Information processing at single neuron level*

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The understanding of mechanisms of higher brain functions expects a continuous reduction from higher activities to lower ones, eventually, to activities in individual neurons, expressed in terms of membrane potentials and ionic currents. While this approach is correct scientifically and desirable for applications, the complete range of the reduction is unavailable to a single researcher due to human brain limited capacity. In this connection, it would be helpful to abstract from the rules by which a neuron changes its membrane potentials to rules by which the information is processed in the neuron. The "coincidence detector", and "temporal integrator" are the examples of such an abstraction.

*Poster presented at NATO ASI Modulation of Neuronal Signaling: Implications for Visual Perception, Nida, Lithuania, 12-21 July, 2000. See also Vidybida A.K. Inhibition as binding controller at the single neuron level. BioSystems, Vol. 48, 1998, p. 263–267; Vidybida A.K. Neuron as time coherence discriminator. Biological Cybernetics, 74(6), 1996, 539-544.

While being useful in constructing artificial networks, the above two abstractions are neither connected with known brain functions, nor they are relevant to the biological nature of nervous cell, including justification of its survival in the natural selection.

In this poster, an alternative abstraction is described, which seems to be free from these shortages. Based on the Hodgkin and Huxley set of equations, we analyze the neuronal reaction to compound stimuli, comprising large number (1000) of EPSP (Box 1). The unitary EPSPs in a compound stimulus are distributed randomly over a time window [0;W]. The probability to fire a spike as a function of W is calculated by means of Monte Carlo method. In this course, several values of proximal $GABA_b$-type inhibition are applied (Box 1, term with g_{iK}). The dependencies obtained (Fig.4) allow to formulate one more abstraction of neuronal functioning (Box 2). In this abstraction the temporal structure of stimulus as well as the inhibition get their information processing meaning. The formulation is expressed in terms of binding, or feature linking — an essential ability of the brain. In this formulation a single neuron is endowed with a meaningful ability, the binding, which might be the reason for survival of excitable cells in the natural selection. The information processing scheme in a single neuron (Fig.5) could be the first step in the bottom-up reductionistic explanation of brain functioning.

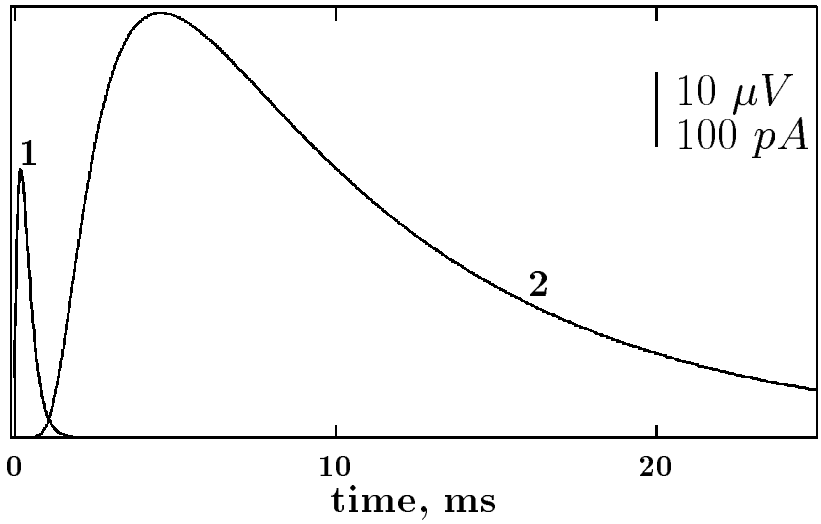

Fig.1. Time course of (1) excitatory sinaptic current in the sinaptic part of membrane, ESC, and (2) excitatory postsynaptic potential in the triggering zone, EPSP

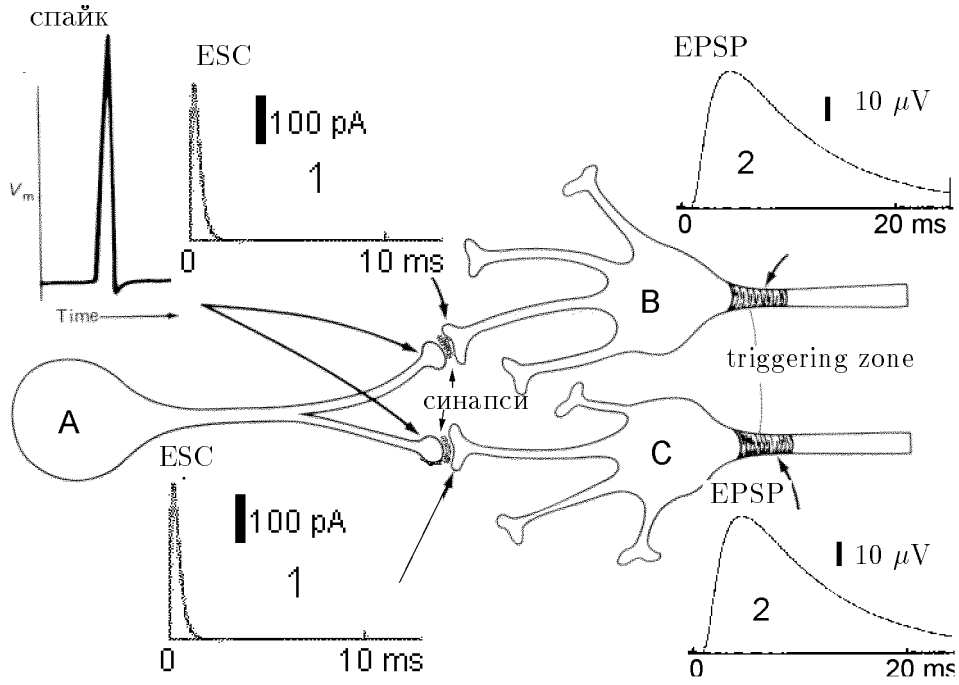

Fig.2. Mechanism of the EPSP forming (modified from: Principles of Neural Science, E. Kandel and J. Schwartz(eds), Elsevier, 1985)

Box 1

Hodgkin and Huxley equations

$$C_M dV/dt = -g_K n^4 (V - V_K) - g_{Na} m^3 h (V - V_{Na}) - g_l (V - V_l) - g_{iK} (V - V_K) + I(t),$$

$$dn/dt = \alpha_n (1 - n) - \beta_n n,$$

$$dm/dt = \alpha_m (1 - m) - \beta_m m,$$

$$dh/dt = \alpha_h (1 - h) - \beta_h h.$$

$$I(t) = -C_M dCompEPSP(t)/dt.$$

Stimulating current in the triggering zone

$$CompEPSP(t) = \sum_{k=1}^{1000} EPSP(t - t_k)$$

Compound potential in the triggering zone. All t_k are chosen randomly from the time window: $t_k \in [0; W]$. See example in Fig.3. Temporal coherence, TC, is defined as $TC = 1/W$.

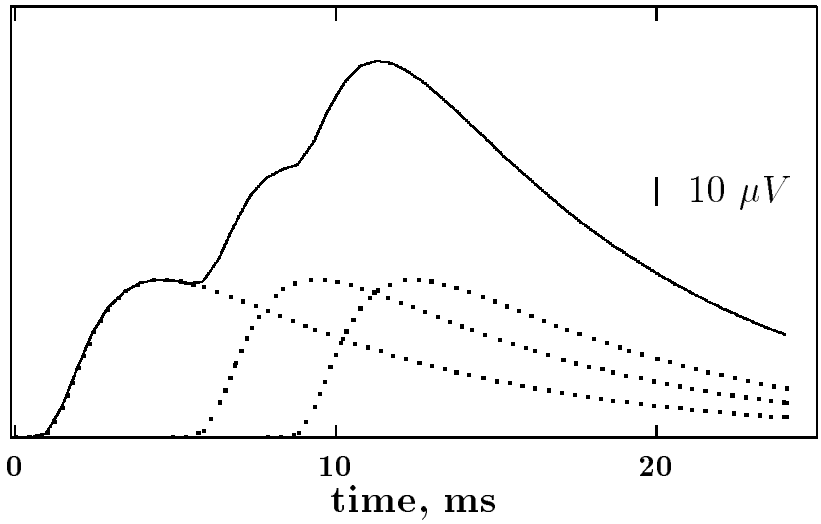

Fig.3. Example of compound stimulus (solid line) comprising three unitary stimuli (dotted lines) as they are seen in the triggering zone

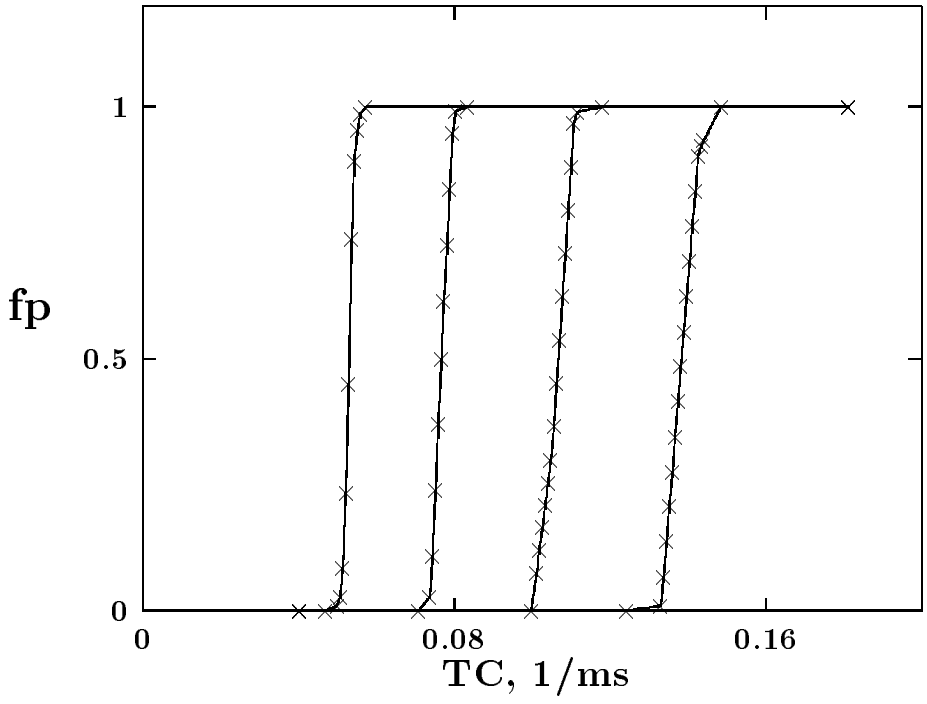

Fig.4. Firing probability vs temporal coherence between the unitary stimuli within the compound stimulus comprising 1000 of unitary stimuli. The four curves correspond consecutively from the left to the right to the inhibition potentials 0.43, 3.08, 5.02, 6.30 mV.

Box 2

Information processing in a generic neuron

1. Excitatory synaptic currents (ESCs, Fig.1) are treated as elementary events registered by the neuron.
2. EPSP, which follows the ESC serves as short term memory mechanism, because its duration is much longer than that for the ESC (Fig.1).
3. A set of elementary events, which are coherent in time, is bound in the neuron into an output spike, which represents the bound event (Fig.5).
4. Inhibition serves as controller of this type of binding (Figs.4,5).

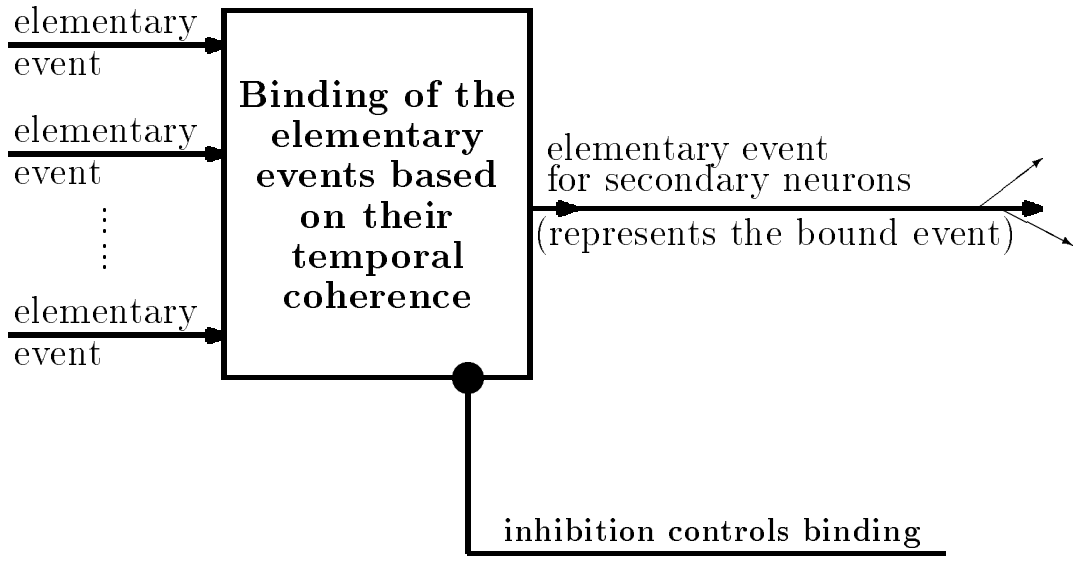

Fig.5. Proposed scheme of information processing in a single generic neuron