IMPULSE CIRCUITS FOR A DISTRIBUTED CONTROL INSPIRED BY THE NEUROANATOMICAL STRUCTURE OF A CEREBELLUM

SHINJI KARASAWA
Miyagi National College of Technology: Natori-shi, Miyagi, Japan 981-1239

JUN-ICHI OOMORI
NEC IC Microcomputer Systems Ltd. Kosugi, Nakahara, Kawasaki, Japan 211-0063

ABSTRACT

This paper describes the intelligent hardware consists of those decision-making circuits (DMC) which function with propagating impulses. The output of DMC stimulates the input of following DMC. The functioning of prepositional DMC coincides with the connecting to the postpositional DMC. A cognitive DMC for the module of impulses on an array of DMC generates an impulse at the data matching. A loop of DMC is able to hold the impulse. A propagating impulse is able to generate serial impulses by means of the circuit inspired by the neuro-anatomical structure of a cerebellum. Such dynamic impulse signal processing may emulate the mechanical principles of the brain mechanisms.

INTRODUCTION

Hebb, D.O., (1949) suggested that a short-term memory was an activation of the neural circuit while the long-term memory kept in the synaptic connections.

Marr, D., (1969) [1] and Albus, J.S., (1971) [2] have proposed functional models for a cerebellar cortex. Although their models could not explain the timing control, those models have explained the function similar to a perceptron.

The computational models for artificial neural networks such as Rumelhart's back propagation method, Hopfield's neural network and Boltzmann machine have provided the programs those have been utilized in the cognitive system. [3], [4]

Although these computing technologies are developed, there are still problems to be solved in the field of machine understanding, such as the interpretations on an affair in the real world. The acquisition of an intelligent behavior on an animal depends on trial and error. It is extensible by the experiences and does not depend on the calculation. The language use and most of our intelligence is acquired by the experiences. The intelligence of a life is inseparable from the body owing to the dependencies of its hardware.

Brooks, R., 1986 [5] proposed "Subsumption architecture" for the behavior control of a robot. "Behavior-Based Artificial Intelligence (AI)" and "Knowledge growth in an artificial animal" [6] have emerged in the field of robotics in 1990's. These building of intelligent systems have been based on the digital technology.

The model proposing in this paper is functioned with propagating impulses. The system is composed of those impulse decision-making circuits (DMC) that assign the next state from the present state. Each DMC functions when the present state satisfies the preconditions of the DMC. This system can be considered as the state machine in which the outputs of the current step are used as a part of inputs for the next step.

The presenting DMC system possesses the circuit-forming capacity that is achieved by the transference from the output of impulse to the connection. The asynchronous timing control of the impulse system is adjusted automatically at the implementation. This machine is learnable from its experiences. The foundations for such non-computational hardware artificial intelligence are discussed in this paper.

HEURISTIC IMPLEMENTATION OF DECISION-MAKING CIRCUITS

Fig.1 shows the model of intelligence inspired by a nerve system of an animal. Here, each neuron operates an individual function. Each operation can be described by a preposition of "If then rule". The biochemical reaction of a neuron could not continue the same action. So, a unit of the action forms an impulse. The operation of this system accompanies with the propagation of the impulses. The pattern of impulses represents the present state. The functioning points may coincide with the connecting points of DMC. It makes possible to implement the DMC autonomously.

The development of this DMC system is achieved by the additional implementation of DMC without changing the established structure. This extensible system becomes complex according to the developments towards more sophisticated behaviors.

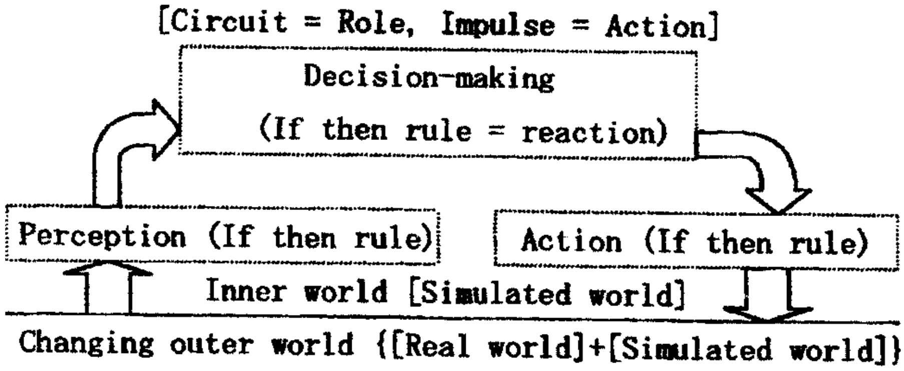
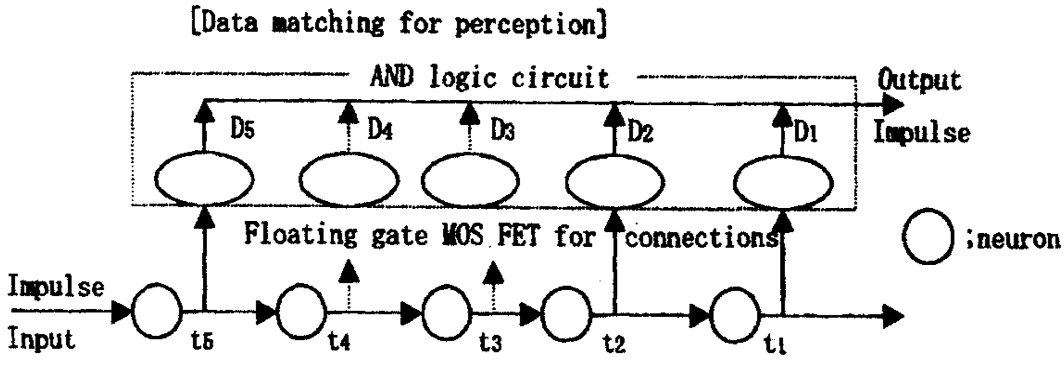


Fig.1 A model of Decision-Making Circuits (DMC) for a living creature

As a result of a trial manufacturing, we found that the DMC system of an intelligent robot looks like a neural structure of a brain. [7] So the author proposed the decoder-for-neuron translation model in which the decoder is the representative of a neuron. [8],[9],[10] This method was applied to neuroanatomical structures in a brain and the attempts were effective to obtain the functional models.

The following impulse circuits may emulate the learning mechanism of a brain.



A Charge Coupled Device (CCD) is used for the transmission of serial impulses. The references are memorized into floating gates in MOS FET at the end of segmentation.

Fig.2 A matched filter without segmentation for transmitting serial impulses

Fig.2 shows the data matching circuit on a transmitting series of impulses. One set of serial impulses for a reference is memorized at once at the end of segment. The circuit generates an impulse at the moment of data matching. Although this circuit is simple, it is able to discriminate the series of propagating impulses without segmentations.

Fig.3 shows a series of delay circuits and the array of AND circuits. This circuit is able to distribute the serial data on the paralleling lines in space.

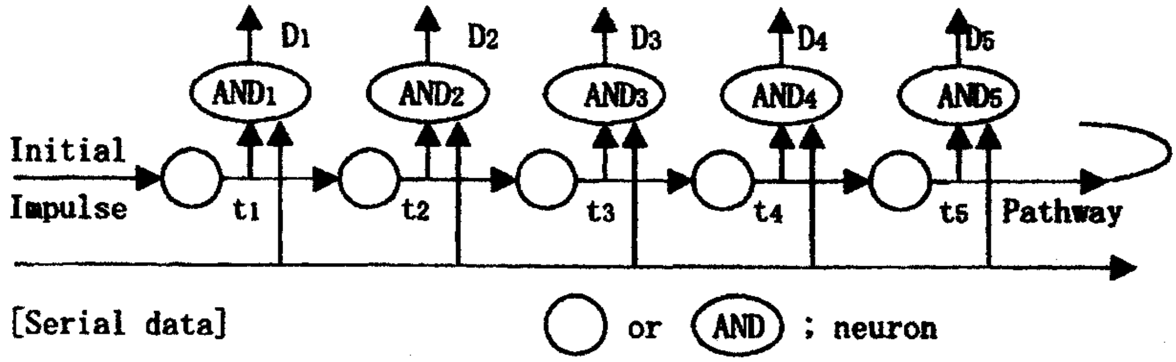


Fig.3 The serial-in/parallel-out converter in an impulse system

A recurrent loop is able to hold an impulse. The rounding impulse in a loop transmits one way owing to the refractory period. It spikes neighboring neurons and the repeat of spiking promotes the synaptic connection i.e. the closer connection becomes the closer. On the other hand, the register in a digital system holds data but this holding state is static.
Since an excitatory impulse (positive potential) cannot suppress the excitatory activity, the inhibitory impulse (negative potential) is needed in this system. The rounding impulse in a loop will vanish by adding an inhibitory impulse.

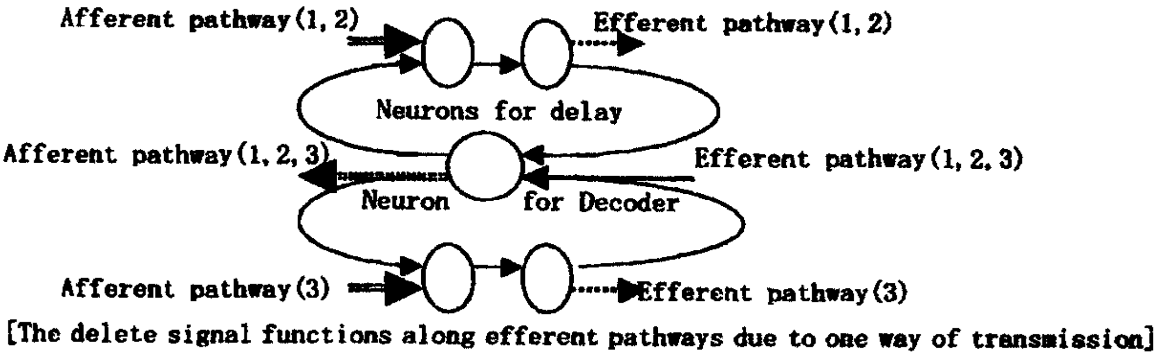


Fig.4 A looped impulse circuit for short-term memory

The looped DMC will be organized by a DMC. The neuron that binds loops functions as a decoder. The organizing DMC is shown in the center of Fig.4. The self-organized connections will form a feature of tree. Each branch of the structure has the individual meaning that depends on the connections. The meaning of impulse is only a functioning. Then, the intelligent system needs and possesses a great number of pathways.
Another way to get a short-term memory is achieved by increasing of the number of impulses and it is realized by putting together the outputs on a line of delay elements. By using serially arranged DMC as shown in Fig.3, the data on the distributed lines with different delay time can be manipulated by a combinational logic circuit.

IMPULSE SIGNAL PROCESSING IN A CEREBELLUM

Since the neural structure on a cerebellum is investigated precisely, the proposing impulse circuits and the mechanical principles can be inspected by the neuroanatomical structure of a cerebellum. The explanations on the function of each neuron in a cerebellum are given in this section from the viewpoint of impulse signal processing in order to give the foundations of the impulse circuits.

[The OR logic operation by an inhibitory neuron]

Purkinje cell is the conspicuous neuron in a cerebellum. [11] The Purkinje cell has numerous dendrites. The cell is derived by many synaptic excitations of parallel fibers and a mossy fiber and it is also derived by synaptic inhibitions of stellate cells and a basket cell. The synaptic integration due to the physical potential in the neuron is linear. But the functioning of a neuron is threshold logic on the physical potential and the neuron initiates a non-linear biochemical reaction i.e. the generation of an impulse. [12]

In generally, the reaction of an excitatory neuron is the action potential that is observed by driving a membrane toward positive potential. This action potential accompanies with the negative potential for surroundings.

The reaction of hyperpolarization in an inhibitory neuron is observed by holding the potential of membrane below threshold. The negative potential activates the ionized chloride (Cl-) channels permeable. The equilibrium potential of the Cl- in a neuron is a little lower than the negative resting potential.

The output of Purkinje cell is an inhibitory fiber. The inhibitory neuron will generate an inhibitory impulse at the absence of excitatory impulse. So, we can consider that [excitatory OR] logic is achieved in case of the adding of inhibitory impulse suppresses the generation of excitatory impulses, where the excitatory impulses are generated at the absence of inhibitory impulse. The connections for [OR] logic are needed in order to control the motor neuron. The inhibitory neuron in a cerebellum such as Purkinje cell, stellate cell and basket cell may function as the promoter for a module of serial impulses.

By the way, [AND] logic among the constituents is considered as the highest threshold values on the data matching. Then, there is the possibility that [OR] operation is realized by lowering the threshold. But, [OR] circuit realized by the lowering method will become very sensitive in case of thousands of inputs and it is not available for the practical use.

[The impulse signal processes in a cerebellum]

There are a great many granule cells in a cerebellum. The axon of granule cell, that is the parallel fiber, makes synaptic connection with dendrites of Purkinje cell. The impulse, which is sent from a mossy fiber, propagates in the granular layer and it makes a route. Here, the mossy fiber receives the signal from a ganglion or a cerebrum.

On the other hand, a climbing fiber coils around the cell body of a Purkinje cell. The climbing fiber arises in an inferior olive or a dorsal funicular nucleus. This climbing fiver receives the signal from the muscle by way of spinal cord.

It is considered that the climbing fiber informs firing data from muscles, because the serial excitations by a climbing fiber and transmitting excitations by granule cells make synaptic connections with dendrites of the Purkinje cell. The time interval in a sequence of impulses is set by the granule cells those axons do not connect with the dendrites. After that, the propagation of a commanding impulse along the pathway of granule cells accompanies with the generation of serial impulses to the Purkinje cell.

The imitating operation of the cerebellum is the music box that memorizes serial data in a line of pins on the drum. The pins fillip a vibrator during rolling of the durum. Since the transmission of an impulse along a pathway of granule cell makes a series of impulses for serial control of a muscle, the pathway for a propagating impulse corresponds to the line for pins and the synaptic connections correspond to the pins.

Fig.5 shows an impulse generator for a serial control. Here, each synaptic connection is formed at the propagating step of the commanding impulse while the impulse come via climbing fiber assigns the point of the connection. This impulse circuit is inspired the neuroanatomical structure of a cerebellum.

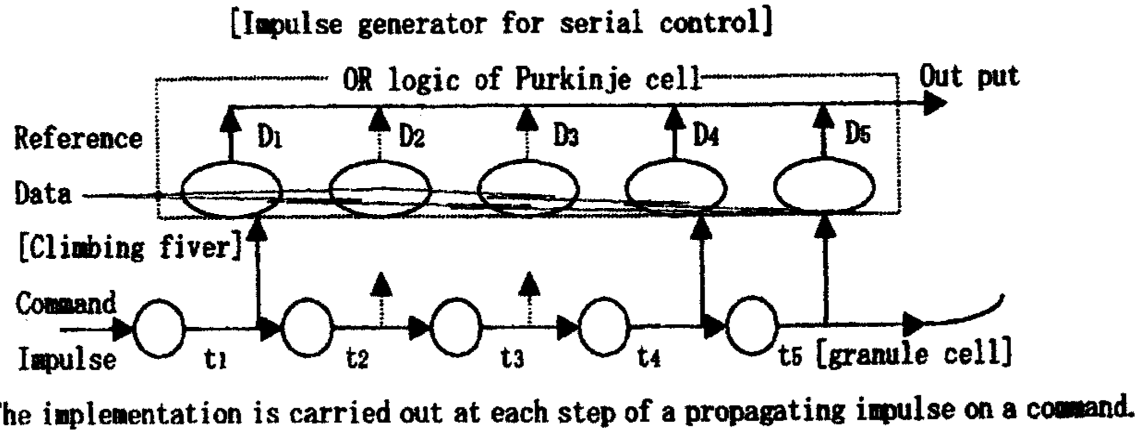


Fig.5 Automatic implementation of impulse circuit for serial control of output

DISCUSSIONS

[Self-Organization of a central nervous system]

The central nervous system has the ganglion in which each neuron makes decision according to the impulses from gathered neurons. Although the summit of neurons makes decision and it connects between afferent pathways and an efferent pathway, the summit of DMC will change the role as a junction when a new DMC extends the pathway.

The number of DMC is increased according to the developments. There will be overlapped DMC with different pattern of inputs but the same output. The connections yield the categorization. The relevant DMC are implemented near by in space. It will form a domain. The heuristic implementation of DMC for a serial behavior has locality in time domain. The temporal locality is also memorized in the locality of a space domain. Some of the domains will form a clustering.

The preconditions of DMC will increase according to the developments. There will be overlapping excitations of DMC with different sizes of inputs where the DMC of the common concept possesses less limitation and the widely covered DMC has large number of conditions. The concurrent excitation of localized DMC makes possible to produce the organizing DMC which provides a logical relationship in the system. The additionally linked network of organizing DMC may yield the logical connections and the grammar in the linguistic domain.

Although the neural system is organized by the bottom-up approach, the design for a manufacturing of the layered structure of DMC system will be done by a top down approach such as a structured design methodology in VLSI. [13]

[Applications]

There are two kinds of segmentations in the software cognitive system. One is the segmentation due to the signal processing and the other is the segmentation of the input. The latter is recognized as a result of recognition. The facts make difficulties in the software cognitive system. The hardware cognitive system will solve the difficulties, for the paralleling circuits are able to operate concurrently. The paralleling operations of the data matching do not need the segmentation of the signal processing. This proposing impulse system is available for the interface between a computer and the real world.

The functioning of each circuit in a digital system is synchronous but that in an impulse system is asynchronous. The asynchronous timing of the impulse circuits is adjusted at the implementation. The technology on the asynchronous operation is not yet established. We can manufacture the impulse signal processing system by using established technologies of synchronous digital circuits at this stage.

The proposing autonomous implementation of intelligence has the advantage in the field of the interface that deals with a great number of data on the things and affaires in the real world. The serial impulse generator inspired by the neuroanatomical structure of a cerebellum shown in Fig.5 can be used in the distributed adaptive serial control such as a phonetic synthesizer.

We have manufactured some impulse circuits consist of transistors. But the realistic device will be realized in the form of VLSI, for today's VLSI technology is able to manufacture the proposing device. Moreover, the transmitting impulse in a charge-coupled device (CCD) can be transferred into the charge on a floating gate in a floating gate MOS FET. This mechanism will be available for the automatic implementation.

CONCLUSIONS

The state machine, which comprised of many DMC where DMC are operated with the propagation of impulses, is proposed for a model of the brain mechanism. Each DMC discriminates the present state and assigns the next state accompanying with the propagation of impulses. The implementation of DMC is carried out by the connections assigned by the functioning points. The matched-filtering circuit for the propagating impulses is able to discriminate the serial impulses without segmentation. The rounding activity of an impulse in a looped circuit may function as a working memory. The module of loops can be bound by the DMC that functions as a decoder for the constituents. Moreover the impulse propagating along a stepped pathway is able to generate a series of impulse. These impulse circuits make possible to explain serial aspects of the brain mechanism.

Generally speaking, the bases of intelligence are declarative i.e. DMC. The functions should be implemented in the form of impulse DMC, for the impulse DMC system is able to function without the segmentation on processing. The proposing impulse circuits are available for the implementation of the primitive intelligence. The field of interface on the digital computer longs it. The presenting impulse signal processing will be available as the parts of architecture on the extensible intelligent VLSI.

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