A Logic Petri Net Method to Analyze the Well-structured Property of WS-BPEL

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ABSTRACT  
A Web service process is well-structured, means its branch flows are splited and converged correctly in the logical structure. Well-structure is an important property to guarantee a service process to work normally. To detect the well-structured property of Web service process described by WS-BPEL, a logical Petri net method is proposed. The service process based on WS-BPEL is modeled as a service net form logical petri nets and the well-structured property is mapped into the features of logic expressions in the logical transitions of the service net. The formal definition and decision method of well-structure is proposed and the examples are also provided to show how to detect whether a service net is well-structured or not. From the proposed method in this study, the well-structured property of WS-BPEL can be easily analyzed.

Key words: Web service, well-structure, logic petri net, WS-BPEL

INTRODUCTION  
Web service is a mature technology to achieve the network-based software oriented service computing. A lot of Web services with small grain and simple functions were developed and deployed in the Internet. The software developer can invoke them to build new application system or compose them into Web service processes to cater complicated service requests.

To realize service composition effectively, many composition languages and interface specifications are proposed, such as WS-BPEL, WS-CDL and WSCI. WS-BPEL is the mainstream language of service composition in the industry. However, WS-BPEL is not a strict formal composition language and it adopts the XML format codes to describe the service process. The structural defects of the Web service process, such as interactive deadlock, structure redundancy, or non-well structure cannot be discovered from the code of WS-BPEL directly. These structural defects are the fatal errors for the Web service processes and should be detected and eliminated.

A Web service process is well-structured means that its branch processes are splited and converged correctly in the logical structure. The concept of well-structure is frequently used in the research of workflow (Eder et al., 2013; Ha and Suh, 2008; Van der Aalst et al., 2011). Since the Web service process is similar with workflow, many researchers introduced well-structure into the study of Web service to express whether the logical structure is correct and soundness in the service process. However, most of the proposed methods (Chae et al., 2008; Li et al., 2011; Xiong et al., 2010) are with a high complexity in detect the well-structured property.

How to easily analyze the well-structured property of WS-BPEL is focused in this study. A method to analyze whether a service process based on WS-BPEL is well-structured or is proposed which based on logic petri net.
SERVICE NET BASED ON LOGIC PETRI NET

A logic petri net is generated by appending the logic expressions on some of the transitions in petri nets. It had been successfully used to the model and analyze the real-time cooperative systems (Du et al., 2007), E-commerce workflows (Du et al., 2009) and the Web service processes (Hu et al., 2014). Now the definitions of logical petri net and service net are provided.

Definition 1

Logic petri net: \( \text{LPN} = (P, T, F, I, O, M) \) is a logic petri net if the following hold:

- \( P \) is a finite set of places
- \( T \) includes three subsets of transitions, i.e., \( T = T_D \cup T_I \cup T_O \), where, \( T_D \) denotes a set of traditional transitions, \( T_I \) denotes a set of logic input transitions and \( T_O \) denotes a set of logic output transitions
- \( F \) is a flow relation, i.e., a set of directed arcs \( F \subseteq (P \times T) \cup (T \times P) \)
- \( I \) is a mapping function from a logic input transition to a logic input expression, i.e., \( \forall t \in T_I, \ I(t) = f_i \)
- \( O \) is a mapping function from a logic output transition to a logic output expression, i.e., \( \forall t \in T_O, \ O(t) = f_o \)
- \( M: P \rightarrow \{0, 1\} \) is a marking function, \( \forall p \in P, \ M(p) \) denotes the token count in \( p \)
- The firing rules of the transitions in \( \text{LPN} \) are defined as follows:
  - \( \forall t \in T_D, \ if \ P \subseteq t: M(p) = 1, \ t \ is \ enabled. \ If \ t \ is \ enabled, \ it \ can \ fire \ and \ generate \ a \ new \ marking \ M' \ is \ generated \ from \ current \ marking \ M, \ denoted \ by \ M[t \rightarrow M'], \ where:\
    \[
    M'(p) = \begin{cases} 
    M(p) - 1, & p \in t - t \\
    M(p) + 1, & p \in t - t - t \\
    M(p), & \text{otherwise}
    \end{cases}
    \]
  - \( \forall t \in T_I, \ I(t) = f_i, \ if \ f_i | M = t \bullet, \ i.e., \ all \ input \ places \ of \ t \ satisfy \ the \ input \ expression \ f_i \ at \ M, \ t \ is \ enabled. \ If \ t \ is \ enabled, \ it \ can \ fire \ and \ generate \ a \ new \ marking \ M', \ where:\
    \[
    M'(p) = \begin{cases} 
    M(p) - 1, & p \in t \\
    M(p), & \text{otherwise}
    \end{cases}
    \]
  - \( \forall t \in T_O, \ O(t) = f_o, \ if \ \forall p \in \bullet t: M(p) = 1, \ t \ is \ enabled. \ If \ t \ is \ enabled, \ it \ can \ fire \ and \ a \ new \ marking \ M' \ is \ generated \ and \ \exists S \subseteq \bullet, \ S \ must \ satisfy \ f_o | M' = \bullet t \bullet:\
    \[
    M'(p) = \begin{cases} 
    M(p) - 1, & p \in t \\
    M(p) + 1, & p \in S \\
    M(p), & \text{otherwise}
    \end{cases}
    \]

Definition 2

Service net: A service net is a labeled logic petri net and defined as \( \text{SN} = (\text{LPN}, I, O, \Gamma, \varphi) \) where:
LPN is the net model of the service net with the following rules:
- \( P = P_c \cup P_d \) is a set of places, where \( P_d \) is a set of data places interacting with the exterior Web services and \( P_c \) is a set of control places which represent the states of the Web service
- \( T = T_d \cup T_p \cup T_o \) is a set of transitions, where \( T_p \) represents the operations in a service process; \( T_d \) and \( T_o \) denote the set of logic transitions used to control the business flow in the service process
- \( F \) represents the transformational relation between service operations and service states
- \( i \) and \( o \) are two special control places, where \( i \) is the initial place and \( o \) is the terminal place of a service process, with \( i \neq o = \emptyset \) and the initial marking \( M_o(i) = 1 \), \( M_o(p) = 0 \) for any other place \( p \)
- \( \varphi : T \rightarrow \Gamma \) is a bidirectional mapping, where \( \Gamma \) is a alphabet

**MAPPING RULES BETWEEN SERVICE NET AND WS-BPEL**

Many literatures had provided the methods to convert the service process described by WS-BPEL into petri net. There are some open-source engines, which can analyze and run WS-BPEL, such as RiftSaw and ActiveBPEL2.0. With the help of engine tools, the model transformation can be easily achieved. Since focusing on the well-structured property of WS-BPEL, the mapping rules between the main control structures of WS-BPEL and service net are proposed in this section.

The control structure of WS-BPEL includes the labels of `<receive>`, `<reply>`, `<invoke>`, `<sequence>`, `<if>`, `<pick>`, `<flow>`, `<while>` and `<repeatUntil>` (Tan et al., 2009). To simplify the structure of converted model from WS-BPEL to service net, control structures with similar functions are classified into the same category. The mapping rules of control structure between WS-BPEL and service net are presented in Fig. 1. The label `<variables>` in the WS-BPEL is mapped into a place with a variable name.

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Fig. 1: Mapping rules between WS-BPEL and service nets
DEFINITION OF WELL-STRUCTURE

The definition of well-structured in WS-BPEL is based on the concept of well-structured workflow nets. A well-structured service process is that which parallel branches initiated by an AND split should be synchronized by an AND joint. And the alternative branches initiated by OR split should be synchronized by an OR joint.

Let \( F = \{ f_1, f_2, \ldots, f_k \} \) be a set of service processes, \( t_\circ \) and \( t_i \) be two logic transitions linking \( F \) with parallel or alternative structure.

Definition 1

Logic expression on parallel or alternative structure: \( O(t_\circ) \) and \( I(t_i) \) represent the logic expressions on \( t_\circ \) and \( t_i \), respectively. To distinctly differentiate the type of logic transitions, the logic expressions \( O(t_\circ) \) and \( I(t_i) \) should be formulated as the following standard forms.

- \( O(t_\circ) = f_1, i \wedge \neg f_2, i \wedge \ldots \wedge \neg f_n, i \wedge f_{n+1}, i \wedge \ldots \wedge f_j, i \), denoted as \( O_v \)
- \( O(t_\circ) = f_1, o \wedge f_2, o \wedge \ldots \wedge f_j, o \), denoted as \( O_h \)
- \( I(t_i) = f_1, o \lor f_2, o \lor \ldots \lor f_j, o \), denoted as \( I_v \)
- \( I(t_i) = f_1, i \lor f_2, i \lor \ldots \lor f_j, i \), denoted as \( I_h \)

A symbol \( \circ \) is introduced to represent the type of logical expression of logical transition.

Definition 2

Matching logical transitions: Let \( F = \{ f_1, f_2, \ldots, f_k \} \) be a service net, \( t_1 \) and \( t_2 \) are the logical transition to link \( F \), \( \forall f_j: \pi_i(f_j, i) = t_1 \), \( \forall f_j: \pi_2(f_j, o) = t_2 \), \( 1 \leq j \leq n \). If \( t_1 \) and \( t_2 \) are logical input transition and logical output transition or in converse, \( t_1 \) and \( t_2 \) are called matching logical transitions.

Definition 3

Synergetic expression: Let \( F = \{ f_1, f_2, \ldots, f_k \} \) be a service net, \( t_\circ \) and \( t_i \) are the logical transition to link \( F \), \( \forall f_j: \pi_i(f_j, i) = t_\circ \), \( \forall f_j: \pi_2(f_j, o) = t_i \), \( 1 \leq j \leq n \). If \( \partial(t_\circ) = O_v \land \partial(t_i) = I_v \) or \( \partial(t_\circ) = O_h \land \partial(t_i) = I_h \), \( O(t_\circ) \) and \( I(t_i) \) are called the synergetic expression, they are denoted as \( O(t_\circ) \circ \partial(t_i) \).

Definition 4

Well-structured service net: \( SN \) is a service net, if \( \forall t, c, e \in SN \), \( \exists t_\circ: O(t_\circ) \circ \partial(t_i) \circ t_\circ \in SN \), \( \exists t_\circ: I(t_i) \circ \partial(t_\circ) \circ t_i \) then \( SN \) is a well-structured service net.

DETECT WELL-STRUCTURED IN WS-BPEL

Decision method: From definition 4, two steps need to be checked in analyze whether a Web service process is well-structured. One is whether its logical transitions are occurred dually, i.e., a logical input transition with a corresponding logical output transition, the other is whether the dual

Algorithm 1: Detect well-structure in the service process based on WS-BPEL

Input: A service process \( SP \) described by WS-BPEL

Output: Whether the service process \( SP \) is well-structured or not

- Construct the service net \( SN \) for \( SP \) from the mapping rules
- Traverse the \( SN \) to find the dual logical transitions and check whether they are matching logical transitions
- For each matching logical transitions, check their logical expression is synergetic expression or not
- If all the dual logical transitions are matching logical transitions with synergetic expression, then the \( SP \) is well-structured, otherwise, the \( SP \) is not well-structured
logical transitions are with a matching expression. A concise algorithm to detect whether a WS-BPEL based service process is well-structured is proposed in algorithm 1.

**Examples:** Due to the algorithm 1, there are two types of service net which are not well-structured. One is with non-matching logical transition, the other is with non-synergic expression.

Figure 2 shows two service nets while Fig. 2a is well-structured and Fig. 2b is not well-structured. The logical transition $t_{\text{out}}$ is with a non-matching logical transition, i.e., there is no

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**Fig. 2(a-b): Service net with non-matching logical transition**

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Fig. 3(a-b): Service net with non-synergic expression
logical transition matching $t_{o2}$. The branch flow $f_1$ and $f_2$ should be converged first by a logical input transition and then synchronized by the logical transition $t_{o1}$, i.e., the well-structured service process is shown as the service net in Fig. 2a.

Similarly, Fig. 3 shows two service nets while Fig. 3a is well-structured and Fig. 3b is not well-structured. The logical transition $t_{o1}$ and $t_{o2}$ are with non-synergetic expression. The logical expression of logical transition $t_{o1}$ is $p_1 \land p_2 \land \lnot p_3 \lor \lnot p_1 \land \lnot p_2 \land p_3$, it means that the branch flow $f_1$ and $f_2$ should be executed simultaneously or only the branch flow $f_3$ is executed. The branch flow $f_1$, $f_2$, and $f_3$ are not permitted to be executed simultaneously. However, the logical expression of logical transition $t_{o2}$ is labeled a logical expression $p_4 \land p_5 \land p_6$, all the branch flow $f_1$, $f_2$, and $f_3$ should be executed simultaneously while the logical transition $t_{o1}$ is triggered. Thus, the expression labeled on the logical transition $t_{o1}$ and $t_{o2}$ is not a synergetic expression and the service net is not well-structured.

The service net shown in the Fig. 3a is well-structured, the logical expression of logical transition $t_{o2}$ is updated as $p_4 \land p_5 \land p_6$ and it is the synergetic expression of $p_4 \land p_5 \land p_6$.

**Comparison:** The method based on Communicating Reachability Graph (CRG) (Li et al., 2011) and the siphon based method (Xiong et al., 2010) to analyze the well-structured property were provided based on the petri net. The communicating reachability graph is a variant of the coverability tree, thus it cannot avoid the space explosion when the service process with a complicated business flow. The siphon based method was also faced the same problem since the coverability tree need building when the siphon of the petri net was computed. Since the two petri net based methods were with the problem of space explosion they could only be used to detect the well-structured property of simple service processes. An efficient result cannot be achieved when the above method used to analyze the well-structured property of complicated service processes. The comparison of our proposed method and the above methods (Li et al., 2011; Xiong et al., 2010) is shown in Table 1. The logic petri net method is not with the problem of space explosion and it is also with a high efficiency since the coverability tree is not built when analyzing the well-structured property.

**CONCLUSION**

Well-structure is a vital property of service processes. Since WS-BPEL is not with a formal format, it is difficult to detect the well-structured property in the service process described by WS-BPEL. A logical petri net method to analyze the well-structured property of WS-BPEL is proposed in this study. By mapping the WS-BPEL into a service net modeling by logic petri net, the well-structured property is converted by the restriction of logical expression in the service net. The well-structured property is easily analyzed by detecting whether the logical transitions are with the synergetic expressions. The examples are also given to shown the efficiency of the proposed method in this study.
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