Verification of Behavior-aware Privacy Requirements in Web Services Composition

Jiajun Lu
College of Computer Science and Technology, Nanjing University
of Aeronautics and Astronautics, Nanjing, 210016
Email: lujiajun.ck@163.com

Zhiqiu Huang and Changbo Ke
College of Computer Science and Technology, Nanjing University
of Aeronautics and Astronautics, Nanjing, 210016
Email: zqhuang@nuaa.edu.cn

***Abstract*—Privacy has been acknowledged to be a critical concern for many collaborative business environments. Recently, verifying whether Web services composition satisfies privacy requirement is a hot spot for privacy protection. However, little research focuses on behavioral privacy requirement. This paper proposes an approach based on model checking to verify the satisfiability of behavior-aware privacy requirements in services composition. Firstly, we extract LTL specification from the behavior constrains of privacy requirements. On the other side, the behavior of BPEL process is modeled by extended interface automata, which supports privacy semantics. Then it is transformed to Promela description, the input language of the model checker SPIN. Finally, we illustrate the verification of privacy requirements with SPIN.**

***Index Terms*—Web services composition, behavior-aware privacy requirements, model checking, SPIN**

I. Introduction

Recently, Web services are applied widely in the academic and industry field as a new distributed computing model [1]. Users have to submit some personal information, which is privacy sensitive, to service providers to finish the necessary business. Because of the fact that the technologies of Web services spring up and users' requirements increase rapidly, multiple web services are composed to fulfill more business requirements [2] as the single Web service is not competent. In the process of composing, service providers may expose some of user's sensitive information to other collaborators. Owing to none of protocols between services and users is designed to specify the behavior, it is hardly to guarantee that user's personal data is exposed and applied according to users' intension, especially in cloud computing environment [3,4,5]. As a result, it is becoming a critical problem to ensure that services composition concurrently fits users' privacy demands while users' business requirements are meet.

In the information system and software engineering domain, privacy protection represents the capability that the individual control the collection, exposition and maintenance of information about themselves [6]. As Web service privacy has became a research hot spot of service computing, many organizations have proposed a series of software industry standards and technology implementation frameworks supporting privacy protection. The Platform for Privacy Preferences (P3P) [7] presented by W3C and corresponding privacy preferences description language APPEL (A P3P Preference Exchange Language) [8] are capable to define privacy policy of service providers and privacy preferences of users. OASIS provides eXtensible Access Control Markup Language (XACML) [9] to manage access control and extend support for privacy policy via privacy policy profile. Some researchers add privacy property into the role-based access control model RBAC. As a result, a privacy-aware role-based access control model is put forward to describe privacy-related access control policy [10].

In order to fulfillment the functional requirement, web service provider must choose a group of Web services to achieve business target while ensure that the disclosure of users' privacy data meets their privacy requirements. As a result, it is necessary to analyze privacy requirements of service composition in the design phrase, that is, verify whether Web service composition utilizes privacy data according to privacy policies. At present, some research working on this aspect has been done in the domestic and overseas. Yin Hua Li and Boualem Benatallah correspond Web service business process execution language (WS-BPEL) with P3P policy description and verify the consistency [11]. Linyuan Liu and Zhiqiu Huang transform access authority on privacy data into the privacy policy, model services composition and verify the privacy requirement on the model at last [12]. Adam Barth et al. expresse privacy properties of service users with linear temporal logic (LTL) formulas and verify privacy requirement based on the composition model [13]. The authors in paper [14] model service assembly with hypergraph and provide the method to transform, furthermore propose an algorithm which can achieve the minimal privacy disclosure service assembly. However,

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the privacy requirements above which researchers consider just restrict the single Web service's access on privacy data. It is hardly sufficient to protect privacy in cross-organizational services composition. The interaction between services must to be taken into account in privacy protection. To supplement current research, this paper proposes a model checking approach based on temporal properties verification to check the satisfiability of behavior-aware privacy requirement in Web services composition. The main ideas of our work can be depicted as Fig.1.

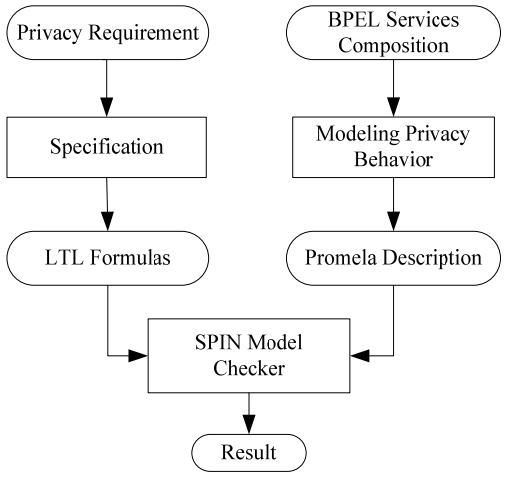


Figure 1. The framework of privacy requirement verification

The remainder of this paper is organized as follows. Section 2 analyzes behavior-aware privacy requirement combining particular application scenario. Section 3 presents the method to extract the LTL specification of privacy requirement. Section 4 models the behaviors of BPEL services composition by extending interface automata to support privacy semantics and transforms form interface automata of BPEL to Promela description. Section 5 uses SPIN model checker to verify whether the behaviors of services composition satisfy with the privacy requirement through a case study. Finally Section 6 concludes the paper.

II. Privacy Requirement Analysis

The interaction of services in composition may bring about unexpectable privacy concerns. As the privacy requirements of users are becoming more and more distinct, some requirement constraints focus on the interaction behavior of services, namely behavior-aware privacy requirement. The constraints comprise three types, data-activity dependency, data dependency and data mutex.

Take a shopping online scenario as example. There are several collaborative services: *OnlineShopping*, *Creditcard*, *Debitcard*, *Shipper*, *E-mail* and *Message*. At the beginning, the buyer sends an order request (*OrderReq*) to the *OnlineShopping*. Then the service *Creditcard* and *Debitcard* can be chosen as two kinds of online payment methods. If payment is successful, *OnlineShopping* informs the service *Shipper* to deliver the goods. After the *OnlineShopping* receives arrival message of the goods, it informs the buyer to pick up the goods by invoking the service *E-mail* or *Message*. Fig.2 presents the web service invocation of shopping online process.

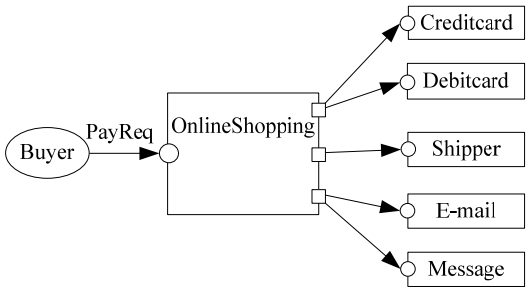


Figure 2. The service invocation of *OnlineShopping* process

The *OnlineShopping* process needs to collect user's privacy data *name*, *credit*card_no, *debitcard_no*, *address*, *e-mail* and *mobile_no*, and then discloses some of them to the collaborative services as required. The behavior-aware privacy requirements involved in this services composition can be divided into three types, just as follows:

1. Date-activity dependency. These requirements limit that the access of individual privacy data must take the occurence of certain activity as a condition. For example, data *mobile_no* can be accessed only after activity *Shipper* has finished.

2. Data dependency. The access sequence of multiple privacy data is restricted in these requirements. For example, data *address* can be accessed after *creditcard_no* was used.

3. Data mutex. The use of some privacy data must be mutually exclusive in a service composition. For example, *mobile_no* and *creditcard_no* cann't be both possessed by the *OnlineShopping* process.

All the three types of constraints can be described as the temporal relations between data and activities or between data and data, and further expressed by LTL formulas.

III. LTL Specification of Privacy Requirement

Linear Temporal Logic (LTL) is based upon the propositional calculus and used to describe assertions that changes over time through introducing temporal operators [15]. LTL formulas are constructed from atomic propositions, logical operators "$\wedge$", "$\vee$", "$\neg$", and temporal operators. Some LTL temporal operators indicating the future are X (meaning "next"), G ("globally"), F ("eventually"), and U ("until"). The corresponding past time operators in LTL are Y (meaning "yesterday"), H ("historically"), O ("once") and S ("since"). The semantic of LTL temporal operators can be easily defined on finite length service composition privacy behaviors. Given a services composition model M and an LTL property Φ, we say that $M \models \Phi$, iff for any path ω, $\omega \models \Phi$. The three types of behavior-aware privacy requirements discussed in Section II can totally be

described as temporal properties in a computation path (for short "path") and further expressed with LTL formulas. Especially, the mutex constrains of privacy data in data mutex privacy requirement can also be transformed to temporal relation between them. The correspondence between privacy requirement types and LTL formulas are shown in Table 1.

TABLE 1.
THE CORRESPONDENCE BETWEEN PRIVACY REQUIREMENT TYPES AND LTL FORMULAS

Type	Example	LTL formula	Explanation
Data-activity dependency	Privacy data *name* can be used after activity *Login* has finished.	$\mathrm{G}(name \rightarrow \mathrm{G}(Login))$	If data *name* is going to be accessed, it is required that activity *Login* has occurred.
Data dependency	Privacy data *address* can be accessed after *name* was used.	$\mathrm{G}(address \rightarrow \mathrm{O}(name) \Leftrightarrow \neg(\neg name\ \mathrm{U}\ addres)$	If data *address* is going to be accessed, it is required that data *name* has been used. In other words, it is not allowed that *address* is accessed while *name* has not been used.
Data mutex	Privacy data *creditcard_no* and *mobile_no* couldn't be used by a service composition.	$\mathrm{G}[(creditcard\_no \rightarrow \mathrm{G}\neg mobile\_no) \vee (mobile\_no \rightarrow \mathrm{G}\neg creditcard\_no)]$	If data *creditcard_no* has been accessed, data *mobile_no* will not be used any more, vice verse.

Based on the correspondence, we can transform different types of privacy requirements to LTL specification.

IV. MODELING THE PRIVACY BEHAVIORS OF SERVICES COMPOSITION

In this paper, we use SPIN model checker [16,17] to verify whether the behaviors of BPEL services composition satisfy privacy requirements. The input language of SPIN is called Promela, a modeling language for finite-state concurrent processes. Promela specifications allow us to model BPEL workflow using a set of concurrent processes that can communicate with each other. We implement the modeling of privacy behavior in two phases: (1) model the interface behaviors of BPEL process by extending interface automata to support privacy semantics, (2) transform from the interface automata model to Promela description. The interface automata as an intermediate model achieved the extraction of control information and privacy data of BPEL.

A. BPEL Modeling with Interface Automata

Interface Automata (IA) is a formal model to describe the temporal aspect of software component interface. Specifically, it's designed to capture effectively both input assumptions and output guarantees about the order of the interactions between a component and its environment. For more details, please refer to [18]. Besides, the description of interfaces and behaviors for a component is either supported by IA. As a result, IA is employed to express interface behaviors of service. The operations in the service interface correspond to the actions in IA. Since the privacy data will be accessed when the service is invoked, we add the corresponding privacy data requirement to every transition, which is called Privacy Interface Automata (PIA).

Definition 1: PIA. A privacy interface automata can be defined as $P := <V_P, V_P^{init}, A_P, D_P, \Gamma_P>$, where:

- V_P is a finite set of states, each state $v \in V_P$.
- V_P^{init} is the set of initial state, $V_P^{init} \subseteq V_P$. We require that V_P^{init} contains at most one state. If $V_P^{init} = \emptyset$, then P is called empty.
- A_P is a finite set of actions, including Input, Output and Internal actions: A_P^I, A_P^O and A_P^H, they are mutually disjoint. We denote $A_P = A_P^I \cup A_P^O \cup A_P^H$.
- D_P is a finite set of privacy data access arrays, for short privacy array. For each privacy array $d \in D_P$, it is consisted of $|O|$ elements, where O denotes a finite set of privacy data objects. As the elements of array $d[i] \in \{0,1\}$ ($0 \le i \le |O|$), 1 denotes to access privacy data i and 0 denotes not.
- Γ_P is a finite set of transitions, $\Gamma_P \subseteq V_P \times A_P \times D_P \times V_P$.

We use state transition sequence with privacy array to express the behavior of a PIA: $v_0 \xrightarrow{a_0, d_0} v_1 \xrightarrow{a_1, d_1} \cdots \xrightarrow{a_{n-2}, d_{n-2}} v_{n-1} \xrightarrow{a_{n-1}, d_{n-1}} v_n$, where n is a non-negative integer. The system starts from state v_0, transits to v_1 via a_0 and requests access d_0, and then transits to v_2 via a_1 and requests access d_1, the rest may be deduced by analogy.

Based on the PIA definition and WS-BPEL specification [19], the transformation from BPEL process

to PIA is presented as Fig.3. Some typical primitive activities and structured activities are listed as examples.

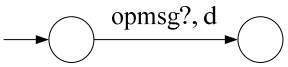
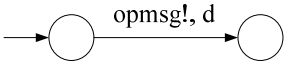
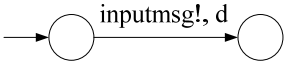
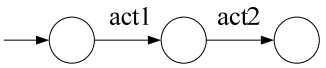
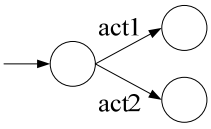
BPEL	Sample Code	Transformation
receive	< receive operation = "op" variable = "opmsg"⋯ />	
reply	< reply operation = "op" variable = "opmsg" ⋯ />	
invoke	<invoke operation = "op" inputVariable = "inputmsg" ⋯ />	
sequence	<sequence> <⋯act1⋯> <⋯act2⋯> </ sequence >	
switch	<switch> <case condition = " "> act1 </case> <case condition = " "> act2 </case> </ switch >	

Figure 3. Translation from BPEL to PIA

As shown in the figure, the input message of **receive** statement corresponds to an input action in the transition of PIA, while the output message of **reply** and **invoke** statement corresponds to an output action. Data variables in the message can be obtained from the WSDL of services. The privacy array is constructed by all privacy data in the message variables, and then added to the transition of PIA. Especially, when modeling **invoke** statement, we only consider unidirectional invoke activity, which only sends call requests to collaborative services in the composition and doesn't need any response. The reason is that generally privacy data only appears in request message rather than response message of a Web service.

Example 1: Fig.4 describes the BPEL process of *OnlineShopping* discussed in Section II.

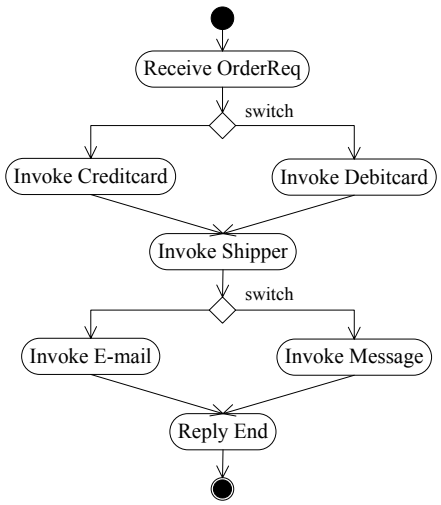


Figure 4. The BPEL process of *OnlineShopping*

The process *OnlineShopping* sends or receives message from collaborative services through operations described in the interfaces. Each message variable would likely contain some privacy data so that the privacy data may be accessed when the message is delivered. The privacy data involved in process *OnlineShopping* is listed in Table 2.

TABLE 2.
PRIVACY DATA IN PROCESS *ONLINESHOPPING*

Activity	Operation	Message	Privacy Data
receive	OrderReq?	orderReq	name, creditcard_no, debitcard_no, address, e-mail, mobile_no

invoke	Creditcard!	creditcardReq	name, creditcard_no
invoke	Debitcard!	debitcardReq	name, debitcard_no
invoke	Shipper!	shipReq	name, address
invoke	E-mail!	e-mailReq	name,e-mail
invoke	Message!	messageReq	name, mobile_no
reply	End!	endReq	N/A

Based on the definition of PIA and the transformation rule from BPEL to PIA, the PIA model of *OnlineShopping* is illustrated in Fig.5.

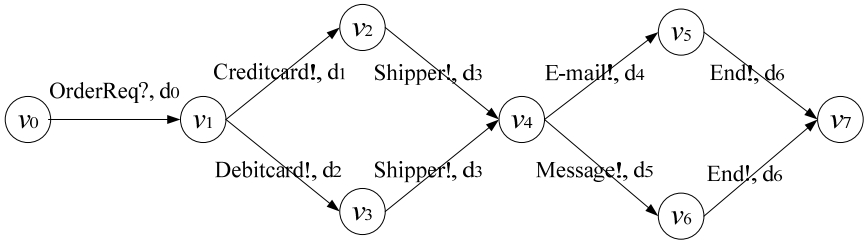


Figure 5. The PIA model of *OnlineShopping*

We label a privacy data access array for each transition of PIA. The corresponding actions and privacy arrays of the PIA model of *OnlineShopping* are shown in Table 3, where elements of each array denote the privacy data *name*, *creditcard_no*, *debitcard_no*, *address*, *e-mail* and *mobile_no* respectively. The elements of the array indicate whether *OnlineShopping* requests to access a privacy data, where 1 indicates that it requests and 0 indicates not.

TABLE 3.
THE OPERATIONS AND PRIVACY ARRAYS OF *ONLINESHOPPING*

OrderReq?, d_0	Creditcard!, d_1	Debitcard!, d_2	Shipper!, d_3
1, 1, 1, 1, 1, 1	1, 1, 0, 0, 0, 0	1, 0, 1, 0, 0, 0	1, 0, 0, 1, 0, 0
E-mail!, d_4	Message!, d_5	End!, d_6	
1, 0, 0, 0, 1, 0	1, 0, 0, 0, 0, 1	0, 0, 0, 0, 0, 0	

In Fig.5, after *OnlineShopping* receives the input action OrderReq? in the initial state v_0, the state transits to v_1. In this transition process, *OnlineShopping* collects the privacy data *name*, *creditcard_no*, *debitcard_no*, *address*, *e-mail* and *mobile_no* respectively. When the output action Creditcard! occurs, the state transits from v_1 to v_2. In this transition process, *OnlineShopping* discloses privacy data *name* and *creditcard_no* to collaborative service *Creditcard*. All of the subsequent behaviors of *OnlineShopping* can be deduced.

B. Transformation from PIA to Promela

A BPEL Web services composition specified using PIA will be transformed into Promela specification which consists of a set of concurrent processes. Each process represents the action in the transition τ of PIA and is connected by a set of communication channels. The processing steps of the transformation algorithm are as follows:

1. Traverse the transition τ of PIA model and get the action a and privacy array d to build new activities in array *Activities*. Then create transfers between activities in array *Transfers* (distinguish from transition in PIA). If τ has more than one next transition τ' in PIA, set condition to each transfer.

2. Traverse the array *Transfers* to generate the declaration of array **mtype** and **channel** message.

3. Traverse the activity of *Activities* to generate the variable declaration of the activity and involved privacy data. Create a new **proctype** process for each activity. Search the *Transfers* in each activity and add transfer's condition to the related process unless it is empty. If the current activity is the start activity of the transfer, then generate an output message. If it is the end activity, then generate an input message.

4. Label the finish of the activity and the access of corresponding privacy data at the end of each process.

Algorithm 1: Transformation from PIA to Promela
Input: The PIA model of BPEL process, PIA
Output: The Promela description of BPEL process, Promela

```
for all τ ∈ PIA.Γ_P
   Acitvities.addNewActivity (getAction (τ), getData (τ));
   for all τ' ∈ PIA.Γ_P
      //the arrival state of τ equals to the start state of τ'
      if (getArrivalState (τ) = getStartState (τ')) then
         Transfers.addNewTransfer(getAction(τ),
                  getAction(τ'), condition); //create transfer
for all transfer ∈ Transfers
   //create definition of mtype and channel message
   Promela.NewMtype (transfer);
   Promela.NewChanmsg (mtype);
for all activity ∈ Acitvities
   Promela.NewVariable (activity); //variable declaration
   // proctype process declaration
   Promela.NewProctype (activity);
   for all transfer ∈ Transfers
      Promela.proctype.AddCondition (
            getCondition(transfer));
      if (getStartActivity(transfer) = activity) then
         //generate the output message
         Promela.proctype.SendMsg(getNum(transfer),
               transfer); //getNum() is to get the position of
                          //transfer in array mtype
      if (getEndActivity(transfer) = activity) then
         Promela.proctype.ReceiveMsg(getNum(transfer),
               transfer);   //generate the input message
   Promela.SetTrue (getVariable(activity));
   // label the finish of the activity
return Promela;
```

V. Privacy Requirement Verification

Take the shopping online scenario in Section II as example to illustrate the verification of behavior-aware privacy requirements with model checker SPIN. The BPEL process and PIA model have been presented in Section IV.

According to Algorithm 1, firstly, we should transform from the PIA model to Promela description, which consists of type declaration (mtype), channel declaration (chan msg), variable declaration, process declaration (proctype) and so on, to indicate the communication among processes. Some code fragment is listed in Fig.6.

```
mtype = { creditcard_req, debitcard_req,
      creditcard_shipper, debitcard_shipper, email_req,
      message_req, email_end, message_end};
chan msg1 = [2]of{mtype};
……
// variable declaration of condition
bool creditcard_select = true;
bool email_select = true;
……
// variable declaration of the finish of an activity
bool end_done = false;
……
// variable declaration of privacy data
bool email_no = false;
bool mobile_no = false;
……
active proctype orderReq(){
   if
   ::(creditcard_select == true) -> msg1!creditcard_req
   ::(creditcard_select == false) -> msg2!debitcard_req
   fi;
}
active proctype creditcard(){
   msg1?creditcard_req;
   creditcard_no = true;  creditcard_done = true;
   msg3!creditcard_shipper;
}……
active proctype end(){
   if
   ::(email_select == true) -> msg7?email_end
   ::(email_select == false) -> msg8?message_end
   fi;
   end_done = true;
}
```

Figure 6. Promela description of the PIA model of *OnlineShopping*

The behavior-aware privacy requirements in shopping online scenario are as follows:

1) After service *Shipper* has finished, privacy data *mobile_no* is allowed to be accessed.

2) Only after privacy data *debitcard_no* has been used, *e-mail* could be accessed.

3) Privacy data *creditcard_no* and *mobile_no* could not be used by a service composition.

The requirements can be categorized as data-activity dependency, data dependency and data mutex. According to the correspondence between privacy requirement types and LTL formulas listed in Table 1, they can be expressed with LTL as follows:

- ✧ $\mathbf{G}(mobile\_no \rightarrow \mathbf{G}\ shipper\_done)$
- ✧ $\neg(\neg debitcard\_no\ \mathbf{U}\ email\_no)$
- ✧ $\mathbf{G}[\ (creditcard\_no \rightarrow \mathbf{G}\neg mobile\_no) \vee (mobile\_no \rightarrow \mathbf{G}\neg creditcard\_no)]$

Then, translate the formulas above into the form that SPIN model checker can recognize:

✧ **[ ]** (*mobile_no* -> **[ ]** *shipper_done*) (1)

✧ ! (! *debitcard_no* **U** *email_no*) (2)

✧ **[ ]** ((*creditcard_no* -> **[ ]** ! *mobile_no*) || (*mobile_no* -> **[ ]** ! *creditcard_no*)) (3)

Finally, input the Promela description of process *OnlineShoping* and LTL formulars into SPIN and verify them. As Fig.7, when verifying formular 1, "errors: 0" occurs. After exhausting state space, the fact that all paths meet LTL formula 1 implies that Promela model satisfies the specification.

```
Full statespace search for:
        never claim             + (never_0)
        assertion violations    + (if within scope of claim)
        acceptance   cycles     + (fairness enabled)
        invalid end states      - (disabled by never claim)

State-vector 84 byte, depth reached 43, errors: 0
       59 states, stored
       49 states, matched
      108 transitions (= stored+matched)
        0 atomic steps
hash conflicts:         0 (resolved)
```

Figure 7. The result of verifying formula 1

The result for verifying formula 2 is below. Program breaks off at the depth 30 and a counter-example "assertion violated !(emil_no)" is achieved. It means that LTL formula 2 is not be satisfied by an existing path starting from the initial state. As a result, the model doesn't satisfy this specification.

```
LuJiajun@LuJiajun-PC /cygdrive/c/cygwin/workspace
$ spin -a -f "! ! ( ! debitcard_no U email_no)" onlineshopping.txt

LuJiajun@LuJiajun-PC /cygdrive/c/cygwin/workspace
$ gcc -DNFAIR=3 -o pan pan.c

LuJiajun@LuJiajun-PC /cygdrive/c/cygwin/workspace
$ ./pan -a -f
warning: for p.o. reduction to be valid the never claim must be stu
(never claims generated from LTL formulae are stutter-invariant)
pan:1: assertion violated  !(email_no) (at depth 30)
pan: wrote onlineshopping.txt.trail

(Spin Version 6.2.5 -- 3 May 2013)
Warning: Search not completed
        + Partial Order Reduction
```

Figure 8. The result of verifying formula 2

When analyze file .trail provided by SPIN, a counter-example path is found: queue1 (msg1) -> queue2 (msg3) -> queue3 (msg5), which indicates process *OnlineShopping* invokes service *Creditcard*, *Shipper* and *E-mail* in sequence and privacy data *email_no* is used without accessing data *debitcard_no*. The second requirement is violated.

When verifying formula 3, programme breaks off at the depth 30 and a counter-example "assertion !(ceditcard_no && mobile_no)" emerges just as Fig.9 shows.

```
LuJiajun@LuJiajun-PC /cygdrive/c/cygwin/workspace
$ ./pan -a -f
warning: for p.o. reduction to be valid the never claim must be stutter
(never claims generated from LTL formulae are stutter-invariant)
pan:1: assertion violated  !((creditcard_no&&mobile_no)) (at depth 30)
pan: wrote onlineshopping.txt.trail

(Spin Version 6.2.5 -- 3 May 2013)
Warning: Search not completed
        + Partial Order Reduction

Full statespace search for:
        never claim             + (never_0)
        assertion violations    + (if within scope of claim)
        acceptance   cycles     + (fairness enabled)
        invalid end states      - (disabled by never claim)

State-vector 84 byte, depth reached 30, errors: 1
```

Figure 9. The result of verifying formula 3

The counter-example path: queue1 (msg1) -> queue2 (msg3) -> queue3 (msg6) in the file .trail records that process *OnlineShopping* invokes service *Creditcard*, *Shipper* and *Message* in sequence and privacy data *creditcard_no, address* and *mobile_no* are totally accessed. The third requirement is violated.

VI. Conclusions

This paper employs model checking technology to verify behavior-aware privacy requirement in Web services composition. Firstly, analyze behavior-aware privacy requirements and transform behavior constrains into temporal property expressed with LTL. Then, model the behaviors of BPEL services composition with PIA, an extension to the interface automata with privacy semantic. Moreover, transform it to Promela description. Finally, input the Promela description and LTL formula into SPIN to verify whether the behaviors of BPEL satisfy the privacy requirement.

Web services composition requires the collaboration of services, which leads that the privacy issues refer to variable research aspects. This paper aims at the access control of private data without considering the duration of the data. Consequently, our future work is to extend the existing approach to model time property of privacy, and further verify it.

Acknowledgment

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References

[1] K. Yue, X. Wang and A. Zhou, "Underlying techniques for Web services: a survey", Journal of Software, vol. 15, no. 3, pp. 428-442, March 2004.

[2] S. Dustdar and W. Schreine, "A survey on web services composition", International Journal of Web and Grid Services, vol. 1, no. 1, pp. 1-30, 2005.

[3] M. A. ALZain, B. Soh and E. Pardede, "A Survey on Data Security Issues in Cloud Computing: From Single to Multi-Clouds", Journal of Software, vol. 8, no. 5, pp. 1068-1078, May 2013.

[4] J. Wu, Q. Shen, T. Wang and Y. Zhu, "Recent Advances in Cloud Secutity", Journal of Computers, vol. 6, no. 10, pp. 2156-2163, Oct 2011.
[5] B. Xu, N. Wang and C. Li, "A Cloud Computing Infrastructure on Heterogeneous Computing Resources", Journal of Computers, vol. 6, no. 8, pp. 1789-1796, Aug 2011.
[6] I. Goldberg and D. Wagner, "Privacy-enhancing technologies for the Internet", In Compcn'97. Proceedings, IEEE. IEEE, 1997, pp. 103-109.
[7] W3C Group, "The Platform for Privacy Preferences1.1 Specification (2006)", http://www.w3.org/TR/P3P11.
[8] L. Cranor and M, "Marchiori. A P3P Preference Exchange Language 1.0. W3C Working Draft", 2002, 15.
[9] T. Moses, "Extensible access control markup language version 2.0 (XACML)", OASIS Standard, 2005.
[10] Q. Ni, E. Bertino, et al, "Privacy-aware role based access control. ACM Transactions on Information and System Security (TISSEC)", vol. 13, no. 3, Article 24, July 2010.
[11] Y. Li, H. Paik and B. Benbernou, "Formal consistency verification between BPEL process and privacy policy", Proceedings of the 2006 International Conference on Privacy, Security and Trust: Bridge the Gap between PST Technologies and Business Services, ACM, 2006: 26.
[12] L. Liu, Z. Huang, F. Xiao and G. Shen, "Verification of privacy requirements in Web services composition", 2010 Second International Symposium on Data, Privacy, and E-Commerce, 2010, pp. 117-122.
[13] A. Barth, J. Mitchell and A. Datta, "Privacy and utility in business processes", 20th IEEE Computer Security Foundations Symposium (CSF'07), 2007, pp. 279-294.
[14] L. Zhao, Z. Huang and L. Liu, "Research on privacy disclosure analysis for Web services composition", Journal of Frontiers of Computer Science and Technology, vol. 6, no. 4, pp. 319-326, April 2012.
[15] M. Huth and M. Ryan, "Logic in Computer Science Modelling and Reasoning about Systems", Cambridge, UK: Cambridge University Press, 2004.
[16] H. Shi, W. Ma, M. Yang and X. Zhang, "A Case Study of Model Checking Retail Banking System with SPIN", Journal of Computers, vol. 7, no. 10, pp. 2503-2510, Oct 2012.
[17] G. J. Holtzman, "The SPIN Model Checker, Primer and Reference Manual", 2003.
[18] T. Henzinger, "Interface automata", ACM SIGSOFT Software Engineering Notes, ACM, 2001, 26(5), pp. 109-120.
[19] OASIS, "Web Services Business Process Execution Language (WS-BPEL) Version2.0", http://docs.oasis-open.org/wsbpel/2.0/ CS01/wsbpel-v2.0-CS01.html, 2007.

Jiajun Lu was born in 1988 and received the B.S. degree in Computer Science and Technology. Now he is a master candidate at College of Computer Science and Technology, Nanjing University of Aeronautics and Astronautics, Jiangsu, China. His research interests include service-oriental computing and privacy.

Zhiqiu Huang was born in 1965. He received his Ph.D. degree in Computer Science from Nanjing University of Aeronautics and Astronautics in 1999. Now he is a professor and Ph.D. supervisor at College of Computer Science and Technology, Nanjing University of Aeronautics and Astronautics. His research interests include software engineering, formal methods, cloud computing and privacy.
E-mail: zqhuang@nuaa.edu.cn

Changbo Ke was born in 1984. He is a Ph.D candidate of Nanjing University of Aeronautics and Astronautics. His research interests include security and privacy of information system and ontology-based software engineering.