

The Analytical Method of Web Services Composition Based on Action Patterns

Xiangwei Liu¹, Wenjun Hao² and Xianwen Fang²

¹*Department of Management, Anhui University of Science and Technology,
Huainan Anhui, 232007, China*

²*School of Science, Anhui University of Science and Technology,
Huainan Anhui, 232001, China*

xwfang@aust.edu.cn, 280060673@qq.com, fangxianwen@hotmail.com

Abstract

In the word of service-oriented architecture and collaboration, it is important to deal with sub-services of cooperating components. In existing research, functions to meet and behavior predictability are two major aspects of Web services composition, but there are some limitations to treatment of behavioral constraints. In this paper, we model a component by an open Petri net, and investigate action patterns as a means to descript and analysis of behavior constraint under the condition that subnets composition are satisfied. This approach can effectively describe the constraint of behaviors, achieve behavior interaction between services and model a component that meets specific behavioral relations. Finally, the theoretical analysis and simulation results show the effectiveness of the method.

Keywords: *web services composition, open Petri net, action patterns, behavioral profile*

1. Introduction

With the development of network technology, Web service is becoming a new mode of Internet applications. It has a very important significance to reuse the network resource to meet the complex needs of the application, because the network services generally have simple structure and function.

Due to the depth research of the service behavior and model structure, more and more researchers pointed out that, for services, not only consider the static factors, such as semantics, syntax, but also consider the internal dynamic factors, such as data flow, control flow, interaction protocols and state transition behavior attributes. When the combination of multiple services, the interaction between the service behaviors will be complicated, prone to the state-explosion problem, which made the calculation and determination of the time complexity more difficulty.

There are a lot of different approaches have been proposed to discuss Web service composition and their behavior relationships. Web service composition is mainly divided into two categories, one is based on the combination of process-driven workflow, state calculus and process algebra model described method [1-3], another is automatic composition based on semantic description [4]. Wil M. P. *et al.* proposed the concept of service composition tree based on an open Petri net [5], and given a sufficient condition for proper completion to determine whether the sub-service can be combined. [6] is also based on the condition of soundness and models a sun-service by a colored Petri net, then discusses the compatibility and similarity. Based on bisimilarity and inspired by recent advances in the theory of reactive

systems, [7] defines a congruence is the largest bisimulation. Martin theory has been proposed to discuss the behavior congruence and compatibility of web service composition in [8]. However, it has some limitations to determine the consistency by bisimulation, which only reflect consistent or inconsistent. Until Weidlich M. [9-11] proposed the concept of behavioral profile that can accurately characterize the degree of similarity of the two models and can be further used to analyze the combined model credibility requirements. Fang et al [12, 13] further proposed the trustworthy Web services composition methods based on the behavioral profile.

In this paper we first model sub-services by open Petri nets, then define action patterns about activity transitions which can become an additional condition to mine the behavior relations between activities. In addition, the information on the labels is important for behavioral profile to capture constraint relations between activity transitions.

2. Preliminaries

Petri net is used to model web service because of its intuitive graphical symbol, rich theoretical analysis technology, and suitable for a variety of computer languages to describe. In the web services composition, it is not only to achieve the internal structure of subnets, but also the exchange of information between sub-services. In this paper, we model a component by a Petri net, and communication is done through an interface, modeled by input and output places. We call such a Petri net with an interface an open Petri net. The definition as follows:

Definition 1 (open Petri net) [5] An open Petri net is a 8-tuple (P, I, O, T, F, i, f, l) , where:

- (1) (P, T, F) is a Petri net;
- (2) P is a finite set of places, $P \neq \phi$;
- (3) T is a finite set of transitions, $T \neq \phi$;
- (4) I is a set of input places, $\bullet I = \phi, I \bullet \neq \phi$;
- (5) O is a set of output places, $\bullet O \neq \phi, O \bullet = \phi$;
- (6) P, I, O and T are pair wise disjoint;
- (7) M_i is the initial marking, M_f is the final marking and M_f is a deadlock;
- (8) $l : T \mapsto \Gamma$ is a mapping assigning to each activity transition a label.

In the remainder, in order to later described simple, we use OPN as the short-hand notation of open Petri net, and call the set $P_0 = I \cup O$ the interface places of the OPN .

The basic concepts in open Petri net, such as the definition of firing sequence, the preset or postset of places and transitions are in consistent of Petri net refer to the literature [14]. It is necessary to explain that the initial and final marking can not mark interface places. If M is a marking of an OPN , we say that a transition t is enabled in a marking M , in symbols $M[t >$. If a transition t firing results in a new marking M' , it's denoted by $M[t > M'$. We write $M[\sigma > M'$ if there exists a firing sequence $\sigma \in T^*$ that M' is reachable from M through σ . The set of all possible markings which are reachable from an

initial marking is denoted by $R(N)$, $R(N) = \{M' \mid \exists \sigma \in T^*, M[\sigma > M']\}$. If we don't consider the interface places and all associated flow relationship between them in OPN , there is a marking $M_f, M_f \in R(N)$, where $\exists t \in T$ let $M_f[t > .$ This marking is called terminate marking which the token number in these places is more than 0, while in other places the tokens are adsorbed.

Two open Petri nets can be composed by fusing interface places and communication is done through an interface. In this paper, we focus on the component of sub-services with interfaces. And two $OPNs$ are composable if they satisfy the condition as follows.

Definition 2 (Composable condition of $OPNs$)^[2,5,6] Two open Petri nets OPN_1 and OPN_2 , their composition is $COPN = OPN_1 \oplus OPN_2$, where:

- (1) $\forall M, M' \in R(COPN), \exists \sigma \in (T_1 \cup T_2)^*$, such that $M \xrightarrow{\sigma} M'$;
- (2) For $OPN_1, M|_{OPN_1} \xrightarrow{\sigma|_{OPN_1}} M'|_{OPN_1}$;
- (3) For $OPN_2, .$

The composable condition of $OPNs$ claims that there exists a firing sequence in a component which its projection in each subnet does not produce unwanted behavior relations. At this point, we think that the service behavior is compatibility, *i.e.*, $\exists \sigma \in T^*, M_0[\sigma > M_f$, such that $\forall M \in R(N), M[\sigma' > M_f \wedge M_f(p) \neq 0$. Note that M_0 is the initial marking of $CNET$.

3. Problem Analysis

In the second section, the composable condition shows how the subnets can be associated in order to achieve behavior interaction between interfaces. As shown in Figure 1, there are three components, 1, 2 and 3. 1 and 2 is composable, as well as 2 and 3. However, the composition of three has a deadlock, *i.e.*, we can not find a firing sequence in the net work that from the initial marking to final marking. Moreover, the flow relations increase between subnet interfaces, and some internal behavior relations would change because of the labels in the activity transitions. These changes, some satisfy the demand, some can be deleted, and even let the composition has a deadlock. Sequence fragment $\{v_2, t_2\}$ shown in Figure 1 has a deadlock.

In order to illustrate the hidden problem in composition, we give an example of shopping. There are two kinds of buyers in the Taobao mall, gold and ordinary member. When the gold go to shopping online, the seller would send his goods after accepts order information, he does not need to check whether have received the electronic bill. And the gold enjoys the points for prizes promotions or discount merchandise. However, ordinary member does not enjoy neither promotion. But once the amount of consumption reaches a certain amount, he can apply to become a Gold Member.

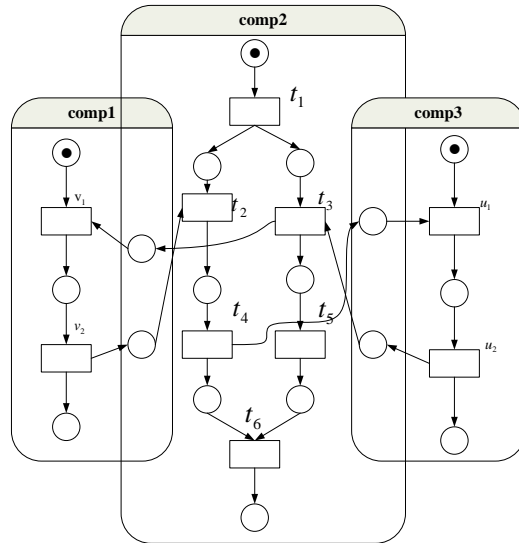


Figure 1. Model Components of COPN

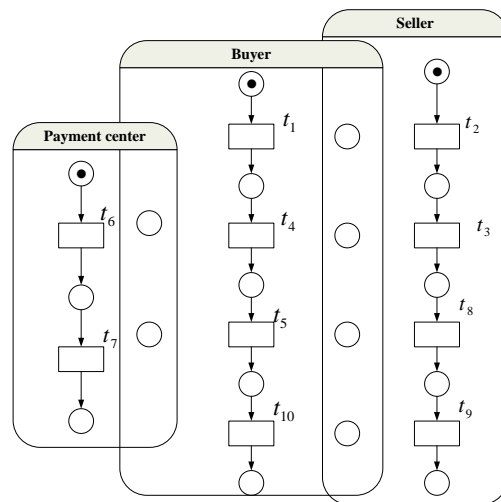


Figure 2. Model Components of Shopping

Figure 2 has three components, payment center, buyers and sellers, they are described by three open Petri nets. As shown above. If buyer is an ordinary member B , the firing sequence is $\sigma = \{t_1, t_2, \dots, t_9, t_{10}\}$, and the three components are composable. But if buyer is a gold member A , when A sent order information to the seller at t_1 , there are three cases: (1) sellers directly delivery goods to A , so $t_3 \sim t_8$ in firing sequence σ does not need to perform; (2) The seller sends Points exchange for prizes information to A , and deliveries goods after receives the answer, so the firing sequence is $\{t_1, t_2, t_3, t_4, t_5, t_8, t_9, t_{10}\}$; (3) when A sends order information to the seller, A also requires points continue to accumulate and not exchanges for prizes. Then the sequence occurs as same as (1). This shown that different flow relationships are decided by different label information on the activity transitions. If we are able to bind customers'

requirements and information as a constraint of the behavior relations, the compositional model's credibility will be greatly enhanced.

4. Action Patterns and Behavioral Profile

In order to solve the problems in the previous section, add labels on activity transitions of OPN has great importance for constraint part of the action behavior. At this stage, we consider the action of a label to be characterized by a verb that indicates a certain operation. We formalize this interpretation by a verb function. The concepts of verb function are described as follows:

Definition 3 (Verb function) [15, 16] For a given open Petri net $OPN = (P, I, O, T, F, i, f, l)$, the verb function is denoted by $v: \Gamma \mapsto V$, i.e., for $\forall t \in T$, such that $v_a(t) = v_a(l(t))$. We use $V_{OPN} = \bigcup_{t \in T} \{v_a(t)\}$ to denote the set of all verbs of an open Petri net OPN .

The verb stems from a noun indicating the action. Verb function indicates the different actions included in the activity transitions, and one activity often has more than one verb. For example, as t_2 shown in Figure 2, receives the order information and sends the message, has "receive" and "send" two actions. This implies the relationship between the preset and postset of a transition. Further, we formalize the notion of action pattern of OPN as follows.

Definition 4 (Action pattern) [15, 16] For a given open Petri net $OPN = (P, I, O, T, F, i, f, l)$, the verb collection is denoted by $V_{OPN} = \bigcup_{t \in T} \{v_a(t)\}$, action patterns is denoted by $AP = (OPN, V_a)$, such that $V_a \subseteq V_{OPN}$ and $\exists v(l(t) \notin V_a)$.

$P_0 = I \cup O$ is the set of interface places, $\{V_T(t) \mid t \in T \wedge ((t \times p_0) \cup (p_0 \times t)) \subseteq F\}$ is interface action patterns of OPN , AP_{p_0} is its short-hand notation. Action pattern is a set of verbs, does not provide information about what the order do with these actions. In other words, we can find some verbs or activities in $COPN$, but we don't know the order relationship, which result in a variety of compositions. To address this question, behavioral dependencies between the actions need to be identified.

For a network running, there is a certain relationship between the sequences of activity transitions. To capture behavioral aspects on the level of pairs of transitions, we apply the notion of behavioral profile. The behavioral profile is grounded on the notion of weak order, if there exists an execution sequence in which one transition occurs after the other.

Definition 5 (Weak order relation) [9-11] Let $OPN = (P, I, O, T, F, i, f, l)$ be an open Petri net, T^* is the set of firing sequences. The weak order relation $\succ \subseteq (T \times T)$ contain all pairs (x, y) , t such that here is a firing sequence $\sigma = t_1, \dots, t_n \in T^*$ with $i \in \{1, \dots, n-1\}$ and $i < j \leq n$, for which holds $t_i = x$ and $t_j = y$.

The weak order relation indicates that transitions on an occurrence sequence are associated with each other. We can define behavioral profile as follows.

Definition 6 (Behavioral profile) [9-11] Let $OPN = (P, I, O, T, F, i, f, l)$ be an open Petri net. A pair $(x, y) \in T \times T$ is in one of the following relations:

- (1) Strict order relation: $x \rightarrow y$, if $x \succ y$ and $y \not\succeq x$;
- (2) Exclusiveness relation: $x + y$, if $x \not\succeq y$ and $y \not\succeq x$;
- (3) Interleaving order relation: $x \parallel y$, if $x \succ y$ and $y \succ x$.

The set of all three relations is the behavioral profile of OPN , denoted by $BP_T = \{\rightarrow, +, \parallel\}$. The relation of the behavioral profile, with $x \rightarrow^{-1} y$ as the inverse strict order relation for $x \rightarrow y$.

5. The Method of Web Service Composition based on Action Patterns and Behavioral Profile

There are a lot of different approaches have been proposed to achieve web service composition. In general, all of them are classified into two classes, one is based on the state calculus which applies to the description of the static system, but difficult to handle dynamic characteristics; another is semantic-driven method that is to find the optimal composition, but lack of the evaluation model. The approach proposed in this section is based on open Petri net, not only has a good formal semantics and intuitive graphical description, but also has a good advantage of description in the dynamic operation of the concurrency, synchronization, conflict, deadlock and so on. The basic concepts are summarized in second section, and behavioral profile only capture the relationship between a single transition. In order to ensure the correctness of the composition system, firstly, we need to consider whether achieve the interaction behavior between subnets, what about behavioral compatibility, then whether produce the correct execution sequence or not, and finally examine the behavior effect and its credibility.

Definition 7 (Verbs set of $COPN$) A tuple $C = (\bigcup_{i=1}^n OPN_i, V)$ is a verb collection, where;

(1) $\bigcup_{i=1}^n OPN_i$ is a nonempty finite set of open Petri nets that they are composable components;

(2) $V = \left\{ V(t) \mid t \in T, T \in \bigcup_{i=1}^n OPN_i \right\}$ is the set of all actions in the verb collection of components.

In general, the data mining techniques are used to explore the relationship between transitions. But we capture relationship between activities with their actions and labels. Based thereon, two elementary notions can be defined as follows.

Definition 8 (Support set, Strength) A tuple $C = (\bigcup_{i=1}^n OPN_i, V)$ is a verb collection; where:

(1) Support set: n is the number of action A in C , and n_0 is the number of A in action pattern AP , If the set of A in AP is denoted by X , and $n_0 \leq n$, we denote the support for set X with $\text{sup}(X)$. The minimum level of support for sets to be min sup which has the minimum number of required, denoted by $\text{min sup}(X)$, for which holds $\text{sup}(X) \geq \text{min sup}(X)$.

(2) Strength: there are two action sets X and Y in AP with $X \cap Y = \phi$, we called $\frac{\text{sup}(X \cup Y)}{AP}$ is the strength of X and Y in AP , denoted by $\text{str}(X \cup Y)$.

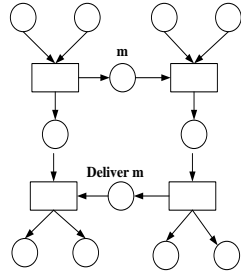


Figure 3. $\text{sup}(re) = 1$

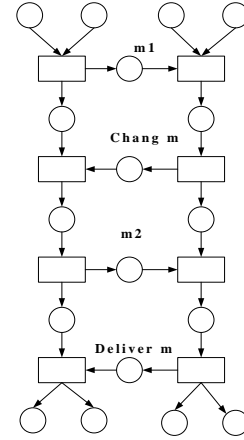


Figure 4. $\text{sup}(re) = 2$

Support set and strength have an important role to explore the behavior relationships between activity transitions in action patterns. They reflect a certain activity transition in the occurrence of an action pattern. Many relationships will be produced in the composition process of subnets. We need to keep the relationships that help to achieve the desired behavioral effects, while the other relationships can be excluded with the action pattern of the support set and strength requirements. Take an example in third section, the seller receives a buyer's order information, he identifies the category of the customer first, then decides the next step behavior. If the support set of action-“receive” information of buyer is 1, the part of service composition as shown in Figure 3, while the support set is 2, as shown in Figure 4.

We introduce action pattern-behavioral profile as an approach to capture the behavior relationships between the sequence fragments. Support set reflects the frequency of occurrence of a certain action, the strength shows the times of co-occurrence actions in a given sequence. These can be used as a tool to derivate behavior relations and to help get the target modeling.

Definition 9 (Action pattern-Behavioral profile) $\bigcup_{i=1}^n OPN_i$ is a nonempty finite set of composable open Petri nets, $C = (\bigcup_{i=1}^n OPN_i, V)$ is its verb collection, $APBP = (R, \text{min sup}, \text{con})$ is an action pattern-behavioral profile of $OPNs$, where:

(1) R : $X, Y \subseteq V \times V, V \times V \in \{\rightarrow, \rightarrow^{-1}, +, \parallel\}$, i.e., X and Y constitute of pairs of actions for which behavioral relations are specified;

(2) min sup is the value of the required minimal support;

(3) con is the value of the required minimal that satisfies the desired behavioral effects, between 0 and 1.

Based thereon, given a set of service components, firstly, it is necessary to determine whether the service components can be composable, and it is important to satisfy the composable condition of components. Then looking for the relationship between the associated activity transitions in behavior filed.

Algorithm 1: Judgment the composable of the subnets

Input: A_1, \dots, A_n , services components

Output: result of the judgment

(1) Modeling components based on open Petri nets get OPN_1, \dots, OPN_n . In view of the components are grouped in pairs, when $1 \leq i \leq n$, first consider OPN_1 and OPN_2 ;

(2) OPN_1 and OPN_2 are composable if and only if $(P_1 \cup I_1 \cup O_1 \cup T_1) \cap (P_2 \cup I_2 \cup O_2 \cup T_2) = (I_1 \cap O_2) \cup (O_1 \cap I_2)$, their composition is $OPN_1 \oplus OPN_2$. Next, go to step (3), on the contrary, the algorithm terminates;

(3) According to definition 2, if $OPN_1 \oplus OPN_2$ satisfies the condition, go to step (4), on the contrary, the algorithm terminates and output OPN_1 and OPN_2 are incomposable;

(4) When $i \geq 2$, $OPN_1 \oplus OPN_2 \oplus \dots \oplus OPN_i \oplus \dots \oplus OPN_n$ satisfies the condition, if $r: \{2, \dots, n\} \rightarrow \{1, \dots, n-1\}$ which holds:

1) $\forall r(i) < i$, 2) $\forall 1 \leq i < j \leq n$, $(i \neq r(j) \Rightarrow I_i \cap O_j = \varnothing \wedge O_i \cap I_j = \varnothing) \wedge (i = r(j) \Rightarrow I_i \cap O_j \neq \varnothing \vee O_i \cap I_j \neq \varnothing)$. The algorithm terminates and output the components are composable. On the contrary, they are incomposable.

(5) The algorithm terminates and output the result.

Algorithm 1 can find the components that satisfy the composable condition, but can not get the constraint relations between components unless the flow relationship is determined. But if the AP and $APBP$ is given, we can judge the behavior constraint relations of system whether satisfy the users' expected results. This is shown in Algorithm2.

Algorithm 2: Judgment the behavior constraints satisfiability of the composable components

Input: $COPN$, the composition of open Petri nets, AP , $APBP = (R, \min \sup, con)$

Output: result of the judgment

(1) Identify the set of interfaces of each open Petri net, denoted by p_1, \dots, p_n , and $T = \bigcup_{i=1}^n (\bullet p_i \cup p_i \bullet)$ is the collection of their preset and postset. For $\forall t_a, t_b \in T$, such that $(t_a, t_b) \in \{\rightarrow, \rightarrow^{-1}, +, \parallel\}$;

(2) $v(t_{a_1}), \dots, v(t_{a_k})$ are the set of each action in AP , for $\forall 1 \leq i \leq k$, such that $|v(a_i)| \geq \min \sup(t_{a_i})$, go to step (3). On the contrary, the algorithm terminates, outputs dissatisfy;

(3) M_0 is the initial marking and M_f is the final marking, calculate the correlation matrix A ;

(4) Calculate X by the equation $M_f = M_0 + A^T X$, if $\forall x_i \in X$, $x_i \geq 0 \wedge x_i \in z$, $\lambda(t_{a_i}/\sigma) = |v(a_i)|$ and satisfy the value of con , go to step (3). On the contrary, outputs dissatisfy;

(5) The algorithm terminates and output the result.

6. Conclusion

In this paper, we have presented a novel approach to deal with web services of cooperating components and model a component by an open Petri net. There are two steps to complete the composition. The first step, given the composable condition that requires there is at least one execution sequences to ensure that the model does not deadlock. The second step, generate behavior sequences that satisfy customers' needs and their expected behavior results under the condition of knowing the behavioral profiles and action patterns of some actions.

In the future, we aim at extending our approach in two directions. In the service composition process, it is imperative to investigate flow arcs and behavior relations changing with the impact of action patterns. Another direction of the future work is further research on model synthesis with action patterns and testing the correctness of the model.

Acknowledgments

We would like to thank the support of the National Natural Science Foundation of China under Grant No.61340003, No.61272153, No.61100058, No.61170059 and No.61170172, the Natural Science Foundation of Educational Government of Anhui Province of China (KJ2012A073, KJ2011A086), Anhui Provincial Natural Science Foundation (1208085MF105), Anhui Provincial Soft Science Foundation (12020503031), the Academic and Technology Leader Foundation of Anhui Province (DG119).

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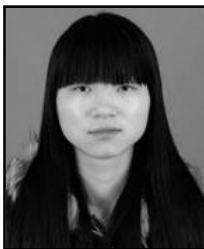
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Authors



Xiangwei Liu, She received the M.A. degree from Anhui University of Finance and Economics, China, in 2005. She is currently an associate professor with the Department of Computer Science and Engineering, Anhui University of Science and Technology, China. Her current areas of research are Web service computing, Petri net and formal verification of software. He has published more than 20 papers in the international academic journals, these papers are embodied more than 20 times by SCI and EI and are cited more than 60 times by others.



Wenjun Hao, She received the M.A. degree from Anhui University of Science and Technology, China, in 2011. She is currently a lecturer with the Department of Computer Science and Engineering, Anhui University of Science and Technology, China. Her current areas of research are concurrent theory, Petri net and formal verification of software.



Xianwen Fang, He received M.A. degree from Shandong University of Science and Technology, China, in 2004, and PhD. degree in the key Lab of Service Computing at Tongji University in 2011. He is currently a Professor with the Department of Computer Science and Engineering, Anhui University of Science and Technology, China. His research interests include Petri net, trustworthy software and Web services. He has published more than 60 papers in domestic and international academic journals and conference proceedings. These papers are embodied more than 40 times by SCI and EI and are cited more than 100 times by others.