SEA/Aspect: Dynamic Visualization and Composition of Concerns in Aspect-Oriented Modeling (AOM)

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Abstract. The Aspect-Oriented Modeling (AOM) aims to raise the abstraction level from code to models in the representation of aspect-oriented systems. With the modeling of aspects it is possible to view the crosscutting concerns into the core concerns of the system through the composition of models, which eases the system comprehension. This paper aims at the representation of aspect-oriented systems using UML, through a lightweight profile, modeling the most important features of Aspect-Oriented Programming (AOP) and enabling alternating views of the system dynamics. The developer may create different compositions of the core and the crosscutting models, visualizing only the core models, the crosscutting models, or the core intertwined with the crosscutting models. Aspects can be enabled or disabled dynamically, by updating the compound model, with no effort demanded from the developer. The concerns are differentiated in the compound model by different colors. The proposed solution is implemented as a tool, named SEA/Aspect, that enables the automatic generation of sequence diagrams resulting from the intertwining of aspects, which also allows the selection of which aspects will be composed.

Keywords: Aspect-Oriented Modeling, UML, Model Composition, Model Visualization, Model Weaving, Modeling Tool

1 Introduction

A system consists of a set of requirements, where each requirement can be considered a customer's concern. The **core concerns** captures the core functionality and impact only a part of the system, while the **crosscutting concerns** captures functionality that impacts one or more parts of the system [?]. The AOP's goal is the modularization of these concerns, so that they are kept in separate modules that implement the core concerns of an application [?].

The most elementary way to represent aspect-oriented programs is directly at the code level. One of the limitations of this form is that the concerns modularization makes it difficult to understand the execution flow, since the system dynamic is visualized only after the composition of concerns, or with the aid of tools for visualizing the effect of the aspects in the system core. Another limitation of the direct implementation in code is that with the low-level of abstraction, the developer may be overwhelmed with implementation details rather than on the interaction of the core and crosscutting concerns. This paper focus in the modeling of aspect-oriented applications, based in the AspectJ language, finding appropriate modeling abstractions for the language constructs.

An aspect-oriented system demands the representation of the characteristics inherent to AOP and may have their understanding facilitated by alternating the views of the application dynamic, visualizing the behavior of crosscutting concerns composed with the behavior of core concerns. As we are working in the modeling of aspect-oriented applicatons, the model of a crosscutting concern will be referred as a crosscutting model and the model of a core concern as a core model. The Unified Modeling Language (UML), the standard language used to model object-oriented systems [?], could be used for aspect-oriented systems, but it have elements that cannot be represented with the standard meta-model. To overcome this limitation, the language could be extended by two ways: via a lightweight extension through a profile, or an extension through the modification of the language meta-model.

Some approaches have been proposed for the modeling of aspect-oriented systems using UML. The Reusable Aspect Models (RAM) [?] approach represents the structure and the behavior of a system, using class, sequence and state machine diagrams. The composed models generated by RAM are difficult to understand due to the excess of syntactic elements and because the core and crosscutting concerns are not explicitly differentiated in the compound model. Regarding to the language extension mechanism, RAM extends the UML meta-model by introducing non-standard language constructs, while this paper extends the UML through a profile. Cottenier's paper [?] proposes an aspect visualization engine, with the representation of the AOP's characteristics and the visualization of the effect of aspects in the system core, but with low-level of abstraction in the modeling and with contructions close to the target language code. Evermann's proposal [?] contributes with an AspectJ profile that represents most part of the AOP characteristics, but does not allow capturing multiple join points with wildcards. Klein's approach [?] use extended sequence diagrams to model the system behavior and allows the composition of multiple aspects in the same joinpoint. However, the approach of Klein does not allow the representation of pointcuts with wildcards. Jacobson's approach [?] represents aspects in terms of use cases, but modifies the UML meta-model by adding non-standard language constructs and does not performs automatic model composition. Theme/UML [?] supports the modeling of core and crosscutting concerns, automates the composition of models and represents the characteristics of AOP. Theme/UML modifies the UML meta-model and is dependent on the version 1.3 of the language. Carton's proposal [?] aims to overcome this limitation, creating a marking profile to represent Theme/UML accordingly to the UML standards.

However, the model composition is still limited to the constructs available on the version 1.3 of the UML.

This paper proposes an approach to model aspects using UML, which allows the representation of the system's structure and behavior, the automatic composition of core and crosscutting models, enabling alternating views of the system dynamics (with and without the explicitation of the aspects) and, thus, facilitating the model understanding and maintenance. To allow the modeling of aspect-oriented systems, a lightweight profile is defined. This profile is within the language standards and can be used in CASE tools that support importing profiles. The proposed profile uses some stereotypes from Evermann's work [**?**] and introduces some constructions to represent the behavior of aspect-oriented systems. The constructions are based on the AspectJ language [**?**], which is the standard language for AOP with Java.

With the proposed profile, it is possible to model the core and crosscutting concerns of aspect-oriented applications. The profile gives subsidies to perform the composition between a core model and crosscutting models, obtaining a model with the aspect behavior inserted at different execution points, without any effort from the developer. An aspect visualizer, implemented in the SEA environment [**?**], allows the dynamic enabling of aspects, visualizing only the behavior of the core models, the crosscutting models, or the composition of one or more crosscutting models with a core model automatically. The developer differentiates the behavior of each concern by different colors in the compound model.

This article is organized as follows: section II presents the proposal for specification of aspect-oriented software. The section III deals with the aspects composition and the visualization toggling tool. Section IV presents a case study using the proposed tool. The conclusions are in section V.

2 Specification of Aspect-Oriented Software

Figure 1 shows the UML profile to represent the structure and behavior of aspect-oriented applications. The profile may be used in CASE tools that support importing profiles through the XML Metadata Interchange (XMI) [**?**]. Relative to the structural modeling, this paper uses some definitions from an AspectJ profile [**?**], which allows the representation of the AOP's structural characteristics. The definitions used from Evermann's profile are the *CrosscuttingConcern* and the *Aspect* stereotypes, that are colored in beige in the profile diagram. A stereotype extends an element from the UML meta-model improving its semantics. In this paper, a meta-model element being extended will be represented inside parentheses. The *CrosscuttingConcern* stereotype extends (*Package*) and contains a set of aspects and classes. It represents a concern that impacts one or more parts of the system. The *Aspect* stereotype extends (*Class*), contains inter-type declarations and some configuration properties as: type of aspect instantiation, associated pointcut and a flag to indicate if this aspect is privileged. Inter-type declarations allows injection of new members (method, attribute) on a class, change of inheritance hierarchy and new interfaces implementation. To represent inter-type declarations, a new stereotype denominated *ClassExtension* was created. This stereotype extends (*Class*) and is related to another stereotype named *Introduction*. The later is used to mark which member is being inserted on a given class, or which inheritance relationship is being added, or which interface is being implemented. The stereotype *Introduction* extends the meta-model elements (*Attribute*), (*Operation*), (*Generalization*) and (*Realization*).

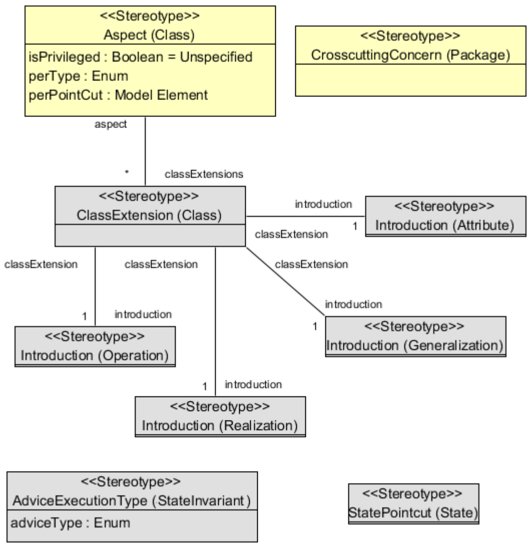


Fig. 1. UML Profile to model Aspect-Oriented Applications.

Besides inter-type declarations and aspect configurations, an aspect contains pointcuts and advices. Evermann's profile [**?**] represents pointcuts within the aspect definition, but without the possibility of capturing multiple join points, because it is not possible to use wildcards in the pointcut specification. In the Evermann's approach, a pointcut refers to a specific model element that must be explicitly specified by the modeler. This approach represents pointcuts with the UML state machine diagram. Each transition represents the capture of one or more join points, with the possibility of using wildcards. If the capture of all the join points is satisfied, that is, if the conditions for triggering a transition are satisfied, it is considered that the system has met a certain pointcut. The stereotype *StatePointcut* extends (*State*) and represents a pointcut. The composition of pointcuts is achieved by composing different state machines. The stereotype that represents pointcuts can be seen in the bottom right of figure 1.

The figure 2 shows the definition of pointcuts using the proposed approach. The pointcut *AnyCall* captures calls (*call* pointcut) to any method of any class, using a wildcard to match any return type, any class and any method name with any number of parameters. The pointcut *RoomTarget* captures the occurences of a call when the target object (*target* pointcut) is of the type *Room*. Each pointcut is represented as a state in the state machine diagram. The pointcut signature is specified in the transition, which allows the use of wildcards to capture multiple joinpoints. When the pointcut state is reached, it means that the system has captured the execution points specified by the pointcut signature in the transition label.

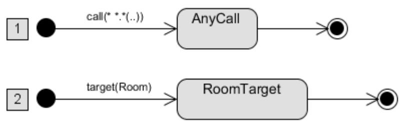


Fig. 2. The definition of two pointcuts.

The AspectJ language allows the composition of pointcuts with the logical operators *and*, *or* and *not*. The proposed approach performs the automatic composition of pointcuts using state machine digrams. The figure 3 shows the composition of the pointcuts *AnyCall* and *RoomTarget* using the *and* operator. The compound state machine contains a state with a *concurrent region*, containing sub-states that execute concurrently: *AnyCall* and *RoomTarget*. The synchronization occurs with the *fork* and *join* nodes, which means that the final state (*AnyCall AND RoomTarget*) only will be reached if both states (*AnyCall* and *RoomTarget*) are reached. This is the semantic of the *and* operator in the AspectJ language. The figure 4 shows the composition of the pointcuts using the *or* operator. Here the semantics is a bit different, because the system will reach the final state (*AnyCall OR RoomTarget*) when any of the pointcuts are reached. This is represented in the compound state machine, that shows direct transitions from both states to the final state.

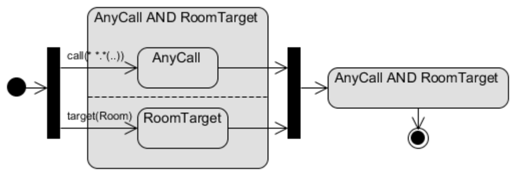


Fig. 3. The composition of two pointcuts with the AND operator.

A pointcut captures the execution points of a system to inject behavior in these points. This behavior is the advice, that is directly associated with a pointcut. Sequence diagrams are used to represent the behavior of the core concerns (core model) and the crosscutting concerns (crosscutting models). An aspect can

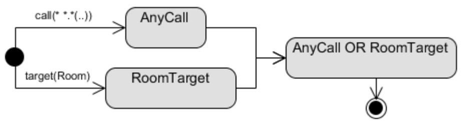


Fig. 4. The composition of two pointcuts with the OR operator.

have one or more advices and each one is represented by a crosscutting model. The behavior of an advice executes when it's associated pointcuts are satisfied, i.e, all joint points are captured. As we model pointcuts with state machines and advices with sequence diagrams, the connection of the advices with pointcuts should be achieved using syntatic elements of these diagrams. We implement this connection using state invariants. A state invariant is an interaction fragment associated with a lifeline on the sequence diagram, representing a run-time constraint on the participants of the interaction. We use the reachability of a state as the constraint to trigger the advice execution.

The definition of a crosscutting model (as a sequence diagram) begins adding the aspect as the first lifeline of the diagram. A state invariant, which represents the satisfaction of a pointcut, is associated to the aspect lifeline. This means that the sequence of messages occurs only when the system achieves the state pointcut represented by the state invariant. A stereotype named *AdviceExecutionType* is used to determine when the sequence of messages will be performed: before, around or after the triggering of a pointcut. This stereotype extends (*StateInvariant*) and can be viewed in the bottom left of the figure 1.

The connection between advice and pointcuts can be better understood in the example of the figure 5. This figure shows the pointcut previously specified to capture any method call on any class with any numbers of parameters (*AnyCall*). The log aspect defines a crosscutting model that logs a message using a *Logger*. The crosscutting model is described as a sequence of messages in a sequence diagram. This diagram contains a state invariant that refers to the *AnyCall* pointcut. A state invariant must have the advice execution type set as a tagged value to specify when the advice behavior will be executed. In this example, the advice behavior will be executed *after* the execution points captured by the *AnyCall* pointcut. The message *log()* will be executed only when the state *AnyCall* is achieved.

3 AspectJ Pointcut Modeling

This section shows the modeling of the most important pointcuts of the AspectJ language.

4 Composition and Visualization of Aspects

The profile is added to the SEA environment [?], which supports UML diagramming. The SEA/Aspect is a tool which allows the selection of which crosscutting

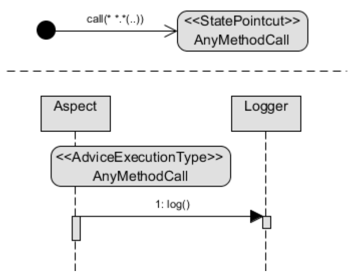


Fig. 5. The connection between pointcuts and advices using state invariants.

models will be intertwined together with the core models of the system. One can automatically visualize only the core models, the crosscutting models, or core intertwined with crosscutting models. Aspects can be enabled or disabled dynamically, by updating the compound model, with no effort demanded from the developer. This automatic updating allows the toggling of views, visualizing different model compositions.

The SEA/Aspect has two different phases to output a compound model: **selection** and **composition**. In the selection phase, the developer selects the core and crosscutting concerns to compose. One or more aspects can be composed at the same time. The composition phase uses wildcard matching and has the following steps:

– **Match:** Find the execution points of the core model that are impacted by the crosscutting models. This information is obtained from the pointcuts defined in the crosscutting models. The algorithm is separated in three steps:
  1. **Find the pointcut:** To obtain the pointcut from the crosscutting sequence diagram (crosscutting model), the algorithm looks for state invariants stereotyped as *AdviceExecutionType*. This state invariants maps to the state that defines the pointcut.
  2. **Separate the pointcut:** The composer uses a regular expression to separate a pointcut in four parts: **pointcut type**, **return type pattern**, **identification pattern** and **exception pattern**. The pointcut type is mandatory and is one of the types supported by the AspectJ language, which includes *execution*, *call*, *this* and others. The return type pattern is optional and specifies the return type of the pointcut. The identification pattern is mandatory and contains the signature to be matched in the core model. Finally, the exception pattern is optional too, and is used to capture execution points that throws exceptions of a given type
  3. **Match the execution points:** This step starts using the identification pattern to find the context information about the impacted concepts, like package and class context of a given method, for example. When all concepts inside a given context are captured, the algorithm uses another regular expression to match the names of the captured concepts. For

instance, when matching a method, the algorithm check return type, parameters (name, type and number of parameters) and the method signature. Finally, the composer check for exception throws, if any. As output, the concepts (classes and methods) impacted by the crosscutting models are stored to be used in the merge activity.

– **Merge:** Merge concepts of the crosscutting models with the impacted core model concepts. The merge receives as input the impacted core model concepts that should be merged with croscutting ones. The merge purpose is to inject a set of messages, lifelines, combined fragments and other sequence diagram concepts in the core sequence diagram (core model), adding new behavior defined in the crosscutting sequence diagrams (crosscutting models). To achieve this, the algorithm is separated in two steps:
    1. **Find the advice type:** Retrieve the advice type from the state invariant defined by the crosscutting model. The supported advice types are: *before*, *around* and *after*. The advice type gives the information of when the messages should be injected in the core sequence diagram.
    2. **Inject the messages:** At this time, the algorithm knows the impacted concepts, the messages to inject from the crosscutting model and when the messages should be inserted. The next step is the messages injection and reordering, because the injection of a message triggers a reordering event in the sequence diagram. With all the messages injected and ordered, the composer paints each message name with the correspondent crosscutting model color, to differentiate which message comes from which aspect. The merge produces as output a compound sequence diagram with the crosscutting concepts composed in the core sequence diagram.

5 Case Study

This section presents a case study to assess the applicability of the proposed approach in the modeling of an application. The case study is based in the Hotel Management System extracted from Jacobson's book [?]. This example allows the modeling of important aspect-oriented funcionalities and is consolidated in the literature. The Hotel Management System is composed by a set of use cases, like the check in and check out of customers, reservation of rooms, handling of a waiting list and a loyalty program that allows the user to earn and redeem points.

The concerns represented in this case study are the following:

– Check Out Customer: After the stay, the customer pays the bill and check out from the hotel.
– Earn Loyalty Points: The customer earns loyalty points after paying the bill.

The first concern being modeled is the reserve room functionality, that is a system core concern and can be viewed in the figure 6. As this is a core concern,

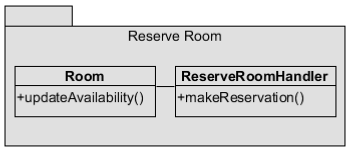


Fig. 6. Case Study: Reserve Room Structural Model.

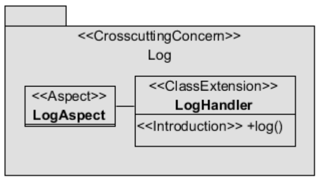


Fig. 7. Case Study: Log Structural Model.

it doesn't contains aspects neither class extensions, only classes to implement the concern. It has the class *Room* with the method *updateAvailability()* and the class *ReserveRoomHandler* with the method *makeReservation()*. The crosscutting concern to log how many requests were done to a *Room* is modeled in the figure 7. It defines the *LogAspect* and one class extension named *LogHandler*, that

Finally, we have the crosscutting concern to handle waiting list in the figure 8. The structural model of this concern defines the *WaitingListAspect* and three class extensions (with some introductions). The first one is the *WaitingListHandler*, that is the controller between the system and the waiting list, the second adds methods to the *Reservation* class to create reservations and the later is the *WaitingList*, that contains the pending reservations.

The models presented until now represents only the structure of the concerns, which is not sufficient to understand the system as a whole. We need to represent the system's dynamic too. Sequence diagrams are used to represent the behavior of core and crosscutting concerns, using the profile and the process proposed by this approach. The modeling of concerns using behavioral diagrams gives subsidies to achieve the toogling of views, that allows better understanding of aspect-oriented applications, visualizing the effect of the aspects in the system.

We start with the sequence diagram of the reserve room concern, that can be viewed in the figure 10. In a room reservatiom, if the room isn't available, an exception is raised in the method *updateAvailability()*, otherwise, the reservation is done and the customer receives a confirmation code.

The other concerns to be modeled are the crosscutting concerns, that contains pointcuts and advices. The log concern needs to account the number of requests to a room. To achieve this, we define a pointcut that captures the calls to the *Room* class. This pointcut is modeled using the state machine diagram and can be viewed in the figure 11.

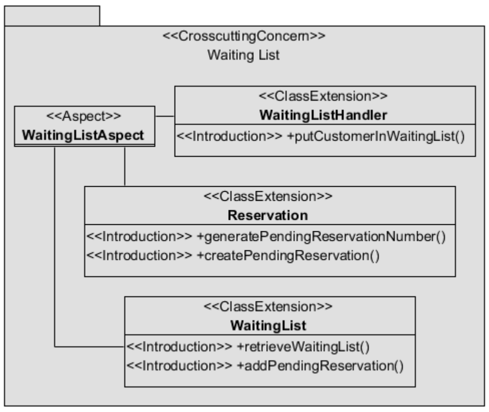

<<CrosscuttingConcern>>
Waiting List
<<Aspect>>
WaitingListAspect
<<ClassExtension>>
WaitingListHandler
<<Introduction>> +putCustomerInWaitingList()
<<ClassExtension>>
Reservation
<<Introduction>> +generatePendingReservationNumber()
<<Introduction>> +createPendingReservation()
<<ClassExtension>>
WaitingList
<<Introduction>> +retrieveWaitingList()
<<Introduction>> +addPendingReservation()

Fig. 8. Case Study: Waiting List Structural Model.

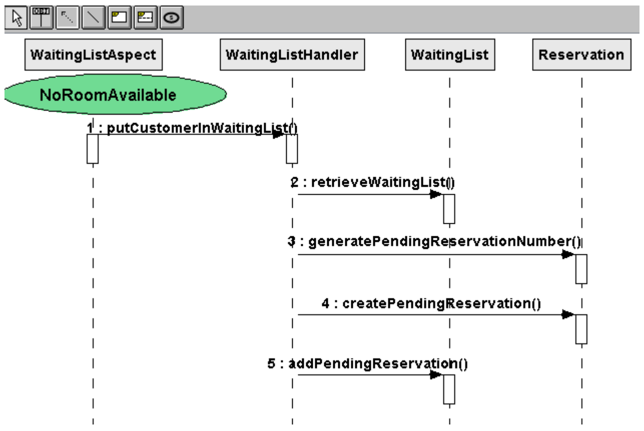

WaitingListAspect
WaitingListHandler
WaitingList
Reservation
NoRoomAvailable
1 : putCustomerInWaitingList()
2 : retrieveWaitingList()
3 : generatePendingReservationNumber()
4 : createPendingReservation()
5 : addPendingReservation()

Fig. 9. Case Study: Waiting List Sequence Diagram.

With the pointcut defined, we create the sequence diagram to the log concern. The diagram can be view in the figure 13 and contains as the first lifeline the *LogAspect*. Accordingly to the proposed approach, an aspect in the sequence diagram must have a state invariant associated, which is the trigger to execute the sequence of messages. In this case, the state invariant *RoomCall* is associated with the *LogAspect* and points to a pointcut previously defined in the state machine diagram. The semantics here is that the sequence of messages will execute only when the pointcut is satisfied. The message to be executed when the pointcut is satisfied is a call to the method *log()* of the *Logger* class. It is important to be aware of the advice execution type, that is defined as a tagged value in the state invariant. The proposed approach supports three types of advice types: before, after or around. In this case, the advice type is after, which means that the log behavior will execute after any method call to the *Room* class. The sequence

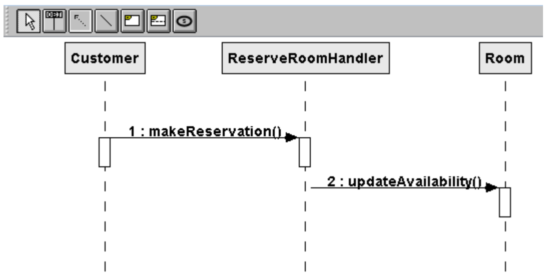


Fig. 10. Case Study: Reserve Room Behavioral Model.

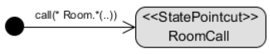


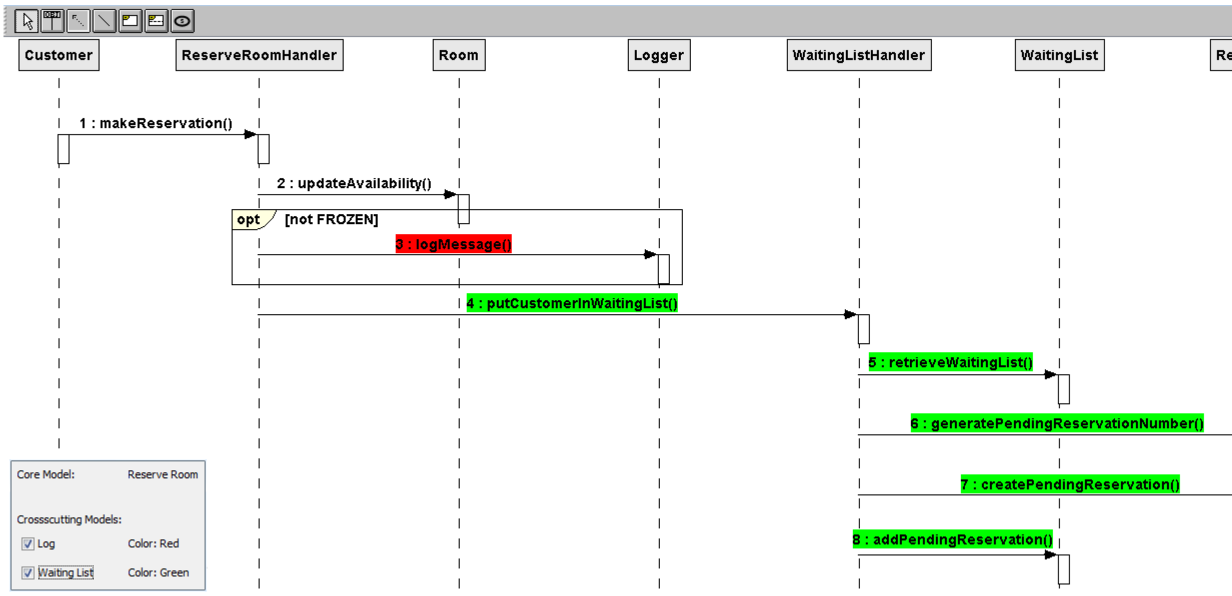
Fig. 11. Case Study: Log Pointcut Definition.

diagram contains a combined fragment of type optional, that defines that the log only will be performed if the application is not frozen. An application is not frozen when it is running in the development environment.

The last concern to be modeled is the waiting list, that adds the customer to a waiting list when a room isn't available. To achieve this, we need a pointcut that captures when a customer try to reserve a room without success, because it is unavailable. The pointcut in the figure 14 captures calls to the method *updateAvailability()* of the *Room* class, raising the *NoRoomsAvailable* exception.

Besides the pointcut definition, we need to define the behavior of how a customer is added to the waiting list. This behavior is modeled in the sequence diagram of the figure 9. The diagram has the *WaitingListAspect* as the first lifeline and has a sequence of messages to be executed when the system raises an exception that no rooms are available. These messages will be executed after the exception raising, because the advice execution type of the state invariant is after.

After the structural and behavioral modeling of all the core and crosscutting concerns, the modeler may interchange the model views, selecting which concerns he wants to see composed in the same diagram. The SEA/Aspect tool allows the selection of more than one model to be composed at the same time. The figure 12 shows a compound model, with the concerns of reserve room, log and waiting list composed together. The compound diagram shows the model selector in it is right bottom, that allows changing the models that are being show. The messages of different concerns are painted with different colors, as each concern has a color associated with it. This is useful to differentiate which messages comes from which aspect in the compound model.


Customer
ReserveRoomHandler
Room
Logger
WaitingListHandler
WaitingList
Re
1 : makeReservation()
2 : updateAvailability()
opt
[not FROZEN]
3 : logMessage()
4 : putCustomerInWaitingList()
5 : retrieveWaitingList()
6 : generatePendingReservationNumber()
7 : createPendingReservation()
8 : addPendingReservation()

Core Model: Reserve Room

Crossscutting Models:

✓ Log	Color: Red
✓ Waiting List	Color: Green

Fig. 12. Case Study: Reserve Room composed with Log and Waiting List.

6 Conclusion

This work has proposed an approach to model aspect-oriented systems using UML, with a specific profile that allows to implement an aspect visualizer in the SEA environment. The SEA/Aspect tool performs the composition between core and crosscutting models automatically, allowing the visualization of the aspect dynamics in a system.

The main advantages of the proposed approach in relation to the others are: the representation of all the characteristics of AOP, like the capture of multiple join points with the representation of the aspect behavior; the definition of a profile within the UML standards, which can be added in any CASE tool and the

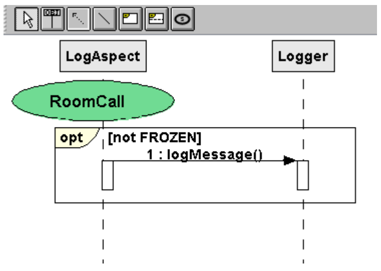


Fig. 13. Case Study: Log Sequence Diagram.

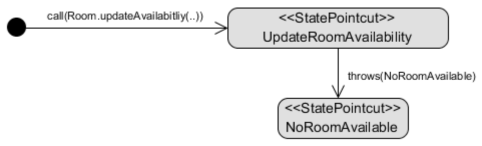


Fig. 14. Case Study Waiting List Pointcut Definition.

composition and automatic visualization of the effect of the aspects in the core models in the SEA environment, facilitating the understanding and maintenance of aspect-oriented systems.