On modeling internal organs and meridian system based on traditional Chinese medicine

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Abstract. In traditional Chinese medicine, internal organs imply five viscera and six bowels. Five viscera mean liver, heart, spleen, lung and kidney, and six bowels mean gallbladder, small intestine, stomach, large intestine, urinary bladder and triple energizer. Also, meridian system represents the passage of metabolites in the human body. In this paper, we deal with construction of Petri net model of internal organs and meridian based on traditional Chinese medicine. At first, we introduce relations of mutual generation and mutual restriction between five viscera to make a basic Petri net model of five viscera based on five-elements theory. Analyzing the relation between five viscera and six bowels, we propose a model of internal organs that include five viscera and six bowels. After that, through investigating the syndrome of internal organs as well as the function of pericardium meridian, we propose a Petri net model including internal organs and meridians by combining the model of internal organs with meridians. Finally, we do simulation of the proposed model by using CPN Tools to show how our model works.

Keywords: traditional Chinese medicine, five-elements theory, five viscera and six bowels, meridian system, modeling, Petri net

1 Introduction

Traditional Chinese medicine or oriental medicine has been widely applied in treating disease in China as well as in various asian countries since ancient times. This is because of its less secondary effect and possible curing for ahead sick and incurable disease. Especially acupuncture and moxibustion therapy that stimulate acupuncture points in meridian system to treat disease have spread rapidly since the times when acupuncture and moxibustion therapy were admitted by WHO in 1989 and 361 acupuncture points were standardized by WHO in 2006. However mechanism of meridian system is still not scientifically elucidated and many of related researches and treatments have been made empirically and clinically. Therefore it is required to develop new knowledge to elucidate acupuncture and moxibustion treatment [1].

In traditional Chinese medicine, internal organs include five viscera and six bowels. Five viscera mean liver, heart, spleen, lung and kidney, and six bowels

mean gallbladder, small intestine, stomach, large intestine, urinary bladder and triple energizer. Five viscera and six bowels imply the systematic functions of human body rather than internal organs of human anatomy. Five viscera and six bowels are closely related each other and have the correspondence relationship between liver and gallbladder, heart and small intestine, spleen and stomach, lung and large intestine, kidney and urinary bladder, respectively. Once one becomes sick, the other has high possibility of abnormalities. Such relationship is expressed in five-elements theory of traditional Chinese medicine [2]. In Chinese medicine, human body is also thought of a complex and interconnected system, and consists of meridian system that connects skin to inner organs from head to foot. The elements of meridians are considered as the acupuncture points of the body. Stimulating acupuncture points on the body, various diseases can be treated and prevented [2].

Recently, five viscera of traditional Chinese medicine have been studied through modeling and quantitatively analyzing [3]. Fusing five-elements theory and fuzzy system theory, Sun et al. have proposed a fuzzy model (called Sun's model hereafter) of five viscera by focusing on the physiological equilibrium states of liver, heart, spleen, lung and kidney [4]. Based on the evolution law of five viscera, Guo et al. have proposed a quantitative measurement model in order to realize five-elements theory [5]. Nevertheless these models have a common problem that they are difficult to be used in simulating the behaviour of five viscera as well as six bowels. On the other hand, Petri net is a modeling and analyzing tool of systems and can represent and analyze static structure and dynamic behaviour of a system. There have been many success stories on modeling biological systems and elucidating the mechanisms by Petri nets. On modeling and simulation of meridian system using Petri net [6], P.A. Heng et al. have presented an intelligent virtual environment for Chinese acupuncture learning and training using state-of-the-art virtual reality technology in order to develop a comprehensive virtual human model for studying Chinese medicine [7]; J. Pan and M. Zhou have modeled and analyzed meridian system by adopting Petri net methods [8]. However, these studies deals with meridian system only, without taking into account of the internal organs, five viscera and six bowels. We aim to propose a Petri net model for both internal organs and meridian system in order to finally elucidate the mechanism of meridian system as well as the internal organs.

In this paper, we are to propose a method of modeling both internal organs and meridian system by using discrete Petri nets as the first step towards elucidating meridian system. Section 2 introduces five-elements theory in traditional Chinese medicine and gives basic knowledge of Petri nets. Section 3 describes a model of internal organs including both five viscera and six bowels based on five-elements theory. Section 4 introduces a concept of "syndrome" used in traditional Chinese medicine and describes syndrome of five viscera and six bowels as well as the function of a meridian, pericardium meridian, to propose a Petri net model including internal organs and meridian system. Section 5 shows simulation of the proposed model by using CPN Tools [9] to show how our model works.

2   Five-Elements Theory and Petri Nets

2.1   Five-Elements Theory

According to ancient Chinese five-elements theory, the five elements, wood, fire, earth, metal and water are indispensable to the daily life of mankind. And in five-elements theory of traditional Chinese medicine, five viscera, liver, heart, spleen, lung and kidney, are mapped to the five elements respectively. Liver flows Qi through over the body free of all care, as a tree getting taller; Heart warms the body as fire; Spleen produces nutrients, as soil that produce all things; Lung takes down Qi and Bodily Fluid, as astringent action of the metal; Kidney pools Mind and adjusts the moisture of the body, as water that flows to the low place from on high [2].

In five-elements theory, there are generation and restriction relationships between five viscera. Generation is that of mother-to-child relationship to give birth to the other party and is circulating in the order of wood $\rightarrow$ fire $\rightarrow$ earth $\rightarrow$ metal $\rightarrow$ water [2]. Restriction is to suppress the other party in the order of wood $\rightarrow$ earth $\rightarrow$ water $\rightarrow$ fire $\rightarrow$ metal [2]. In traditional Chinese medicine, health is maintained if generation and restriction relationships are balanced, and hence cause of the disease and methods of treatment can be investigated from the interrelationship of five viscera. Fig.1 shows the generation and restriction relationships.

In addition, five viscera and six bowels have relations that interact with each other. That is, liver and gallbladder, heart and small intestine, spleen and stomach, lung and large intestine, and kidney and urinary bladder interact with each other, respectively. Triple energizer consists of upper energizer, middle energizer and lower energizer, which are the paths for Qi and Bodily Fluid to pass. Since triple energizer does not corresponds to any one of five viscera, we are not to deal with it in this paper.

2.2   Petri Nets and Colored Petri Nets

A Petri net is one of several mathematical modeling languages for the description of concurrent systems [6][10]. A Petri net is a weighted directed bipartite graph and consists of two types of nodes, transitions (i.e. events that may occur, signified by bars) and places (i.e. conditions, signified by circles). Places may contain a number of marks called tokens. Any token distribution over the places will represent a configuration of the net called a marking. The directed arcs with weights describe which places are pre- and/or postconditions for which transitions (signified by arrows). A Petri net is expressed by a 5-tuple $PN = (P, T, A, W, M_0)$. Here, $P = \{p_1, p_2, ... p_{|P|}\}$ is a set of places, $T = \{t_1, t_2, ... t_{|T|}\}$ is a set of transitions, $A \subseteq (P \times T) \cup (T \times P)$ is a set of arcs, W is weight function $A \mapsto \{1, 2, ...\}$ and M_0 is initial marking $P \mapsto \{0, 1, 2, ...\}$.

Colored Petri nets (CPN) is extended from Petri nets by adding colors to tokens and is a discrete-event modeling language combining the capabilities of Petri nets with the capabilities of a high-level programming language. It allows
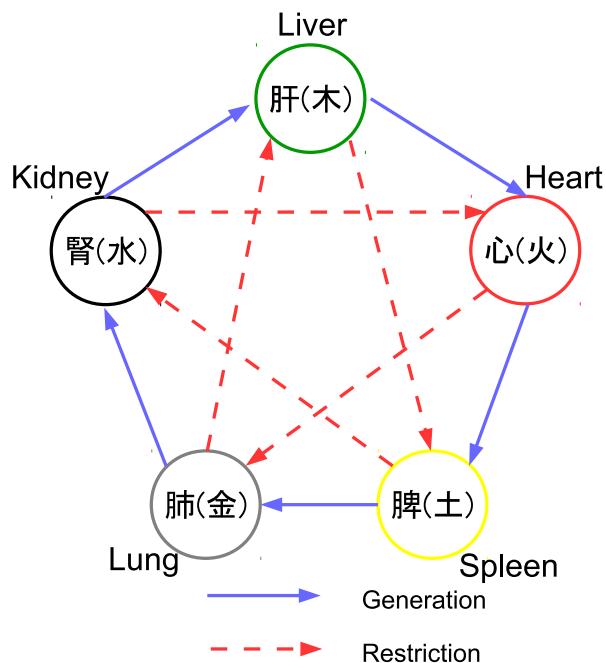
Fig. 1. Generation and restriction relationships between five viscera.

tokens to have a data value attached to them. This attached data value is called token color. A Petri net is a tuple $CPN=(P,T,A,\Sigma,C,N,E,G,I)$ [11], where, P, T and A are the same as Petri net, Σ is a set of color sets and contains all possible colors, operations and functions. C is a color function and maps places into colors. N is a node function and maps A into $(P\times T)\cup(T\times P)$. E is an arc expression function and maps each arc into the expression. G is a guard function and maps each transition into guard expression. I is an initialization function and maps each place into an initialization expression.

3 Construction of Petri Net Model of Internal Organs

3.1 A Control Model of Five Viscera

In Sun's model [4], physiological equilibrium states are quantitatively defined in domain $(-1,1)$ individually for liver, heart, spleen, lung and kidney, and a fuzzy model had been proposed based on five-elements theory. The domain is divided into $(-1,b_1)[b_1,a_1)[a_1,a_2](a_2,b_2](b_2,1)$ as shown in Fig.2, which respectively five states, weak, little weak, equilibrium, little strength, strength. These five states respectively represent dysfunction and no power of generation $((-1,b_1))$, delicate health and weak power of generation $([b_1,a_1))$, health and stable state $([a_1,a_2])$,

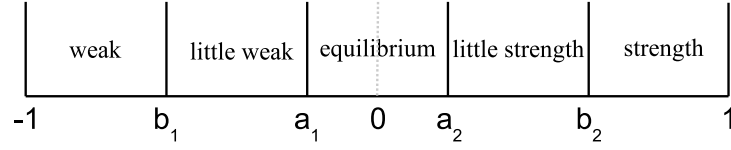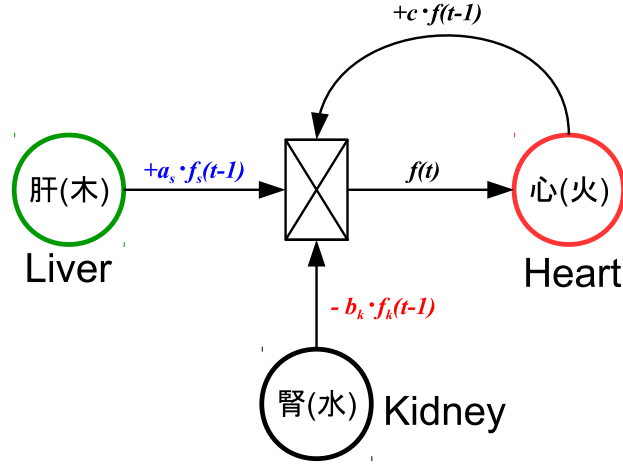**Fig. 2.** Five viscera's state.

Fig. 3. Generation and restriction relationship.

Excess and disease state with power of restriction $((a_2, b_2])$, and severe state of excess $(b_2, 1)$.

Among five viscera, there are generation and restriction relationships. In the case of heart, it is generated by liver but restricted by kidney, which is shown in Fig.3. Meanwhile, liver may loss its energy itself. Therefore, the state of liver at time t, $f(t)$, is expressed by the following equation that is modified from Sun's model [4]:

$$f(t) = a_s \cdot f_s(t-1) - b_k \cdot f_k(t-1) + c \cdot f(t-1) \qquad (1)$$

where, t is the time, a_s, b_k, c are non-negative parameters, $a_s \cdot f_s(t-1)$ represents generation affection (f_s is the state of liver) and $b_k \cdot f_k(t-1)$ represents restriction affection (f_k is the state of kidney).

3.2   A Petri Net Model of Five Viscera

Here, we propose a Petri net model of five viscera based on Sun's model. Firstly, we give a model for a single viscus as shown in Fig.4. Places, p_{in} and p_{state}, are
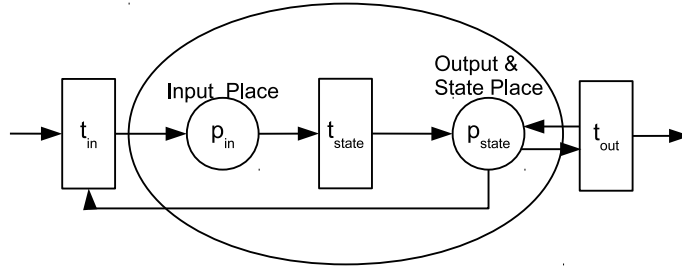
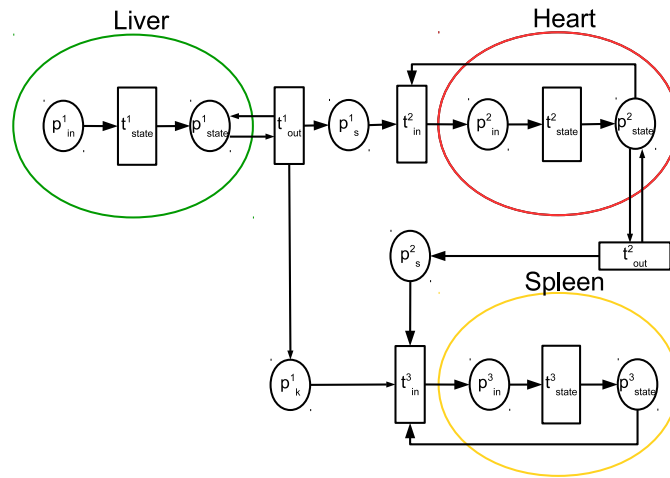**Fig. 4.** A Petri net model for a single viscus.

Fig. 5. A model including generation and restriction.

called input place and state place, and the token in state place is called state token whose value expresses the state of the viscus. t_{in} is called input transition that works to calculate the state value of Eq. (1). t_{state} is called state transition and works to generate a state of the viscus. The token with calculated state value passes through p_{in} and t_{state} and then arrive at p_{state}. t_{out} is called output transition and works to generate and restrict other viscera.

Fig.5 shows a Petri net model including relationship of generation and restriction between viscera. This model is comprised of three single viscus models, the models of liver, heart and spleen, which are connected by places p_s^1, p_k^1 and p_s^2. Places p_s^1 and p_k^1 express liver's generation and restriction affection to heart and spleen, respectively, and these two places are respectively called generation-output place and restriction-output place of liver. Tokens in generation-output and restriction-output places are respectively called generation token and restriction token. Similarly, p_s^2 is generation-output place of heart.
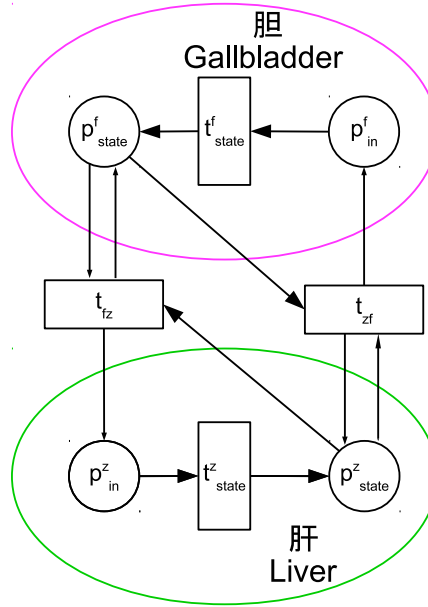
Fig. 6. A Petri net mode of liver and gallbladder.

Since liver generates heart and restricts spleen, state token of liver flows through output transition t^1_{out} to generation-output place p^1_s (that is also an input place of heart model) and to restriction-output place p^1_k (that is also an input place of spleen model). In the same way, state token of heart flows to generation-output place p^2_s that is an input place of spleen model.

3.3 A Petri Net Model of Internal Organs

The Petri net shown in Fig.6 can be treated as a model of any one pair of five viscera and six bowels (say liver and gallbladder). Hence to make a full model that includes both five viscera and six bowels, we need only to consider how to connect these models together into one model.

Five viscera and six bowels are in the relationship of the front and back, such as liver and gallbladder, heart and small intestine, spleen and stomach, lung and large intestine, and kidney and urinary bladder. Each of these pairs interacts with each other to maintain life. Such a pair, for example liver and gallbladder, is modeled by Petri net as shown in Fig.6. This model is made by adding transitions t_{zf} and t_{fz} and connecting them to the single model of liver and gallbladder. t_{zf} and t_{fz} represent the affections from liver to gallbladder and from gallbladder to liver, respectively.

Synthesizing the models we have made till now, we can complete a model of internal organs. The process is summarized as follows: (1) Make a single model
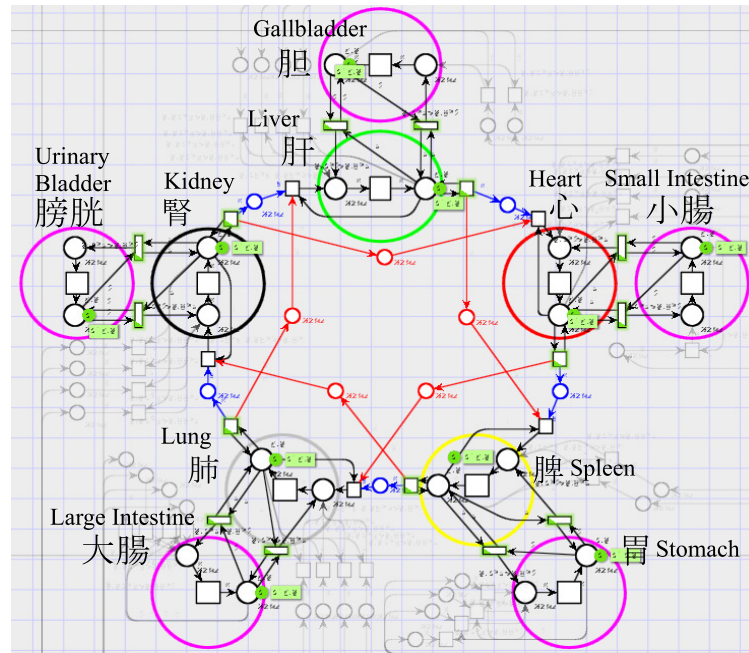
Fig. 7. A complete Petri net model of internal organs.

for each of five viscera as Fig.4; (2) Connect these single models according to generation and restriction relationship between five viscera as Fig.5; (3) Add to the model of each viscus by the model of its pair partner of six bowels as Fig.6. Then the complete model is obtained as shown in Fig.7.

4 A Combined Model of Internal Organs and Meridian Based on Syndrome

4.1 Meridians and Acupuncture Points

In traditional Chinese medicine, meridian system is considered as important channels to transfer Qi (means energy) and blood in human body. Meridian system is divided into meridians and collaterals [12], [13]. Meridians are main part of meridian system and represent paths that trend almost upside down. Collaterals play the role of branches and connect all the way to the whole body.

Meridians consist of twelve principal meridians and eight extra meridians. Twelve principal meridians include three Yin and three Yang meridians of hand and also three Yin and three Yang meridians of foot. Here, Yin and Yang are the concept of duality forming a whole and mean respectively sunny side and shady side (e.g., the palm and the back of the hand). Yin meridians belong to
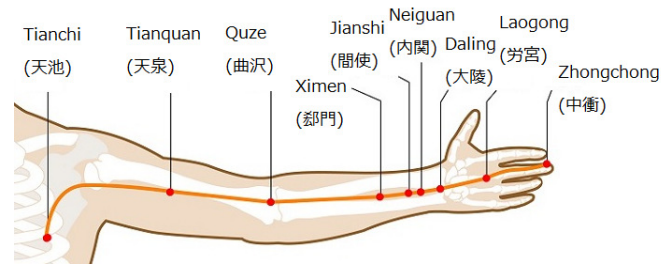
Fig. 8. Pericardium meridian containing nine acupuncture points (from [14]).

five viscera and Yang meridians belong to six bowels. Each principal meridian has acupuncture points. In eight extra meridians, only Renmai and Dumai have acupuncture points. Twelve principal meridians along with Renmai and Dumai are thought of main meridians [12]. Collaterals consist of fifteen collaterals and other collaterals (tiny collateral, superficial collaterals and musculature that is not connected to internal organs).

Acupuncture points exist in twelve principal meridians, Renmai and Dumai. Through these acupuncture points, Qi passes inside and outside of body and thus various diseases can be prevented and cured by stimulating these acupuncture points [2, 12, 13]Here, we consider the modeling of pericardium meridian. Pericardium meridian is an important Yin meridian of hand and is closely related to heart. It begins near the heart, goes down each arm to the palms and then goes to the tip of the middle finger. As can be found in Fig.8, pericardium meridian contains nine acupuncture points, Tianchi, Tianquan, Quze, Ximen, Jianshi, Neiguan, Daling, Laogong and Zhongchong.

4.2 Relationship between Internal Organs and Pericardium Meridian Based on Syndrome

In traditional Chinese medicine, "syndrome" is a measure to evaluate the state and physical condition of human body [2, 12, 13]. The acupuncture points of pericardium meridian are efficacious against various symptoms. For example, Quze corresponds thirsty; Ximen heartbeat, shortness of breath and tenosynovitis; Neiguan motion sickness, hangover, hiccup and chronic gastritis; Daling rheumatoid arthritis and halitosis; Laogong stomatitis, thirsty and forgetful; and so on [15].

On the other hand, when the states of internal organs are no longer normal, various functions will be modulated by each organ. For example, in liver the dispersing and dredging function and the capability to store the blood are probably decreased; in heart abnormalities may occur in the blood stream; in spleen the functions of transportation and transformation, which send up the lucid Yang and govern the blood, may be decreased; in lung dissipating and exerting effect may become weak; and in kidney functions of storing the essence of

Table 1. The relationship between internal organs and acupuncture points of pericardium meridian.

Five Viscera	liver	heart	spleen	lung	kidney	
Tianchi (天池)						
Tianquan (天泉)						
Quze (曲沢)	*	*		*	*	
Ximen (郄門)	*	*	*	*	*	
Jianshi (間使)						
Neiguan (内関)	*	*	*	*	*	
Daling (大陵)						
Laogong (労宮)	*	*		*	*	
Zhongchong (中衝)						
Six Bowels	gallbladder	small intestine	stomach	large intestine	urinary bladder	triple energizer
Tianchi (天池)						
Tianquan (天泉)						
Quze (曲沢)			*	*		
Ximen (郄門)	*					
Jianshi (間使)						
Neiguan (内関)	*	*	*	*		
Daling (大陵)			*	*		
Laogong (労宮)			*	*		
Zhongchong (中衝)						

life and regulating the metabolism of water are probably decreased. In the case of six bowels, the abnormalities related to digest, absorption and excretion may probably occur. [2, 12, 13].

Combining these syndromes due to the modulations of internal organs with the effect of acupuncture points of pericardium meridian, we can make a table representing the relationship between each internal organ and each acupuncture point of pericardium meridian as shown in Table.1, in which notion "*" shows the efficacious relations. For example, the acupuncture point Quze is supposed to be efficacious against the symptoms related to liver, heart, lung and kidney, as well as stomach and large intestine.

4.3   Modeling Internal Organs and Pericardium Meridian

Here, we construct a model of pericardium meridian and combine it with the model of internal organs proposed in the last section according to Table 1. As we have stated, meridians and acupuncture points connect skin and inner organs of body. Stimulating an acupuncture point, the signal is transmitted to the meridian and then circulation of Qi and flood is improved, which makes internal organs active. In the case of Quze, when it is stimulated, liver, heart, lung and kidney, as well as stomach and large intestine, are activated.

Based on the above, we modeled the influence of a single acupuncture on a single organ as shown in Fig.9. Acupuncture point is represented by a transition, stimulation of the acupuncture point is represented by firing the transition. Fitting together with state token of the single organ, the token generated by the firing goes through transition t_p to the input place of the organ, and it further moves to the state place (Output&State Place). Thus activation of the organ is represented.
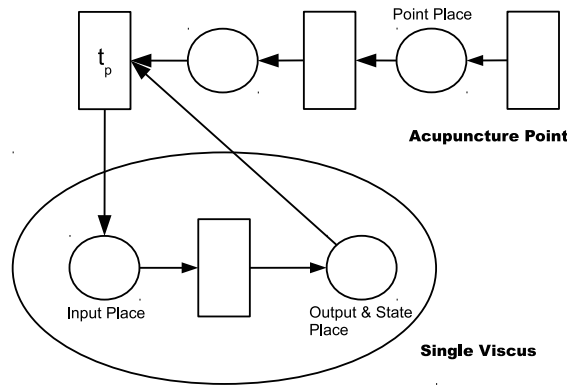

Fig. 9. A combined model of single acupuncture point and single organ.

Applying the same way as Fig.9 for all the organs according to Table 1, we finally get a complete model of internal organs and pericardium meridian as shown in Fig.10. Note that plural tokens generated by plural acupuncture points are accumulated at one place.

5   Simulation using CPN Tools

We have done simulation by using CPN Tools [9] for the model of Fig.10. The parameters are set as follows:

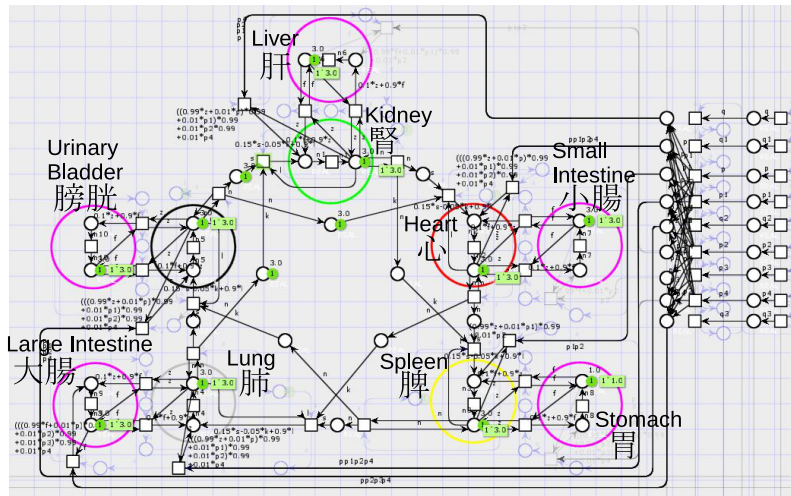**(1)** Data type for each place is defined by REAL;

Fig. 10. A complete Petri net model of internal organs and pericardium meridian.
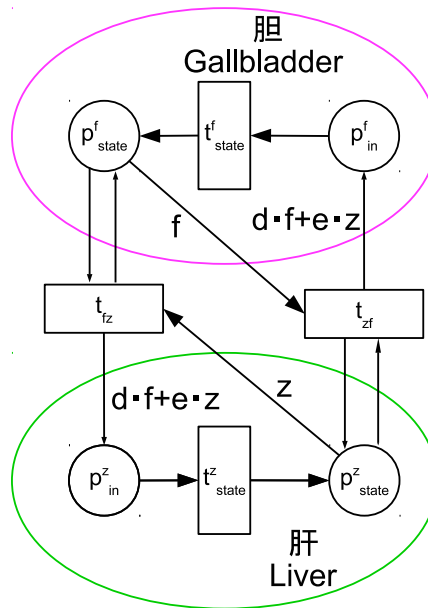

Fig. 11. Parameter setting for model of liver and gallbladder.

(2) Value of state token of each organ is defined in domain $(0.5, 5.5)$, which means that $(0.5, 1.5)[1.5, 2.5)[2.5, 3.5](3.5, 4.5)(4.5, 5.5)$ respectively five states, weak, little weak, equilibrium, little strength, strength;

(3) The parameters a_s, b_k, c in equation $f(t) = a_s \cdot f_s(t-1) - b_k \cdot f_k(t-1) + c \cdot f(t-1)$ are defined as $a_s = 0.15 b_k = 0.05 c = 0.90$;

(4) For each pair of five viscera and six bowels (e.g. liver and gallbladder as shown in Fig.11), set expression z for arc (p^z_{state}, t_{fz}), f for (p^f_{state}, t_{zf}), $d \cdot f + e \cdot z$ for (t_{zf}, p^f_{in}) and $d \cdot z + e \cdot f$ for (t_{fz}, p^z_{in}), where d and e are defined as $d = 0.90 e = 0.10$;

(5) One stimulation of each puncture point provides 0.01 active influence on the related organ.

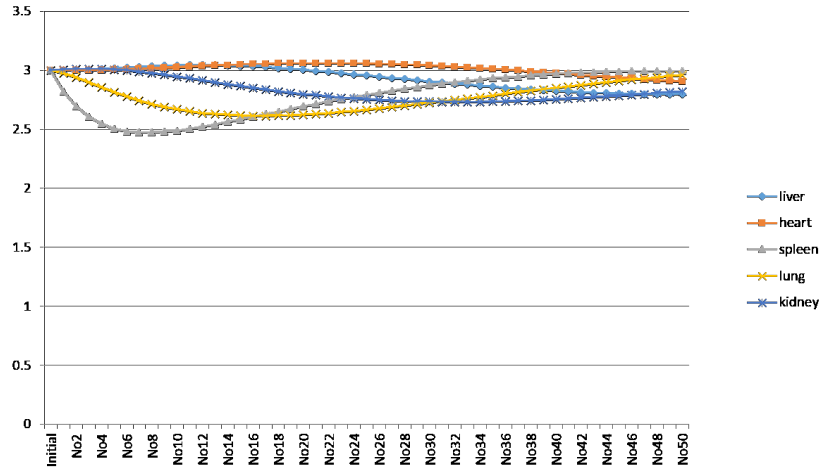Note that all the constants are temporarily decided for the simulation.

Fig. 12. Change of states of five viscera.

Simulations have been done based on the above parameters. We suppose that initially stomach is in weak state with state token value "1" and all the other organs are in normal state with "3". Among acupuncture points, Quze, Neiguan, Daling and Laogong have influence on stomach, and we choose Daling to do the stimulation for 50 times. Simulation results are shown in Fig.12 and Fig.13.

From Fig.12 and Fig.13 we can observe the following phenomenons. At first, weak stomach adversely affects spleen directly, and thus spleen weakens rapidly and its state value becomes lower than 2.5. Due to weakening of spleen and also the relationship of generation and restriction between five viscera, all the viscera gradually weaken except heart. On the other hand, spleen directly strengthens stomach and the acupuncture point, Daling, is stimulated continuously. These
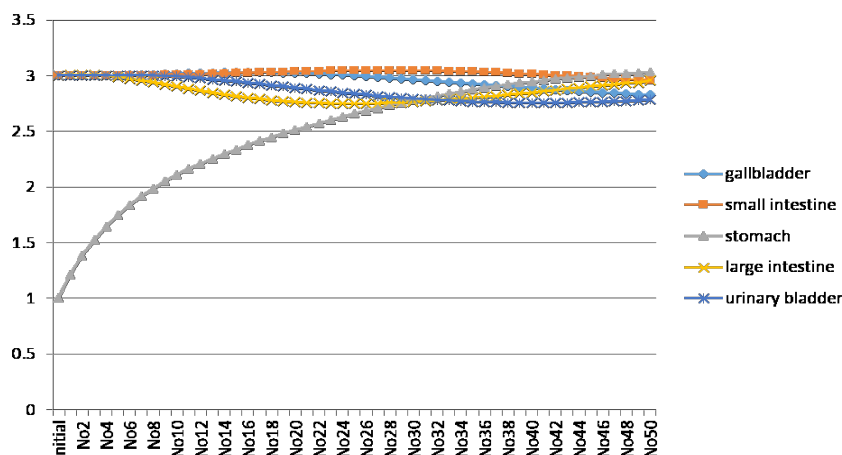
Fig. 13. Change of states of six bowels.

actions strengthen stomach rapidly and as the result stomach recovers its state value to 2.5 when Daling is stimulated 22 times. After that, all the organs recover gradually and finally get to health state with state values almost 3 when Daling is stimulated 50 times. Of particular interest is that any organs of six bowels are almost not affected by stomach except large intestine.

6   Conclusions

We have proposed a method of constructing Petri net model for internal organs and meridians based on traditional Chinese medicine. According to five-elements theory and the control model proposed by Sun et al., we have proposed a Petri net model of five viscera by considering the generation and restriction relationship between five viscera. Taking into account of the relationship of front and back between five viscera and six bowels (except triple energizer), we have made a model of internal organs. Through investigating the syndrome of internal organs as well as the function of pericardium meridian, we have proposed a Petri net model including internal organs and meridians by combining the model of internal organs with meridians. Finally, we do simulation to show how our model works by using CPN Tools.

It should be pointed out that this work does not intend to be a scientific contribution to medical science in the sense as it is usually understood. As the future works, we are to (1) decide parameters for all the transitions and places, as well as for tokens and arcs on the basis of the data of acupuncture treatment site; (2) do simulation to verify the validity of the proposed model and the parameters, in order to improve the model; (3) develop a method to construct a Petri net model for the whole human body.

Acknowledgement

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