July - August 2020
ISSN: 0193-4120 Page No. 5641 - 5649

Dynamic Characteristics of Biological Neural Network Based on Discontinuous Excitation Function

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Abstract

The neural network based on the theory of biological neural network has a wide range of applications, but the difference between artificial neural network and biological neural network is that it is difficult to accurately describe the dynamic behaviour of neurons, and functional equations need to be introduced. Based on this, this paper first studies the corresponding operation mechanism of biological neuron and artificial neural network, and then analyses the function and type of discontinuous excitation function of neural network and the properties of excitation function. Finally, the global dissipativity, finite time stabilization and Mittag-Leffler synchronization of neural networks based on discontinuous excitation functions are presented, which broaden the application range of discontinuous excitation functions in the field of neural network dynamics.

Keywords: *Biological Neural Network, Discontinuous Excitation Function, Dynamic Characteristics ;*

1. Introduction

With the continuous development of bionics, human beings have a deeper understanding of biological neural network, and gradually apply it to other fields. The construction of artificial neural network is based on the research of biological neurons and constantly achieve breakthroughs. Generally speaking, the biological neural network system has several characteristics as shown in Figure 1, which makes the artificial neural network based on the theory of biological neural network have a wide application basis. For example, it has good applicability and intelligence in many fields such as biology, medicine and social economy.

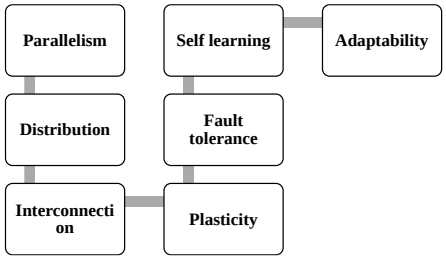

Figure1. The characteristics of biological neural network system.

In the biological neural network, the excitation of the cell body is realized through the synaptic junction. That is to say, these junctions will transmit the signal to the cell body after receiving the biological signal, so that the amount of information will be accumulated continuously, and the cell body can be excited when it exceeds a certain degree[1]. The difference between artificial neural network and biological neural network is that it is difficult to accurately describe the dynamic behavior of neurons. Therefore, differential equation is helpful to solve this problem. However, due to its own limitations, it is difficult to describe the whole characteristics of biological neurons, such as memory characteristics and historical data.

As an important part of the field of calculus, fractional calculus has several typical characteristics as shown in Figure 2. It can describe the actual system of biological neurons more completely, so it can solve the problem of incomplete description of neurons. Thanks to the above characteristics and advantages of fractional calculus, it has been widely used in the theoretical research fields of elasticity,

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July - August 2020
ISSN: 0193-4120 Page No. 5641 - 5649

circulation and biology, as well as the engineering practice fields such as electromagnetism, climate, geology and medicine.

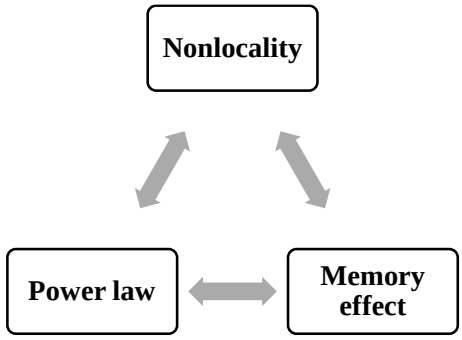

Figure 2. The typical characteristics of fractional calculus.

In addition, compared with the traditional integer order derivative, fractional calculus has the advantages shown in Table 1 below, so it has significant application advantages in the field of artificial neurons. The first mock exam of biological neurons is stimulated by the transformation of the input function of the transformation function, and the output of neurons is generated. The active level of biological neural network often contains several different states, and the transition between these different states is discontinuous in most cases, which requires the research of fractional order neural network to include discontinuous excitation function, so as to realize the simulation of biological neuron signal output and information transmission between neurons.

Table 1. The advantages of fractional calculus.

Aspects	Advantages
Overall	Historical information that can describe the development of system functions
Matching	Better matching between integer order model and experimental data
Power law	The scale of individuals in the system varies greatly
Adaptability	Widely used in theoretical research and engineering practice
Genetic	Memory describing complex substances and processes

Biological neurons have the function of association and memory. The storage and memory samples of artificial biological network play an important role in the simulation of its dynamic characteristics. With the continuous iteration and development of artificial intelligence technology, the development of artificial neural network theory and its application in many fields has become one of the future development directions of artificial intelligence, and plays an important role in improving intelligent technology. Therefore, it is of great theoretical and practical value to study the dynamic characteristics of biological neural networks based on discontinuous functions.

2. Biological neuron and artificial neural network

2.1. Working mechanism of biological neurons

he information transmission and processing of biological neurons is an electrochemical activity. Dendrites receive external stimuli due to electrochemical effects. The process of summation of excitatory or inhibitory input signals from different dendrites by biological neurons is called integration. When the membrane potential generated by the spatiotemporal integration of biological neurons exceeds the threshold potential, the neurons are in an excited state and produce excitatory electrical pulses, which are output through axons; otherwise, no electrical pulses are generated and they are in the inhibition state. The connection strength between biological neurons can be changed by external stimulation, which constitutes the basis of learning function. The basic composition of biological neuron model is shown in Figure 3.

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July - August 2020
ISSN: 0193-4120 Page No. 5641 - 5649

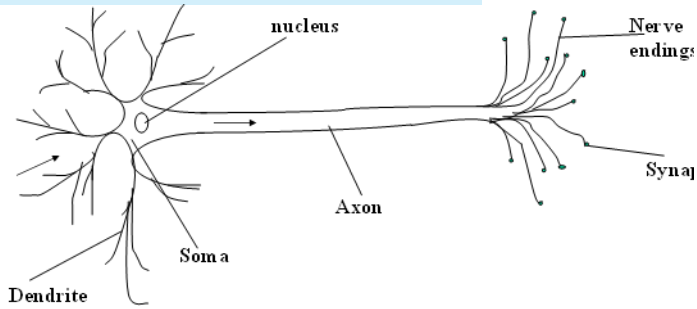

Figure3.he basic composition of biological neuron model.

2.1.1. Basic characteristics of biological neurons

Biological neurons have the following typical characteristics. Firstly, biological neurons are connected to each other, and the strength of the connection between them has an important impact on the quality of their signal transmission. Secondly, the connection strength between biological neurons can be changed, which can be realized by learning and training. In addition, the strength of the connections between the neurons in the biological neural network will change adaptively with the external excitation signal. External signals can stimulate or inhibit biological neurons. Biological neurons have specific thresholds, and the cumulative effect of received signals will play a decisive role in the state of neurons.

The synapses of biological neurons have the following characteristics. Firstly, the postsynaptic membrane potential of excitatory synapses of biological neurons increases with the increase of the binding number of neurotransmitters and receptors. However, the postsynaptic membrane potential of inhibitory synapses of biological neurons decreased with the increase of the binding number of neurotransmitters and receptors. Secondly, biological neurons also have spatiotemporal integration, including spatial accumulation of excitatory and inhibitory signals from different dendrites, and temporal accumulation caused by the persistence of input signals on the membrane potential of neurons.

2.1.2. Intelligent path of robot group control intelligent manufacturing

The information processing of biological neural network has the following characteristics as shown in Table 2, that is, distributed storage and fault tolerance, parallelism, hierarchy and systematicness, integration of information processing and storage, self-learning and self-organization, etc. these characteristics make the biological neural network gradually complete the processing and processing of information.

Table 2. Characteristics of the information processing of biological neural network.

Characteristics	Typical performance
Fault tolerance	Local or partial errors in neurons do not affect the global results
Parallelism	Neurons perform large-scale parallel processing at the same time
Information processing & storage	Neurons have both processing and storage functions
Self-learning & self-organization	The neurons learn and organize themselves
Systematicness and hierarchy	Information processing is hierarchical processing

2.2. Artificial neural network and artificial neuron

Artificial neural network (ANN) is a computational model that abstracts, simplifies and simulates the biological structure of the brain. It is a widely parallel and interconnected network composed of adaptive simple units. Its organization can simulate the interaction of biological neural system to real world objects. The components of artificial neural network are shown in Figure 4.

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July - August 2020
ISSN: 0193-4120 Page No. 5641 - 5649

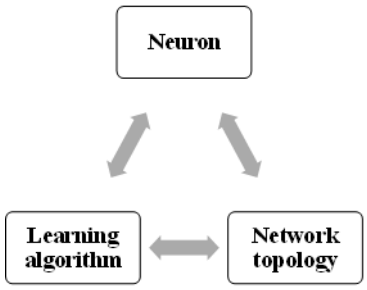

Figure 4. The key components of artificial neural network.

2.3. Abstraction and Simulation of biological neurons

For the excitation function, there is the structure as shown in figure 5 below. If the neuron is in the active state, the excitation function output is 1; if the neuron is in the inhibition state, the excitation function output is 0.The excitation function of artificial neuron is as shown in following formula 1.

$$y = f(A) = f(\sum w_i x_i - \theta) \quad (1)$$

The connection weight between u_j and u_i is w_{ij} ,when $w_{ij} > 0$, it is called positive connection, which indicates that u_j can activate u_i, when $w_{ij} < 0$ is called negative connection, which indicates that u_j has inhibitory effect onu_2[2].

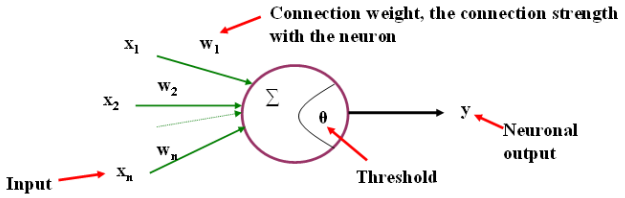

Figure 5. Abstraction and Simulation of biological neurons.

2.4. The working process of neurons

The input signal x_i is received from each input. According to the connection weights w_i , the weighted sum of all inputs$A$ is calculated:

$$A = \sum_{i=1}^{n} w_i x_i - \theta \quad (2)$$

The output Y is obtained by transforming a certain excitation function f:

$$y = f(A) = f(\sum_{i=1}^{n} w_i x_i - \theta) \quad (3)$$

The working process of the artificial neuron is shown in Figure 6 below.

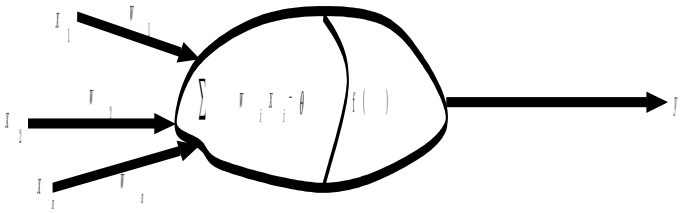

Figure 6. The working process of the artificial neuron.

2.5. Topological structure of neural networks

The neural network is composed of several neurons connected according to a certain topological structure, which is generally divided into forward network and feedback network. Among them, the forward network only has the connection mode from each neuron in the upper layer to all the neurons in the next layer. The network is composed of several layers of neurons, including input layer, intermediate layer and output layer. Each layer is connected in sequence, as shown in Figure 7. The flow direction of information is from the input layer to the middle layer and out of the output layer. The three-layer feedforward neural network can not only approach any function with arbitrary precision, but also approach its derivatives with arbitrary precision.

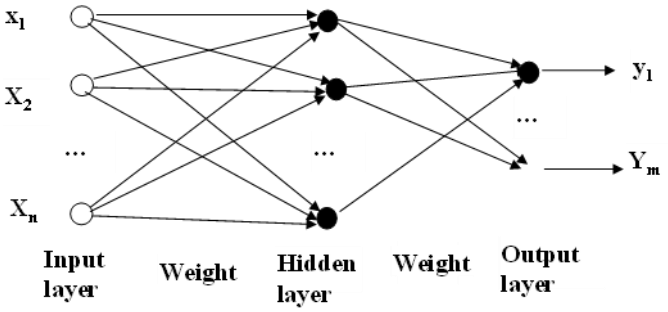

Figure7. Structure of multilayer feedforward artificial neural network.

The feedback network allows the output of a neuron to be fed back to the neurons in the same or previous layer. The feedback network includes

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July - August 2020
ISSN: 0193-4120 Page No. 5641 - 5649

feedback feedforward network, interconnection forward network and extensive interconnection network. The output layer of the feedback forward network has feedback connection to the input layer, the same layer neurons of the interconnection forward network are interconnected, and any two neurons in the network of the wide interconnection network can be connected.

2.5.1. Characteristics of artificial neural network

Artificial neural network is based on the device or computer which can be realized in physics to simulate the structure and function of neural network in biological brain, and it is applied in engineering and other scientific fields. Artificial neural network is not exactly the same copy of the biological neural network simulation, but to take advantage of the part to overcome the current computer or intelligent computing system cannot solve the problem, such as learning, recognition, control and so on. The improvement of the function of artificial neural network depends on the level of physical devices or software system, and the level of understanding of network structure and mechanism in biological brain.

2.5.2. Advantages of artificial neural network

Similar to biological neural network, artificial neural network has the advantages of parallelism, fault tolerance, distributed storage, self-adaptive and self-organizing learning ability. Among them, in terms of parallelism, the artificial neural network is mainly connected by simple units in parallel, and operates collectively under the control of clock, with high processing efficiency. Secondly, in terms of fault tolerance, the local or part of the neural network errors will not affect the global results, and the artificial neural network can automatically correct the errors. In addition, in the aspect of distributed storage, the information of artificial neural network is stored in the connection right of the network, which is decentralized, not in the memory. Moreover, the connection weight and threshold of the artificial neural network can be obtained by learning, and can be self-adaptive and self-organized according to the external environment.

2.5.3. Basic functions of artificial neural network

Artificial neural network has many functions, such as associative memory, nonlinear mapping, classification and recognition, and optimization calculation. At the level of associative memory, artificial neural network has the functions of self-association, other association and incomplete pattern self-association[3]. Secondly, in the nonlinear mapping function level, the nonlinear mapping rules are automatically extracted from the input samples through the neural network to realize the prediction function of the output samples. In addition, at the level of classification and recognition function, the classification and recognition ability of artificial neural network is stronger, and the recognition and classification are more accurate. The comparison with traditional classification and ANN methods is shown in Figure 8.

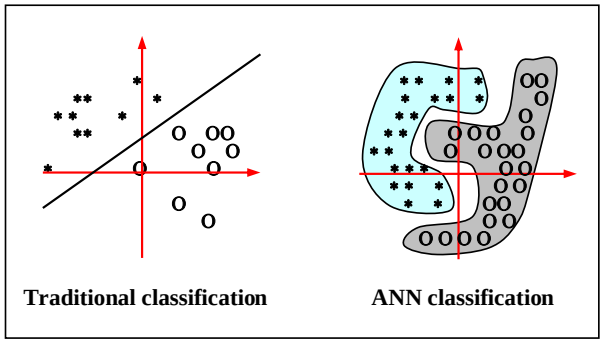

Figure 8. The comparison with traditional classification and ANN methods.

3. Discontinuous excitation function of neural networks

3.1. Discontinuous excitation function of neural networks

The function of neural network excitation function mainly includes controlling the excitation of input to output, the function conversion of input and output, and the transformation of possible infinite field input into the output of specified limited range[4]. The types of neural network excitation function mainly include threshold function, linear function, nonlinear function and S-type function, as shown in Figure 9 below.

Among them, the S-type function has the function of nonlinear amplification coefficient, which can transform the input signal from negative

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July - August 2020
ISSN: 0193-4120 Page No. 5641 - 5649

infinity to positive infinity into output between - 1 and L. for larger input signal, the amplification coefficient is smaller; for smaller input signal, the amplification factor is larger. The S-type excitation function can be used to deal with and approximate the nonlinear input / output relationship, and the original step output curve of nerve cells can be passivated into a smooth curve.

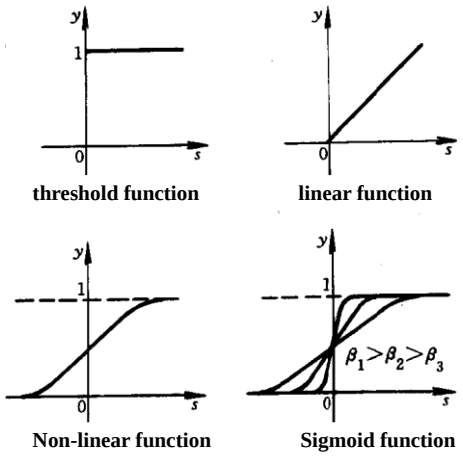

Figure 9. The types of neural network excitation function.

3.2. Properties of excitation function of neural networks

Generally speaking, the excitation function of neural network has the typical characteristics of nonlinearity, differentiability and monotonicity. In terms of nonlinear characteristics, when the excitation function is linear, a two-layer neural network can approximate almost all the functions. However, if the excitation function is an identical excitation function, this property will not be satisfied. Moreover, if the identical excitation function is used, then the whole network is equivalent to the single-layer neural network. Secondly, in the differentiability of the excitation function, it means that the optimization method is based on gradient. In addition, in the monotonicity level, when the excitation function is monotonic, the monolayer network can guarantee to be convex function.

When the excitation function of neural network is about identical excitation function, if the initialization of parameters is a small value of random, then the training of neural network will be very efficient[5]. Otherwise, you need to set the initial value carefully. When the output value of excitation function is limited, the gradient based optimization method will be more stable, because the representation of features is more significantly affected by the limited weight. When the output of excitation function of neural network is infinite, the training of model will be more efficient. In this case, smaller learning rate is needed.The advantages and disadvantages of commonly used neural network excitation functions are shown in Table 3 below.

Table 3. The advantages and disadvantages of commonly used neural network excitation functions.

Function	Advantages	Advantages
Sigmod	In line with the reality	Easy for the gradient to disappear; Power operation is relatively time-consuming.
Thah	In line with the reality	Easy for the gradient to disappear; Power operation is relatively time-consuming.
ReLU	Fast convergence speed	The output is not zero mean; Some neurons may never be activated.
Radial basis	Fast convergence speed	The output is not zero mean; Some neurons may never be activated.
Bipolar Sigma	Fast convergence speed	Easy for the gradient to disappear; Power operation is relatively time-consuming.

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July - August 2020
ISSN: 0193-4120 Page No. 5641 - 5649

At present, the most widely used neural network excitation function is ReLU, which is due to the use of ReLU activation function, which will save a lot of calculation in the whole process. However, the premise of the application of ReLU excitation function is to set the learning rate reasonably and pay attention to the state of neurons in the process of training. It should pay attention to setting the learning rate, which cannot make many dead neurons appear in the process of network training.

4. Dynamic characteristics of neural network based on discontinuous excitation function

4.1. Mittag Leffler synchronization of neural network based on discontinuous excitation function

The discontinuous excitation function benefits from its high gain excitation property, so it is more helpful to solve the constraint problem than the continuous excitation function[6]. The neural network model with global convergence of integer order neural network with discontinuous excitation function is more consistent with the actual dynamic behavior of the system. Therefore, the discontinuous excitation function can better represent a series of practical problems such as convergence to equilibrium point in finite time, so it has better applicability in engineering practice.

The research of neural network system based on discontinuous excitation function mainly involves its application in integer order and fractional order neural network. Among them, the fractional order neural network model based on discontinuous excitation function compared with the integer order neural network model based on discontinuous excitation function can better simulate the neurons of biological neural network system, so it can more accurately describe the actual problems, so it is more often used to describe the dynamic behavior of neural network.

The fractional order neural network system based on discontinuous excitation function is mainly based on non-smooth analysis and control theory. It can obtain more sufficient criterion than mittag Leffler synchronization. On the other hand, the time delay of fractional order neural network based on discontinuous excitation function will change the dynamic behavior of neural network system, resulting in the difficulty of synchronization of neural network system.

4.2. Global dissipativity of neural networks based on discontinuous excitation function

As one of the typical properties of neural network dynamics system, dissipative analysis has important applications in the theoretical and practical fields of several aspects as shown in Figure 10 below, and has achieved fruitful research success in the theory and application field of integer order neural network. Therefore, the dissipative analysis of neural network based on discontinuous excitation function, especially the dissipative property of neural network with time delay and discontinuous excitation function, is of great value for further analysis of dynamic characteristics of neural network.

At the same time, the global dissipative analysis of neural network system with time delay and discontinuous excitation function can obtain faster convergence rate[7]. As an important problem of dynamic characteristics of neural network system, the finite time stability and stabilization of neural network system based on discontinuous excitation function has great research value in engineering application. In addition, the discontinuity of discontinuous excitation function makes it possible to better study the existence of global solutions for integer order and fractional order neural network systems.

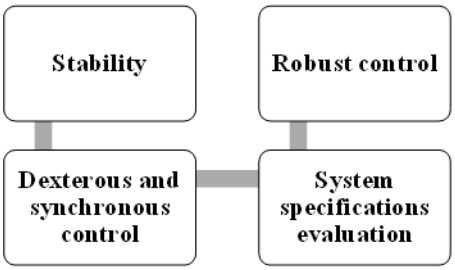

Figure 10. Dissipative analysis applications in the theoretical and practical fields.

4.3. Finite time stabilization of neural networks based on discontinuous excitation function

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The nonlocality and weak singularity of fractional order neural network with discontinuous excitation function can better describe the actual characteristics of the system, and based on its infinite memory characteristics, it can also improve the performance of the system, so it has been widely studied in recent years. Secondly, the neural network system based on discontinuous excitation function can better deal with the nonlinear practical network problem of high slope. In addition, because the system parameters will fluctuate in a specific range and affect the stability of the system, it is of great practical value to study the dynamic behavior of neural networks based on discontinuous excitation function and parameter uncertainty, such as in the field of control theory and system identification.

The introduction of discontinuous excitation function makes the neural network system easy to become a right-hand discontinuous system, which brings a series of problems such as complex nonlinear behavior, failure of classical solutions of differential equations and classical theory. The finite time stabilization of fractional order uncertain neural networks with discontinuous excitation functions is an extension of the right discontinuous neural networks. Therefore, based on FP framework, the right-hand discontinuous neural network system is analyzed, and the existence of global solution of neural network based on discontinuous excitation function is obtained.

The existence of the equilibrium point of neural network based on discontinuous excitation function is obtained from the study of three aspects as shown in Figure 11, and sufficient criteria for finite time stabilization are obtained. The problem of finite time stabilization of fractional order uncertain neural networks based on discontinuous excitation function is mainly to solve the existence of system equilibrium. In addition, based on non-smooth analysis, the finite time stabilization criterion of uncertain neural network based on discontinuous excitation function is constructed, and the upper bound of system residence time is estimated based on the system parameters and control gain of neural network.

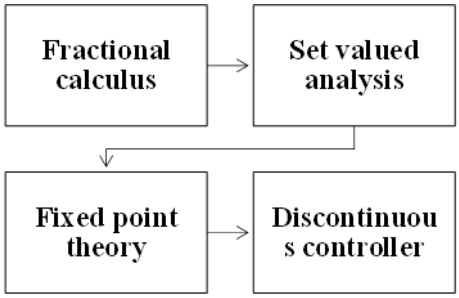

Figure11. Existence of neural network equilibrium point based on discontinuous excitation function.

5. Conclusion

In summary, through the introduction of transformation function, the transformation of network input is carried out to simulate the performance of biological neurons subjected to external stimulation, thus generating neuron output, which is the simulation process of excitation function. In most cases, the transition between different states of biological neural network is discontinuous, which requires the research of fractional order neural network to include discontinuous excitation function, so as to realize the characterization of biological neuron signal output and information transmission between neurons, and solve the problems in theory and engineering practice.

In this paper, through the research on the operation mechanism of biological neuron and artificial neural network, including the basic characteristics of biological neuron, the topological structure and functional characteristics of neural network. The function and type of the discontinuous excitation function of neural network and the properties of the excitation function are analyzed, which lays the foundation for the study of the dynamic characteristics of biological neural network with discontinuous excitation function. Finally, the application and research of global dissipation, finite time stabilization and Mittag-Leffler synchronization of neural network based on discontinuous excitation function are given, which further broaden the application range of

July - August 2020
ISSN: 0193-4120 Page No. 5641 - 5649

discontinuous excitation function in the field of neural network dynamics.

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