Toward the Alignment and Traceability between Business Process and Software Models

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Keywords: Alignment, Traceability, Model Transformation, BPMN Model, Class Diagram, MVC, Use Case Model.

Abstract: The current paper presents an approach to derive static and functional software models from a business process model (bpm), including trace links between business-system and system-system artifacts. This approach is based on a set of well-defined rules that transform a source model represented with the Business Process Model and Notation (BPMN), into a UML class diagram structured according to the model view controller design pattern, a UML use case model, and a trace model. All artifacts, except the trace model, are represented according to the standards (BPMN and UML). To show the feasibility of our approach we apply it on a topical case study.

1 INTRODUCTION

A business is perceived through two models: a business process model that represents the way operations are carried out to accomplish the business goals, and an information system (IS) model used by software/IT designers to implement the software system. A business cannot be competitive unless its business process is aligned with its IS. Indeed, a perfect alignment maximizes return on investment, and is key to a coherent governance and success of the business (Christiansen et al., 2007). Therefore, it is important to bring closer business process- and IS modeling activities. In modern software development methods, analysts start the development process with an inception phase where they must acquire a deep knowledge of the business process model. This phase is crucial since it prepares for requirement discovery and analysis. However, artifacts produced in this phase are not well exploited in downstream software development phases.

Recent researches propose the model driven architecture (MDA) approach (OMG, 2006) as a solution to bridging the gap between heterogeneous models that are often localized in different levels of the MDA. For example, a business process model is to be placed at the CIM (Computation Independent Model) level, and software models are part of the PIM (Platform Independent Model) and PSM (Platform Independent Model) levels. The passage from CIM to PIM or from PIM to PSM is possible by applying a set of transformation rules. In this paper, we focus on the transformation of a business process model to IS requirement and analysis models, namely a UML use case model (UCM) and a UML class diagram. The idea behind the transformation is to consider the business process model as the source of requirements and to derive software requirement specifications and analysis artifacts from it. However, there is continuously a request to check if the business and the software artifacts are aligned when one of them changes.

Hence, model transformation raises a new research challenge that aims to maintain models always aligned. This challenge is addressed by applying the traceability mechanism. As research on alignment is limited, there is a need for more investigation in the topic. In this context, the present paper proposes a foundation for business and system analysts, to generate a CD and a UCM from the business process model and notation (BPMN) (OMG, 2013), and to establish traceability between the business-system and the system-system elements.

The paper is organized as follows. The next section presents related works. Then, in section 3, we propose a set of rules to transform and maintain traceability between a business process model and UCM and CD. In sections 4, we show the applicability of the proposed approach through a demonstration case study. Finally, section 5 draws some conclusions and future works.

Bouzidi, A., Haddar, N., Ben-Abdallah, M. and Haddar, K.
Toward the Alignment and Traceability between Business Process and Software Models.
DOI: 10.5220/0009004607010708
In Proceedings of the 22nd International Conference on Enterprise Information Systems (ICEIS 2020) - Volume 2, pages 701-708
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2 RELATED WORK

In this section, we summarize existing works on alignment of business process models to IS model artifacts.

(Khlif et al., 2018) propose a MDA-compliant approach to generate a CD and a UCM from an annotated BPMN model. The authors suppose that the BPMN task labels follow some grammatical patterns and propose to annotate activities, pools and lanes of the BPMN model manually to add information about activity performers, resources, etc. before carrying out the transformation. Then they propose a set of transformation rules based on the added annotation.

(Rhazali et al., 2016) define a semi-automatic transformation from CIM level represented by a BPMN model into the PIM level represented by a UCM and CD structured according to the MVC architecture. The authors propose five rules to obtain the UCM and two rules to generate the CD. The transformation rules consider only a reduced subset of business process model elements. In addition, the authors transform each activity into a use case, which leads to a high number of use cases with low granularity.

(Rodríguez et al., 2010) propose vertical MDA transformation rules to generate semi-automatically a UCM and a CD including security aspects from business process models. Then, they manually refine the obtained diagrams using checklists to add security aspects to the target diagrams. In this approach, there is no difference between manual and automated activities. In addition, the authors transform each activity into a use case, which leads to a high number of use cases concerns security tasks only.

(Sepulveda et al., 2017), (Brdjanin et al., 2018), (Cruz and Cruz, 2018) and (Liew et al., 2004) propose structure-based transformation rules from BPMN to UC and/or CD, which in some cases do not meet the semantics of BPMN and UML. Most of these approaches do not derive complete diagrams and may generate complex diagrams. Moreover, the traceability between the source and target models or between target models is out of the scope of all proposed approaches.

3 BUSINESS PROCESS TO USE CASES AND CLASS DIAGRAM

We propose a MDA compliant-approach called Business Process to trace Use case model and Class Diagram (BPtraceUCD). According to the abstraction levels of MDA, our approach is a CIM to PIM one. The CIM level captures the business process model represented with BPMN 2.0 model (OMG, 2013), while the UC model and the CD of the IS are part of the PIM level. Throughout the transformation from CIM to PIM, we define trace links between business-system and system-system elements to ensure that the IS model meets the business requirements and that the CD supports them. We take the BPMN and the UML standards without any adaptation and we assume that the reader is familiar with them. Figure.1 shows an overview of our approach.

3.1 Transformation of Pools and Lanes

In this section we propose a set of rules that transform pools and lanes of a BPMN business process model. Before applying the rules to the model, we create an empty CD and an empty UCM.

R1. For each pool \( p \) in the BPMN model:
1. If \( p \) has a child lane set then create a system boundary \( sb \) in UCM;
2. Traceability: Create a link stereotyped \( \text{Trace} \) from \( p \) to \( sb \).

Empty lanes/pools do not contain child lane sets. They are often used to represent internal roles of organizational units (e.g., Manager, Associate), and systems (e.g. enterprise application). We transform them into classes by defining the following rule.

R2. Transform each empty lane/pool \( p \) to an actor in the UCM and to three classes \( MUser_p, VUser_p \) and \( CUser_p \) as in the MVC pattern. Add links stereotyped \( \text{Trace} \) from \( MUser_p, VUser_p \) and \( CUser_p \) to \( p \).

3.2 Transformation of Fragments

A fragment is defined in our previous works (Bouzidi et al., 2018), (Bouzidi et al., 2017) and (Bouzidi et al.,) as a sequence of BPMN tasks executed in the
same lane, and that handle the same business entity, i.e. the same item aware element (IAE). Hence, each fragment \( f \) is characterized by its lane, its IAE and the tasks that compose it.

R3. Transform each fragment \( f \) characterized by its lane, its IAE \( i \) and the tasks that compose it into a use case called \( Manage_i \).

A fragment may contain gateways, exception events, or which are important indicators for nominal, alternatives or exceptions scenarios of the derived use case. Therefore, we define R4 that builds scenarios according to the fragment components. Sometimes, the input and the output elements of a fragment do not exhibit the same IAE. Hence, the transformation and traceability rules defined previously remain valid, but we should add an association between the classes corresponding to the input and the output elements.

R4. For each fragment \( f \) in a business process model:

1. If \( f \) does not contain any gateway or exception event, create a nominal scenario.
2. If \( f \) contains a gateway, create a nominal scenario \( SI \) from the sequence of tasks involved in the execution of the default path of the gateway.
   - Create an alternative scenario from each sequence of tasks involved in the execution of an alternative path of the gateway.
3. If \( f \) contains an exception event, create a nominal scenario \( SI \) from the sequence of tasks involved in the execution of the default path of \( f \).
   - Create an exception scenario \( S2 \) from the sequence of tasks involved in the execution of the path that contains tasks linked to the exception event.
   - Create a dependency relationship from \( SI \) to \( S2 \).
4. If \( f \) has an input IAE \( in \) and an output IAE \( out \), then:
   - Create in the UCM a use case called \( Manage_{in} \).
   - If \( in \) is different from \( out \), then in the CD: (i) apply R12 to add an association between the entity classes \( M_{in} \) and \( M_{out} \) that represent respectively \( in \) and \( out \). Its navigability is set from \( M_{in} \) to \( M_{out} \), (ii) apply R13-R16 to get the multiplicity of the association, (iii) create classes called \( VManage_{in} \) \( CManage_{in} \), stereotyped respectively boundary and control.
   - Apply R5.3
   - For each automated task (non manual), apply R10 to add actions to the scenario.

   - Traceability: Create links stereotyped Trace (i) from the use case \( Manage_{in} \) to \( f \), (ii) from \( M_{in} \), \( M_{out} \) \( VManage_{in} \) \( CManage_{in} \) to the use case \( Manage_{in} \).

In a BPMN business process model, IAEs are data objects, data stores, data inputs, and data outputs. They are required or produced by BPMN activities to fulfill their business goals. From a software development viewpoint, the classes of the domain CD persistent business entities and correspond to the IAEs in the BPMN models. The most recent BPMN version, BPMN 2.0, allows business process models to be highly detailed. The details include the specification of persistent data (OMG, 2013) by using data stores to indicate that data remain beyond the process life cycle, that is after the process execution ends (OMG, 2013). To distinguish between persistent and non-persistent classes we propose to update persistent properties to true for each class generated from a data store.

R5. For each IAE \( i \)

1. If there is not any class in domain CD traced to \( i \), then add a class to CD called \( M_i \). Add the stereotype Entity to the class.
2. If \( i \) is a data store then set \( M_i \). persistent to true.
3. If \( i \) is a data input/output/object, then create a label and a text field in the boundary class representing the fragment that manipulates \( i \), otherwise \( i \) is a data store create a combo-box that corresponds to \( i \).
4. Create associations between \( M_i \) and \( CManage_i \), and between \( CUser \) and \( M_i \).
5. Traceability: create links stereotyped Trace from \( M_i \) to \( i \) if it does not already exist.

In BPMN, conditional sequence flows and outgoings of gateways may be written according to the following syntax: \( IAE.att \) where \( att \) indicates a particular characteristic of \( IAE \); for example \( product.brand \). This semantics is close to the concept of class attributes in UML. Therefore, we define the following rule:

R6. For each sequence flow label \( l \) written according to the syntax \( IAE.att \) where \( att \) indicates a particular characteristic of \( IAE \), generate an attribute called \( att \) in the class \( MIAE \) generated from \( IAE \).

Traceability : create a link stereotyped Trace from \( att \) to the label \( IAE.att \).

On the other hand, data object references may specify different states of the same data object. Hence, we transform information as follows:
R7. Apply the state design pattern of (Gamma, 1995) to IAEs with states. This design pattern defines three classes namely a context class, an abstract class which name is the concatenation of the name of the data object and the word state, and concrete classes. Each concrete class represents a state of the data object (cf. Figure 3).

3.3 Transformation of Exception and Signal Events

BPMN defines error, cancel and compensation event types to trigger exception actions. In UML, classes stereotyped exception are used to represent exception situations. Therefore, we propose the following rules:

R8. Transform each exception event into a class called EventLabel stereotyped exception.

R9.
1. Transform each Signal event in the BPMN model into a class called SignalEventLabel stereotyped Signal, and a boundary class called VSIGNALEventLabel.
2. Create an operation named activateEventLabel() in the class, CManage, that represents the fragment incorporating the signal event (created by R4.4).

3.4 Transformation of Tasks

In BPMN, tasks meet the UML action semantics, as they are executable elements in a BPMN process. Accordingly, we define the following rule:

R10. For each automated task t within a fragment f that manipulates a business entity i:
1. Create an action of a scenario in the use case Manage, and an operation called t() in the class CManage;
2. If t is a user task, then create a button in the class VManage;
3. Create an association between VManage and CManage to t.
4. Traceability: Create trace links stereotyped trace from:
   - CManage, and VManage to the use case Manage;
   - VManage and CManage to t.

Tasks often need a data input in and/or a data store (ds) to be executed. We transform this data to parameters of the operations derived from the tasks.

R11. Transform the input IAEs of a task t into parameters of the operation t(). The return type of the operation is generated from the output IAEs.

3.5 Generation of Associations between Classes

When a task t has an input in, and a different output IAE out, this means that there is a relationship...
between \textit{in} and \textit{out} established through \textit{t}. Thus we define the following rule.

**R12.** if a task \textit{t} has input data \textit{in}, and different output data \textit{out}, then create an association between the classes corresponding to the input and those corresponding to the output if it is not already created by \textbf{R4.4}.

We can deduce association multiplicity from three BPMN elements: (i) IAEs, (ii) gateways and (iii) loop task/rollback sequence flows. BPMN enables to represent an IAE as a single object (data object/input/output/store) or as a data collection. A single object indicates that the execution of a task requires or produces a single instance data, while a collection of data indicates that the data object represents a collection of instance data. Accordingly, we define rules \textbf{R13-R16} to determine the multiplicity of an association.

**R13.** If an task \textit{t} generates an association in the CD, and if it has as input/output a single object \textit{i}, and if the execution of \textit{t} depends on a condition, for example it is preceded by an exclusive/inclusive gateway, then the minimum multiplicity on the side of the class \textit{M}_i is 0.

\textbf{R16.} If a task \textit{t} generates an association in the CD, (\textit{i} is a data collection) the multiplicity is (1..*).

Further, a task may be a loop task, that is a task with looping behavior. This means that the task may be performed multiple times. It is also possible to specify a maximal number of iterations.

**R14.** If a loop task \textit{t} is linked to some BPMN element (exception event, item aware element, etc) and generates in the CD an association to a class that derives from that element, then the multiplicity at this association end is (1..\textit{N}) where \textit{N} indicates the number of iterations. If the number of iterations is not indicated, the multiplicity is (1..*).

**R15.** If a task \textit{t} generates an association in the CD, and if it has as input/output a single object \textit{i} and if the execution of \textit{t} depends on a condition, for example it is preceded by an exclusive/inclusive gateway, then the minimum multiplicity on the side of the class \textit{M}_i is 0.

**R16.** If a task \textit{t} generates an association in the CD,
and if it has input data \( i \), and if \( t \) is performed after a merging gateway, then the minimum multiplicity on the side of the class \( M \) is 0.

3.6 **Generation of extends and includes Relationships**

We proved in (Bouzidi et al., 2017) that an includes relationship between two use cases is generated from a redundant task \( t \). By applying rule \( R10 \), \( t \) is transformed into an action in a scenario executed within a use case \( uc \). Therefore, we propose to replace this action with the display of the view of a use case \( uc \), to indicate that \( uc \) invokes \( uc \) and uses its action \( t \). Simultaneously, we create a dependency between the view classes and the control classes traced with \( uc \) and \( uc' \). Furthermore, we create traceability relationships from the target to the source elements of the transformation. We denote this transformation rule by \( R17 \).

On the other hand, if \( t \) is a target ref of an outgoing of a gateway, then we create an extends relationship from \( uc \) to \( uc' \) instead of an includes one. Furthermore, we proved that an extends relationships is generated from an exclusive or inclusive gateway between two fragments. Hence, we propose to define scenarios that display the view of the extending use case when the extended use case invokes it. We also create a dependency relationship between the view and the control classes of the extending and the extended use cases, and trace links between related elements. We denote this transformation rule by \( R18 \).

4 **CASE STUDY**

Our illustrative case study (cf. Figure 4) is a typical business process for online purchasing and selling. It is decomposed into fragments according to our fragment definition (cf. Figure 4). As the fragments \( F2, F3, F6 - F10 \) are composed of one task, the name of each one of them is the name of the task it contains. For example, \( F2 \) is called *Check stock availability*. However, \( F1, F4 \), and \( F5 \) contain many tasks. Hence, we manually name them: (i) \( F1 \): *Prepare a purchase order*; (ii) \( F4 \): *Acquire raw materials*; and (iii) \( F5 \): *Manage Charge penalty and compensate*.

Figure 2 and Figure 5 depict respectively the generated use case diagram (UCD) and an extract of the generated CD organized according to the MVC pattern.

By applying \( R1 \) on the pool *Seller*, a system boundary called *Seller* is generated in the UCD, and a trace link between them is created. Moreover, we apply \( R2 \) on the empty lanes Stock manager and Sales, and on the empty pool Customer to derive three actors: Stock manager, Sales, and Customer, three entities called MUser, VUser, and CUser, and trace links from each actor or class to its empty lane/pool.

By applying \( R5 \) on the IAES we add to the CD the entities PurchaseOrder, Customer, Cart, Product, Payment, PenaltyCancellation, StockAvailability, RawMaterials, SupplierCatalog, and Invoice. \( R5 \) also derives the entities DBWarehouse and SupplierCatalog and initializes their property persistent to true as they are generated from data stores.

Further, \( R7 \) applied on the data objects *Product* and *Purchase order* produces an abstract class called ProductState and a concrete class called Packaged, which are linked by a generalization relationship. It also adds a composition relationship between the classes ProductState and Product, an abstract method called packaged() to the class ProductState, a concrete method called packaged() to the concrete class Packaged, an attribute called state, and its getter and setter setProductState() in the class Product.

Next, we apply \( R6 \) on the sequence flow labels Product, price; 100000, and Product, items; quantity=0.0 to create the attributes price and items.quantity in the entity class Product.

Also, \( R3 \) is applied on \( F1 \) to create a use case called *Prepare purchase order* in the UCD. Then, \( R4.4 \) generates a boundary and a control class called respectively VPreparePurchaseOrder and CPreparePurchaseOrder and an association between them, and an aggregation from VPreparePurchaseOrder to CUser. \( R4.4 \) calls the rules \( R5.3 \) to create associations from the entities Product, Cart and PurchaseOrder to CPreparePurchaseOrder and MUser, and \( R12 \) to create a n-ary association from the classes Product and Cart to the entity PurchaseOrder, (iii) \( R13 \) to update the multiplicity of ass to 1..1 on the side of Product and Cart, and (iv) \( R15 \) to update the multiplicity to 0..1 on the side of PurchaseOrder.

Furthermore, \( R9 \) is applied on the signal events that belong to the fragments \( F1 \) and \( F5 \) to create a signal class called PurchaseOrderCancellation and a boundary class called VPurchaseOrderCancellation. This rule associates the created signal classes to the classes CPreparePurchaseOrder and CManagePenaltyAndCompensate.

As the fragment \( F1 \) contains a gateway, we apply \( R4.2 \) on \( F1 \) to obtain (i) a nominal scenario NS that contains three actions *show cart items, add product to cart, fill customer information* (NS is considered as a nominal scenario because it represents a sequence of activities involved in the execution of the default path of an exclusive gateway; (ii) an alternative scenario that includes the actions *add prod-
uct to cart, Cancel purchase order. F1 contains an error event. Therefore, we apply R4.3 and R10 on F1 to create an exception scenario that contains one action called Cancel purchase order. As the task Cancel purchase order appears in both F1 and F5, by applying R17 and R18 on this task, we obtain, in the UCD, a use case called Cancel purchase order. As the task Cancel purchase order appears in both F1 and F5, by applying R17 and R18 on this task, we obtain, in the UCD, a use case called Cancel purchase order. As the task Cancel purchase order appears in both F1 and F5, by applying R17 and R18 on this task, we obtain, in the UCD, a use case called Cancel purchase order. As the task Cancel purchase order appears in both F1 and F5, by applying R17 and R18 on this task, we obtain, in the UCD, a use case called Cancel purchase order. As the task Cancel purchase order appears in both F1 and F5, by applying R17 and R18 on this task, we obtain, in the UCD, a use case called Cancel purchase order. As the task Cancel purchase order appears in both F1 and F5, by applying R17 and R18 on this task, we obtain, in the UCD, a use case called Cancel purchase order. As the task Cancel purchase order appears in both F1 and F5, by applying R17 and R18 on this task, we obtain, in the UCD, a use case called Cancel purchase order. As the task Cancel purchase order appears in both F1 and F5, by applying R17 and R18 on this task, we obtain, in the UCD, a use case called Cancel purchase order. In addition, R17 creates in the CD (i) a control class called CCancelPurchaseOrder, and a boundary class called VCancelPurchaseOrder, (ii) two aggregation relationships respectively from the class CManage penalty and compensate to the class VCancelPurchaseOrder, and from the class CPreparePurchaseOrder to the class VCancelPurchaseOrder, two buttons called display cancel purchase order are added respectively to VManagePenaltyAndCompensate and VPreparePurchaseOrder. Further, R17 creates (i)
trace links between the use case Prepare purchase order and the control class CCancelPurchaseOrder and VCancelPurchaseOrder, and the use case Manage charge penalty and compensate, and the classes CCancelPurchaseOrder and VCancelPurchaseOrder, (ii) and a trace link Trace respectively between the task Cancel purchase order, the use case Cancel purchase order, the extends and includes relationships and the classes CCancelPurchaseOrder and VCancelPurchaseOrder.

Figure 6 depicts and example of the trace links established between F1, the use case PreparePurchaseOrder, and the classes CPreparePurchaseOrder and VPreparePurchaseOrder, which maintain them always aligned. For example, if a new task is added to F1, then a new action and a new operation should be added respectively to the scenarios of the use case PreparePurchaseOrder, and the class CPreparePurchaseOrder.

5 CONCLUSION

In the current work, we propose, BPtraceUCD, a semi-automatic transformation and traceability approach that transforms a BPMN business process model to a UCM and a CD structured according to the MVC design pattern. The transformation models serve as a mean to obtain aligned heterogeneous models, while the defined traceability links enable to keep model elements always aligned even if they evolve, hence reducing the analysis time to recognize sources of misalignment. Our approach is innovative since it accounts for both the semantic and structural aspects of BPMN and UML specifications in the context of the static and functional viewpoint of the IS.

In addition, it deals with the traceability challenge between business and software models, and between software models themselves. Ongoing work is oriented towards broadening the model transformations and the traceability management, attempting to carry out the dynamic viewpoint of the IS namely sequence diagrams.

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