

On the Controlled Evolution of Process Choreographies

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Abstract

Process-aware information systems have to be frequently adapted due to business process changes. One important challenge not adequately addressed so far concerns the evolution of process choreographies, i.e., the change of interactions between partner processes in a cross-organizational setting. If respective modifications are applied in an uncontrolled manner, inconsistencies or errors might occur in the sequel. In particular, modifications of private processes performed by a single party may affect the implementation of the private processes of partners as well. In this paper we present a formal framework that allows process engineers to detect how changes of private processes may affect related public views and - if so - how they can be propagated to the public and private processes of partners. In particular, we exploit the semantics of the applied changes in order to automatically determine the adaptations necessary for the partner processes. Altogether our framework provides an important contribution towards the realisation of adaptive, cross-organizational processes.

1. Introduction

The economic success of an enterprise more and more depends on its ability to flexibly and quickly react on changes at the market, the development, or the manufacturing side. For this reason companies are developing a growing interest in improving the efficiency and quality of their internal business processes and in optimizing their interactions with business partners and customers. Recently, we have seen an increasing adoption of business process automation technologies by enterprises as well as emerging standards for business process orchestration and choreography in order to meet these goals. Respective technologies enable the definition, execution, and monitoring of the operational processes of an enterprise. In connection with Web service technology, in addition, the benefits of business

process automation and optimization from within a single enterprise can be transferred to cross-organizational business processes (*process choreographies*) as well. The next step within this evolution will be the emergence of the agile enterprise being able to rapidly set up new processes and to quickly adapt existing ones to changes in its environment.

One important challenge not adequately dealt with so far concerns the evolution of process choreographies, i.e., the controlled change of the interactions between partner processes in a cross-organizational setting. If one party changes its process in an uncontrolled manner, inconsistencies or errors regarding these interactions might occur in the sequel. Generally, the partners involved in a process choreography exchange messages via their public processes, which can be considered as special views on their private processes (i.e., the process orchestrations). If one of these partners has to change the implementation of his private process (e.g., to adapt it to new laws or optimized processes) the challenging question arises whether this change affects the interactions with partner processes and their implementation as well. Obviously, as long as a modified business process is not part of a process choreography, change effects can be kept local. The same applies if changes of a private process have no impact on related public views.

In general, however, we cannot always assume this. The modification of a private process may not only influence corresponding public processes, but also the public and private processes of its partners. For this reason, it is indispensable for any IT infrastructure to provide adequate methods for (automatically) *propagating* changes of a private process to the partner processes (if required). This important issue has not been considered by current approaches so far. As a consequence adaptations of process choreographies have turned out to be both costly and error-prone. Note that the handling of respective changes is not trivial since we must be able to precisely state which effects on partner processes result after adapting a (private) process. In any case we need precise and formal statements about this in order to avoid implementation holes later on.

In this paper we present an approach that addresses these challenges in detail and that allows for the controlled evolution of process choreographies. We show how changes of a private process may affect related public views and - if so - how they can be propagated to the public/private processes of partners as well. In order to be able to precisely state whether change propagations to partner processes become necessary or not we introduce a formal model based on annotated Finite State Automata. We further exploit the semantics of the applied change operations in order to derive necessary adaptations automatically. Due to the autonomy of partners, however, private partner processes cannot be adapted automatically to changes of a process choreography. However, our approach allows for the comprehensive assistance of users in accomplishing this task in a correct and effective manner. Finally, we restrict our considerations to structural changes (e.g., the insertion or deletion of process activities). Other adaptations of process models (e.g., the change of transition conditions) require a similar approach, but are outside the scope of this paper. We do also not address dynamic changes (i.e., the migration of running choreographies to respective changes at the type level) in this work. Dynamic adaptations of choreographies and process instances, however, constitute an important part of our overall change framework [11, 12].

Section 2 introduces a practical application scenario which is used throughout the paper in order to illustrate basic concepts of our formal framework. In Section 3 we discuss basic issues related to process choreographies and interactions between partner processes. In particular, we introduce our formal model and show how it can be used to automatically generate public processes out of private ones – this provides the basis for dealing with process changes later on. Section 4 presents a classification of changes and Section 5 provides methods for propagating changes on behalf of selected scenarios. Section 6 sketches implementation issues and Section 7 discusses related work. Finally, we close with a summary and an outlook on future work in Section 8.

2. Practical Scenario

The example scenario used for further discussion is a simple procurement process within a virtual enterprise. It comprises a buyer, an accounting department, and a logistics department. The accounting department approves an order (*order* message) sent by a buyer and forwards it to the logistics department (*deliver* message) in order to deliver the requested goods. The logistics department then confirms the receipt (*deliver_conf* message) to the accounting department, which forwards this message (extended by the expected delivery date and the parcel tracking number) to the buyer (*delivery* message). Furthermore, the buyer may

perform parcel tracking (*get_status* and *status* messages) of the shipped goods. Corresponding messages are forwarded by the accounting department to the logistics department. The overall scenario is depicted in Fig. 1.

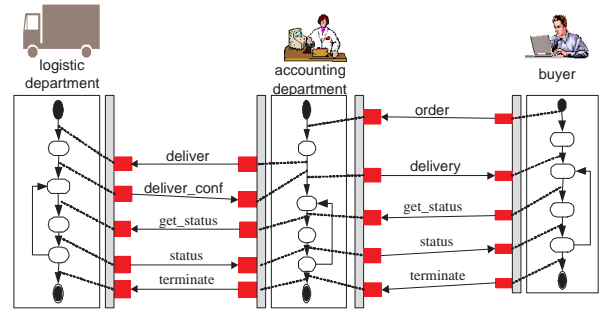


Figure 1. Example Overview

The sketched scenario represents a *process choreography*, i.e., a conversation between partner processes. More precisely, the participating partners exchange messages via their *public* processes, which constitute special views on the respective *private processes* [2]. We describe the private process of the accounting department in more detail denoting it according to the BPEL (Business Process Execution Language for Web Services) specification [3]. To keep the example simple, we abstract from the structure of the exchanged messages and use simplified message names. Concrete message structures could be, for example, taken from the RosettaNet Partner Interface Processes (PIPs) 3A4 (Request Purchase Order), 3A7 (Notify of Purchase Order Update), and 3B2 (Notify of Advanced Shipment) [13].

Regarding Web services, for example, messages are exchanged by invoking operations at the respective partner sites. A Web service may comprise one or more operations (grouped within porttypes) which can be specified using WSDL (Web Service Definition Language). Each operation then represents a potential message exchange between partners. If an operation contains only one single input message, it is considered to be asynchronous, otherwise the operation is synchronous. Regarding our example all operations are asynchronous except the synchronous *getStatusOP* operation provided by the *logistics* service.

The description of private processes can be based on such porttype definitions (i.e., Web service specifications) by directly referring to them. In the following, private processes are denoted in BPEL [3] and are therefore specified in terms of tasks (named *activities* in the BPEL terminology) representing basic pieces of work to be performed by potentially nested services. The control flow of a BPEL process constrains the possible execution orders of its activities and is based on constructs for selective (*switch* and *pick* activities), sequential (*sequence* activity), and parallel (*flow*

activity) execution. In addition, a BPEL process defines the data flow between process activities (variable handling and *assign* activity for mapping data between messages) regardless of their concrete implementation. Based on this understanding, the process model of one partner includes activities realizing its interaction with the other partners. These interactions are represented by exchanging messages (*receive*, *reply*, *invoke*, and *pick* activities in BPEL).

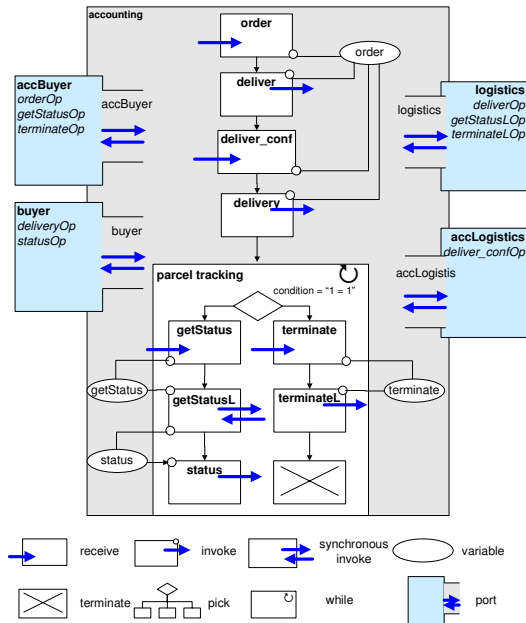


Figure 2. Accounting BPEL Private Process

The BPEL specification of the accounting department private process is depicted in Fig. 2. The partnerLink definition associates a partner name to a bilateral interaction between two roles. The association of roles to concrete parties and operations is done in the partnerLinkType definition contained in the related WSDL file.

The process starts by receiving an *order* message sent by the buyer, which is then forwarded to the logistics department via a *deliver* message. The logistics department answers asynchronously with a *deliver_conf* message. The accounting department process receives this message and forwards it to the buyer via a *delivery* message. Since the buyer is allowed to do parcel tracking arbitrarily often, this step is embedded in a non-terminating loop within the accounting process. More precisely, the accounting department may receive a *get_status* message sent by the buyer, which is then followed by a synchronous invocation of the logistics *get_statusL* operation (representing two messages) and the reporting of the respective status back to the buyer (via a *status* message). Alternatively, it must be possible to terminate the accounting as well as the logistics process

at some point in time. For this, a *termination* message can be initiated by the buyer; this message is then sent to the accounting department process, which forwards it to the logistics process. After this both processes are terminated.

As a second example consider the private process of the buyer, which is depicted in Fig. 3. – We omit further details and focus on the bilateral interaction between the accounting and buyer process in the following.

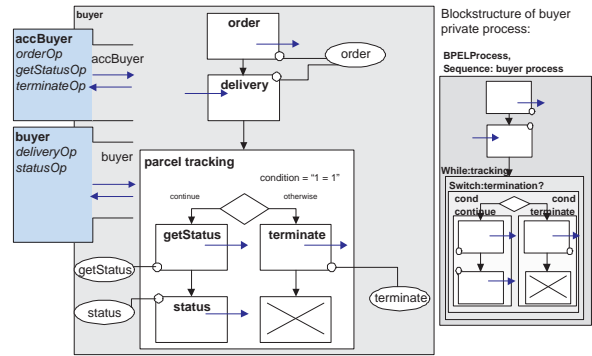


Figure 3. Buyer BPEL Private Process

3. Process Choreographies

In this section we discuss basic issues related to the evolution of choreographies between partner processes. We show how this can be supported in a (semi-)automated way.

3.1. Overview

For several reasons business processes steadily evolve. Thus process-oriented information systems have to be continuously adapted as well. As long as the modified processes are not part of a process choreography, change effects can be kept local. The same applies if changes of a private process have no impact on related public processes. In general, however, we cannot always assume this.

Regarding process choreographies the modification of a private process may not only influence related public processes, but also the public and private processes of partners. As an example take an activity inserted into a private process and invoking an external operation of a partner process (by sending a corresponding message to it). If the partner process is not adapted accordingly (e.g., by inserting a receive activity processing the message sent) the execution of the modified process choreography could fail. Thus it is crucial to provide adequate methods to (automatically) propagate changes of a private process to partner processes.

Fig. 4 depicts our overall approach for the controlled evolution of process choreographies. Assume that private

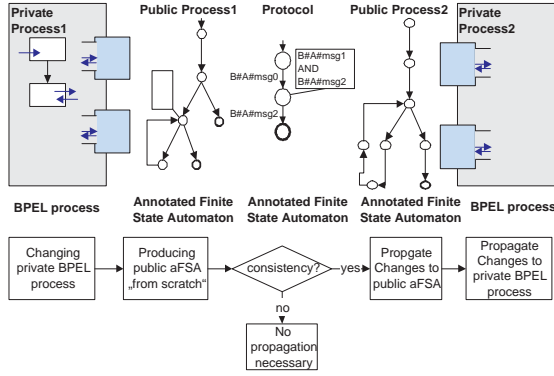


Figure 4. General Approach

process 1 (left side of the figure) is modified. Then, at first, the public view on this process is recreated in order to reflect changes that might affect the interactions with partner processes. If this results in a modification of public process 1 (and only then) we further check whether adaptations of public process 2 (right side of the figure) become necessary as well. This is accomplished by calculating the consistency of the two public processes, i.e., the guarantee of a deadlock free execution of the interaction. In case of inconsistency the change of public process 1 has to be propagated to public process 2¹; otherwise the execution of the process choreography will fail. We exploit the semantics of the applied changes in order automatically adapt public process 2 in such a case. After having performed respective modifications the adaptation of private process 2 becomes necessary as well. However, due to the autonomy of the partners and due to the privacy of the mission critical business decisions (represented in the private process), an automatic adaptation of private processes is generally not desired. Nevertheless the system should adequately assist process engineers in accomplishing this task by suggesting respective adaptations of private process 2.

3.2. Formal Model

The approach sketched above (i.e., the correct propagation of private process changes) requires a formal model for representing public processes. For this, different approaches have been proposed in literature, which can be classified according to their underlying communication model: The models suggested by van der Aalst [1] and Martens et.al. [8], for example, support asynchronous communication. By contrast synchronous communication is supported by Wombacher et.al. [18]. Since Web services often use synchronous communication based on the HTTP

¹We formalize this fundamental statement by providing a general correctness criterion in Section 4.2.

protocol, in the following we apply the annotated Finite State Automata model as introduced in [18].

We use annotated Finite State Automata (aFSA) to represent message sequences that can be handled by a public process. Transitions of such an aFSA are labeled, whereas a label $A\#B\#msg$ indicates that party A sends message msg to party B (see, for example, the left aFSA in Fig. 5). Furthermore, we can differentiate between mandatory and optional messages. This is achieved by annotating states with logical expressions. In the right aFSA from Fig. 5, for example, the depicted conjunctive annotation expresses that both messages $B\#A\#msg1$ and $B\#A\#msg2$, which may be sent by party B , have to be supported by a trading partner. Thus the messages are mandatory.

Obviously, the aFSAs of two interacting public processes must meet certain constraints in order to ensure correct execution of the respective process choreography. We formalize this and summarize basic aFSA characteristics necessary for the further understanding. Hence, we introduce the definitions of formulas² used in the annotations, before introducing the aFSA.

Definition 1 (Definition of Formulas)

The syntax of the supported logical formulas is given as follows: (i) the constants *true* and *false* are formulas, (ii) the variables $v \in \Sigma$ are formulas, where Σ is a finite set of messages, (iii) if ϕ is a formula, so is $\neg\phi$, (iv) if ϕ and ψ are formulas, so is $\phi \wedge \psi$ and $\phi \vee \psi$. – The set of all formulas is defined as E .

Based on the set of formulas E the standard Finite State Automaton (FSA) [7] is extended as follows:

Definition 2 (annotated Finite State Automaton (aFSA))

An annotated Finite State Automaton A is represented as a tuple $A = (Q, \Sigma, \Delta, q_0, F, QA)$ where Q is a finite set of states, Σ is a finite set of messages, $\Delta : Q \times \Sigma \times Q$ represents labeled transitions, $q_0 \in Q$ is a start state, $F \subseteq Q$ constitutes a set of final states, and $QA : Q \times E$ is a finite relation of states and logical terms within the set E of formulas.

The graphical representation of an annotated Finite State Automaton (aFSA) is based on the usual representation of FSA. States are represented as circles and transitions as arcs (annotated with labels). Final states are depicted as states with thick line. In addition to FSA, an aFSA can have state annotations (denoted as squares connected to the respective states). Fig. 5 shows two aFSA examples: Transitions are labeled whereas a label represents a message exchanged between party A and party B . More precisely, a label comprises the sender, the recipient, and the name of the respective message.

²The logical formulas are specified adapting the definition in [5].

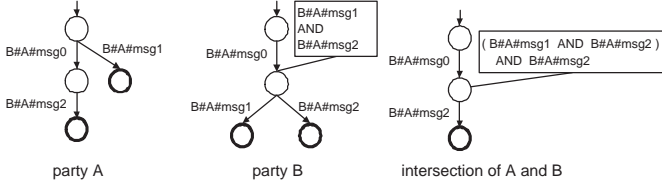


Figure 5. aFSA Representation

In our framework, a public process (in terms of aFSA models) can be automatically derived from the specification of a private one. In [19], for a subset of BPEL, we have provided respective mapping rules.

Based on the given aFSA definition, intersection and emptiness operations can be defined (cf. [18]), which are quite similar to the ones of standard FSA.

Definition 3 (Intersection of two aFSAs)

Let $A_1 = (Q_1, \Sigma_1, \Delta_1, q_{10}, F_1, QA_1)$ and $A_2 = (Q_2, \Sigma_2, \Delta_2, q_{20}, F_2, QA_2)$ be two aFSA. The intersection $A := A_1 \cap A_2$ of these automata is given by $A = (Q, \Sigma, \Delta, q_0, F, QA)$, with: $Q = Q_1 \times Q_2$, $\Sigma = \Sigma_1 \cap \Sigma_2$, $q_0 = (q_{10}, q_{20})$, $F = F_1 \times F_2$, $\Delta = \{((q_{11}, q_{21}), \alpha, (q_{12}, q_{22})) \mid \beta \in \{\alpha, \varepsilon\}, (q_{11}, \beta, q_{12}) \in \Delta_1, (q_{21}, \beta, q_{22}) \in \Delta_2\}$, and $QA = \bigcup_{(q_1, e_1) \in QA_1, (q_2, e_2) \in QA_2} \{((q_1, q_2), e_1 \wedge e_2)\}$

In particular, the intersection of two aFSAs is based on the usual cross product construction of automata intersection, where state annotations are combined by conjunction. Fig. 5 illustrates the intersection applied on party A and B. Note that the resulting aFSA only contains those transitions that can be processed by both automata. The annotation in the intersection automaton is the conjunction of the annotation contained in party B and the default annotation of party A, that is, $B\#A\#msg2$, resulting in $(B\#A\#msg1 \wedge B\#A\#msg2) \wedge B\#A\#msg2$.

Based on the intersection automaton, it can be checked whether the accepted language is empty or not. Emptiness means that one of the aFSAs has at least one mandatory transition within an execution sequence not supported by a trading partner’s aFSA. Again this emptiness test is based on standard automaton emptiness test, where it is checked whether the automaton contains a single path to a final state. Regarding aFSAs this emptiness test has to be extended by requiring that all transitions of a conjunction associated to a single state are available in the automaton and a final state can be reached following each of these transitions.

As a consequence, two automata are consistent, if their intersection is non-empty; i.e., there is at least one path from the start state to a final state, where each formula annotated to a state on this path evaluates to *true*. In particular, a variable becomes *true*, if there is a transition labeled equally

to the variable from the current state to another state where the annotation evaluates to *true*. Finally the automaton is non-empty, if the annotation of the start state is *true*.

For the above example the intersection automaton for parties A and B is depicted in Fig. 5. This aFSA is empty since it does not contain the mandatory transition labeled $B\#A\#msg1$: The variable $B\#A\#msg2$ of the annotation evaluates to *true* since there is a path to a final state. By contrast the variable $B\#A\#msg1$ is evaluated to *false* because there is no such transition available at that state providing a path to a final state.

The non-emptiness of the intersection of two automata guarantees for the absence of deadlock with respect to the execution of these two automata. This property can be derived due to the differentiation between mandatory and optional messages in an automaton. Deadlock freeness is also called *consistency*. If consistency is defined between two parties then we call it *bilateral consistency*.

3.3. Public Process Generation

We assume that the private process has been specified with BPEL. We sketch how BPEL "blocks" from a private process have to be mapped to states of the related public process (represented by an aFSA). As we will see later, this mapping is useful when changing process choreographies. In this context it is not worth applying the mapping on the originator side of a change. However, when propagating changes of a public process to its underlying private process the mapping can be used to determine the blocks in the private process to be modified.

The mapping is illustrated on behalf of the buyer process. It is based on a depth first traversal of the BPEL structure where each block represents a part of the automaton. As a consequence of the strict nesting of a BPEL document, the names of the blocks are associated with a particular state of the resulting automaton model.

State Number	BPEL Block Name
1	BPELProcess, Sequence:buyer process
2	Sequence:buyer process
3	Sequence:buyer process, While:tracking, Switch:termination?, Sequence:cond continue, Sequence:cond terminate
4	Sequence:cond continue
5	Sequence:cond terminate

Table 1. Buyer Mapping Table

Regarding the private and the public part of the the buyer process (as depicted in Figures 3 and 6) we obtain the mapping shown in Table 1. It represents the relation between the state numbers (aFSA of the public process) and the BPEL

block names (BPEL specification of private process) of the private and the public process. Note that a single state in the public process may be assigned to several BPEL elements since, in general, not all elements have an effect on the public process. As a consequence, the required modifications can be limited to the first block mentioned due to the depth first traversal of the private process.

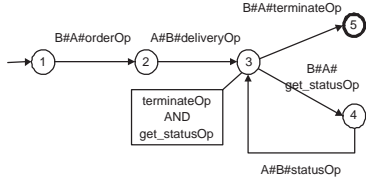


Figure 6. Buyer Public Process

3.4. View Generation

As a basis for bilateral consistency checking, it has to be ensured that the processes to be compared are representing the bilateral message exchanges only. Deriving the bilateral view of a public process is illustrated next on behalf of the accounting process. The accounting private process (cf. Fig. 2) can be transformed in a public process (cf. Fig. 7).

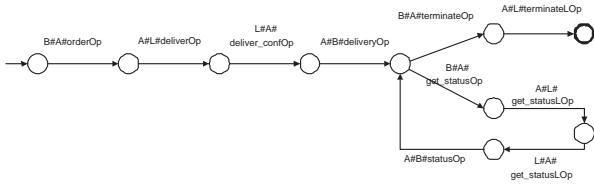


Figure 7. Accounting Public Process

The view $\tau_P(wf)$ of party P on the public process wf is generated by relabeling all transitions not related to P . For example, in the buyer view $\tau_{Buyer}(Acc)$ of the accounting process, messages exchanged with Logistics are relabeled with the empty word ε . Effected messages are $A\#L\#deliverOp$, $L\#A\#deliver_confOp$, $A\#L\#terminateLOp$, $A\#L\#get_statusOp$, and $L\#A\#get_statusOp$. The minimized Buyer view of the Accounting public process is shown in Fig. 8a).

Applying the same method for the Logistics results in the automaton depicted in Fig. 8b).

4. Process Choreography Evolution

Process changes are classified in two dimensions: The first one (*change framework*) specifies whether the change

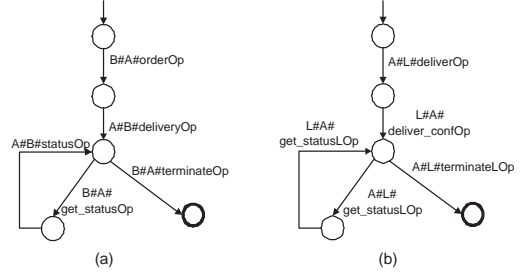


Figure 8. Accounting Public Process: (a) Buyer View (b) Logistics View

adds message sequences to an automaton (*additive change*) or removes messages from it (*subtractive change*). The second dimension (*change propagation*) indicates whether a process change has effects on trading partners or not, i.e., whether the protocol the trading partners agreed has to be modified (*variant change*) or not (*invariant change*).

4.1. Change Framework

At first we give a definition for the difference between two aFSAs. This definition is then used to characterize two basic kinds of change operations on public processes.

Definition 4 (Difference of two aFSA)

Let $A_1 = (Q_1, \Sigma_1, \Delta_1, q_{10}, F_1, QA_1)$ and $A_2 = (Q_2, \Sigma_2, \Delta_2, q_{20}, F_2, QA_2)$ be two aFSA. The difference $A := A_1 \setminus A_2$ of these two aFSA is given by $A = (Q, \Sigma, \Delta, q_0, F, QA_1)$ with: $Q = Q_1 \times Q_2$, $\Sigma = \Sigma_1 \cap \Sigma_2$, $q_0 = (q_{10}, q_{20})$, $F = F_1 \times (Q_2 \setminus F_2)$, $\Delta = \{((q_{11}, q_{21}), \alpha, (q_{12}, q_{22})) \mid \beta \in \{\alpha, \varepsilon\}, (q_{11}, \beta, q_{12}) \in \Delta_1, (q_{21}, \beta, q_{22}) \in \Delta_2\}$

This definition requires that the automata are complete; i.e, for every state there exists an outgoing transition for each element of the alphabet Σ .

In this paper we focus on additive and subtractive changes and their application to aFSAs. Based on respective change operations more complex changes can be defined. Our framework also considers other operations (e.g., to shift process activities) as well as complex changes (defined by applying a set of basic changes operations). Their treatment, however, is outside the scope of this paper. Based on the difference operator we can give a formal definition for additive/subtractive changes:

Definition 5 (Additive / Subtractive Change Operations)

Let A be the aFSA of a public process and let δ be a change operation which transforms A into another aFSA A' . Then:

- δ is an additive change operation $:\iff A' \setminus A \neq \emptyset$

- δ is a subtractive change operation : $\iff A \setminus A' \neq \emptyset$

Based on this definition additive (subtractive) changes of an aFSA correspond to the addition (deletion) of potential message sequences to (from) this aFSA. Note that this does not relate to the structural complexity of the respective private or public processes.

4.2. Propagation Criterion and Invariant Changes

Let A and B be the aFSAs of two public partner processes and let $A \cap B \neq \emptyset$ be the protocol (choreography) between them. If A is changed to A' (by applying change operation δ) the challenging question is whether δ has to be propagated to B or not. Intuitively, no propagation is needed if the protocols before and after applying δ are equivalent. Formally: $A \cap B \equiv A' \cap B \iff$

$$(A \setminus A') \cap B = \emptyset \wedge (A' \setminus A) \cap B = \emptyset$$

This constraint, however, is too restrictive since we can also ignore options that are completely under the control (i.e., are to be decided) by the party having performed the change. More precisely, no propagation is needed if $A' \cap B \neq \emptyset$ (assuming that A and B have been bilaterally consistent before the change).

Definition 6 (Variant and Invariant Changes)

Let A and B be the aFSAs of two public processes which are consistent, i.e., $A \cap B \neq \emptyset$. Let δ be a change operation which transforms A into another aFSA A' . Then:

- δ is an invariant change : $\iff A' \cap B \neq \emptyset$
- δ is a variant change : $\iff A' \cap B = \emptyset$

The aFSA B expresses all options it considers as being mandatory for the respective public process. Thus if public process A' has been changed in a way such that these options are no longer met, change propagation becomes necessary. Accordingly we can state that changes are invariant (i.e., no change propagation is needed) if the intersection between A' and B does not become empty. Note that this can apply for both additive and subtractive changes.

In summary, if the changed public process A' is still consistent with the public process B of a partner it is considered as being invariant and no further actions are needed. By contrast if A' and B turn out to be inconsistent, additional actions become necessary in order to guarantee the successful execution of the processes. How corresponding actions look like is discussed in the following section.

5. Selected Evolution Scenarios

We discuss selected change scenarios and provide methods for propagating (variant) changes to partner processes.

5.1. Invariant Additive Change

At first we consider invariant additive changes. For example, assume that the accounting process wants to provide an additional order message format to buyers. This change can be realized by adding an alternative activity (`order_2`) to the accounting process which then receives and processes respective messages $B\#A\#order_2Op$ (cf. Fig. 9).

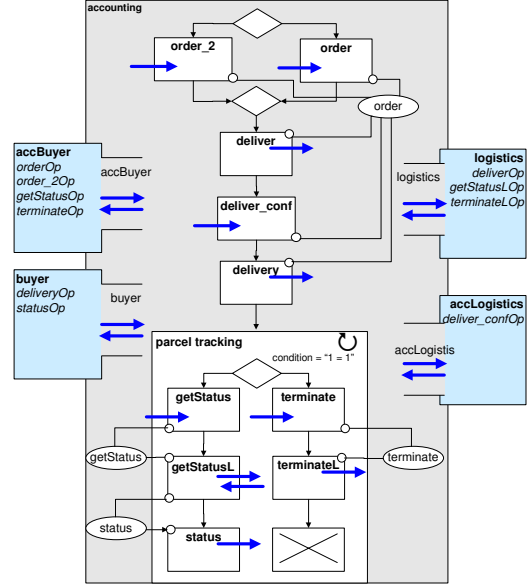


Figure 9. Invariant Change of Accounting Private BPEL Process

Since the added message $B\#A\#order_2Op$ is received by the accounting workflow, the buyer view on the respective public process changes (cf. Fig. 10a). However, from the viewpoint of the buyer this change does not require an immediate treatment and propagation to its public and private process. The reason is that the intersection automaton (cf. Fig. 10b) of the modified public view of the buyer on the accounting process and the buyer's current public process (cf Fig. 6) is non-empty. Thus, no change propagation and therefore no further actions are required.

Invariant subtractive changes can be handled accordingly and are therefore not further treated in this paper. Generally, when adding received messages to a process or removing sent messages from it we can obtain invariant changes.

5.2. Variant Additive Changes

The formal basis for variant additive changes is provided by Def. 5 and Def. 6: Let A and B be the aFSAs of two public processes and let $A \cap B \neq \emptyset$ be the protocol between

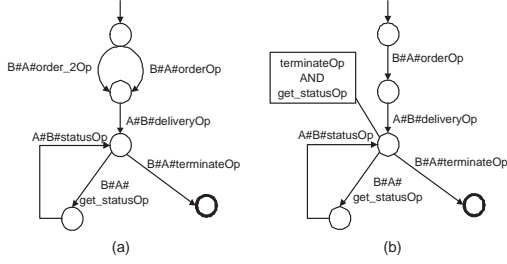


Figure 10. (a) Public Buyer View on Accounting Process After Invariant Change (b) Intersection of a) with Buyer Public Process

them. Let further δ be a change operation transforming A into A' . Then: δ is called *variant additive change* if the following constraint holds: $A' \setminus A \neq \emptyset \wedge A' \cap B = \emptyset$.

According to Def. 6 change propagation to B and the related private process become necessary now. We illustrate this scenario by an example. Assume that the accounting private process shall be extended with the option to cancel orders (e.g., due to a product being out of stock). This change can be accomplished by adding a respective decision node and an activity to send the cancel message to the buyer ($A\#B\#cancelOp$) – the result is depicted in Fig. 11.

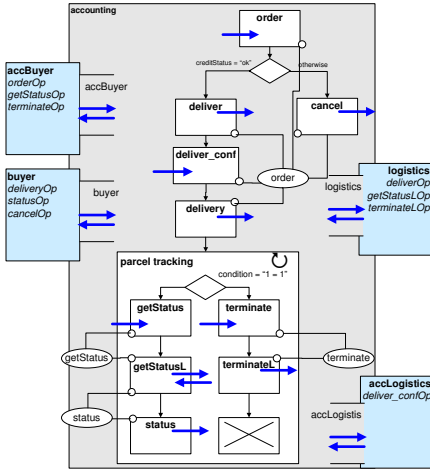


Figure 11. Additive Change of Accounting Private BPEL Process

Next we derive the new version of the accounting public process and apply the buyer view on it (cf. Fig. 12a). Then we calculate the intersection of this automaton with the one of the buyer public process (cf. Fig. 6) which results in the automaton shown in Fig. 12b). Note that this

automaton is empty since there exists no transition labeled $A\#B\#cancelOp$ on any path to a final state. This makes the annotation containing this message invalid and therefore results in an empty automaton. As a consequence, the variant change of the accounting process has to be propagated to the buyer process.

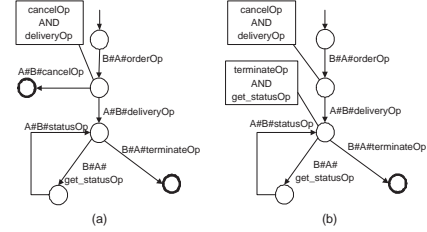


Figure 12. Accounting Process After Additive Change: (a) Public (Buyer) View (b) Intersection of a) with Buyer Public View

We now sketch the steps necessary for propagating additive changes to the opponent's private/public process:

1. Recalculate the opponent's public view on the new public process of the change originator and determine the newly inserted sequence (i.e., the messages potentially exchanged with the opponent's public process).
2. Calculate the union of the opponent's current public process and the newly introduced message sequence (cf. Step 1.) The resulting aFSA provides the basis for potential adaptations of the opponent's public process.
3. Based on the outcome of Step 2 we can derive those regions of the opponent's private process where adaptations may have to be performed.
4. Perform the necessary changes of the opponent's private process.
5. Recalculate the opponent's public process. If it is consistent with the public process of the change originator we are finished. Otherwise, go back to the previous step and repeat it with a modified set of changes.

We explain the different steps along our example:

ad 1) We determine the changes of the buyer view on the accounting public process A' . Based on this we calculate potential adaptations of the buyer public process B . More precisely we determine $A'' := \tau_{Buyer}(A') \setminus B$ (cf. Fig. 13a). In general, we have to consider the difference $\tau_{Buyer}(A') \setminus (\tau_{Buyer}(A) \cap B)$. However, since only those message sequences must be added to B which have not been contained before, derivation of $\tau_{Buyer}(A') \setminus B$ is sufficient.

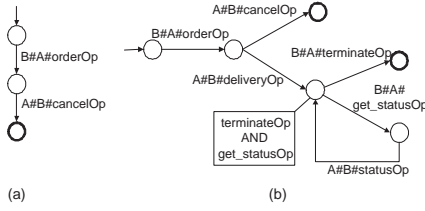


Figure 13. (a) Difference at Buyer View of Accounting Public Process (minimized) (b) New Buyer Public Workflow (minimized)

ad 2) We calculate the union of the described difference (cf. Step 1) with the original buyer public process. Based on this we can derive potential changes of the buyer public process. – The union of two aFSAs can be created using the complement and intersection operator in accordance to the deMorgan law: $A \cup B \equiv \overline{\overline{A} \cap \overline{B}}$; thus, $B' := A'' \cup B$ (cf. Fig. 13b).

ad 3) We apply the potential changes to the buyer public process. The regions to be adapted in the corresponding private process can then be derived from the states that have been modified for the buyer public process. For this we use the mapping that was created when generating the buyer public process out of the corresponding private one. Note that observable states can be mapped to a particular process region and that non-present transitions provide a hint on what is missing exactly.

In order to derive the states which have been changed when transforming aFSA B to aFSA B' the difference automaton is traversed parallel to the original public process (comparable to bi-simulation). In particular, the first state where the difference automaton contains a transition which is not contained in the original public process, indicates the state where a new transition has been added. The missing transition indicates which message has to be additionally considered by the private process. With regard to the Buyer public process, this is the case for state number 2 in the original public process as depicted in Fig. 6.

From the mapping table it can be derived that the change in the Buyer private process is related to the block specified by the sequence activity labeled "buyer process". In particular, the receive delivery activity contained in the sequence has to be changed to a pick activity allowing to receive either the delivery message or the cancel message. Information which has to be added can be derived from the difference automaton depicted in Fig. 13a). Fig. 14 shows the resulting Buyer private process.

ad 4 and 5) Finally, we perform the change of the private process accordingly and recalculate the public process on it. After this we check whether the intersection of the changed

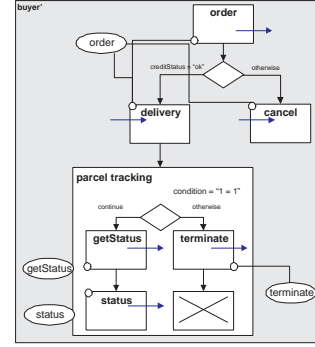


Figure 14. Buyer Process after Propagation of Additive Changes

buyer public process and the buyer view of the accounting public process is non-empty, i.e. whether the related aFSAs are bilaterally consistent.

5.3. Variant Subtractive Changes

The formal basis for variant subtractive changes is also provided by Def. 5 and Def. 6: Let A and B be the aFSAs of two public processes and let $A \cap B \neq \emptyset$ be the current protocol between them. Let further δ be a change operation transforming aFSA A into aFSA A' . Then: δ is called a *variant subtractive change* if the following constraint holds: $A \setminus A' \neq \emptyset \wedge A' \cap B = \emptyset$. According to Def. 6 change propagation to B and the related private process becomes necessary again. As an example assume that the original accounting private process (cf. Fig. 2) is changed to the one from Fig. 15. Here, the previously unlimited number of parcel tracking iterations is now constrained to at most one parcel tracking request. This change can be realized, for example, by removing the loop from the original process and adding a decision on whether parcel tracking is omitted or carried out once. Furthermore both paths then finish with an exchange of the terminate messages.

The buyer view on the accounting public process, which is derived from the accounting private process, is depicted in Fig. 16a). The intersection automaton of the buyer view on the accounting public process with the buyer process (cf. Fig. 6) is depicted in Fig. 16b). The intersection automaton is empty, since there exists an annotation containing the *get_statusOp* message which is not available as a transition. Thus, the annotation evaluates to false making the complete automaton empty. Similar to additive changes propagation of subtractive changes is required. The propagation approach is similar to the additive change:

1. Calculate the removed sequence by comparing the current public process with the former public process of

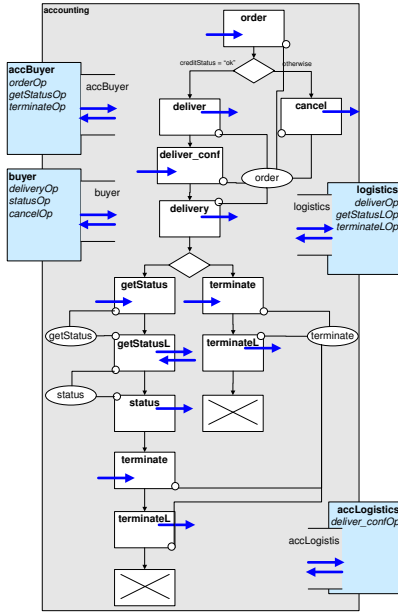


Figure 15. Accounting Private Process after Subtractive Change

the party where the change occurred.

2. Calculate the difference of the opponents public process with the removed execution sequence.
3. Derive the areas in the opponent's private process where changes have to be performed.
4. Perform the necessary changes of the opponent's private process.
5. Recalculate the opponent's public process. If it is consistent with the public process of the change originator we are finished. Otherwise, go back to the previous step and repeat it with a modified set of changes.

ad 1) The changes of the buyer view on the accounting public process and its effect to the buyer public process are calculated. Similar to additive changes, the difference is calculated by $A'' := \tau_{Buyer}(A') \setminus B$ (cf. Fig. 17a).

ad 2) The next step calculates for the buyer public process the removed execution sequences (represented in the difference automaton of Step 1). For this the difference $B' := B \setminus A''$ is determined. The modified buyer public process is depicted in Fig. 17b).

ad 3) Similar to additive changes, we use the mapping table of the buyer original public and private process to determine the area, where changes have to be performed. However, in the subtractive case the relevant state is observed

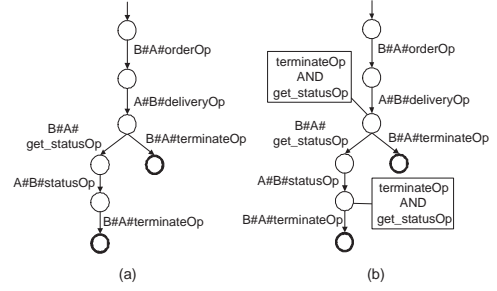


Figure 16. (a) Buyer view of the Accounting Public Process after Subtractive Change (b) Intersection of a) and Buyer Public Process

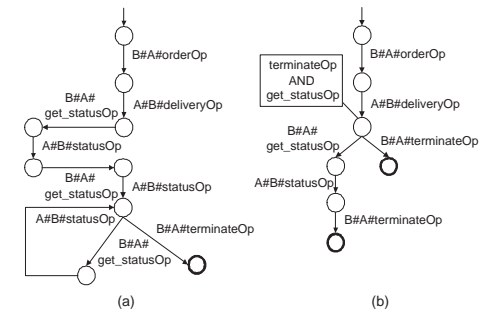


Figure 17. (a) Difference of Buyer View of Accounting Public Process and Buyer Public Process (minimized) (b) Buyer Public Process after Subtractive Change

when the original buyer public process provides a transition, which is not provided by the modified public process. With regard to the original buyer public process depicted in Fig. 6, state 4 provides a transition to state 3 which is not supported in the modified public process. Thus, a performed change gets visible at that state. The change required in the private process has to be performed either on the block labeled "cond continue" or in a higher level block. In our example, the block "While:tracking" is the relevant one (i.e, the one providing the loop). In particular, the loop has to be removed and additional activities have to be added to enumerate the two options of parcel tracking.

ad 4) The resulting Buyer private process is depicted in Fig. 18. Again, information on what has to be changed can be derived from the difference automaton shown in Fig. 17.

ad 5) Finally, after this propagation of changes, the intersection of the changed Buyer public process and the buyer view of the accounting public process is non-empty, that is they are bilaterally consistent again. Thus, no further prop-

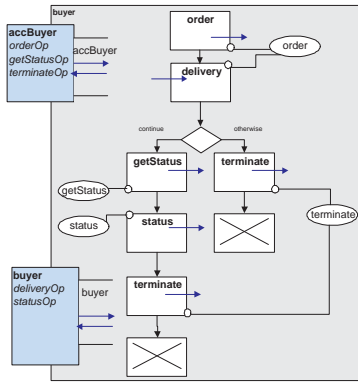


Figure 18. Buyer Private Process after Propagating Subtractive Change

agation with the buyer is needed. However, the propagation with the logistics has to be performed in a similar way.

6. Implementation Issues

We have implemented the core of the presented approach in a proof-of-concept prototype [18]. Further, a partial mapping from BPEL (private processes) to annotated Finite State Automata (public processes) has been realized [19] and been used for implementing service discovery [20]. The extension of classical UDDI proposed in this context uses BPEL specifications of public processes and bilateral consistency to improve the precision of service discovery results. Finally, we have proposed a protocol to derive a potential cross-organizational process (i.e., a potential service composition in Web Service notation) in a decentralized way resulting in a set of services as a basis for consistency checking [16].

These building blocks can be used for setting up the concrete change framework as described in this paper. As indicated the only information which has to be exchanged between partners is about the changes applied to public processes. The difference calculation as well as the necessary adaptations of the own public and private processes can be accomplished locally. Finally, decentralized consistency checking can be applied to guarantee the successful introduction of the changes and the consistency of the changed choreography. How these final steps can be carried out has been already described in [17].

With ADEPT2 we have further provided a powerful proof-of-concept prototype of an adaptive process management system [10]. Among other features ADEPT2 enables the propagation of process schema changes to running process instances. Based on this, changes of private processes can be propagated to already running process in-

stances. However, so far we have not integrated ADEPT2 with the building blocks mentioned above. This integration will enable dynamic changes of process choreographies at the instance level as well and will be one of the next steps in the implementation of our overall change framework.

7. Related Work

Checking consistency of a cross-organizational process can be based on the set of potential execution sequences. A straightforward approach is to check consistency on a centralized representation of the cross-organizational process, which has to be split into several public processes afterwards. This principle was applied to different process description formalism in the past, like Workflow Nets (WF Nets) [2], guarded Finite State Automata [6], Colored Place/Transition Nets [21], and Statecharts [15]. However, these top-down approaches are based on centralized consistency checking, which is different to what we have addressed in this paper.

By contrast, the bottom-up approach of constructing the cross-organizational process out several public processes has not been investigated in sufficient detail so far. Respective proposals have been made, for example, in [1, 6, 8]. However, they require centralized decision making and are also not constructive; i.e., they only specify criteria for various notions of consistency but do not provide an approach to adapt public processes in a way making the overall cross-organizational process consistent. In addition, these approaches neither address synchronous communication nor allow for decentralized consistency checking.

Issues related to the dynamic change of workflows have been investigated in great detail in the literature (e.g., [14, 4, 9, 11]). Respective approaches address ad-hoc changes of single process instances as well as process schema evolution (i.e., the controlled change of process types and the propagation of these modifications to already running process instances [4, 11]). However, these approaches focus on the adaptation of process orchestrations, i.e., process instances controlled by a single endpoint. By contrast, issues related to changes of process choreographies have been neglected so far. What can be learned from approaches dealing with dynamic changes of process orchestrations is the idea of controlled change propagation. These approaches aim at propagating process type changes to running process instances without losing control, i.e., without causing inconsistencies or errors in the sequel. Similarly, we have provided an approach for the controlled propagation of the changes of private processes within a choreography to the choreography itself and the respective partner processes.

8. Conclusion and Future Work

The controlled evolution of private processes, the correct adaptation of related public views, and the effective propagation of these changes to partner processes will be key ingredients of future service-oriented infrastructures, ultimately resulting in highly adaptive process choreographies. Together with our previous work on process choreographies [18, 19] and process evolution [12, 11] the presented framework enables a powerful approach for realizing adaptive, cross-organizational business processes.

In this paper we have focussed on structural process changes. We have presented our framework for introducing changes to private processes, for recalculating related public views automatically, and for propagating resulting modifications to partner processes if required. The very important aspects of our work are its practical relevance and its formal foundation. We have provided a formal model and precise criteria allowing us to automatically decide which adaptations become necessary due to changes of private partner processes. The treatment of different change scenarios adds to the completeness of our approach. Finally, we have implemented the basic mechanisms presented in this paper in a proof-of-concept prototype.

We have put emphasis on the adaptation of private/public process models and of related interactions between process partners. Another challenging issue is the treatment of running process instances (participating in a choreography) when changing private and public process models. The co-existence of different versions of a process choreography is a must in this context. For long-running choreographies, in addition, change propagation to already running instances is highly desirable. In the ADEPT project [10, 11, 12], we developed and implemented advanced concepts for the controlled evolution of process schemes and the dynamic migration of related process instances to new schema versions. In principle, these concepts can be applied to process choreographies as well. Due to the autonomy and distributed execution of partner processes, however, more advanced procedures become necessary. The same applies if we have to cope with ad-hoc changes at the level of individual choreographies (e.g., to deal with exceptional situations). These and other issues will be subject of future publications.

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