Fuzzy System Composed of Analogue Fuzzy Cells

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Abstract: The human intelligence is product of the communicative collaboration between neurons in the brain. The speed of data processing and the number of answers depends on the number of neurons and the number of synaptic connections between neurons. The model of neural network is the human brain, which includes neural networks used for perception and conversion inputs into stimuli, neural networks used for preparing the appropriate answers the activities, and neural networks to make activities. Since the operation of artificial neural network made of analogue circuits is similar to the operation of a simplified organic brain, i.e. a functional center in the brain, therefore the operational mode is fuzzy operation, as well. Therefore, the analogue neural system does not require fuzzifier and defuzzifier. The neural network has structural stability by the catastrophe circuits, the reflex courses operated in accordance with Thom's catastrophe theory.

Keywords: catastrophe theory, fuzzy neuron, nervous system

1 Introduction

The operation and power of a neural system is based on the reflex courses which are used as high-speed, real-time communicational devices. The operation of reflex course can be described by the application of formal description [1] [6].

Let the neural cell be considered as a finite-state machine during the real-time operational period [7]. It can be described by the application of formal description by Chomsky. Then the mathematical object for the description of the finite-state machines is the following:

$$M=\{Q, \Sigma, \delta, F\}, \tag{1}$$

where M is the symbol of the finite-state machine, Q is the set of states, Σ means the set of inputs, δ is the set of operational rules, and F is the set of finite-states [3].

2 Analog Neural Cells

Organic neural networks include a lot of neural cells with different functions. Artificial intelligence can be built of networks of artificial reflex courses. This simplification occurs that the number of neural units can be reduced. In accordance with the structure of organic reflex course, three basic types of neural cells has been designed; they are the afferent neural cell, the moto-neuron, and the interim neural cell. These neural cells can be used compose a fuzzy system.

2.1 Formal Description of the Afferent Neural Cell

The afferent neural cells percept stimuli originated from the environment. One an afferent neural cell can be connected to single receptor, only. The output of

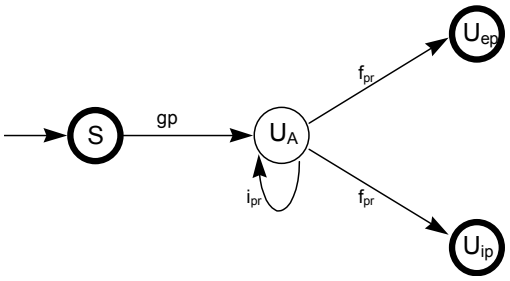

Figure 1
Finite-state machine of afferent neural cell

receptor is the generator potential. If the voltage of generator potential is high enough then an action potential will be generated on the axon of neural cell. The action potential may occur either excitation, or inhibition. In the first case it is called excitatory post synaptic potential *epsp*, in the second case it is inhibitory post synaptic potential *ipsp*.The model of afferent neural cell is shown in Figure 1.

The finite-state machine of the afferent neural cell can be described by the following mathematical objects

$$Q=\{S, U_a, U_{ep}, U_{ip}\}, \quad (2)$$

where S means the symbol of initial state, U_a is the symbol of membrane potential on the afferent neural cell, U_{ep} is the symbol of excitatory potential on the post synaptic neural cell, and U_{ip} is the symbol of inhibitory potential on the post synaptic neural cell.

$$\Sigma=\{gp, i_{pr}, f_{pr}\}, \quad (3)$$

where gp means the generator potential on the output of receptor, i_{pr} is the symbol of inhibitory pre-synaptic potential, and is the symbol of pre-synaptic facility potential.

$$\delta=\{(S, gp)=U_a, (U_a, i_{pr})= U_a, (U_a, f_{pr})=U_{ep}, (U_a, f_{pr})=U_{ip}\}, \quad (4)$$

and

$$F=\{U_{ep}, U_{ip}\}. \quad (5)$$

It can be said by expressions (6.2)-(6.5) that the finite-state machine of the afferent neural cell is a non-determined, fully specified finite-state machine during the real-time operational period.

2.2 Formal Description of the Moto-neuron

Function of moto-neuron is to influence the operation of muscles, to generate activities. Action reflex is an uncontrolled activity of the muscles which may be occurred by the excitatory post-synaptic potential. If the excitatory post-synaptic potential is eliminated then the moto-neuron will go into initial state.

The model of finite-state machine of moto-neuron is described by the following expressions, and it is shown in Figure 2.

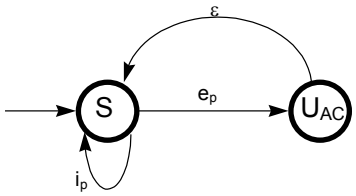

Figure 2
Finite-state machine of the moto-neuron

$$Q=\{S, U_{AC}\}, \quad (6)$$

where S is the symbol of set of initial states, and U_{AC} is the symbol of action potential on the output of moto-neuron.

$$\Sigma=\{e_p, i_p, \varepsilon\}, \quad (7)$$

where e_p is the symbol of excitatory post-synaptic potential, i_p is the symbol of inhibitory post-synaptic potential, and ε is an empty terminal.

$$\delta=\{(S, i_p)=S, (S, e_p)=U_{AC}, (U_{AC}, \varepsilon)=S\}, \quad (8)$$

and

$$F=\{U_{AC}\}. \quad (9)$$

It can be said, that the finite-state machine of moto-neuron described by mathematical objects (6)-(9) is determined, fully specified finite-state machine during the real-time operational period.

2.3 Formal Description of the Interim Neural Cell

The model of finite-state machine of the interim neural cell is shown in Figure 3. The function of this neural cell is the data processing to produce one or more reactions. Data are sensed internal and external signals.

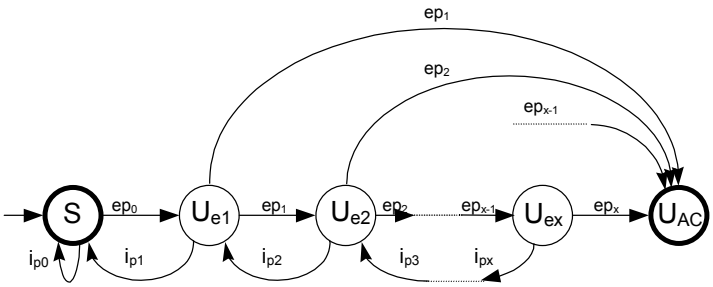

Figure 3
The finite-state machine of interim neural cell

The finite-state machine of the interim neural cell can be described by the following mathematical objects.

$$Q=\{S, U_{e1}, U_{e2}, ..., U_{ex}, U_{AC}\}, \quad (10)$$

where S is the symbol of set of initial states, U_{e1} , U_{e2} , ..., U_{ex} are the symbols of membrane potentials, and U_{AC} is the action potential of the interim neural cell in its finite state.

$$\Sigma=\{ep_0, ep_1, ..., ep_x, ip_0, ip_1, ..., ip_x\}, \quad (11)$$

where ep_0, ep_1, ..., ep_x are the symbols of excitatory post-synaptic potentials, and ip_0, ip_1, ..., ip_x are the symbols of inhibitory post-synaptic potentials.

$$\delta=\{(S, ep_0)=U_{e1}, (S, ip_0)=S, (U_{e1}, ip_1)=S, (U_{ej}, ep_j)=U_{e(j+1)},$$
$$, (U_{ej}, ep_j)=U_{AC}, (U_{ex}, ep_x)=U_{AC}, (U_{ej}, ip_j)=U_{e(j-1)}\}, \quad (12)$$

where $j=1, 2, ..., x$, and

$$F=\{U_{AC}\}, \quad (13)$$

where U_{AC} is the symbol of action potential on the axon of interim neural cell.

It can be said that the model of finite-state machine of the interim neural cell described by mathematical objects (10)-(13) is non-determined, not fully specified finite-state machine during the real-time operational period.

3 The Analogue Fuzzy System

The neural cells described above are involved into a large scale fuzzy system. This fuzzy system consists of all types of neural cells, the afferent neural cell, and the moto-neuron, and the interim neural cell, similarly to the organic nervous system [2] [4] [5].

3.1 FIS with Network of Reflex Courses

The fuzzy system composed of analogue circuits consists of circuits of reflex courses. The structure of that FIS is shown in Figure 4. The fuzzifier does not make computation to get fuzzy values, but it produces neural output signals, the

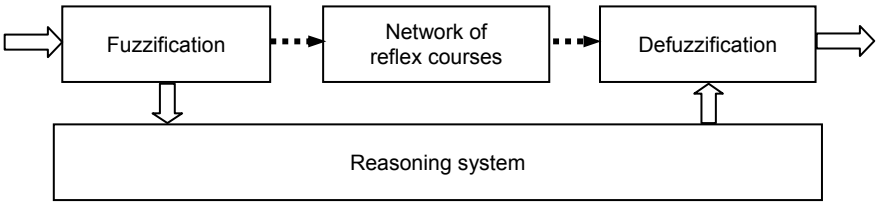

Figure 4
The scheme of fuzzy inference system with reflex courses

membrane potentials which are answers to stimuli. The fuzzy reasoning system is made by network of interim neural cells where the rules are set by the synaptic networks. All controlled functions require individual fuzzy reasoning network having the appropriate rules. Defuzzifier will not decide crisp values, it function is making activative moto-neurons which have to be running.

The network for operating by Thom's catastrophe theory is completed with an additional unit which is not owned by fuzzy systems: a by-pass network of reflex courses. This by-pass network is active when the stimuli are out of normal range. Then the output voltage occurred by the network of reflex courses will be connected to the proper output device. In this case, the reasoning system will be shortcut by the reflex courses because fuzzy rules are invalid in operation. Then the controlled process will be constrained by the by-pass network to set the parameters of controlled process into the range of structurally stable operation [5].

3.2 Catastrophe FIS Composed of Analogue Circuits

The analogue catastrophe fuzzy inference system having physiological structure similar to the organic nervous system is a fuzzy inference system without fuzzifier and defuzzifier but with reasoning system having by-pass network the reflex course. Fuzzifier and defuzzifier are unnecessary ones because the nervous system built of analogue circuits operates like the organic system. Decision making is running over two tracks, the reasoning system built of interim neurons connected to afferent neurons and moto-neurons being parts of reflex courses, and the reflex courses which consist of afferent neurons, interim neurons and moto-neurons shown in Figure 5. The reasoning system has the same structure like the catastrophe fuzzy inference system shown in Figure 4.

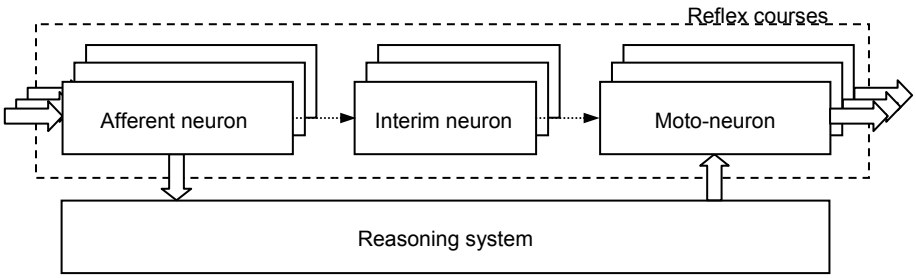

Figure 5
The scheme of analogue catastrophe fuzzy inference system

Conclusion

Analogue circuits applied for real-time operation give new opportunity for controlling extremely high speed or extremely low speed processes:

- the analogue neural network consists of three basic types of analogue neural cells: the afferent neural cell, the interim neural cell and the moto-neuron, which cells has similar architecture but different operations,

- the intelligence of analogue neural network is implemented by hardware synaptic connections, and this connections transfer the membrane potentials from one a neural cell to other neural cells,
- operation of analogue neurons in fuzzy neural networks is described with mathematical objects by Chomsky's rule, the formal description of regular languages,
- the catastrophe FIS includes the network of the *reflex course*s which are the circuit realization of Thom's theory.

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