

Design Time Validation for the Correct Execution of BPMN Collaborations

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Abstract: Cloud-based Software-as-a-Service (SaaS) providers want to grow into the space of business process outsourcing (BPO). BPO refers to the systematic and controlled delegation of many steps of a company's business process. BPO is a new and important extension to SaaS, as it allows the provider to add more value in the online application services and as it enables the outsourcer to obtain more cost efficiency. BPO results in decentralized federated workflows. To describe these workflows, companies often use business process modeling languages. Currently, Business Process Modeling Notation (BPMN) is one of the best-known standards. It is crucial to ascertain that the modeled workflow is executed as intended. Errors that happen during execution of a federated workflow can come with huge costs. Validating the model is limited to syntactical checks and there is little support for validating the execution at design time. In this paper a method is presented to validate the correct execution of BPMN 2.0 Collaborations. The methods in this research use concepts from virtual time previously described for Web Services Choreography Description Language (WS-CDL). To validate the results of this research, the Eclipse BPMN modeler was extended with an implementation of the validation method.

1 INTRODUCTION

In current competitive markets, cloud-based Software-as-a-Service (SaaS) providers no longer want to manage all parts of their business processes themselves. They want to focus on their core business activity to stay ahead of competition. By growing into the space of business process outsourcing (BPO), they can delegate many steps of their business process, e.g. billing, managing e-mail or shipping packages. For example, a company that offers design engineering software that involves running simulations, can resort to different service providers that offer simulation software. BPO is a new and important extension to SaaS, as it allows the provider to add more value in the online application services and enables the outsourcer to obtain more cost efficiency.

BPO always results in decentralized federated business process flows. With decentralized federated workflows it is important to accomplish the same quality as with in-house business processes and ensure proper execution of the workflows. Errors that happen after deploying the workflow can lead to huge

costs. Hence, it is important to detect possible execution issues during design time.

Companies often use business process modeling languages to describe workflows. One of the best-known standards, which already offers constructs to model decentralized workflows by means of choreographies and collaborations, is Business Process Modeling Notation (BPMN). In this research we focus on validating the correct execution of BPMN 2.0 Collaborations. When modeling a collaboration it is crucial to ascertain that the model will be executed as intended. First, in some cases not every operation in a Collaboration will be executed at runtime, despite the fact that the designer modeled this step. Second, when modeling the different elements in a Collaboration (e.g. Events, Tasks and Message Flows between Participants) in a certain order, this order is not always guaranteed at runtime. Finally, when designing activities in parallel, it is not always the case they are executed in parallel at runtime. Detecting these issues at design time is important, since it can point to errors in the workflow logic that can turn into serious problems in a production environment.

The paper focuses on a method to validate if the

modeled Collaboration is executed at runtime as intended by the designer. Although only several BPMN elements are currently supported, most Collaborations can be modeled with only these BPMN elements. The method identifies the issues described before and provides feedback at design time.

The validation method in this research uses the concept of time vectors, which was previously described for WS-CDL (Van Seghbroeck, 2011). An approach similar to the tokens, introduced in the BPMN specification (Omg et al., 2011) “*as an aid to define the behavior of a Process*” is used to facilitate the implementation.

The remainder of this paper is structured as follows. A more concrete use case of BPO is given in Section 2. Section 3 gives an overview of related work on validation methods for BPMN. Some background on the differences between BPMN and WS-CDL is given in Section 4. Time vectors are explained in Section 5. Section 6 gives an overview of the validation method. The implementation is presented in Section 7. And finally, conclusions are drawn and future work is discussed in Section 8.

2 USE CASE: SIMULATION AS A SERVICE

The design of complex engineering products, such as planes and cars, commonly has a defined set and sequence of activities (often in an interleaved sequence). These activities are engineering and simulation activities. Engineering activities mainly represent data in- and output tasks (e.g. requirements, design parameters, etc.) and approval/decision tasks. Simulation activities take models and parameters as input, and usually analyze characteristics which are mentioned in the user-defined constraints and which must be met. Engineering activities form a high-level view on the process referred to as the engineering workflow. Simulation activities are usually needed in the course of the engineering workflow in order to validate design parameters at an early stage, referred to as the simulation workflow.

The procedure, described in Figure 1, is a collaboration between three companies. Company A is a company with engineers to design and test car parts. Companies B and C offer a simulation engine as a service. Figure 2 shows the modeled Collaboration. The numbers correspond to the steps of the use case scenario.

1. The team leader (TL) of Company A sets up a new design
2. Domain Expert Engineer (DEE) of A enters many requirements and constraints and other context information for the specific simulation of the design
3. DEE specifies the parameters for a simulation of the design
4. TL starts the design simulation
5. The engineering workflow of A contacts the simulation SaaS of Company B
6. B provides the results to A
7. TL is notified to revisit the results
8. TL can choose to run an additional simulation using the simulation SaaS of Company C

Figure 1: Steps of the Simulation as a Service use case.

3 RELATED WORK

Existing research deals with verifying the correctness of business process models, more precisely the soundness property. Soundness means that the process can be correctly terminated and does not contain tasks that will never be executed. The latter is similar to the first issue mentioned in the introduction. This soundness property was first introduced to the field of Business Process Modeling (BPM) by (Aalst, 1998) by translating workflows into Petri Nets and was further perfected by (Wynn et al., 2009). Due to this, Petri Nets are commonly used as intermediate formalisms by soundness verification frameworks (Morimoto, 2008). (Dijkman et al., 2008) shows how to correspond BPMN elements into Petri Net structures. A Petri Net can be verified with the ProM framework (Dijkman et al., 2008). However, not all the components in BPMN can be translated into Petri Net structures. For instance, it is difficult to define the correspondence of Message Flows (Kherbouche et al., 2013). In addition to this, the known frameworks that verify the soundness, lack the verification of correct order and parallel execution.

Tools known as analyzers or model checkers (Kherbouche et al., 2013), e.g. SPIN (Holzmann, 1997) and NuSMV2 (Cimatti et al., 2002), are often used to automate the verification methods. These model checkers can be used to verify whether business process models satisfy properties formalized in e.g. LTL (Linear Time Logic). The business process

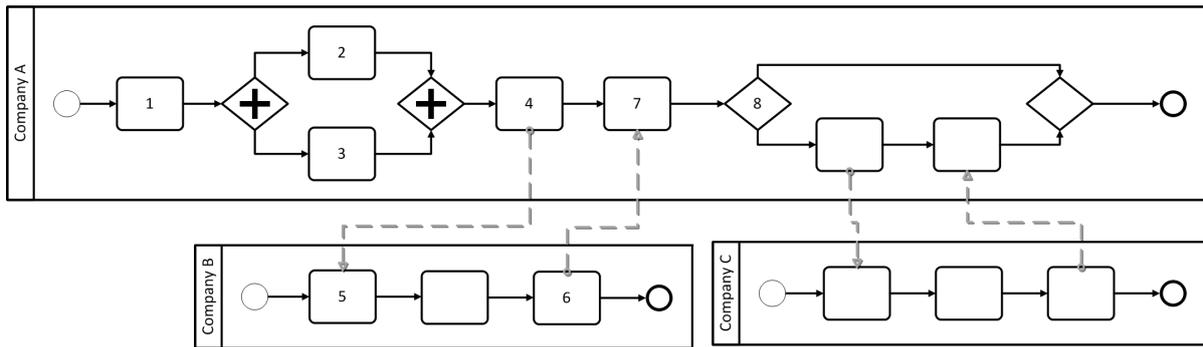


Figure 2: Relation of Engineering and Simulation Workflows. The numbers correspond to the steps of the use case scenario.

model must be described in one of the model checker input languages, e.g. the Process Meta-Language, or Promela, used by SPIN. Business processes can be remodeled using Promela, with the Promela implementation then internally translated into an automaton and verified. This method was used in (Solaiman et al., 2015), but it does not support parallel BPMN constructs and the user is required to manually enter LTL logic to define the order that should be verified. In contrast to this research, the presented method supports parallel BPMN constructs and no manual intervention is necessary.

Different other existing frameworks are compared in a survey (Groefsema and Bucur, 2013), however none of them verify the order or parallel execution of Message Flows, Tasks, Events, etc. in a Collaboration. (Tantitharanukul et al., 2010) checks for deadlocks and livelocks using finite automata. (Kherbouche et al., 2013) transforms BPMN to Kripke structures and used the SPIN modeler with validation properties expressed in LTL. It validates the soundness, e.g. deadlocks, livelocks and multiple termination errors. (Poizat and Salaün, 2012) transforms BPMN to LOTOS NT process algebra.

Research initiatives that resort to well-established process algebras, e.g. the popular π -calculus, or other formal models, such as Promela, LTL or Chor, to validate interaction protocols, are based on the formal inference rules defined within the process algebra. Enforcing these inference rules can again be handled by model checkers (such as SPIN and NuSMV) to execute the validation. These validation efforts, however, typically adopt a common assumption when checking the ordering within the protocol. For example, in the definition of the inference rule used to resolve an interaction, sending and receiving a message are considered together as one atomic action, whereas in reality sending and receiving happen on completely different systems.

To the authors knowledge, little research has been conducted on validating BPMN Collaborations.

(Van Seghbroeck, 2011) presented an interesting method to verify order of interactions in multi party protocols. The method uses a set of ordering rules and an extension on the concept of time vectors. The described method was targeted at WS-CDL, but is adapted in this research to support BPMN. Although WS-CDL seemed a promising candidate standard at that time, it is never really embraced by the community. By using this vector time concept the method presented here, does not rely on transforming BPMN to another intermediary model. It merely conceptually annotates the BPMN Collaboration with the time vectors.

4 BPMN VERSUS WS-CDL

Since Business Process Modeling Notation (BPMN) is very different from Web Services Choreography Description Language (WS-CDL), the method originated in (Van Seghbroeck, 2011) has to be adopted to support BPMN. In this section an overview of the most important differences between WS-CDL and BPMN is given. BPMN is a specification where the designer describes the different activities the partners need to execute. These activities can lead to interactions between the different partners. The sole purpose of WS-CDL is to describe peer-to-peer collaborations of participants by defining, from a global viewpoint, their common and complementary observable behavior. So WS-CDL is definitely not an execution language, but it tells us how and with which messages the distinct parties should interact.

BPMN is based on graph models to design the flow by connecting the different elements (e.g. Tasks, Events and Gateways) together. By connecting these elements the designer defines the order. This is also different from WS-CDL, which is based on block models. WS-CDL has a Sequence, a Parallel, and a Choice construct to define elements that

have to be executed sequentially, in parallel, or non-deterministically, respectively.

Unlike WS-CDL, BPMN does not have a single element to depict an interaction, which denotes communication between participants. In BPMN interactions are defined using Message Flow objects. These Message Flows can be created between Tasks (send and receive Tasks), between different types of Events (throw and catch Events), and a combination thereof.

5 SUPPORTED BPMN ELEMENTS

BPMN elements can be categorized in five categories: Flow Objects, Connecting Objects, Swimlanes, Data and Artifacts (Omg et al., 2011). The first three categories are the main graphical elements to define the workflow logic. There are three Flow Objects: Events, Activities and Gateways. There are four ways of connecting the Flow Objects to each other or to other information: Sequence Flows, Message Flows, Associations and Data Associations. Only the first two Connecting Objects are used for workflow behaviour. Finally, there are two ways of grouping the primary modeling elements through Swimlanes: Pools and Lanes. Additional variations exists on these basic categories (e.g. Start Event, Task, Parallel Gateway, etc.).

This research only supports a select set of BPMN elements, primarily elements that define the workflow logic (Figure 3). This restriction does not limit the expressive power, since most BPMN Collaborations

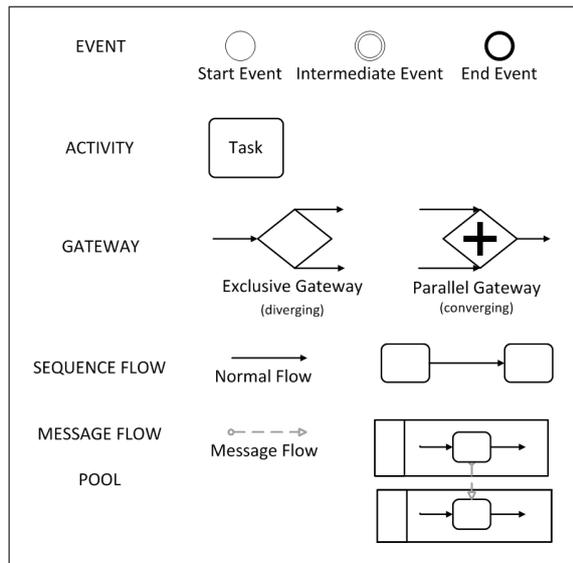


Figure 3: A core selection of supported BPMN elements.

can be represented using only these elements (e.g. a Service Task can be replaced by a send and receive task).

6 EXTENDED TIME VECTORS

Introducing the concept of logical clocks and logical time allows ordering the different executable Events, Tasks, Message Flows, etc., further on referred as events, in a BPMN Collaboration. This enables the identification of issues related to parallel and correct order of execution of events.

The first logical clocks were initially invented by Lamport to determine the order of events in a distributed system. These clocks are a simple mechanism, by which the *happened before* ordering (\rightarrow), in which: $a \rightarrow b$ if a must occur before b , can be captured numerically (Lamport, 1978). The original concept of time vectors, which solved some issues with Lamport's logical time, was introduced by (Chandy and Lamport, 1985) and (Mattern, 1988). Each process of a distributed system has a logical timestamp, based on vectors of timestamps (time vector). A process increments its time vector when an event happens.

If $a \nrightarrow b$ and $b \nrightarrow a$ the two events may have occurred concurrently. Since BPMN supports parallel structures by means of Parallel Gateways, an extra relation $a \parallel b$ needs to be defined, denoting that event a and b must happen in parallel. (Van Seghbroeck, 2011) defined this extension in his work, which will be further elaborated in the remainder of this section.

Similar to a distributed system, where each process is equipped with a representation of virtual time (e.g. time vectors), in a BPMN Collaboration, each Participant P_i has a vector $V_i = [c_1, c_2, \dots, c_n]$ of length n , where n is the total number of Participants in the Collaboration. Each element of the time vector has the following format: $V_i[j] = c_j = (t_j, \vec{X}_j)$. These vector elements, further on referred as time objects, represent the last known timestamp of Participant P_j , where t_j is an integer clock value, similar to the clock value used in regular time vectors, and \vec{X}_j is a vector of time objects. The vector \vec{X}_j represents the parallel paths from a Participant and consequently the length of the vector is the number of parallel paths.

Each executed event makes the local time vector of its Participant increment, i.e. a Participant P_i increments its own time object in V_i . If the executed event happens on a parallel path, the time object on the parallel path is incremented.

if $\vec{X}_i = []$ **then**
 $V_i[i] + 1 = (t_i + 1, [])$
else if $\vec{X}_i = [c_1, \dots, c_k, \dots, c_m]$ **then**
 $V_i[i] + 1 = (t_i, [c_1, \dots, c_k + 1, \dots, c_m])$
end if

According to (Chandy and Lamport, 1985), when a process sends a message, it includes its time vector with the message. On receiving a message, the receiver combines his knowledge of time with the time vector in the message. Sending messages is defined in a BPMN Collaboration with its Message Flows. Section 6.1 explains which operations are needed on time vectors to support this mechanism. Section 6.2 explains how the extension on the time vectors is used when traversing through Parallel Gateways.

6.1 Message Flows

In case of a Message Flow between two Participants, the time vector of the sender and receiver are incremented (because there is a send and receive event). The receiving Participant P_r combines its own time vector with the time vector of the sending Participant P_s . This is done with the component-wise supremum $V_r := \text{sup}(V_r, V_s)$, i.e. for two time vectors a and b , $\text{sup}(a, b) = c$ such that $\forall i: c[i] = \text{sup}(a[i], b[i])$. In order to correctly evaluate the supremum of time objects, at least the \leq ordering relation needs to be defined. Here is also the comparator \parallel defined, for denoting parallel time objects (Van Seghbroeck, 2011).

For two time objects $a = (t_a, \vec{A})$ and $b = (t_b, \vec{B})$:

- $a \leq b \Leftrightarrow \begin{cases} \forall j: \vec{A}[j] \leq \vec{B}[j], & t_a = t_b, \\ t_a < t_b, & \text{otherwise.} \end{cases}$
- $a < b \Leftrightarrow a \leq b \wedge a \neq b, \text{ and}$
- $a \parallel b \Leftrightarrow t_a = t_b \wedge (\exists j, k: j \neq k \wedge \vec{A}[j] < \vec{B}[j] \wedge \vec{A}[k] > \vec{B}[k])$

For two time vectors a and b , where $a[i] = (t_a, \vec{A})$ and $b[i] = (t_b, \vec{B})$

- $a \leq b \Leftrightarrow \forall i: a[i] \leq b[i]$
- $a < b \Leftrightarrow a \leq b \wedge a \neq b, \text{ and}$
- $a \parallel b \Leftrightarrow \exists i: a[i] \parallel b[i]$

Suppose in the above definitions the elements of two parallel vectors of different lengths need to be compared, the shorter of the two vectors is resized to match the other vector and the missing elements are set to 0.

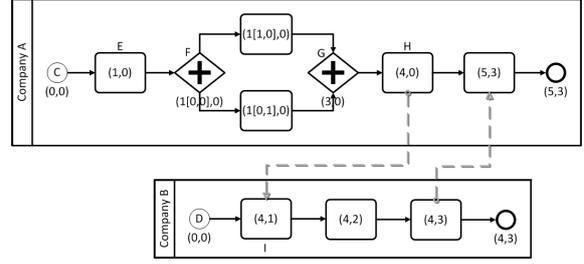


Figure 4: Use case annotated with time vectors.

6.2 Parallel Gateways

At Parallel Gateway elements, parallel time vectors must be either created or removed. When a diverging Parallel Gateway splits the flow in the Process of a Participant P_i with time vector $V_i[i] = (t_i, [])$ in multiple parallel paths. A new time vector V_{fork} , such that: $V_{fork}[j] = V_i[j] (\forall j, j \neq i)$ and $V_{fork}[i] = (t_i, [(0, []), \dots, (0, [])])$. The size of the parallel vector is equal to the number of outgoing Sequence Flows of the Gateway. From this moment on, the events happening in a particular path k only change the k^{th} time object of this parallel time vector. When a new diverging Gateway occurs in the k^{th} path, again a new hierarchy level is added to the k^{th} time object of the parallel vector.

When a converging Parallel Gateway is encountered, a new vector V_{join} is introduced, with $\forall j: V_{join}[j] := \text{sup}_k(V_{i,k}[j])$. Let (t_x, \vec{X}) be the time object corresponding with the time object (t_x, \vec{X}) where the different parallel paths are joined from $V_{i,k}[i]$ (it is clear that this time object is part of $V_{join}[i]$). The parallel paths part, \vec{X} , of the corresponding time object is again set to the empty vector and $t_x := t + \sum_j \text{sup}_k(v_{k,j})$.

6.3 Example

Figure 4 shows the Collaboration from the use case in Section 2, but without Company C involved. It is now annotated with the time vectors.

- Start Events C and D of Company A and B begin with time vector (0,0). Which means both time objects of both companies are set to 0.
- Task E increments the time vector of A.
- Gateway F adds a new parallel time vector with size equal to the number of outgoing paths, in this case there are two paths: $(1[0,0], 0)$.
- The task on each parallel path increments this parallel time vector: $(1[1,0], 0)$ and $(1[0,1], 0)$.
- Gateway G first joins both time vectors. This results in the time vector $(1[1,1], 0)$. Second, the

value of the time object of A is incremented with the values of the parallel time vector, $(3[0,0],0)$. Finally the parallel time vector is again set to the empty vector, $(3,0)$.

- Task H and I are both part of a Message Flow. Conceptually, A includes its time vector with the Message sent to B. B updates its time vector using the time vector of A. This results in the time vector $(4,1)$

7 VALIDATION METHOD

This section explains the validation method, which is based on previous work for WS-CDL (Van Seghbroeck, 2011). In this previous work all structures that realize choices are removed in advance. Since it is unknown at design time which choice will be executed, all possible choices must be evaluated. In BPMN this is also the case with its Exclusive Gateway element. Taking a different path can have different consequences for the events after the Exclusive Gateway. For example, the number of Tasks and Events can differ between the different paths or a specific path can introduce a Message Flow, so the time vector after the Exclusive Gateway can differ according to the chosen branch. Therefore, the first step in this validation method, removes all Exclusive Gateways. This results in multiple new Collaborations, without Exclusive Gateways. This first step is depicted on Figure 5. These new Collaborations allow validating every

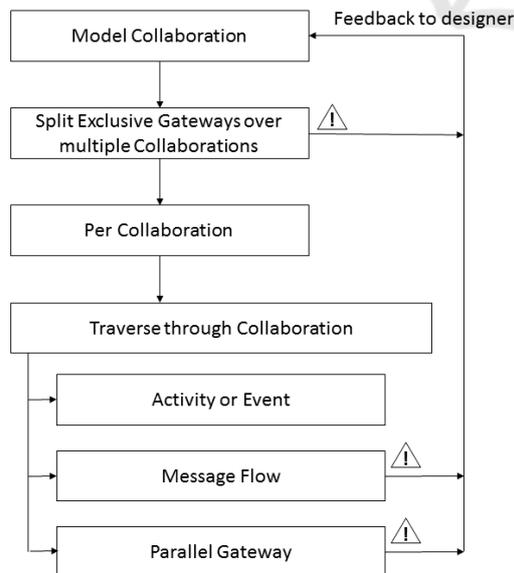


Figure 5: An overview of the different steps of the validation method.

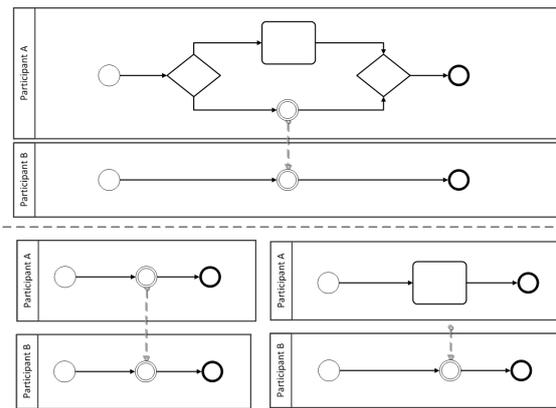


Figure 6: Removing Exclusive Gateways results in 2 new Collaborations. The bottom right Collaboration is an invalid Collaboration, as the Message Flow has no sending counterpart.

possible execution path in the original Collaboration. Splitting Exclusive Gateways over new Collaborations also leads to identifying a first issue, some BPMN elements may never be reached and thus never get executed. Issues with parallel execution and order can be identified by traversing through each Collaboration while incrementing the vector times, as described in Section 6.

The remainder of this section illustrates the three different issues: soundness of a Collaboration (Section 7.1), parallel execution of Events and Tasks (Section 7.3) and order of Message Flows (Section 7.2).

7.1 Validation of Soundness of the Collaboration

Figure 6 shows a Collaboration between two Participants. One of the Participants can either execute the Task or the Event. By splitting the original collaboration, two new Collaborations are created, one with the Participant A choosing the Task and one with the Participant A choosing the Event.

In Figure 6 it is clear that the Collaboration is invalid. Participant A choosing for the Event (bottom left) can result in a valid execution, but when Participant A chooses for the Task this creates a serious issue: Participant B will keep on waiting for a message to arrive. Therefore the entire Collaboration is faulty and cannot be executed as intended by the designer, an error should be thrown.

7.2 Validation of Order of Message Flows

When encountering a Message Flow, The receiving Participant combines its knowledge about the time

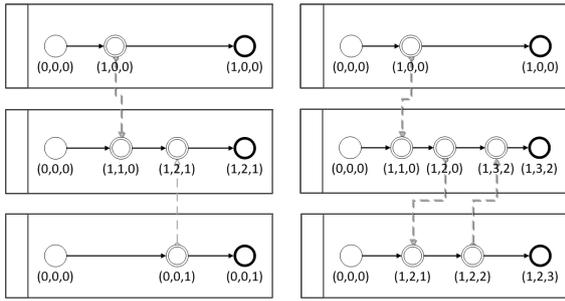


Figure 7: The order of interactions on the left collaboration is invalid. A solution is given in the right collaboration.

with the time vector of the sending Participant. Nevertheless, if the receiving Participant time object is different than the knowledge the sending Participant vector clock has about the receiving Participant time object, the order can not be verified.

The Collaborations depicted in Figure 7 show an example of an invalid Message Flow and a possible solution.

7.3 Validation of Parallel Execution of Tasks and Events

To validate if Events and Tasks are executed in parallel, there must not be an order in them. In Figure 8 it is clear that C and D happen in sequential order ($C < D$). Due to the interactions between the two Participants, events A and B , are executed in order as well ($A < B$), in contrary to what the designer modeled.

Since the relation “ \parallel ” is not transitive, all the Events and Tasks of the parallel paths need to be compared two by two. But, because the elements on each path are ordered, it is sufficient to compare the first and last elements.

8 IMPLEMENTATION

An existing modeling tool is extended with an im-

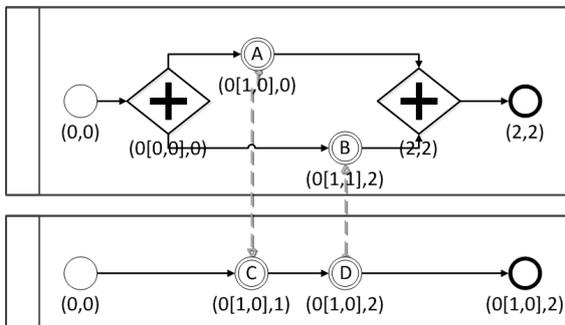


Figure 8: Event A and B in the Collaboration are modeled as parallel events, but are at runtime executed sequentially.

plementation of the validation method (Section 8.1). Section 8.2 gives a breakdown of the method with corresponding pseudo code.

8.1 Existing BPMN 2.0 Tooling

There already exists different BPMN modeling tools. RedHat with its jBPM (Red Hat, 2015a), an open-source workflow engine written in Java that can execute business processes described in BPMN 2.0, offers a web based BPMN2.0 modeler (Red Hat, 2015b) and an Eclipse plugin. However, both tools only support a subset of the BPMN 2.0 specification and additional elements specific for jBPMN. The jBPMN Eclipse plugin is an extension of a generic BPMN 2.0 compatible Eclipse plugin developed by Eclipse (Eclipse, 2015). Other initiatives also extend this Eclipse plugin, e.g. Camunda (Camunda, 2015), Imixs-Workflow (Imixs, 2015) and Activiti (Activiti, 2015). These initiatives complement the Eclipse plugin with extensions for respectively Camunda-BPMN, Imixs-BPMN and Activiti. We also choose to extend the generic Eclipse BPMN2 modeler.

In the Eclipse modeler validations are limited to syntactical checks, but it is possible to include custom validations. We extended the Eclipse Modeler with custom validation classes that implement the aforementioned validation method. The error mechanism of the Eclipse plugin is used to provide feedback to the designer.

8.2 Breakdown of Validation Method

Throughout the validation method, a concept of *cursor*s is used. Think of cursors moving along Sequence Flows and passing through the different Flow Elements in the Process of a Participant. This is similar to the concept of *tokens*, which is introduced in the BPMN specification as a theoretical concept “*as an aid to define the behavior of a Process*” (Omg et al., 2011). A Process is instantiated by the Start Event producing a token. This token then traverses through the Flow Elements until it is eventually consumed by the End Event. This flow of tokens represents the execution semantics of BPMN models, i.e. the flow describes how a process engine would execute the model. The validation method in this research can easily be integrated in tooling that support the token mechanism.

Before validating the Collaboration, all Exclusive Gateways must be removed. To remove these Gateways, a depth first traversal, following the Sequence Flows, starting from the Start Event, will result in all possible paths (algorithm 1).

Algorithm 1: Removing Exclusive Gateways.

```

procedure REWRITE(process)
2:   StartEvent startEvent  $\leftarrow$  process.startEvent
   new List processes
4:   new Process p
   processes.add(p)
6:   VISIT(startEvent, p, processes)
   return processes
8: end procedure

procedure VISIT(e, p, L)
10:  p.add(e)
   if e is End Event then
12:    return
   else if e is Gateway then
14:   if e is Exclusive Gateway then
     L.remove(p)
16:   for all outgoing Sequence Flow sf do
     Process p'  $\leftarrow$  p
18:     L.add(p')
     e  $\leftarrow$  sf.targetRef
20:     VISIT(e, p', L)
     end for
22:   else if e is Parallel Gateway then
     for all outgoing Sequence Flow sf do
24:       e  $\leftarrow$  sf.targetRef
       VISIT(e, p, L)
26:     end for
     end if
28:   else
     e  $\leftarrow$  moveNext(e)
30:     VISIT(e, p, L)
     end if
32: end procedure

```

After splitting the original Collaboration up into different Collaborations without Exclusive Gateways, the validation method continues for each individual Collaboration as described by Algorithm 2.

Algorithm 2 uses as few data structures:

- *C* is a list of cursors traversing through the different Processes in the Collaboration.
- *V* is a map to map each cursor to a time vector.
- *SEND* and *RECV* are maps that contain the Flow Nodes that are respectively sending and receiving a Message, mapped to their corresponding Message Flow.
- *G* is a map to map each Process to a stack with Gateway elements.

The map *G* is used to validate parallel execution of Events and Tasks. When a converging Gateway joins

the parallel paths, both the converging Gateway and the diverging Gateway that initially created the parallel paths are needed for the validation method (to compare the order of the first and last elements). Therefore, every time a cursor traverses through a diverging Gateway, the Gateway is pushed on the stack. Popping the last Gateway off the stack, when encountering a converging Gateway, returns the other diverging Gateway. The *SEND* and *RECEIVE* maps makes it easier to look up Flow Elements that are part of a Message Flow and find their counterpart via the Message Flow.

First, all cursors are set on the Start Events of the different Processes. The cursor traverses over the Flow Elements, incrementing the time vectors, until the cursor is on either a (diverging or converging) Parallel Gateway or a Flow Node that is part of a Message Flow (lines 3-8 in Algorithm 2).

When a cursor reaches a Flow Node that is part of a Message Flow, before moving the cursor further, both the sending and receiving Participant its cursor has to reach the sending or receiving Flow Element (lines 9-19 in Algorithm 2).

If the cursor reaches a diverging Parallel Gateway, the cursor will be duplicated over the different outgoing Sequence Flows leaving the Gateway (lines 20-26 in Algorithm 2).

When a cursor reaches a converging Parallel Gateway, it has to first wait until all cursors of the incoming Sequence Flows ending in the Gateway, have reached the Gateway. Then, a check is done to validate if the events in the parallel paths are executed in parallel, and finally, a single cursor will leave the Gateway (line 28-37 in Algorithm 2).

Feedback to the designer is provided by throwing exceptions. This happens on line 12 and 32 when a Message Flow causes an ordering issue and when Events and Tasks are not properly executed in parallel respectively.

9 CONCLUSIONS AND FUTURE WORK

Business Process Outsourcing (BPO) is an interesting way for companies to again focus on their core business. In contrast to in-house business processes or most SaaS offerings, BPO always result in decentralized federated workflows. Designing such workflows is very difficult, especially with regard to soundness and correctness. In order to ensure a Collaboration is executed as modeled by the designer, we have presented a method to validate the correct execution of BPMN 2.0 Collaborations at design time.

Algorithm 2: Validation of a Collaboration (without Exclusive Gateways).

Require: $C, V, SEND, RECV, G$

```

1:   while  $\neg(\forall C \text{ reached End Event})$  do
2:     for all cursor  $c$  do
3:       while  $hasNext(c) \wedge \neg(SEND(c) \vee$ 
4:          $RECV(c) \vee c \text{ is Gateway})$  do
5:         if  $\neg(c \text{ is Start Event} \vee \text{End Event})$ 
6:         then
7:           increment  $V_c$ 
8:         end if
9:          $c \leftarrow moveNext(c)$ 
10:        end while
11:       if  $c$  is send/rcv then
12:         if rcv/send counterpart reached then
13:           if  $\neg val\_msgflow(send, rcv)$  then
14:             Throw Exception
15:           end if
16:           increment  $V_{send}$ 
17:           increment  $V_{rcv}$ 
18:            $V_{receiver} \leftarrow sup(V_{send}, V_{rcv})$ 
19:            $moveNext(c_{send})$ 
20:            $moveNext(c_{rcv})$ 
21:         end if
22:       else if  $c$  is diverging Gateway then
23:          $G_c.push(c)$ 
24:         for all outgoing Sequence Flow do
25:           Cursor  $c' \leftarrow c$ 
26:            $C.add(c')$ 
27:            $moveNext(c')$ 
28:         end for
29:          $C.remove(c)$ 
30:       else if  $c$  is converging Gateway then
31:         if all cursors reached gateway then
32:            $g \leftarrow G_c.pop()$ 
33:           if  $\neg validate\_parallel(g, c)$  then
34:             Throw Exception
35:           end if
36:            $c \leftarrow join(c_0, \dots, c_k, \dots, c_m)$ 
37:            $moveNext(c)$ 
38:         end if
39:       end if
40:     end for
41:   end while

```

The validation method is based on previous research for WS-CDL. The method evaluates the soundness of a Collaboration and the order and parallel execution of Events, Tasks and Message Flows. For a prototype implementation, the BPMN Eclipse plugin is extended to support the validation method. Feedback to the user is provided by using Eclipses error mechanism. In this way the designer is notified when the decentralized workflow contains problems, all in a real-time fashion, during the design phase.

Currently the prototype only supports the basic

BPMN modeling and a few extended modelling elements. Although this set of elements is sufficient to describe most Collaborations, future versions of the tool will allow all BPMN 2.0 elements. For most elements this will mean translating the extended elements to the basic set of BPMN constructs part. Next to this, future work also holds, implementing additional validation methods, mainly focused on the data flow.

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REFERENCES

- Aalst, W. V. D. (1998). The application of petri nets to workflow management.
- Activiti (2015). Activiti Modeler. <http://activiti.org>.
- Camunda (2015). BPMN tool for process modeling - Camunda Modeler. <https://camunda.org/bpmn/tool>.
- Chandy, K. M. and Lamport, L. (1985). Distributed snapshots: Determining global states of distributed systems. *ACM Trans. Comput. Syst.*, 3(1):63–75.
- Cimatti, A., Clarke, E. M., Giunchiglia, E., Giunchiglia, F., Pistore, M., Roveri, M., Sebastiani, R., and Tacchella, A. (2002). Nusmv 2: An opensource tool for symbolic model checking. In *Proceedings of the 14th International Conference on Computer Aided Verification, CAV '02*, pages 359–364, London, UK, UK. Springer-Verlag.
- Dijkman, R. M., Dumas, M., and Ouyang, C. (2008). Semantics and analysis of business process models in bpmn. *Inf. Softw. Technol.*, 50(12):1281–1294.
- Eclipse (2015). Eclipse BPMN2 Modeler. <https://www.eclipse.org/bpmn2-modeler>.
- Groefsema, H. and Bucur, D. (2013). *A survey of formal business process verification: From soundness to variability*, page 198203. SciTePress.
- Holzmann, G. J. (1997). The model checker spin. *IEEE Trans. Softw. Eng.*, 23(5):279–295.
- Imixs (2015). Imixs Workflow Modeler. <http://www.imixs.org/modeler>.
- Kherbouche, O., Ahmad, A., and Basson, H. (2013). Using model checking to control the structural errors in bpmn models. In *Research Challenges in Information Science (RCIS), 2013 IEEE Seventh International Conference on*, pages 1–12.
- Lamport, L. (1978). Time, clocks, and the ordering of events in a distributed system. *Commun. ACM*, 21(7):558–565.

- Mattern, F. (1988). Virtual time and global states of distributed systems. In *Parallel and Distributed Algorithms*, pages 215–226. North-Holland.
- Morimoto, S. (2008). A survey of formal verification for business process modeling. In Bubak, M., van Albada, G., Dongarra, J., and Sloot, P., editors, *Computational Science ICCS 2008*, volume 5102 of *Lecture Notes in Computer Science*, pages 514–522. Springer Berlin Heidelberg.
- Omg, O. M. G., Parida, R., and Mahapatra, S. (2011). Business Process Model and Notation (BPMN) Version 2.0. *Business*, 50(January):170.
- Poizat, P. and Salaün, G. (2012). Checking the realizability of bpmn 2.0 choreographies. In *Proceedings of the 27th Annual ACM Symposium on Applied Computing, SAC '12*, pages 1927–1934, New York, NY, USA. ACM.
- Red Hat (2015a). jbpm - open source business process management - process engine. <http://www.jbpm.org>.
- Red Hat (2015b). Web-based bpmn2.0 designer for jbpm. <https://github.com/droolsjbpm/jbpm-designer>.
- Solaiman, E., Sun, W., and Molina-Jimenez, C. (2015). A tool for the automatic verification of bpmn choreographies. In *Services Computing (SCC), 2015 IEEE International Conference on*, pages 728–735.
- Tantitharanukul, N., Sugunasil, P., and Jumpamule, W. (2010). Detecting deadlock and multiple termination in bpmn model using process automata. In *Electrical Engineering/Electronics Computer Telecommunications and Information Technology (ECTI-CON), 2010 International Conference on*, pages 478–482.
- Van Seghbroeck, G. (2011). *Design-time validation and execution of service choreographies*. PhD thesis, Ghent University.
- Wynn, M., Verbeek, H., van der Aalst, W., ter Hofstede, A., and Edmond, D. (2009). Business process verification finally a reality! *Business Process Management Journal*, 15(1):74–92.