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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

I. Progress on the behavioral and the molecular biological goals:

1. We have finished, as originally proposed, the software and first actual physical system for computer-controlled training procedures, with which to shape animal behavior and to perform learning-conditioning experiments.
2. We have constructed molecular biological vectors for generating muscarinic cholinergic receptor proteins pertaining specifically to all of the five known muscarinic receptors--this work follows on previous AFOSR-funded work relating to cholinergic enhancement of associative learning [14,15,11-13].

II. Progress into the implications of attractors, perturbation analysis of neurons, and the use of language theory:

3. We have developed the conceptual rationale and conducted computer experiments to show that attractor gradients provide an integrative principle that globally acts on all synapses in a network of "cooperative" neurons. The consequences of this are extensive, and much naturally falls out naturally, e.g: synaptic strengths are optimally set with one another; the size of the

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network is self-limiting; networks require trainable thresholds in their constituent neurons, along with trainable synaptic strengths, to perform even simple tasks; and both task-specific and multifunctional neurons functionally emerge from the action of the attractor gradients. The work began with [7,8] and its extension is described in [1]. Presently we are limited only by computational power for extending the implications of the work and for obtaining the data rapidly with which to complete the first set of publications.

4. We have identified the cellular basis for dissipative action [6]. As an analogy, it is easy to see how heat dissipates perturbations in a simple pendulum with friction. But what is it that does the dissipation in the central nervous system or in computer simulations of biologically realistic networks?
5. The answer to the above question in (4) has come from a series of noise- and chaos-perturbation studies of neurons and networks of neurons (The first of a series of findings are presented in [4], which will be sent to *J. Neurophysiol.* within the next month).
6. We have identified the basis of variation in the action of single and groups of neurons. Previous AFOSR-funded work has shown that variation is essential in adaptive function of networks that can produce many different patterns of activity [e.g., 10,11]. Here we show where the variations come from [4]. We have also obtained evidence for the mechanism by which multiple patterns emerge [2,4].
7. We have ported considerably from formal language theory and theoretical physics to describe quantitatively the trains of action potentials that are used to transmit information between neurons. Additionally, we have implemented the formalism of finite-state automata to construct machines that represent this information [3,5]. The major consequence of this work is that it provides a vast theoretical formalism with which to handle the information flow in networks. The ultimate consequence is that network function might be examined from the point of view of statistical mechanics.
8. A collaboration has been established with Dr. Seth Wolpert, Department of Electrical Engineering, University of Maine, to construct analog VLSI networks of neurons as we have described them. This work will not only allow us to perform experiments (extremely) rapidly in ways that can not be done in typical desktop computers, but it will also allow us begin to implement the findings in networks that can be rapidly trained to perform particular functions that are normally found only in behaving animals.

PUBLICATIONS that have arisen in part or completely from funds in AFOSR-92J-0140:

1. Mpitsos, G.J., Attractor Gradients: Architects of Organization in Biological Systems. In *Chaos and Society*, 1994. In Press.
2. Mpitsos, G.J. and Edstrom, J., Bifurcation dynamics, multifunctionality, and variation in computer simulation of biologically realistic neural networks, (1994).
3. Mpitsos, G.J. and Edstrom, J.,Symbolic dynamics of firing patterns and information transfer in neural networks, (1994). In Preparation.
4. Edstrom, J. and Mpitsos, G.J., Complex self-organization in simple synapses and neuron membrane: Perturbation analysis, (1994). In Preparation.
5. Edstrom, J. and Mpitsos, G.J., Finite state automata: Characterization of network function and structure, (1994). In Preparation
6. Edstrom, J, and Mpitsos, G.J, Mechanism for dissipative action in attractor networks (1994). In preparation.
7. Mpitsos, G.J. and Burton, R.M., Convergence and divergence in neural networks: Processing of chaos and biological analogy, *Neural Networks, 5* (1992) 605-625.
8. Burton, R.M. and Mpitsos, G.J., Event-dependent control of noise enhances learning in neural networks, *Neural Networks, 5* (1992) 627-637.
9. Mpitsos, G.J. and Soinila, S., In search of a unified theory of bioloigcal organization: What does the motor system of a sea slug tell us about human motor integration. In L. Nadel and D.L. Stein, 1991 Lectures in Complex Systems, SFI Studies in the Sciences of Complexity, Addison-Wesley, 1992, pp. 67-137.

   Original in: K.M. Newell and D. Corcos, Variability and Motor Control, Human Kinetics, Champaign, 1993, pp. 225-290.

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10. Mpitsos, G.J. and Cohan, C.S., Convergence in a distributed motor system: Parallel processing and self-organization, *J. Neurobiol., 17* (1986) 517-545.
11. Mpitsos, G.J. and Cohan, C.S., Comparison of differential Pavlovian conditioning in whole animals and physiological preparations of *Pleurobranchaea:* Implications of motor pattern variability, *J. Neurobiol., 17* (1986) 498-516.
12. Mpitsos, G.J. and Cohan, C.S., Differential Pavlovian Conditioning in the Mollusk *Pleurobranchaea, J. Neurobiol., 17* (1986) 487-497.
13. Mpitsos, G.J. and Cohan, C.S., Discriminative behavior and Pavlovian conditioning in the mollusc *Pleurobranchaea, J. Neurobiol., 17* (1986) 469-486.
14. Mpitsos, G.J., Murray, T.F., Creech, H.C. and Barker, D.L., Muscarinic antagonist enhances One-trial food-aversion learning in Pleurobranchaea., *Brain Res Bull, 21* (1988) 169-179.
15. Murray, T.F. and Mpitsos, G.J., Evidence for heterogeneity of muscarinic receptors in the mollusc *Pleurobranchaea, Brain Res. Bull., 21* (1988) 181-190.
16. Soinila, S. and Mpitsos, G.J., Immunohistochemistry of diverging and converging neurotransmitter systems in molluscs, *Biol. Bull., 181* (1991) 484-499.