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SOME LOGIC FUNCTIONS REALIZED ON A STATIONARY NONLINEAR DENDRITE
2. Inhibitory synapses

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Abstract. Binary logic functions $'AND'$ and $'OR'$ of negations are realized by a dendritic branch with nonlinear current-voltage characteristic of membrane. The neuron with such dendrites is a complex logic system performing a great number of elementary logic operations.

Key words: neurocomputer, dendrite, synapse, current-voltage nonlinearity, bistability.

1. Introduction. Starting from the McCulloch and Pitts neuron, neurophysiological mechanisms for information processing by a neuron are simulated. In many cases logic functions are realized. Inhibitory mechanisms play here an important role. Inhibition is used in the models of neural networks in rather a simplified way (as well as the concept of neuron itself). We consider it quite reasonable to illustrate the performance of logic operations by using an inhibitory mechanism in nonlinear dendrites, i.e., before the advent of a signal to the body of a neuron. To be more exact in this paper we continue a numerical analysis of logic operations realized by two synapses located on a single dendritic branch, whose membrane has an N-shaped current-voltage characteristic ($C-V$) (two stable and one unstable points-bistable dendrite, Fig. 1). The mathematical model of the considered bistable dendrite branch and the method for solving this problem used in this paper, are described in the previous work (Garliauskas *et al.*, 1992).

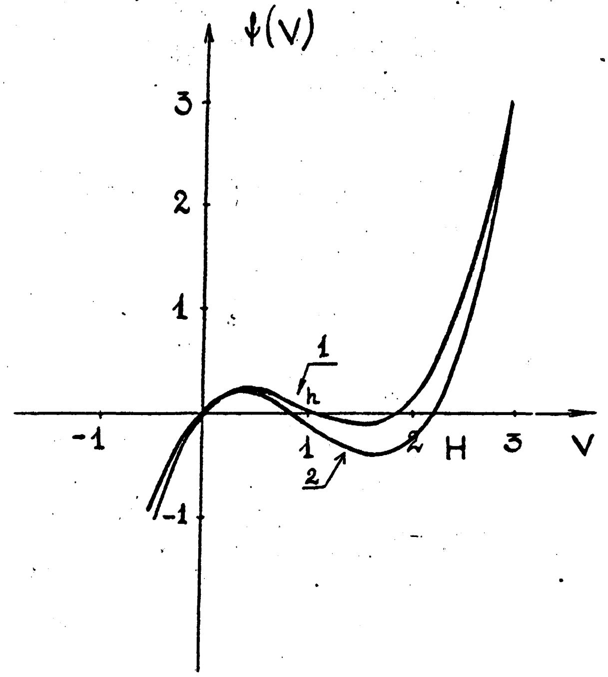

Fig. 1. Current-voltage characteristics of the dendritic branch membrane; the curve $f(V)$ in canonic form of the cable equation satisfies the requirement $f(V) \to V$ when $V \to 0$. 1) $b = 0.55$; 2) $b = 0.65$.

2. Parameters of the model. A dendritic branch with two synapses under investigation is loaded with linear ohmic resistance (Fig. 2). We use here, in distinction to the previous paper, $C - V$ with parameter $b = 0.65$ at which a greater depth of the negative part of $C-V$ is achieved (previous $b = 0.55$, Fig. 1). Such a necessity is due to the fact that at the value $b = 0.55$ the output $C - V$ of the dendritic branch has only one zero for the value of the potential

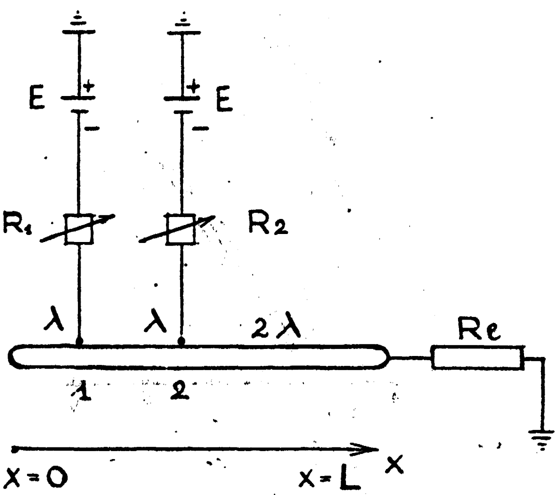

Fig. 2. The scheme of a dendritic branch with ohmic load R_l; R_1, R_2 are internal resistances of synapses, E is electromotive force of synapses.

$V = 0$ (see Fig. 3a), while at $b = 0.65$ the output $C - V$ has two zeroes (at the distal end $V \approx 0$ and $V \approx H$), (see Fig. 3b). At stable depolarization ($V \approx H$) logic interaction of two inhibitory synapses makes sense. The localization of inhibitory synapses on dendrites is well established (Dutar, Nicoll, 1988). There are two types of synaptic inhibition in central nervous system:

1) the slow potassium inhibitory current is characterized in our model by $E = -2$;

2) quicker one of chloride nature has $E = -1$; in comparison, previously modelled excitating current of mixed calion nature was characterized by $E = +7$.

3. Results. Recalling Garliauskas *et al.* (1992) that if we restrict ourselves to a binary logic, then the stable point close to the rest potential (RP, $V = 0$) corresponds to the logic value '0', and the stable point of the output $C - V$ of the branch at which the distal end of a dendrite is stably depolarized (SD, $V = H$) corresponds to the logic value '1' (see Fig. 3b).

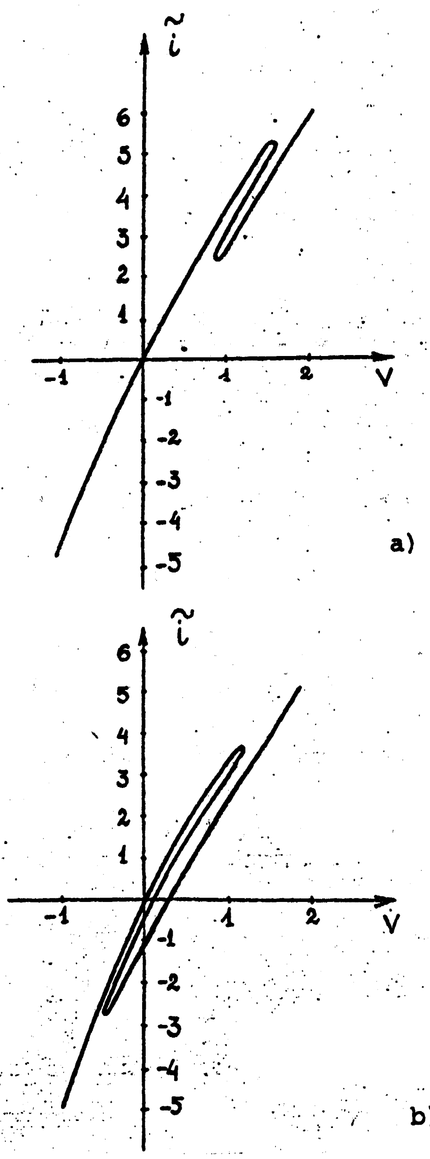

Fig. 3. The output current-voltage characteristics of the dendritic branch; $L = 4\lambda$; $R_1 = R_2 = \infty$; $R_e = w/3$; a) $b = 0.55$; b) $b = 0.65$.

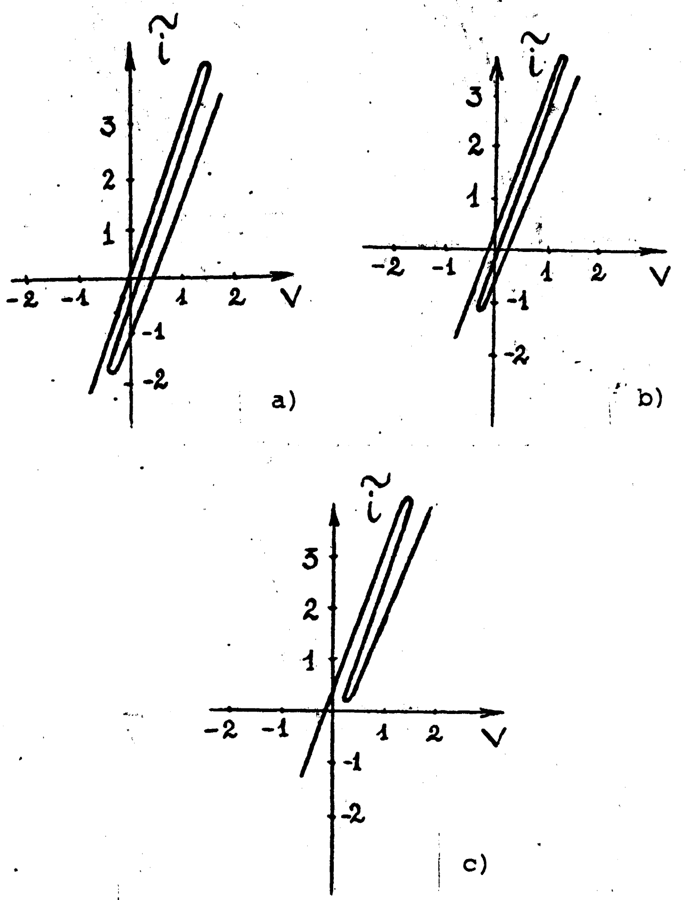

Fig. 4. The example of conditional logic multiplication of negations; output current-voltage characteristics of the dendritic branch with one and two active inhibitory synapses are presented. The left-hand branch of the curves corresponds to the vicinity of the rest potential ($V \approx 0$) and the right-hand one on a) and b) corresponds to the vicinity of stable depolarization potential ($V \approx H$). $E = -2$; a) $R_1 = 15w$, $R_2 = \infty$; b) $R_1 = \infty$, $R_2 = 15w$; c) $R_1 = R_2 = 15w$.

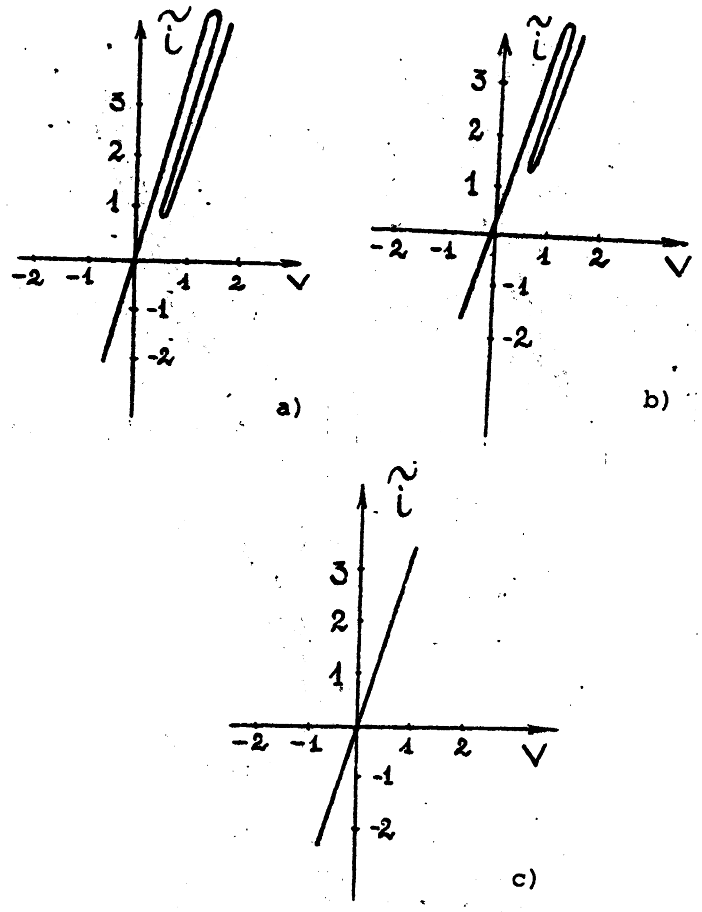

Fig. 5. The example of logic summation of negations. The left-hand branch of the curves in a) and b) corresponds to the vicinity of the rest potential; c) illustrates the left-hand branch of dendrite's output current-voltage characteristic (the right-hand branch and the loop of negative resistance got beyond the boundary of c)). $E = -2$; a) $R_1 = 5w$, $R_2 = \infty$; b) $R_1 = \infty$, $R_2 = 5w$; c) $R_1 = R_2 = 5w$.

Fig. 4 illustrates a realization of the logic multiplication of negations, namely, if a *SD* ('1') is the initial state, then only activation of both inhibitory synapses switches the branch to the state $V \approx 0$, i.e., *RP* ('0'). One can see that in initially stably depolarized dendrite simultaneous action of two inhibitory synapses switches off the stable depolarization and the rest potential is established at the distal end.

In Fig. 5 a relation of the logic summation of negations is presented: output current-voltage characteristics of the cable with one (Fig. 5a and 5b) and two (Fig. 5c) active inhibitory synapses are presented; both a separate activation of each of the inhibitory synapses and their simultaneous activation switches the branch from *SD*, i.e., state '1', to the *RP*, i.e., to state '0'.

4. Discussion. The presented results support the idea of the logic dendritic function realized on a separate neuron dendritic branch not including the entire cell's membrane.

The simulation results (not presented here) using chloride inhibitory synapses ($E \approx -1$) also show a possibility of imitating the inhibitory logic functions discussed above.

The imitation of so-called silent inhibition is an important functional aspect of model considered here. The silent inhibitory effects when none noticeable inhibitory postsynaptic potentials in the soma appear and the excitation caused by some inputs is blocked. The mechanism of silent inhibition is physiologically important, for example, for explanation of a selective reaction of visual neurons to the movement of a stimulus in the receptive field (Barlow and Levick, 1965; Torre and Poggio, 1978).

From the principal viewpoint the theory of bistable dendrites is antisymmetric with respect to the middle zero of the $C - V$ of the dendrit's membrane (unstable point, $V = h$, see Fig. 1). Antisymmetry implies a replacement of *RP* by *SD*, an inward current by the outward one, excitatory synapses by inhibitory ones and vice versa, and consequently, a replacement of a binary logic function by the same function of negations.

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