CHAPTER 6

Conclusion

This thesis has successfully incorporated the adaptive property of a phenomenological large scale neural model into a smaller-scale neural network by taking the approach of scientific reduction and using the model reference principle. The original contributions made by this thesis are as follows.

- An Eckhorn dipole network (E-DN) was designed that has the elastic rebound capability of a Grossberg dipole network (G-DN). But unlike G-DN, the rebound is achieved by network design and not as counterpart to Grossberg's elastic weight equations.
- The timing and duration of B-stimulus input in the E-DN produces emergent network properties that are not captured in the G-DN.
- Eckhorn network (E-N) performance evaluation is achieved by comparing the Grossberg network (G-N) output with a transformed E-N output. The transformation is a moving-point average (MPA) as defined in Figure 2.13 of chapter 2.
- The E-N has a performance surface that exhibits steep changes between regions of one performance index to another, indicating the need for using techniques such as gain-scheduling. In other words, during the transitions on the performance surface, use of gradient methods is not effective.
- The issue of "context-dependant choice" seen in level-coded model [Grossberg 1978] is also encountered in the E-N, as seen in the push-weight procedure of the algorithm.

- The conditioning performance surface (on which the adaptation is based on) is different from the conditioned performance surface as shown in Figure 5.6.
- The adaptive algorithm employed was successful in adapting the E-N; the learning rate is about 2.4x slower than that of the reference model, G-N. However, this performance factor can be optimized and the result reported here does not mean E-N adaptation is inherently slower.

The network developed in this work is a new network topology for pulse-coded neural networks. Although its constituent building block is a standard Eckhorn layer of linked Eckhorn neural units (ENU), the novelty in the network topology lies in the manners by which these layers are interconnected with one another. The resulting network is significantly more functionally purposive than the few standard Eckhorn topologies previously reported. The network is also much more biologically plausible than is the PCNN system commonly used in engineering applications [Lindblad & Kinser 2005].

This thesis has demonstrated that the employment of model-reference adaptation (MRA) technique is a powerful design tool for the development of new function-oriented pulse-coded neural networks (PCNNs). Network function is defined at the higher network system level by the G-N. MRA is then used to produce an adaptation performance surface. The performance surface is a key and fundamental tool for future development of entirely PCNN-level adaptation algorithms.

This thesis has also demonstrated that mapping from the G-N level of modeling to the E-N level of modeling is a non-trivial task. E-N level networks are shown to exhibit emergent properties that are not exhibited at the G-N level. The full implications of this finding are not yet known.

Topics for future research

The unexpected (non-elastic) property of E-DN described in chapter 4 is most likely a consequence of either the way in which elastic modulation is effected in this particular pulsing-mode network or a consequence of elastic modulation of weights as proposed by Grossberg. The presence of the elastic weights mechanism at the Grossberg modeling level cannot help but be reflected at the pulse-modeling level. Changes in the level signals in a Grossberg model must correspond to changes in spiking rate and/or spiking time in a pulse-coded network.

The fact that such changes in the phasing of spike train packets produces emergent properties, as demonstrated in chapter 4, raises the issue of the biological substrate for Grossberg’s elastic weights. There is little doubt Grossberg was inspired by short-term synaptic potentiation and depression when he introduced the notion of elastic weights. But at the scale of the Grossberg model, weights are not synapses and so, if the elastic weight hypothesis is correct, the elastic function cannot be immediately due to such low-level synaptic phenomena. The nature of elastic weight modulation due to network-level fatigue effect is not clear. Chapter 4 results raise this as a significant research question.

By raising this question, one also raises the question of what sort of changes in Eckhorn network behaviors would be introduced if elastic weight dynamics were somehow directly introduced into the feeding field weights of the basic Eckhorn dendrite model (of an ENU). Grossberg’s differential equation for weight elasticity is not directly implementable in pulse-mode neural networks. Therefore the question is raised: what is the pulse-mode functional counterpart to Grossberg's differential equation? This, too, is a topic for future research.

For this thesis, the transformation of spiking activities from the Eckhorn network to level-activities is based on MPA. This means that activity is proportional to spiking frequency. For instance, consider two cases with only two spikes. If case-1 has spiking interval T_1 and T_2 for case-2, such that $T_1 < T_2$, then $MPA_1 > MPA_2$. Consider a third case, where three spikes occur with $T_{2a} + T_{2b} = T_2$. Though case-3 has three spikes, $MPA_1 > MPA_3$. Application of this transformation procedure assumes that functional neuroenergetics of the cortex is proportional to the ensemble firing frequency [Smith 2002]. Apart from the work done by Smith et al. in the somatosensory cortex, research on the calibration of fMRI activities with electrical activities in the cortex with respect to various neurotransmitter systems and brain regions is still an open field. Therefore, an accurate transformation process from a spiking-model neural network in the future should have a stronger neurophysiological basis of fMRI.

The performance index (P) for the algorithm is based on the conditioning performance surface of E-N. Performance surface of E-N during conditioning (i.e., with B, D and S-stimulus) is different from conditioned performance surface. This difference in shape of performance surface with and without D-stimulus should have further investigation.

The objective of this thesis was to get a PCNN adaptive based on foundations that are close to psychology and biology. However, we have not yet investigated any optimization techniques that can speed the adaptation. For future research, optimization techniques such as dynamic programming might be implemented to achieve the optimum parameter values.

Using the model-reference method, this thesis has shown that adaptation of PCNN is possible based on Hebb's laws. Thus, the next step would be to develop new methods by which the Eckhorn network can auto-adapt without the need of Grossberg reference as the "teacher".