A Novel Neural Network Model
Upon Biological and Electrical Perceptions

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Abstract: - Modeling of a neural network (NN) is presented. This study is targeted to compose a highly capable processor.

Proposed model is based on knowledge of biological and artificial NN developed until nowadays.

An advantage of the proposed model is forward and reverses couplings with positive and negative signs for synaptic coupling of neurons. Neurons are connected mutually and allocated multiple accesses, total large numbers of neurons are included in the NN is the second advantage. The other point is that operation of NN is done with timing is synchronously. The size of NN is far large than ever proposed.

The proposed model is applied for the analysis of time-space data analysis. This scheme was found sufficiently useful to solve the problem which was impossible to be solved.

Key-Words: - synaptic coupling, membrane discharge, equivalent circuit, excitation, recurrent

1 Introduction
Existence of nerves in brain is now popular which motivated psychologist, physicist, and mathematician to know in detail of nerve and NNs.

In the area of artificial neuron, binary code model was presented by McCulloch, and Little in 1943 and 1974.

Strength of synaptic coupling was predicted as origin of memory and learning by D.O. Hebb in 1949.

Single- and multi-layered perceptrons were presented in 1962 and 1989.

Single layer perceptron, multi layer perceptron, Hopfield model, and Kohnen model are provided with much attention. Single layer perceptron was proved essentially impossible to mathematical issues. The later was presented with much interesting but not so today because of less theory to connect their layers.

Symmetrical spin model was provided by J.J. Hopfield in 1982, which was applied successful to solve traveling salesman problem (TSP). This scheme was found successful to matched conditions for the case less than 30 cities, but it was not converged at about 100 cities.

Processing of time-space data is described with novel NN configuration.
2 Nerves and Neurons
2.1 Biological Nerves
A giant axon of nerve was observed by J. Z. Young (biological symposium at Long Island in 1936.) Electric behaviors were then investigated by A. L. Hodgkin et al (journal for general physiology of science since 1939.)

(i) Nerve
A nerve is composed of dendrites, soma, axon with terminals. Electric current into a dendrite is carried into a soma through dendrite.

Multiple input currents are added at numerous dendrites, and output is sent to post-neurons through axon with axon terminals.

(ii) Dendrite, axon & synapse
A nerve is a processor with accumulation (summation), discharging (excitation) and remote transmission. These functions are very similar to MOS transistors with multiple inputs and multiple or a few outputs.

Synapse plays an important role of transmission of input and output currents through multiple numbers of dendrites and axon terminals.

Synaptic coupling is done with a pre-synapse (axon terminal) and a post-synapse (dendrite or soma). Synaptic coupling is done much chemically and rarely with direct electrically.

(iii) Membrane and hillock
Membrane covering soma plays an important role of changing to itself by pull-in sodium ion, and pull-out potassium ion to develop impulse signal trains and then discharging of electric high potential impulses. The voltage of a neuron exceeds threshold potential, high potential impulses are discharged and transmitted to post neurons.

2.2 Artificial Neurons
The NN of perceptrons by Rosenblatt and Rumelhart are attributed by parallel of serial coupling of neurons which guides impulse signals to one direction. This model is assumed to provide limited capability of processing because without recurrent coupling.

The NN by Hopfield is attributed by symmetrical configuration of parallel; anti-parallel spins, synaptic couplings \( W_{ij} \), \( W_{ji} \), binary code statistically defined, and asynchronous operation. Hopfield model was applied successfully to solve TSP under limited conditions. Convergence is successful for 30 cities at not for 100 cities.

3 Modeling of Artificial Neural Network
A NN is composed of much of neurons packed in 3-D space. Impulsive electric signal is transmitted among neurons which are connected mutually. This system is perceived as a multiple dimensional hyper plane operated by time sequence signals, which is a time-space system.

Modeling of a NN is based on useful and effective knowledge observed by biological and electrical studies written above.

3.1 Modeling of a Neuron
Permittivity of synaptic coupling depends on membrane potential. Deep modification of coupling strength and long time delay of impulse transmission are specific features. Synaptic coupling is done with chemical compound or direct connection of dendrite to soma. These characteristics are exhibited by time constant of parallel C-R circuit with variable resistance R and condenser C.

\[
\text{Synaptic permittivity (arbitrary unit)}
\]

\[
\text{Threshold}
\]

\[
\text{Membrane potential}
\]

\[
\text{resting excitation}
\]

\[
0.5
\]

\[
1
\]

When membrane potential of soma is increased and exceeds threshold, sodium ion flows inside and potassium ion flows outside through ion channel of neuron, and membrane potential is rapidly increased to be impulse waveform.

Accumulated charge through input synapses from adjacent neurons is discharged at hillock as impulse trains at hillock when membrane potential exceeds threshold value. Impulse waveform is steady independent to potential and current. Discharging is triggered by voltage of membrane.

Value of permittivity synapse depends on membrane potential as shown in Fig.1.

Discharging impulse is transmitted from hillock to end of axon. This channel is seemed as a low-loss electric channel covered by glia-cell. This effect is expressed by a low-pass filter with cascaded inductance and capacity.

Pre-synapse is input coupling of a neuron made of axon terminal of pre-neuron, and dendrite of a
neuron. Post-synapse is output coupling of a neuron composed of axon terminal and dendrite of post-neuron.

In actual neuron, synaptic coupling is done from axon terminal toward dendrite at input point of a neuron, and from post-axon terminal to dendrite of post-neuron. Actual organs of pre- and post- synapses are composed of dendrite and axon terminal, or axon terminal directly to membrane of post neuron. Transmission of electric charge is unidirectional and only $W_{ij}$ has value and $W_{ji} = 0$.

Equivalent electric circuit of a neuron is shown in Fig.2.

3.2 Modeling of a Neural Network

Actual biological NN is a system composed of large number of neurons accumulated in 3-D space. System size is known as $10^2 \sim 10^5$ or more.

Reflecting above knowledge, a mathematical modeling is made of a hyperspace with multiple orthogonal axes.

(i) Summation operation

Potential and current of membrane of a neuron are assumed as $V_i$, $I_i$, and $I_i$ is induced by current through synapses connecting to other neurons. Modeling of a neuron is written by current equation as follows.

In this study, all of neurons are connected mutually with each other.

$$I_i = \sum_j W_{ij} V_j - U_i,$$

$$W_{ij} \neq W_{ji}, \quad (1)$$

$$W_{ii} = W_{ij} = 0,$$

where, $I_i$: input current of i-th neuron (A),

$V_j$: output voltage of j-th neuron (V),

$W_{ij}$: permittivity of j-th to i-th neuron (S),

$U_i$: threshold of i-th neuron (A). Attribution of $W_{ij}$ in equation (1) is an important point of concept of this study.

Threshold for discharge of an actual neuron is defined by potential not by current but. Permittivity $W$ is defined by sodium and potassium current depending on the potential of membrane.

$W_{ij}$ is permittivity of input- or output- couplings of pre- and post- neurons through synapses depending on membrane potential and are essentially non-linear. Unit of $W_{ij}$ is permittivity [S/m] or inverse of coupling resistance [Ohm, Ω].

(ii) Discharge (excitation)

Hillock is essentially expressed by parallel circuit of condenser of membrane, sodium and potassium resistances of ionic current, and a switch of discharging.

Piecewise linear approximation is used together with sigmoid function for mathematical analysis.

(iii) Directivity of coupling

In this study, $W_{ij}$ has also value of recurrent or recurrent connection from j-th neuron to i-th neuron. This modeling is not confirmed by anatomical study of neurons, but this is assumed that recurrent coupling is done by neuron itself or a circuit. It is essentially regained for generation of an impulse train for firing.
4 Applications to Location Estimation

An example of application is shown in Fig. 3. At each sensor, impulse signals are received from acoustic emission sources generated at arbitrary times. Locations of multiple sources are distributed in arbitrary position in a space. This study is to find each location without depending on generation time of each impulse signals.

Totally four sensors are used for a system described in Chap.4. NN is composed of a 4-D hyperspace with 4 orthogonal axes.

This theme is induced into solving following equation whose solutions are given by the operation of convergence.

\[ E = AF_1 + \frac{1}{2} BF_2 + \frac{1}{2} CF_3, \quad --- (2) \]

F1: Normalized Error of observed and estimated impulse arrival times [no dimension],
F2: Degree of super-positions of wave-fronts from source locations [no dimension],
F3: Difference of calculated and assumed number of effective solutions [no dimension].

A NN is composed to solve equation (2).

\[ E = -\sum_{i,j} W_{ij} \cdot V_i \cdot V_j / 2 + \sum_i U_i \cdot V_i \quad --- (3) \]

\( V_i \): output voltage of i-th neuron [V],
\( U_i \): threshold current of i-th neuron [A],
\( W_{ij} \): conductance of i-th to j-th neuron [S].

A physical problem to find locations for time-space sequence data is expressed as a mathematical problem to solve equation (2), which corresponds to convergence problem of electric energy written by equation (3).

The following is obtained from equation (2).

\[ E = \left[ \frac{\delta}{2} \right] \left( \frac{\delta_{xp} \delta_{pq} \delta_{xz} \delta_{wy}}{2} + \frac{\delta_{xp} \delta_{qw} \delta_{xz} \delta_{wy}}{2} + \frac{\delta_{xp} \delta_{pq} \delta_{zw} \delta_{wy}}{2} + \frac{\delta_{xp} \delta_{qw} \delta_{zw} \delta_{wy}}{2} \right) + \frac{1}{2} V_{xyzw} \cdot V_{xyzw} \]

\[ + \left( AD_{xyzw} - CN_0 \right) V_{xyzw}. \quad --- (4) \]

The following is then obtained by the relation of equation (3) and (4).

\[ W_{xyzw, pqrs} = -\frac{\delta}{2} \left( \frac{\delta_{xp} \delta_{pq} \delta_{xz} \delta_{wy}}{2} + \frac{\delta_{xp} \delta_{qw} \delta_{xz} \delta_{wy}}{2} + \frac{\delta_{xp} \delta_{pq} \delta_{zw} \delta_{wy}}{2} + \frac{\delta_{xp} \delta_{qw} \delta_{zw} \delta_{wy}}{2} \right) - \frac{x}{x}, \quad --- (5) \]

\[ U_{xyzw} = AD_{xyzw} - CN_0. \quad --- (6) \]

The solutions of analysis by a novel configuration of NN are shown in Fig. 3 as an example. It is sufficiently shown that newly proposed scheme and NN modeling are twice useful and effective to solve problems which are impossible to express by mathematical equation for software for Neumann computers.

Mathematical treatment and process of convergence are referred by accompanied paper[7].

5 Conclusions

A first model was proposed based on novel concept of synapse coupling to compose a NN. Forward and reverse coupling of neurons are used with different values of coupling. Operation of NN was done with timing synchronously.

Newly composed NN could be converged being found with large size of neurons as compared to conventional examples.

Advanced modeling is now under study.
References:


