jointly directed by Dr. N. DeClaris and myself, both of the University of Maryland, with involvement primarily of C. Kohli. The main results to come out of this research in the pulse coded hardware area were the development (primarily by B. Wilamowski) on the Polish side of a bipolar circuit that acted as an action-potential-like-pulse generator [Wilamowski 75] and a companion MOS circuit [Kulkarni-Kohli 76] developed on the US side (primarily by C. Kohli) as well as a pulse processing circuit jointly developed [Czarnul 76] (primarily by C. Czarnul). Probably it is fair to say that of all the circuits developed during the historical period of 1930 - 1980, only the MOS circuit of [Kulkarni-Kohli 76] has survived with any type of vitality and that in a form very much modified and improved upon to take advantage of present day technology; see the paper by G. Moon and that by M. de Savigny which follow in this volume. But all of the historical circuits, which were primarily of the pulse processing type well into the 1980s, have served the purpose of leading us step by step to better artificial neural networks. It is also clear from the historical record that the lack of funding during the 1975-1985 decade led to a new breed of researchers and a new set of ideas, most of which were not founded upon the pulse processing philosophy. One important change of emphasis that has come about has been the concentration of interest upon synaptic influences, as incorporated in modern theories via the weights. In the research into the 1970s most of the circuits concentrated upon developing axon behavior with the synaptic junctions somewhat overlooked. In any event, it is refreshing for me to see an upsurge of interest in the pulse coding techniques since there are clear advantages, as biological systems discovered eons ago.

Because of the intrinsic interest in neural networks and the evident significance to the future of hardware developments to the field of artificial neural networks, it seems to me of considerable importance to have a well documented history of the hardware developments, especially of pulse coded circuits. Thus, I have tried to concisely put down some of what I am aware. But this is only a start and in the end I would emphasize that only an outline of what I consider to be the historically significant activities into the mid 1970s have been given here. And probably of that some has been missed as I discovered by recently locating a paper on a pulse code optoelectronic-magnetic neuron by Bray in 1961 [Bray 61]. In my mind this is a field of which we who are alive today can take great pride when we come to the point of being able to sit as elders on our porch swings relating the developments of the times to our grandchildren, as historically elders have done through the ages. Thus, it is with considerable anticipation that I await a thorough treatment by a competent historian of this fascinating field of modern history.

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KLUWER ACADEMIC PUBLISHERS
Boston / Dordrecht / London
1994