A Version-based Approach to Address Flexibility of BPMN Collaborations and Choreographies

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Abstract: Process flexibility is an important issue in the business process management area: it has mainly been investigated in the context of intra-organisational processes but it received little attention in the context of processes crossing the boundaries of companies. This paper addresses the issue of BPMN collaborations and choreographies flexibility, advocating a version-based approach. Indeed versions, which have been recognised as a powerful mechanism to face flexibility of internal processes of companies, are used to address flexibility of processes crossing the boundaries of companies, modelled as collaborations or choreographies in BPMN. Thus this paper extends BPMN collaborations using versions. It also introduces algorithms supporting the mapping from versions of collaborations into versions of choreographies. This paper mainly focuses on static aspects of collaboration and choreography versioning.

1 INTRODUCTION

Flexibility has been the focus of numerous works in the Business Process Management (BPM) domain. On the one hand, several taxonomies to characterise process flexibility have been proposed in literature. The more suitable one is given in (Reichert and Weber, 2012). This taxonomy differentiates between two times for process flexibility: flexibility at design-time, which refers to foreseeable changes which can be taken into account in modelled process schemas, and flexibility at run time, which refers to unforeseeable changes occurring during process execution. In addition, this taxonomy identifies four needs of flexibility:

- *Variability*, for representing a process differently, depending on the context. Each process schema is represented as a variant: variants share the same core process whereas the activity execution differs from variant to variant.
- *Adaptation*, for handling occasional situations or exceptions which have not been necessarily foreseen in the process schema.
- *Evolution*, for handling changes in processes, which require occasional or permanent modifications in their schemas.
- *Looseness*, for handling processes whose schemas are not known before, and which correspond to non-repeatable, unpredictable, and emergent processes. Such processes require loose specifications.

On the other hand, several contributions have been made to address process flexibility, mainly in the context of intra-organisational processes –e.g., (Rosemann and Aalst, 2007), (Adams et al., 2007), (Hallerbach et al., 2010), (Ekanayake et al., 2011), (Zhao and Liu, 2013). However, process flexibility is still an open issue in the context of Inter-organisational Processes (IoP), which are processes crossing the boundaries of companies, and which are modelled as collaborations or choreographies in BPMN (Business Process Model and Notation). Note that BPMN is the standard notation for process modelling: it is promoted by the OMG (OMG, 2011) and serves as a basis for process specification in several process management systems. IoP flexibility may be related to the availability of involved processes or to the collaboration or the choreography schema. Research efforts about IoP flexibility mainly address process availability in the context of dynamic inter-organisational processes. Dynamic inter-organisational processes refer to processes where the different partners involved are not necessarily known at design-time, or can evolve at run-time –*e.g.*, they become unavailable or their quality of service decreases significantly (Chebbi et al., 2006). The provided solutions support finding new partners offering requested services, along with negotiation, contracting and service execution. Flexibility of schema collaboration or choreography has been rather neglected and the following research question has to be addressed: *how to model collaborations or choreographies able to deal with IoP variability, adaptation and evolution?*

This paper addresses this research question advocating a version-based approach. Indeed the notion of version has been recognised as a key notion to deal with process flexibility in intra-organisational context (Ekanayake et al., 2011), (Zhao and Liu, 2013), (Ben Said et al., 2014), and more precisely, to deal with process variability, process evolution and process adaptation (when adaptation can be defined at design-time), according to Reichert and Weber's taxonomy. On the other hand, versions make the migration of processes running according to an old schema to a new one easier to perform (Ben Said et al., 2014).

More precisely, the paper contribution is twofold. First the paper extends BPMN for collaboration versioning, mainly focusing on static aspects. Secondly the paper gives a set of algorithms implementing the mapping from versions of collaborations into versions of choreographies.

Accordingly this paper is organised as follows. Section 2 gives the background of the paper. It also introduces the radiological examination process, which motivates the need for flexibility of processes crossing the boundaries of companies. Section 3 addresses the modelling of versions of collaborations: it introduces BPMN4V which is an extension of BPMN to support version of collaboration modelling, mainly focusing on static aspects of version modelling. Section 4 describes recommended algorithms implementing the mapping from version of collaborations into corresponding versions of choreographies using a tree-based approach. Section 5 compares our approach with related works and concludes the paper, giving some directions for future works.

2 BACKGROUND

This section introduces the background of the paper, namely collaboration and choreography modelling in BPMN. It also presents the radiological examination example, which will be used through the paper to illustrate collaboration and choreography versioning.

2.1 Concepts for BPMN Collaboration and Choreography

BPMN 2.0 allows the creation of three basic types of diagrams within an end-to-end process (OMG, 2011): (i) a *Private Process* is internal to a specific company. It describes a sequence of activities performed within the organisation in order to carry out an objective. It is depicted as a directed graph. (ii) a *Collaboration* depicts the interactions between two or more business entities (each one represented by a process) in order to carry out a common business target. These interactions specify the orchestration between the partners involved as message flows, *i.e.* messages exchanged between partners. (iii) a *Choreography* is another way to model interactions between partners. Unlike collaborations, the focus is not on orchestration of the work performed within partners, but rather on the exchange of information (messages) between them. Note that BPMN collaboration describes both orchestration of partners activities and messages exchanged, thus BPMN choreography can be deduced from BPMN collaboration.

As this paper deal with BPMN collaboration and choreography flexibility, we present below the necessary concepts for collaborations and choreographies modelling.

Regarding collaborations, each involved partner is seen as a participant that represents a *PartnerEntity* (*e.g.*, a company) or a *PartnerRole* (*e.g.*, a buyer, a seller, or a manufacturer). A participant is often responsible for the execution of a *Process*. A process involved in a collaboration is a *FlowElementContainer* that may contain *SequenceFlow* and *FlowNode* (*Gateway*, *Event* and *Task*). More precisely, processes of collaboration are provided within tasks, events and the way these tasks and events are synchronised using sequence flow and gateways. Furthermore, within a collaboration, participants are prepared to send and receive *Messages* within *Message flows*. A message flow illustrates the flow of messages between two interaction nodes. An *Interaction node* is used to provide a single element as the source (*send* relationship) or the target (*receive* relationship) of a message flow, and therefore of a message. An interaction node can be a participant, a task or an event. Note that within a collaboration, tasks (and events) are considered as the "touch point" between participants. Only those tasks (or events) that are used to communicate with the other participants are included. They define the public part of the process. As a consequence, all other internal (*i.e.*, private) tasks or events of the process are not shown in a collaboration diagram (OMG, 2011).

A *Choreography* is a FlowElementContainer that may contain sequence flow and *FlowNode* (gateway, event and choreography activitiy). A *Choreography activity* represents a point in a choreography flow where an interaction occurs between two or more participants. A choreography activity can be a choreography task or a sub choreography. A *ChoreographyTask* is an atomic activity in a choreography that represents an interaction in which one or two messages are exchanged between two participants. A *SubChoreography* is a compound activity in a chorography that contains the flow of other choreography activities.

2.2 The Radiological Examination Collaboration

The radiological examination collaboration, inspired from (Reichert and Weber, 2012), describes how a clinic interacts with a radiology centre for X-ray examination towards clinic patients. Note that these two companies are independent.

Three cases are possible, each one corresponding to a version of the collaboration. Due to lack of space, Figure 1 only shows the first version of the collaboration, in which each participant process is represented in a specific pool. This first version starts when a clinic's patient needs a radiological examination. Thus the clinic sends a request for an X-ray examination to the radiology centre. After checking the request, either the centre sends back a reject notification to the clinic, or it notifies the clinic of the chosen X-ray appointment. On the appointment day, the clinic drives the patient to the radiology centre. After the X-ray examination, the radiologist interprets the examination and sends the result of this interpretation to the clinic. Note that in this first version of collaboration, messages exchanged (*e.g.*, result of the interpretation) are paper documents transmitted manually.

The second version of the collaboration is suitable when the patient cannot be driven to the radiology centre. In this case, a radiologist from the radiology centre takes specific portable X-ray material from the radiology centre to the clinic to perform the requested X-ray in the patient's room.

In order to improve the quality of their services, both the clinic and the radiology centre implement a specific application supporting the automation of their interaction. Thus a new version of the collaboration is defined. In this version, exchanged messages are electronically transmitted within application. In addition, before interpreting the examination, the radiologist can interact with the patient's doctor for additional information.

According to the taxonomy of Reichert and Weber, this example highlights two flexibility needs: variability and evolution. Indeed the second version of the process is a variant of the first version as it is suitable, when the patient cannot move to the radiology centre. The third version is rather an evolution of the first version of the process as the interactions between the clinic and the radiology centre are no longer manual interactions but they are directly encoded in a specific application.

3 VERSIONING BPMN COLLABORATIONS

This section introduces the notion of version and presents the versioning pattern we recommend to model both entities and their corresponding versions. Then the section describes the provided extensions to BPMN for version of collaboration modelling. Finally, this section illustrates the modelling of the first version of the Radiological Examination collaboration.

3.1 Version Concept

A version corresponds to one of the significant states (*i.e.*, values) an entity (*e.g.*, a collaboration, a process) may have during its life cycle. So, it is possible to describe changes occurring to entities through their different versions. These versions are linked by a derivation link; they form a derivation hierarchy.

When created, an entity is described by only one version. The definition of every new version is done by derivation from a previous one: such versions are called derived versions. Of course, several versions may be derived from the same previous one: these are called alternatives; they capture the variability of the corresponding process and they correspond to their various variants. Thus, using the notion of version, it becomes possible to model collaborative process flexibility and more precisely, collaborative process schema variability (through the notion of alternative or variant), collaborative process schema adaptation which can be modelled a priori in the schema, and collaborative process schema evolution. (Ben Said et al., 2014).

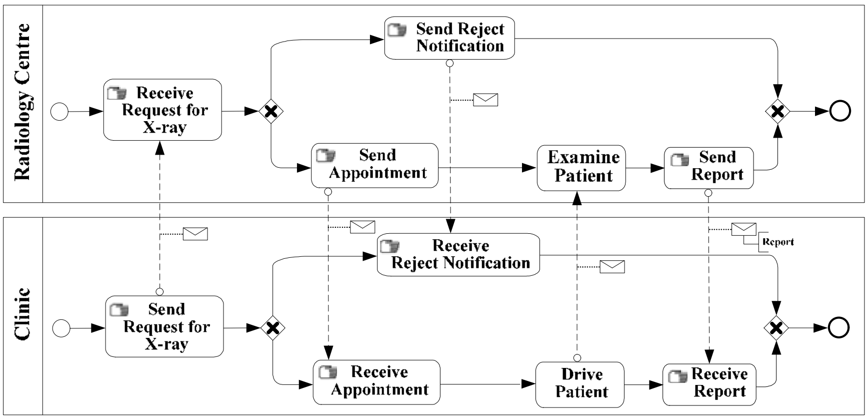

Figure 1: Version 1 of the Radiology Examination collaboration.

We introduce a versioning pattern to support version modelling. The underlying idea is to model, for each versionable class (a versionable class is a class for which we handle versions) of the BPMN meta-model for collaborations, both entities and their corresponding versions. The versioning pattern is given in Figure 2. Each versionable class is described as a class, called *Versionable*. We associate to each versionable class, a new class, called *Version of Versionable*, whose instances are versions of Versionable, and two links: (i) the *is_version_of* composition, which links each instance of the Versionable class with its corresponding instances of the Version of Versionable class; and (ii) the *derived_from* relationship, which supports version derivation hierarchy modelling. This latter relationship is reflexive and the semantics of both relationship sides is: (i) a version (SV) succeeds another one in the derivation hierarchy and, (ii) a version (PV) precedes another one in the derivation hierarchy. Regarding versions, we also introduce attributes such as version number, creator name, creation date and state in the Version_of_Versionable class.

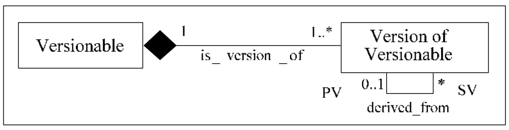

Figure 2: Versioning pattern.

3.2 BPMN4V: Extension of BPMN for Collaboration Version Modelling

We model versions of collaborative processes providing extensions to the BPMN 2.0 collaboration meta-model previously presented. More precisely, we use the previous versioning pattern to make some classes of BPMN 2.0 collaboration meta-model versionable. Figure 3 presents the resulting meta-model, namely BPMN4V (BPMN for Versions). BPMN 2.0 classes are visualised in white while BPMN4V classes are visualised in grey.

In order to keep track of collaboration flexibility, we propose to make some classes of BPMN2.0 meta-model versionable using the versioning pattern introduced before. More precisely, we recommend handling versions for the following BPMN 2.0 classes: Collaboration, Message, Process, Task and Event. In fact, each of these classes represents key concepts for collaborations and plays a strong role in the definition of a collaboration. The idea is to keep track of changes occurring to components which play a part in the description of how the collaboration is carried out.

Generally speaking, a new version of an element (*e.g.*, collaboration) is defined according to changes occurring to it: these changes may correspond to the addition of information (property or relationship) or to the modification or the deletion of existing ones. More precisely, regarding messages, we consider that a modification of their property ItemDefinition results in the creation of a new version of message. For instance, if Report is a message referring to a paper document (Itemkind value is physical), and as a result of technical changes, if it becomes an electronic document (Itemkind value is information) then a new version of Report has to be created. However we do not necessarily create a new version of message if there is change in the interaction in which the message is involved. Indeed an interaction (i.e., a message flow) being defined as the triplet (message, send node, receive node), where send and receive nodes are interaction nodes involved in the message exchange that either correspond to versions of task or versions of event, changing the interaction

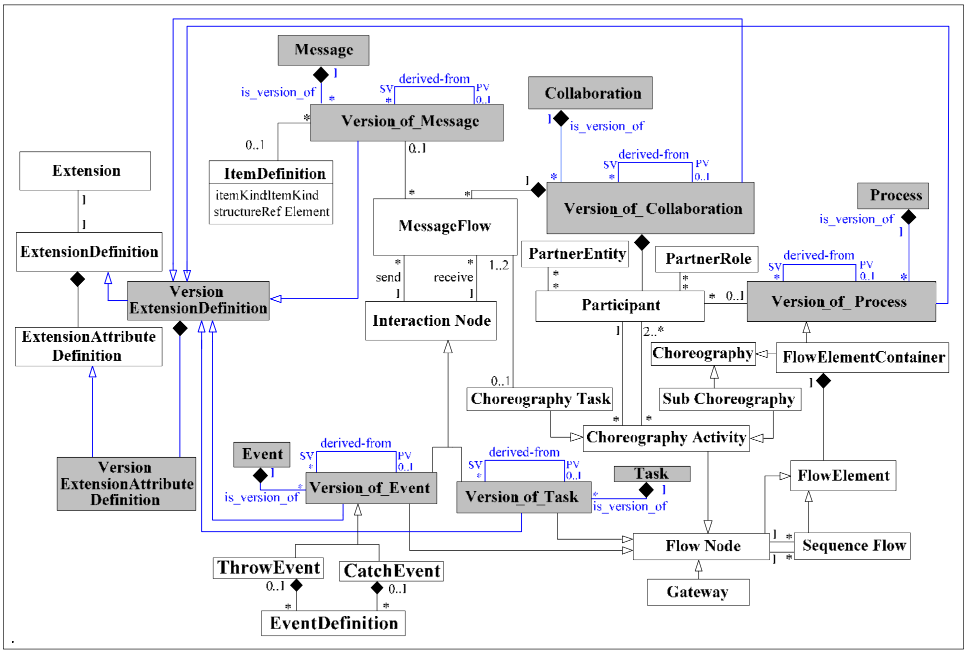

Figure 3: BPMN4V: extension of BPMN for version of collaboration modelling.

does not necessarily lead to the creation of a new message. For instance, if message M is sent from task A to task B, and if a new task C is defined after an organizational change and the message is no longer sent from A to B but rather from C to B, then we do not create a new version of the message M if it carries the same information. Thus we manage M.v1 as a message exchanged between A and B, and M.v1 and we also manage M.v1 as a message exchanged between C and B.

Regarding processes, we create new versions when there are changes to the involved tasks and/or events or in the way they are linked together using sequence flows and gateways. In the same way, changes to tasks and events may result in the creation of new task and event versions. In addition, we create new versions of tasks or events involved in message exchange, when there are changes to the exchanged messages.

Finally, regarding collaborations, new versions may result from changes to participants involved. Thus when we add or delete a participant, it is necessary to adapt the current collaboration to this change: we have to incorporate the added participant or to possibly replace the deleted one. New versions of collaborations may also result from changes to involved processes or exchanged messages. Exchanged messages have an important impact in collaboration flow. Thus any change in a sent or a received message affects the involved tasks or events, and consequently the involved process. So, when we add (or delete) a message, we have to add (or to delete) a received and a send activity, which leads to changing the process schema. In this case, the other processes involved in the collaboration have in turn to be adapted to this change to ensure continued collaboration.

On the other hand, BPMN 2.0 meta-model provides extension mechanisms through classes *Extension*, *ExtensionDefinition* and *Extension AttributeDefinition*, and, as suggested in (OMG, 2011), each recommended extension has to be assigned to these classes. Therefore, we recommend adding the classes *VersionExtensionDefinition* and *VersionExtensionAttributeDefinition* to model the specific attributes which versionable classes include (version number, creator name, creation date and state). Thus each Version of Versionable class of the meta-model is a sub-class of the abstract class VersionExtensionDefinition.

3.3 BPMN4V Instantiation: Modelling the Radiological Examination Collaboration

Figure 4 gives an instantiation of BPMN4V for the modelling of the first and third versions of the Radiological Examination collaboration (C.v1 and C.v3). In this figure, we model both the versions of the collaboration and the versions of the two processes involved in this collaboration.

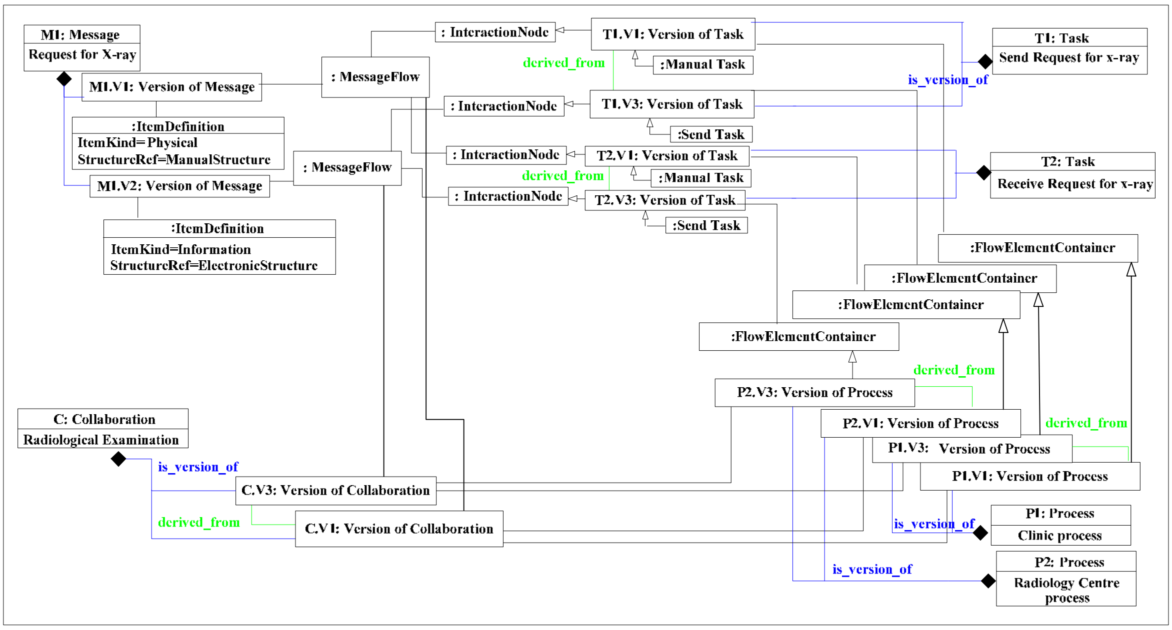

Figure 4: Instantiation of BPMN4V meta-model.

C.v1 and C.v3 differ from one another in their partner processes, tasks type and message flows. Thus we have defined two versions of the clinic process, namely P1.v1 and P1.v3, each one defining the behaviour of the clinic partner in each version of the collaboration. We have also defined two versions of the radiology centre process, namely P2.v1 and P2.v3, each one defining the behaviour of the radiological centre partner in each version of the collaboration. P1.v1 and P2.v1 hold for the first version of the collaboration C.v1 whereas P1.v3 and P2.v3 hold for the third version C.v3.

Versions of processes involved in versions of the Radiology Examination collaboration also differ from one another in their component tasks and their coordination. For instance, we have defined two versions of the send task *Send Request for X-ray*. The first one *T1.v1* participates in *P1.v1* whereas the second one *T1.v3 participates in P1.v2. T1.v3* has been created first and *T1.v3* has been derived from *T1.v1* since there is change in the task type.

Finally, Figure 4 defines the versions of messages involved in the collaboration. For instance, we have defined two versions of the message *Request for X-Ray*. The first one *M1.v1* holds for *C.v1* and refers to a paper document whereas the second one, *M1.v3*, holds for *C.v3* and refers to an electronic document.

4 MAPPING VERSIONS OF CHOREORGAPHIES

As indicated before, BPMN collaboration describes both orchestration of partners activities and messages exchanged, thus BPMN choreography can be deduced from BPMN collaboration. For this reason, we provide algorithms mapping versions of collaborations into versions of choreographies instead of directly model versions of choreographies. This section presents our approach supporting the mapping versions of collaborations into versions of choreographies. It includes four steps:

- Step 1 builds a VP-Tree for each version of process involved in the considered version of collaboration. Building a VP-Tree requires breaking down each version of process into fragments.
- Step 2 links the VP-Trees built in the previous step. More precisely, a Linked-VP-Tree is composed of the VP-Trees of the considered version of collaboration along with links corresponding to messages exchanged.
- Step 3 deduces the corresponding VC-Tree *i.e.*, the corresponding version of choreography represented as a tree.
- Finally, step 4 deduces the corresponding choreography, represented according to the BPMN meta-model, from the VC-Tree.

The following sub-sections detail these four steps, mainly providing the recommended algorithms for each step.

4.1 From Versions of Collaborations to VP-Trees

The first step of the approach consists of building VP-Trees for each version of process involved in the considered version of collaboration. To do so, we decompose these versions of process into fragments and we deduce the corresponding VP-Trees.

4.1.1 Process Fragmentation

Process fragmentation consists of decomposing each version of process involved in the considered collaboration into canonical single-entry single-exit (SESE) fragments. To do so, we propose to use the algorithm proposed by (Polyvyanyy et al., 2012) to decompose a process model into canonical SESE fragments. Figure 5 shows the result of SESE decomposition for the Radiology Centre process of the first version of the Radiological Examination collaboration, according to (Polyvyanyy et al., 2012)'s algorithm. This decomposition results in F0, F1, and F2 SESE fragments. As the name suggests, each SESE fragment has exactly one incoming and exactly one outgoing edge. For instance, the internal structure of fragment F2 is a sequence of tasks (Send Appointment, Examine Patient, Send Report) whereas fragment F1 consists of a branching of Send Reject Notification task and F2 fragment. Furthermore, SESE fragments can be embedded in other SESE fragments: note how fragment F0 aggregates the Start Event, Receive Request for X-ray task, F1 fragment and End Event to a SESE fragment.

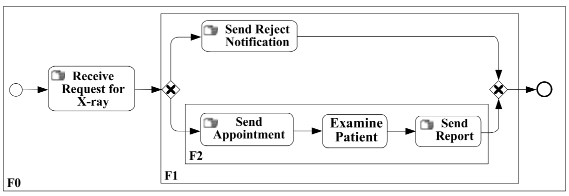

Figure 5: Canonical SESE fragments of the Radiology Centre process.

To sum up, a fragment of a process version involved in a version of collaboration is composed of versions of tasks, start and end events, and fragments synchronised by control patterns (modelled as sequence flows or gateways).

4.1.2 Deducing VP-Trees from Fragments

VP-Trees are deduced from the identified fragments. A VP-Tree is a tree having the following structure, according to the ML language syntax.

```
VP-Tree::= VP-Node
VP-Node::= TerminalVP-Node |Non-
    terminalVP-Node
Non-terminalVP-Node::= SEQ({VP-Node})|
      CHC({VP-Node}) | PAR({VP-Node}) |
      RPT(VP-Node)
TerminalVP-Node::= Task
```

A VP-tree is defined as a VP-node. We distinguish two types of nodes: terminal nodes and non-terminal nodes. A non-terminal node can be a sequence (SEQ), a choice (CHC), a parallelism (PAR) or a repetition (RPT) of –a set of– nodes. A terminal node corresponds to a task (supporting message exchange). Note that it is useless to keep the start and end events of fragments. These events will be added at step 4 when deducing the BPMN choreography.

Our recommended algorithm, namely *Build-VP-Tree*, implementing the mapping from a fragmented version of process to its corresponding VP-Tree, uses the mapping rules given in Table1.

Table 1: Mapping rules from Fragment to VP-Tree.

Fragment	VP-Tree
Version of Task	Task
Fragment	Non-terminalVP-Node
Control Pattern	Nature of a Non-terminal VP-Node (SEQ, CHC, PAR…)

Moreover, this algorithm uses the following set of functions supporting the handling of both fragments and trees:

- isTask(f) returns *true* if the fragment *f* is a version of task, otherwise *false*,
- isEvent(f) returns *true* if the fragment *f* is an event, otherwise *false*,
- getComponents(f) returns the set of versions of tasks, and/or fragments that compose the fragment *f*,
- getControlPattern(f) returns the control pattern of the fragment *f*,
- defineTerminalVP-Node(t) defines the terminal VP-node corresponding to the task *t*,
- defineNon-terminalVP-Node(f,p) defines the non-terminal VP-node corresponding to the fragment *f* synchronised by the control pattern *p*,
- getCurrVP-Tree(vpt) returns the current node in the VP-Tree *vpt*,

- addVP-Node(n,vpt,p) adds the VP-node *n* to the VP-Tree *vpt*; n is added as a son of the node *p*.

The algorithm implementing this mapping is the following.

```
Build-VP-Tree(f:Fragment):VP-Tree
Local n: VP-Node, vpt: VP-Tree
Begin
   If IsTask(f) Then
      n=defineTerminalVP-Node(f)
      addVP-Node(n,vpt,
            getCurrVP-Tree(vpt))
      return vpt
   Elseif not IsEvent(f) Then
      /* f is a fragment */
      n=defineNon-terminalVP-Node(f,
            getControlPattern(f))
      AddVP-Node(n,vpt,
            getCurrVP-Tree(vpt))
      For Each c in getComponents(f)
         return Build-VP-Tree(c)
      End For
   End If
End
```

Figure 6 illustrates the result of this step with respect to the first version of the Radiological Examination collaboration. The previous algorithm has been performed to each fragmented version of process involved in the considered version of collaboration. Each resulting VP-Tree is defined as a sequence of terminal VP-nodes corresponding to versions of tasks, and non-terminal VP-nodes corresponding to embedded fragments.

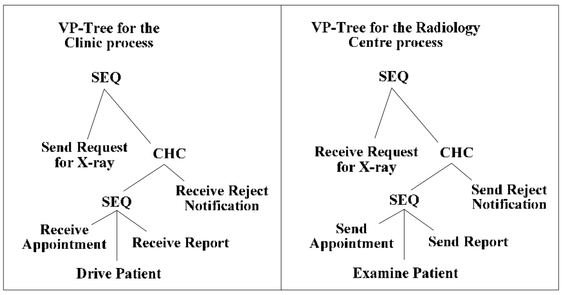

Figure 6: VP-Trees for the first version of the Radiological Examination collaboration.

4.2 From VP-Trees to Linked-VP-Trees

The result of step 1 is a set of VP-Trees representing versions of processes involved in the considered version of collaboration. The second step of the approach aims at linking these VP-Trees to capture messages exchanged in the considered version of collaboration. The result is a Linked-VP-Trees, defined according to the following structure:

```
Linked-VP-Trees:= ({VP-Tree},{Link})
Link:= (SourceNode, TargetNode,
     Message)
SourceNode := Task
TargetNode := Task
```

A Linked-VP-Trees involves a set of VP-Trees and a set of links. A link is defined as the triplet (SourceNode, TargetNode, Message), where the source and target nodes are terminal VP-nodes, more precisely tasks, involved in each involved VP-Tree and the message is the information transmitted between these nodes.

Our recommended algorithm for building Linked-VP-Trees, namely *Build-Linked-VP-Trees*, uses the mapping rules presented in Table 2.

Table 2: Mapping rules from Message flows to Linked-VP-Trees.

Message flow	Linked-VP-Trees
MessageFlow	Link
sourceRef of MessageFlow	SourceNode of a link
targetRef of MessageFlow	TargetNode of a link
messageRef of MessageFlow	Message of a link

Moreover, the proposed algorithm uses the following set of functions supporting the handling of message flows and Linked-VP-Trees:

- getMessage(mf) returns the message corresponding to the message flow *mf*,
- getSourceNode(mf) returns the terminal VP-node (more precisely the task) corresponding to the source of the message flow *mf*,
- getTargetNode(mf) returns the terminal VP-node corresponding to the target of the message flow *mf*,
- addVP-Tree(t,lvpt) adds the VP-Tree *t* to the Linked-VP-Trees *lvpt*,
- addLink(l,lvpt) adds the Link l to the Linked-VP-Trees *lvpt*,
- defineLink(n1, n2, m) defines the link from the terminal VP-node *n1* to the terminal VP-node *n2* and supporting the message *m*.

The algorithm implementing this mapping includes two parameters corresponding to the considered set of VP-Trees to be linked and to the list of message flows exchanged between the corresponding versions of processes.

```
Build-Linked-VP-Trees(setof-VPT:   {VP-
Tree},setof-MF: {MessageFlow}):
                        Linked-VP-Trees
Local n1, n2: VP-Node, l: Link
```

```
   mf: MessageFlow, vpt: VP-Tree
   l-vpt: Linked-VP-Trees
Begin
   For each vpt in setof-VPT
      addVP-Tree(vpt,l-vpt)
   End For
   For Each mf in setof-MF
      n1=getSourceNode(mf)
      n2=getTargetNode(mf)
      l=defineLink(n1,n2,
                  GetMessage(mf))
      addLink(l,l-vpt)
   End For
   Return l-vpt
End
```

Figure 7 illustrates the result of this step with respect to the first version of the Radiological Examination collaboration, thus considering the two VP-Trees presented in Figure 6. The different links of this Linked-VP-Trees are shown as blue arrows.

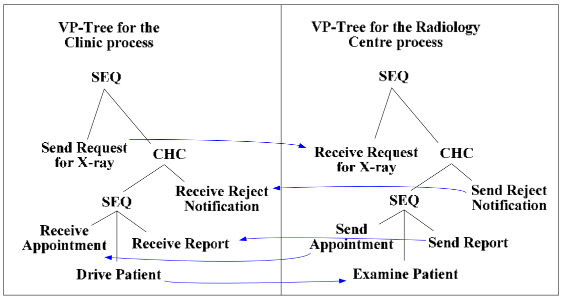

Figure 7: Linked-VP-Trees for the first version of the Radiological Examination collaboration.

4.3 From Linked-VP-Trees to VC-Tree

The third step of the approach deduces a VC-Tree (Version of Choreography Tree) from the obtained Linked-VP-Trees. A VC-Tree has the following structure:

```
VC-Tree ::= VC-Node
VC-Node::= Non-terminalVC-Node |
    TerminalVC-Node
Non-terminalVC-Node::= SEQ({VC-Node})|
      CHC({VC-Node}) | PAR({VC-Node}) |
      RPT(VC-Node)
TerminalVC-Node::= ChoreographyTask
ChoreographyTask::= (SenderParticipant,
      Message, ReceiverParticipant)
```

A VC-Tree includes non-terminal VC-nodes and terminal VC-nodes, which are choreography tasks. A non-terminal VC-node can be a sequence (SEQ), a choice (CHC), a parallelism (PAR) or a repetition (RPT) of –a set of– VC-nodes. A choreography task is defined as a triplet (SenderParticipant, Message, ReceiverParticipant) indicating that a message is sent from a participant to another one.

We detail in the following the recommended algorithm for deducing VC-Trees. This algorithm, namely *Build-VC-Tree*, uses the following mapping rules.

Table 3: Mapping Rules from Linked-VP-Trees to VC-Tree.

Linked-VP-Trees	VC-Tree
Non-terminalVP-Node	Non-terminalVC-Node
Nature of a Non-terminal VP-Node (SEQ, CHC, PAR…)	Nature of a Non-terminal VC-Node (SEQ, CHC, PAR…)
Task and Link	ChoreographyTerminalNode
Task source of a link	SenderParticipant of a ChoreographyTerminalNode
Task target of a link	ReceiverParticipant of a ChoreographyTerminalNode
Message of a link	Message of a ChoreographyTerminalNode

Moreover, the proposed algorithm uses the following set of functions supporting the handling of Linked-VP-Trees and VC-Trees:

- isTask(n) returns *true* if the VP-node *n* is a task, otherwise *false*,
- getLink(n) returns the link in which the VP-node *n* is involved,
- getSource(l) returns the terminal VP-node source of the link *l*,
- getReceiver(l) returns the terminal VP-node corresponding receiver of the link *l*,
- getMessage(l) returns the message of the link *l*,
- father(n) returns the non-terminal VP-node which is the father of the node *n* if *n* is not root of the VP-Tree, otherwise it returns *n*,
- brother(n) returns the VP-node which is a brother of the VP-node *n*,
- nextChild(n) returns the VP-node corresponding to the next child of the VP-node *n*
- goingOnBrowsing(n) returns *true* if we have to go on browsing the sub-tree that the VP-Node *n* belongs to, otherwise *false*,
- listOfChildren(n) returns the children of the non-terminal VP-Node *n*,
- getControlPattern(n) returns the control pattern of the non-terminal VP-node *n*,
- getCurr(vct) returns the current node in the VC-Tree *vct*,
- defineChoreographyTask(n1,m,n2) defines a

choreography task which will be added to the VC-Tree to be build: *n1* is the sender participant, *m* is the message to be send and *n2* is the receiver participant,

- defineNon-terminalVC-Node(n,p) defines the non-terminal VC-Node corresponding to the non-terminal VP-Node *n* synchronised by the control pattern *p*,
- addVC-Node(n,vct,p) adds the VC-Node *n* to the VC-Tree *vct* as a son of the non-terminal VC-Node *p*.

The algorithm implementing this mapping is the following. It includes a single parameter which corresponds to a node of one of the VP-Trees of the mapped Linked-VP-Trees. The first value for this parameter is `root(initial(l-vpt))`, which corresponds to the root of the initial VP-Tree of the mapped Linked-VP-Trees *l-vpt*. In the considered example (*cf.* Figure 5), the initial VP-Tree is the VP-Tree of the Clinic process.

```
Global vct: VC-Tree

Build-VC-Tree(n: VP-Node)
Local n2: VP-Node, l:Link, m: Message
      ctn: Non-terminalVC-Node
Begin
   If isTask(n) Then
      l=getLink(n): m=getMessage(l)
      If n=getSource(l) then
         n2=getReceiver(l)
      Else
         n2=getSource(l)
         n=getReceiver(l)
      End If
      /* we define a choreography
      task ct and its corresponding
      non-terminal VC- Tree node ctn */
      ct=defineChoreographyTask(n,m,n2)
      ctn=defineNon-terminalVC-Node(
      father(n2),getPattern(father(n2))
      /* we add these nodes to vct */
      addVC-Node(ctn,vct,getCurr(vct))
      addVC-Node(ct,vct,getCurr(vct))
      If goingOnBrowsing(n2) Then
         /* we go on browsing */
         Build-VC-Tree(brother(n2))
      End If
   Else
      /* n is a non-terminal VP-Tree
      node: we define its corresponding
      non-terminal VC-Tree node */
      ctn=defineNon-terminalVC-Node(
      father(n),getPattern(father(n))
      /* we add this node to vct */
      addVC-Node(ctn,vct,getCurr(vct))
      /* we go on browsing */
      Switch getPattern(n)
         SEQ, RPT:
            Build-VC-Tree(nextChild(n))
            Break
         CHC, PAR:
            For c in listOfChildren(n)
             Build-VC-Tree(c)
            End For
      End Switch
   End If
End
```

Figure 8 illustrates the result of this step with respect to the first version of the Radiological Examination collaboration, thus considering the Linked VP-Trees previously presented in Figure 7. Each triplet corresponds to a choreography task of the VC-Tree thus defining respectively its sender participant, its message and its receiver participant.

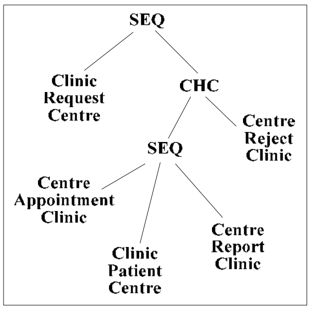

Figure 8: VC-Tree for the first version of the Radiological Examination collaboration.

Note that the deduced VC-Tree have to be reduced to delete the control patterns unnecessarily added to the VC-Tree. For instance, the following VC-Tree SEQ(A,SEQ(B)) have to be reduced to SEQ(A,B). Due to lack of space, we do not detail the algorithm implementing this reduction.

4.4 Deducing Versions of Choreographies

The final step of the approach deduces BPMN choreographies from VC-Trees. The recommended algorithm implementing the mapping from VC-Tree to BPMN choreography uses the mapping rules given in Table 4. More precisely, Table 4 indicates that choreography terminal nodes of VC-Tree correspond to Choreography Task of BPMN choreography whereas non-terminal nodes of VC-Tree, and more particularly the nature of these nodes (SEQ, CHC, PAR, RPT) helps in identifying the BPMN coordination pattern, defined using sequence flows and/or gateways. Note that we obviously specify a start event and an end event in the deduced BPMN choreography.

Table 4: Mapping rules from VC-Tree to BPMN Choreography.

VC-Tree	BPMN Choreography
Non-terminalVC-Node	BPMN control pattern: Sequence Flow and/or Gateway
ChoreographyTask	BPMN ChoreographyTask
SenderParticipant of a ChoreographyTask	Initiating participant of BPMN ChoreographyTask
ReceiverParticipant of a ChoreographyTask	Participant of BPMN ChoreographyTask
Message of a ChoreographyTask	name of a BPMN ChoreographyTask

Our recommended algorithm, namely *Build-Choreography*, uses the following set of functions supporting the handling of both VC-Tree and BPMN choreography:

- isChoreographyTerminalNode(n) returns *true* if the VC-Node *n* is a choreography terminal node, otherwise *false*,
- listOfChildren(n) returns the children of the non-terminal-VC-Node *n*,
- defineChoreographyTask(n) defines the BPMN choreography task corresponding to the choreography terminal node *n*,
- definePattern(n) defines the BPMN control pattern (gateway, sequence flow) corresponding to the nature of the non-terminal-VC-Node *n*,
- addChoreographyTask(t,c) adds the BPMN choreography task *t* to the BPMN choreography *c*,
- addControlPattern(p,c) adds the BPMN pattern *p* to the BPMN choreography *c*.

The algorithm implementing this mapping is the following.

```
Build-Choreography (vct: VC-Tree):
   BPMN-Choreography
Local t: BPMN-ChoreographyTask
       p: BPMN-ControlPattern
   ch: BPMN-Choreography
   c: VC-Tree
Begin
   If
   isChoreographyTerminalNode(vct)Then
      t = defineChoreographyTask(vct)
      addChoreographyTask(t,ch)
      return ch
   Else
      -- vct is a non-terminal-VC-node
      pa = definePattern(vct)
      addControlPattern(p,vct)
      For Each c in listOfChildren(vct)
         return Build-Choreography(c)
      End For
   End If
End
```

Figure 9 illustrates the result of this step with respect to the first version of the Radiological Examination collaboration thus considering the VC-Tree previously presented in Figure 8. Note that a start and an end event have been added to the resulting choreography.

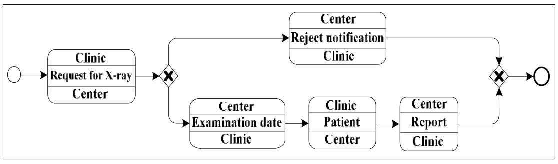

Figure 9: BPMN choreography for the first version of the Radiological Examination collaboration.

5 CONCLUSION

This paper has addressed BPMN collaborations and choreographies flexibility using versions. More precisely it has extended the BPMN meta model for collaboration to support collaboration versioning. Then it has introduced a set of algorithms implementing a four step approach for mapping versions of collaborations to corresponding versions of choreographies.

Our contribution addresses an important issue in the BPM area which is Inter-organisation Process (IoP) flexibility. Indeed, process flexibility has been mainly considered in an intra organisational context. In such a context, several contributions have addressed one or several flexibility needs: for instance, (Rosemann et al., 2007) and (Hallerbach et al., 2010) dealt with intra-organisational process variability using variants, while (Adams et al., 2007) addressed intra-organisational process adaptation and more precisely exception handling for processes. We also found contributions advocating versioning to deal with process flexibility needs and more precisely process variability, evolution and adaptation: e.g., (Ekanayake et al., 2011), (Zhao and Liu, 2013), (Ben Said et al., 2014). More particularly, (Ben Said et al., 2014) proposed to extend BPMN to model versions of private processes, considering thus only processes internal to a single company.

On the other hand, process flexibility has been rather neglected in the context of Inter-organisational Processes (IoPs). However, we have found two main contributions dealing with this issue. Firstly (Fdhila et al., 2015) addressed change propagation from a partner process towards the processes of the other partners involved in a collaboration or in a choreography. More precisely, they provide a set of algorithms to deal with changes of process schema by adding, deleting, replacing or updating process fragments, but they do not consider changes that can affect messages (*i.e.*, information) exchanged between process partners. Moreover, this contribution does not exactly deal with the issue addressed in this paper which is how to model collaborations or choreographies able to deal with IoP variability, adapation and evolution. Secondly, (Boukhedouma et al., 2013) proposed a service-based approach to model IoPs by combining processes and SOA. More precisely, they provide high-level patterns for service (adding, removing, substituting services), control flow and interaction adaptation. Note that this contribution addresses IoP evolution but it does not address IoP variability and adaptation. Thus IoP flexibility is still an open issue and we believe our contribution, which extends (Ben Said et al., 2014) considering versions of processes crossing the boundaries of companies, to be a step forward in addressing the flexibility of BPMN collaborations and choreographies.

However this contribution has the following drawbacks, which will be addressed in future works. Firstly this paper has extended BPMN to model versions of collaborations and has proposed algorithms to deduce the corresponding versions of choreographies. This choice is mainly due to BPMN collaborations, which subsume choreographies, highlighting both the orchestration of involved partners activities and messages exchanged. However, BPMN practitioners can also directly model choreographies without modelling corresponding collaborations: thus we also have to extend BPMN to directly model versions of choreographies. The second drawback is related to the algorithms supporting the mapping from version of collaborations into versions of choreographies. These algorithms are based on the following assumption: the mapped versions of collaboration have to be consistent in that they do not include any dead-lock, cycle and so on. On the other hand, the recommended algorithms take into account neither intermediate events of collaboration versions, nor events source or target of message flows. Finally these algorithms have to be implemented and evaluated. Their implementation is in progress and their evaluation will be addressed shortly.

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