A POSSIBLE STRUCTURE FOR PHYSIOLOGICAL CONTROLLER

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Abstract: In this work, the authors have shown how to synthesise a controller with neurones. Using a mathematical model, we have demonstrated the possibility to create different structures with special functions like amplification, attenuation, integration, etc. Because the control structures are essential for biological systems, we assert that, with a minimum number of neurones, the brain can create local controllers, which are also subordinated to the hierarchical system.

Key words: Neural model, controller, bioengineering.

BIOLOGICAL MODEL

The human brain is the most highly organized form of matter known. It has been estimated that the human central nervous system, which of course includes the spinal cord as well as the brain itself, consists of about 10 billion (10^{10}) nerve cells. Biological neurons have a fairly simple large-scale structure, although their operation and small-scale structure is immensely complex.

The basic cell of the nervous system is the neuron. A typical neuron, as the pyramidall cell from the cortex, is presented in fig. 1. It is composed from three parts:

- The body cell named soma
- Dendrites
- Axon. The axon can be as short as a fraction of a millimeter or as long as a meter, depending on its place and function. In very thin axons these impulses travel at less than one meter per second; in others, for example in the large axons of the nerve cells that activate muscles, they travel as fast as 100 meters per second.

The interneuronal connections consist in great number of synapses. There may be only a few hundred to 200.000 synapses for each neuron.

The input signal enter the neuron through the dendrites and the soma synapses. These signals are integrated on the soma and leave the neuron through the axon as an unique output. The output signal, a train of impulses, is then sent down the axon to the synapses of other neurons.

The information is transmitted as an electrical signal (action potential - fig. 2), frequency modulated, on the dendrites and the axon. On the soma, the information is processing like a signal amplitude modulated.

The complex intellectual capacity of the brain can not be explained by the physiological function of each neuron. The explanation consists in an explosive interconnection between great number of neurons, that provide different level of complexity, functional flexibility and a great plasticity.

The new concept of the cortex functions (Greger, Windhorst, 1996) provides that cortical information processing occurs according to building block or modules. These are basic circuits (inhibitory, excitatory, oscillatory, etc.) in all the levels of central nervous system and canonical circuits at the cortex. The characteristic operations of a given region arise from its particular combination of canonical circuits.

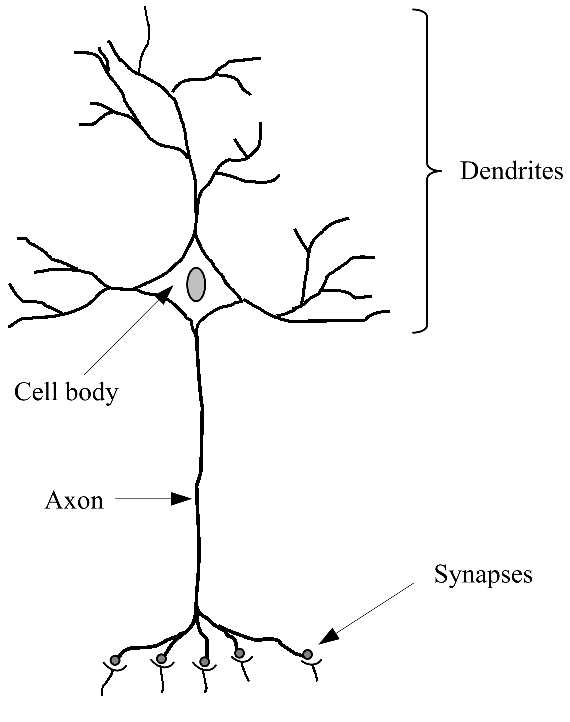

Fig. 1. Structure of large neuron of the brain
(From Guyton: Basic Neuroscience, Anatomy and Physiology, Philadelphia, W.B.Saunders Company, 1996)

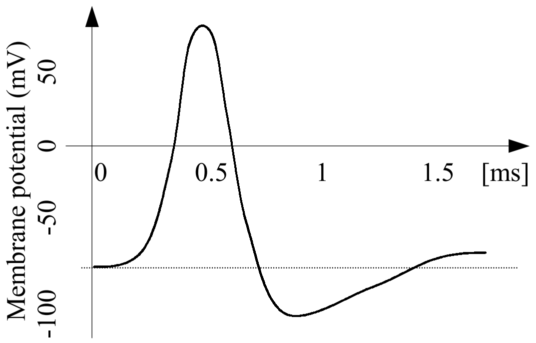

Fig. 2. Action potential
(From Guyton: Basic Neuroscience, Anatomy and Physiology, Philadelphia, W.B.Saunders Company, 1996)

MATHEMATICAL MODEL

The work of Hodgkin and Huxley and their equations for ionic channels have created the natural starting point for the discipline of computational neuroscience. This led to various types of mathematical models of neurones. The authors propose a model, described by the input-output relation:

$$f_e(t) = 1(t-\tau)\left\{\sum_{i=1}^{n}\alpha_i\left[u_i(t)-\upsilon_{i0}\right]-\sum_{j=1}^{m}\beta_j\left[v_j(t)-w_{j0}\right]\right\} \qquad (1)$$

where:

- $u_i(t)$, $i=\overline{1,n}$ - represents the excitatory afferents;
- $v_j(t)$, $j=\overline{1,m}$ - represents the inhibitory afferents;
- $\nu_{i0}(t)$, $i=\overline{1,n}$ - represents the values of the thresholds for excitatory afferents;
- $w_{j0}(t)$, $j=\overline{1,m}$ - represents the values of the thresholds for inhibitory afferents;
- α_i, β_j, $i=\overline{1,n}$, $j=\overline{1,m}$ - represents the weight of synapse *i* or *j*;
- $f_e(t)$ - represents the efferent signal;
- τ - represents an input-output delay time constant.

The relation (1) can be rewritten like:

$$f_e(t) = 1(t-\tau)\left[\sum_{i=1}^{n}\alpha_i u_i(t)-\sum_{j=1}^{m}\beta_j v_j(t)\right]+ \\ +1(t-\tau)\left[\sum_{j=1}^{m}\beta_j w_{j0}-\sum_{i=1}^{n}\alpha_i\upsilon_{i0}\right] \qquad (2)$$

We can make the notation:

$$r = \sum_{j=1}^{m}\beta_j w_{j0}-\sum_{i=1}^{n}\alpha_i\upsilon_{i0} \qquad (3)$$

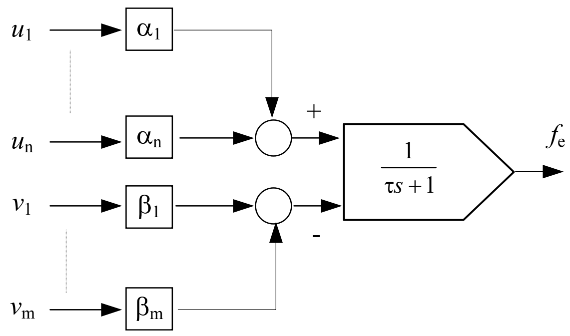

Fig. 3. Structure of equivalent neuron.

where *r* is a residual, which can be neglected. The symbolical transfer function is:

$$H(s) = e^{-\tau s} \approx \frac{1}{1+\tau s} \qquad (4)$$

Using this model (fig. 3), we have demonstrated the possibility to create different structures with special functions like amplification, attenuation, integration, etc. (Iancu, 1998).

SYNTHESIS OF CONTROLLER

In fig. 4 is represented a neural structure who reproduce an integrator. From this figure it is possible to write the next relations:

$$f_{e1}(s) = \frac{\alpha_{11}}{\tau s+1-\alpha_{21}\alpha_{12}}u(s) \qquad (5)$$

If $\alpha_{12} = \alpha_{21} = 1$, relation (5) becomes:

$$f_{e1}(s) = \frac{\alpha_{11}}{\tau}\frac{1}{s} = \frac{1}{T_i s},\quad T_i = \frac{\tau}{\alpha_{11}} \qquad (6)$$

In fig. 5 is represented a neural structure which reproduce an amplifier. We have the next relations:

$$f_{e1}(s) = \left[\alpha_{11}+\alpha_{12}\alpha_{21}\frac{1}{\tau s+1}\right]\frac{1}{\tau s+1}u(s) \qquad (7)$$

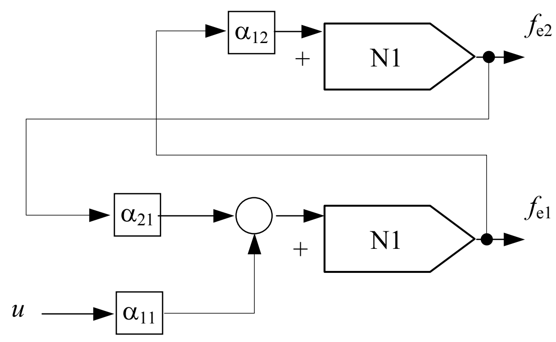

Fig. 4.

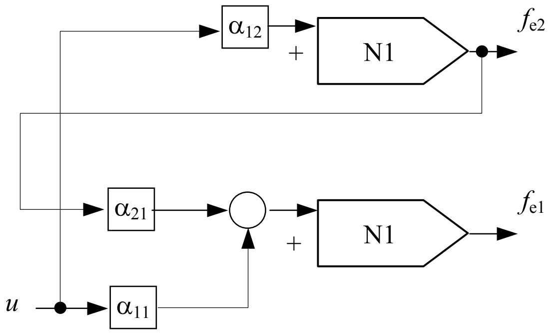

Fig. 5.

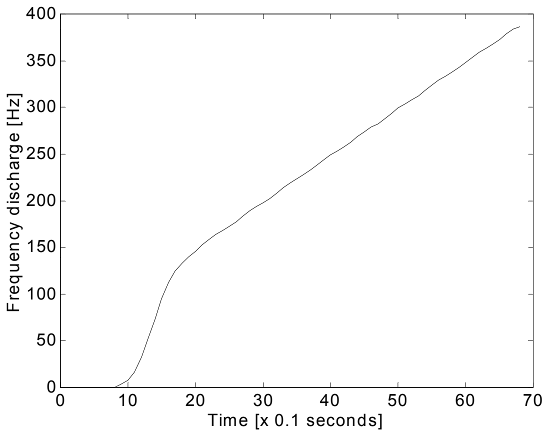

Fig. 5. Response of neural PI controller

$$f_{e2}(s) = \alpha_{12} \frac{1}{\tau s + 1} u(s) \quad (8)$$

For a constant input,

$$u(s) = \frac{1}{s} u_o \quad (9)$$

the steady-state values for (7) and (8) are:

$$f_{e1st} = \lim_{s \to 0} s f_{e1}(s) = (\alpha_{11} + \alpha_{12}\alpha_{21}) u_o \quad (10)$$

$$f_{e2st} = \lim_{s \to 0} s f_{e2}(s) = \alpha_{12} u_o \quad (11)$$

If we combine the two structure results an PI controller which is building using just six neurons. The result of simulation is represented in fig. 5.

CONCLUSION

Because the control structures are essential for biological systems, we have shown in this paper how to synthesise a controller with neurones. In conclusion, we assert that, with a minimum number of neurones, the brain can create local controllers, which are also subordinated to the hierarchical system. Also, each neuron are in use a minimal number of synapses, so it can be simultaneous a constitutive part for another neural structure. This aspect is an argument for the optimally structure of the brain.

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