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# Aspect Model Unweaving <sup>★</sup>

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**Abstract.** Since software systems need to be continuously available, their ability to evolve at runtime is a key issue. The emergence of models@runtime, combined with Aspect-Oriented Modeling techniques, is a promising approach to tame the complexity of adaptive systems. However, with no support for aspect unweaving, these approaches are not agile enough in an adaptive system context. In case of small modifications, the adapted model has to be generated by again weaving all the aspects, even those unchanged. This paper shows how aspects can be unwoven, based on a precise traceability metamodel dedicated to aspect model weaving. We analyze traceability models, which describe how aspects were woven into a base, to determine the extent to which an aspect has affected the woven model in order to determine how it can be unwoven. Aspect unweaving is finally performed by applying inverse operations of a sub-sequence of the weaving operations in opposite order.

## 1 Introduction

Since software systems need to be continuously available, their ability to evolve at runtime is a key issue. A very promising approach is to implement such systems as Dynamically Adaptive Systems (DAS), including self-adaptation and dynamic evolution facilities. Modern execution platforms like Fractal [1], OpenCOM [2] or OSGi [3] propose low-level APIs to reconfigure (add/remove/update components, add/remove bindings, etc) a system at runtime. However, with no higher level support, reconfiguration rapidly becomes a daunting and error-prone task to specify, validate, implement and understand. Indeed, implementing a reconfiguration script consists in identifying the components and bindings involved in the reconfiguration, and writing the whole sequence of atomic actions in a correct order. It is really difficult to validate the effect of such a script before actually executing it, detect dependencies or interactions between different scripts, etc.

Recently, some approaches [4,5] use Model-Driven Engineering (MDE) and Aspect-Oriented Modeling (AOM) techniques at runtime (*models@runtime* [6]) to tame the complexity of DAS. Keeping a model synchronized with the running system offers a high-level support for reasoning about the system [4] before actual adaptation. The first step of the dynamic adaptation process consists in selecting, according to the context, the most adapted architectural model. Then,

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after validation of the model, the running system is automatically adapted by analyzing the selected model. This prevents the designer from writing low-level platform-specific reconfiguration scripts by hand.

However, AOM approaches and tools [7,8,9,10,11] were formerly designed to operate at design-time, where performance (especially time) issues are not so critical. The key problem of current AOM weavers is that in case of small modifications, the adapted model has to be generated by again weaving all the aspects, even those unchanged. In other words, if the configuration is currently composed of  $n$  aspects, and if one of them should be “unwoven” (because of a change in the context), we have to restart from a core base model (containing the mandatory elements) and weave the  $n - 1$  unchanged aspects. More precisely, this means that we should detect the join points of the  $n - 1$  aspects, matching their associated pointcut model, and weave these aspects. The weaving process itself is efficient: it simply consists in adding or removing some model element and setting attributes and references. However, the join point detection step is more complex: for example, it can rely on graph theory to match sub-graphs in a graph, or rely on Prolog (logic programming) back-end [12] to execute queries on a fact base. In the second case, this requires to transform back and forth the base model, its metamodel (fact) and the pointcut (query) into Prolog artifacts, before actually executing the query. With no real support for aspect unweaving, AOM is not agile enough in an adaptive system context.

This paper shows how aspects can be unwoven, based on a precise traceability metamodel dedicated to aspect model weaving. We analyze traceability models, which describe how aspects were woven into a base, to determine the extent to which an aspect has affected the woven model in order to determine how it can be unwoven. Aspect unweaving is finally performed by applying inverse operations of a sub-sequence of the weaving operations in opposite order.

The remainder of the paper is organized as follows. Section 2 presents an overview of the existing approaches used in this paper. Section 3 introduces essential definitions on the unweaving of aspect models. Section 4 describes a traceability metamodel for aspect model weaving, and shows how a traceability model can be exploited. The main section of this paper is Section 5 which details our unweaving method. Finally, Section 6 presents related work and Section 7 concludes this paper.

## 2 Background

This section presents first GeKo [13], a generic aspect model weaver, and then an operation-based model construction approach. The objective of this paper is to present how we combined GeKo with this approach to support the unweaving of aspect models.

### 2.1 GeKo: A Generic Aspect Model Weaver

GeKo [13] is a generic aspect-oriented model composition and weaving approach easily adaptable to any metamodel with no need to modify the domain metamodel or to generate domain specific frameworks. It keeps a graphical representation of the weaving between an aspect model and the base model. It is a tool-supported approach with a clear semantics of the different operators used to define the

weaving. The formalization of GeKo allows clearly identifying the sets of removed, added and altered elements.

In this sub-section, we introduce GeKo through an example of class diagram weaving, but GeKo can be used to weave other models such as state diagrams, sequence diagrams, feature diagrams, etc. . . Fig. 1 shows an example of weav-

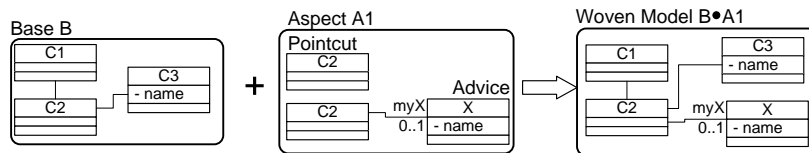


Fig. 1: Example of Class Diagram Weaving with GeKo

ing with GeKo. The result of the weaving of the advice class diagram into the base class diagram is shown in the *Woven Model* of Fig. 1. The weaving process is two-phased. The first step consists in the detection of the match points corresponding to the *Pointcut* diagram. This detection step uses a Prolog-based pattern matching engine which yields a mapping from the pointcut model to the base model for each detected join point. In Fig. 1, the detection yields a mapping from the class *C2* of the *Pointcut* model to the class *C2* of the *Base* model. The second step consists in the composition of the advice model with the base model at the level of the match points previously detected (for each match point the advice model is composed). The composition is based on the definition of a mapping between the pointcut and the base model (automatically obtained from the detection step), and a mapping between the pointcut and the advice model (specified by the user). These mappings are defined over the concrete syntax of models by linking model elements. These links are fully generic and do not use any domain-specific knowledge, so that we can define mappings for any domain metamodel. These mappings allow the identification of several sub-sets of objects in the base and advice models characterizing the objects of *base* which have to be kept, to be removed and to be replaced with those of *advice*. Note that in the remainder of the paper, when the mapping between the pointcut and the advice model is obvious, we will omit to specify it.

## 2.2 Operation-Based Model Construction

In [14], the authors proposed to use a sequence of model construction operations to check consistency rules. In our paper, we present an approach which allows the generation the sequence of construction operation corresponding to the weaving of a sequence of aspects  $A_1, A_2, \dots, A_n$  in a base model  $B$ . Consequently, similar to [14], we can use the generated sequence of operations to check consistency rules, but in this paper, we will rather use the operation-based approach to efficiently unweave an aspect from a woven model.

More specifically, in [14] the authors propose to represent models by sequences of elementary construction operations, rather than by the set of model elements they contain. They propose four elementary operations inspired from the *MOF* reflective API [15] : 1) *create(me,mc)* corresponds to the creation of a model element instance *me* of the meta-class *mc*; 2) *delete(me)* corresponds to the deletion of the model element instance *me*; 3) *setProperty(me,p,Values)* corresponds to

the assignment of a set of *Values* to the property  $p$  of the model element  $me$ ; 4)  $setReference(me, r, References)$  corresponds to the assignment of *References* to the reference  $r$  of the model element  $me$ .

### 3 Unweaving Definitions

#### The *weave* Operation:

Let  $mp$  be a match point corresponding to pointcut of an aspect  $A_i$  and a base model  $B$ , i.e.,  $mp$  is a place in  $B$  where the pattern defined by the pointcut model in  $A_i$  matches. The weaving of  $A_i$  in  $B$  at the level of  $mp$  can be defined by a sequence of construction operations:

$$weave(A_i, mp) = \sigma_{mp,1}^i \bullet \sigma_{mp,2}^i \bullet \dots \bullet \sigma_{mp,k}^i$$

Fig. 1 shows a weaving example with class diagrams. Since there is only one match point  $mp$  at which the pointcut of  $A_1$  matches, the sequence of construction operation to implement the weaving of  $A_1$  is:

$$\begin{aligned} weave(A_1, mp) = & create(X, EClass) \bullet setProperty(X, name, \{X\}) \bullet \\ & create(nameAtt, EAttribute) \bullet setProperty(nameAtt, name, \{"name"\}) \bullet \\ & setReference(X, EAttribute, \{nameAtt\}) \bullet create(ref, EReference) \bullet \\ & setProperty(ref, name, \{"myX"\}) \bullet setProperty(ref, EType, \{X\}) \bullet \\ & setReference(C2, EReference, \{ref\}) \end{aligned}$$

If  $A_i$  matches  $B$   $h$  times, the weaving of the aspect  $A_i$  into  $B$  can be defined by the sequence of construction operations:

$$\begin{aligned} weave(A_i) = & weave(A_i, mp_1) \bullet weave(A_i, mp_2) \bullet \dots \bullet weave(A_i, mp_h) \\ = & \sigma_{mp_1,1}^i \bullet \dots \bullet \sigma_{mp_1,k}^i \bullet \sigma_{mp_2,1}^i \bullet \dots \bullet \sigma_{mp_2,k}^i \bullet \dots \bullet \sigma_{mp_h,1}^i \bullet \dots \bullet \sigma_{mp_h,k}^i \end{aligned}$$

The weaving of a sequence of aspects  $A_1, A_2, \dots, A_n$  is defined by:

$$weave(A_1, A_2, \dots, A_n) = weave(A_1) \bullet weave(A_2) \bullet \dots \bullet weave(A_n)$$

#### Undoing a weave operation:

For an aspect  $A_i$  and a match point  $mp$ , we define the *undo* operation  $undo(A_i, mp)$  as the execution, in opposite order, of the sequence of *inverse* construction operations of the construction operations of  $weave(A_i, mp)$ . More formally,

$$undo(A_i, mp) = undo(\sigma_{mp,1}^i \bullet \sigma_{mp,2}^i \bullet \dots \bullet \sigma_{mp,k}^i) = inverse(\sigma_{mp,k}^i) \bullet inverse(\sigma_{mp,k-1}^i) \bullet \dots \bullet inverse(\sigma_{mp,1}^i), \text{ where:}$$

$\sigma_{mp,j}$	$inverse(\sigma_{mp,j})$
$create(me, mc)$	$delete(me)$
$delete(me)$	$create(me, mc)$ (in practice, $mc$ is easily obtained from the sequence of construction operations)
$setProperty(me, p, value)$	if $\exists setProperty(me, p, value') \in weave(A_{k,k < i})$ then $setProperty(me, p, value')$ else $setProperty(me, p, \emptyset)$
$setReference(me, r, ref)$	if $\exists setReference(me, r, ref') \in weave(A_{k,k < i})$ then $setReference(me, r, ref')$ , else $setReference(me, r, \emptyset)$

If we note  $mp_k, k \in \{1, \dots, h\}$  the match points corresponding to the weaving of an aspect  $A_i$  in a base  $B$ , we can extend the notion of *undo* to all the match points by:

$$undo(A_i) = undo(A_i, mp_h) \bullet undo(A_i, mp_{h-1}) \bullet \dots \bullet undo(A_i, mp_1)$$

#### Unweaving:

Let  $A_1, A_2, \dots, A_n$  be a sequence of aspects that have been woven into a base model  $B$  to result in a woven model  $BW$ . Unweaving of an aspect  $A_i$  from  $BW$  should

result in a model that is equivalent to the model obtained by starting again with the base model  $B$  and weaving all aspects into  $B$  again in the same order, but omitting  $A_i$ . More formally,  $\forall i \in \{1, \dots, n\}$ ,

$$unweaving(A_i) = \begin{cases} weave(A_2, A_3, \dots, A_n) & i = 1 \\ weave(A_1, A_2, \dots, A_{i-1}, A_{i+1}, \dots, A_n) & 1 < i < n \\ weave(A_1, A_2, \dots, A_{n-1}) & i = n \end{cases}$$

## 4 Aspect Traceability Metamodel

### 4.1 Traceability Metamodel for GeKo

Weaving in GeKo is asymmetric, i.e., the weaving process is performed by applying a set of operations on a *base model*<sup>4</sup>. During the model weaving process, to compose an advice model with a base model, GeKo can: (1) *Remove* a model element from the base model; (2) *Add* a model element to the base model. The added model element is defined in the aspect’s advice model; (3) *Replace* a model element of the base model by a model element of the aspect’s advice model. This *replace* operation can be considered as a sequence of *remove* and *add* operations (remove the replaced element and add the element which replaces it); (4) *Update* the *properties* of a base model element (e.g. change the name of a model element); (5) *Update* the *references* that a base model element has towards other model elements.

We propose to keep a trace of the application of these operations as the weaving takes place. For this, we defined the traceability metamodel for aspect model weaving presented in Fig. 2. The *WovenAspectSequence* class is the root class of the metamodel presented in Fig. 2. It contains a sequence of *AspectWeaving*. An *AspectWeaving* references a *Base*, a *Result* and an *Aspect* model. An *Aspect* model is composed of a *Pointcut* and an *Advice* model. All these models are defined by a list of *ModelElements*. The *AspectWeaving* class is also associated with a list of *PointcutMatches*. Each *PointcutMatch* stores the list of base model elements that were used to obtain this particular match when matching the pointcut of the aspect model to the base model. Each of the referenced base model elements is essential, i.e., if only one were omitted, the pointcut model would not match the base anymore. Finally, the class *PointcutMatch* also stores the effects of the weaving of the advice model of the aspect at this particular match point. *PointcutMatch* is associated with a sequence of *ConstructionOperations*. There are five types of possible operations corresponding to the five GeKo operations: *Replace*, *Remove*, *Add*, *UpdateReference*, *UpdateProperty*.

### 4.2 Using the Traceability Model

Once a sequence of aspects  $A_1, A_2, \dots, A_n$  is woven with a base model  $B$  to produce a woven model  $BW$ , the information stored in the traceability model contains the complete trace of operations that transformed  $B$  into  $BW$ . To re-execute the

<sup>4</sup> Since aspects can be applied to other aspects, the GeKo base model can, of course, be any model, even an advice model of some other aspect.

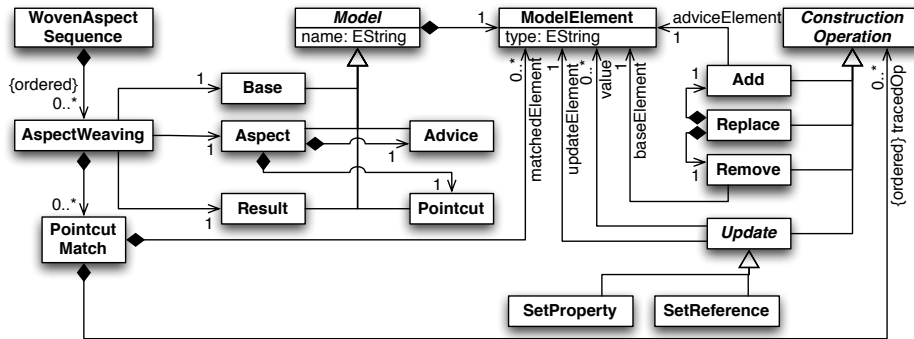


Fig. 2: Traceability Metamodel

weaving, it suffices to start with  $B$ , and execute the associated sequence of elementary construction operations, which can be easily obtained by concatenating the sequence of  $tracedOp$  for each aspect weaving and for each associated match point. This sequence of construction operations is used in the algorithms presented in the next section.<sup>5</sup>

The traceability model can also be used to determine the *impact* that the weaving of an advice model at a match point had on the final woven model. We define the impact of a match point of the pointcut model in  $A_i$  as all the model elements in the final woven model that were directly or indirectly changed because of the weaving of the advice model of  $A_i$  at the match point.

For instance, if an aspect  $A_i$  adds a model element, then this model element might be used in a match point of a following aspect  $A_{k,k>i}$ , which again triggers the weaving of the advice model of  $A_k$ . Hence, the impact of weaving the advice model of  $A_i$  is not limited to the changes specified in the advice model of  $A_i$ , but also includes the changes specified in the advice model of  $A_k$ . The same reasoning can be applied to  $A_k$  as well, and hence the impact of a weaving of  $A_i$  at a match point can potentially include changes in all advice models of aspects  $A_{k,k>i}$ .

To determine the impact of a pointcut match, not only *Add* operations have to be considered. *SetReference* and *SetProperty* operations can also result in the creation of a match point of subsequent aspects  $A_{k,k>i}$ . For instance, the *SetProperty* operation can be used by an aspect  $A_1$  to change the value of the *balance* field of an object to 200. A following aspect  $A_2$  might declare a pointcut which matches for all objects that have a *balance* attribute with a value  $\geq 100$ . In this case, the impact of  $A_1$  should only include the changes specified in the advice model of  $A_2$  if the previous value of *balance*, i.e., the value that *balance* had *before* weaving  $A_1$ , was  $< 100$ . The detailed algorithm that calculates the impact of a match point  $mp$  of an aspect  $A_i$  is shown in Alg. 1.

## 5 Using the Traceability Model for Unweaving of Aspects

This section presents the core contribution of our paper. It shows how the tracing information gathered during the model weaving (see section 4) can be used to unweave aspects from a woven model in an efficient way.

<sup>5</sup> Note that the construction operations defined in the traceability metamodel are implemented using the MOF primitives presented in subsection 2.2.

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**Algorithm 1:**  $Impact(A_i, mp)$ 

---

**Input:** the aspect  $A_i$ , the match point  $mp$ , the traceability model corresponding to the weaving of the aspects  $A_1, A_2, \dots, A_n$  in a base model  $B$   
**Output:** the set of pairs  $(A_k, mp')$  where the match point  $mp'$  of the aspect  $A_{k,k>i}$  is impacted by the weaving of  $A_i$  at the match point  $mp$

```
k ← i + 1
while k ≤ n do
  foreach operation σ ∈ weave(A_i, mp) do
    foreach match point mp' of A_k do
      if σ == add(elt, eltType) and elt is shared with mp' then
        | impact ← impact ∪ (A_k, mp')
      end
      if σ == setReference(elt, ref, {eltList}) and elt and ref are shared
        with mp' and the previous set of values for the reference ref is not
        included in the set of values for the reference ref of elt of the
        pointcut of A_k then
        | impact ← impact ∪ (A_k, mp')
      end
    end
  end
  k ← k + 1
end
```

---

Let  $A_1, A_2, \dots, A_n$  be a sequence of aspects woven into a base model  $B$  resulting in a woven model  $BW$ . As presented in the definitions section, unweaving an aspect from  $BW$  is equivalent to re-weaving all aspects  $A_1 \dots A_n$  into  $B$  except for  $A_i$ . Re-weaving is, however, very inefficient. Not only does the tool have to re-execute all construction operations defined by the  $n - 1$  advice models of the aspects  $A_{j,j \neq i}$ , but it also has to re-execute the pattern matching algorithm that searches for match points based on the patterns defined in the  $n - 1$  pointcut models.

The technique presented in this paper allows a tool to unweave an aspect  $A_i$  from  $BW$  without having to re-weave all the aspects  $A_{j,j \neq i}$  into  $B$ . Depending on the nature of the relation between the aspect  $A_i$  and the aspects  $A_{k,k>i}$  that were woven into the base model after  $A_i$ , unweaving  $A_i$  is more or less complicated. In the following discussion, we distinguish 3 different cases. At this point, the reader is reminded that our solution is based on the use of the generic weaver called GeKo, which performs aspect weaving using the operations 1) *add* model element, 2) *remove* of a model element, 3) *replace* model element (which can be seen as a remove followed by an add), 4) *set property*, and 5) *set reference*.

### 5.1 Case 1, Independent Aspects:

*Informal description:* In the most advantageous case,  $A_i$  is independent of the aspects  $A_{k,k>i}$  that were woven after  $A_i$  to obtain  $BW$ . This situation occurs when  $A_i$  neither introduced model elements which were used in a match point of one of the aspects  $A_{k,k>i}$ , nor removed model elements which could have formed a match point for a  $A_{k,k>i}$ , nor changed any properties or references that were used or could have been used in a match point of one of the aspects  $A_{k,k>i}$ .



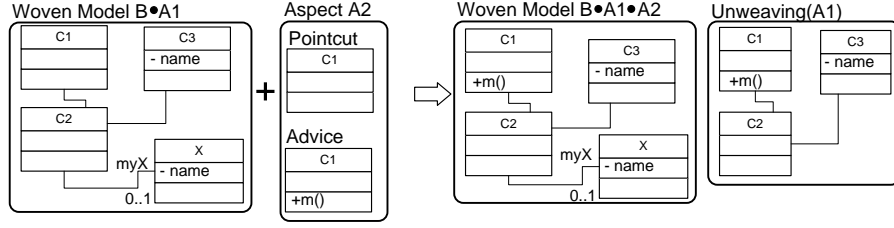


Fig. 3: Weaving of  $A_2$  and Unweaving of  $A_1$  (previously presented in Fig. 1)

Fig. 3 shows an example illustrating this case. The example presents the weaving of an aspect  $A_2$  into the model obtained after the weaving of the aspect  $A_1$  already presented in Fig. 1. The resulting model is  $B \bullet A_1 \bullet A_2$ . In this example,  $A_1$  is independent from  $A_2$ , because the model elements introduced (the class  $X$ ) and the changes to model elements (adding of the reference to  $C2$ ) are not part of the match point of  $A_2$  (which matches on the class  $C1$ ). Also,  $A_1$  does not remove any model elements from  $B$ .

*Unweaving of Independent Aspects:* Unweaving of aspect  $A_i$  simply consists in undoing the weave operation, i.e., in applying, for each match point, the inverse construction operations in opposite order of the construction sequence defined by  $weave(A_i, jp)$ . More formally:

If match point  $mp$  of  $A_i$  is independent of  $A_{k,k>i}$ :  $unweave(A_i, mp) = undo(A_i, mp)$   
 $\Rightarrow$  If  $A_i$  independent of  $A_{k,k>i}$ :  $unweave(A_i) = undo(A_i) = \forall mp_{A_i} : undo(A_i, mp)$ .  
Therefore, in Fig. 3, the unweaving of  $A_1$  consists in applying  $undo(A_1)$ , i.e., applying inverse operations in opposite order of the construction sequence  $weave(A_1)$ .

$unweave(A_1) = undo(A_1) = setReference(C2, EReference, \emptyset) \bullet$   
 $setProperty(ref, EType, \emptyset) \bullet setProperty(ref, name, \emptyset) \bullet delete(ref) \bullet$   
 $setReference(X, EAttribute, \emptyset) \bullet setProperty(nameAtt, name, \emptyset) \bullet$   
 $delete(nameAtt, \emptyset) \bullet setProperty(X, name, \emptyset) \bullet delete(X)$

## 5.2 Case 2, General Aspects:

*Informal description:* In the worst case, when the weaving of an aspect  $A_i$  removes or changes model elements in the base model, it is possible that these elements could have been used to form a match point of an aspect  $A_{k,k>i}$ . As a result, the unweaving of the aspect  $A_i$  could introduce completely new match points for the following aspects  $A_{k,k>i}$ . In this case, the unweaving of  $A_i$  cannot be done by simply applying a sequence of undo operations. Unfortunately, the pattern matching operation that detects match points corresponding to the pointcut models in the aspects  $A_{k,k>i}$  has to be launched again.

Fig. 4 shows an example of Final State Machine (FSM) weaving illustrating this case. The example presents the successive weaving of the aspect  $A_1$  and  $A_2$  into the base model  $B$ . The resulting model is  $B \bullet A_1 \bullet A_2$ . The weaving of aspect  $A_1$  consists in replacing the state  $c$  by a state  $e$  and by removing the state  $a$ . The weaving of aspect  $A_2$  consists in replacing the state  $a$  by a state  $b$  with a loop transition. After the weaving of  $A_1$ ,  $A_2$  matches only once, but without  $A_1$ , the pointcut of  $A_2$  would also match against the first  $a$  state that was removed when

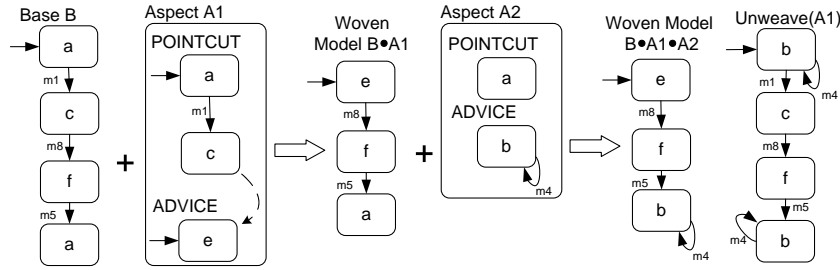


Fig. 4: Weaving of  $A_1$  and  $A_2$  into  $B$ , and Result of the Unweaving of  $A_1$

$A_1$  was woven. This example shows that the only solution to unweave  $A_1$  is first to unweave  $A_2$ , then to unweave  $A_1$  and finally to weave  $A_2$  again.

*Unweaving General Aspect  $A_i$ :* To unweave a general aspect  $A_i$  the idea is to first compute index  $j > i$  such that  $A_i$  is not general for the aspects  $A_{h,i \leq h < j}$ . The second step consists in unweaving of the aspects  $A_{k,k \geq j}$  in the opposite order of the sequence of weaving, i.e.,  $A_n$  first, then  $A_{n-1}, \dots, A_j$ . For these unweavings, since the aspect unwoven is always the last aspect that had been woven, the unweaving operation corresponds to the *undo* operation. The next step is to unweave  $A_i$ . The final step consists in weaving of the aspects  $A_{k,k \geq j}$  in the same order as the initial sequence of weaving.

Depending on the value of  $i$  and  $j$ , it might be faster to start from scratch, i.e., start with  $B$  and re-execute the weave operations of the aspects  $A_1 \dots A_{i-1}$  stored in the traceability model rather than to unweave aspects  $A_j \dots A_n$  and  $A_i$ . The cut off values of  $i$  and  $j$  at which it is better to re-weave than to unweave depends heavily on the number of match points of each aspect, and the number of construction operations needed to implement the weaving of each match point. If the length of the sequence of construction operations for weaving aspects  $A_1 \dots A_{i-1}$  is smaller than the length of the sequence of operations for weaving  $A_i, A_j \dots A_n$ , then re-weaving is more efficient than unweaving.

### 5.3 Case 3: Additive Aspects

*Informal description:* Some aspects  $A_i$  are not general, i.e., they did not remove or alter elements which could have been used in a match point of a following aspect  $A_{k,k > i}$ , but are also not independent, because they added or changed model elements which were later on used in a match point of at least one of the  $A_{k,k > i}$ . We call these *additive* aspects.

Fig. 5 presents an example of this case.  $A_1$  introduces a message  $m4$  from  $O2$  to  $O3$  after an exchange of messages  $m1, m2$  between  $O1$  and  $O2$ .  $A_2$  introduces an message  $m5$  after any message  $m4$ . If we consider the sequence of weaving  $A_1 \bullet A_2$  as shown in Fig. 5,  $A_1$  is clearly an additive aspect. The message  $m4$  introduced by  $A_1$  is matched by the pointcut model of aspect  $A_2$  and hence creates a match point. Also,  $A_1$  does not remove any model elements.

*Unweaving of Additive Aspects:* In the case of an additive aspect  $A_i$ , the unweaving of the aspect does not simply consist in undoing the weave operation of  $A_i$  as for the case of independent aspects, because some elements added by the weaving of  $A_i$  have been used to form match points of aspects  $A_{k,k > i}$ , and hence

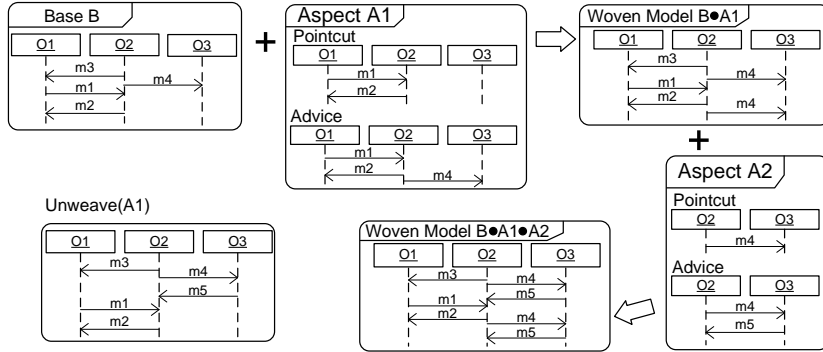


Fig. 5: Weaving of  $A_1$  and  $A_2$  into  $B$ , and Result of the Unweaving of  $A_1$

resulted in further changes to the model. Therefore, the unweaving operation has to also undo the weaving of all advice of aspects  $A_{k,k>i}$  that were woven because of a pointcut match that contained elements that  $A_i$  added or changed.

Let us consider the example of Fig. 5. To unweave the aspect  $A_1$ , we have to remove both the operations directly related to the weaving of  $A_1$  (i.e., the introduction of a message  $m4$ ) and the operations related to the match point of  $A_2$  formed by elements introduced by  $A_1$ . In Fig. 5, the pointcut model of  $A_2$  matched twice in the model  $B \bullet A_1$ , once on each message  $m4$ . However, only the second match is due to  $A_1$ , and therefore only the second introduction of a new message  $m5$  has to be undone.

More formally, to unweave an aspect  $A_i$ , we apply the algorithm described in Alg. 2 for all the match points of  $A_i$ . It describes that, to unweave an additive aspect  $A_i$ , we have to also recursively unweave the *impacted* match points of aspects  $A_{k,k>i}$ . These impacted match points can, of course, be of any type, i.e., independent, additive, or general.

#### 5.4 Classification of Aspects

This section presents how our tool classifies a match point of an aspect into one of the 3 cases described above, followed by the complete algorithm of classification.

*Conditions for Detecting General Aspects:* To determine if  $mp$  of  $A_i$  is *general*, we must check if  $A_i$  modified or removed model elements that could have created a match point for one of the pointcuts of one of the following aspects  $A_{k,k>i}$ . Note that when the advice model in  $A_i$  *removes* an element which corresponds to an element of a match point of an aspect  $A_{k,k>i}$ ,  $mp$  is immediately classified as general. However, as specified in Algorithm 3, additional conditions have to be respected in the case where  $A_i$  only modifies (with *setReference* or *setProperty*) an element which corresponds to an element of a pointcut of an aspect  $A_{k,k>i}$ . For instance, when  $A_i$  modifies the reference of an element  $elt$ , this modification cannot remove a match point if  $elt$  was previously added by  $A_i$ .

*Condition for Detecting Additive Aspects:* To determine if  $mp$  of  $A_i$  is *additive*, we check if  $A_i$  is not general and if  $A_i$  adds and modifies any model elements which are used to form a match point of a following aspect  $A_{k,k>i}$ . Note that when  $A_i$  *adds* an element used to form a match point  $mp'$  of an aspect  $A_{k,k>i}$ ,  $mp'$  cannot be a match point of  $A_k$  anymore when  $A_i$  is unwoven. However, when

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**Algorithm 2:**  $additiveUnweave(A_i, mp, A_{k,1 \leq k \leq n})$ 

---

**Input:** the aspect  $A_i$ , the additive match point  $mp$  to unweave, the traceability model corresponding to the weaving of the sequence of aspects  $A_1, A_2, \dots, A_n$  in a base model  $B$ . The sequence  $A_{k,1 \leq k \leq n}$  is such as there is no general match point  $mp'$  of an aspect  $A_j$  impacted by  $A_i$  or recursively by a match point of an aspect impacted by  $A_j$

**Output:** the sequence of unweaving operations  $\sigma$

$\sigma \leftarrow undo(A_i)$

Let  $impact$  be the set of model elements added or modified by the advice model of  $A_i$  when applied to  $mp$  (see Alg. 1)

$j \leftarrow i + 1$

**while**  $j \leq n$  **do**

**foreach** match point  $mp'$  of the aspect  $A_j$  **do**

        Let  $me$  be the set of model elements associated with the match point  $mp'$

**if**  $me \cap impact \neq \emptyset$  **then**

$\sigma \leftarrow unweave(A_j, mp') \bullet \sigma$

**end**

**end**

$j \leftarrow j + 1$

**end**

---

$A_i$  modifies an element that used to form a match point  $mp'$  of an aspect  $A_{k,k>i}$  (with *setReference* or *setProperty*),  $mp'$  can still be a match point even after  $A_i$  is unwoven. This is the case if the *previous* value of the property or reference being modified also resulted in the creation of the same match point.

*Condition for Detecting Independence:*  $mp$  of  $A_i$  is *independent*, if  $mp$  is neither general nor additive.

More formally, to classify the match point of an aspect  $A_i$  with respect to the following aspects  $A_{k,k>i}$ , we apply Alg. 3. Note that for space reasons, Alg. 3 does not show how to handle the *setProperty* operation, but the conditions are exactly the same as for the *setReference* operation. To extend this classification for a match point of  $A_i$  to the aspect  $A_i$  itself, we use the following rules: 1)  $A_i$  is general if for all match points of  $A_i$ , at least one match point is general; 2)  $A_i$  is additive if  $A_i$  is not general and at least one match point of  $A_i$  is additive; 3)  $A_i$  is independent if  $A_i$  is neither general nor additive.

## 5.5 Complete Unweaving Algorithm

To unweave  $A_i$ , the first step consists in the determination of the lowest index  $j \geq i$  of an aspect that contains a *general* match point  $mp$  that needs to be unwoven because of the unweaving of  $A_i$ . In other words,  $j$  is the index of the first aspect  $A_j$  in the sequence of aspects whose match point  $mp$  cannot be unwoven by applying a sequence of undo operations.

This is done by the *lowestGeneralIndex* algorithm presented in Alg. 4. This index is then used in the general unweaving algorithm presented in Alg. 5. The first foreach loop unweaves the general aspects. The *lowestGeneralIndex* allows us to ensure that for all unweaving operations in the second foreach loop (even

---

**Algorithm 3:** *classify*( $A_i, mp$ )

---

**Input:** the aspect  $A_i$ , the match point  $mp$ , the traceability model corresponding to the weaving of the sequence of aspects  $A_1, \dots, A_n$  in a base model  $B$

**Output:** Classification of the application of the advice model of  $A_i$  at the match point  $mp$  and the aspects  $A_{k,k>i}$

```
if  $i = i$  then
|  $mp$  is independent
else
| if  $\exists delete(elt) \in weave(A_i, mp)$  such as  $elt$  corresponds to a model element of
| a pointcut of  $A_{k,k>i}$  OR  $\exists setReference(elt, ref, \{eltList\}) \in weave(A_i, mp)$ 
| such that  $elt$  is shared with a match point of  $A_{k,k>i}$  and  $elt$  is an element not
| added by  $A_i$  and the previous set of values for the reference  $ref$  is not
| included in the set  $eltList$  then
| |  $mp$  is general
| else
| | if  $\exists add(elt, eltType) \in weave(A_i, mp)$  such as  $elt$  is shared with a match
| | point of  $A_{k,k>i}$  OR
| |  $\exists setReference(elt, ref, \{eltList\}) \in weave(A_i, mp)$  such as  $elt$  and  $ref$ 
| | are shared with a match point of  $A_{k,k>i}$  and the previous set of values for
| | the reference  $ref$  is not included in the set of values for the reference  $ref$ 
| | of  $elt$  of the match point of  $A_k$  then
| | |  $mp$  is additive
| | else
| | |  $mp$  is independent
| | end
| end
end
```

---

for the operations recursively called), the match point  $mp$  is either independent or additive, but never general. As a result, the unweaving operation consists in either the undo operation or the operation described in Alg. 2. Finally, the last for loop executes the necessary re-weaving, if any.

## 6 Related Work

Although the method described in this paper is applied in the context of the GeKo aspect model weaver, the same ideas can easily be generalized to other model weavers (such as [9,16,17,18]), once an appropriate traceability model is constructed.

In [17], the authors present an interesting way to modify models before and after their composition, by means of the use of a language of directives. This support is not automatized, but in our approach, the directive language could be used to apply the generated unweaving sequence of elementary operations.

To the best of our knowledge and belief, no Aspect-Oriented Modeling approach provides support for aspect model unweaving. At the platform level, however, some approaches provide support for weaving and unweaving.

FAC (Fractal Aspect Component) [19] is an open-source aspect-oriented extension to the Fractal component model [1]. It combines Component-Based Software

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**Algorithm 4:** *lowestGeneralIndex*( $A_i$ )

---

**Input:** the aspect  $A_i$ , the traceability model corresponding to the weaving of the sequence of aspects  $A_1, \dots, A_n$  in a base model  $B$   
**Output:** the *lowest index of a general aspect impacted by  $A_i$*   
Let  $j$  be the smallest index  $> i$  such that  $A_i$  is not general for the sequence of aspects  $A_{h, i \leq h < j}$   
 $lowestGeneralIndex \leftarrow j$   
**foreach** couple  $(A_h, mp')$  impacted by the match points of  $A_i$  **do**  
    **if**  $\exists l$  such that  $h < l < j$  and the match point  $mp'$  of  $A_h$  is general for a match point of  $A_i$  **then**  
        |  $lowestGeneralIndex \leftarrow l$   
    **end**  
**end**

---

---

**Algorithm 5:** *unweave*( $A_i$ )

---

**Input:** the aspect  $A_i$ , the traceability model corresponding to the weaving of the sequence of aspects  $A_1, A_2, \dots, A_n$  in a base model  $B$   
 $j \leftarrow lowestGeneralIndex(A_i)$   
**for**  $k = n \dots j$  **do**  
    | apply  $undo(A_k)$   
**end**  
**foreach** match point  $mp$  of the aspect  $A_i$  **do**  
    **if**  $classify(A_i, mp) = independent$  **then**  
        | apply  $undo(A_i, mp)$   
    **else**  
        |  $additiveUnweave(A_i, mp, A_{k, 1 \leq k \leq j-1})$   
    **end**  
**end**  
**for**  $k = j \dots n$  **do**  
    |  $weave(A_k)$   
**end**

---

Development (CBSD) and Aspect-Oriented Programming (AOP) by integrating CBSD notions into AOP, and vice-versa. FAC introduces new aspect-oriented structures into the Fractal platform: Aspect Component (AC), Aspect Domain (AD) and Aspect Binding (AB). An Aspect Component is a regular component that encapsulates a crosscutting concern providing advice pieces of code as services. An Aspect Binding is a binding that links an AC to other components. Finally, an AC and all the aspectized components bound via ABs constitute an Aspect Domain (AD). Note that FAC leverages the notion of shared components provided by Fractal to allow components to be contained in several ADs. Basically, weaving an aspect component consists in creating the composite component corresponding to the AD, containing the components of the aspect itself as well as the components impacted by the aspect (still contained by their former container), and introducing bindings. Unweaving the aspect consists in removing all these previously introduced elements. However, no real description of the unweaving process is provided, especially when an aspect depends on other aspects.

Very similar to FAC is AOpenCOM [20], which provides aspect-oriented construction for the OpenCOM component model [2]. Again, very few details are provided about the unweaving process.

CaesarJ [21] extends Java with aspect-oriented constructs. It combines AspectJ-like constructions (pointcut/advice) with advanced modularization and composition techniques such as virtual classes and mixins. Aspects can dynamically be deployed or undeployed on all the join points currently identified in the JVM matching the pointcut. Similarly to above mentioned approaches, no detail is given on the unweaving strategy, especially when aspects are interacting.

In this paper, we have proposed clear and formalized unweaving strategies at the model level, independently from any metamodel. Depending on how an aspect interacts with the other, we precisely determine the way the aspect should be unwoven. With the emergence of the notion of *models@runtime*, it becomes important to optimize approaches and tools usually used at design-time. In previous work [4], we use AOM and MDE in order to manage complex dynamic software product lines at runtime. Each dynamic feature of the system is represented as an aspect model [22] (an architecture fragment), which is selected depending on the context. When the context changes, new aspects can be selected while others are discarded. Working at the model level provides a better basis for reasoning, validation, and automation [4,5]. However, without support for unweaving, we had to systematically restart from a core base model and weave again all the aspects, which is very inefficient.

## 7 Conclusion

In this paper we have presented a method to efficiently unweave an aspect  $A_i$  from a sequence of aspects  $A_1 \dots A_n$  woven into a base model  $B$ . Our method is based on the use of a traceability model recording construction operations at weave-time. The traceability model allows the determination of the relation between  $A_i$  and the following aspects. According to this relation, which is either *independent*, *additive* or *general*, the unweaving is more or less complicated. If no general relationship is detected, unweaving can be performed by directly applying a set of undo operations to the woven model.

Although the method described in this paper is applied in the context of the GeKo aspect model weaver, we believe the same ideas can easily be applied in other tools, once an appropriate traceability model is constructed.

In the future, we plan to apply and evaluate the performance of our unweaving method in the context of dynamic, adaptive systems.

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