NEURAL-TYPE MICROSYSTEMS-CIRCUIT STATUS

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ABSTRACT

This tutorial-like paper reviews the progress and gives the latest results on neural-type microsystems. The write-up summarizes the ideas, giving key references, with the talk presenting circuit realizations and accompanying theory.

I. INTRODUCTION

Neural-type microsystems are microelectronic structures which possess signal processing capabilities of physiological neural systems. The long-range goals of studies in the area are not to model physiological systems or to replace present computing systems but the goals are to obtain systems performing new functions not available yet in man-made constructs. Biological systems are known to have such capabilities, for example to recognize and differentiate minute differences in patterns or to make inferences and prove theorems.

Our interest then is in neural-type networks which are interconnections of basic neural-type components. These components are of three classes: 1) Neural-Type cells (neurons), 2) Neural-Type Junctions, and 3) Neural-Type Lines (neuristors). Although the distinction between the three is often hard to make in practice, conceptually we can consider the cells as the devices that do dynamical signal processing, the junctions as devices where signals are combined, and lines as devices along which signals are transmitted from cells to junctions. In the following sections each of these components is discussed separately after which neural-type networks are considered. Because of their extent and detail necessary and important for accuracy in print, the circuits and accompanying mathematics are reserved for the talk itself with the nature of the ideas and some of the basic referencing given here.

II. THE NEURAL-TYPE CELL

Probably the first consideration of a cell of the type of interest is that of Turing (1) who considered a ring of degree two cells. These were linearly coupled to the two nearest neighbors in the ring such that oscillations (i.e., the cell alive) resulted when all coupling was connected but signals decayed to zero when any connection was broken (i.e., the cell dies). In contrast to high degree cells which incorporate nonelectrical behavior, for example those of Davison (2), Turing's cells are appropriate for microsystems because of their simplicity. However, Smale (3) has pointed out that Turing's cells are really not practical for physical constructions due to the non-structural stability of the equations. Consequently, Smale introduced degree four cells, based upon Van der Pol's oscillators, with linear coupling. Again these seem rather complicated for physical constructions and searches in other directions have taken place. One such direction is toward that of the Morshita neuron (4), this being basically a first order linear system with coupling to its surroundings through nonlinearities. One of the simplest cells is the two transistor first-order MOS-RC circuit (5a, p. 97) which, when a third, feedback, MOSFET is added (6), exhibits more interesting properties, including output pulse repetition rate controlled by input amplitude. Another direction which holds equal promise, if not more, is toward hysteretic neurons (7), these being first order nonlinear systems with (to this date) linear coupling to the surroundings, the nonlinearity being hysteresis. Consequently, circuits to give completely adjustable hysteresis in microelectronic form have been developed (8). An alternate and quite simple neural-type cell has been introduced by Parkhideh (9) for CAD of neural networks; Parkhideh's cell has its dynamics introduced through delay which follows a nonlinearity for threshold and saturation effects and around which feedback for refractoriness occurs.

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III. NEURAL-TYPE JUNCTIONS

Neural-type junctions are close in concept to neural-type cells, and, hence, it is often hard to differentiate the two. But devices where the primary emphasis is upon the nonlinear combining of signals into the cell have been introduced. To be considered in this class are those of Leung, et.al. (10)-(12) where exponentials of functionals of the cell inputs occur. More generalized are the mathematical junctions of DeClaris (13) where fast and slow time dynamics are introduced. Both of these two types of junctions, of Leung and DeClaris, are rather abstract and, hence, as yet difficult to implement in microelectronic form. Consequently, Kohli (14, p. 83) has introduced a simple MOS-R-C junction which is readily extended in several ways, for example to include excitatory and inhibitory behavior.

IV. NEURAL-TYPE LINES

Probably neural-type lines are the most extensively studied of the neural-type system components. Since neural-type lines are essentially analogs of the nerve axon, perhaps the extent of consideration of them stems from the pioneering 1952 work of Hodgkin and Huxley (15). But the real importance of them in an engineering context stems from 1960 with the beginning work of Crane (16) where the name "neuristor" was introduced. A rather complete bibliography on neuristors and neuristor-type devices is given in (5) from which it becomes clear that only after 1972 with the pioneering work of Polish researchers, Wilamowski-Czarnul-Bialko (17), did practical structures suitable for integrated circuit realization begin to appear. These were bipolar transistor-RC lines developed under a Polish-American program that also led to MOS-RC lines (5, p. 89). However, much remains to be done, for example, the development of difference-differential equations for the description of "saltatory" lines (i.e., RC lines with lumped active loading) or the implementation by hardware of equations derived from the physiology of the situation, as in Cowan (18).

Since neural-type lines contain active nonlinear elements for pulse regeneration and delay in the lines, it is conjectured that all neural-type systems can be constructed solely from them.

V. NEURAL-TYPE NETWORKS

Although there appears to be an extensive literature on the nervous system, and some studies relevent to systems interests (19)(20), and a great proportion of the works on large scale systems theory are applicable to neural-type systems, little really exists in the way of studies specific to circuits practically realizable in microelectronic form. Probably the first relevant study is the 1973 one of Parkhideh (9) where computer aided analysis was carried out on interconnections of some 30 neurons and 200 axons which represented feeling through the skin. Tokura and Morshita (21) did computer studies on a network containing 50 neurons which led Dimopoulos (22) to a generalization of Morshita's neuron which was applied to obtain stability results on specific large scale structures (23), as for example ones using 100 neurons similar to the cerebellum (24). The computer aided results of Parkhideh and Dimopoulos are impressive and indicate that other areas of study of computers in conjunction with neural networks, as probabilistic database retrieval of Niznik (25), could be profitable. In any event, studies such as that of Ajmera (26) on retina-type neural-type systems look promising for using neural-type components in the construction of new signal processing systems.

Certainly results available give credance to the conjecture that large-scale neural networks using identical cells can achieve desirable properties solely by virtue of the topology of interconnections.

VI. CONCLUSIONS

The field of neural-type microsystems appears to be one of promise that is just in its infancy. Certainly it is one applicable to VLSI technology where new types of signal processing will be important to future developments. At this point only some of the groundwork has been laid, with some theory and some basic relevant circuits on hand with an overall view of the total systems concepts beginning to emerge.

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