# Graphical Debugging of Distributed Applications
## *Using UML Object Diagrams to Visualize the State of Distributed Applications at Runtime*

Andreas Koch and Albert Zündorf
*Software Engineering Research Institute, Kassel University, Wilhelmshöher Allee 73, Kassel, Germany*

Keywords: Tool, Debug, Distributed, UML2, Objectdiagram, Eclipse.

Abstract: While debugging is one of the most time consuming tasks software developers perform, the tool support, especially for distributed applications, is lacking according to many professional developers. The Visual Debugger is an approach to provide an easy-to-use tool which gives software developers an abstract view on the current state of their application in debugging sessions. While similar tools for non distributed applications already exist, the Visual Debugger addresses the more complex debugging scenarios in distributed applications. Therefore, several views with different levels of abstraction of the current state of an application are provided. Although the approach may be adapted to other object oriented programming languages, the current target of the Visual Debugger is languages running on the Java Virtual Machine with the focus on Java.

## 1 INTRODUCTION

Debugging is one of the most time consuming tasks in the daily work of a software developer. To tackle this challenge, many tools were developed in research as well as in the industry. Additionally, in each modern IDE as Eclipse, IntelliJ IDEA or NetBeans some kind of debugging support is already integrated. Although so much work was invested into this area, there are still many professional software developers not satisfied with the provided support of debugging tools. (Layman et al., 2013)

Started in a research project with industrial partners, the Visual Debugger presented in this paper is an approach to fill the gap of an easy-to-use, but helpful visualization of the state of distributed and non distributed Java applications as a helper in debugging sessions.

To explain the usage of the Visual Debugger, at first it must be positioned in the debugging process. This process can be separated into several steps:

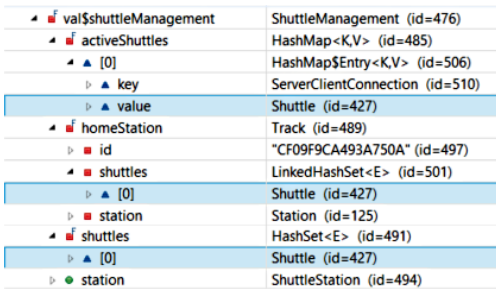
1. An unwanted behaviour of an application takes place.
2. The problematic part of the source code is located.
3. The source code is changed to prevent this behaviour.
4. The test scenario is reproduced to ensure this changed behaviour is correct.

The steps 1, 3 and 4 are already well supported by tools and frameworks like logging or testing frameworks, mature source code editors and more. In contrast, the second step is the most crucial and most time consuming part of this process because there are a lot of different sources of an unwanted behaviour, that must be considered: logical failures in algorithms, performance issues, not catched exceptions and many more.

Most of these sources result in the same simple outcome: values are changed or not changed as expected. To find a reproducible test scenario to trigger unwanted behaviour can be challenging. But even if this scenario is found, the search for the erroneous source code is difficult. One common problem is the inability to understand the current state of the application in a reasonable amount of time when the unwanted behaviour occurs.

Apart from the research area, in the industry, most available debugging tools focus on a textual view on the application state. One example, which can be found in most IDEs and therefore is probably the most used tool during debugging sessions, is a tree representation of the runtime state of objects like the variables view in the Eclipse IDE in figure 1. This has indeed proven to be useful in many debugging situations, but tends to be less helpful in object oriented programming languages when the application state becomes more complex. One reason is the visualiza-

Koch A. and Zündorf A..
Graphical Debugging of Distributed Applications - Using UML Object Diagrams to Visualize the State of Distributed Applications at Runtime.
DOI: 10.5220/0005233202230230
In *Proceedings of the 3rd International Conference on Model-Driven Engineering and Software Development* (MODELSWARD-2015), pages 223-230
ISBN: 978-989-758-083-3
Copyright © 2015 SCITEPRESS (Science and Technology Publications, Lda.)



```
◢ val$shuttleManagement        ShuttleManagement  (id=476)
  ◢ activeShuttles             HashMap<K,V>  (id=485)
    ◢ ▲ [0]                    HashMap$Entry<K,V>  (id=506)
      ▷ ▲ key                  ServerClientConnection  (id=510)
      ▷ ▲ value                Shuttle  (id=427)
  ◢ homeStation                Track  (id=489)
    ▷ ■ id                     "CF09F9CA493A750A" (id=497)
    ◢ ■ shuttles               LinkedHashSet<E>  (id=501)
      ▷ ▲ [0]                  Shuttle  (id=427)
    ▷ ■ station                Station  (id=125)
  ◢ shuttles                   HashSet<E>  (id=491)
    ▷ ▲ [0]                    Shuttle  (id=427)
  ▷ ● station                  ShuttleStation  (id=494)
```

Figure 1: A snippet of the Java heap in the Eclipse variables view.

tion of a graph structure in a tree. Relations between objects are only visible from one object to another. This results in duplications of objects in the variables view, when different objects have relations with the same child. As an example: browsing the state of the topmost object in figure 1 (id=476), the highlighted object with id 427 is reachable (and therefore visible) three times with different paths. Another reason this view is problematic in distributed (or concurrent) scenarios is, it only provides data for the current state the user is looking at. Resuming the program execution results in losing the current viewpoint and the state needs to be re-evaluated again at the next interruption of the execution. The situation is worsened when a distributed application comes into play. This increases the complexity of the state of an application. Usually objects live on different Java Virtual Machines (JVM) on the same or even on physically separated devices.

Hereinafter, the terms object and instance are used in the following way. While the term instance is used to describe the instantiation of a class in a (single) JVM, object is used when two or more equals instances on different JVMs are meant.

Understanding the current state of a distributed application becomes more difficult, because during a debugging session much more state changes take place. Each time the developer is forcedoo to re-evaluate the state. The identification of different instances of an object on different JVMs complicates a debugging session as these state changes force developers to identify equal instances on different JVMs again and again. Additionally, unexpected program behaviour is more difficult to reproduce, which often results in repeatedly executed debugging sessions until the unwanted behaviour appears again and the source behind it can be located. During the debugging sessions a lot of time is spent to understand the current state. The focus of the Visual Debugger is to provide an abstract view on the part of the application state that is relevant for a debugging session.

Due to the different requirements distributed and non distributed applications have, the Visual Debugger provides two modes. One, which targets mainly on applications running in a single JVM and another mode, that adds additional functionality to support the visualization of distributed applications. This paper focuses on the second mode, but explains in the following sections some basic behaviour which is valid for both modes and necessary to understand the sections focused on distributed scenarios.

## 2 RELATED WORK

Although graphical debugging tools are researched quite well, they are rarely found as commercial product. Especially when distributed applications come into play, most existing tools are limited in their usability. Besides, many of these tools focus on visualizing program behaviour instead of the application state.

Some tools that follow a similar idea as the Visual Debugger are Jive (Gestwicki and Jayaraman, 2005) and the eDobs (Geiger and Zündorf, 2002) (Geiger and Zündorf, 2006). But both tools lack of support for the special requirements of distributed applications.

There are tools, that are targeted at distributed applications, but serve a different use case. One example for this tool section is the JRastro (da Silva et al., 2003). While the Visual Debugger provides an abstract view on the state of the application during the execution, JRastro helps with finding performance problems by visualizing the communication between the different nodes of the application. Tools following a similar idea than JRastro are Atropos (Lönnberg et al., 2011), JACOT (Leroux et al., 2003) or JaVis (Mehner, 2001).

JAVAVIS (Oechsle and Schmitt, 2001) shows the internal behaviour and state of an application with UML sequence and object diagrams. But its usability for distributed applications is limited as it is targeted on sequential program execution.

JAN (Löhr and Vratislavsky, 2003) uses object diagrams to visualize the state of an application, but its focus is on the animation of different states of an application to understand the behaviour of a program instead of debugging it.

## 3 ARCHITECTURE OF THE VISUAL DEBUGGER

To visualize a complex graph structure like the Java heap, an obvious choice is to use an object diagram.

In the Visual Debugger standard UML2 object diagrams are used. While this forced us to use a strongly formalized and predefined syntax, it provides easy interoperability with other tools. Each model created during a debugging session can be used as input in other UML compatible tools, for example as part of the test documentation.

Three of the main design goals were to create acceptance, simplicity and usability. Creating acceptance is difficult because many software developers have an existing workflow and a given set of tools they use in their daily work. To get into this workflow a tight integration into the tools they use is necessary. For Java developers this includes on the one hand developing a tool for their IDE of choice and on the other hand integrating the tool into already existing tools in the IDE itself. To achieve simplicity, the information to be shown in the object diagram should be as few as necessary for the current debugging session and easily extendible/reducible by the user. Usability can mainly be achieved with a well designed UI. This is one point many existing research tools for debugging are lacking of. Therefore, we decided to use an existing object diagram editor and extended it when necessary.

As already mentioned, the Visual Debugger was not planned as stand-alone application but a tool integrated into existing IDEs. Due to their plug-in support, the first choice was to develop it as a plug-in for the Eclipse IDE. The decision in favour of Eclipse leads to several benefits. At first, it is well established in the open source as well as in the commercial community. Eclipse is based on the Open Service Gateway initiative (OSGi) specification and has an easy to use plug-in architecture. At last, with the Java Development Tools for Eclipse (JDT) there is a layer available for the Java Debug Interface (JDI).

The drawback is that a tight entanglement with the Eclipse IDE must be provided for a good usability. To antagonise a too strong coupling the Eclipse and JDT related parts of the Visual Debugger are split into Eclipse specific and more general plug-ins.

With the focus on Java applications the data necessary to visualize the heap must be retrieved directly from the JVM. Running a JVM application in the debug mode makes those data accessible via the JDI. The JDI is a component in the Java Platform Debugger Architecture (JPDA). It provides a set of interfaces for retrieving and requesting this information. A common way to request data from a JVM is to register *EventRequest*s which notify each requester with an *Event*, when they are triggered. There are several types of events. The most important type for the Visual Debugger is the *LocatableEvent*. These are related to the source code and are triggered, for example, when a specific line in the source code is executed, a method is called or the field of an object is changed. Besides, there are events that notify about started/stopped threads respectively loaded/unloaded classes in a JVM or state changes of the JVM itself.

On top of the JDI, Eclipse delivers with the JDT an easy-to-use layer to access the heap of a JVM. The JDT is a mature framework and used in almost all debugging tools integrated into the Eclipse IDE. It provides utilities to register requests, collect values or control the program execution with customizable breakpoints.

As written before the Visual Debugger uses no own implementation of an object diagram editor, but an already existing one. The UML Lab object diagram editor is an intuitive editor with powerful layouting mechanisms. Although it is a commercial tool in general, it is completely free of charge when used for academic purposes. Thus, it matches the needs of the Visual Debugger to address academical users as well as industrial ones. The editor is based on the (open source) Graphical Editor Framework (GEF), which is the de-facto standard for developing editors for Eclipse. Therefore extensibility of the object diagram editor in UML Lab is given without the need to have any deeper knowledge about the (closed source) editor itself.

## 4 EXAMPLE PROJECT

To show different use cases of the Visual Debugger, an example project is explained briefly in the following. The project simulates transportation shuttles. There are two kinds of nodes available: on the one hand the Shuttle Management Node and on the other hand the Shuttle Node. While the first kind only exists once in this distributed application, the second one can be started multiple times, one for each available shuttle. The term Node means in this scenario a different Java Virtual Machine.

Both components share the majority of their datamodel, expecially all objects have the property id. This property is used as an unique identifier to find the same objects on different nodes. The simulation itself is rather simple. Shuttles move from track to track while people are waiting at stations, which may be connected to a track. When a shuttle reaches a track with a station, all people will enter the shuttle, unless its maximum capacity is reached.

## 5 VISUALIZING A HEAP OBJECT AS A DIAGRAM OBJECT

Before we have a deeper look into the visualization of distributed applications, the visualization of a heap object in general will be explained. Using the UML2 object diagrams, the formal specification is already given. Each instance on the Java heap is mapped to an object (*InstanceSpecification*) in the diagram. Each primitive variable of an instance is mapped to an attribute assignment in its object in the diagram. Each reference to another non primitive Java instance is translated into a link (*InstanceSpecification*) between the two corresponding objects in the diagram.

According to the UML2 specification each *InstanceSpecification* in an object diagram must be related to a *Classifier* to define the type of this instance. If the *InstanceSpecification* represents an object, this has to be a *Class*, if it is a link, this has to be an *Association*. Similar requirements exist for the other artefacts in an object diagram like *Slots* or *Types*. As a result, it is necessary to maintain a class diagram while the object diagram is created and modified.

To create this class diagram, the necessary information must be extracted from the runtime data. As this diagram shall be accessible over at least one whole debugging session, a mapping must be persisted. Table 1 shows equivalent mappings of the different artefacts from the JDI, the JDT and the UML2 meta-model. While *Class*, *Property* and *Interface* can be mapped easily, the empty spaces in the other rows indicate that not for each element an exact one-to-one mapping can be found. Especially associations must be treated in a specific way. On the one hand, they can be used uni- or bidirectional and on the other hand, a bidirectional association can be a composition or an aggregation. The last two examples are not supported by the Visual Debugger, because they are in most scenarios not identifiable by inspecting only the runtime data. An inspection of the source or byte-code would be necessary. As the detection of those structures is difficult, and the value of these additional information is limited, we currently ignore these special cases. To identify uni- and bidirectional associations different approaches were tested. Finally, this led us to an approach where no association should be refactored after its definition. Therefore the object graph in the JDT is analyzed as a whole and pairs of object instances referencing each other are searched. Each of those pairs results in a bidirectional association and all other found references become an uni-directional association.

In addition to the differentiation between uni- and bidirectional, the cardinality of an association must be determined; is it a one-to-one, a one-to-many or a many-to-many association. This can be easily achieved by looking at the type of a field. If it is a *Collection* or an *Array*, the property of the association is to-many; to-one otherwise. If one direction is to-many, the collection instance in the heap is abstracted into direct links to the contained objects.

Table 1: Comparison of the mapping artefacts from JDI (com.sun.jdi), JDT (org.eclipse.jdt.internal.debug.core.model) and the UML2 meta-model.

| JDI/JDT | UML2 |
|---|---|
| ClassType / JDIClassType | Class |
| Field / (JDIFieldVariable) | Property |
| InterfaceType / JDIInterfaceType | Interface |
| PrimitiveType / — | PrimitiveType |
| ArrayType / JDIArrayType | — |
| — / — | Association |

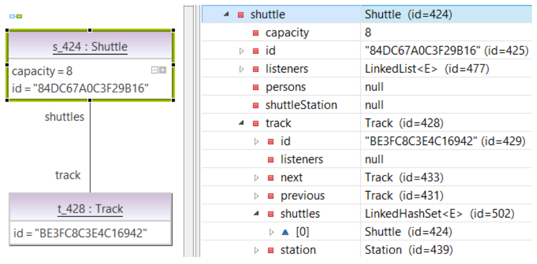
While the creation of the class diagram is done automatically without the user noticing it, the object diagram is usually only changed by direct input from the user. To get a responsive UI for the tool the storage of the mapping data of object diagrams is even more important for providing a fast synchronization process.

Table 2 shows the different mapping pairs between the UML2 meta-model and the JDT interfaces. The mappings are straightforward.

Table 2: Comparison of the mapping artefacts from JDT and the UML2 meta-model.

| JDT | UML2 |
|---|---|
| JDIObjectValue | InstanceSpecification |
| JDIPrimitiveValue | LiteralSpecification |
| JDIObjectValue | InstanceValue |

To give an example of a visualized object, figure 2 compares an instance of the type *Shuttle* in the Eclipse variables view on the right side with the corresponding object in the Visual Debugger on the left side. The visualization of the object itself (s_424) and its primitive variables id and capacity is a direct one-to-one mapping. Links are treated differently. The reference



```
shuttle                 Shuttle  (id=424)
  capacity              8
  id                    "84DC67A0C3F29B16" (id=425)
  listeners             LinkedList<E>  (id=477)
  persons               null
  shuttleStation        null
  track                 Track  (id=428)
    id                  "BE3FC8C3E4C16942" (id=429)
    listeners           null
    next                Track  (id=433)
    previous            Track  (id=431)
    shuttles            LinkedHashSet<E>  (id=502)
      [0]               Shuttle  (id=424)
    station             Station  (id=439)
```

Figure 2: Comparison of the object diagram visualization with the same data in a tree.

to the track (t_428) on the right side equals the link between the two objects on the left side. At the bottom in the variables view a back reference from the track instance to the shuttle instance via the *shuttles* collection indicates, that this link is bidirectional, which can be seen in the diagram on the left side, too.

## 6 THE SYNCHRONIZATION PROCESS

In the following section a deeper look into the underlying synchronization process of transforming heap data to UML2 objects and vice versa is taken. This process can be separated into two different modes.

As a short definition for these modes, one could say:

**Batch Mode.** This mode is active when a whole JVM or one or more separate threads are paused.

**Live Mode.** This mode is active when a JVM is not paused in any kind.

Per definition both modes can be active at the same time, when one or more threads are paused, but not the whole JVM. Depending an the currently active mode(s), the interaction with the object diagram is significantly different.

Generally, the Visual Debugger is designed to be fault tolerant to occurring errors within the synchronization process. One quite regular error scenario would be a failed data retrieval from a JVM while the synchronization is in process. This specific task will then be postponed and repeated later. The drawback of this approach is that the object diagram may be in an asynchronous state to the heap data for an undefined time.

### 6.1 Batch Mode

With the *IDebugEventSetListener* the JDT provides an easy method to react to state changes of the JVM or single threads. Each time a state change indicates a paused thread/JVM, the batch mode of the Visual Debugger runs a full synchronization of the current object diagram.

Each synchronization cycle is structured as follows: At first, each (visible and invisible) object in the diagram is taken and its current data is synchronized with the runtime heap data. When these tasks are finished the post synchronization tasks are triggered. The most important task is the synchronization of links. As already said, links must be treated separately, because a link is usually based on the combination of several artefacts in the runtime data. The link synchronization consists of the following steps:

1. All existing links in the diagram are searched
2. For each, its existance is checked in the Java heap
3. For all objects in the object diagram, the runtime object is retrieved and all non primitive fields with a value not equal null are collected
4. For each non primitive field, it is considered part of a new link
5. All possible link candidates found in the last step are evaluated
   (a) If the properties of two of them belong to the same association, they are merged
   (b) If the properties of two of them do not belong to an association but they cross-reference each other, they are assumed as bidirectional association and they are combined. This is a trade-off in the algorithm to detect bidirectional associations. This can lead to false positives, but prevents object diagrams flooded with unidirectional links.
6. For every remaining link candidate a link in the object diagram is created, the other ones are deleted

The described evaluation of the runtime data is executed sequentially to ensure that all class and object diagram parts are updated correctly before the link evaluation starts.

Any interaction with the object diagram is only available during batch mode. This includes adding new objects to the object diagram as well as the automatic expansion of the object diagram based on the already existing content.

### 6.2 Live Mode

The live mode is active when a JVM is not paused entirely. As long as at least one thread is running, the live mode is still active for this JVM. Its synchronization behaviour is based on *EventRequest*s from the JDI. These requests can be registered in a running JVM to receive data updates without pausing threads in the JVM. To be more precise threads are actually stopped for a short amount of time to react to events (triggered by the requests), but automatically resumed afterwards. The event handling is done asynchronously to minimize the effect on the runtime behaviour of the JVM. This enables the object diagram to be updated without the user noticing an impact on the program execution. There are several request types available in the JDI, but only the *ModificationWatchpointRequest*, *AccessWatchpointRequest*, *MethodEntryRequest* and *MethodExitRequest* types are used in the Visual Debugger.

The *ModifcationWatchpointRequest* can be registered on a field of a class. This can be a field in general or restricted to a specific instance of a class to reduce the number of events to evaluate. This request type is used to supervise all primitive fields and all to-one links.

The *AccessWatchpointRequest*, *MethodEntryRequest* and *MethodExitRequest* types are used to supervise to-many links. As mentioned earlier, to-many links can be based on a variety of Java components; each subtype of *Collection*, arrays or an own implementation of a data structure. To support each of them with a reasonable effort, a general approach must be available. Additionally, for specific types like Arrays or commonly used subtypes of the *Collection* interface like *LinkedList* or *HashSet* a specific handling is implemented due to runtime reasons.

The general approach is mainly based on the *MethodEntryRequest* and *MethodExitRequest*. For each field identified as source of a to-many link, the according instance is supervised by adding a *MethodEntryRequest* and a *MethodExitRequest* to each method the target type has. Every time a *MethodEntryRequest* is triggered, the field value and all instances it references are analysed. When the *MethodExitRequest* of the same method is triggered, the field value is analysed again and the delta is calculated. Any new contained object results in a new link, each removed object triggers the deletion of the according link. To optimize the general approach *MethodEntryRequests* are only evaluated as long as no other evaluation is in process. This prevents unnecessary calculations during call chains within the same object. For specific class types like *LinkedList* or *HashSet* the knowledge about the source code of the class can be used to improve the runtime of the analysis. Only methods that affect the content of the underlying collection need to be considered. This usually excludes the majority of methods which access the collection read-only.

As especially primitive values can change very often during runtime, not every event needs to be and can be evaluated in detail. The evaluation is scheduled with an interval from 500ms, which led to the best results for us. During this 500ms each event change is represented as an internal *LiveEvent*. If a change affects an already existing *LiveEvent*, the event is updated, newly created otherwise. The mapping to a *LiveEvent* must be done in the callback method of the debug listener, because only during the callback the JDI values of an event are stable. After each 500ms all collected *LiveEvent*s are evaluated asynchronously and the object diagram is updated accordingly. To prevent an unwanted behaviour during the synchronization process because of an asynchronously updated *LiveEvent*, each *LiveEvent* contains a stable and an unstable state. The stable state is locked, when the synchronization starts and unlocked, when it is finished.

## 7 CHALLENGES OF VISUALIZING THE STATE OF A DISTRIBUTED APPLICATION

All the previously explained behaviour does not differ when debugging a distributed and a non distributed application. However, a distributed application makes additional demands on the Visual Debugger. This includes identifying shared objects as well as keeping those shared objects updated in the object diagram.

In distributed applications some objects usually exist on different JVMs, which means they are distinct instances in separated JVMs. To work with these instances the application must be able to identify them. A common approach is to give an object an unique identifier. This identifier is usually stored in the object as a primitive value. Therefore the Visual Debugger uses a couple of basic property names like id or uuid to search for these identifiers. Additional property names can be added via the preferences.

A significant difference between the visualization of distributed and non distributed applications is the usage of batch and live mode. In a non distributed application the first entry point into a debugging session is always the batch mode. As mentioned earlier, adding objects to the diagram is only possible in batch mode. A first breakpoint must be used to put all objects into the diagram which are interesting for this session. At this point pausing all JVMs at once can be necessary to avoid a race condition. When the program execution is resumed the live mode is activated and the visible objects are automatically updated until the next breakpoint is reached or another event pauses the program execution. This includes manually pausing a JVM or a stepwise continuation. This debugging cycle is repeated while the debugging session is active.

Switching to a distributed application leads to a more complicated data retrieval. The entry point into a debugging session is still the batch mode, where first objects from one or more JVMs are added into the object diagram. The first difference at this point is the behaviour after adding an instance. All existing mirrored instances of this object in all JVMs should be supervised and updated as if they would be in live mode. To achieve this, all instances of this object must be found in other JVMs on the first hand. Here we differ between two scenarios:

A JVM is started from within the Eclipse IDE. Each of those JVMs can be supervised right from their launch. Therefore, another subtype of *EventRequest* is used, the *ClassPrepareRequest*. When this request is registered events are fired as soon as a class is loaded in the JVM. This class can be analysed for an identifier property and if one is found changes to this property can be tracked. As those identifier properties usually only change once for each instance (when they are initialized) the overhead is reasonable. Each class that does not own a valid identifier property will not be supervised as they are not shared across JVMs.

A JVM is started from another IDE or on another node and a remote debugging session is started. This JVM is probably running for a long time and all relevant classes for a debugging session are already loaded. Nevertheless, the process described above is still initiated to keep track of newly loaded classes. If an instance of a class is searched that was already loaded before the remote debugging session was started, it must be searched explicitly. Depending on the amount of instances of a class this search can be expensive. Therefore, this analysis is done asynchronously.

Each object with an initialized identifier will be stored internally and mapped with all its instances on the other JVMs. This enables the Visual Debugger to access these shared objects much faster during the ongoing debugging session.

A special treatment is necessary when an object from one JVM is added while not all other JVMs having this class already loaded. In this scenario the class is explicitly loaded (if available in this VM) and the already explained supervising process is triggered.

## 8 THE DISTRIBUTED MODE

With the example project from chapter 4, the usage of the Visual Debugger in different scenarios will be shown. The following sections explain the two different available view modes.

**Detail Mode.** The detail view mode is similar to the behaviour of the Visual Debugger in a non distributed application. Each instance in each JVM is displayed as an own object in the object diagram. In figure 3 a debug scenario with the shuttle simulation project is shown. There are in total five objects, two from a Shuttle Node running in one JVM (on the left) and three from the Shuttle Management Node running in another JVM (on the right). The highlights are added after the screenshot was made to improve the visibility. Comparing the id properties of the objects reveals, that the two *Shuttle* instances and the two *Track* instances are the same objects on different JVMs. Due to the naming conventions in the Visual Debugger, the same objects have different names on different JVMs. Each name usually includes the internal id of an instance in the JVM. Regarding the *Shuttle* instances the ids are 422 for the left (s_422) and 462 for the right instance (s_462). This convention helps identifying instances in other debugging tools, like the variables view, faster.

This mode is especially useful, if it is important to supervise the changes of one or more objects on specific JVMs.

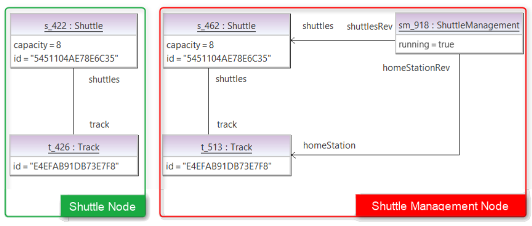
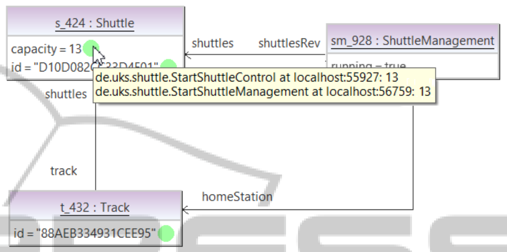


Figure 3: Object diagram showing several objects from different JVMs with the detail mode activated.



de.uks.shuttle.StartShuttleControl at localhost:55927: 13
de.uks.shuttle.StartShuttleManagement at localhost:56759: 13

Figure 4: Object diagram showing several objects from different JVMs with the combined mode activated.

**Combined Mode.** When the combined mode is activated all instances of the same object in different JVMs are combined into one single object in the diagram. In figure 4 a similar scenario as in figure 3 is shown. Compared to the detail mode, the object diagram is reduced from five to three objects.

To still get the information which value each property and link has on the different JVMs an overlay is added to each of these artefacts. In figure 4 the overlay for attribute assignments is active. Next to each attribute assignment a small circle is drawn to give an indicator of its stability. A green circle means that the value is the same on each JVM. A red circle means, that the value at least on two JVMs differs. This can, but must not be problematic. If specific attribute values are not synchronized between (all) JVMs, an integer could probably stay at zero or a string value may stay null. At this point it is up to the developer to decide whether this is an unwanted and problematic behaviour of the application or not. Additionally, a tooltip is available if the attribute value of the instance on each JVM is interesting for the user. In figure 4 the tooltip indicates, that the capacity property has in both instances, in the Shuttle Node and the Shuttle Management Node, the value 13.

## 9 CONCLUSIONS

In this paper the Visual Debugger and its usage with distributed applications is presented. The main purpose of the tool is to give a view on the current state of an application by showing all relevant objects during a debugging session. This is achieved with an UML2 object diagram visualizing objects on the Java heap.

Although the Visual Debugger has been proven to be useful in a successful recent research project, there are still open areas. During a debugging session a regularly observed problem is that several changes in the object diagram happen too fast to follow them. Therefore an additional replay mode would be helpful where all changes in the object diagram during the last debugging session can be repeated forwards and backwards. If a debugging session must be repeated several times to find the source of an unwanted behaviour, each restart forces the user to fill the object diagram again with objects. An automatic restoration of diagrams when the same debugging scenario is repeated would be helpful.

Nevertheless, the Visual Debugger should be seen as addition to existing debugging tools and not as a replacement. Thus, a tight integration into the Eclipse IDE was an important design goal. During debugging sessions which focus on supervising the state of a specific, but known part of the application the Visual Debugger delivers the most value.

One important lesson we learned so far is, that the Visual Debugger has a steep learning curve; independent from the experience of the software developer. Students as well as professional developers (working in the industry for years) shared similar problems when they are confronted with an unknown kind of tool like the Visual Debugger. We currently develop a tutorial addressing this problem.

## REFERENCES

da Silva, G. J., Schnorr, L. M., and de Oliveira Stein, B. (2003). Jrastro: A trace agent for debugging multithreaded and distributed java programs. In *SBAC-PAD*, pages 46–54. IEEE Computer Society.

Geiger, L. and Zündorf, A. (2002). Graph Based Debugging with Fujaba. Barcelona, Spain.

Geiger, L. and Zündorf, A. (2006). edobs - graphical debugging for eclipse. *ECEASST*, 1.

Gestwicki, P. and Jayaraman, B. (2005). Methodology and architecture of jive. In *SoftVis '05: Proceedings of the 2005 ACM symposium on Software visualization*, pages 95–104, New York, NY, USA. ACM.

Layman, L., Diep, M., Nagappan, M., Singer, J., DeLine, R., and Venolia, G. (2013). Debugging revisited: Toward understanding the debugging needs of contemporary software developers. In *ESEM*, pages 383–392. IEEE.

Leroux, H., Rquil-Romanczuk, A., and Mingins, C. (2003). Jacot: a tool to dynamically visualise the execution of concurrent java programs. In Power, J. F. and Waldron, J., editors, *PPPJ*, volume 42 of *ACM International Conference Proceeding Series*, pages 201–206. ACM.

Löhr, K.-P. and Vratislavsky, A. (2003). Jan -java animation for program understanding. In *HCC*, pages 67–75. IEEE Computer Society.

Lönnberg, J., Ben-Ari, M., and Malmi, L. (2011). Java replay for dependence-based debugging. In Loureno, J. and Farchi, E., editors, *PADTAD*, pages 15–25. ACM.

Mehner, K. (2001). Javis: A uml-based visualization and debugging environment for concurrent java programs. In Diehl, S., editor, *Software Visualization*, volume 2269 of *Lecture Notes in Computer Science*, pages 163–175. Springer.

Oechsle, R. and Schmitt, T. (2001). Javavis: Automatic program visualization with object and sequence diagrams using the java debug interface (jdi). In Diehl, S., editor, *Software Visualization*, volume 2269 of *Lecture Notes in Computer Science*, pages 176–190. Springer.