

SPIKE SYNCHRONIZATION IN NETWORKS OF LATERALLY COUPLED MODEL NEURONS

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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 role in biological information processing. The current hypothesis is based on the assumption that coherent sensory data, e.g. neighboring features belonging to the same object, such as velocity and direction of motion, contrast, texture, color etc., are labelled by synchronized activity of the corresponding neurons. In this sense non-coherent features are represented by neurons showing asynchronous impulse generation, but eventually equal firing rate. Thus motivated, necessary conditions for the synchronization of spikes in networks of "integrate-and-fire" model neurons are reported. The problem of the integration of synchronized activity by postsynaptic neurons, e.g. for the purpose of feature linking, is investigated in an analytical study dealing with requirements of possible evaluation processes.

2. NETWORK MODEL AND MEASURE OF THE SYNCHRONIZATION QUALITY

We describe the somatic potential $D_i(t)$ of a model neuron (unit) as a leaky integrator, i.e. the constant external input $E_i(t)$ is integrated according to an exponential function (time constant typically 10ms). When the potential surpasses the threshold θ an axonal impulse $A_i(t)$ of 1ms duration is triggered and the potential is reset to the value D_{re} . After a refractory period of 0.5ms the integration starts again (cf. Fig. 1A).

We simulated one-dimensional and cyclically closed networks consisting of such units that are laterally coupled according to Fig. 1B. All interconnections are either *inhibitory* or *excitatory*. In order to quantify the degree of synchronization we introduce a quality factor η . The value $\eta=1$ is reached if all units start firing simultaneously. Because every simulation starts from randomized somatic potentials and owing to a noisy threshold ($N_i(t)$), the generation of impulses becomes asynchronous if the network is not coupled ($C=0$), which results in an $\eta=0.3$ for a firing rate of $150s^{-1}$. We evaluate the quality of synchronization within the first 50ms (η_{50}) and in the interval 150-200ms (η_{200}) after $t=0$.

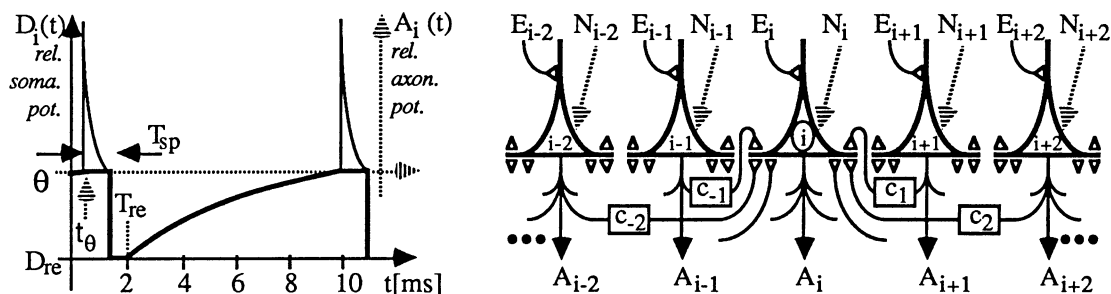


FIGURE 1

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

(B) Interconnection scheme of the one-dimensional network

3. RESULTS OF THE NUMERICAL SIMULATIONS

We observe good synchronization (typically $\eta_{200} > 0.7$) for the following standard parameters: number of units $n_s=64$, number of bilateral connections $k_s=8$, integral lateral coupling strength $C_s=+0.4$, an excitation that causes an uncoupled unit to fire at the rate $R_{As}=150s^{-1}$, lateral transmission delay $\tau_s=0\mu s$,

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and a temporal increment of the simulation of $\Delta t_s = 100 \mu s$. The influence of various deviations from these parameter values on the synchronization was reported earlier in [3]. Here we demonstrate the effects of inhibitory lateral couplings ($C < 0$) and of wide range variation of the lateral delays τ .

i) It turned out that synchronization is achieved by either *inhibitory* or *excitatory* lateral coupling. The corresponding values for the lateral delay and coupling strength are complementary: non-delayed excitatory coupling results in excellent synchronization, whereas non-delayed inhibitory coupling desynchronizes ($\eta < 0.3$), similar to the delayed excitatory coupling with $\tau = 2ms$ (cf. Fig.2A). In contrast to the excitatory coupling, very good synchronization is reached after an extremely short time interval (20-40ms after $t=0$) if delayed ($\tau = 2ms$) inhibitory interactions are considered. This is due to non-linear temporal effects of IPSPs (inhibitory postsynaptic potential) on the triggering of impulses: the delaying influence of IPSPs on the triggering of spikes is stronger for somatic potentials near the threshold than for low somatic potentials. Because advancing impulses are stronger delayed than later arriving ones, synchronization results.

ii) We observed that the tolerable delay τ for $\eta_{200} > 0.7$ is a function of the lateral coupling strength C (cf Fig.2B). We found an upper limit of $\tau = 250 \mu s$ for the lateral delay in case of excitatory lateral couplings ($C = + C_s$). Because the temporal sampling implies an intrinsic delay $\tau \approx \Delta t/2$, the simulations thus must be computed with a temporal increment $\Delta t \leq 0.5ms$.

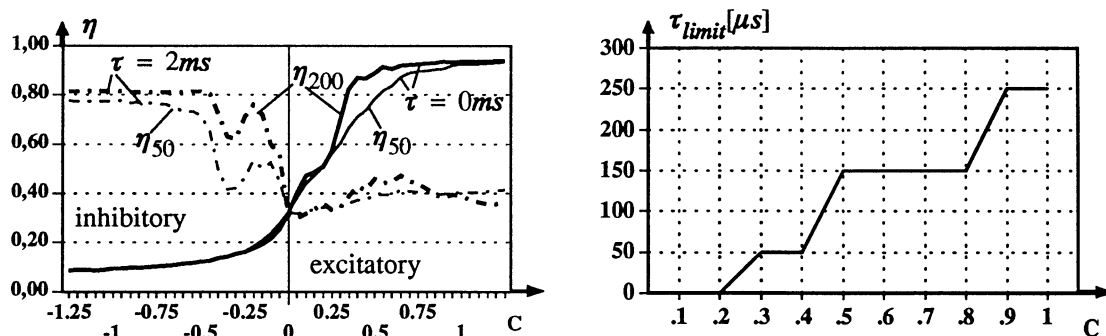


FIGURE 2

(A) synchronization and lateral coupling strength

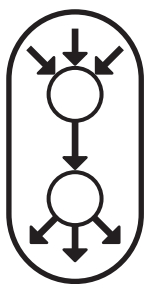
(B) tolerable time delay τ_{limit} (for $\eta_{200} > 0.7$) as a function of the lateral coupling strength

4. ANALYTICAL INVESTIGATION OF POSTSYNAPTIC IMPULSE EVALUATION

The evaluation of synchronous activity indicating coherent features may be performed by integration of the affiliated spikes at postsynaptic neurons. Investigations of Abeles [4] showed that typically 30 synchronous EPSPs (excitatory postsynaptic potential) are sufficient to trigger a neural impulse. We assume that all EPSPs are summed up by a leaky integrator. Hence, by use of the 'z-transformation' we can compute the number of presynaptic spikes that is required to trigger postsynaptic impulses as a function of the degree of synchronization. It turned out that 30 EPSPs are indeed a good estimate as long as they are started within one millisecond. With decreasing synchronization this number rises steeply. From the postsynaptic neuron's point of view, it's possible to determine a minimal quality of synchronization in order to link coherent features. Besides the just described impulse evaluation we must be aware of different, e.g. local dendritic, coincidence detection mechanisms.

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. Cyb.* 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. (ed.) *Artificial Neural Networks*. Vol. 2. Elsevier, Amsterdam, pp. 1771-1774.
- [4] Abeles M. (1982) *Local Cortical Circuits. An Electrophysiological Study*. Springer, Berlin.



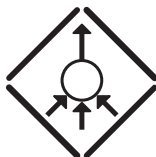
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