

Consistency of Business Process Models and Object Life Cycles

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Abstract. Business process models and object life cycles can provide two different views on behavior of the same system, requiring that these models are consistent with each other. However, it is difficult to reason about consistency of these two types of models since their relation is not well-understood. We clarify this relation and propose an approach to establishing the required consistency. Object state changes are first made explicit in a business process model and then the process model is used to generate life cycles for each object type used in the process. We define two consistency notions for a process model and an object life cycle and express these in terms of conditions that must hold between a given life cycle and a life cycle generated from the process model.

Keywords: consistency, business process model, object life cycle, activity diagram, state machine, UML

1 Introduction

Business process models are nowadays a well-established means for representing business processes in terms of tasks that need to be performed to achieve a certain business goal. In addition to tasks, business process models also show the flow of *business objects* in a process. Complete behavior of business objects is usually modeled using a variant of a state machine called an *object life cycle* (see e.g. [5]). Object life cycle modeling is valuable at the business level to explicitly represent how business objects go through different states during their existence.

There are situations where it is beneficial or even required to use both process models and object life cycles. Consider an insurance company that uses business process models for execution and also maintains explicit business object life cycles. Life cycles may serve as a reference to employees for tracking progress of business objects. For instance, in response to an enquiry about the state of a submitted claim, an employee can explain the current claim state to the customer in the context of the entire claim life cycle that shows all the possible states and transitions for claims. Another example is encountered in compliance checking, where existing business process models are benchmarked against best practice models (e.g. ACORD [2] and IFW [4]) given as object life cycles. Given a best practice object life cycle, it is required to ensure that an existing business process model is compliant with it.

When both business process models and object life cycles are used, it is required that these models are *consistent* with each other. Inconsistencies can lead to unsatisfied customers or compliance violations. For example, a customer may be discontent if he/she is incorrectly informed about the processing that still needs to be done before his/her claim is settled. On the other hand, inconsistencies between an existing process model and a best practice object life cycle lead to compliance violations that can cause legal problems for a company.

Consistency of object-oriented behavioral models, such as scenarios and state machines, has already been extensively studied [9, 10, 16, 18]. However, the relation between business process models and object life cycles is not yet well-understood, which makes it difficult to reason about their consistency.

In this paper, we present our approach to establishing consistency of a business process model and an object life cycle. In Section 2, we introduce subsets of *UML2.0 Activity Diagrams (UML AD)* and *State Machines (UML SM)* [3] chosen for business process and object life cycle modeling, respectively. In Sections 3 and 4, we describe our proposed solution that comprises a technique for object life cycle generation from a process model and two consistency notions that can be checked using the generated life cycles. Finally, we discuss related work in Section 5, and conclusions and future work in Section 6.

2 Business Process Models and Object Life Cycles

UML AD is one of the most widely used languages for business process modeling. We consider process models in a subset of UML AD that includes *action nodes* and *control nodes* (decision, merge, fork, join, start³, flow final and activity final nodes). All these nodes can be connected with *control* and *object flows*. *Input* and *output pins* are used to model connection points that allow object flows to be attached to nodes, with the exception of start nodes that may not have outgoing object flows. Each object pin has an *inState* attribute that allows one to specify the possible states of objects passed through this pin. Data inputs and outputs of processes are modeled using *input* and *output parameters*. Our experience with case studies has shown that in practice most process models are created using this subset of UML AD. Therefore, currently we do not consider more advanced elements such as loop nodes and parameter sets, and further assume that hierarchy in process models can be flattened. The reader is referred to the UML AD specification [3] for further information about the language.

Figure 1 shows an example business process model for a *Claims handling* process from the insurance industry that is represented in the chosen subset of UML AD. In this diagram, we can see that the *Claims handling* process starts when a *Settlement* in state *Requested* is received by the process. Next, a new *Claim* object is created in state *Registered* by the *Register new claim* action. The *Claim* further goes through a number of processing steps that change its state and at the end of the process it is either found to be fraudulent, or it is rejected or settled and subsequently closed.

³ These are called *initial nodes* in UML AD, but renamed here to avoid confusion with initial states of object life cycles introduced later.

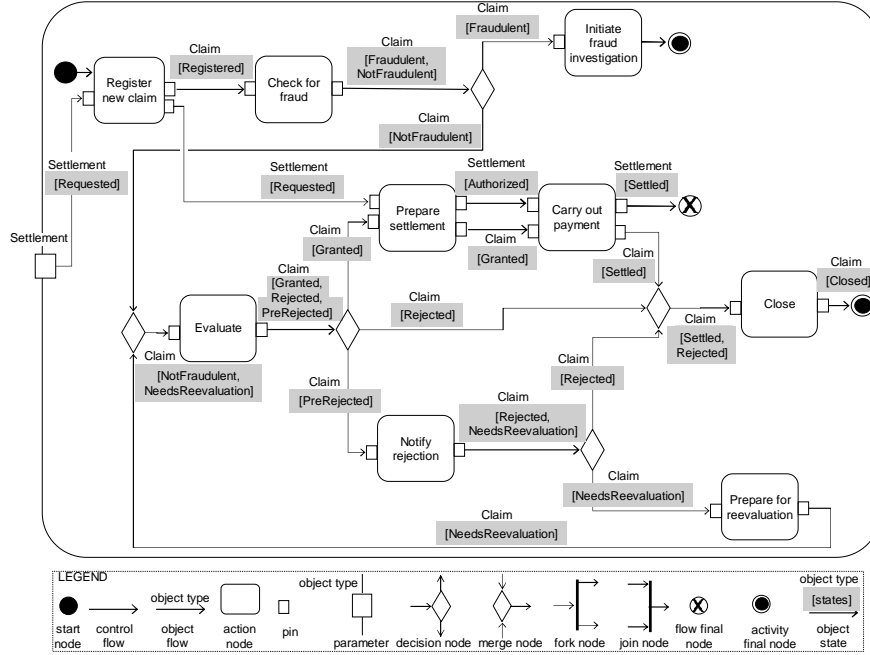


Fig. 1. *Claims handling* business process model

In Figure 1 we use a slightly tailored graphical representation of the chosen UML AD subset. We indicate object type above an object flow and not above each pin, because we make a simplifying assumption that an object flow can only connect two pins of the same type. We also assume that given two connected object pins (output pin and input pin), the states associated with the output pin are accepted by the input pin, i.e. the set of states of the output pin is a subset of the set of states of the input pin. In Figure 1 we indicate the states associated with the output pin on the connecting object flow.

Associating states with object pins is optional in UML AD, but required in our approach, as this explicit information about object states allows us to establish a relation between a business process model and object life cycles.

For modeling object life cycles, we use a subset of the UML SM language. This subset comprises *states*, with one *initial state* and one or more *final states*, and *transitions* connecting the states. Transitions that are initiated by a particular triggering event can be labeled with a *trigger label*. As our main application is in a business environment, we choose a simple notation for object life cycles, without considering composite and concurrent states of state machines.

Figure 2 shows two example life cycles for *Claim* and *Settlement* object types. In (a), it can be seen that all objects of type *Claim* go through state *Registered* directly after the initial state and pass through either *Fraudulent* or *Closed* states before they reach a final state. In (b), it is shown that after a *Settlement*

is *Authorized*, the payment for the *Settlement* can either be made in full or in a number of installments.

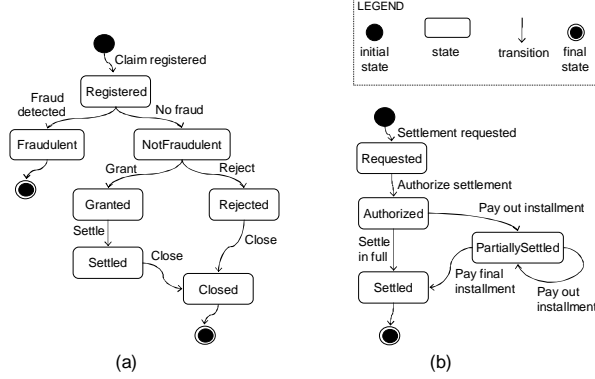


Fig. 2. Object life cycles: (a) *Claim* (b) *Settlement*

In this paper we use the following definition for an object life cycle, adapted from the definition of a UML State Machine in [14]:

Definition 1 (Object life cycle). *Given an object type o , its object life cycle $OLC_o = (S, s_\alpha, S_\Omega, L, T)$ consists of a finite set of states S , where $s_\alpha \in S$ is the initial state and $S_\Omega \subseteq S$ is the set of final states; a finite set of trigger labels L ; a set of labeled transitions $T \subseteq S \times L \cup \perp \times S$, where for each transition $t = (s_1, l, s_2)$, s_1 is the source state and s_2 is the target state.*

We assume that an object life cycle is well-formed when the initial state has no incoming transitions, a final state has no outgoing transitions, and all other states have at least one incoming and at least one outgoing transition.

The *Claims handling* process model in Figure 1 and the life cycles in Figure 2 are concerned with behavior of the same object types: *Claim* and *Settlement*. We need to define what it means for these models to be consistent and how to check their consistency. According to an existing methodology for managing consistency of behavioral models [6, 8], the consistency problem must first be identified by determining the *overlap* between the given models. Then, model aspects that contribute to the consistency problem must be mapped into a suitable *semantic domain*, where *consistency conditions* can be defined and checked.

An overview of our proposed solution is shown in Figure 3. In Step 1, we make the overlap between a business process model and object life cycles explicit by adding object state information to the process model using the *inState* attribute of object pins (as in Figure 1). Next in Step 2, we generate a life cycle for each object type used in the process. This generation step takes us to the UML SM as the semantic domain, where we can then define and check consistency between the generated life cycles and the given ones (Step 3), which in turn allows us to determine the consistency between the business process model and the given life cycles (Step 4). The next two sections describe the generation of life cycles from a process model and the proposed consistency notions, respectively.

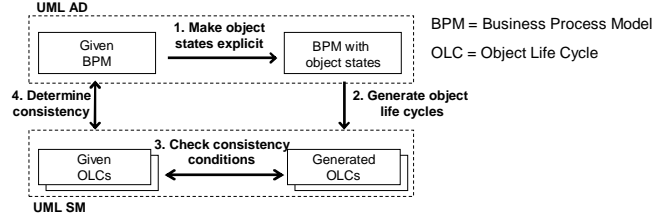


Fig. 3. Solution overview

3 Generation of Object Life Cycles

An object life cycle generated from a given business process model for a particular object type should capture all possible state changes that can occur for objects of this type in the given process. Initial and final states also need to be identified for each generated life cycle.

Given a business process model P where each object pin is associated with a non-empty set of states, we generate an object life cycle for each object type used in P . For an object type o , we first create an object life cycle OLC_{oP} that contains only the initial state. Then, for each unique state associated with object pins of type o , a state is added to OLC_{oP} . Transitions and final states are added to OLC_{oP} according to the generation rules shown in Figure 4.

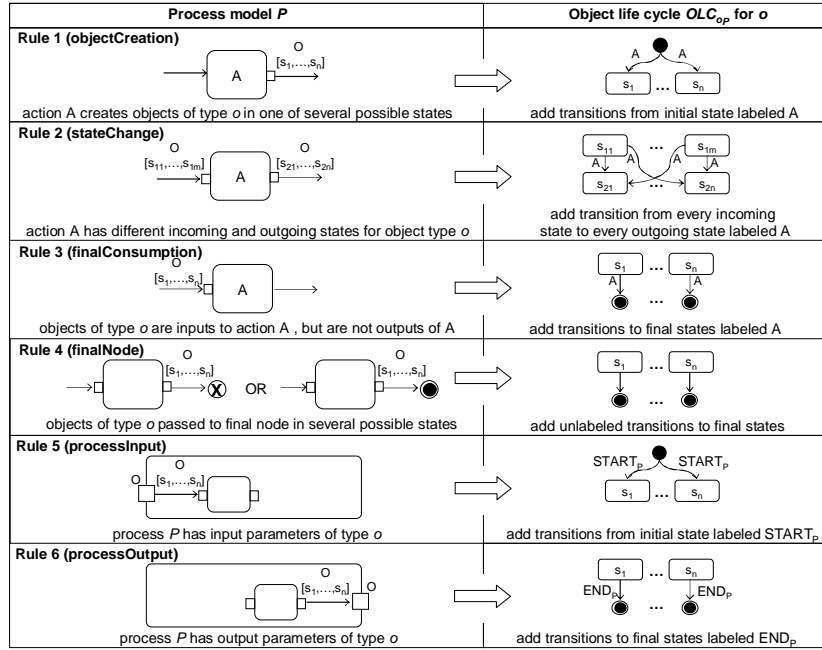


Fig. 4. Rules for object life cycle generation

Each row in Figure 4 represents a high-level generation rule, where the left-hand side shows patterns that are matched in the process model P and the right-hand side shows what is created in the generated object life cycle OLC_{o_P} . Consider for example **Rule 2 (stateChange)**, which is applicable when some action A has input and output object pins of type o . When states of the output object pin are not the same as those of the input object pin, we deduce that action A changes the state of objects of type o . In OLC_{o_P} , a transition from each incoming state to each possible outgoing state for objects of type o is added, for all cases where the outgoing state is different from the incoming state. These transitions are labeled A to indicate that they are triggered during the execution of this action. In **Rules 5** and **6**, the generated transitions are given special labels ($START_P$ and END_P) to indicate that these transitions are triggered as the process begins and ends execution, respectively. The rules ensure that the generated object life cycles are well-formed, provided that all object pins in the given process model are associated with non-empty state sets. All the generation rules are explained in detail in a longer version of this paper [13].

Figure 5 shows life cycles for *Claim* and *Settlement* object types (right-hand sides of (a) and (b), respectively) generated from the *Claims handling* process model in Figure 1 according to the generation rules presented in this section.

In the next section we show how generated object life cycles are used for defining consistency conditions to establish whether a given process model is consistent with a given life cycle for a particular object type.

4 Consistency of Object Life Cycles

We identify two consistency notions for a given business process model and an object life cycle: *life cycle compliance* and *coverage*. A given process model is *compliant* with a given life cycle for a particular object type, if the process initiates only those state transitions for objects of this type that are defined in the given life cycle. Compliance allows objects of the given type to traverse only a part of their given life cycle in the process. On the other hand, *coverage* requires that objects traverse the entire given life cycle in the process, but additional transitions not defined in the given life cycle may also be incurred in the process.

Depending on the circumstances, one or both of these consistency notions may be required to hold. For example, if the *Claims handling* process (Figure 1) is used for execution and the *Claim* life cycle (Figure 2 (a)) is referenced by employees for interpreting the state of *Claim* objects, both compliance and coverage must hold. If the process is not compliant with the life cycle and takes *Claim* objects into states not shown in the life cycle or performs different transitions, this will disconcert the employees. On the other hand, customers will be incorrectly informed and thus unsatisfied if the process does not provide a coverage of the life cycle. An example of this occurs if a customer expects a *Claim* in state *Granted* to eventually reach state *Settled* according to the given life cycle, but this never happens in the *Claims handling* process.

We next give more precise definitions of compliance and coverage, providing consistency conditions that must hold between a life cycle generated from a

process model for a particular object type and a given life cycle for that type. We first give two definitions that simplify the expression of consistency conditions that follow. Definitions 2 and 3 can be applied to any two object life cycles:

$OLC_o = (S, s_\alpha, S_\Omega, L, T)$ and $OLC'_o = (S', s'_\alpha, S'_\Omega, L', T')$.

Definition 2 (State correspondence). A state correspondence exists between a state $s \in S$ and a state $s' \in S'$, if and only if one of the following holds: $s = s'$, $s = s_\alpha$ and $s' = s'_\alpha$, or $s \in S_\Omega$ and $s' \in S'_\Omega$.

Definition 3 (Transition correspondence). A transition correspondence exists between a transition $t = (s_1, s_2) \in T$ and a transition $t' = (s_3, s_4) \in T'$ if and only if there are state correspondences between s_1 and s_3 , and between s_2 and s_4 .

In Definition 2, we define a *state correspondence* between two states in different object life cycles if the states are equal (i.e. have the same name), if they are both initial states or they are both final states. In Definition 3, we define a *transition correspondence* between two transitions if there are state correspondences between their sources states and between their target states.

In Definitions 4 and 5, P is a given process model, $OLC_o = (S, s_\alpha, S_\Omega, L, T)$ is a given life cycle for object type o and $OLC_{o_P} = (S_P, s_{\alpha_P}, S_{\Omega_P}, L_P, T_P)$ is the life cycle generated from P for o .

Definition 4 (Life cycle compliance). A business process model P is compliant with an object life cycle OLC_o if and only if for each transition $t_P \in T_P$ that is not labeled $START_P$ or END_P , there exists a transition $t \in T$ such that there is a correspondence between t_P and t .

According to Definition 4, life cycle compliance requires that each transition in the generated object life cycle has a transition correspondence to some transition in the given life cycle. However, there are two exceptions to this consistency condition: transitions labeled $START_P$ and END_P in the generated object life cycle. These transitions are generated when the given process model P has input or output parameters of object type o . We do not place restrictions on these transitions, thus allowing objects of type o to be received by and passed from the given process in any state and not necessarily a state following the initial state or preceding a final state.

Definition 5 (Life cycle coverage). A business process model P provides a coverage of an object life cycle OLC_o if and only if all of the following conditions hold between OLC_o and OLC_{o_P} : (a) For each transition $t \in T$ there exists a transition $t_P \in T_P$ such that there is a correspondence between t and t_P , (b) There are no transitions labeled $START_P$ or END_P in T_P .

Condition (a) in Definition 5 requires every transition in the given object life cycle to have a transition correspondence to some transition in the generated life cycle. Furthermore, condition (b) requires that the given process does not have input or output parameters of the given type, hence objects of this type must be created and reach their final states within the process boundaries.

We next illustrate the notions of life cycle compliance and coverage using examples. Figure 5 shows the given object life cycles for the *Claim* and *Settlement* object types on the left and the object life cycles generated from the *Claims handling* process on the right. Transitions that have a correspondence between them are marked with the same number, while transitions without a correspondence are marked with a cross.

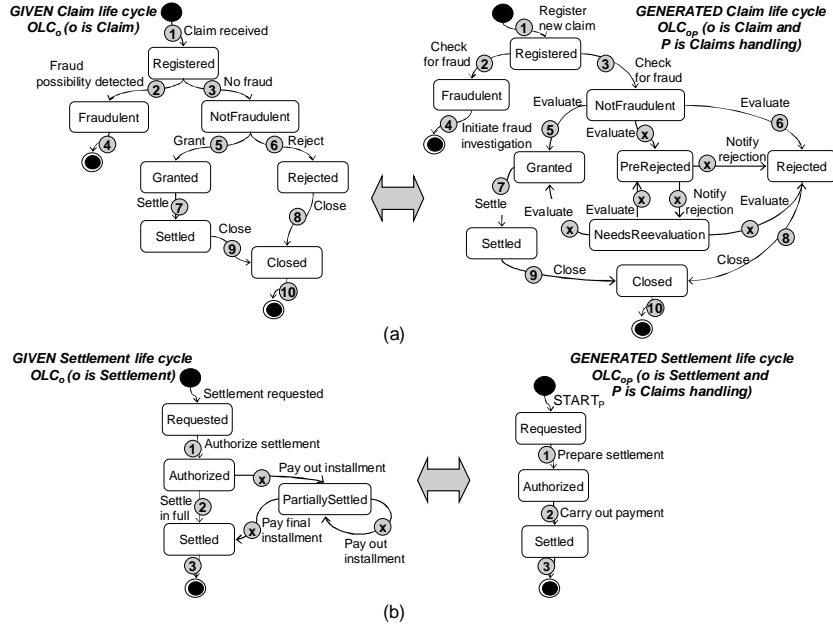


Fig. 5. Consistency of *Claim* and *Settlement* object life cycles

The *Claim* life cycles in Figure 5 (a) satisfy all the consistency conditions for life cycle coverage. Condition (a) from Definition 5 is satisfied since all the transitions in the given *Claim* life cycle have a correspondence to transitions in the generated *Claim* life cycle, and condition (b) is satisfied since the generated *Claim* life cycle does not contain transitions labeled $START_P$ or END_P . Therefore, the *Claims handling* process provides a coverage of the given *Claim* life cycle. However, the *Claims handling* process is not compliant with this life cycle, due to transitions in the generated life cycle without transition correspondences to transitions in the given life cycle. Figure 5 (b) shows that the *Claims handling* process is compliant with the given *Settlement* life cycle, but does not provide a coverage for it.

5 Related Work

A related research area is *object life cycle inheritance*, where consistent specialization of behavior is required (see e.g. [5, 11, 14]). Currently, our main goal

is to establish a link between business process models and object life cycles, and life cycle inheritance is not in focus. However, sometimes it may be required that the relation between a given process model and an object life cycle is a certain type of specialization. Thus, it would be beneficial for our approach to make use of the consistency notions already defined for life cycle inheritance.

Another related area is *synthesis of state machines from scenarios* [18, 16], where scenario specifications are used to generate state machines for the objects that participate in these scenarios. There are several significant differences between process models and scenarios however, e.g. process models do not generally describe alternative scenarios and show the flow of objects between tasks rather than interaction between objects via messages modeled in scenarios. In state machine synthesis, it is possible that a synthesized state machine contains so-called *implied scenarios* [15, 12], i.e. behaviors that are not valid with respect to the original scenario specifications. A similar phenomenon can occur in our life cycle generation step, which we plan to investigate further as future work.

Our consistency notions are related to the concepts of *equivalence* and *refinement* of formal process specifications [7]. However, as discussed in [17], it is challenging to apply the existing definitions to languages such as UML AD and SM, as they do not have an agreed formal semantics. As future work we intend to establish a relation of our consistency notions to the existing equivalence and refinement definitions and investigate which are most appropriate in practice.

6 Conclusion and Future Work

Consistency of business process models and object life cycles needs to be ensured in situations where process models manipulate business objects with an explicitly modeled life cycle. In this paper we have presented our approach to establishing this consistency. Our main contributions include a precise definition of two consistency notions, namely life cycle compliance and coverage, and a supporting technique for the generation of object life cycles from process models that enables consistency checking. With regards to tool support, we have developed a prototype as an extension to the IBM WebSphere Business Modeler [1] that allows us to capture object states in business process models, generate life cycles from process models and check the consistency conditions.

As future work, we intend to validate the proposed approach using a larger case study. We also plan to extend the approach to enable compliance and coverage checking for *several* process models that use objects of the same type and a life cycle for this type. Further future work includes an investigation of implied scenarios in the context of our life cycle generation and establishing a clear relation between our proposed consistency notions and the existing equivalence and refinement definitions.

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