RC22321 (C0202-001) February 1, 2002
Computer Science

IBM Research Report

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Wei Ding, Zhong Tian, Lei Zhang, Jian Wang, Jun Zhu, Haiqi Liang
IBM Research Division
China Research Lab
2/F No. 7, 5th Street
Shangdi, Haidian District
Beijing 100085, P.R. China

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Wei Ding, Zhong Tian, Lei Zhang, Jian Wang, Jun Zhu, Haiqi Liang
{dingw, tianz, lzhang, wangwj, zhujun, lianghq}@cn.ibm.com
IBM China Research Lab
4F, Haohai Building, 5th Shangdi Street
Haidian District, Beijing China 100085

Abstract: Business process management systems facilitate the understanding and execution of business processes, which tend to change frequently due to changes inside and outside of an enterprise. Therefore, there is a prominent need for analytical methods to verify the correctness of business process models. One key element of such business process is its control flow. We show how a flow specification may contain certain structural conflicts that could compromise its correct execution. Identifying such conflicts is computationally complex and requires efficient algorithms specific for target system language. We present a verification approach and algorithm that employs condition reachable matrix to identify structural conflicts in inter-enterprise business process models. The main contribution of the paper is a new technology for identifying structural conflicts and satisfying well-defined correctness criteria in inter-enterprise business process models.

Keywords: Business Process Model, Conflict Analysis, Conditional Reachable Matrix

1. INTRODUCTION

In the information age, e-Business is key to business survival. AMR Research reports that e-Business drastically increases the needs for effectively managing complex, cross-enterprise business processes (BP). e-Business Process Management requires a combination of process modeling and analysis, application execution, workflow management, application integration, and process intelligence. Consequently, business processes related to inter-enterprise exchange are becoming increasingly important. A flow specification may contain certain structural conflicts that could compromise its correct execution. This paper focuses on effective inter-enterprise BP verification.

A BP verification method used in Action Portal Model[1] is adapted the algorithms coming from Yang's in Phenomenon Porcess Program[2]. The method is to construct a complete state transition diagram to simulate all possible execution paths of the process and check whether they are consistent. This, however, would face the combinatorial explosion problem leading to poor performance. In [3] some verification problems are covered and the complexity of selected correctness problems are identified, but no concrete verification procedures are available. [4] and [5] propose Petri Net based verification procedures. The technology in [5] is developed for checking the consistency of transactional workflows including temporal constraints. However, the technology is restricted to acyclic workflows and only gives the necessary conditions. [6] proposes a reduction technology and defines a soundness criterion. The workflow processes considered is acyclic free-choice Petri nets in essence.

This paper differs from the above approaches by focusing on inter-enterprise BP. Few papers [7, 8] explicitly focus on the problem of verifying the correctness of interorganizational workflows. [7] specifies the interaction between domains in terms of message sequence charts and the actual overall workflow is checked with respect to these message sequence charts. A similar, but more formal and complete approach is presented in [8]. The authors give local criteria, using the concept of scenarios (similar to runs or basic message sequence charts), to ensure the absence of certain anomalies on the global level.

In the rest of the paper, section 2 defines a generic BP modeling language for building process models, and section 3 analyzes the structural conflicts of inter-enterprise BP models and their correctness criteria. Based on structural conflicts analysis, a verification approach that employs condition reachable matrix is presented in section 4. We present our conclusion is section 5.

2. INTER-ENTERPRISE BUSINESS PROCESS MODELING

Fig.1 shows our modeling objects which include: nodes, connectors and flows.

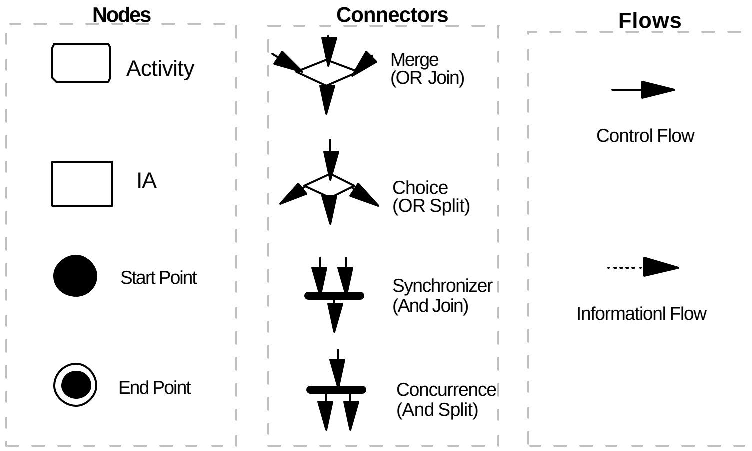

Fig.1 Inter-Enterprise BP modeling objects

There are mainly four types of nodes: ***Activity*** is a work to be done to achieve certain objectives. ***IA*** (Information Artifact) corresponds to the exchange of message between multiple BPs. The model should have one ***Start Point*** and at least one ***End Point***.

There are four types of BP logical connectors: **Choice (OR-Split)**, **Merge (OR-Join)**, **Concurrence (AND-Split)** and **Synchronizer (AND-Join)**. A*nd-split* is used to represent concurrent paths within a BP. A*nd-join* is applied to synchronize such concurrent paths. *Or-split* is used to model mutually exclusive alternative. *Or-join* is applied to join mutually exclusive alternative paths into one path.

There are two types of flows: ***control flow*** and ***information flow***. *Control flow* links two nodes in the intra-enterprise BP model. *Information flow* links two IAs or IA-with-activity to represent information sending/receiving action.

3. STRUCTURAL CONFLICT DEFINITION IN INTER-ENTERPRISE BP

Let us clear our assumptions and definitions in this section. Section 4 will discuss our conflict detection approach and algorithms based on these concepts. A process model using modeling objects in section 1 is a Directed Acyclic Graph (DAG). To simplify the discussion, we assume that the model

- does not have any loops, which are edges from a vertex to itself;
- does not have any multiple edges between pairs of nodes;
- does not have any iteration structure;

Let us discuss some basic concepts before identifying structural conflicts and correctness criteria for inter-enterprise BP model.

3.1 Basic terms

Definition 1: ***Instance subgraph:*** an instance subgraph represents a subset of business process model that may be executed for a particular instance of a business process.
An instance subgraph can be generated by visiting its nodes on the semantic basis of underlying modeling structures. The or-split, which is exclusive and complete, is the only structure in a business process model that introduces more than one possible instance subgraphs. At runtime, the BP model selects one of the alternative execution paths for a given instance of the business process by activating one of the outgoing flows originating from the or-split condition object. Figure 2 shows a business process graph and its two instance subgraphs.

Definition 2: ***Choice Path*:** A choice path of node n is a sequence of choice branch <*c1,c2...ck*> from start point to node *n*.

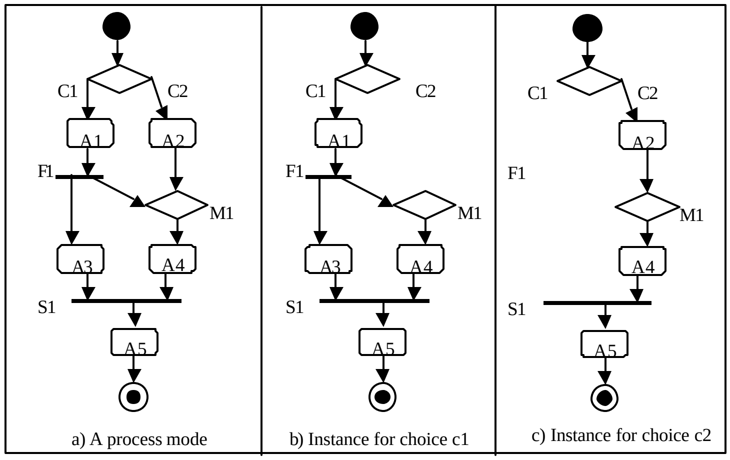

Fig.2 Example intra-BP Model with flow deadlock structural conflicts

Choice path is a useful definition that represents a node in some instance subgraph of the BP model. A node may have several different choice paths. *ChoiceSignpost* is a choice set which represents the entire choice path by set. If two nodes in intra-enterprise BP model have the same choice path, then the two nodes are always in the same instance subgraph. Activities A1 and A3 serve as a good example in Figure 2.

Definition 3 :*An intra-enterprise BP model (Intra-BPM) is a tuple:* intra-BPM=(*N*, *F*), where:

- *N* is a finite set of nodes (without IA).
- $F \subseteq (N \times N)$ is a finite set of control flows representing directed edges between two nodes.

Definition 4 :*An inter-enterprise BP model (Inter-BPM) is a tuple:* Inter-BPM=(*N1,F1,N2,F2,M,T*), where:

- *N1* is a finite set of partner1's nodes (without IA).
- $F1 \subseteq (N1 \times N1)$ is a finite set of partner1's control flows.
- *N2* is a finite set of partner2's nodes (without IA).
- $F2 \subseteq (N2 \times N2)$ is a finite set of partner2's control flows.
- *M* is a finite set of IA pairs.
- *T* is a finite set of information flows representing directed edges between two nodes.

A formal notation of BP model used in the conflict detection is given as the following,

i. For each flow $f \in F$:
   - *start*[*f*] = *n* represents start node *n* of *f*.
   - *end*[*f*] = *n* represents end node *n* of *f*.

ii. For each node and connector $n \in N$:
   - *type*[*n*] ∈{*Start Point, End Point, Merge, Choice, Synchronizer, Concurrence, Activity*} represents type of *n*.
   - *dout*[*n*] : number of outgoing flows from *n*.
   - *din*[*n*] : number of incoming flows to *n*.
   - *Choicesignpost*[*n*,i] where $n \in N$ *and* $1 \leqslant i \leqslant din[n]$,represents choice set of node n entry i from start point to node n. If the node has only one entry(for example :activity), parameter i can be omitted.

iii. For each IA pair $m \in M$ has only one sender and receiver:
   - *Receiver*[m]= n={ $m : m \in M$, n: n ∈N1∪N2, *type*(n)={activity} and $\exists t \in T$, where *start*[t] = *m* and *end*[t] = *n* }, n is the receiver activity of the IA pair m.
   - *Sender*[m]= n={ $m : m \in M$, n: n ∈N1∪N2, *type*(n)={activity} and $\exists t \in T$, where *start*[t] = *n* and *end*[t] = *m* }, n is the sender activity of the IA pair m.

3.2 Inter-Enterprise BP Structure Conflict Definition

Definition 5: A business process model is said to be structural correct if and only if it is:

a. **Syntactically correct:** Each object satisfies object types and the number of incoming and outgoing flows connected to them.
b. **Reachable and termination error free:** Each node is reachable from the Start Point and the End Point can be reached from this node.

Before detecting for BP structural conflicts, the model should be syntax correct and meeting the assumptions we made earlier. Structural conflicts are not the only types of possible errors in BP models. However, they do represent primary sources of errors in flow specifications and can be identified independently. We put inter-enterprise BP structural conflicts into two categories: intra-BP and inter-BP conflicts. Intra-BP model correct criterion guarantees proper termination of the model for all instance subgraph. Inter-BP model correct criterion guarantees proper interaction of multiple partners for all instance subgraph.

Definition 6: ***Correct intra-enterprise BP model:*** For any instance subgraph, the flow must terminate eventually at end point.

As or-join and and-join are the only two structures in a BP model that may cause the improper flow termination, we can further define two types of such structural conflicts, flow deadlock and lack of exclusion, as the following,
Definition 6.1: Flow deadlock - Joining exclusive choice with a synchronizer results into a flow deadlock conflict.
A flow deadlock at a synchronizer structure blocks the continuation of a business process path since one or more the incoming transitions of the synchronizer are not triggered. Figure 2 shows an instance subgraph with flow deadlock structural conflict. In figure 2 c), the process instance will have a deadlock at synchronizer S1 if it selects choice C2. Accordingly, this instance would not terminate properly as A5 can not be executed.
Definition 6.2: Lack of exclusion - Joining two or more concurrent paths with a merge structure introduce lack of exclusion conflict.

A lack of exclusion at a merge structure causes unintentional multiple activation of nodes that follow the merge structure. Figure 3 shows an instance subgraph with the lack of exclusion structural conflict. In figure 3 c), the process instance will have a lack of exclusion if it selects choice C2, since two parallel activities A3 and A4 will multiply activate the nodes that follow the merger node m1, then the instance would not terminate properly.

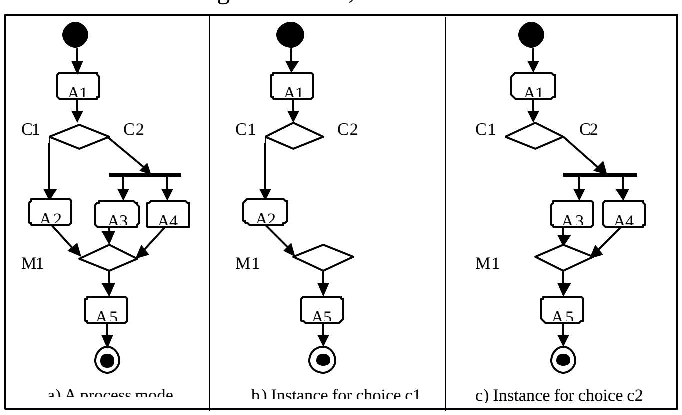

Fig.3 Example intra-BP Model with exclusive join structural conflicts

Correct intra-enterprise BP model should not have flow deadlock and lack of exclusion structural conflicts. A BP model is free of flow deadlock structural conflicts if it does not generate an instance subgraph that contains only a proper subset of the incoming nodes of an and-join node, i.e. for any synchronizer in the model, the *ChoiceSignposts* of all synchronizer entries are equal. A BP model is free of lack of exclusion structural conflicts if it does not generate an instance subgraph that contains more than one incoming nodes of an or-join node. i.e. for any merge in the model, the any two *ChoiceSignposts* of all merge entries have no intersection.

Definition 7: ***Well mapped inter-enterprise BP model:*** for any instance subgraph in inter-enterprise BP model, there is no dangling IA.

A dangling IA is an IA associated only with sender or receiver, i.e. an IA produced in one side is not consumed by the other side, vice versa. There are two forms of dangling IA in an inter-BP model, dominant and recessive. The former is easy to catch as the IA does not have connection with any IA from partner side. The latter is more complex and difficult to catch. It is caused by different choice path at runtime when the instance subgraph of both partners are fixed. We call this kind of conflicts as *different choice path structural conflict.* In Figure 4, although all the IAs are matched in the model, they are not well mapped. When PARTNER1 selects choice C1 at runtime, it can only produce IA11. IA22 at PARTNER2 is dangling, hence the difference choice path structural conflict.

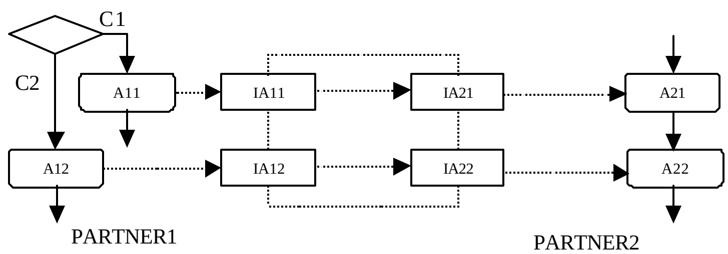

Fig.4 Example inter-BP Model with choice mapping structural conflicts

Definition 8: ***Well ordered inter-enterprise BP model:*** In a well mapped inter-enterprise BP model, the partial order of IA pairs enable both side procedure terminate eventually at end point for any instance.

At runtime, the BP model of each partner executes a sequence of defined activities depending on the path chosen. Some activities may produce or consume IA. If an activity consumes IA, the activity can be executed only when the IA is available. Otherwise the activity would never be activated. Thus, we have these two definition,

Definition 8.1: IA deadlock - Inconsistent sequence of IA production/consumption results into an IA deadlock. An IA deadlock between partners blocks the continuation of a business process path of both side since two activities need IA and the IA is not available.

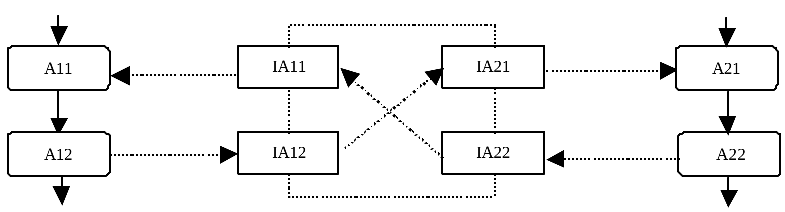

Fig. 5 Example inter-BP Model with IA deadlock structural conflicts

Figure 5 shows an inter-BP model with IA deadlock structural conflict. At runtime, activity A11 in partner A need to consume IA11 and then activate A12 to produce IA12. However, activity A21 in partner B need to consume IA21 and then trigger A22 to send IA22. So the inter-BP model would deadlock.

Definition 8.2: Lack of synchronization - Inconsequent sequence of IA production/consumption introduces lack of synchronization. Strictly speaking, lack of synchronization will not result in deadlock in an inter-BP model, but it is not economical in real life. Figure 6 shows an inter-BP model with two kinds of lack of synchronization structural conflict.

Definition 9 :*A correct inter-enterprise BP model satisfies the following requirements:*

i. Each intra-enterprise BP model is correct;
ii. Inter-enterprise BP model is well mapped;
iii. Inter-enterprise BP model is well ordered;

The common point in both cases of conflict detection is to examine all possible instance subgraphs of a BP model. The or-split is the only structure in a business process model that introduces more than one possible instance subgraphs. The number of possible instance subgraphs could grow exponentially as the number of or-split and or-join structure increases in a BP specification. Therefore, a brute force method to generate all possible instance subgraphs of a BP model to ensure correctness is not computationally effective.

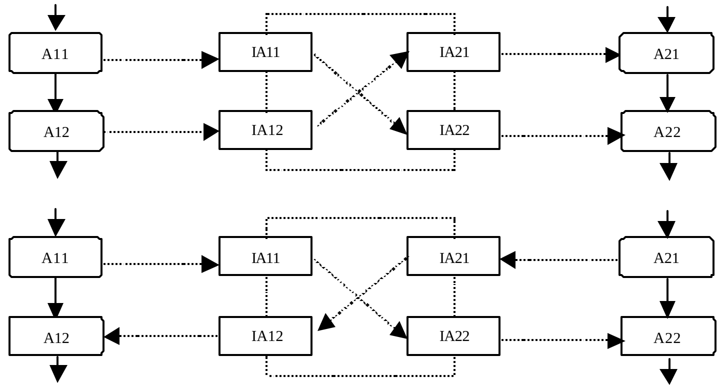

Fig. 6 Example inter-BP Model with Lack of synchronization structural conflicts

4. CONFLICT DETECTION ALGORITHM

In this section, both effective intra/inter BP conflict detection algorithms are introduced, given the innovative definition of condition reachable matrix as basis.

Condition Adjacency Matrix

Suppose $G=(N,F)$ is an intra-BP model where $|N|=n$. For simplicity, here we suppose *type*[*n*]={activity}. The condition adjacency matrix $A(G)$, with respect to the nodes, is the $n \times n$ matrix with I as its $(i,j)th$ entry when node *ni* and *nj* are directly adjacent, and Φ as its (i,j)th entry when they are not adjacent, and choice set, for example $\{C1\}$, as its (i,j)th entry when they are adjacent by choice *C1*. In other words, if its adjacency matrix is $A(G)=[a_{ij}]$, then

$$a_{ij} = \begin{cases} I \\ C \\ \Phi \end{cases}$$

Condition Reachable Matrix

According to condition adjacency matrix of an intra-BP model, node condition reachability can be calculated. The condition reachable matrix represents the mutually reachable properties of any two nodes in the model. Its generation procedure is described as follows.

Procedure: Condition reachable matrix generation *(A(G): n×n condition matrix)*

```
M:= A(G);
For i:=1 to n
Begin
  for j:=1 to n
  Begin
    If M[j,i]≠ Φ then
       For k:=1 to n
         Begin
               A[j,k]:=A[j,k]∪ {A[i,k]∩M[j,i]}
         End
  End
End
```

Conflicts Detection Algorithm

The intra BP conflict detection procedure is described as follows.

Procedure: ***Intra-BP model structural conflict detection***

For any node n, n ∈N

If type(n)={synchronizer} and Choicesignpost[n,1]= Choicesignpost[n,2]= ......= Choicesignpost[n,k] (k is the number of entry of node n) Then

The BP model contains no flow deadlock conflicts

Else

Report node n with flow deadlock

If type(n)={merge} and Choicesignpost[n,i]⋂Choicesignpost[n,j]≠ Φ, i≠j (i and j are the any two entry of node n) Then

Report node n with exclusive join conflicts

The inter BP conflict detection procedure is described as follows.

Procedure: ***Inter-BP model structural conflict detection***

For any IA pair m, m ∈M

If Choicesignpost[Receiver(m)]≠Choicesignpost[Sender(m)] Then

Report nodes Receiver(m) and Sender(m) with choice mapping structural conflicts

For any two IA pair mi and mj, mi ∈ M,mj ∈M

Switch

Case 1 (Receiver(mi)∈N1 and Receiver(mj)∈N1) or (Receiver(mi)∈N2 and Receiver(mj)∈N2)

If (Receiver(mi)→Receiver(mj) and sender(mj)→sender(mi)) or Receiver(mj)→Receiver(mi) and sender(mi)→ sender(mj)) Then

Report the four activities that link IA pair mi and mj contains lack of synchronization conflicts

Case 2 (Receiver(mi)∈N1 and Receiver(mj)∈N2) or (Receiver(mi)∈N2 and Receiver(mj)∈N1)

If Receiver(mi)→Sender(mj) and Receiver(mj)→sender(mi)) Then

Report the four activities that link IA pair mi and mj contains IA deadlock conflicts

If Sender(mi)→Receiver(mj) and Sender(mj)→Receiver(mi)) Then

Report the four activities that link IA pair mi and mj contains lack of synchronization conflicts

Here →is a reachable symbol, For example, for node n1 and n2, n1 →n2 represents n2 is reachable from n1.

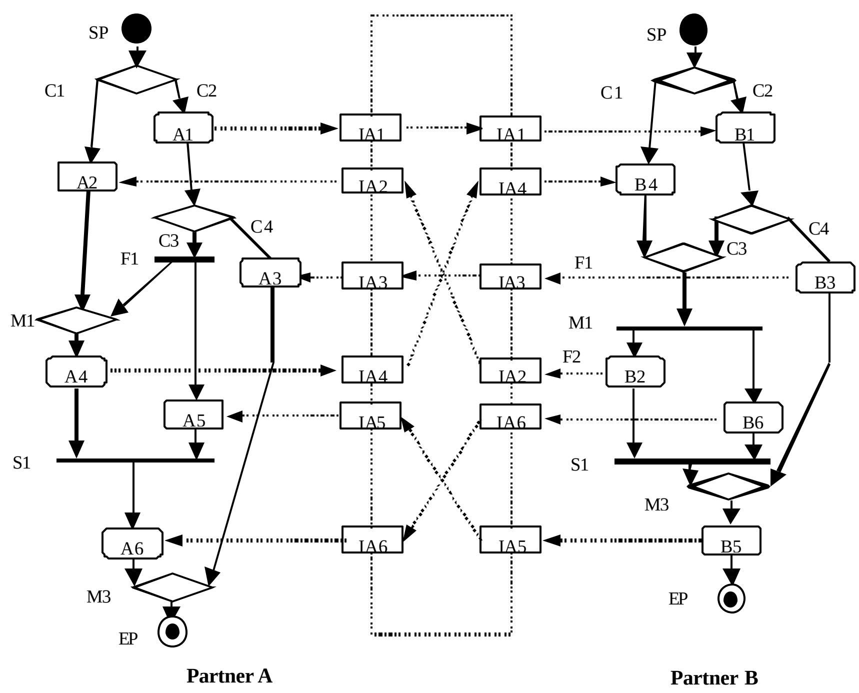

Fig. 7 an inter-enterprise business process model

Case Study

An inter-enterprise business process model is shown in Figure 7. Corresponding condition adjacency/reachable matrices can be seen in Table 2~4.

Table. 2 Condition adjacency matrix of partner A

	SP	A1	A2	A3	A4	A5	A6
SP	Φ	C2	C1	Φ	Φ	Φ	Φ
A1	Φ	Φ	Φ	C4	C3	C3	Φ
A2	Φ	Φ	Φ	Φ	I	Φ	Φ
A3	Φ	Φ	Φ	Φ	Φ	Φ	Φ
A4	Φ	Φ	Φ	Φ	Φ	Φ	I
A5	Φ	Φ	Φ	Φ	Φ	Φ	I
A6	Φ	Φ	Φ	Φ	Φ	Φ	Φ

Table. 3 Condition reachable matrix of partner A

	SP	A1	A2	A3	A4	A5	A6
SP	Φ	C2	C1	C2 ⋂C4	C1⋃(C2⋂C3)	C2⋂C3	C1⋃(C2⋂C3)
A1	Φ	Φ	Φ	C4	C3	C3	C3
A2	Φ	Φ	Φ	Φ	I	Φ	I
A3	Φ	Φ	Φ	Φ	Φ	Φ	Φ
A4	Φ	Φ	Φ	Φ	Φ	Φ	I
A5	Φ	Φ	Φ	Φ	Φ	Φ	I
A6	Φ	Φ	Φ	Φ	Φ	Φ	Φ

Table. 4 Condition reachable matrix of partner B

	SP	B1	B2	B3	B4	B5	B6
SP	Φ	C2	C1⋃(C2⋂C3)	C2 ⋂C4	C1	I	C1⋃(C2⋂C3)
B1	Φ	Φ	C3	C4	Φ	I	C3
B2	Φ	Φ	Φ	Φ	Φ	I	Φ
B3	Φ	Φ	Φ	Φ	Φ	I	Φ
B4	Φ	Φ	I	Φ	Φ	I	I
B5	Φ	Φ	Φ	Φ	Φ	Φ	Φ
B6	Φ	Φ	Φ	Φ	Φ	I	Φ

Table. 5 Different choice path structural conflicts analysis

	SP	A1	A2	A3	A4	A5	A6
SP	Φ	C2	C1	C2 ⋂C4	C1⋃(C2⋂C3)	C2⋂C3	C1⋃(C2⋂C3)
	SP	B1	B2	B3	B4	B5	B6
SP	Φ	C2	C1⋃(C2⋂C3)	C2 ⋂C4	C1	I	C1⋃(C2⋂C3)
Conflict	No	No	Yes	No	Yes	Yes	No

Let's use the synchronizer S1 in partner A side, and Merge M3 in partner B side to illustrate the conflict detection procedure introduced in the paper

ChoiceSignpost[S1,1]=*ChoiceSignpost*[A4]=C1⋃(C2⋂C3),

ChoiceSignpost[S1,2]=*ChoiceSignpost*[A5]=C2⋂ C3,

As *ChoiceSignpost*[S1,1]≠*ChoiceSignpost*[S1,2], there is a flow deadlock reported at S1.

Similarly,

ChoiceSignpost[M3,1]=C1⋃(C2⋂C3), *ChoiceSignpost*[M3,2]=C2 ⋂C4,

ChoiceSignpost[M3,1]⋂*ChoiceSignpost*[M3,2]=[C1⋃(C2⋂C3)]⋂(C2⋂C4)=(C2⋂C3)⋂(C2⋂C4)=Φ

Hence, M3 is free of exclusion structural conflict.

Different choice path structural conflict of the given inter BP model can be analyzed through comparing the partners' condition reachable matrices, as shown in Table 5.

5. CONCLUSION

In this paper we report our approach of using condition reachable matrix for detecting structural conflicts in inter-enterprise business process models. A graphic process model representation is provided as basis for our verification approach and corresponding algorithms. Correctness criteria of inter-enterprise BP model and major several major types of structural conflicts are identified. An effective algorithm based on condition reachable matrix is then illustrated for both intra and inter-BP structure conflict verification.

The approach is intuitive and natural. Structural conflicts can be identified easily and accurately with the generation of condition reachable matrix. Whereas, as different parties may have different vocabulary/symbol to represent same condition branch expressions, the algorithm we reported in this paper still need to rely on user participation to avoid reporting ontology misunderstanding as conflicts.

Although the approach presented in this paper deals with business process model that can be represented by a directed acyclic graph (DAG), our further study finds the method can be applied to BP model with cycles and iteration structure.

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