Specifying Aspect-Oriented Design Constraints in AspectJ

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ABSTRACT
Aspect-oriented programming comes with new composition mechanisms which permit to modularize code which crosscuts other modules using traditional composition techniques. Although such mechanisms permit a better modularization they do not guarantee it: if the aspect-oriented code is better modularized depends on the design of the aspect-oriented applications. This paper describes typical design failures in AspectJ and introduces a tool implemented on top of AspectJ which permits to specify design constraints on AspectJ code.

1. INTRODUCTION
Aspect-oriented software programming [5] is about modularizing concerns which cannot be cleanly encapsulated using traditional composition techniques. To achieve this better kind of separation of concerns [2] aspect-oriented languages like AspectJ [1] offer different composition mechanisms on top of the existing ones. Nevertheless, although these mechanisms permit to modularize crosscutting code, they do not guarantee a better modularization. If the resulting aspect-oriented applications really modularize the different concerns depends on the programmer's design decision. A misuse of the composition mechanism might directly lead to bad modularization and incorrect applications.

AspectJ already offers to specify constrains on the object-oriented application to be woven by declaring errors which refer to pointcuts. The pointcuts are related to object-oriented features in Java but not to aspect-oriented features in AspectJ. Hence, it is not possible to specify constraints on the usage of the new composition mechanisms pointcut, advice and introduction. In that way error declarations in AspectJ do not help to check if certain design constraints are obeyed in a given application or not. This paper presents a tool which permits to specify design constraints on the usage of the aspect-oriented features of AspectJ.

In the following section we describe a number of typical design failures committed when developing applications in AspectJ. There we concentrate on the usage of introductions. Afterwards we present the tool AJDC (AspectJ Design Checker) and illustrate its basic features. Afterwards we show how the tool permits to prevents programmers to commit the previous shown design failures. Finally, we conclude the paper and give an outlook on specifying design constraints in the code.

2. TYPICAL ASPECTJ DESIGN FAILURES
2.1 Tangled introductions
A typical implementation of the visitor design-pattern [3] in AspectJ is shown in figure 1: two interface VisitedElement and Visitor are created and the double-dispatch method is introduced to the interface VisitedElement. Hence, every class implementing the interface gets the double dispatch method. To adapt the abstract visitor aspect it has to be connected to the target classes, that means the interface VisitedElement just has to be introduced. There are different ways of performing such introductions.

```java
interface VisitedElement {}
interface Visitor {
    visit(A node); visit(B node); visit(C node);
}
aspect VisitedElementLoader {
    public void VisitedElement+.accept(Visitor v){
        v.visit(this);
    }
}
class ConcreteVisitor implements Visitor{...}
```

Figure 1: Abstract Visitor

For example one aspect could introduce the interface to all classes in different declare parents statements or one aspect could introduces the interface in to all targets by using an appropriate type pattern. Nevertheless, it is also possible to define an aspect for each visited class and introduce them VisitedElement.

```java
aspect MakeAVisitedElement {
    declare parents: A implements VisitedElement;}
aspect MakeBVisitedElement {
    declare parents: B implements VisitedElement;}
aspect MakeCVisitedElement {
    declare parents: C implements VisitedElement;}
```

Figure 2: Tangled introductions

Figure 2 shows such a code which connects the visitor by defining one aspect for each target class. In that case the introductions, which logically belong to one single concern occur in several aspects and contradict the aimed separation of concerns, because the introductions are not separated in one single module. We call such occurrences of introductions tangled introductions. In this concrete example the tangled introductions obviously contradict the aimed design of the visitor aspect.
2.2 Container Misusage
In [4] we designated the previous implementation as an application of the often occurring pattern called indirect introduction: the interface VisitedElements depicts a container to which members are introduced and which can be later assigned to a target class. The intention of a container is to be used only within introductions. Nevertheless, if a class directly implements the container it automatically receives all its members. This is usually a design failure: a container is a placeholder for a number of extrinsic features. By directly implementing such a container the difference between intrinsic and extrinsic class features is mixed up. Figure 3 shows such a misuse of a container. Although there are no tangled introductions, the implements-relationship between D and VisitedElement comes logically from the visitor concern. Hence, this relationship should be specified in the same module like the other introductions. We call such design failures container misusage.

```java
aspect AllVisitedClasses {  
declare parents: A implements VisitedElement;  
declare parents: B implements VisitedElement;  
declare parents: C implements VisitedElement;  
class D implements VisitedElement {...
}
```

Figure 3: Container Misusage

2.3 Fragile, Aspect-Dependent Classes
Classes which directly access introduced members are quite fragile, since they directly depend on the aspect which performs the introduction but this dependency cannot be seen in the code. Furthermore such classes mix up intrinsic and extrinsic class members: an introduced member is extrinsic and concern specific while the usual class members are usually regarded as intrinsic members. If an intrinsic member depends on an extrinsic member, the difference between intrinsic and extrinsic features is mixed up.

```java
import java.util.ArrayList;
import java.util.Arrays;
import java.util.List;

public interface Subject {}  
public interface FieldAccessCount {}  
aspect SubjectLoader {  
public List Subject.obs = new ArrayList();  
pointcut stateChanges(Subject s):  
(set(“*”) && target(s) && target(Subject));  
after(Subject s): stateChanges(s) {  
for(Iterator i = s.obs.iterator(); i.hasNext();) {  
(Observer)i.next().update();  
}
}  
}
```

Figure 4: Fragile, aspect-dependent class

In case the aspect performing the introduction is only temporarily woven, e.g. just for debugging purposes, and not part of the final product the class cannot be compiled if the aspect is unwoven. Figure 4 contains such a fragile, aspect-dependent class which uses the introduced member numFieldAccesses in method toString. Since in this concrete case the aspect is just woven for debugging purposes, TargetClass is fragile, since it cannot be compiled without the woven aspect. We call classes which depend on introduced members fragile classes.

2.4 Accidental Overridden Extrinsic Methods
Methods introduced to a class can be overridden by subclasses. Such things usually happen accidental, because the programmers of the subclass are not aware of the introduced extrinsic method.

Accidental overridden extrinsic methods often lead to unexpected behavior: the introducing aspect expects a certain behavior of the target class because of the introduction, but instead subclasses of that aspect behave in a different way. From our point of view extrinsic members should be overridden only by aspects which perform an introduction on subclasses, because this makes clear that an extrinsic feature is overridden.

```java
aspect PerformIntroduction {  
public void (TargetClass).doSomething() {...
}  
class TargetClass {}  
class TargetClassSubClass extends TargetClass {  
// accidental overridden method  
public void doSomething() {...
}
```

Figure 5: Overridden extrinsic method

2.5 Introducing Mutual Exclusive Containers
Assume two abstract aspects in the system like given in figure 6: every class to which Subject is introduced can play the role of a subject in the observer design pattern, i.e. whenever the state of the subject changes its observers are informed. Classes to which FieldAccessCount is introduced have a variable counter which is increased every time a public field is accessed.

```java
public interface Subject {}  
public interface FieldAccessCount {}  
aspect SubjectLoader {  
public List Subject.obs = new ArrayList();  
pointcut stateChanges(Subject s):  
(set("*") && target(s) && target(Subject));  
after(Subject s): stateChanges(s) {  
for(Iterator i = s.obs.iterator(); i.hasNext();) {  
(Observer)i.next().update();  
}
}  
}
```

Figure 6: Weaving Mutual Exclusive Aspects

At the design level it is clear that both interfaces should never be connected to the same target class, since both containers (and the aspects they represent) are mutual exclusive: every time the field obs is accessed the counter is increased which directly leads to informing the observers, and so on. Since both aspects are designed to be mutual exclusive, the developer should be prevented from connecting both to the same class at weave time.
3. AJDC: ASPECTJ DESIGN CHECKER

AspectJ provides the possibility to specify constraints within the code. Errors and warnings can be declared which consist of a referring pointcut and a message. At weave time it is checked if any errors and warning should be thrown. In such a case the specified message is shown to the developer. In AspectJ pointcuts just refer to object-oriented constructs like method calls but do not permit to refer to any aspect-oriented feature. Hence, it is not possible to declare any errors which might occur because of design failures caused by introductions like illustrated above.

AJDC (AspectJ Design Checker) is a small extension of the language AspectJ. It permits to write errors and warnings which are based on AspectJ language features. Hence, it permits to specify constraints on object-oriented and aspect-oriented features. For specifying the errors (and warnings), AJDC provides an own (logical) pointcut language which is based on the logical programming language TyRuBa [6]. AJDC generates facts and rules out of the parse tree to be compiled and provides some rules for retrieving information like subclass relationships. For example the predicate fieldAccess permits to determine all field accesses, or class permits to determine all classes to be compiled.

```java
aspect ForbidMyClassSubclass {
  ajdcError forbidSubclass
  (No MyClass subclass allowed: ?class) =
  forbiddenSubclass(?classId);
  ajdcPointcut forbiddenSubclass(?class) =
  class(?classId,MyClass) && superclass(MyClass,?class);
}
```

Figure 7: Forbid MyClass subclasses

In addition to AspectJ AJDC provides three new keywords: ajdcError, ajdcWarning and ajdcPointcut. The first ones are for specifying the error or warning messages which should be thrown, ajdcPointcut specifies the pointcuts responsible for triggering the errors and warnings. All three constructs are specified within classes or aspects. In the pointcut definition the programmer can use all language features of TyRuBa. The syntax slightly differs from TyRuBa. For example conjunction and disjunction are expressed by the boolean operators || and && from Java.

```java
Error thrown by "forbidSubclass" in "ForbidMyClassSubclass":
(No MyClass subclass allowed: A)

Error thrown by "forbidSubclass" in "ForbidMyClassSubclass":
(No MyClass subclass allowed: B)

2 errors
```

Figure 8: Thrown Error messages

Figure 7 shows an example of an error declaration in AJDC: an error forbidSubclass with the error message (No MyClass subclass allowed: ?class) which refers to a pointcut forbidSubclass. The error message contains a logical variable which is replaced every time the corresponding pointcut delivers a corresponding value. The pointcut substitutes ?class with the name of each subclass of MyClass. That means for every subclass of MyClass an error is thrown at compile time. Of special interest is the variable ?classId in the pointcut predicate. For each node in the parse tree a unique id is generated. This id can be used for performing more complex queries on the parse tree.

In case there are classes A and B that extend MyClass the compiler throws an exception as shown in figure 8.

4. ASPECT-ORIENTED DESIGN CONSTRAINTS IN ASPECTJ

In this paper we neglect to introduce the whole features of AJDC. Instead we just introduce only those which are used to specify design constraints to protect developers from the previous mentioned failures.

4.1 Tangled Introductions

The tangled introduction in 2.1 occurs, because the interface VisitedElement was introduced in more than one aspect to the corresponding target classes. Hence, at weave time it should be checked if such a design failure was made and the programmer should be prevented from compiling such tangled introductions.

```java
aspect VisitedElementLoader {
  ajdcError forbidTangledIntroductions {...msg} =
  allIntroducingAspects(?aspect);
  ajdcPointcut allIntroducingAspects(?aspect) =
  FINDALL(
    introducedType(?aspect, VisitedElement),
    ?aspect, ?aspectList
  ) && length(?aspectList,?length) &&
  greater(?length,1) &&
  member(?aspect,?aspectList);
  ...
}
```

Figure 9: Preventing tangled VisitorElement introduction

Figure 6 contains the code which specifies that an error should be thrown when a programmer tries to compile code which contains a tangled introduction of VisitedElement. The pointcut allIntroducingVariables has one parameter (?aspect). In case there is more than one aspect which performs an introduction of VisitedElement, the pointcut substitutes ?aspect with the aspects' names and delivers it to the error definition. FINDALL, greater and member are valid TyRuBa terms and will not be discussed here. The term introducedType(?aspect, Visited) substitutes ?aspect with all aspects which introduce VisitedElement.

4.2 Container Misuse

To prevent container misuse an exception should be thrown whenever a class directly implements a container, i.e. the implements relationship exists without any corresponding introduction. AJCD provides the predicate implements with two parameters for getting all interfaced implemented by a class: the term implements(Aclass,?interface) substitutes all interface implemented by Aclass to the variable ?interface. The term introducedType with three parameters can be used
to determine what interfaces are introduced to what classes in a certain aspect. E.g. introducedType(?aspect, MyInterface, ?targetClass) determines all aspects which introduce MyInterface to a target class.

|public class VisitedElementLoader { |
|   ajdcError forbidContainerMisusage {.msg} = |
|   misusingContainerClass(?class); |
|   ajdcPointcut misusingContainerClass(?class) = |
|   implements(?class, VisitedElement) && |
|   NOT(introducedType(?introductingAspect, VisitedElement, ?class)); |
|...|

**Figure 10: Preventing VisitorElement misuse**

To prevent the programmer from a container misuse like given in figure 3 we specify an error every time a class implements VisitedElement without the existence of a corresponding introduction. The code is given in figure 10. The pointcut misusingContainerClass determines all classes which implement the interface VisitedElement whereby this implement-relationship does not come from an introduction.

4.3 Fragile Classes

To prevent fragile classes like shown in figure 4 error messages should be thrown whenever introduced members are used within ordinary classes.

|public class WarnFragileFieldAccess { |
|   ajdcWarning fragileFieldAccessWarning{.msg} = |
|   fragileFieldAccess (?class, ?fN, ?targetClass); |
|   ajdcPointcut fragileFieldAccess(?c, ?fN, ?tc) = |
|   field(?fieldID, ?tc, ?type, ?fN) && |
|   fieldAccess(?fAID, ?tc, ?type, ?fN) && |
|   introducedNode(?classID, ?fAID) && |
|   NOT(introduced(?fAID)); |
|...|

**Figure 11: Preventing Fragile Classes**

The clause fieldAccess(?fAID, ?tc, ?type, ?fN) determines all accesses of fields having the identifier ?fN of type ?type in class ?tc and the id ?fAID. The term introduced(?fAID) determines if the node with the id ?fAID was introduced. The clause field(?fieldID, ?tc, ?type, ?fName) determines fields with the identifier ?name of type ?type in class ?tc (including super-class fields). ParentNode determines all nodes in the parse tree which are parents of second parameter. Hence, the pointcut fragileFieldAccess in figure 11 determines all field not introduced accesses of introduced fields.

4.4 Introducing Mutually Exclusive Containers

To prevent the introduction of mutually exclusive containers to one class the developer has to define that such containers cannot be connected to the same target classes. That means a pointcut referred by an error declaration has to be defined which determines if a there is a class which implements the mutual exclusive containers. The corresponding pointcut for the example from figure 6 is shown in figure 12.

|Figure 12: Preventing mutual exclusive aspect weaving|

5. CONCLUSION

In this paper we identified some often occurring design failures committed in AspectJ applications which contradict the achieved aim of separation of concerns and presented the tool AJDC which permits to specify aspect-oriented design constrains on AspectJ application. Such constraints are specified inside the code and checked at weave-time.

Since design constraints are specified inside the code they become part of the module which is logically responsible for the constrains. Nevertheless, there are constraints, which are not logically part of one single module. For example the prevention of fragile classes is more a general design guideline than an aspect-specific design constraint. Hence, for such cases new modules should be created which just contain the constraint definition. Furthermore, the developer has to be careful when defining constraints. For example it is not that clear when a container is misused: there are examples which prefer to connect to container directly declaring a corresponding implements in the class definition.

Mainly, design constraints are interesting for developers which provide collections of abstract aspect which assume a certain design when connected to applications.

6. ACKNOWLEDGMENTS

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7. REFERENCES