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Analyzing the Consistency of Business Process Based on Behavioral Petri Net

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Abstract

Analyzing the consistency is the important part of business process management (BPM). Existing researches only consider the structural consistency of process model, or analyzing the single data. However, sometimes, the model is consistency without considering data in real life, while it is inconsistency after analyzing control and data. In this paper, based on the labeled behavioral Petri net, considering the change of data, the control flow and data flow of business process model is established from the perspective of partner process, and then obtains the interactive process model by interacting them. In the end, according behavior profile and behavior mapping, the behavior vector of the mapping transitions is given to calculate the behavioral distance vector and gets the behavior compatibility between the corresponding process models. If all behavior compatibilities can close to 1, BPM is consistency, and vice versa. In addition, it is proven that the method is valid by analyzing the theory and example.

Keywords: *Behavioral Petri net, Behavioral distance vector, Interactive process model, Behavior compatibility*

1. Introduction

The stage of constructing business process model is the core part for every company to realize informatization management. Because the computer technology is constantly updated, people's requirements of the credibility of the business process model are increasingly high. It is a burning problem to analyze the consistency and seek the change region of business process model in business process management (BPM).

Now, many researchers have given some solutions to solve the problem of BPM consistency. Through the notion of behavior equivalence and the criterion of trace equivalence are defined, the consistency of business process model is analyzed as discussed by elsewhere [1- 2]. Then in order to improve the limitation brought by such strict criterion, the notion of behavior profile is given and the behavioral consistency of business process model is analyzed as discussed [3-6]. With the extensive application of these studies, people analyze the consistency by mutual simulation and the behavioral similarity of BPM as discussed by Vladimiro Sassone [7]. In addition, Bonchi [8] applies this method to service composition, and then analyzes the consistency of business process model after composition. The above researches mainly analyze the consistency of their structure, *i.e.*, control flow model is only considered. In actual applications, the consistency of business process model doesn't only depend on the consistency of control flow, but also depend on the consistency of data flow. Therefore, these researches are imperfect. Impact on the modeling and execution of business process model is control flow and data flow. As discussed by Peng [9], the problem about security and convenience

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of querying data brings a heated debate in our daily life. Moser [10] describes the application of control flow and data flow of business process model in detail, and points the accuracy of modeling business processes also depends on data flow. As discussed by Batchelder [11], data flow has a certain degree of influence to the consistency of business process model. And Kumar [12] designs an evolutionary approach to detect effective intrusion based on dataset by considering conflicting objectives. Lecue [13] introduces the way of building data flow which is important in service composition. On the other hand, data flow is limited by the form of pure data, rarely depicted data model. In fact, most of researches mainly take the structure of control flow or the change of pure data in place into account, to analyze the consistency of net. But the change of data will produce some imperceptible influence, causing the inconsistency of business process model.

2. Motivative Example

For example, a customer, shopping on line, confirms payment after receiving goods, while net system is attacked by hacker. After receiving money by payment operation, hacker revises the amount of money, and sends the reduced money to payment center. At the same time, payment center only inform the customer and the seller that the trade is success, but they all ignore the real amount of money. Then seller will find the amount of money is wrong, when checks the account. It is obvious that the balance of capital flow has problems. Because of the change of data, it is necessary that clearly studies whether inconsistency of control flow affects consistency of data in BPM, or inconsistency of data flow affects consistency of business process model. However, according to the method of Wang et al. [5], this business process model in Figure 1 is consistency, which means the change of data affects the consistency of it. So, analyzing consistency of control flow and data flow is significant for accurately analyzing consistency in BPM.

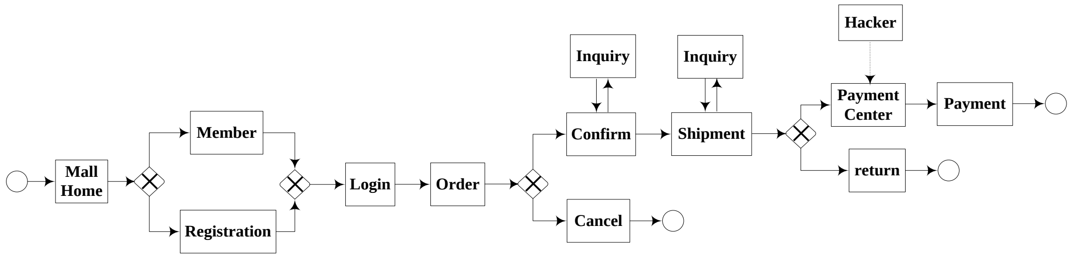

Figure 1. The Business Process Model of Shopping on Line

3. Basic Concepts

This paper gives some main notions, and other related notions are given by Weidlich and Grossmann, *et al.*, [14-17].

Definition 1(Labeled behavioral Petri net) A labeled behavioral Petri net of business process is a five tuple $LBP = (S, P; F, L, l)$, and satisfies:

(1) S is the set of states, and $S \neq \phi$.

(2) P is the set of activities, and $P \neq \phi$, $S \cap P = \phi$.

(3) $F \subseteq (S \times P) \cup (P \times S)$ is the flow relation.

(4) L is the set of all labels.

(5) l is a labeling function, *i.e.*, $l : P \rightarrow L \setminus \{\phi\}$.

Definition 2(Control flow) a control flow of $LBP = (S, P; F, L, l)$ is a four tuple $CF = (S_C, P_C; F_C, L_C, l_C)$, and satisfies:

(1) S_C is the set of states, and $S_C \neq \phi$, $S_C \subset S$.

(2) P_C is the set of activities, and $P_C \neq \phi, P_C \subset P$.

(3) $F_C = (S_C \times P_C) \cup (P_C \times S_C)$ is the flow relation.

(4) L_C is the set of all labels.

(5) l_C is a labeling function.

Obviously, control flow restricts the structure of business process model during execution.

Definition 3(Data flow) a data flow of P_D is a four tuple $DF = (S_D, P_D; F_D, L_D, l_D)$, and satisfies:

(1) S_D is the set of states, and $S_D \neq \phi, S_D \subset S$.

(2) P_D is the set of activities, and $P_D \neq \phi, P_D \neq \phi$.

(3) $F_D = (S_D \times P_D) \cup (P_D \times S_D)$ is the flow relation.

(4) L_D is the set of all labels;

(5) l_D is a labeling function.

Obviously, data flow, different with control flow, restricts and describes data information of business process model during execution, *i.e.*, a behavioral Petri net of business process model is built by interacting control flow with data flow. Therefore, considering consistency of both control flow and data flow is the main part of further studying consistency of business process model.

4. Calculating the Behavior Compatibility

Establishment, analysis and execution of business process model all depends on control flow and data flow. As discussed by Zhou, *et al.*, [15], the relation of control flow and data flow is dependence on each other. Li, *et al.*, [16] discuss the way to detect anomaly in BPM based on control flow and data flow. Obviously, consistency of control flow and data flow has a certain impact on BPM. For accurately analyzing the degree of influence from them, this paper proposes the behavior compatibility.

Definition 4(Partner process) Let $AP = (S, P; F, L, l)$ be a partner process of LBP.

(1) S is the set of states.

(2) P is the set of activities, which is classified into internal and external activities (P^e and P^i), $P \neq \phi, S \cap P = \phi$ and $P^e \cup P^i = P$.

(3) $F \subseteq (S \times P) \cup (P \times S)$ is the flow relation.

(4) L is the set of all labels, which is classified into internal and external labels(L^e and L^i) corresponding to P, and $L^e \cup L^i = L$.

(5) l is a labeling function.

Internal activities are only invoked by AP, and don't invoke activities, shown as rectangles. External activities are further classified into triggered and triggering activities (P^{ing} and P^{ed}), shown respectively as and. A triggering activity can invoke an activity of LBP, but a triggered activity is invoked by it. Obviously, if all external activities in AP are triggered activities, AP is passive.

Definition 5(Behavior mapping) a behavior mapping M between a partner process AP and behavioral Petri net LBP maps each external activity of AP to one activity of LBP in which triggering activities are mapped to triggered activities, and vice versa.

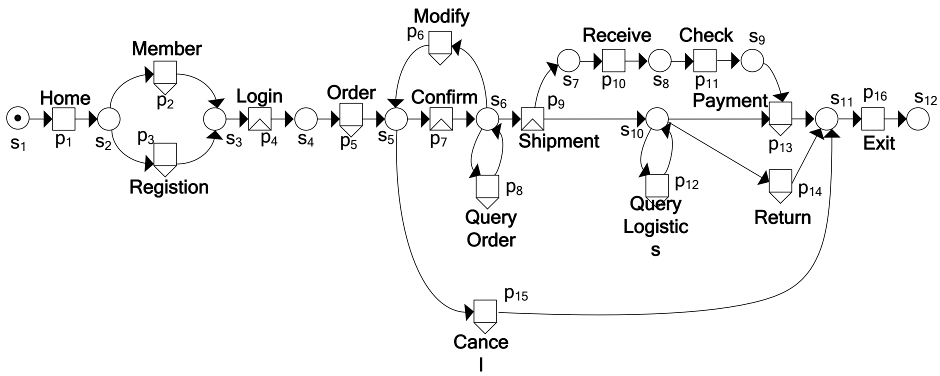

Figure 2. Control Flow of Shopping Process Model

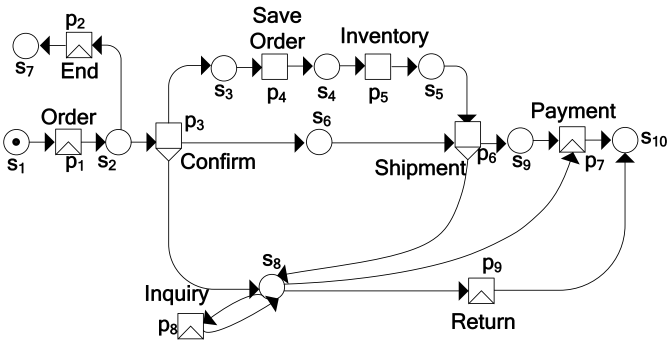

Figure 3. Data Flow of Shopping Process Model

In fact, every business process model has two partner processes, *i.e.*, control flow and data flow. A control flow in Figure 2 is one partner process of the shopping model mentioned in second part, and a data flow in Figure 3 is also another partner process.

It is visible that a business process model can be built by interacting control flow with data flow. Therefore, behavioral compatibility between them can analyze the major factor of affecting consistency of business process model. Interaction model and behavioral compatibility are defined as follows.

Definition 6(Interaction model) Based on behavior mapping, the interaction of net $N_1 = \{S_1, P_1; F_1, L_1, l_1\}$ and $N_2 = \{S_2, P_2; F_2, L_2, l_2\}$ is noted by $N_1 \otimes N_2$, i.e., $N_1 \otimes N_2 = (S_1 \cup S_2, P_1 \cup P_2, F_1 \cup F_2, L_1 \cup L_2, l_{N_1 \cup N_2})$ where mapped activities are same and other elements are different. During this operation, if N_1 is the main process of interaction, it is denoted by $N_1[N_2] \otimes N_2$, *i.e.*, those redundant but not final states are removed based on $N_1[N_2] \otimes N_2$.

Definition 7(Behavioral value) Let $LBP = (S, P; F, L, l)$ be a behavioral Petri net, which behavioral value $V_B(p_1, p_2)$ of pairs of $(p_1, p_2) \in P \times P$ is defined as follows:

(1) If $p_1 + p_2$, it holds $V_B(p_1, p_2) = 0$.

(2) If $p_1 \to p_2$ or $p_1 \to^{-1} p_2$, it holds $V_B(p_1, p_2) = 1$.

(3) If $p_1 \| p_2$, it holds $V_B(p_1, p_2) = 2$.

Definition 8(Behavioral distance vector) Let $LBP = (S, P; F, L, l)$ be a behavioral Petri net, $P = \{p_1, p_2, \cdots, p_n\}$ be a set of external activities, and $M = \{t_1, t_2, \cdots, t_m\}$ be a behavior mapping, such that

(1) behavior vector can be expressed as,

$$X = \left\{ \sum_{i=1}^{n} V(t_1, p_i), \sum_{i=1}^{n} V(t_2, p_i), \cdots, \sum_{i=1}^{n} V(t_j, p_i), \cdots \sum_{i=1}^{n} V(t_m, p_i) \right\} = \{x_1, x_2, \cdots, x_j, \cdots, x_m\},$$

(1) where $n = |P|$ is the number of activities, and $0 < j \le m$.

(2) behavioral distance vector can be obtained as,

$$D = \left(\frac{x_1 - x_{\min}}{x_{\max} - x_{\min}}, \frac{x_2 - x_{\min}}{x_{\max} - x_{\min}}, \cdots, \frac{x_j - x_{\min}}{x_{\max} - x_{\min}}, \cdots, \frac{x_m - x_{\min}}{x_{\max} - x_{\min}} \right) = (d_1, d_2, \cdots, d_m) \quad ,$$

(2)

where $x_{\min} = \min\{x_1, x_2, \cdots, x_m\}$ and $x_{\max} = \max\{x_1, x_2, \cdots, x_m\}$.

Definition 9 (Behavior compatibility) Let LBP_1 and LBP_2 be two behavioral Petri nets. The behavioral distance vectors of LBP_1 and LBP_2 is noted by $D = (d_1, d_2, \cdots, d_m)$ and $D^* = (d_1^*, d_2^*, \cdots, d_m^*)$ respectively. Therefore, behavior compatibility between LBP_1 and LBP_2 can be calculated by formula,

$$BC = \frac{\sum_{i-1}^{m} d_i \times d_i^*}{\sqrt{\left(\sum_{i=1}^{m} d_i^2\right) \times \left(\sum_{i=1}^{m} d_i^{*2}\right)}} . \tag{3}$$

Table 1. Behavior Mapping between Process Models

t		M(t)
Control Flow	Data Flow	Shopping Process Model
p_5	p_1	Order
p_7	p_3	Confirm
p_9	p_6	Shipment
p_{13}	p_7	Payment
p_{14}	p_9	Return
p_8	p_8	Inquiry
p_{12}		
p_{15}	p_2	Cancel

Based on the above definitions, two partner processes of business process model, using behavioral Petri net, is control flow and data flow. Then, according to interaction model, they are interacted by set control flow and data flow as the main process respectively. In the end, to get the behavior compatibility between these process models, behavioral distance vectors of two partner process and their interaction models are calculated on the basis of behavior profile. In this paper, the algorithm is given as follows.

Algorithm 1. Calculation of behavior compatibility between process models

Input: the behavior Petri net of business process $LBP = (S, P; F, L, l)$; the behavior mapping M; the behavior profile $BP_{LBP} = \{\rightarrow, \rightarrow^{-1} +, ||\}$; T_1 is the set of mapping activities of control flow; T_2 is the set of mapping activities of data flow; $|T_1|$ and $|T_2|$ are the number of their elements; $n = |M|$.

Output: behavior compatibility BC_1, BC_2, BC_1^* and BC_2^*.

Step1: Based on definitions 1, 2, 3 and 4, after shifting from business process model to behavioral Petri net $LBP = (S, P; F, L, l)$, its partner processes is given that is control flow $CF = (S_C, P_C; F_C, L_C, l_C)$ and data flow $DF = (S_D, P_D; F_D, L_D, l_D)$.

Step2: Based on the definition 6, interaction models $CF[DF]\otimes DF$ and $DF[CF]\otimes DF$ are got by set control flow and data flow as the main process respectively.

Step3: Based on the definition 5, the set of mapped activities in $CF[DF]\otimes DF$ is denoted by Q_1 and that in $DF[CF]\otimes DF$ is denoted by Q_2, corresponding to T_1 and T_2 respectively.

Step4: Based on definitions 7 and 8, corresponding to T_1, behavior vector X_1 and behavioral distance vector $D_1 = (d_{11}, d_{12}, \cdots, d_{1i})$ of control flow are given ; corresponding to T_2, behavior vector X_2 and behavioral distance vector $D_2 = (d_{21}, d_{22}, \cdots, d_{2j})$ of data flow are given; corresponding to Q_1, behavior vector Y_1 and behavioral distance vector $D_3 = (d_{31}, d_{32}, \cdots, d_{3k})$ of process model $CF[DF]\otimes DF$ are given ; corresponding to Q_2, behavior vector Y_2 and behavioral distance vector $D_4 = (d_{41}, d_{42}, \cdots, d_{4t})$ of process model $DF[CF]\otimes DF$ are given.

(1)If $|T_r| < |Q_s| \le n$ in which has $r,s = \{1,2\}$, existing $t \in T_r$ and $q_1, q_2 \in Q_s$ in behavior mapping of partner processes, it holds $M(t) = q_1$ and $M(t) = q_2$, i.e., $\sum_{i=1}^{|T_r|} V(t, p_i)$ corresponding to the element of Y_s is calculated by $\sum_{i=1}^{|Q_S|} V(q_1, p_i) + \sum_{i=1}^{|Q_S|} V(q_2, p_i)$, meeting $|X_r| = |Y_s|$, then returns to step 5;

(2)If $|Q_s| < |T_r| \le n$ in which has $r,s = \{1,2\}$, existing $q \in Q_s$ and $t_1, t_2 \in T_r$ in behavior mapping of partner processes, it holds $M(t_1) = q$ and $M(t_2) = q$, i.e., $\sum_{i=1}^{|Y_S|} V(q, p_i)$ corresponding to the element of Y_s is calculated by $\sum_{i=1}^{|T_r|} V(t_1, p_i) + \sum_{i=1}^{|T_r|} V(t_2, p_i)$, meeting $|X_r| = |Y_s|$, then returns to step 5;

(3)If $|Q_s| < |T_r| \le n$ in which has $r,s = \{1,2\}$, then returns to step 5.

Step5: Based on the definition 9, the behavior compatibility BC_1 between $CF = (S_C, P_C; F_C, L_C, l_C)$ and $CF[DF]\otimes DF$ is calculated; the behavior compatibility BC_2 between $DF = (S_D, P_D; F_D, L_D, l_D)$ and $CF[DF]\otimes DF$ is calculated; at the same time, it also works out the behavior compatibility BC_1^* and BC_2^* between $DF[CF]\otimes DF$ and them.

This algorithm, according to behavior profile, regards the activities in behavior mapping as basis to calculate behavior vector and behavioral distance vector among control flow, data flow and their interaction models, and then works out the behavior compatibility between these process models, for comprehensively analyzing the major factor and the degree of impact on BPM from control flow and data flow.

5 Analyzing Example

Existing researches haven't a specific description about the change of data flow, but also don't analyze the change of both control and data flow in detail. In this paper, these disadvantages are solved.

Figure 4 and 5, according to Figure 1, 2 and 3, give its partner process. Depending on the algorithm, the interaction models $CF[DF]\otimes DF$ and $DF[CF]\otimes DF$ is obtained by interacting control flow $CF=(S_C,P_C;F_C,L_C,l_C)$ with data flow $DF=(S_D,P_D;F_D,L_D,l_D)$, seeing Figure 4 and 5.

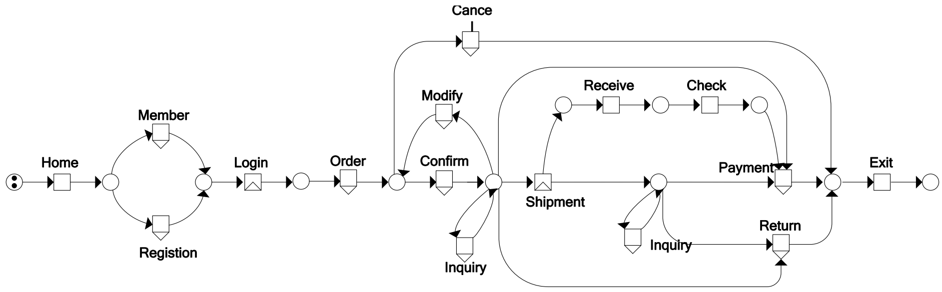

Figure 4. Interaction Model $CF[DF]\otimes DF$

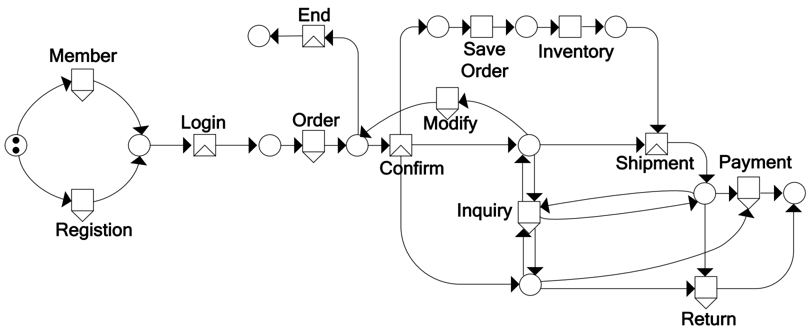

Figure 5. Interaction Model $DF[CF]\otimes DF$

Then, based on $M(t)=\{order, comfirm, shipment, payment, return, inquiry, cancel\}$ in Table 1, behavior vectors of these process models can give, $X_1=(11,14,10,8,8,26,4)$, $X_2=(6,6,5,4,4,7,1)$, $Y_1=(11,14,10,8,8,26,4)$, and $Y_2=(10,14,14,8,8,14,4)$. At the same time, behavioral distance vectors is $D_1=(\frac{7}{22},\frac{10}{22},\frac{6}{22},\frac{4}{22},\frac{4}{22},1,0)$, $D_2=(\frac{5}{6},\frac{5}{6},\frac{2}{3},\frac{1}{2},\frac{1}{2},1,0)$, $D_3=(\frac{7}{22},\frac{5}{11},\frac{3}{11},\frac{2}{11},\frac{2}{11},1,0)$, and $D_4=(\frac{6}{10},1,1,\frac{4}{10},\frac{4}{10},1,0)$.

Finally, the result is obtained, that is $BC_1=1.00$, $BC_2=0.90$, $BC_1^*=0.75$ and $BC_2^*=0.59$. Obviously, in this example, all of behavior compatibility can't achieve a high value, indicating the business process model is inconsistency. The major factor of impact on it is found by analyzing behavior compatibility of both control flow and data flow.

6. Conclusion

Analyzing consistency is the important part of BPM. According to the disadvantages of existing researches, this paper proposes a method from the perspective of partner process to analyze the consistency of business process model by considering control flow and data flow.

In this paper, according to behavioral Petri net, control flow and data flow are described based on the notion of partner process. Based on behavior profile and behavior mapping, behavior value is given, and then obtains behavior vector which is used to calculate behavioral distance vector. In order to observe the structure of business process model, interaction models can be built by interacting control flow with data flow. In the end, the consistency of business process management is analyzed by calculating behavior compatibility. This method avoids one-sidedness of variables, and overcomes the limitation of analyzing consistency of process model.

In the future, future work will study the behavioral relation of control flow and data flow by adding the token. In addition, the way of seeking change region is considered, and then adjustment is proposed to achieve the requirement of modeling.

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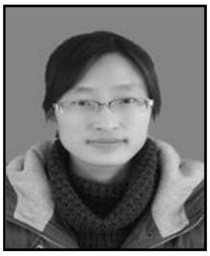

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