Carefully reworded reprint of a contribution to:
Proceedings of the IJCNN '92. Edited by B.Z. Yuan, K.H. Zhao and J.E. Dayhoff
Publishing House of Electronics Industry, Beijing, pp. 809-810 (1992)

Spike Synchronization in Networks of Laterally Coupled Model Neurons

Alfred NISCHWITZ, Helmut GLÜNDER[*‡], Peter KLAUSNER, Andreas von OERTZEN

Lehrstuhl für Nachrichtentechnik, Technische Universität München
Arcisstraße 21, D-8000 München 2, F.R. Germany
Email: alfred@lnt.e-technik.tu-muechen.de
[*]Institut für Medizinische Psychologie, Ludwig-Maximilians-Universität
Gœthestraße 31, D-8000 München 2, F.R. Germany

1. INTRODUCTION

Recent electrophysiological investigations in cat visual cortex [1, 2] suggest that temporal correlations of single neural impulses or bursts of impulses play a fundamental rôle in biological information processing. The current hypothesis is based on the assumption that coherent sensory data – for example neighboring features belonging to the same object, such as velocity and direction of motion, contrast, texture, color etc. – are labeled by synchronous activity of the corresponding neurons. In this sense, incoherent features are represented by neurons showing asynchronous impulse generation, but possibly equal firing rate. Thus motivated, necessary conditions for the synchronization of spikes in networks of formal "integrate and fire"-neurons are reported. The issue concerning the integration of synchronous activity by post-synaptic neurons, for example for feature linking, is considered with respect to requirements of possible evaluation processes.

2. NETWORK MODEL AND MEASURE OF SYNCHRONY

We describe the somatic potential $\varphi_i(t)$ of a formal neuron (unit) as a leaky integrator, i.e., a constant input $e_i(t)$ is integrated according to an exponential function of time constant 10 ms. When the potential surpasses the threshold θ, an impulse $p_i(t)$ of 1 ms duration is triggered and the potential is reset. After a refractory period of 0.5 ms, the integration starts again (Figure 1A).

We simulated one-dimensional and cyclically closed networks consisting of laterally coupled units (Figure 1B), with all interconnections being either *inhibitory* or *excitatory*. To quantify the level of synchrony, we introduce a quality factor η that becomes $\eta = 1$, if all units fire simultaneously. Because our simulations started from randomized somatic potentials and owing to noisy thresholds $(\theta + n_i(t))$, an ensemble of uncoupled units ($W = 0$) generates asynchronous impulses leading to $\eta = 0.3$ for a firing rate of 150/s. Synchrony was evaluated during the first 50 ms (η_{50}) and in the interval 150…200 ms (η_{200}).

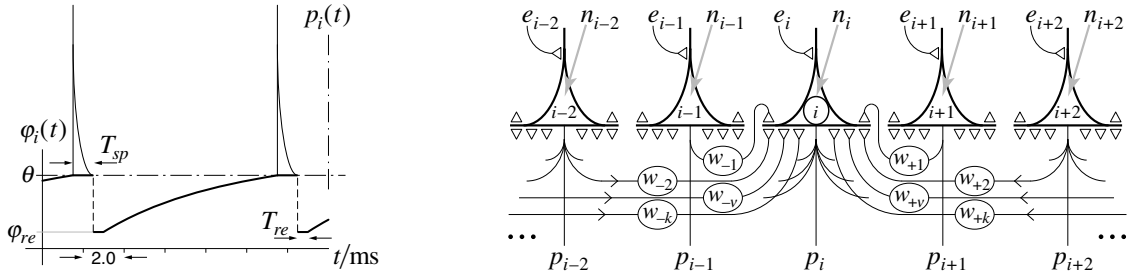

FIGURE 1

(A) Typical time-courses of the somatic potential and of the axonal impulses of an isolated unit

(B) Interconnection scheme of the one-dimensional network composed of recurrently coupled units

3. RESULTS OF NUMERICAL SIMULATIONS

In simulations with the temporal increment $\delta t_S = 100\mu s$ of networks consisting of $n_S = 64$ units, we observed good synchrony ($\eta_{200} > 0.7$) for the standard parameter values: $k_S = 8$ bilateral connections, integral lateral coupling strength $W_S = 0.2$, lateral transmission delay $\vartheta \approx 0$ms, and a constant external

‡ supported by the "Volkswagen-Stiftung" under the grant I/65 914

stimulation that causes an uncoupled unit to fire at the rate of $150/\mathrm{s}$. How deviations from the standard values affect the synchrony was reported before [3]. Here, we discuss spike synchronization in networks with inhibitory lateral coupling ($W < 0$) and for a certain range of transmission delays.

i) It turned out that synchronization can be achieved by either *inhibitory* or *excitatory* lateral coupling. The corresponding transmission delays and coupling strengths are complementary: Without delay, excitatorily coupled networks produce excellent synchrony, whereas inhibitorily coupled ones desynchronize ($\eta < 0.3$), similar to those with delayed ($\vartheta = 2\mathrm{ms}$) excitatory coupling (Figure 2A). In contrast however, very good synchrony develops rapidly (20…40 ms) in networks with delayed ($\vartheta = 2\mathrm{ms}$) inhibitory coupling. This behavior results from the non-linear effect that IPSPs (inhibitory post-synaptic potentials) have on the triggering of impulses: The delaying effect of IPSPs on the spike generation is stronger for somatic potentials near threshold than for those near the resting potential, and synchrony occurs because advancing impulses are stronger retarded than late ones.

ii) With respect to levels of synchrony $\eta_{200} > 0.7$, the tolerable delay becomes an increasing function of the integral coupling strength W (Figure 2B). In case of the excitatory lateral coupling, we determined an upper limit for the delay of $\vartheta = 250\mu\mathrm{s}$. Because temporal sampling implies an average intrinsic delay of $\vartheta = \delta t/2$, such networks must be simulated with temporal increments $\delta t \leq 500\mu\mathrm{s}$.

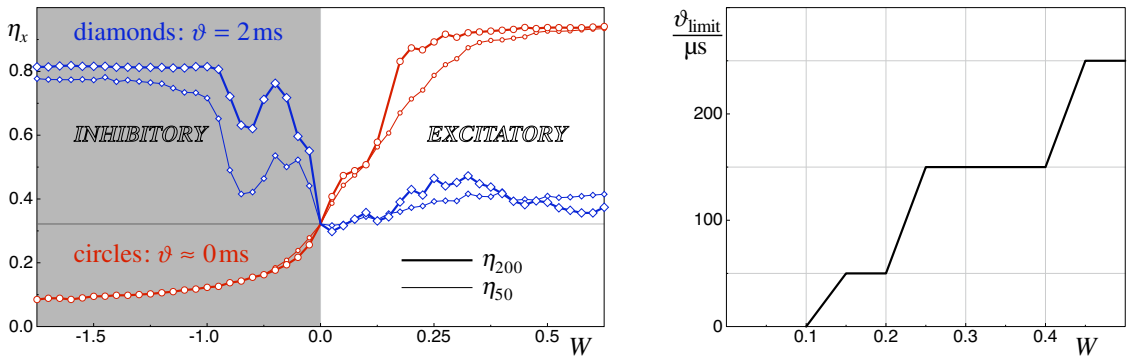

FIGURE 2

(A) Synchrony η as a function of the coupling strength W with and without transmission delays

(B) Tolerable delay $\vartheta_{\mathrm{limit}}$ for $\eta_{200} > 0.7$ as a function of the coupling strength W

4. INVESTIGATION OF POST-SYNAPTIC IMPULSE EVALUATION

The evaluation of synchronous activity indicating coherent features may be performed by the integration of spikes by post-synaptic neurons. Investigations of Abeles [4] show that typically 30 synchronous EPSPs (excitatory postsynaptic potentials) on average suffice to trigger a spike in a pyramidal cell. With the assumption that EPSPs are summed by a leaky integrator and by use of the "z-transformation", we analytically computed the number of pre-synaptic spikes as a function of their synchrony that are required to trigger a post-synaptic impulse [5]. It turned out that 30 EPSPs is indeed a good estimate, if they arrive within a millisecond at the cell soma. With decreasing synchrony this number rises steeply. From a post-synaptic neuron's point of view, it is therefore possible to determine the minimum level of synchrony for the linking of coherent features. However, besides this "somatic" kind of impulse evaluation, one must consider other coincidence detection mechanisms, for example "local dendritic" ones.

REFERENCES

[1] Eckhorn R., Bauer R., Jordan W., Brosch M., Kruse W., Munk M. and Reitboeck H.J. (1988) Coherent oscillations: a mechanism of feature linking in the visual cortex? *Biol. Cybern.* **60**: 121-130.

[2] Gray C.M., König P., Engel A.K. and Singer W. (1989) Oscillatory responses in cat visual cortex exhibit inter-columnar synchronization which reflects global stimulus properties. *Nature* **338**: 334-337.

[3] Nischwitz A., Glünder H. and Klausner P. (1991) Synchronization of spikes in populations of laterally coupled model neurons. In: Kohonen T., Mäkisara K., Simula O. and Kangas J. (eds.) *Artificial Neural Networks* (vol. 2). North-Holland, Amsterdam, pp. 1771-1774.

[4] Abeles M. (1982) *Local Cortical Circuits. An Electrophysiological Study*. Springer, Berlin.

[5] Nischwitz A. (1992) Impulse evaluation by model neurons. *This proceedings volume*, pp. 832-837.