A Simulation Environment for Designing and Examining Biological Neural Network Models

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SUMMARY We develop a simulation environment for designing and examining a neural network model at the network level. The aim of our research is to enable researchers investigating neural network connective models to save time by being equipped with a graphical user interface and database of the network models. This environment consists of three parts: (1) the kernel of the simulation system, (2) NNDBMS (Neural Networks DataBase Management System), and (3) a system for displaying simulation results in various ways.

key words: simulation environment, neural networks, connective models, graphical user interface, NNDBMS

1. Introduction

Throwing light on the information processing ability of animals, especially humans, is one of the most difficult problems. In the nervous system, which processes the information, no matter how complicated a single neuron may be, it cannot play a role in the processing of information without interacting with other neurons. In other words, the nervous system is based on the interactions of neurons as well as the functioning of each individual neuron. Thus we consider that all information processing phenomena in animals can be represented using connective neural models. Such a structural approach, which involves the design of a model of neural networks and the clarification of neural mechanisms by analyzing them, is helpful. In general, the dynamics of these models is very complex. Therefore, a computer simulation is useful.

In this letter we present a simulation environment for designing and examining a neural network model at the network level. This environment is distinguished by its use of a graphical user interface and database of network models.

The remainder of this letter is organized as follows. Section 2 is a brief survey of the overall organization of this environment. In Sect. 3 we describe the features of the system. In Sect. 4 we demonstrate these features. In Sect. 5 we discuss the present work and compare it to related studies. Finally, Sect. 6 is a summary of the present work.

2. Overview

This environment consists of three principal parts as shown in Fig. 1. The first is the kernel of the simulation system, which is a simulation program[1]. This program receives simulation data of neurons and synapses, simulates them, and supplies the results. The second is NNDBMS (Neural Networks DataBase Management System). This system enables users to construct, merge, and adjust networks visually and interactively. The third is NNES (Neural Networks Examining System). This system can display the simulation results in various ways. Both NNDBMS and NNES are equipped with a graphical user interface, based on the X-Window System*. In short, whereas NNDBMS is a system for communicatively designing neural network models, NNES is a system for interactively displaying the results of simulation.

3. Details of the Environment

3.1 Kernel of Simulation System[1]

The kernel of the simulation system is programmed in the C-language, and can be run both in a UNIX environment and on personal computers. The aims at this stage are as follows: 1) to obtain simulation data, 2) to simulate, and 3) to output the results.

Our neuron model is a modified form of Perkel's model[2]. There are various single-neuron models; thus
it is difficult to select one of them. We adapt this neuron model for our system because while it is very simple and easy to simulate on computers, its action resembles that of real neurons to the greatest extent that we can simulate a neural system at the connective network level.

Figure 2 illustrates our neuron model. This neuron model can simulate temporal summations as well as spatial summations by means of connections of neurons, because it possesses a temporal characteristic essentially.

3.2 NNDBMS[3]

A neural system is comprised of few connective styles, for example, feedforward excitation, and recurrent inhibition[4]. Therefore, we are able to easily identify the same structural circuits or a certain small functional unit in a neural network. Such a circuit, which Shepherd (1990) called the basic circuit[4], is roughly defined as the unit composed of the minimum number of elements and connections required to capture the essence of the functional operations. For the above reason, when we design neural network models, it is best to construct the basic circuits first and then combine them.

NNDBMS is the system for visually and interactively designing neural network connective models; constructing basic circuits, storing them, and combining them. For these purposes, this system has three main modules: construct-, merge-, and adjust-module as shown in Table 1 and Fig.3. First, in the construct-module, a user can construct a basic circuit by combining components: neurons and synapses. Second, in the merge-module, a user can merge the networks that were previously constructed. A user chooses from two merging operations: identifying neurons in A-network with ones in B-network or connecting neurons with new synapses. Selection of the merging neurons can be achieved by indicating the square region containing them by means of pointing device (ex. Fig.5(b); gray-colored neurons are chosen by a user). Third, in the adjust-module, a user can adjust the networks in the database. Adjusting the neural network models means changing the parameters of their neurons and synapses or deleting unnecessary neurons and synapses.

Table 1 Module and function of NNDBMS.

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<tr>
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3.3 NNES

NNES is a system for visually and interactively examining neural network connective models, that is, displaying the simulation results in various ways.

This system receives the results from the kernel of the simulation system, and displays them as graphical output from an angle specified by a user. Examples of the display are shown in Fig.4. Whereas the left figure shows a display of the potential, threshold, and firing of a single neuron, the right one shows a display of the firing time course for many neurons.

4. Examples

The use of this environment is demonstrated using a simple example. Figure 5 shows a model of retinal ganglion cells. X-on-type retinal ganglion cells respond when the center of the receptive field is illuminated.

At first, a researcher models a basic circuit (central window of Fig.3). This basic circuit is considered to be the small receptive field consisting of ten inhibitory neurons and one excitatory neuron at their center. Next, he arranges the basic circuits vertically and horizontally 16 times each to overlap each receptive field. In this case, he executes only eight merging operations. This retinal ganglion network consists of 836 neurons and 2560 synapses. Figure 6 shows that this ganglion receptive field model enhances edges of the stimulus.

5. Discussion

Simulation environments can be classified according to the types of neural models that they are based on. There are two classes of neural simulators. One is based on artificial neural models, for example, MIRRORS/II[5] and SFINX[6]. The other is based on biological neural models, for example, PABLO[2], BOSS[7],[8], and
Fig. 3  Display of NNDBMS.

(a) activation of single neuron
solid line: threshold; dashed line: potential
(b) diagram of many firing neurons
points: firings

Fig. 4  Examples of displayed results.
Genesis[9]. We consider our environment to be included in the latter class rather than the former.

Both NNDBMS and NNES of our environment are equipped with a graphical user interface, based on the X-Window System. Of course, Genesis[9], MIRRORS/II[5], and SFINX[6] also have graphical user interfaces. However, their graphical user interfaces are mainly used to display the results. As we demonstrate in the example offered in Sect.4, NNDBMS of our environment enables users to design neural network connective models visually and interactively. Our environment is unique with respect to this point, that is, it may be distinguished from other environments due to the ease of designing and examining neural network connective models.

In all operations in NNDBMS, their implementation, for example, the method by which they modify data of connections is invisible to a user. Moreover, a user can reuse previously constructed networks. Therefore, design of a larger network requires little effort as shown in Sect.4.

In the display of networks, their topography is automatically handled by means of the layer data and area data which point to the position in the layer. By way of illustration, the neurons of Fig.5 are arranged of themselves. When a user first constructs a basic circuit, for example, the construct-module in Fig.3 (enclosed by central window), the neurons implicitly contain the hierarchical data (i.e. layer data) and two-dimensional area data in a layer. By means of these data, neurons are automatically positioned as shown in Fig.5(a), and when networks are merged, they are also arranged of themselves (Fig.5(c)) by determining the internal layer and area data successively from the identified neurons (gray-colored ones in Fig.5(b)). Although we do not consider this automatic arrangement to be perfect, it contributes greatly to the operation of this environment.

6. Conclusion

We have developed a simulation environment for designing and examining neural network connective models. In this environment, there are very few discrepancies between the connective model of neural networks visu-
alized by an investigator and the model shown on the computer display. Therefore it is very easy for the user to design and examine neural network models. Moreover, an investigator can save much time compared to the case of having no graphical user interface and no database of network models.

In this letter, we have shown only two types of displayed simulation results, however there are several more (see, for instance, Ref. [10]). Due to the complexity of the nervous system, further display types are required, and their realization is left to our future work.

References