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Capturing Dynamic Program Behaviour with UML Collaboration Diagrams

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Abstract

The UML provides means to specify both static and dynamic aspects of object-oriented software systems and can be used to assist in all phases of a software development process. With growing support by CASE tools, its applications become more and more widespread. In addition to the automatic generation of class code from diagrams, the recovery of static structure from source code has become common, too. In this paper however, we focus on the extraction of behavioural information from program code. We introduce a restricted meta model for Java code and present a new approach to extract the required data, which will then be rendered as UML collaboration diagrams.

Keywords: UML collaboration diagram, re-documentation, reverse engineering, Java, dynamic behaviour, meta model.

1 Introduction

The Unified Modeling Language (UML, [14] [15] [17]) provides means to describe static and dynamic aspects of object-oriented software systems with a graphical notation, which is founded on a semi-formal basis. It allows specification on different levels of detail (e.g. design vs. implementation) and therefore suits well to assist in all phases of software development processes. While many CASE tools support the UML today, some also provide a bridge between design and implementation through code generators. The most common deployment is the use of class diagrams to specify the static structure of a program which is then converted into a number of class stubs in a given programming language.

In [5], it is shown that it is also possible to adapt this procedure to dynamic behaviour. The authors present an approach for the transformation of collaboration diagrams into Java code. Diagrams are used to graphically specify the functional behaviour of objects in terms of the interactions between them. For each object, the collaboration context is shown and also, the methods called at other objects are displayed in temporal order of their invocation. The diagrams are used as input for a set of transformation rules, from which Java code segments can be derived.

While the application of UML in CASE tools assisting forward engineering processes is rather wide-spread concerning modeling of static structure, some tools like Rose [16] and Together [20] additionally provide reverse engineering facilities in the same field. From existing source code provided as input, UML class diagrams can be created which describe the static aspects of the software. Further research on this subject involves lifting these implementation-view class diagrams to a more abstract level to allow deployment of the more advanced features of UML [6].

Concerning forward engineering, modeling and code generation of dynamic behaviour are also supported by some CASE tools, like e.g. Rhapsody [9] and Statemate [10]. Both use UML statecharts as specification notation. In an effort to realize roundtrip engineering of static as well as dynamic program structures, the Fujaba environment [21] combines both forward and reverse engineering techniques. It is based on UML diagrams and *story driven modeling* (SDM) [11].

In this paper, we present a UML-based approach to extract information about the dynamic behaviour of programs and show additionally, how UML collaboration diagrams can be used for graphical representation of the results. To our knowledge, reverse engineneering of Java with UML collaboration diagrams has not been studied before. Our approach is meant to yield a partial program-flow analysis. As [5] elaborates, collaboration diagrams are suitable as a basis for automatic code generation for operations. This diagram kind allows to describe the interaction of objects by means of messages exchanged between them, as well as the *collaboration context*, i.e. the structural information upon which the interaction relies. However, it is not possible to specify all dynamic aspects of a given system. Therefore, we focus on the aforementioned two kinds of information, namely object interaction and collaboration context.

To give a better understanding on how we intend to use collaboration diagrams for showing the dynamic behaviour of Java programs, we present a small example that shows two simple classes exchanging messages.

```
public class HelloWorld{

    public HelloWorld(){
        hello();
    }

    public void hello(){
        System.out.println
            ("Hello World");
    }
}
```

The focus of the collaboration diagram in fig. 1 is on method `hello()` from class `HelloWorld`. The "user" stereotype icon on the left represents an external caller of the method who is not relevant here. The call from the user shows always the examined method and points to the class declaring it. The only action in method `hello()` is a call to `println()` from class `PrintStream`, via the static attribute `out` from class `System` (this is the usual way of calling `println()` in Java). The collaboration context shows therefore instances of classes `HelloWorld` and `PrintStream` as well as a link between both with the attribute name on it. The interaction encompasses the call to `hello()` from an external user and the call to `println()` from `HelloWorld` to `PrintStream`.

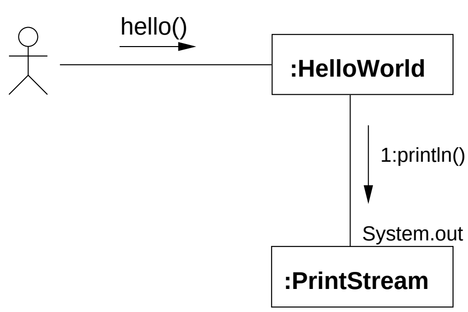

Figure 1. A Collaboration Diagram for HelloWorld

Our approach relies on the UML meta model and proposes a restricted Java meta model. As far as we know a meta model in the style of the UML meta model has not been yet proposed for Java. However, as the meta models for OMT in [4] and Booch in [19] show, UML was by far not the first object modeling technique with a meta model as a formal foundation.

In the field of reverse engineering, related work encompasses [18], which describes the use of high-level petri nets to reverse engineer Java applets and [3], which concentrates on parametrized Java types. [2] analyses the UML with a focus on round-trip and reverse engineering capabilities, while [1] employs UML for the reverse engineering of web sites. Lastly, the results of this paper are influenced by our earlier work on properties of UML class diagrams [7].

The following sections of this paper are structured as follows. In section 2, we will introduce a meta model for parts of Java, which will allow us to bring the necessary information from the Java code into a canonical form, which in turn enables us to extract information about the static structure as well as the object interaction. Based on the mapping rules introduced in section 3, we present a recursive algorithm for the processing of the information from an instance of the meta model in section 4 and go through an exemplary application in section 5. We close with considerations about questions of applicability and a final conclusion.

2 Java Meta Model

To analyze programs written in Java, it is at first necessary to know their structural composition (a complete description of the language can be found in the Java Language Specification [8]). A specification of the program structure is not only required for the mere parsing of the program code (in Java, this may be source code or byte code). In our approach, it is also important for the following step of processing the data: In the given scope of representing existing program structures with UML diagrams, we decided to take a similar approach for our specification of the Java language. In the fashion of the UML document [13], a meta model is used for this purpose. The meta model is based on information from the Java Language Specification and focuses on those parts that are necessary for the creation of collaboration diagrams. The data extracted from the program code may be represented as an instance of the meta model, which will be used for the generation of the final collaboration diagrams.

Since Java has - as can be expected from an object-oriented language - a certain level of complexity, it is clear that there are certain parts of the language description that are irrelevant with respect to the goals headed for in this paper: There is no representation for them in our meta model. The meta model presented here should contain only those parts that are required for the rendering of collaboration context and interaction between objects. Two UML class diagrams suffice to capture these: diagram "Types" (fig. 2) shows the coherence between types and values, their specializations as well as the classes needed to interconnect both. Thereby, the relation between classes and objects is modeled, too. The left generalization hierarchy shows values specialized to primitive and reference values which are again specialized to null references. The right generalization hierarchy displays Java types with specializations to primitive and reference types which again are specialized to interface, class and array types. The connection between these two hierarchies is established by the class Variable and the class JavaObject: Variables hold values and possess a declared type; JavaObjects are pointed to by ReferenceValues and also possess a type. Note that the declared type of a Variable is not necessarily the same as the type of the Object: each Object is an instance of a Class that must be compatible with the declared type of the Variable which holds the reference pointing to the Object. The declared type of a Variable is known at compile-time, while the dynamic type of the Object (i.e. the Class that the Object belongs to) can only be determined at run-time.

The second diagram "Invocations" (fig. 3) describes those parts of Java method structures which are necessary for the representation of the relations between classes and methods as well as the invocation of methods by concrete objects. Classes and also methods may have references to objects and additionally, in methods, the invocation of other methods on objects can be specified. This requires the meta model to provide associations between these different conceptual entities. An invocation refers to exactly one method, has many parameter variables, has a return value variable and an owner being again a variable. A method has formal parameters, a result type, and is owned by a class. Which method is actually associated to the invocation depends on the dynamic type of its object.

For some of the classes from the meta model, constraints exist which cannot be expressed by means of the class diagram notation itself. Therefore, it is necessary to refine the meta model with additional constraints, which are given in OCL [12] notation. The main issue of these is to ensure consistency between values and types. The following set of OCL expressions is an exemplary excerpt from the complete list that would be necessary for translation of Java programs into collaboration diagrams. It shows a selection of the basic constraints which are required for the example in section 5.

Array

1. The type of an Array must always be ArrayType.
```
context Array inv:
self.type.oclIsKindOf(ArrayType)
```

ClassInstance

1. The type of a ClassInstance must always be ClassType.
```
context ClassInstance inv:
self.type.oclIsKindOf(ClassType)
```

ClassType

1. The name of the `instance` field, referring to the object created when calling the classes' constructor, is always `"this"`.
```
context ClassType inv:
self.instance.name="this"
```

Variable

1. A variable holding a primitive value always has a primitive type.
```
context Variable inv:
self.value.oclIsKindOf(PrimitiveValue)
implies
self.type.oclIsKindOf(PrimitiveType)
```

2. A variable holding a reference value always has a reference type.
```
context Variable inv:
self.value.oclIsKindOf(ReferenceValue)
implies
self.type.oclIsKindOf(ReferenceType)
```

3. The type of a Variable must always conform to the type of the JavaValue held by the Variable.
```
context Variable inv:
self.value.type.oclIsKindOf
                    (self.declaredType)
```

Invocation

1. The type of an invocation's return value must conform to the result type of the invocation's method.
```
context Invocation inv:
self.returnValue.type.
oclIsKindOf(self.method.resultType)
```

Both diagrams have an intersection (the classes JavaType, ClassType, and Variable) which can be regarded as the core of the meta model. However, the information shown in this part differs. For the concerned classes, only those attributes and associations are shown that are relevant in the respective context. This approach of showing data selectively is consistent with the UML semantics guide.

The association `ClassType.instance` for example appears in the Invocation diagram for better readability but primarily, because it is only relevant for the representation of the runtime structure. It refers to the variable which is called `this` in the source code, i.e. the object of a certain class that is created when the classes' constructor is called.

3 Mapping Rules

Once an instance of the meta model has been created, a set of rules is needed that specifies how to use the information represented by it for the construction of the desired

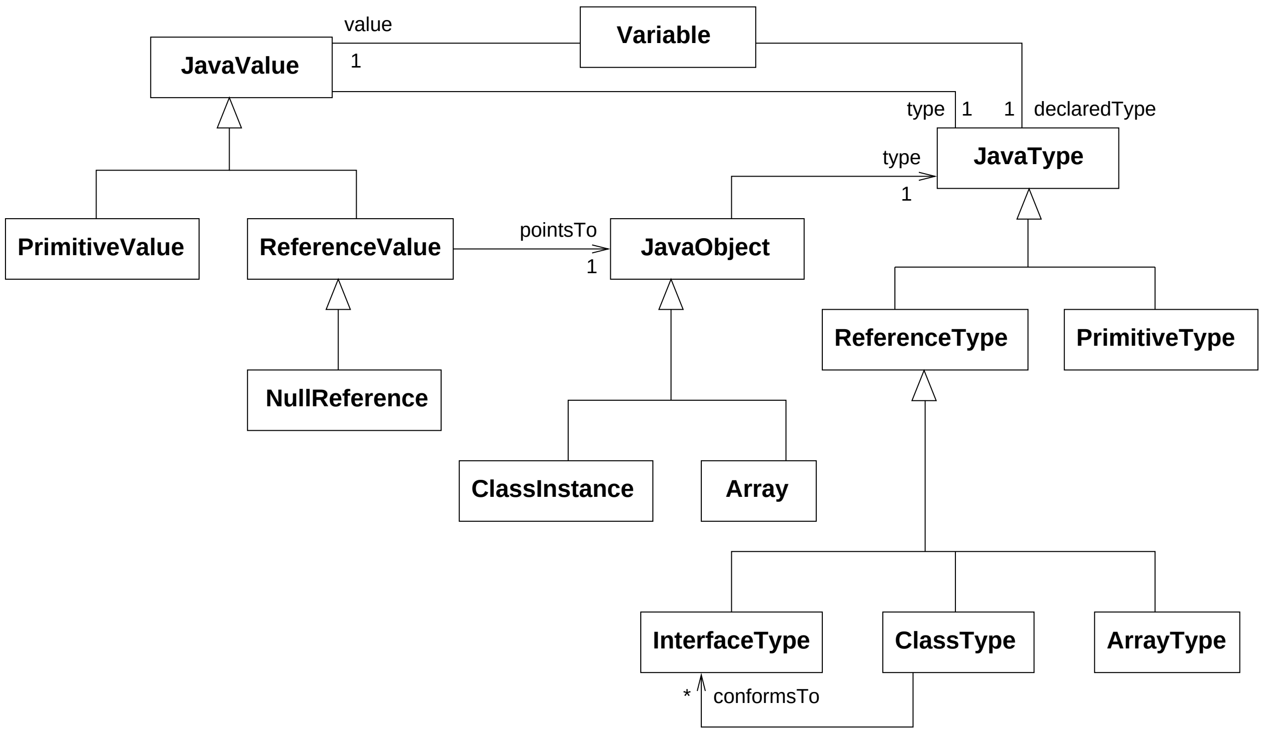

Figure 2. Types

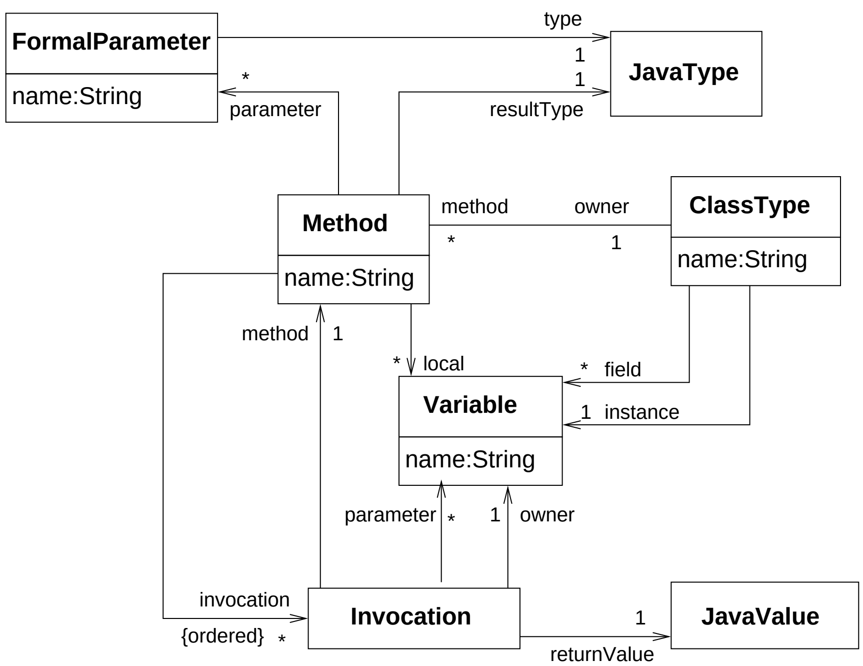

Figure 3. Invocations

view on the program code. In our case, the view is a collaboration diagram. A crucial point in this translation is that in our model, we have only descriptions of classes, some of them with object-valued attributes, while in the resulting collaboration, we show only instances of the classes. Therefore, we have to provide rules for the representation of attributes and their transformation into elements of the collaboration context, and also for the transformation of classes into such elements.

Anticipating section 4 that describes the procedure of translation, two possible cases emerge which indicate that an object has to be added to the collaboration context: it may be the source of a method invocation or its destination. Invoking a method requires that a link exists between the source and the destination object. After determining the source and destination object of a link, both have to be examined if they are already part of the context. If not, they are added.

The rules are divided into two parts: The first one holds rules for the creation of links, which belong to the collaboration context. The second part contains rules for the establishment of messages between objects, i.e. the interaction between objects.

1. The connecting links between objects are derived from a classes' member variables. If source and destination object of a link are identical, the link is a self reference and the stereotype self is added to it.

   (R.1) `ClassType.field` holds information about a link between two objects.

   (R.1a) `ClassType.name` → Type of the link's source object.

   (R.1b) `ClassType.field.declaredType` → Type of the link's destination object.

   (R.1c) `ClassType.field.name` → Rolename at destination end. Since a link is used here as a representation of a class attribute, no rolename is given for the source end of the link.

2. A method invocation is shown in the collaboration diagram as a message between two linked objects.

   (R.2) `Method.invocation` → Message between two objects.

   The source object from which an invocation is performed is given by a reference to the class declaring the method. In the resulting collaboration diagram, this object is the originator of the message. For example, given an invocation `out.println()` that is part of the method `hello()` in class `HelloWorld`, `HelloWorld` is the class declaring the method in question (`hello()`) and the source object is an instance of this class.

   (R.2.1) `Method.owner.instance` → Source object of invocation.

   The source object's type is `Method.owner.instance.declaredType`, which can be validly shortened to `Method.owner`, because the attribute `instance.type` of a class is always its identity.

   (R.2.1a) `Method.owner` → Type of invocation-source object.

   The destination object on which the invocation of a method is performed is either a self reference to or a member attribute of the owner class, or held by a variable of the method declaring the invocation. For example in an invocation `out.println()`, `out` is the destination object. For an invocation `println()`, where the object is omitted, the destination object is implicitly `this`.

   (R.2.2) `Method.invocation.owner` → The invocation's destination object (the object, on which the invocation is performed).

   (R.2.2a) `Method.invocation.owner.declaredType` → Type of invocation-destination object.

   The name of the invoked method is used as message label. In terms of the aforementioned HelloWorld example, `println()` is the method name that is used as label for the message sent from the source object of type HelloWorld to the destination object `out` (whose type is not relevant here).

   (R.2.3) `Method.invocation.method.name` → Message label.

4 Procedure

The transformation procedure consists of two modular parts, which convert the information from the Java program code into a canonical form and then create a collaboration diagram from it. In the first step, the information from the program code is represented as an instance of the Java meta model introduced in section 2. No transformation occurs in this stage, since the diagrammatic form is just another representation of the information contained in the program code. However, this notation shows intentionally only a subset of the information.

Once the model is complete, it is imaginable to apply different strategies to it to extract and transform the contained information. This way it is possible to create different views of the same model, depending on the aspects that are to be emphasized. In the context of this paper, we create a collaboration diagram to show the interaction between classes by using the algorithm presented below, which is given here in an OCL-like pseudo code to distinct it from the Java code of the example following afterwards.

```
traverseModel(m:Method){
  for each inv:Invocation in m do{
   //[*]
    source:Variable=m.owner.instance;
    dest:Variable=inv.owner;
    addContext(source, dest);
    addInteraction(source,
                   dest,
                   inv.method)

   traverseModel(inv.method)
  }
}
```

[*]: The `source` of an `interaction` is always the `this` instance created by the owner class of the observed method, as the owner class holds the specification of the method, which is given by the method's source code in the respective class.

The method `traverseModel(...)` describes the algorithm that is used to extract the information from the model (see fig. 4 for an example situation). It traverses parts of the model's underlying datastructure in depth-first order and constructs the collaboration diagram. In the initial call, it is passed a reference to the method for which the diagram is generated. Based on the entities of the model and the transformation rules given above (see section 3), it establishes the new catenations and entities that constitute the collaboration diagram. When using only the method `addContext(...)`, the collaboration context is established by adding the respective `source` and `dest` objects to the object model of the collaboration (if not yet contained) and by establishing links between them. When using the method `addInteraction(...)` too, the complete diagram including the description of the dynamic behaviour (i.e. the messages exchanged between objects) is created.

Note that the collaboration context created by the algorithm contains only those objects that are involved in the interaction. Attributes of classes or methods that are not used for method invocation do not appear. This characteristic pays tribute to the intention of this paper, not to emphasize the static structure of the program code, but its behavioural aspects as well as the underlying parts of the static structure.

5 Example

This section presents an example that uses the algorithm described above to create a collaboration for a simple method from the Java source code given below. The code describes a window (as part of a graphical user interface) holding a text pane (i.e. a container displaying a string of ASCII characters). The pane in turn has a content, which holds the text string to show in the pane. We want to capture the collaboration and interaction of the method `Window.display()` that displays the window and its content on the screen. The actual drawing is done by the method `drawDecorations()`, which is not interesting here. The method `draw()` from `TextPane` is called by `Window` to delegate the rendering of the pane to the component itself. To do so, `TextPane` must first request its current content by calling `getContent()` on its `Content` attribute and then calling `paint()` to do the actual rendering. This finishes the procedure.

```
public class Window{
    private TextPane tp;
    public Window(){tp=new TextPane();}

    public void display(){
        this.drawDecorations();
        tp.draw();
    }
    private void drawDecorations(){
        //draw the window and borders
    }
}
public class TextPane{
    Content c;

    public TextPane(){}

    public void draw(){
        String tmp = c.getContent();
        paint(tmp);
    }

    private void paint(String s){
        //draw String into Pane
    }
}
public class Content{
    private String content="";

    public Content(String s){
        this.content = s;
    }
    public void setContent(String s){
        content=s;
    }
    public String getContent(){
        return content;
    }
}
```

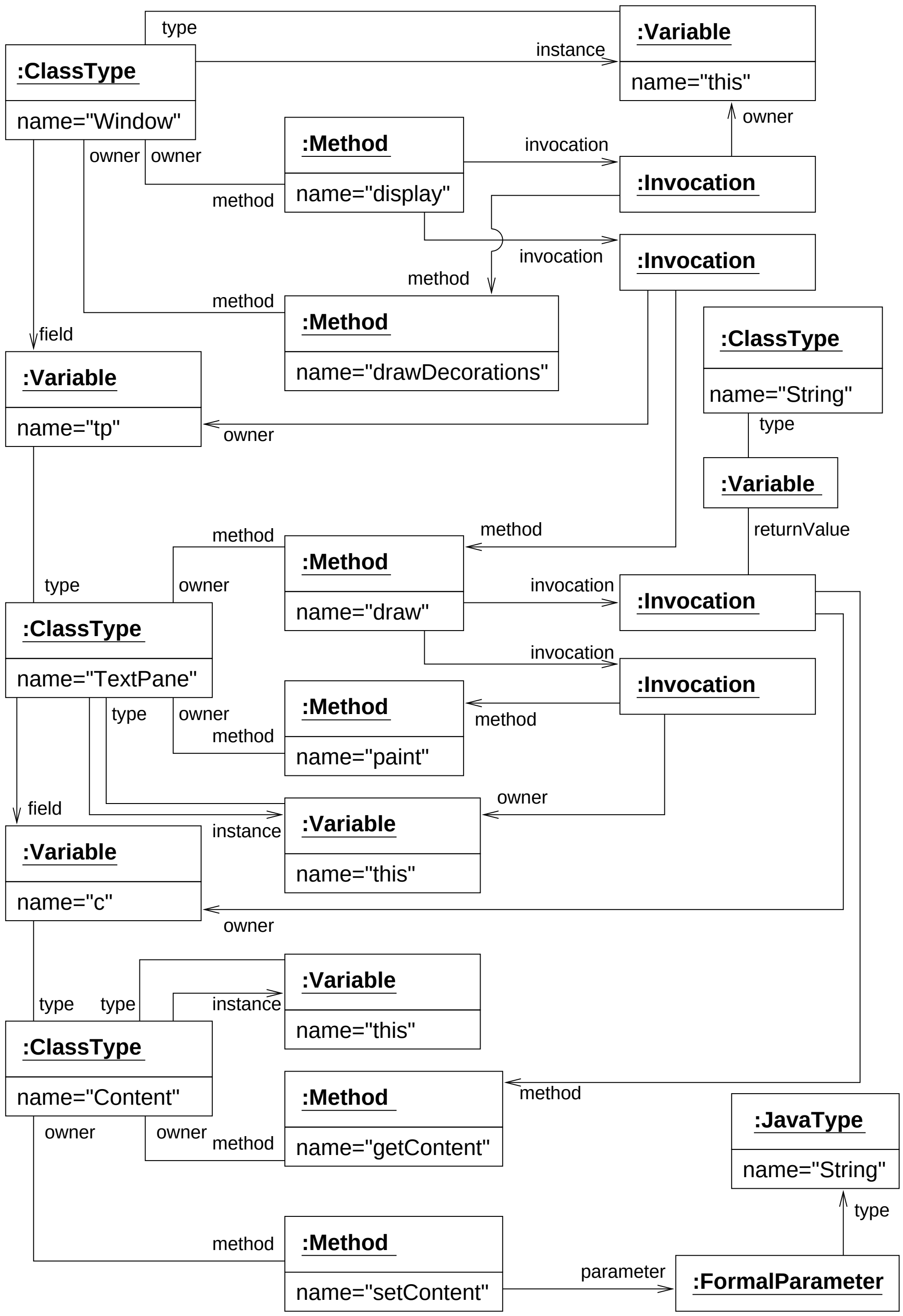

Figure 4. A model that represents the information from the source code

In a first step, the source code is represented as an instance of the Java meta model (fig.4). Now, `traverseModel(...)` is called with method `Window.display()` as parameter and starts walking through the data structure of the model. The first invocation encountered is a call to `drawDecorations()`. Its underlying link is a self reference to Window, as the link's source and destination are identical. The "this" instance of Window is added to the collaboration context and the link is added with the stereotype ≪self≫. Now, the new message is added to the interaction, with the label of the message being provided by the attribute `method.name` of the invocation.

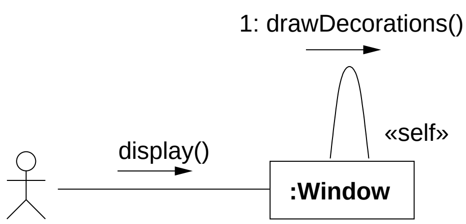

Figure 5. Collaboration Diagram after 1st iteration in display()

In the resulting (yet incomplete) diagram, the caller of `display()`, who is not part of the given source code, is shown as a stereotype icon as shown in [14].

After finishing the first invocation, the `traverseModel(...)` calls itself with `drawDecorations()` as parameter. However, this run does not yield any new insights, as the method does not contain any invocations. The method returns to its previous recursion depth and continues the examination of `display()`.

The second invocation encountered in `display()` is a call to method `draw()`. The source object of the new link is again the self instance of class Window (as for all invocations from a method declared in this class). The destination object, given by the invocation's `owner` attribute, is a Variable with name "tp" and type TextPane. As it is not part of the collaboration context yet, it is added to it, as is the new link. The Variable's name is used as rolename at the link's destination end.

Having finished the second iteration, `traverseModel(...)` calls itself with `draw()` of class TextPane as a parameter. Note that the focus of the algorithm has moved now not only to another method, but also to a different class: The source object of the underlying link is still the "this" instance, but this time of class TextPane, which declares `draw()`.

The first invocation encountered is a call to `getContent()`. The destination object is again given by the invocation's owner, a Variable 'c' with type Context. The new object as well as the link are added to the collaboration context. Then, the new message is added to the diagrams interaction part.

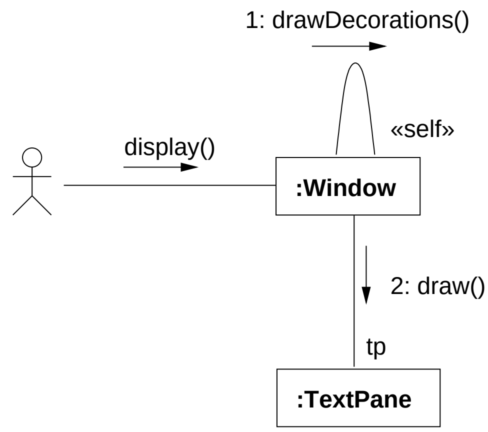

Figure 6. Collaboration Diagram after 2nd iteration in display()

The first two messages (fig. 6) are numbered on the same nesting level, as both are sent from the same source (the instance of Window). For the call of `getContent()`, a new situation arises, as this is a subsequent call, originating from method `draw()` (which in turn was called by `display()`). Therefore, a new nesting level is added for the call to `getContent()` (fig. 7).

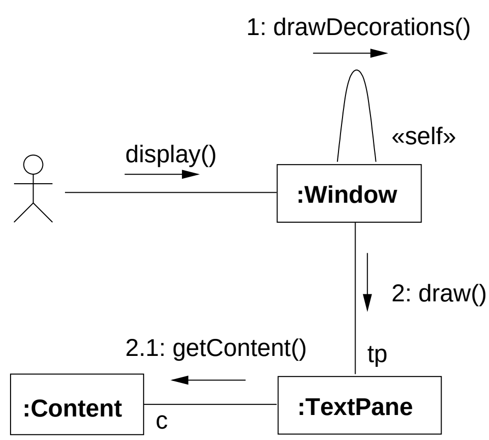

Figure 7. Collaboration Diagram after 1st iteration in draw()

As `getContent()` does not contain any method invocations, `traverseModel()` returns immediately from it and continues with method `draw()`.

The last invocation in `draw()` is a call to `paint()`, which is declared in class TextPane(). Source (the "this" instance of the class declaring `draw()`) and destination (the owner object of the invocation of `paint()`) are identical, what means that the link underlying the message is a self reference. As the respective object (the instance of TextPane) is already part of the collaboration context, only the new link has to be added to it.

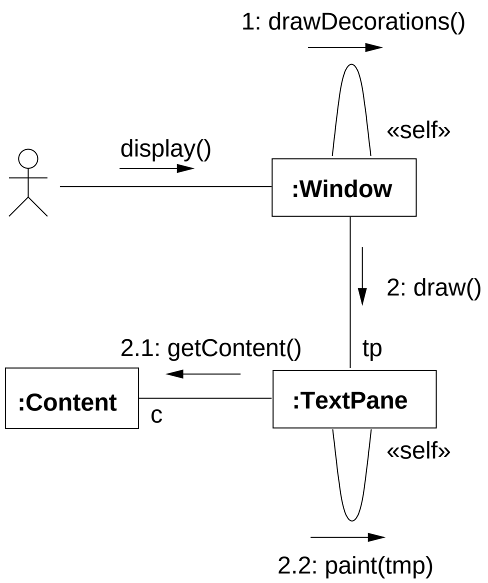

Figure 8. Collaboration Diagram after 2nd iteration in draw()

After adding the message to the diagram, the algorithm jumps into method `paint()`, which does not contain any invocations. Therefore it returns immediately and, as there are no further invocations, terminates.

6 Questions of Usability

The application of collaboration diagrams as described in this paper appears to be useful in many cases. However, the observed methods should not be too large with respect to the number of invocations and referenced objects. For relatively long method bodies, the resulting diagrams tend to be rather long winded. In this situation, it will be possible to use rewrite rules to simplify complex diagrams to simpler and more abstract ones (like we have done this for class diagrams in [6]). For example, it is imaginable to examine the program code for interaction patterns that may be represented with a more compressed notation. This is subject to further research.

Especially concerning non-trivial systems, a sensible use of collaboration diagrams requires a certain degree of interactivity between the communicating objects in question. For the simple cases, a tabular list of method calls can be rendered more easily and provides often better lucidity.

By means of collaboration diagrams, causal chains of method calls can be emphasized while still having the object relations present. However, with increasing size of the chains, the application of sequence diagrams seems more appropriate here and will be studied in the future.

Collaboration diagrams were not originally meant to document Java code, but to model the relationships between objects which play different roles, as well as the interaction between them. If the procedure is reversed as described in this paper, this implies that in the resulting diagrams, only those elements of the Java code can be shown, for which a representation exists in collaboration diagrams. This means that the view on the program code is actually restricted by the way collaboration diagrams are defined in the UML meta model. To amend this, it would be necessary to extend the meta model. For this reason, not all elements of a Java method can be shown precisely by means of a collaboration diagram. This is however, as already stated in the introduction, not the intention of this approach, which aims at the documentation of the relationships between objects and their interaction.

7 Summary and Conclusion

In this paper, we have shown a new approach for capturing information on static structure as well as dynamic behaviour of Java program code. Our approach bases on representing code structures as instances of the Java meta model, which is also presented in this paper and which is based on the Java language specification in [8]. An algorithm is presented which walks through parts of a meta model instance and thereby creates a collaboration diagram showing the object relationships and interaction. The functionality of the algorithm depends on a set of mapping rules that specifies how certain parts of the meta model instance are to be interpreted and used in the resulting diagram.

It is possible to create different views of the program code by exchanging or modifying the algorithm that collects the required information and by providing a new set of mapping rules. With our approach, the dimension of these views is limited not only by the UML meta model (as mentioned before), but also by our Java meta model. It is imaginable to specify views which require extensions or modifications of this meta model. To capture the program flow of methods diagrammatically, for example, it would be necessary to extend the meta model by adding information about program flow constructs, like e.g. iteration and loop.

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