

AspectMaps: Extending Moose to Visualize AOP Software

Johan Fabry^{a,1}, Andy Kellens^{b,2}, Simon Denier^c, Stéphane Ducasse^c

^aPLEIAD Laboratory, Computer Science Department (DCC), University of Chile, Chile, <http://pleiad.cl>

^bSoftware Languages Lab, Vrije Universiteit Brussel, Belgium, <http://soft.vub.ac.be>

^cRMoD Team, INRIA Lille - Nord Europe, France, <http://rmod.lille.inria.fr>

Abstract

When using Aspect-Oriented programming the application implicitly invokes the functionality contained in the aspects. Consequently program comprehension of such software is more intricate. To alleviate this difficulty we developed the AspectMaps visualization and tool. AspectMaps extends the Moose program comprehension and reverse engineering platform with support for aspects, and is implemented using facilities provided by Moose. In this paper we present the AspectMaps tool, and show how it can be used by performing an exploration of a fairly large aspect-oriented application. We then show how we extended the FAMIX meta-model family that underpins Moose to also provide support for aspects. This extension is called ASPIX, and thanks to this enhancement Moose can now also treat aspect-oriented software. Lastly, we report on our experiences using some of the tools in Moose; Mondrian to implement the visualization, and Glamour to build the user interface. We discuss how we were able to implement a sizable visualization tool using them and how we were able to deal with some of their limitations.

Note: This paper uses colors extensively. Please use a color version to better understand the ideas presented here.

1. Introduction

Aspect-oriented programming [15] is a novel programming paradigm that aims at modularizing what are called *crosscutting concerns*. Due to the “tyranny of the dominant decomposition” [25], particular concerns, *e.g.*, logging, tracing, transaction management, and so on, can not be captured in individual modules using classical software engineering techniques. Instead their implementation is scattered throughout various modules, hence crosscutting the implementation of the entire system.

To tackle this problem, aspect-orientation introduces the concept of an *aspect*: a novel kind of module that captures such crosscutting concerns. Key to the notion of aspects is the fact that they introduce an *implicit invocation* mechanism. Rather than invoking the crosscutting behaviour *explicitly* from within the code of a system, this base code no longer contains these calls. To allow implicit invocation, conceptually, each execution step of the application is reified as a *join point*, *e.g.*, a method call, an assignment, ... An aspect then defines the behavior to be executed; an *advice*, to occur on certain join points. These are identified by defining a *pointcut*: a predicate over join points. In other words, while an advice³ implements the actual crosscutting behaviour, pointcuts select at which points in the execution of the system the advice should be executed. Lastly, the static location in the source code that gives rise to a join point at execution time is called a *join point shadow*.

Although aspects open up new possibilities in terms of modularization of crosscutting concerns, the presence of this implicit invocation mechanism can make it more difficult for a developer to understand the behaviour of the system. In literature, various problems have been documented that are caused by this implicit invocation mechanism. One such problem is the *fragile pointcut problem* [14, 16]. Due to the limited expressiveness of pointcut languages,

¹Partially funded by FONDECYT project 1090083

²Funded by a research mandate provided by the “Institute for the Promotion of Innovation through Science and Technology in Flanders” (IWT Vlaanderen)

³In the AOSD literature the term ‘advice’ is used instead of ‘a piece of advice’ and the plural of ‘advice’ remains ‘advice’.

such pointcut expressions are often tightly coupled to the structure of the base code. As a consequence, seemingly safe changes to this base code can have an unexpected and erroneous impact on the behaviour of the aspects that are defined in the system. Similar problems can occur when multiple aspects intervene at a single join point. As it is not immediately clear which aspects intervene at a single point in the execution, and as these aspects potentially interact with each other, this can lead to erratic behaviour [23].

To alleviate these problems and aid developers to understand such software we have proposed the *AspectMaps* visualization. AspectMaps aims to ease code comprehension of software using aspects by offering a scalable visualization of implicit invocation. The AspectMaps visualization is also implemented as a tool, on top of the Moose reverse engineering platform, leveraging the facilities offered by this platform.

This paper discusses the AspectMaps tool and contains two contributions: On the one hand it presents the AspectMaps visualization and tool, showing how it can be used to explore aspect-oriented code of a fairly large application, yielding some interesting observations. On the other hand it provides a discussion of the implementation of the tool. In this part we first introduce our extension to Moose that allows it to also operate on aspect-oriented code. This extension is called ASPIX; it augments the FAMIX [26] meta-model that underlies the Moose platform such that its instances can model aspect-oriented software. Second, we discuss our experiences of using the tools offered by Moose for building visualizations: Mondrian [21], and (for specific kinds of) user interfaces: Glamour [5]. We report how we were able to use these tools to build a reasonably large visualization tool, while avoiding some of their drawbacks.

The intended audience of this paper is twofold, echoing the two main contributions of the tool. On the one hand we have the developers of aspect-oriented software that want to use AspectMaps to gain a better understanding of the software on which they are working. On the other hand we have developers using Moose that may want to build their own analysis tool for aspect-oriented software, or that may gain from our lessons learned building a large analysis tool using the features of Moose.

This paper is structured as follows: We start with giving an introduction to the AspectMaps visualization, and in Section 3 we present the tool, followed by an example case study showing how it can be used. Section 4 introduces ASPIX, our extension to the FAMIX meta-model that allows Moose to be used to analyze aspect-oriented software. This is followed in Section 5 by a report of our experiences on using Moose to build the AspectMaps tool. Section 6 gives an overview of related work, and Section 7 discusses future work and concludes.

2. The AspectMaps Visualization

AspectMaps is a visualization that offers users a detailed overview of implicit invocation. It visualizes where aspects are specified to apply in a system, based on visualizing join point shadows, and how aspects possibly interact at each join point shadow. Moreover this is performed in a scalable way, thanks to a multilevel selective structural zoom. Note that this paper does not focus on the visualization itself: discussing design decisions, arguing its merits, performing a validation, ... This is the topic of a separate publication⁴ [12]. We therefore here only give a summary of the AspectMaps visualization, adapted from [12], before discussing the tool.

For the sake of this discussion, we define that an aspect applies in a certain source code element (a package, class, or method) if for at least one pointcut that is associated with an advice of that aspect, at least one of its join point shadows belong to that element.

AspectMaps supports the traditional pointcut-advice model of aspects on an object-oriented class-based language. The join points we visualize are method calls and method executions. Advice can execute before, around or after a join point, and we distinguish between after returning and after exception throwing. Aspects may contain various advice, and an execution order may be specified between aspects. The above effectively allows us to visualize a subset of AspectJ [15] and Java code (which is arguably the most popular aspect language combination). In this case we ignore inter-type declarations as well as advice that applies to fields. The AspectMaps tool is however not fundamentally restricted to the AspectJ/Java combination and more detail on this is given in Section 4.

The key feature of AspectMaps is having the ability to selectively zoom in on the source code at different levels of granularity. Zooming in from a coarser level to a more fine-grained level reveals more detail. The behavior is analogous to street map applications, *e.g.*, Google Maps, hence the name AspectMaps.

⁴The referenced tech report is not up to date, an updated version is currently in preparation for submission to ICPC 2011

To detail the AspectMaps visualization, the remainder of this section is structured following its different levels of granularity. For each level we show how it is visualized, and to illustrate the tool we use a number of examples in this section. Specifically, for Sections 2.1 and 2.2 we use Spacewar, an example program that is provided with the AspectJ Development Toolkit (AJDT) [7] and is also included an example in the AspectMaps tool. Spacewar defines multiple aspects. For this discussion we visualize the Coordination aspect in green and the EnsureShipIsAlive aspect in red. In section 2.3, we use an additional artificially created example, as Spacewar does not suffice to show all the features of AspectMaps.

Additional material is available at the AspectMaps website <http://pleiad.cl/aspectmaps> e.g., featuring some screen-casts of the tool in action.

2.1. Package Level

When opened, AspectMaps provides an overview of all the packages in the system. For each package, AspectMaps shows a *compact* visualization that details the names of packages as well as which aspects apply in this package. AspectMaps colors the package rectangle with the color of the aspect that applies, if it is currently enabled for visualization. If multiple aspects apply in the package this is indicated by using the color black (which never can be the color of an aspect). An example of this is shown in Figure 1, which shows two packages, named `coordination` and `spacewar`. Multiple aspects apply in the `spacewar` package, indicated by the black color. The contents of packages is not shown at this point.

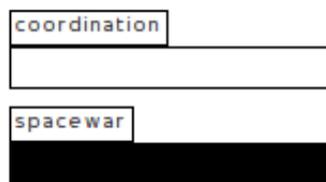


Figure 1: Compact visualization of packages coordination and spacewar.

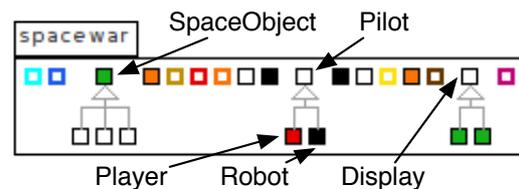


Figure 2: Extended visualization of the spacewar package (annotated with selected class names).

The *extended* visualization of packages is enabled by performing a zoom operation on a selected package by clicking on the package, which reveals package contents. In Figure 2 the package `spacewar` has been zoomed in on, showing the different classes and aspects that it contains. Clicking on the label of the package zooms out, showing the compact visualization again. Additionally, in the compact visualization a pop-up shows the extended visualization when the mouse pointer hovers over the package.

The extended package visualization is a version of the work of Lanza and Ducasse on Polymetric Views [18], which we extended with support for the visualization of aspects. Polymetric Views display entities as boxes the dimensions of which reflect entity properties (LOC, number of methods, ...). A variety of different types of information is shown at this level:

- **Classes:** rectangles with black borders. Inheritance relations are visualized using UML notation.
- **Aspects:** rectangles with thick colored borders. The border color is the color for the aspect (never black).
- **Where aspects apply:** class rectangles have the color of the aspect that applies, black for multiple aspects.
- **Class and aspect metrics:** the user selects which dimension reflects which metric, or none. For the figures in this section we select no metric, for clarity of the discussion.

Note that the polymetric views visualization does not display the names of the classes. AspectMaps echos this: the names of classes and aspects are not shown in their compact visualization. These names are instead revealed at the class level, where classes and aspects show their extended visualization. This visualization is shown as a pop-up when the mouse hovers over a class or aspect, or when the user performs a zoom operation on a class or aspect by clicking on it.

2.2. Class Level

The visualization at the class level is similar to that at the package level. The name of the class is shown, and below a line the instance variables are shown as diamonds and methods are shown as rectangles. The height and width of methods can be determined by a metric. Methods are colored according to the aspects that apply, taking into account the multiple aspect color. Pop-up information on the class name reveals the superclass and for instance variables shows their type and name.

For aspects the name is also given, beneath a line the advice are shown as rectangles, again with dimensions determined by a user-selected metric, and the pointcuts are drawn as ovals. Pop-ups for the aspect show the superaspect, and for pointcuts show the name of the pointcut. Pop-ups for advice show their signature as well as line number in the aspect, as an advice signature does not uniquely identify an advice.

Analogously to the behavior at package level, clicking on the name of a class or aspect performs a zoom out operation, *i.e.*, shows the compact representation of that class or aspect.

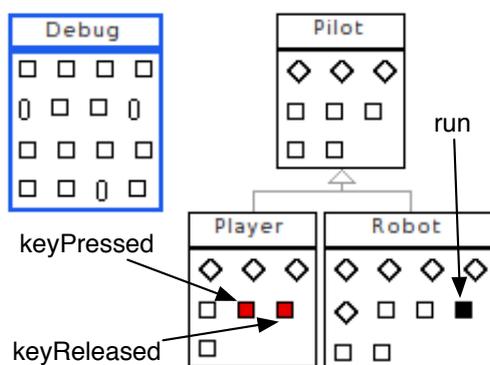


Figure 3: The Debug aspect and the Pilot hierarchy (annotated with selected method names).

In Figure 3 we have zoomed in on all classes in the Pilot hierarchy, as well as the Debug aspect. This reveals that multiple aspects apply on the method `run` of `Game` and that the `EnsureShipsAlive` aspect applies in the methods `keyPressed` and `keyReleased` of `Player`.

Analogous to classes, the compact visualization of methods does not reveal the methods' name. This information, amongst others, is revealed in the extended visualization, at method level. This is shown as a pop-up or when the user clicks on a method.

2.3. Method Level

Method level is the finest level of granularity offered by AspectMaps. At this level a wealth of information is potentially of interest, and hence the visualization is more complex. Only one element is carried over from package and from method level: clicking on the name of the method performs a zoom out operation.

If we consider only one join point, advice can be specified to execute before, around or after this join point. Therefore a visualization of its shadow point needs to separate showing before, after and around advice. Also, at one join point multiple aspects may apply, so the shadow point must be able to show the execution of various advice at that point. Considering the method level, we can have a shadow point for the execution of the method, and within the method body various shadow points for method calls.

Figure 4 shows a template for the visualization of method execution shadow points. On the right, the `destroy` method is displayed using this template: we see that the blue aspect applies before and after. The figure shows how AspectMaps provides the method name and shows before, after and around advice in their separate divisions. Furthermore, the pop-up on the method name reveals the parameter list of the method. We detail next how advice execution is visualized.

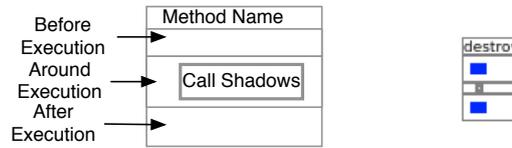


Figure 4: Template for visualization of execution shadow points (left), and an example `destroy` method (right). Figure 7 shows call visualization.

2.3.1. Advice Execution, Run-time Tests, Ordering

To show that an advice applies at a given division of a shadow point, AspectMaps draws a small figure in the color of the corresponding aspect. This is done for all aspects that apply, aligning the figures vertically. Figure 5 shows after execution advice of an example `set` method.

AspectMaps currently has two kinds of figures: a triangle for after throwing advice and a rectangle for all other advice. This is to emphasize the special nature of after throwing advice: it executes when the method terminates by throwing an exception. In the example this is an advice of the red aspect. Moreover, if there is a run-time test involved in evaluating the pointcut for an advice execution (e.g., an if-test or a control-flow pointcut) the figure has a thick border in a contrasting color. In the example this is evident in the green aspect.

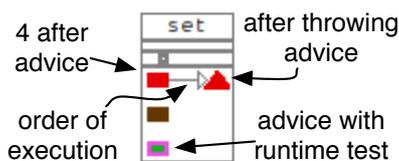


Figure 5: Four after execution advice of a `set` method.

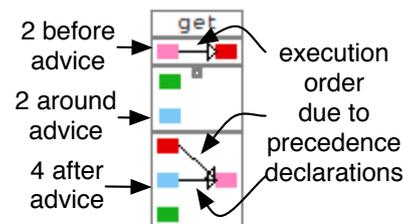


Figure 6: Eight execution advice for a `get` method, with two precedence declarations yielding three ordering arrows.

If multiple advice of *the same aspect* apply at the same shadow point, for each of these a figure is drawn. A gray arrow between these indicates the order in which these advice will be executed, e.g., in AspectJ this is determined by the line numbers of the advice. In the example Figure 5 this occurs for the red aspect. When multiple advice of *different aspects* apply, the order of their application may be specified by the programmer, e.g., using the `declare precedence` construct in AspectJ [15]. When such an order is specified, AspectMaps indicates this by drawing a black arrow between the advice execution figures, indicating the order in which the advices will be executed. In other words: gray arrows indicate execution order as specified by the semantics of the aspect language, while black arrows indicate programmer-specified execution order. A more comprehensive example is given in Figure 6. Considering the after advice, the cyan and red code is run before the pink advice. There is no ordering specified between the green aspect and any of the other aspects, nor between the cyan and red aspects, hence no arrows are drawn. Figure 5 does not show any black arrows, indicating no ordering is specified between the green, brown and red aspects and therefore no claims can be made about the order at which the aspects will be executed at run-time.

2.3.2. Execution and Call Shadow Points

For execution shadow points the groups of figures detailing advice execution are placed in their corresponding locations as given by the template in Figure 4 and illustrated in Figure 5 and 6. In addition to this, a pop-up shows the signature of the advice, including its line number in the aspect source code.

The body of a method may contain multiple call shadow points, sequentially ordered by the source code of the method. We visualize advice execution in this same order, aligning them vertically. The visualization of call shadow points uses the same visualization as execution shadow points. It however orders the before, around and after divisions horizontally instead of vertically. A template of this is shown in Figure 7. The horizontal layout was chosen to

minimize unused space when visualizing, as well as to avoid confusion of what advice execution belongs to which shadow point.

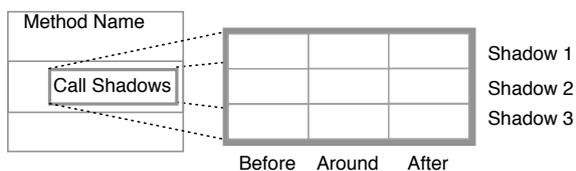


Figure 7: Template for call shadow points

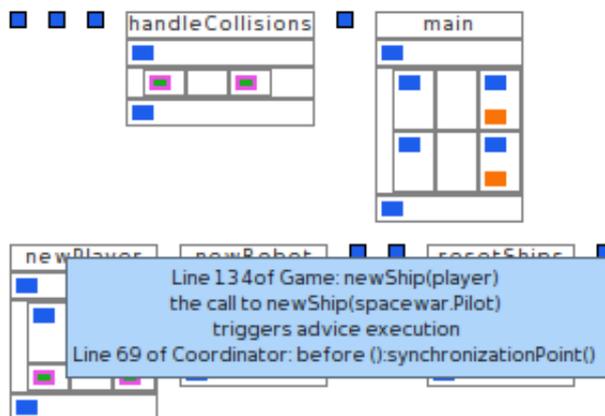


Figure 8: A selection of methods in Spacewar showing call shadow points, as well as a pop-up of one advice execution (in the new-Player method).

In Figure 8 we show a number of methods of the Spacewar example that demonstrate the visualization of call shadow points. This figure also illustrates the pop-up information for each advice execution. It consists of the signature of the advice, including its line number in the aspect source code, as well as the source code for the shadow point.

3. Using AspectMaps

The AspectMaps visualization has been implemented in Pharo, a version of Smalltalk, using Moose [9], a platform for software analysis and reverse engineering. The resulting tool is also called AspectMaps. It is a standalone tool that in its current incarnation can visualize AspectJ/Java code developed with the Eclipse AspectJ Development Toolkit [7].

We introduce the tool here and how it is linked to Eclipse before describing a software exploration session using the tool. The implementation of the AspectMaps tool is discussed in Sections 4 and 5.

3.1. The AspectMaps Tool User Interface

The AspectMaps tool consists of a single window, shown in Figure 9. The top part of the window shows the AspectMaps visualization, and the bottom panel contains multiple controls that determine what is visualized and how. We present these controls next, followed by a description of the context menu of the visualization.

Available Projects. AspectMaps allows for multiple Java projects to be visualized. In the figure these are AMTest and Spacewar 2. Selecting a project shows the visualization in the top part of the window, and populates the *Aspects in Project* list. The hierarchy of packages in a project is also available as a flattened list, by clicking on the expansion triangle shown before the project name. In the figure this is shown for Spacewar 2. Selecting a package from this list restricts the visualization to only show this package.

As the AspectMaps tool is not integrated in an existing Java/AspectJ development environment, the code that is visualized needs to be imported into the tool, which adds it to the list. Importing is required because AspectMaps does not operate on the original source code, but builds its internal model in order to visualize it. (This process is discussed in Section 4.1 and 4.2.) A project can be removed from the AspectMaps tool repository, no longer making it available for visualization, by clicking on the trash icon. Clicking on the folder icon launches an import wizard that will add the project to the model repository. Importing is a two-step process: first the aspectual information of the project is obtained by asking for an .xcr file of the project. Second the OO structure of the project is retrieved, either

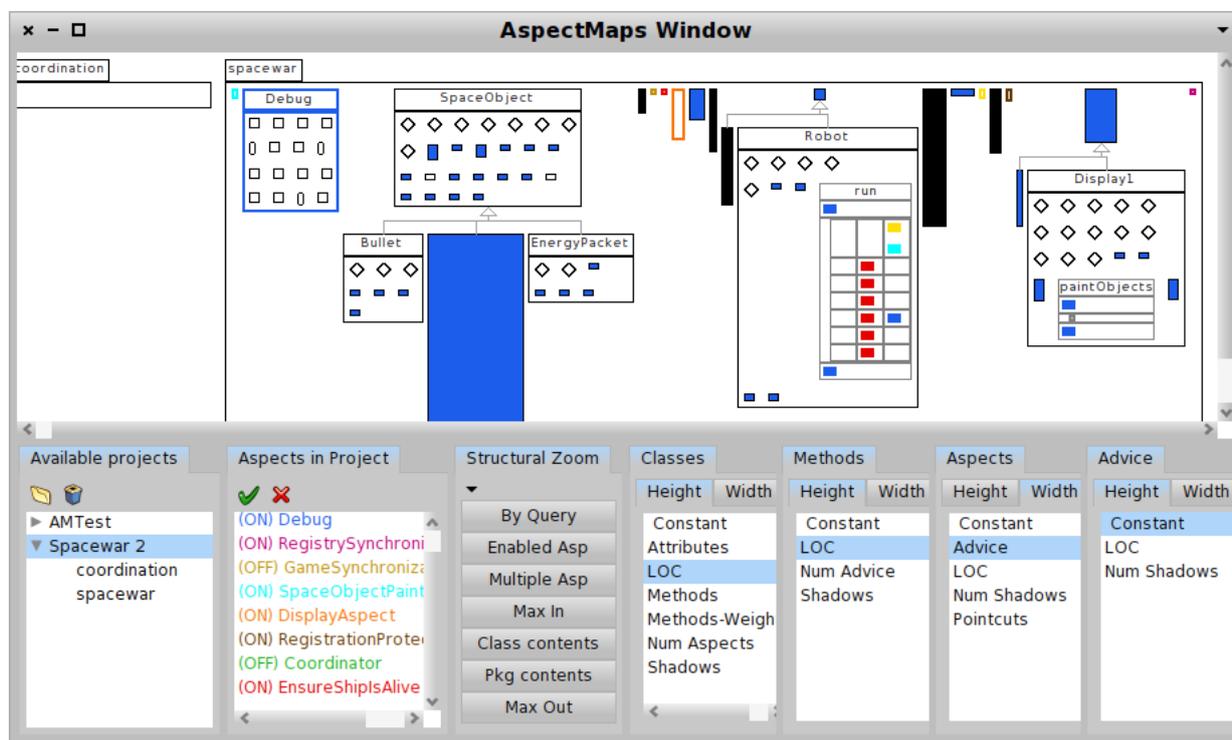


Figure 9: The AspectMaps tool showing a part of Spacewar. Above is the visualization, below is project selection, visualization of aspect selection, zoom shortcut buttons and metrics selection. Non visible metrics choices: class width is Attributes, aspect height is LOC (lines of code).

by indicating the source code directory of the project or by providing a .mse Moose exchange file for the project. How to generate both .xcr and .mse file is discussed in Section 3.2.

Aspects in Project. Two settings for the aspects in the project that is currently being treated are specified here. Firstly, each aspect name is shown in the color that represents it in the visualization. A context menu on the entries in this list allows their color to be changed by selecting it from a list of colors. Secondly, visualization of join point shadows of each aspect can be turned on or off. For example, in Figure 9, visualization of Debug is turned on, while for Coordinator it is off. The context menu on the entries in the list allows this visualization state to be toggled. Clicking the check icon turns on visualization of all aspects in the list, except for the selected aspect, if any. Clicking the cross icon performs the inverse.

Structural Zoom. The structural zoom buttons perform seven different zoom operations on the entities being visualized. In order these are:

By Query: Given a query, which may contain wildcards, zooms in maximally on entities of which their names match.

Enabled Asp: Zooms in maximally on all join point shadows of aspects that are turned on for visualization.

Multiple Asp: Zooms in maximally on all join point shadows where multiple aspects that are turned on are present.

Max In: Maximal zoom level on all entities in the visualization, *i.e.*, all entities show their extended representation.

Class contents: Level showing contents up to classes and aspects, all methods showing their compact representation.

Pkg contents: Zoom level where the packages show their contents, and lower levels show the compact representation.

Max out: Zoom level where all entities show their compact representation.

Classes, Methods, Aspects, Advice. These four tabs allow for a specification of the dimensions of the rectangles that represent these entities, when drawn in the compact representation. This is taken from Polymetric Views [18], as discussed in Section 2.1. By default the value here is constant, yielding small squares for each entity. Selecting a metric for a dimension, *e.g.*, LOC for the height of classes in Figure 9, specifies that the size of this dimension is equal to the value of this metric for the entity that the rectangle represents. Further considering the classes in the example, the width of classes is set to the **Attributes** metric, indicating the number of attributes. The tall class rectangles hence are large classes, and the wide classes have a large number of instance variables. Note that metrics only apply on the compact representation, as in the expended representation the size of an entity rectangle may need to expand to show its contents.

Context Menu of the Visualization. The last control of the visualization is the context menu that is available on selected entities that are being visualized. We have the following context menu items:

On pointcuts: Revealing all join point shadows of this pointcut by zooming in on the methods containing them.

On advices: Revealing all join point shadows of the pointcut of this advice.

On advice execution: Revealing the aspect of the advice and revealing all the executions of this advice.

3.2. Generating Import files for AspectMaps

As said previously, to visualize a project it first needs to be imported into AspectMaps. This import process takes on the one hand the OO structure of the application, *i.e.*, what is defined by the Java code, and on the other hand the aspectual information, *i.e.*, what is defined by the AspectJ code. The import process itself is discussed in more detail in Section 4.1 and 4.2, we describe here how to obtain the files required to perform an import.

To import the OO structure of the project the AspectMaps tool requires a `.mse` file that contains the relevant data of the project being imported. As `.mse` is the standard file format for Moose data interchange, there are multiple tools available that produce a `.mse` file from a Java source directory. One option is inFusion tool by *intooitus*⁵, a second possibility to generate such files is to use VerveineJ⁶. AspectMaps has support for inFusion (limited to UNIX/MacOSX): it can use this tool to generate the `.mse` file on the fly when importing, thus streamlining the process.

A notable drawback of using Java source code to generate the `.mse` is that the code being examined must be correct and fully compliant to the Java standard. This is relevant as the AspectJ compiler, used in Eclipse AJDT, also accepts `.java` files where aspects, pointcuts and advice are defined. Therefore some projects that compile successfully with the AJDT cannot be imported into AspectMaps. To solve this, the developer must ensure that all aspectual code is defined in AspectJ `.aj` files, **not** in `.java` files.

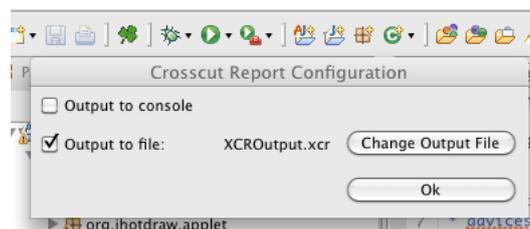


Figure 10: The crosscut report plugin toolbar button (the shamrock) opens the configuration dialog.

The aspectual information of a project is generated by an Eclipse plug-in we implemented. The plugin, called XCut report, is triggered by a successful AspectJ compilation. After an AspectJ project is compiled, it produces the relevant aspectual information. The plugin has a straightforward configuration dialog box, shown in Figure 10. Output

⁵<http://www.intooitus.com/inFusion.html>

⁶<https://gforge.inria.fr/projects/verveinej>

can be turned off (the default state, which effectively disables the plugin), shown on the Eclipse console or written to an .xcr file (or both of the latter). The .xcr file format and the XCut report plugin are discussed in more detail in Section 4.2.1.

3.3. Example Case: AJHotDraw

To show how the AspectMaps tool can be used to explore a given application, we now present a study of AJHotdraw [8] using AspectMaps. We chose this application as it is a widely known example of an aspect-oriented application. AJHotdraw is a fairly large application, consisting of 374 classes and 31 aspects, which serves to illustrate the scalability of our tool. A full investigation of the of the AJHotdraw code is outside of the scope of this paper. We restrict our discussion here to showing how the tool was used to reach some notable conclusions from our exploration.

- A first assessment of the location of classes and aspects, using the Pkg contents button shows that all the aspects are within the ccconcerns package hierarchy.
- Looking at the names of aspects in the Aspects in Project list, we see that of the 31 aspects, at least 15 are dedicated to undo operations.
- Selecting the ccconcerns.tools.undo package in the Available projects (restricting the visualization to only show that package) shows that it contains five undo aspects. Performing a Max in zoom operation reveals that none of these contain a pointcut nor an advice. (Source code inspection reveals that these aspects only perform inter-type declarations, which are not visualized in AspectMaps.)
- Investigating the contents of the other ccconcerns package in the same way we find that the other 10 undo operations are located in the package ccconcerns.commands.undo. These have a name that ends in Undo, except for UndoRedoActivity. All of the former only have one pointcut. Using the context menu item that reveals the shadows of the pointcut we learn that each of these aspects solely affects the execute method of a class with the corresponding name, without the Undo suffix. All of the affected classes are subclasses of AbstractCommand. This is shown by the inheritance edge for subclasses in the same package, and also by the class name pop-up for subclasses in a different package than AbstractCommand.
- Using the Num Shadows metric we see that one of the two most important aspects is CommandContracts. Enabling visualization of this aspect only using the toolbar icon and performing a Enabled Asp zoom, shows that it affects the execute method that is present in almost all classes of the AbstractCommand hierarchy. Manual zooming and exploration of the classes in the hierarchy that are not affected reveal that these do not contain an execute method. According to the same metric, the other important aspect is UndoableCommand. Investigating this aspect in an analogous fashion, we see it only affects the AbstractCommand class and 6 more classes, each of which is a subclass of a Swing component: 4 menu-related classes, and the button and combo-box classes.

In addition to a study of AJHotdraw, AspectMaps has been used to explore Spacewar [12]. We also have performed an intensive user study that reveals that on an exploration of Spacewar, AspectMaps far outperforms the visualization of AJDT [12], which is arguably the most competitive software visualization for aspect-oriented software. Again, a discussion of these results is outside of the scope of this paper as here we focus on the tool.

4. Adding Aspect Support to Moose

The AspectMaps tool is built on top of Moose [9], a platform for software analysis and reverse engineering. Moose offers various facilities for building software engineering tools, ranging from importing data, source-code modeling, querying, to building software visualizations. In the past, Moose has been successfully leveraged for building a wide variety of tools, such as Torch [27] (a tool supporting source-code change integration), SmallDude [4] (a duplication detector), and eDSM [19] (a tool to detect cyclic dependencies). Within the context of this work, we opted to base our tool on Moose for the following reasons:

- **FAMIX.** FAMIX [26] is a language-independent meta-model for class-based programming languages that underpins the Moose tool suite. Using this model allows AspectMaps to achieve a certain level of base and aspect language independence. A downside is that FAMIX however does not provide concepts for representing aspect-oriented constructs.
- **Mondrian.** Mondrian [21] is a domain-specific language for scripting visualizations that is part of the Moose tool suite. It is particularly well-suited for implementing AspectMaps as it does not only offer constructs for declaring the different nodes and edges that make up a visualization, but also provides a means to create highly-interactive visualizations.
- **Glamour.** Similar to Mondrian, Glamour [5] is a domain-specific language for scripting browsers. It provides a convenient way for declaring and composing the user-interface components of AspectMaps.
- **Integration with other tools.** By implementing AspectMaps on top of the Moose platform, we can also leverage the other tools that are part of the Moose platform (to calculate metrics, ...).

As said above, Moose does not provide support for analyzing aspect-oriented software as the FAMIX meta-model family lacks the required concepts. To address this shortcoming, we provided an extension to FAMIX that adds this support, called ASPIX. ASPIX (ASPECTs In famiX) is a generic class-based object-oriented meta-model to which the essential aspect-oriented concepts have been added. The ASPIX model is generic such that it can be used by all of the Moose tools, *i.e.*, enabling Moose to be used to analyze aspect-oriented software. Moreover, basing AspectMaps on ASPIX allows our tool to be used for other combinations of base languages and aspect languages.

In this section we provide a description of ASPIX and detail how model instances can be created, *i.e.*, how aspect-oriented code is represented in our Moose extension and how this code can be imported for analysis.

4.1. ASPIX : ASpects In famiX

To perform visualization, AspectMaps does not consider the actual source code of the program, but instead uses its own model, as do the other tools of Moose. This model is an instance of the ASPIX meta-model, a member of the FAMIX meta-model family [9, 26], which we created such that Moose is able to work with AOP code. ASPIX (ASPECTs In famiX) consists of a generic class-based object-oriented meta-model enriched with information of aspects, pointcuts, advice, advice ordering and shadow points. Analogously to FAMIX, the idea is to have language-specific importers that generate model instances. These can obtain the required information from the source code. AspectMaps currently only has one importer for a base and aspect language combination: Java and AspectJ. In this section we first give an overview of FAMIX, before we detail our aspect-oriented extension ASPIX. The next section details how instances of the model are built based on the data made available by the importer.

The core of FAMIX is a language independent meta-model that describes the static structure of object-oriented software systems. The FAMIX core can describe the structure of object-oriented systems from the namespace level down to variable accesses and method invocations. Figure 11 shows relevant parts of FAMIX core (in grey) that are directly involved in AspectMaps. `Namespace` is the entity with the highest granularity: it is used to represent Java packages in the case of Java systems. `Type` is the meta-description for entities containing methods in FAMIX (as indicated by its `methods` attribute) and `Class` is a specialization of `Type`. `BehaviouralEntity` is a generic meta-description for behaviors, such as its specialization `Method`. It can contain `outgoingInvocations` (for example, method calls) which themselves are described by `Invocation`.

ASPIX extends the FAMIX core with meta-descriptions specific to the structure of an aspect-oriented system. Figure 11 shows (in black) the meta-descriptions, attributes, and inheritance relationships which constitute ASPIX as an extension to FAMIX. Hence, `Aspect` is a specialization of `Type` and contains `namedPointcuts` and `advices`. An `Advice` has a `kind` (before, after, or around), a `precedenceOver` relationship to indicate precedence of the advice over other advices, and a `relation` to its `pointcut` (which can be a named pointcut of the aspect or its own anonymous pointcut). `Pointcut` holds a boolean flag indicating whether evaluating it requires a runtime test. It also points to `joinpointShadows` captured by this pointcut. The meta-description `JoinPointShadow` holds the opposite relation in its `matchingPointcuts` attribute. In the current version of ASPIX, two kinds of join point shadows are described: `ExecutionJoinPoint` which links to a method and `CallJoinPoint` which links to an expression (an instance of `Invocation`).

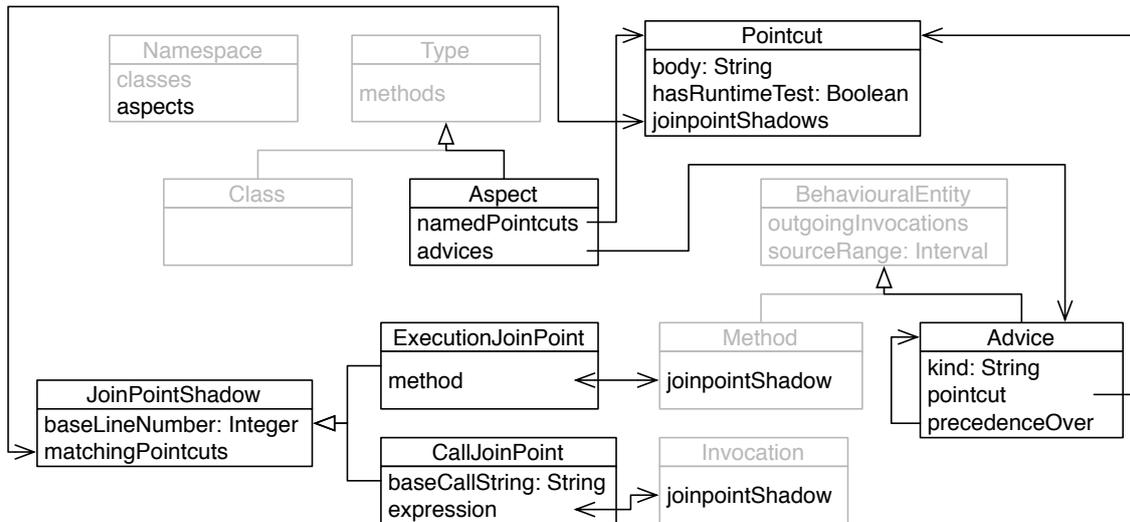


Figure 11: Class diagram of the ASPIX meta-model, with relevant parts of the FAMIX core meta-model shown in grey.

Note that both `Method` and `Invocation` are extended by ASPIX to link back to their respective `joinpointShadow`, while `Namespace` provides a link to its contained aspects.

4.2. Constructing an ASPIX Model

ASPIX models for Java and AspectJ code are created using a two-step process as outlined in Section 3.2. First the Java and AspectJ code are analyzed and the relevant data is exported to an exchange format: an `.mse` file for Java and an `.xcr` file for AspectJ. Second the ASPIX model is created based on joining the information in these two files. The rationale for this two-step process using exchange formats is twofold. On the one hand we maintain a loose coupling between the different parts of the loading operation. On the other hand, in the implementation we are able to reuse as much existing infrastructure as possible.

The former is important as it allows for language independence of the import process by using standardized interchange formats. To allow Moose to work with different base and aspect language combinations, *e.g.*, to load AspectMaps to visualize these, it simply suffices to be able to export this code to a combination of `.mse` and `.xcr` file.

To clarify the creation of both these files and how these are joined to form an ASPIX model, we now discuss both steps of the process in more detail.

4.2.1. Exporting Java and AspectJ code to `.mse` and `.xcr` files

We have chosen to use the standard Moose `.mse` exchange format [17] to import Java code into Moose, yielding FAMIX model instances. This as it allows us to reuse existing Java to `.mse` export tools, as well as the standard Moose file import feature. As said in Section 3.2, when loading in software to be visualized the AspectMaps tool can automatically generate a `.mse` file using the `inFusion` tool and an alternative way to generate them is to use `VerveineJ`.

To the best of our knowledge, there is however no tool that takes AspectJ code and provides structural information of aspects and join point shadow information. Neither are we aware of any standard file format for this information. We therefore built our own export tool and defined a straightforward file format. As mentioned in Section 3.2, the tool we built is an Eclipse plugin, called `XCut Report`. When active, it uses `AJDT` [7] to produce an `.xcr` file whenever AspectJ code is compiled. `XCut Report` hooks into `AJDT` to receive a notification whenever compilation ends successfully. This notification includes a complete structural model of the program that was compiled. The plugin then traverses this structural model, writing the relevant data to the corresponding `.xcr` file.

The structure of an `.xcr` file is a self-describing list of tuples, where each tuple is tab-delimited and separated from the next tuple by a newline. Tuples are grouped according to the nature of the element they describe and groups are separated by an empty line. The first two lines of a tuple group describe the group as follows: a title line describes

the nature of the group and a description line states the structure of the tuples, *i.e.*, the semantics of each field. This file format was chosen because it is straightforward to parse when importing, and moreover it can be easily read when opened by a spreadsheet application (by importing as tab-separated text).

```
Shadows
Base FQN   Base Line Number  Type of Pointcut  Aspect FQN  Pointcut with Test  Advice Line Number  Base Call String//
Call target method  END
[...]
spacewar.Registry 64  execution  spacewar.Debug  false  131  - - END
spacewar.SpaceObject 97  call  spacewar.Debug  false  152  getGame().getRegistry().unregister(this)//
void spacewar.Registry.unregister(spacewar.SpaceObject)  END
spacewar.SpaceObject 97  call  coordination.Coordinator  true  69  getGame().getRegistry().unregister(this)//
void spacewar.Registry.unregister(spacewar.SpaceObject)  END
[...]
```

Figure 12: Part of the .xcr file of Spacewar, showing join point shadows. // indicates the tuple continues on the next line and [...] omitted tuples.

For example, in Figure 12 we show part of the tuple group of join point shadows of the Spacewar example (with each tuple wrapped to fit the size of the page). The example shows that for join point shadows, tuples contain the name of and line number in the advised class, the type of join point, the name of the aspect and line number of the advice, as well as whether the shadow point has runtime tests. For call join points, the signature of the call as well as the source code including the call (Call source code) are also reported.

Special to the .xcr file format is its reliance on line numbers to identify different elements. This is for two separate reasons. Firstly, recall that an advice signature does not uniquely identify an advice. Therefore we use the line number where the advice definition starts as a unique identifier for the advice. Secondly, the file does not contain the complete structure of the program, but solely a partial specification of aspect-related elements. This requires it to refer unambiguously to elements outside the file: the methods where join point shadows are located. To do so, for each join point shadow we include the fully qualified name of the advised class and the line number of the shadow. As we show next, both these uses of line numbers are sufficient to allow us to construct the complete ASPIX model from .mse and .xcr files.

4.2.2. Importing .mse and .xcr files to an ASPIX Model

As the .mse file format is a standard Moose format, Moose straightforwardly creates a FAMIX model instance from a .mse file. Therefore we solely discuss here how processing the .xcr file complements this existing model instance, producing an ASPIX model of the software that is to be visualized.

When the data in the .xcr file is imported in Moose, first the corresponding ASPIX entities are created using the retrieved information. The second part of the import process merges the ASPIX entities into the original FAMIX model and binds entities together: an ASPIX Aspect points to its superaspect, an Advice has its precedence information linked, and most importantly JoinPointShadow entities are bound both to their matching pointcuts and to the FAMIX entity which they represent (either a Method or Invocation)

Binding a JoinPointShadow is somewhat more intricate. Figure 13 shows which information is used to bind an ASPIX JoinPointShadow instance with respectively 1) a pointcut (blue binding) and 2) the advised entity (here an invocation with the red binding). The concrete example used is the last tuple of Figure 12.

To bind the pointcut with the join point shadow, we use first the aspect name *coordination.Coordinator* to retrieve the aspect entity and second, the line number 69 to identify the corresponding *advice69* entity. (Recall that we use the line number where the advice definition starts as a unique identifier for the advice in ASPIX.) This allows us to link back a shadow point to its advices as above. We navigate to the advice pointcut (*synchronizationPoint*) and add the shadow point to the list of *joinpointShadows* in the pointcut, and reciprocally add the pointcut to the list of *matchingPointcuts* in the shadow point.

The process is a bit more complex to bind the shadow point to the advised entity. We use the base name *spacewar.SpaceObject* to retrieve the entity of the advised class. Then the line number 97 allows us to detect the method *die()* where the join point shadow resides, as the range of source code for *die()* starts at 96 and ends at 98. If it is an execution join point, the process stops here and the binding is made between the shadow point entity and the

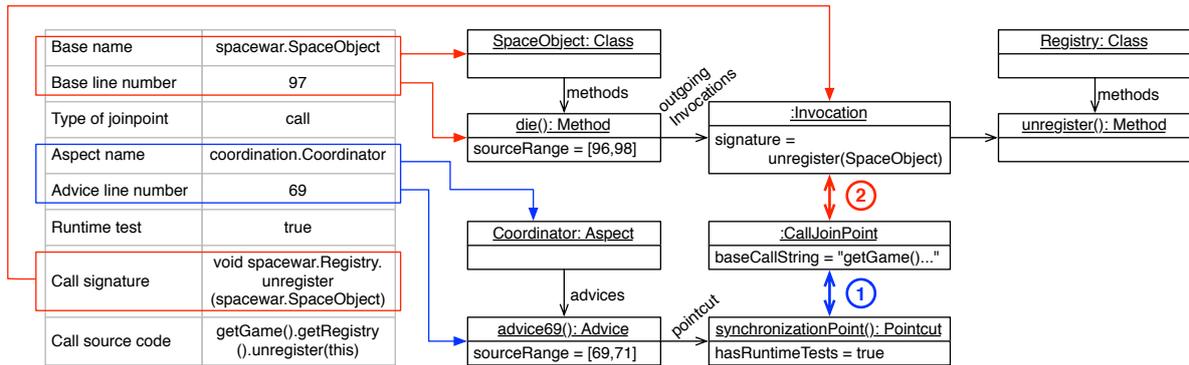


Figure 13: Binding an ASPIX join point shadow (left-hand side table) to a pointcut and an invocation (right-hand side UML object diagram).

method entity. However, if it is a call join point, we iterate over the outgoingInvocations of the `die()` method to detect one matching the call signature `void spacewar.Registry.unregister(spacewar.SpaceObject)` of the shadow point. The shadow point entity and the invocation entity are then bound together.

Other shadow point information is used to fill-in the model: *Type of join point* indicates whether to instantiate a `CallJoinPoint` or an `ExecutionJoinPoint`, *Runtime test* is used to set the flag `Pointcut.hasRuntimeTests` in the corresponding pointcut, and *Call source code* is stored into the field `CallJoinPoint.baseCallString`.

5. Experiences Using Moose to Build AspectMaps

AspectMaps is arguably one of the most complex software visualization tools built using Moose. We experienced this while building the tool, encountering that we were stretching the different Moose tools to their limits. We report here on our experiences such that subsequent implementations of complex visualization tools may also benefit from them.

Firstly, we discuss the Mondrian [20] visualization, reporting on how we avoided the drawbacks of monolithic scripts, introducing the implementation of the structural zoom feature, and presenting how the visualization is kept separate from the ASPIX model. Second we present how we were able to use Glamour [5] to build the user interface of AspectMaps, overcoming the restricted focus of Glamour to building one specific type of user interfaces.

5.1. Visualizing the model with Mondrian

AspectMaps uses the Mondrian [20] information visualization engine, also a part of Moose, to render its diagrams. To draw diagrams in Mondrian the programmer declaratively specifies a graph of nodes, a layout algorithm for these nodes and (optionally) edges to be drawn between nodes. Such specifications are written in Smalltalk, and called Mondrian scripts. In a script for each node the shape to be used in the visualization can be specified, along with a context menu, pop-up and mouse-over actions, if any.

In our experience, Mondrian is a good solution to build software visualizations as it offers sufficient functionality, allows for rapid prototyping and with subsequent refinements can yield the finished visualization. Moreover it is integrated with the other tools in Moose which enables rapid construction of the complete tool, e.g., adding browser-like user interfaces using Glamour [5]. In building AspectMaps we found that we were taxing the Mondrian visualization engine, pushing its limits. We found various bugs, e.g., popups not working correctly, and performance issues, e.g., slow scrolling. The current maintainer of Mondrian was very responsive in addressing all the issues we raised, even adding the node replace feature we needed to implement the structural zoom. In our experience this responsiveness was key in realizing AspectMaps, without it the visualization and tool would probably not have been realized.

To the best of our knowledge, the AspectMaps visualization is one of the largest (if not the largest) Mondrian script in existence. We discuss salient points of the script here to provide pointers to other Mondrian users that need to write large scripts or big visualizations. We first describe how we structured the Mondrian script according to the existing

graph of nodes contained in the ASPIX model, second how the node replace feature added to Mondrian allows for the structural zoom, and third how the combination of class extensions, FAMIX properties and a trait installer make the Mondrian script for AspectMaps a modular extension to the ASPIX model.

5.1.1. Structuring the Mondrian Script

Early prototypes of what would become AspectMaps used monolithic scripts to visualize an ASPIX data structure. These scripts however turned out to relatively quickly become unmanageable. Therefore when setting out to implement the complete functionality of AspectMaps we decided early-on for a modular approach. In our experience, the resulting modularity of the script, as described below, has made it significantly easier to develop and maintain than if it would be a monolithic entity.

AspectMaps visualizes an ASPIX data structure, which is a tree containing packages, classes, aspects, methods, pointcuts and advice. When declaring what is to be visualized we traverse this graph, passing the respective elements to the Mondrian engine along with their visualization specification. We chose not to write one large script that defines the traversal and visualization of each entity. Instead we let each entity itself specify how it is visualized and delegate visualization of its contained entities. This is a natural mapping, and moreover is in accordance with good OO practice. The AspectMaps Mondrian script, *i.e.*, the logic of the visualization is therefore defined as methods in the FAMIX and ASPIX entities Namespace, Aspect, Class, Method, Advice and Pointcut. Consequently we can consider the script itself as a composition of modules, each module a Smalltalk method.

We found that this modularization led to the appearance of several cross-cutting concerns in the script. Some examples are: specifying a context menu for each entity, declaring that entities may not be dragged around the canvas, and the core functionality of the structural zoom feature (discussed in more detail in Section 5.1.2). A straightforward way to address such code duplication is to extract the duplicated code to a method in the superclass. The different methods that comprise the script are however contained in classes that do not have a common superclass. The extraction process resulted in this behavior to be placed in a common ancestor that is relatively far up in the inheritance hierarchy. We do not consider this a clean solution. Arguably the biggest drawback of this is that it adds this behavior to other entities where it does not belong. We have therefore chosen to refactor this common behavior to traits [10]. Put briefly, traits are partial class descriptions, only containing the definition of methods. These can be applied to classes, in effect adding the behavior defined in the trait to the class. Using traits allowed us to effectively group methods that implement the cross-cutting functionality in one module, and selectively compose these modules where required. Moreover we have made good use of the feature of traits that methods defined in the class take priority over likewise-named methods in a trait. We defined generic behavior in the trait, *e.g.*, for drawing the contents of a compact representation of an entity, and let the different entities override this if required, *e.g.*, Aspect has a specific compact representation (not showing anything in its contents).

5.1.2. Node Contents Replacement for Structural Zooming

Arguably a key feature of AspectMaps is its selective structural zoom. This zoom allows a user to selectively drill down to parts of the application of interest. As a result, the visualization is more scalable than if it would use a uniform zoom level. Since the selective structural zoom can also benefit other visualizations, we describe its implementation here.

To enable the structural zoom feature Aspect, Class and Method have both a compact and an extended representation, as discussed in 2. As a general rule, a compact representation gives an overview of the aspects that apply within the element, while the extended representation visualizes the elements at the next level of granularity, each child element according to their own representation. This means that a zoom in operation on these entities consists of specifying that it should show its extended representation while a zoom out operation specifies that the compact representation should be shown.

Each Namespace, Aspect, Class and Method possesses a `shape` attribute that maintains whether they should be visualized in the compact or the extended representation. To draw itself, each entity first declares how to visualize its perimeter. For example, a class specifies that it should be drawn as a black box with minimum height and width according to the metrics selected by the user. This is followed by stating the inner visualization of the entity, according to what is stipulated by the `shape` attribute. In general, the compact visualization consists of filling the perimeter with the color of the aspect that applies in that entity, or the multiple aspect color if more than one aspect applies. The extended visualization collects all the elements at the next level of granularity, *e.g.*, getting the methods and

instance variables of a class, and instructs these entities to visualize themselves within the perimeter. Note that as a consequence of this implementation, a zoom out of a root element, *e.g.*, a `Namespace`, does not affect the zoomed state of its children as their `shape` attributes are not modified. When zooming in again the view is restored to what it was previously, each child represented in the same way (either compact or extended) as it was before.

The above mechanism allows the visualization to draw each entity in its compact or extended state, according to the zoom level indicated by the user. To make zooming in and out on a given element interactive an extra step is however required: we need to dynamically replace the visualization of contents of the entity by new contents. At our request this feature was added to Mondrian by its maintainer. The `forNode:do:` feature takes a node in the visualization graph and replaces its current visualization with the results of executing a Mondrian script (given as a Smalltalk block). After such a replace operation, triggering a redraw of the visualization replaces the affected shapes and causes the layout of the figure to be adapted, if necessary. Note that the dynamic replacement of parts of the visualization differs from redrawing the entire diagram in more than just performance. Dynamic replacement respects the state of scrolling inside the visualization, while a complete redraw resets the view to the top left part of the visualization. The latter is clearly undesirable behavior for when performing a zoom operation.

Implementing the structural zoom is thus a straightforward combination of the above. The Mondrian scripts for `Namespace`, `Aspect`, `Class` and `Method` register a handler on left mouse button clicks: a Mondrian script that will be executed on a click within (specific parts of) their visualization. This script first negates the `shape` attribute, second uses `forNode:do:` to replace its contents being visualized, and third triggers a redraw.

5.1.3. The Mondrian Script as a Modular Extension of ASPIX

ASPIX, being an aspect-oriented extension of the FAMIX meta-model, was conceived as a generic meta-model for aspect-oriented code. The goal for ASPIX is therefore not only to be used for `AspectMaps`, but also for other cases where AO software needs to be analyzed using Moose. Hence the ASPIX model should be free of `AspectMaps`-specific code. The Mondrian script of `AspectMaps` however distributes responsibility of visualization of the different entities in an ASPIX model to these entities themselves. This is achieved by adding methods, attributes and traits to them. If this was performed naively it would pollute the ASPIX meta-model with `AspectMaps`-specific code, negating the generic nature of ASPIX. As this issue potentially applies to all Mondrian visualizations using the modular structure we outlined in Section 5.1.1, we now show how we avoided this pollution through a combination of Smalltalk class extensions, FAMIX properties and programmatically installing traits.

Smalltalk allows for methods of one class to be specified in more than one package thanks to its class extension feature. For example, we can perform a class extension of the class named `Aspect` defined in the package `ASPIX`: in the package `AspectMaps` we define a number of methods for visualization to the `Aspect` class. When the `AspectMaps` package is loaded, these methods are added to the `Aspect` class but remain part of the `AspectMaps` package. The Mondrian script of `AspectMaps` is defined in this way: all the methods added to the different entities are class extensions defined in the package `AspectMaps`. As a result the `ASPIX` package is not polluted by `AspectMaps`-specific methods. This solution however falls short on 2 points: the `shape` attribute and the application of traits. We discuss both next.

Smalltalk class extensions only specify new methods to be added to an existing class, they are unable to add extra state through instance variables. We however need to keep the zoom state of `Namespace`, `Aspect`, `Class` and `Method` in a `shape` attribute that therefore needs to be added to these entities. FAMIX allows for an alternate way in which attributes can be kept for model entities: the use of properties [9]. The advantage of the properties system is that getting and setting of properties can be performed purely by adding methods to the different FAMIX entities. As all ASPIX entities are also FAMIX entities we elected to keep the `shape` attribute as a FAMIX property. Consequently we successfully overcome the limitation of class extensions not being able to add extra state to a class.

Recall that to avoid code duplication in the Mondrian script, common behavior is refactored to a trait. This trait is then composed with the relevant entities in the ASPIX model to yield the full functionality. Trait composition however, like adding state, is not supported by class extensions. We therefore are required to perform trait composition in a separate step. To achieve this we implemented a small trait installer utility⁷ that allows for the installing (and uninstalling) of traits from within application code. As part of the startup routine, the `AspectMaps` tool uses this installer to ensure that the required trait is composed with the different entities in the ASPIX model. This results in the complete functionality of the `AspectMaps` visualization being present after the tool is opened.

⁷Available at <http://www.squeaksource.com/TraitsApplication.html>

To summarize, we were able to maintain a separation between ASPIX as a generic meta-model for AO code and the AspectMaps visualization while maintaining the modularity of the visualization code. To achieve this, we used Smalltalk class extensions to separately specify part of the behavior of the visualization, implemented a trait installer to compose the behavior that was refactored as traits on startup, and FAMIX properties to store the shape attribute.

5.2. Building the User Interface with Glamour

Moose contains a variety of tools to analyze software, for example FAMIX model exploration tools, a tool to build custom visualizations in Mondrian, a tool to build wizards, et cetera. Moose however does not provide any tool for building user interfaces and neither is such a tool available in Pharo. The tool offered by Moose that comes the closest to such functionality is Glamour [5]. It provides for defining only one specific kind of user interface, called browsers. In this section we present how we were still able to use Glamour to build the user interface for the AspectMaps tool. We show how the fundamental paradigm of Glamour can be adapted to apply outside of its intended context, making it usable as a more generic user interface tool.

5.2.1. Browsers According to Glamour

Glamour defines a browser as a user interface dedicated to manipulating models. Browsers visualize the model, allow to navigate in this model and perform actions on model elements where appropriate. One example is the Smalltalk code browser. It shows a fixed structure of a list of packages, a list of classes, a list of categories, a list of methods and a source code field. The browser allows to navigate from packages to classes, from classes to categories of methods, from method categories to methods, and from methods to their source code.

Visually, browsers consist of a collection of panes where each pane shows information specific to the data being browsed. For example, in the Smalltalk Browser the panes are the lists and the source code field being shown. For Glamour, the fundamental paradigm underlying navigation in browsers is the flow of one pane to the next pane. This is realized by having a pane continuously transmit its status to dependent panes. A Glamour specification, called a script, specifies the layout of the different panes of the browser, the contents shown in the different panes, and the transmissions between the different panes. A selection of, or an operation on an element in a pane produce a change in the transmission that is sent to dependent panes. This new transmission then contains the relevant data, *e.g.*, the item that was selected. Dependent panes update their contents on such changes, showing the required data. For example in a Glamour implementation of the Smalltalk browser a selection of a package transmits this selected package to the classes list pane. This pane then shows the classes present in that package.

5.2.2. AspectMaps in Glamour

The AspectMaps user interface however does not straightforwardly conform to this flow paradigm. Selecting an aspect to be visualized in the available projects list immediately shows the visualization in the Mondrian pane, without the other panes being involved. A button press in the Structural Zoom pane does not correspond to a selection of a model element. Moreover, an interaction in any of the other panes updates the Mondrian pane as well. Lastly, the information shown in the Classes, Methods, Aspects and Advice panes is a fixed set of metrics that does not originate from the list of available projects. Nonetheless, by using multiple sources of information flow, allowing empty transmissions and generating falsified selection events, we were able to build the AspectMaps tool using Glamour.

In the AspectMaps tool, the flow of transmissions between the different panes is as follows:

- The Mondrian pane is the destination of transmissions of all the other panes in the user interface except for the Aspects in Project. All of these therefore transmit their selection to the Mondrian pane.
- The Aspects in Project and Structural Zoom panes are also the destination of transmissions from the Available Projects pane, receiving selection events.
- The Available Projects pane is one source of information flow, showing the models present in the repository.
- The Classes, Methods, Aspects and Advice panes are a second source of information flow, showing the list of available metrics (which are available for all models).

The Mondrian pane thus refreshes itself whenever a transmission sent by any of the other panes in the user interface changes. Upon such a refresh, the behavior of the Mondrian script is to first process all its incoming transmissions before redrawing the visualization. This processing first ensures that at least a project has been selected for visualization. Second it enables that when another pane, *e.g.*, a metric pane, has no selection the model can still be visualized. Third it ignores the contents of selection events of the Structural Zoom pane, the reason for which we explain next.

The Structural Zoom pane is subject to a limitation in the current version of Glamour: buttons can only transmit selection events. However performing the zoom operations of the buttons do not correspond to a selection in the model. Instead, clicking on a button launches a visitor on the model, which toggles the `shape` attribute of the different entities accordingly. Therefore to update the visualization when the visit action is finished, a fake selection event is produced. This changes the transmission to the Mondrian pane, causing the visualization to be redrawn.

Recall that the Aspects in Project pane does not transmit its selection events to the Mondrian pane. This is so because it would entail that a selection of an aspect in the list would entail that the visualization is redrawn. This is however not the expected behavior, the visualization should only be redrawn in three cases: activation or deactivation of an aspect or if the aspect color is changed. To achieve this, we use an alternate method for redrawing the Mondrian pane as well as the Aspects in Project pane. This alternate method is the use of Announcement, which can be considered as the Pharo implementation of model-view-controller. Both the Mondrian and the Aspects in Project pane specify that they are dependent on a specific type of announcement that is posted when one of the three above events occurs. As a result both panes refresh themselves, taking into account the new status of the aspect.

The use of announcements is arguably more generic than transmissions, and the AspectMaps tool could possibly be re-implemented using only the former. Glamour however strongly favors the use of transmissions, making them much easier to specify and use⁸. We therefore restricted the use of announcements to a minimum, using them only when necessary. Finding the correct trade-off between the use of transmissions and announcements is out of the scope of this paper.

In our experience Glamour is an outstanding tool to build user interfaces, but only if the architecture of the user interface can be made to fit inside of the flow paradigm. Glamour scripts allow a wide range of functionality to be specified in a simple fashion. As a result implementing basic browsers is straightforward. Glamour is however not just limited to basic browser construction. It is also suited to build advanced browsers through more complex scripts, as shown by the AspectMaps tool.

6. Related Work

Although AOSD is a relatively young field of research, there exist some tools that use visualizations of a aspect-oriented programs to support various development tasks.

The AspectJ Development Toolkit (AJDT) [7] is arguably the most complete and mature tool suite for aspect-oriented programming. AJDT integrates tightly with the Eclipse IDE and offers various facilities for understanding the interactions between aspects and base code. For example, AJDT features the use of gutter markers in the source-code editor to indicate join point shadows for affected entities. Furthermore, AJDT offers a textual “Cross-references View” that lists the signatures of methods affected by an aspect. While these features can provide developers useful information, they do so at a very fine-grained level of granularity, making them less suited for *e.g.* providing developers a global overview of where a particular aspect intervenes in a system. AJDT also offers a dedicated visualization based on the AspectBrowser tool of Shonle *et al.* [24]. This Seesoft-inspired [11] visualization shows the classes and aspects in the entire project as bars, placed side by side. The height of the bar is proportional to the number of lines of code that are present in the entity. Within each bar, each line of source code of that entity is represented by a stripe. The color of this stripe depends on the aspects that intervene at this line of code. In contrast to AspectMaps, this visualization only provides information at this level of granularity. As a result it has scalability issues when considering a large amount of classes and does not reveal structure at a finer-grained level than classes, *e.g.*, showing which methods an aspect affects. Lastly, it does not visualize precedence relationships.

⁸Moreover the current announcement implementation is faulty, leading to a progressive slowdown of the tool when announcements cause the refresh of the Mondrian pane. The workaround is to close and reopen the AspectMaps window.

Other development environments also have some form of tool support for AspectJ. However this support is usually limited to a weaver (*e.g.*, for Netbeans [2], IntelliJ [3] and JBuilder [1]) and a view similar to the Cross-references view of AJDT (*e.g.*, for Netbeans and JBuilder).

Pfeiffer and Gurd [22] propose Asbro, a visualization tool based on Treemaps. A Treemap maps the nodes of a tree to rectangles in a plane, using a space-filling layout. Asbro represents classes or packages as rectangles that are colored with an aspect color if an aspect applies there. The authors assess their tool as being beneficial for obtaining a high-level overview of aspect application, and state that it is scalable up to on average 2100 classes. In contrast to AspectMaps, Asbro does not reveal aspect application at finer levels than types nor does it visualize aspect interactions.

Coelho and Murphy have introduced the ActiveAspects tool [6]. This tool uses an extension of UML to represent aspects, method execution advice and method call advice. As such a graph notation scales poorly when representing a large number of classes, ActiveAspects employs a number of heuristics to limit the number of visualized entities. As their user study has indicated, such a use of heuristics does not always align with the user's wishes. In contrast, our approach also allows developers — by means of the zooming functionality of AspectMaps — to only visualize part of the system. Rather than automating this process, we rely on users of our tool to manually determine which parts of the system are visualized. Furthermore, ActiveAspects does not provide information at a sub-method level, making it impossible to visualize interactions at one given shadow point.

Zhang et al. [28] present ITDVisualizer, an analysis toolkit for assessing the impact of structural modifications through AspectJ inter-type declarations on the behaviour of the system. Due to the inherent obliviousness of such declarations, it can become increasingly difficult for a developer to understand how a program will behave. They propose analyses to assess how the declarations impact the method lookup of the base program, and to identify how particular base-code entities are shadowed by inter-type declarations. To present the results of the analyses to a developer, an integration with Eclipse is offered by means of visual clues (markers) and dedicated views that represent the lookup impact and shadowing impact. This approach is complementary to ours: AspectMaps focusses on the visualization of shadow points while ITDVisualizer aids in comprehending inter-type declarations.

Lastly, the AspectScope work by Horie and Chiba [13] considers aspects as extensions to classes and displays the extended module interfaces of these classes. This however uses a textual tree-based representation, and therefore faces the same scalability issues as the AJDT cross-cutting view.

7. Conclusion and Future Work

Despite the possible advantages of aspect-oriented software development in terms of modularizing a software system, the use of such technology places a burden on a developer's ability to understand the system. Especially the presence of an implicit invocation mechanism — that lies at the heart of aspect-oriented programming, and that introduces an extra level of indirection — can make it difficult to understand overall system behavior.

The AspectMaps tool was introduced to alleviate this problem. AspectMaps offers a scalable visualization that shows the implicit invocations in the source code by visualizing join point shadows where aspects are intervening. Key features of this visualization are a selective structural zooming functionality that progressively reveals more information as a user drills down into the structure of the code, and a fine-grained representation of individual join points that reveals which aspects apply at that join point and in which order.

While AspectMaps is a stand-alone tool, it was conceived as an extension of the Moose reverse engineering platform. The main contribution of this paper is a discussion of the architecture of AspectMaps and the lessons learned from building our tool on top of Moose. Firstly, we introduced ASPIX (ASpects In famiX), which is our aspect-oriented extension of the FAMIX meta model, and discussed how our tool constructs such ASPIX models. Secondly, AspectMaps leverages some of the reusable frameworks and components that are offered by Moose. Our visualization is implemented using the Mondrian visualization engine; the interface of the tool itself was scripted using the Glamour language. Although these frameworks eased the development of AspectMaps, they have an impact on how the implementation of the tool itself is structured. We discussed the impact of this structuring and our experiences in overcoming the limitations that this caused.

There are multiple avenues of future work on AspectMaps. A first path is tackling the limits of the Java and AspectJ import process. Due to our reliance on a source code importer, we only are able to parse fully compliant Java

source code (and not able to import java files that also include AspectJ code). Moreover, we do not fully support all of the intricacies of Java, *e.g.*, anonymous inner classes. A second path is showing inter-type declarations. This is currently not supported (as said in Section 2) and can yield odd visualizations, *e.g.*, in Section 3.3 we encountered a collection of seemingly empty aspects. To tackle this our Eclipse plugin needs to also export this information, the ASPIX model needs to be extended to include inter-type declarations, and the visualization needs to be augmented to represent them. A third avenue of future work is showing join point shadows that apply to fields, which would require an analogue process as above. Lastly, AspectMaps could be extended to support other combinations of base and aspect language by implementing export tools that export their aspectual information to the .xcr format. In combination with (existing) exporters to the .mse format this allows these programs to be imported into Moose as ASPIX models and hence visualized in AspectMaps.

Availability, Additional Information

The AspectMaps tool is open source and available on the AspectMaps website <http://pleiad.cl/aspectmaps>. This page also contains more information, including some screencasts of the tool in action.

Acknowledgments

We wish to thank Éric Tanter, Jacques Noyé, Alexandre Bergel, Awais Rashid, Thomas Cleenerwerck, Kris De Schutter, Kim Mens, and Andrew Eisenberg for their invaluable feedback when discussing early versions of AspectMaps. Thanks also to Andrew Eisenberg for helping us understand the AJDT crosscutting model and Alexandre Bergel for helping out with Mondrian. We are grateful to Theo D’Hondt for supporting this research. This research is partially supported by the IAP Programme of the Belgian State.

References

- [1] AspectJ for jBuilder. <http://aspectj4jbuilder.sf.net/>.
- [2] AspectJ for NetBeans. <http://aspectj-netbeans.sf.net/>.
- [3] The AspectJ plugin for IntelliJ IDEA. <http://intellij.expertsystems.se/aspectj.html>.
- [4] M. Balint, T. Gîrba, and R. Marinescu. How developers copy. In *International Conference on Program Comprehension (ICPC)*, pages 56–65, 2006.
- [5] Philipp Bunge. Scripting browsers with Glamour. Master’s thesis, University of Bern, April 2009.
- [6] Wesley Coelho and Gail C. Murphy. Presenting crosscutting structure with active models. In *AOSD ’06: Proceedings of the 5th international conference on Aspect-oriented software development*, pages 158–168, New York, NY, USA, 2006. ACM.
- [7] Adrian Colyer, Andy Clement, George Harley, and Matthew Webster. *Eclipse aspectj: aspect-oriented programming with aspectj and the eclipse aspectj development tools*. Addison-Wesley Professional, 2004.
- [8] Arie Van Deursen. Ajhotdraw: A showcase for refactoring to aspects. In *In: Workshop on Linking Aspect Technology and Evolution. (2005, 2005)*.
- [9] Stéphane Ducasse, Tudor Gîrba, Adrian Kuhn, and Lukas Renggli. Meta-environment and executable meta-language using Smalltalk: an experience report. *Journal of Software and Systems Modeling (SOSYM)*, 8(1):5–19, February 2009.
- [10] Stéphane Ducasse, Oscar Nierstrasz, Nathanael Schärli, Roel Wuyts, and Andrew Black. Traits: A mechanism for fine-grained reuse. *ACM Transactions on Programming Languages and Systems (TOPLAS)*, 28(2):331–388, March 2006.
- [11] Stephen G. Eick, Joseph L. Steffen, and Eric E. Sumner, Jr. Seesoft—a tool for visualizing line oriented software statistics. *IEEE Trans. Softw. Eng.*, 18(11):957–968, 1992.
- [12] Johan Fabry, Andy Kellens, Simon Denier, and Stéphane Ducasse. Aspectmaps: A scalable visualization of join point shadows. Technical Report TR/DCC-2011-1, DCC – Universidad de Chile, Jan 2011.
- [13] Michihiro Horie and Shigeru Chiba. Aspectscope: An outline viewer for aspectj programs. *Journal of Object Technology, Special Issue: TOOLS EUROPE 2007*, 6(9):341–361, October 2007. http://www.jot.fm/issues/issue_2007_10/paper17/.
- [14] A. Kellens, K. Mens, J. Brichau, and K. Gybels. Managing the evolution of aspect-oriented software with model-based pointcuts. In *European Conference on Object-Oriented Programming (ECOOP)*, number 4067 in LNCS, pages 501–525, 2006.
- [15] Gregor Kiczales, Erik Hilsdale, Jim Hugunin, Mik Kersten, Jeffrey Palm, and William Griswold. An overview of AspectJ. In Jorgen L. Knudsen, editor, *Proceedings of the 15th European Conference on Object-Oriented Programming (ECOOP 2001)*, number 2072 in Lecture Notes in Computer Science, pages 327–353, Budapest, Hungary, June 2001. Springer-Verlag.
- [16] C. Koppen and M. Stoerzer. Pcdiff: Attacking the fragile pointcut problem. In *European Interactive Workshop on Aspects in Software (EIWAS)*, 2004.
- [17] Adrian Kuhn and Toon Verwaest. FAME, a polyglot library for metamodeling at runtime. In *Workshop on Models at Runtime*, pages 57–66, 2008.

- [18] M. Lanza and S. Ducasse. Polymetric views — a lightweight visual approach to reverse engineering. *IEEE Transactions on Software Engineering*, 29(9):782–796, September 2003.
- [19] J. Laval, S. Denier, S. Ducasse, and A. Bergel. Identifying cycle causes with enriched dependency structure matrix. In *Proceedings of the Working Conference on Reverse Engineering*, pages 113–122, 2009.
- [20] Adrian Lienhard, Adrian Kuhn, and Orla Greevy. Rapid prototyping of visualizations using mondrian. In *Proceedings IEEE International Workshop on Visualizing Software for Understanding (Vissoft'07)*, pages 67–70, Los Alamitos, CA, USA, June 2007. IEEE Computer Society.
- [21] M. Meyer, T. Girba, and M. Lungu. Mondrian: An agile visualization framework. In *Symposium on Software Visualization (SoftVis '06)*, pages 135–144. ACM, 2006.
- [22] J.-Hendrik Pfeiffer and John R. Gurd. Visualisation-based tool support for the development of aspect-oriented programs. In *AOSD '06: Proceedings of the 5th international conference on Aspect-oriented software development*, pages 146–157, New York, NY, USA, 2006. ACM.
- [23] M. Rinard, A. Salcianu, and S. Bugrara. A classification system and analysis of AO programs. In *Twelfth International Symposium on the Foundations of Software Engineering*, 2004.
- [24] Macneil Shonle, Jonathan Neddenriep, and William Griswold. Aspectbrowser for eclipse: a case study in plug-in retargeting. In *eclipse '04: Proceedings of the 2004 OOPSLA workshop on eclipse technology eXchange*, pages 78–82, New York, NY, USA, 2004. ACM.
- [25] P. Tarr, H. Ossher, W. Harrison, and S. Sutton. Degrees of separation: Multidimensional separation of concerns. In *International Conference on Software Engineering (ICSE)*, pages 107–119. ACM, 1999.
- [26] Sander Tichelaar, Stéphane Ducasse, Serge Demeyer, and Oscar Nierstrasz. A meta-model for language-independent refactoring. In *Proceedings of International Symposium on Principles of Software Evolution (ISPSE '00)*, pages 157–167. IEEE Computer Society Press, 2000.
- [27] V. Uquillas, S. Ducasse, and T. D'Hondt. Visually supporting source code changes integration: The torch dashboard. In *Proceedings of the Working Conference on Reverse Engineering (WCRE '10)*, pages 55–64. IEEE, 2010.
- [28] D. Zhang, E. Duala-Ekoko, and L. Hendren. Impact analysis and visualization toolkit for static crosscutting in aspectj. In *International Conference on Program Comprehension (ICPC)*, 2009.