2011 International Conference on Computer Science and Information Technology (ICCSIT 2011)
IPCSIT vol. 51 (2012) © (2012) IACSIT Press, Singapore
DOI: 10.7763/IPCSIT.2012.V51.61

Research on the Petri net Model of System Interaction

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Abstract. The System boundary is responsible for interacting with each other in the system's outside and inside. Designing and planning the ways of the boundary interaction reasonably will optimize the performance of the entire system. Biological cells in the Nature perform the function of the system boundary, at the same time they are in charge of substance, energy and information's input and output mechanisms. Cells' performing ways are simple but manifold and very effective. In this article we research the mechanism and the ways of cell membrane interaction and then frame the model of cells interaction based on Petri net and apply the model into system interaction.

Keywords: System Boundary, Cell Membrane, Petri Net, Cells Interaction Model

1. Introduction

Nature and the human society exist generally in a systematic way [1]. Boundary of the system is the boundary to distinguish between system and other systems or environment. At the some time it is the intermediary link among systems and the interactions between system and environment. Research on function of system boundary and way of system boundary is an important way to reveal structure of the entire system, characteristics of the entire system, and trends of the entire system. Designing and planning artificial boundary of the system reasonably helps to optimize the performance of the overall system.

Article [2] [3] has analyzed the meaning and function of the system boundary and has proposed that the boundary should define and express relationship that the system's inputs and outputs. And the diagram of system overview is used to be a tool for the description of the information system's boundary. Article [4][5] summed up the information screen, projection, absorption and deformation movement as the behavior of the boundary interface. Article [6] [7] puts forward the role of environment on the system boundary embodies the role's randomness of environment on the system; internal factors of system whose feature is strong self-organization play a decisive role on the environment. Their co-evolution causes dynamics change of the boundary system. These articles mentioned above aim to clarify definition of the system boundary and the function of the system boundary in theory, but these articles didn't analyze and research the specific ways of the boundary interaction.

Organisms in Nature provide us with natural, excellent examples of how to design interaction relationship among the systems. Cells are not only the basic units that constitute structure and function of a complex organism, but also a stand-alone system to metabolize the organism. Cell membrane has function that it is looked on as boundary of system to exchange information and energy between inside material and outside material. Therefore learning and researching on cell membrane's function plays an important role to improve the autonomy of system. So in this article we research the mechanism and the ways to membrane interaction and then frame the model of cells interaction based on Petri net and apply the model into the system interaction.

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2. Cell Membrane and Its Way of Interaction

A Cell is divided into the cell membrane, cytoplasm and nucleus in its structure. The material membrane is a barrier to access and it has the function of interaction; the cytoplasm is the place of occurrence of various biochemical reactions because there are a variety of organelles, proteins in a cytoplasm; DNA in a nucleus contains all of the information about the heredity, development and trait expression of the living things and the DNA is a cell's control center.

2.1. The way of membrane interaction

In the process of cell metabolism, there are various substances which enter and go out of cells and these substances include ions, small molecules, large molecules, and some particulate matter. In general, the way that these substances across the cell membrane is that the substances of fat-soluble or less polar molecules pass through the cell membrane by physical diffusion; the substances of small water-soluble molecules need to use membrane proteins as mediated tool to complete to pass through cell membrane while the substances of macromolecules and particulate matter can not cross the cell membrane to take in small droplets of liquid and capture food particles by being wrapped by membrane vesicles from the external environment. In addition, cell membrane can also receive external signals to stimulate the cells to respond to the regulate cell's life activities.

Membrane is able to complete these functions, because there is lots of transporting protein on the membrane and according to different structures the protein specifically combines with different external substances, and then transmits substance, energy and information into the cell interior by changes of structure. According to the central theorem, the protein forms by being assembled: it is encoded by the DNA and translated into amino acids ribosome by RNA. The protein is used to help to complete the substance transport.

2.2. Membrane's input-output mechanism

Cell's substance transformation and transportation is a process that it is imported into vector (protein) on the membrane under the DNA control, the environmental impact and the energy support. At the same time, it obtains its own material energy and information which it required by itself from the extracellular environment. Figure 1 shows the mechanism of the cellular interaction model diagram and it is established based on the cellular material transport mechanism.

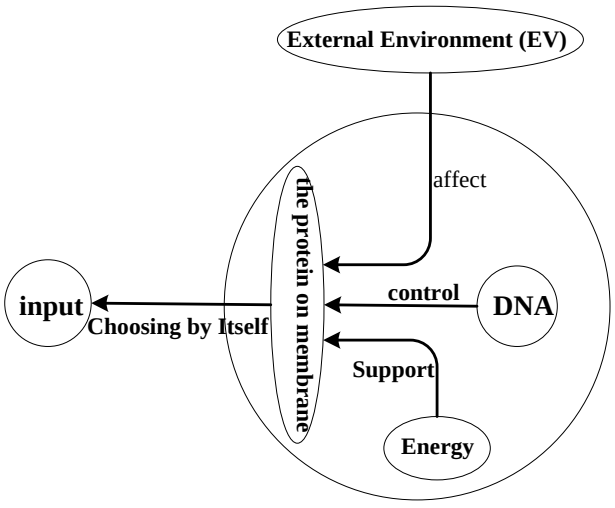

Fig.1. the mechanism model of the cellular interaction

(1). External Environment (EV): The external environment can not be controlled to influence on system activity by the system internal, but it can affect the system decision-making. As far as cells are concerned, external environment includes the concentration of cell membrane's outside, temperature, light, electricity, damage, energy, nutrients, signals and so on.

(2). DNA Control: DNA controls the input and output functions of cell membrane by encoding the protein on membrane.

(3). Energy (En) Support: Because ATP supports power, transmembrane transportation occurs and the active transportation and the vesicular transportation occur by the concentration gradient

(4). Choosing by Itself: Choosing is a process that cell membrane decides whether it gets external substance and information according to its own needs and judgements on the environment.

(5). Input Process(S): The input process is such a process that all of the small molecules and macromolecules including ions, nutrients, and signaling molecules, which can obtain from the cell's environment, enter the cell.

3. the Petri Net Based Membrane Interaction Model

3.1. Petri net

Petri net reflect the links between things realistically through an intuitive graphical representation of the friendly and strict mathematical definition images. It is facilitate to dynamic simulation, description and the analysis of complex biochemical network. Therefore, it becomes one of the hot spots of the method for biological modeling [8] [9]. Petri net reflect the static and dynamic characteristics of the system well by using the Network Graphics to describe the input/output relationship between objects. This is applicable to represent the input/output relationship involved in the cell membrane.

The basic object of the Petri net is the place, transition, and the arc. The meaning of them in the model is as follows.

Place: The place expresses all the reactant including the starting material, the intermediate material and the final material in the biochemical reaction. Here, the place expresses all the materials involved in the transportation on the cell membrane such as kinds of the proteins, hydronium and signaling molecules and so on. And the place also expresses all the environment states which can result in the transition.

Transion: when describing the biochemical net, every transition means a process of biochemical reaction. The transition means the state change of all the participated materials.

Arc: the arc that connects the place and the transition expresses the reaction flow.

E.g. the simple free diffusion in the transmembrane transportation, Under this condition, the not charged lipid - soluble small molecular substances will carry out the transmembrane transportation under the situation that the consistency outside the cell is condenter than which outside the cell. This process can be represented by Petri net as follows:

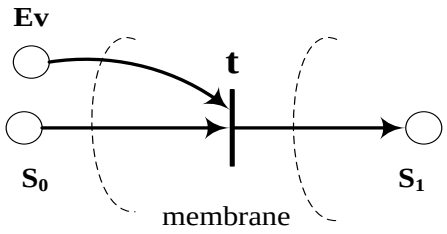

Fig.2. free diffusion

As shown in figure 2:S0 expresses Small molecular substances; Ev expresses concentration difference; t expresses that the small molecular substances through the membrane; S1 expresses that the station of S0 is inside the cell.

3.2. The Petri net Model of cell interaction

According to the above discussion, and typical channel of material's transportion and information's transmission of the cell membrane in the article [10] [11], we can get the Petri net model of cell interactions as shown in Figure 3. According to the material properties, there're four channels of input into cells: passive transport, active transport, and vesicle transport and information transmission. After the input items enter the cell, and in the action of series of proteins and organelles, the input items transformate into output.

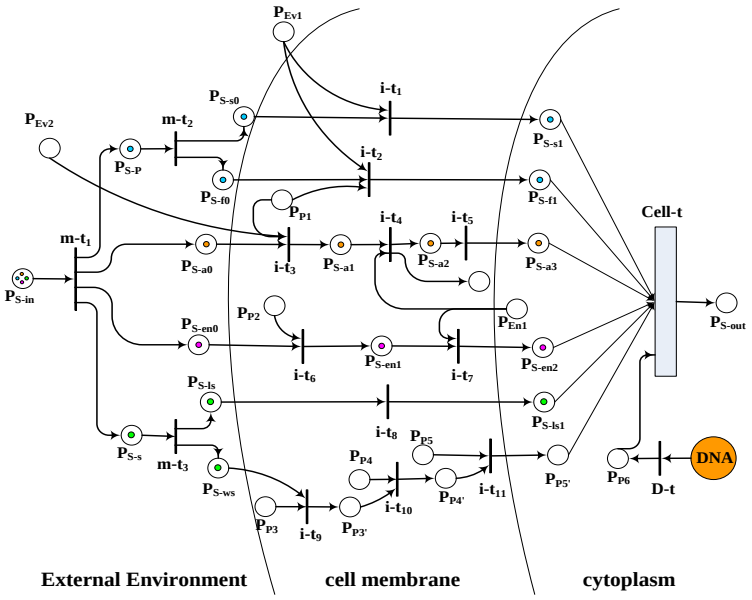

Fig.3. the Petri net model of cell interactions

3.3. Model definition

Definition: Cell interaction Petri net model can be described as a 9 tuple

$PN = \{P^S, P^{S'}, P^P, P^{Ev}, P^{En}, P^D, F, T, C\}$， where：

(1) $P^S = \{P_{S-in}, P_{S-p}, P_{S-s}, P_{S-s0}, P_{S-f0}, P_{S-a0}, P_{S-en0}, P_{S-Is}, P_{S-Ws}\}$ is a finite set of input places;

P_{S-in} expresses that all the material, energy to be input in environment;

P_{S-p} expresses small molecules material or not charged ions;

P_{S-s} expresses all signal molecule to input the Cell;

P_{S-s0} expresses non - polar, small molecules and not charged, polarity small molecule;

P_{S-f0} expresses the polarity of small molecules and ions;

P_{S-a0} expresses all varietes of small molecular substances;

P_{S-en0} expresses the biological macromolecule particles;

P_{S-Is} expresses the liposoluble signals;;

P_{S-Ws} expresses the water-soluble signal;

(2) $P^{S'} = \{P_{S-s1}, P_{S-f1}, P_{S-a1}, P_{S-a2}, P_{S-a3}, P_{S-en1}, P_{S-en2}, P_{S-Is1}\}$ is a finite set of transfer process state of input place in the cell;

(3) $P^P = \{P_{P1}, P_{P2}, P_{P3}, P_{P4}, P_{P5}, P_{P6}\}$ is a finite set of membrane transport protein places;

(4) $P^{Ev} = \{P_{Ev1}, P_{Ev2}\}$ is a set of interactive influence factors places in the environment; where:

P_{Ev1} expresses that the extracellular concentrations of the input materials is stronger then that inside the cell;

P_{Ev2} expresses that the extracellular concentrations of the input materials is diluter then that inside the cell;

(5) P^{En} is cell energy place;

(6) P^D is the DNA place which can encoding the protein and the capacity of place is n， $n \in N$;

(7) $T = \{m\_t_1 ... m\_t_3, i\_t_1 ... i\_t_{11}, d\_t, cell\_t\}$ is a finite set of the transitions;

(8) $F \subseteq (P \times T) \bigcup (T \times P)$ is a set of arcs;

(9) $C = \{C_1, C_2, C_3, C_4\}$ is a set of input color. which expresses the permeable character of input items. C_1 is the small molecule which is apt to diffuse along concentration gradient. C_2 is the materials which inverse concentration gradient into cells and the process need the energy of cell; C_3 is the materials that can't enter the cell directly; C_3 is signal molecules which can cause the cell to react. It isn't the Structure material of the cell or the nutrient materials of the cell.

3.4. The transition and its rules

In order to facilitate description, to classify and determine the transition and its rules are as follows:

Transition of detection: determine the appropriate channels of the inputs according to their diverse properties, which is denoted by $^{m\_t}$;

Transition of channel: conduct the information and energy and transport the materials through the various channels of the membrane, Which is denoted by $^{i\_t}$;

Transition of intracellular conversion: inputs are transformed into outputs, Which is denoted by $^{cell\_t}$.

Transition controled by DNA: control the channels on the cell membrane and the intracellular conversion by gene coding protein, which is denoted by $^{d\_t}$.

(1) Transition rule of detectio: For $P \in \bullet m\_t$,if $M(P)=1$,then transition m_t occurs， after the transition for $P \in m\_t \bullet$, $\forall M(P)=1$.

(2) Transition rule of channel: For $P \in \bullet i\_t$, if and only if all the $M(P)=1$, then i_t occurs, after the transition for $P \in i\_t \bullet$, $M(P)=1$.

(3) Transition rule of intracellular conversion: If $M(P_{p6})=1$, for the other $P \in \bullet cell\_t$, $\forall M(P)=1$, then $cell\_t$ occurs, after the transition for $P \in cell\_t \bullet$, according to the property corresponds of output items $M(P)=1$.

(4) Transition rule of DNA: If $M(P^D)=1$, then transition d_t occurs , after the transition for $P \in d\_t \bullet$, $M(P)=1$.

3.5. Encapsulation of the model

In order to facilitate the establishment of a system model, package rules can be determined as follows

(1) Input and output in the external environment are used for the connection between System;

(2) Membrane which package all input/output channels is used as an the interface to interact with the outside world;

(3) All influence factors of the external is packaged in the external environment;

(4) All internal conversion processes. is packaged within the model .

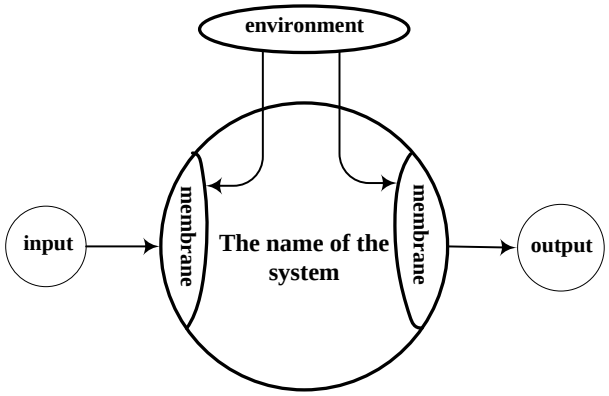

Fig.4: Encapsulation model

Encapsulation model of the system interaction is as shown in figure 4. make this system as the basic unit and through defining the names and the serial numbers of other systems and their properties of the input/output as well as the connection between the systems to establish the system interaction model.

4. Application of the Model

Cell interaction model can be applied to describe natural and artificial system. In the first place, the model which described the interaction channel of the cell can be used in the research of such as biological information and electronic cell. Secondly the model can be use to design artificial automatic control system, at the same time, it can be used to analyse the social systems. Such as satellite system, air navigation system, machinery and equipment systems, traffic and transportation system, economic system, inflation and so on.

When the system is on a large scale, and have numerous units and systemic environment is complex and ever – changing, It's difficult to understand all the information from outside the system. Therefore if the system can perceive the changes in the internal and external environments and take corresponding actions, then the adaptability of the system can be improved greatly.

Figure 5 shows the cell-based interactive model of two systems interaction model

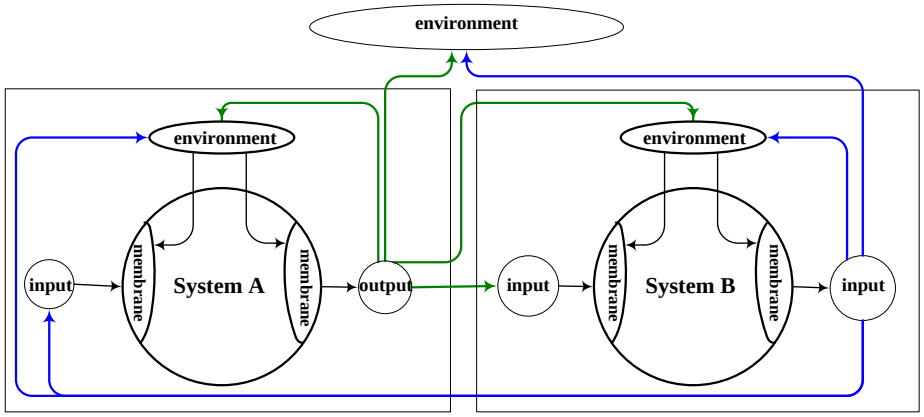

Fig.5. two systems interaction model

In complex systems, each unit should interact with other units or the surrounding environment, material, energy and information exchange. To make coordinated operation of the entire system, it is necessary to ensure that quick and effective interaction, so as to ensure that each have their own material and information needed. The input and output interfaces between systems designed referring to the cell membrane function and mechanism. The interaction between the two systems represents primarily: the output of the system A affect the environment of the system B and the carrier in the boundary of the System B detect the change. According to its own rules and requirements, and self-decision whether to enter. And the output produced by input affects to the system A in the same way. This process makes the system change rapidly in the light of the environment changing, so as to make the whole process more flexible and more adaptive.

5. Conclusion

The article put forward a system modelling method based on the cell interactive mechanism for the system how to improve the efficiency of interaction and autonomy. The theoretical basis of the method is the cell interaction mechanism. The cell interaction model is based on Petri net. According to the different attribute of input items the model use different channels to input/output the system. Therefore, it can be realized quick response to changes in the external environment, and improve the autonomy of systemic interactive and achieve the goal of optimizing system design. There’re some specific problems need further study in the papers, such as DNA how to control the cellulated action, and how to describe the Interaction path among multi – system.

6. Acknowledgements

This paper is supported by the National Natural Science Foundation of China (No.70771091) and the Aeronautics Science Foundation of China (No. 2007ZG53074).

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