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FINAL TECHNICAL REPORT

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Research performed under this grant centered on the computations done by biological networks of nerve cells, and on the theoretical and engineering underpinning of neurobiological computation. The biological studies were in greatest part theoretical analysis of the olfactory (smell) system. This is a very old and "simple" sensory system, and is highly conserved. Animals as different as snails and humans have strong anatomical similarities in their olfactory systems. In addition, the basic architecture of much of old cortex is claimed to be related to that of olfactory cortex, so understandings gained in the olfactory system are potentially applicable to other areas of brain.

During this grant period, our initial work was in extending earlier modeling of the olfactory system of the garden slug Limax Maximus to include the kind of preprocessing which would be essential to a categorical memory for odors based on the relative strengths of a multiplicity of components. [6]. We then turned to modeling the olfactory bulb, the first stage of olfactory information processing in vertebrates. The explicit intent was two-fold: to see whether a simplified version of the biophysics of the olfactory bulb could capture the essential aspects of the oscillatory behavior seen in electrophysiological recordings in bulb; and to try to understand the computational function of the bulb. In the first regard, great simplification does appear adequate, and this opens the way to analytical mathematical approaches [11]. The attempt to define the computational role of the oscillations was less successful [11, 12]. While a consistent view of the role of oscillations was constructed, it as yet lacks a compelling rationale in neurobiology. So the question of whether the view put forward is the correct view of the oscillations must await better experiments designed to test our theoretical ideas. Because of the success of the simplified analytical model of bulb, we also initiated an analysis of a simplified model appropriate to primary olfactory cortex (prepiriform cortex). As in bulb, the idea is to validate (or invalidate) such a model on the basis of comparisons of simulations of a detailed model, real electrophysiology, and simulations of the detailed model. A success in this direction would give confidence to a tractable mathematical description of cortical function. However, this work could only be initiated, and not completed.

A second major focus of research centered on understanding network computation at a more abstract level. Any real computing system, manmade or biological, is a physical system which computes by having a "state" which changes in time. Computation is fundamentally a dynamical process, and both digital and analog computation can be so represented. Many of the papers written emphasize this importance of understanding dynamics, particularly papers [1], [3], [4], and [15]. Others exploit the dynamics in order to solve some particular problem. For example, [18] uses the dynamics of synapse change during development to understand patterns of cell response in early visual processing. Papers [7] and [10] exploit available dynamics to organize time delays in such a way that short stereotype signals occurring over time (such as a spoken word, a bird call, or a facial gesture) can be recognized as a whole. Conserved quantities, or quantities whose change is monotonic in time ("energy functions") have been very useful, both in understanding the dynamics of neural networks and in engineering networks to perform particular tasks. We have noted [15] that the kind of network

found in the olfactory bulb is a "Lagragian network." This fact represents a new "programming tool" for understanding more complex network computation.

Interest in applying ideas from biological neural networks to real problems of engineering raises the issues of how best to implement artificial neural networks in VLSI. In particular, the same network and algorithm can be embedded in VLSI in two separate ways, either a digital form or in an analog form. An analysis of this situation [14] indicates that a digital implementation is always at least as fast as the analog version and that the analog version is much less complex. The compromises and important considerations for the tradeoffs between these include questions such as (1) Can the analog device physics itself be usefully exploited by the algorithm? (2) Is excess accuracy available in the fabrication process? (3) Is absolute speed truly a valid criterion? (4) Is power availability limited? The most significant point is the question of the usefulness of the device physics in the desired algorithms. Particularly for sensory processing, logarithms, exponentials, time delays, and frequency band filters are extremely useful components to processing, and it is in the realm of "early sensory processing" that fully analog neural net hardwares appear to have the greatest potential advantages.

Biology "computes" on the molecular scale as well as at the cellular network level represented by neurobiology. The translation of RNA into protein sequence is readily described as an algorithm carried out by computational machinery at the molecular level. The folding of a protein into its most stable three-dimensional structure is the solution to a very complex optimization problem. Having always been intrigued by these facts, we have spent a little time exploring them for what they can tell us about doing computation at the molecular level. We designed a shift register [5, 8, 9] based on ideas from the molecular electronic complex used in the primary processes of photosynthesis. This design effort was directed at identifying and solving on a conceptual level some of the difficult problems for people talking about "biochips" or molecule-based electronics.

An ability to readily compute the three-dimentional structure of a protein from its primary sequence would be a major boon to molecular biology, biochemistry, and biotechnology. This problem interacts with neural network theory on two levels. First, it provides a physical example of a dynamical system solving a complex problem based on analog variables. Second, successfully using a neural net on a problem as complex as this in a non-trivial fashion will represent a large step forward in conceptualizing neural net computation. Our very small first step is described in [19].

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