Correctness and Completeness of CASE Tools in Reverse Engineering Source Code into UML Model

Hafeez Osman and Michel R.V. Chaudron

***Abstract*—This paper focuses on Computer-aided Software Engineering (CASE) tools that offer functionality for reverse engineering into Unified Modeling Language (UML) models. Such tools can be used for design recovery or round-trip engineering. For these purposes, the quality and correctness of the reverse engineering capability of these tools is of key importance: Do the tools completely reconstruct the UML diagrams? Are the reverse engineering results correct? What kind of information is presented in the result? Based on these questions, we compare eight UML CASE tools (six commercial tools and two open source tools). We evaluate i) the types of inputs that these tools can handle, ii) the types of diagrams that can be reconstructed, iii) the quality of resulting diagrams.**

***Index Terms*—Software Engineering, Reverse Engineering, Software Design, Software Tools.**

I. Introduction

The Unified Modeling Language (UML) has emerged as the de facto standard for graphically representing the design of object-oriented software systems [7]. While UML diagrams are created in forward design, these diagrams are poorly maintained. Maintaining correspondence (between design and implementation) is particularly challenging because over time an implementation tends to evolve considerably from its initial design [14]. Design models produced during the design phase are often forgotten during the implementation phase-under time pressure usually-and thus present major discrepancies with their actual implementation frequently [3]. Timothy C. Lethbridge et al [15] confirm the widely held belief that software engineers typically do not update documentation as timely or completely as software process personnel and managers advocate. At the same time, software engineers working in software maintenance express a need for better documentation. Tools support during maintenance, re-engineering or re-architecturing activities has become important to decrease the time software personnel spend on manual source code analysis and help to focus attention on important program understanding issues [9].

Reverse engineering is the process of analyzing a subject system to identify the system's components and their interrelationships and create representations of the system in other form or at higher level of abstraction [12].

Nowadays, a lot of commercial and open source CASE tools support reverse engineering. CASE tools offer various kinds of capabilities to provide the needed information to the user. These tools provide the capability in generating package and class diagrams based on source codes, object or executable files. These tools provide an automated and semi-automated analysis of the software system regarding the software structure such as class, attribute and operation. Some of the CASE tools extend the UML reverse engineering capabilities by supporting sequence diagram generation based on static analysis. They are also support various programming languages such as C++, java, C#, Delphi, PHP5 and Visual Basic.

For this study, our motivation is to discover to what extent the CASE tools are able to reverse engineer UML diagrams out of source code. We want to know the strengths and weaknesses of the evaluated reverse engineering tools. In order to find the answers, we examined and compared the reverse engineering capabilities provided by the CASE tools. Eight tools have been selected in this paper, namely Visual Paradigm, Rational Software Architect, StarUML, Altova UModel, MyEclipse, Enterprise Architect, MagicDraw and ArgoUML. To understand how the tools analyze class diagram, we have conducted three experiments. The first experiment tried to discover whether tools could be used to do round-trip engineering. In this experiment, we want to know whether the forward code generation capability is compatible with reverse engineering capability. In other words: whether the code that a tool generates from a UML model can be used by the reverse engineering capability to reconstruct to original UML model.

For the second experiment, we tested the tools in indentifying class relationship (association, aggregation and composition) based on the code stated in [3]. This experiment is done to find out whether the tools are capable of identifying class relationships. In the third experiment, we tested the tools of reverse engineering class diagram.

The paper is structured as follows. Section II briefly describes the examined tools and properties used in this evaluation. Section III describes the case study and Section IV explains the approach on how we conducted the experiment. Section V presents our results and findings. Our evaluation

Manuscript received February 29, 2012. This work was supported in part by the Public Service Department of Malaysia. The authors are with the University of Leiden, Niels Bohrweg 1, 2333CA Leiden, The Netherland; e-mail: hosman@liacs.nl or chaudron@liacs.nl.

DOI: 10.5176_2010-2283_2.1.150

will be discussed in Section VI. We suggest future work and present the differences of this paper and other related research in Section VII. This is followed by our conclusion in Section VIII.

II. Examined Tools and Properties

This section describes the examined tools and properties used in this experiment.

A. Examined Tools

The CASE tools were chosen based on the following criteria: i) Capable of performing reverse engineering in Java, ii) Capable to export UML Model to UML Metadata Interchange (XMI) format. Eight well known CASE tools were chosen as listed in TABLE I. For commercial CASE tools, we use fully functional evaluation and academic evaluation version.

TABLE I. LIST OF EVALUATED CASE TOOLS

No	CASE Tools	Information	Vendor	License type
1	Visual Paradigm 8.1	http://www.visual-paradigm.com/	Visual Paradigm	Evaluation
2	MagicDraw 17.0	http://www.magicdraw.com/	No Magic	Evaluation (academic)
3	Altova Umodel 2011	http://www.altova.com/	Altova	Evaluation
4	Enterprise Architect 8.0	http://www.sparxsystems.com.au	Sparx System	Evaluation
5	Rational Software Architect 8.0.1	http://www-142.ibm.com/software/products/my/en/swarchitect-websphere	IBM	Evaluation
6	MyEclipse 8.6	http://www.myeclipseide.com/	Genuitec	Evaluation (academic)
7	StarUML 5	http://staruml.sourceforge.net/	StarUML	Open Source
8	ArgoUML	http://argouml.tigris.org/	Tigris.org	Open Source

To support this evaluation, metrics software that is capable of extracting UML model information from different versions and different type of XMI files is required. SDMetrics[11] fulfilled our requirement and version 2.11(academic license) of this software were used in this evaluation.

B. Examined Properties

1) Reverse Engineering Capability: The reverse engineering tools capabilities are evaluated from the following perspectives:

a) UML Diagrams: Three UML diagram types are selected for our evaluation. First, we evaluate the package diagram. The package diagram is used to group the classes together into high-level unit [1]. Second, we study the class diagram. Class diagrams describe the type of objects in the system and the various kinds of static relationships that exist among them [1]. Third, we evaluate the sequence diagram. Sequence diagrams describe an interaction between objects and actors of the system by focusing on the sequence of messages that are exchanged, along with their corresponding occurrence specifications on the lifelines [2]. Reverse-engineered sequence diagrams can be created through static or dynamic analysis [5]. Only static analysis is used to generate the sequence diagram in this experiment. We analyze all three diagrams by evaluating the process of generating the diagrams and the output in term of completeness and representation.

b) Supported Programming Language(s): Several common programming languages are selected to study the capability of the tools in reverse engineer source code. The selected programming languages are PHP5, C++, Java, C#, Delphi, Python and Visual Basic (V.B.).

c) Additional Types of Input formats: The supported input-types for reverse engineering UML diagrams (in addition to source code; e.g. binaries).

2) Class Diagram Properties: There are two types of basic information about a class that are important for this evaluation. The basic information is the following:

a) Class Attributes and Methods

- Number of attributes: We evaluate the tools' ability to reconstruct all attributes including the type of attribute (public, private, protected) defined in the source code.
- Number of operations: We evaluate the tools' ability to reconstruct all methods (of all: public, private, protected, constructor) defined in the source code. In addition, we assess whether the tools can distinguish public from private or protected methods.
- Getters and Setters: We evaluate the tools' ability to identify the difference between getters and setters and other operations.

b) Class Relationship

- Number and type of Relationship: We evaluate whether the tools reconstruct all relations between classes.

III. Case Study

This section describes the case study used for this paper. The case studies used in our evaluation are as follows:

A. Movie Catalog System (MovieCat)

This case study is a sample case study derived from [6]. We modified the relationship of the classes in order to make sure all types of relationship are presented in the case study. This case study is used to test Class Diagram Properties.

B. Automatic Teller Machine (ATM) simulation system

This fully functional system has a class design and complete implementation source code. The class design was made using forward design. The case study is an ATM simulation example developed by the Department of Mathematics and Computer Science, Gordon College [4]. This simple simulation system is used to show the overall process of UML usage in analysis, design and implementation phase. The complete software documents based on UML were provided that consist of 22 design classes. Some of the elements (especially relationship) in this case study have been modified to suit our requirement

for the experiment. This case study is used to test the Reverse Engineering Capability.

IV. Approach

This section explains the approaches that were used to evaluate the tools. The evaluation is divided into two parts that are: Round Trip Capability and Reconstruction of UML Diagram types.

A. Round Trip Capability

To assess how well the tools can be used for round-trip engineering, we conducted round trip experiment. The experiment is done to compare the difference between the forward design and the reverse engineering design. The experiment begins by creating a sample UML Design (class diagram) that consists of basic information such as attributes and methods (private, protected, public) and class relationship information (such as association, composition and aggregation). Then, we performed forward engineering to produce the source code. Based on forward-engineered-source code, we performed reverse engineering to get the UML Design'. Both UML Design and UML Design' were then compared. This experiment is illustrated in Figure 1.

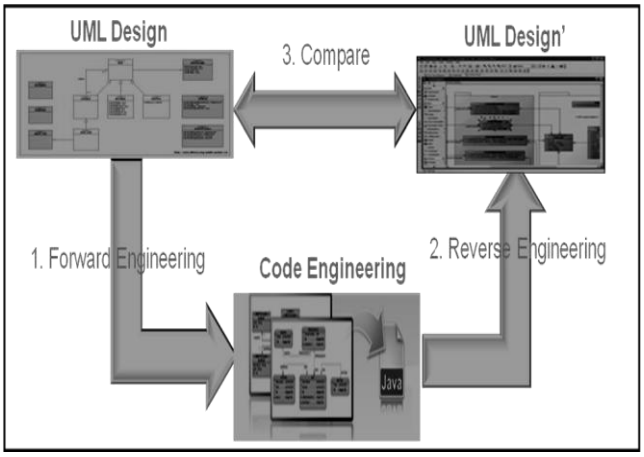


Figure 1. Roundtrip Engineering Experiment

B. Reconstruction of UML Diagram types (Package/class/sequence)

To assess the quality of the reverse engineering of UML diagrams, we conduct the following experiments:

1) UML Diagram Reconstruction capability: Information about the tools' support for diagram types is gathered from the tools' manual. The results of each tested diagrams are evaluated based on a three-level scale. The scale explanations are the following:

- "+" - this scale is set if the tools are able to reverse engineer the specified diagram eventhough there is/are minor information that cannot be analyzed such as aggregation and composition relationship for a class diagram and dependency relationship for a package diagram.
- "o" - this scale is set if the tools are able to reverse engineer the specified diagram but present minimal or basic information about the diagram, for an example, the tool is capable in presenting the class name with attribute and method only. No relationship is presented. Another example is the tools need user intervention to generate the sequence diagram.
- "-" - this scale is set if the tool are unable to reverse the specific diagram.

The tool manuals are also used to collect (the) information about the supported programming language and supported type of reverse engineering sources.

2) Detection of Aggregation, Association and Composition relationship: This experiment aims to test the reverse engineering capability on various types of class relationship based on code defines in [3]. We create different version of source code based on relationship types defined in [3] and use the tools reverse engineering functionality to generate the class diagram. Then, the results were observed.

3) Correctness and Completeness (CnC) of Reconstructed UML Diagram: This experiment aims to test the completeness and the correctness of the result of reconstructed UML diagram based on the CASE tools reverse engineering capability. We begin this task by capturing the expected result derived by the provided case study design document and implementation source code. The expected result for all basic information and relationship is gathered by manual and by using software metrics tool. This evaluation is divided into two sections as described below:

a) CnC of Basic Class Information: A new separated project is created for each tool. All possible options in the reverse engineering function were tested to get the best result. The best reverse engineered class diagram from each tool is exported to XMI or XML file format. Then, the software metrics and evaluation results were recorded.

b) CnC of Reconstruction of Class Relationship: A new project is separately created from the tasks mentioned above and all possible options in reverse engineering function were tested to have the best view of class relationship. Then, manually, the relationships constructed by each tools were evaluated and compared with the expected result. The evaluations were then recorded.

V. Results and Findings

This section, we present the result of our evaluation and findings. The results are divided into two subsections' which are Reverse Engineering Capability and Class Diagram Properties. Complete evaluation results and test diagrams are shown in [16].

A. Reverse Engineering Capability

The assessment was done by using a three-level scale to evaluate the tools in reverse engineering task. The three-level scale are "+" good, "o" minimal and "-" not capable.

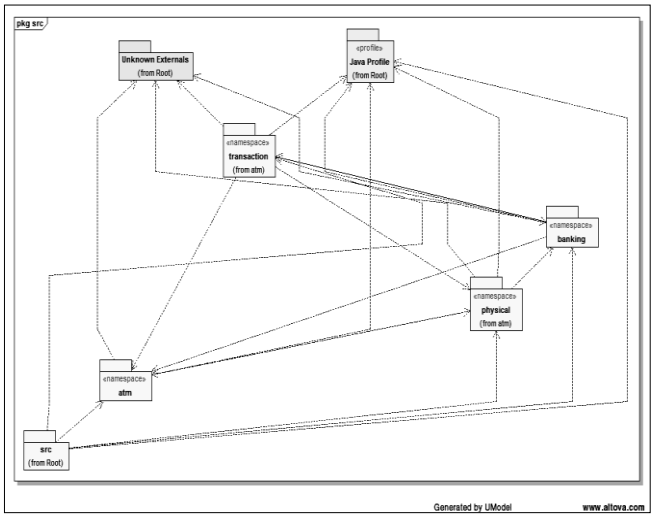


Figure 2. Altova UModel Reverse Engineered Package Diagram

Most of the tools are capable of generating Package Diagrams. Figure 2 shows an example of a reverse engineered package diagram using AltovaUModel. Generally, all the evaluated tools are good at automatically generating class diagrams based on the source code except ArgoUML because the tool is unable to reconstruct class relationship other than inheritance. All CASE tools give an option to the user to separately generate the class diagram using the "drag and drop" function.

TABLE II. SUPPORTED UML DIAGRAM FOR REVERSE ENGINEERING

No	Tools	UML Diagram		
		Package	Class	Sequence
1	Visual Paradigm	+	+	o
2	Altova UModel 2011	+	+	o
3	My Eclipse 8.6	o	+	-
4	Star UML 5	o	+	-
5	Magic Draw 17.0	o	+	-
6	Rational Software Architect v8.0.1	o	+	o
7	Enterprise Architect 9	o	+	o
8	ArgoUML v0.32.2	o	o	-

There are only four tools in our evaluation that have the capability of reverse engineering sequence diagrams. An example of a reverse engineered sequence diagram is shown in Figure 3. To generate the sequence diagram, the user is required to choose a method in a class.

The support of different tools for reverse engineering different UML Diagram is given in TABLE II.

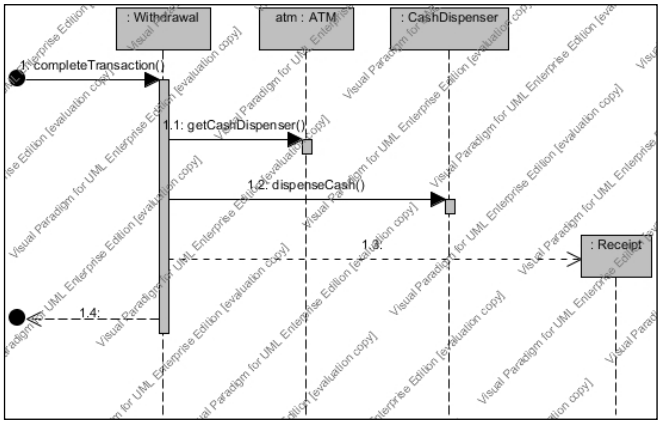


Figure 3. Visual Paradigm Reverse Engineered Sequence Diagram

The supported programming languages results are presented in TABLE III. It shows that the Enterprise Architect is able to reverse engineer all the programming languages listed in this evaluation. We also found that all evaluated tools are able to reverse engineer source codes in Java.

TABLE III. SUPPORTED PROGRAMMING LANGUAGE

No	Tools	Programming Language						
		PHP 5	C++	Java	Delphi	Phyton	V.B	C#
1	Visual Paradigm	**Y**	**Y**	**Y**	N	**Y**	N	N
2	UModel Altova	N	N	**Y**	N	N	**Y**	**Y**
3	My Eclipse	N	N	**Y**	N	N	N	N
4	StarUML	N	**Y**	**Y**	N	N	N	**Y**
5	MagicDraw	N	**Y**	**Y**	N	N	N	**Y**
6	Rational Software Architect	N	**Y**	**Y**	N	N	**Y**	**Y**
7	Enterprise Architect	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
8	ArgoUML	N	**Y**	**Y**	N	N	N	**Y**

Overall, the evaluated tools are able to use source code files such as .java, .cpp and .cs. They also offer an option to the user to specify the source directory where the source code is located and automatically determine the source code file from the directory.

For additional type of input format, Visual Paradigm, Altova and Enterprise Architect are capable of decompiling a java bytecode (.class), dynamic link library (.dll), execution file (.exe) and java archive (.jar). The tools then generate class information that enables the users to construct a class diagram. The full results for other supported type of sources are shown in TABLE IV.

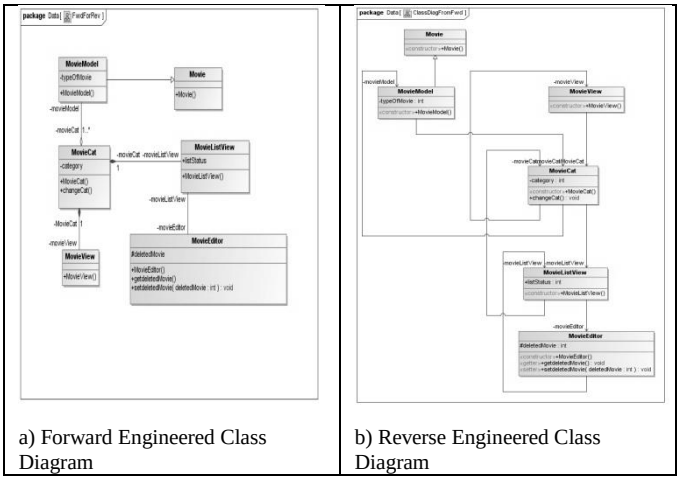
TABLE IV. ADDITIONAL TYPES OF INPUT FORMAT

No	Tools	Supported Type Of Source			
		Source	Class/ Object/ Dynamic Link Library	Executable	Other
1	Visual Paradigm	.Java, .cpp, .h, .php	.dll, .class, .inc	.exe, .jar	Source Directory, .zip
2	Altova UModel	.Java	.dll, Global Cache (GAC), MSVS .Net, .class	.exe, .jar	Source Directory
3	MyEclipse	.Java	-	-	Source Directory
4	MagicDraw	.Java, .cpp, .h, .cc, .cs	-	-	Source Directory
5	Rational Software Architect	.Java, .cpp, .h, .cc,	-	-	Source Directory
6	Enterprise Architect	.java, .h, .cs, .hpp, .pas, .php, .php4, .inc, .py, .vb, .cls, .frm, .ctl	.class, .dll	.exe, .jar	Source Directory
7	StarUML	.Java,.cpp, .h, .cs	-	-	Source Directory
8	ArgoUML	Java, .cpp, .cs	.class	.jar	Source Directory

B. Class Diagram Properties

This subsection presents the assessment for the class diagram properties. The result is divided into three subsections which are Round Trip Findings, Class Relationship Test, and Class Diagram Correctness and Completeness.

1) Round Trip Findings: We found that the CASE tools can easily extract all the listed class attributes and operations. However, the results vary for class relationships. All the tools except ArgoUML show the same result that association and inheritance were correctly reconstructed but aggregation and composition are visualized as association. ArgoUML only can reconstruct inheritance relationship. Rational Software Architect shows the association, aggregation and composition as dependency. Most of the tools declare the association, aggregation and composition in the forward engineering code as link declaration as stated in [6]. As shown in Figure 4, the forward class diagram consists of multiple elements. It has public, protected and private for attribute and method. It also has aggregation, composition, association and inheritance for relationships. The tool is able to reconstruct all information for attribute and method but the aggregation and composition relationships are reconstructed as association relationship.



a) Forward Engineered Class Diagram

b) Reverse Engineered Class Diagram

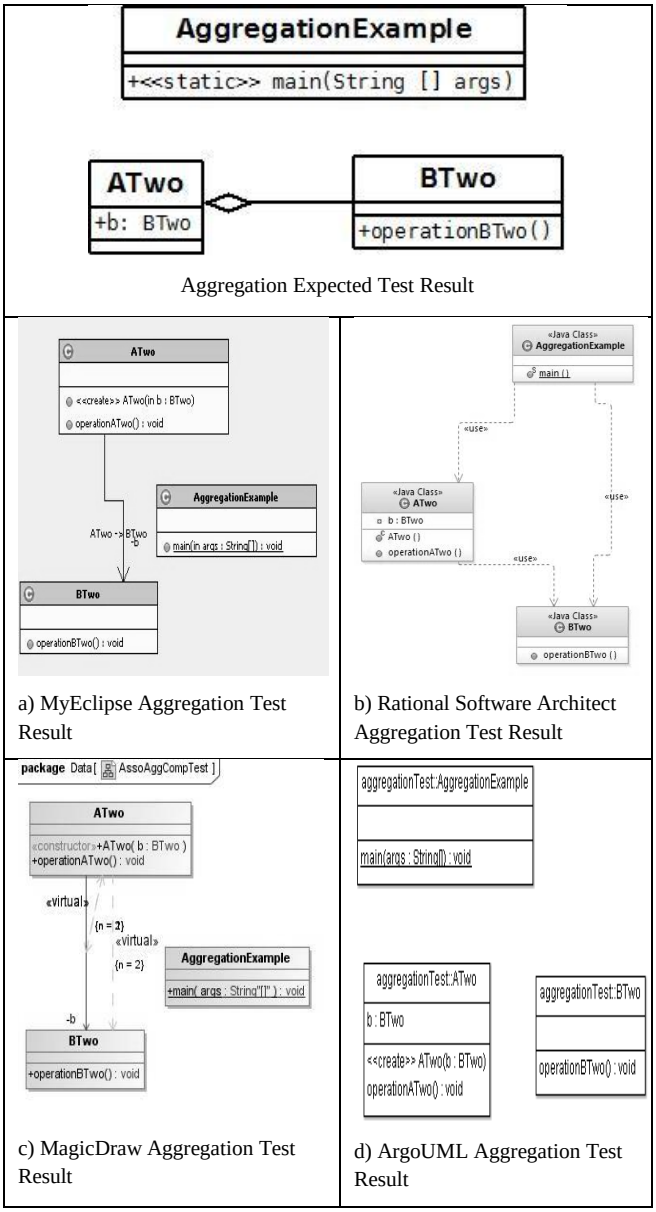
Figure 4. Round Trip Test Result

This is the reason why the tools were not able to differentiate the type of class relationship.

TABLE V. CLASS RELATIONSHIP TEST RESULT

No	Tools	Association	Aggregation	Composition
1.	Visual Paradigm	No relationship presented	Present as association	Present as association
2.	Altova UModel	No relationship presented	Present as association	Present as association
3.	MyEclipse	No relationship presented	Present as association	Present as association
4.	MagicDraw	Present as dependency	Present as association and dependency	Present as association and dependency
5.	Enterprise Architect	No relationship presented	Present as association	Present as association
6.	Rational Software Architect	Present as dependency	Present as dependency	Present as dependency
7.	StarUML	No relationship presented	Present as association	Present as association
8.	ArgoUML	No relationship presented	No relationship presented	No relationship presented

2) Class Relationship Test: Based on the source code that was presented in [3], we found that all the evaluated tools are unable to detect the required class relationship. Visual Paradigm, Altova UModel, StarUML, MyEclipse, MagicDraw and Enterprise Architect give the same result that all association relationships were unable to be generated while the aggregation and composition relationship was presented as association relationship. On the other hand, Rational Software Architect shows different result by generating all the class relationship as dependency relationship. ArgoUML is unable to reconstruct all aggregation, composition and association as required. The detailed results of the test are shown in TABLE V. Examples of diagram that test aggregation for four different CASE tools is shown in Figure 5.



a) MyEclipse Aggregation Test Result

b) Rational Software Architect Aggregation Test Result

c) MagicDraw Aggregation Test Result

d) ArgoUML Aggregation Test Result

Figure 5. Examples of Diagram on Aggregation Test

3) Class Diagram Correctness and Completeness: Class Diagram Correctness and Completeness evaluation is divided into two parts; Class Attributes and Methods and Class Relationship.

a) Class Attributes and Methods: This evaluation presents the capability of the CASE tools in identifying and differentiates class attributes and methods or operations.

Number of Attribute (NA): We expected the tools to extract 79 attributes (NA) from the case study. Visual Paradigm, Enterprise Architect, ArgoUML and Rational Software Architect successfully extracted all the attributes as shown in Figure 4. Other tools like Altova UModel, MyEclipse, StarUML and MagicDraw show some weakness in this operation where they were unable to extract all the expected attributes.

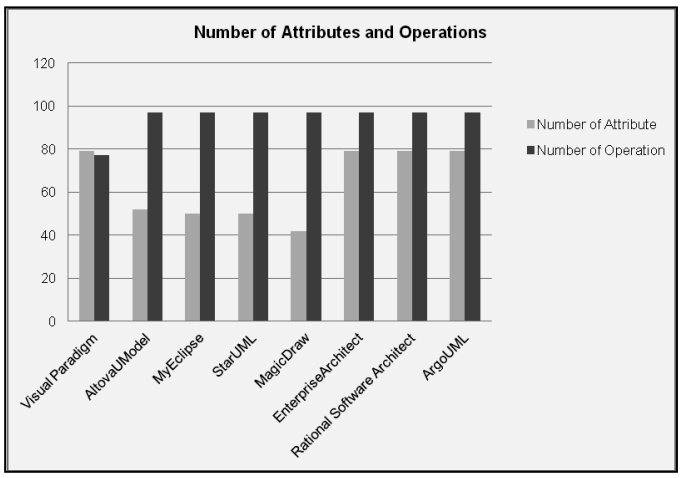


Figure 6. Number of Attributes and Operations

Number of Operations (NO): The number of operations (NO) expected to be extracted by the tools is 91. However, most of the tools found more. The additional operations come from the operations that are derived from the superclass which is also redeclared inside the inherited classes or subclasses. This shows that the reverse engineering tools did not check for the usage of superclass operations. StarUML did not completely extract all operations because it is unable to extract 4 constructors of 4 classes. Visual Paradigm was only capable to extract 77 operations. In addition, we also assess the Number of Public Operations (NPO). The expected NPO of the case study is 83. Overall, all the evaluated tools are capable of identifying the NPO except Visual Paradigm and StarUML. Visual Paradigm identified 63 NPO and StarUML identified 79 NPO. This is a consequence of the weakness of these tools in extracting operations.

Number of Setters (NS): All the tools are capable to identify all expected NS.

Number of Getters (NG): All 32 expected getters were successfully identified by six of the evaluated tools. Only Visual Paradigm did not identify all the getters.

b) Class Relationship: From the Round Trip Experiment, and Class Relationship test, we found that the evaluated tools can only identify the association and inheritance (generalization) relationship. In the code, the proposed guidelines that enable recognizing different relation-types describe in [3] were not used. Hence, we further evaluate the relationship of the class by evaluating the tool capability in extracting association and inheritance relationship. We have extracted all the link declarations in our case study and use it as the expected result.

From the case study, there are 37 association relationships and 4 inheritance or generalization relationships that make it 41 in total. Of these relationships, 3 are bidirectional. The result of this observation is shown in TABLE VI. By completing this observation, we found that only Rational Software Architect is capable of reconstructing bidirectional relationship. Other tools except ArgoUML reconstruct bidirectional relations by means of two separate links in opposite directions. An example of bidirectional relationship presented by Enterprise Architect is shown in Figure 7.

TABLE VI. RELATIONSHIP CORRECTNESS

No	Tool	Total Relationship Count	Association		Inheritence	
			Association Relationship count	Association Correctness (%)	Inheritence Relationship count	Inheritence Correctness (%)
1	Rational Software Architect	30	26	67.57	4	100
2	Visual Paradigm	31	27	54.05	4	100
3	Star UML	31	27	54.05	4	100
4	Enterprise Architect	31	27	54.05	4	100
5	MagicDraw	31	27	54.05	4	100
6	Altova Umodel	31	27	54.05	4	100
7	MyEclipse	20	16	27.03	4	100
8	ArgoUML	4	0	0	4	100

The Rational Software Architect tool is also able to show single relationship for source code that declared two separated link relationships to the same class. Other tools show this kind of relationships as two separated associations. With those advantages, Rational Software Architect presented the highest percentage of relationship correctness. Visual Paradigm, Star UML, Enterprise Architect, MagicDraw and Altova UModel show the same percentage of correctness where the result in each extracted relationships are almost the same. However, MyEclipse shows some weakness in extracting the association relationship and ArgoUML was unable to reconstruct all listed required relationship except Inheritance relationships.

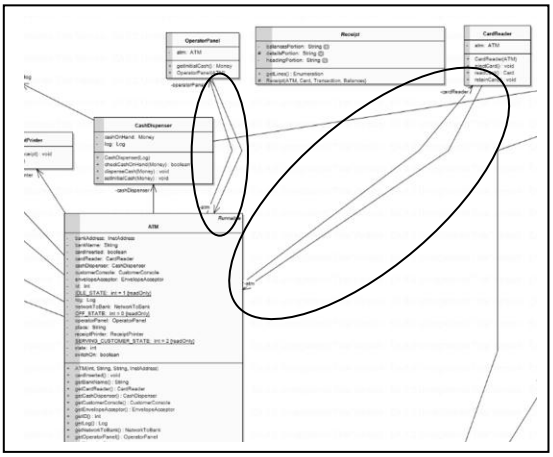


Figure 7. Bidirectional Relationship with two Separated Links

VI. DISCUSSION

This section discusses about the experiment that has been conducted and its result.

Strength: Most of the tools are excellent in presenting the class attributes and methods. The tools are capable of extracting source code, visualizing the class diagram and enabling the user to manipulate the generated diagram. Some of the tools such as Altova UModel and Visual Paradigm are able to automatically generate the class diagram. Most of the tools need user intervention to drag and drop the classes in the project explorer-canvas to recreate a class diagram. This drag and drop function can be useful to the user to select the reverse engineered classes that they want to visualize in the class diagram. Of course, user intervention requires additional effort.

Weakness: All CASE tools are unable to correctly identify all the class relationship. Most of the tools identify aggregation and composition relationships as association relationships. Rational Software Architect shows the result differently by presenting dependency relationships for all class relationships that were tested. For further investigation, we tested all evaluated tools by generating the source code based on design and then we reverse engineered the generated source code to produce the design. This test shows that we are unable to generate the same design that we created. We observed the generated source code and it shows the tools did not differentiate code generations between those types of relationship. This may be the reason why the tools are unable to produce the class relationship correctly. The tools' weakness(es) in generating code (forward engineering) and reverse engineer source code for class relationship have mentioned by Ralf Kollmann et al. [7] in 2002 and Akehurst et al. [13] in 2007. Although this paper is more recent, the tools are still unable to generate correct class relationships and present the relationship in reverse engineering functionality. However, two tools (MagicDraw, Rational Software Architect) give additional information by presenting dependency relationships as an addition to class relationship (association, aggregation and composition). These tools present a lot of dependency relationships (some of which are redundant) that make the resulting generated class diagram appear disorganized and sometimes confusing. The aggregation and composition relationship are crucial to show how the software works. This relationship information may give some hints for the software engineer or software maintainer which classes are important based on the software design before they browse the source code. The class relationship knowledge (especially which class to initiate after another) has to be discovered before the software engineer or software maintainer touch the source code.

Today, CASE tools support the reverse engineering capability by not only using source code as input but also support object or class files and executable files such as .jar and .exe. Some tools such as Altova UModel, Rational Software Architect and Visual Paradigm offer more functionality where they are able to present sequence diagrams based on the reverse engineering result. Although they are not able to automatically generate the sequence diagram, it at least may help the software engineer or software maintainer to understand the class interactions. Overall, from the user point of view, the functionality to do reverse and forward engineering are easy to access by the user and the tools give good instruction and information to the user to use the functionality and analyze the results.

The experiments that we conducted in this paper rely on manual observation of the test result and from the support of a software metrics tool. As we know that some of the inputs are

based on XMI files, we did not consider faulty XMI generation by UML CASE tools. We also did not consider if the software metrics tools used was unable to extract some of the metrics from the XMI files.

VII. Related work and future work

This section discusses works that are related to this paper and present our proposed for future work.

Several evaluations and comparisons on reverse engineering tools have been made [7, 10, 9, 8, 13, 17 and 18]. Ralf Kollmann et al. [7] presented a study which examined the reverse engineering capabilities of two CASE tools (Rational Rose, Borland Together) and compare the result with two academic prototype (Fujaba, IDEA). It shows the comparison between commercial CASE tools and academic CASE tools by presenting the strengths, weaknesses and similarities of the tools' capability. In our study, we examined six commercial CASE tools and two open source CASE tools that we believe are commonly used in the Industry. We extend the examination by observing the capabilities of the tools in reverse engineering the source code into package diagram and sequence diagram.

Jussi Koskinen and Tero Lehmonen [10] analyzed ten reverse engineering tools. The paper analyzed the capabilities in term of four aspects: data structures, visualization mechanisms, information request specification mechanisms and navigation features. Their paper focused on the information retrieval capabilities of the selected tools. Their selected tools do not offer the same functionality as our tools because not all tools are capable of reconstructing UML class diagrams. In our paper, we have selected tools that support reconstruction of UML models and support Java source code.

Bellay and Gall [9] presented a study to compare reverse engineering tools for the C programming language. Four reverse engineering tools were selected in the study. The study aimed to show the differences of the strength and weakness of the selected reverse engineering tools based on their usability, extensibility and applicability for embedded software systems. The tools selected in their study are different in functionality and capability. In our study, our evaluated tools are comparable because the functionality of the evaluated tools is relatively similar.

Gahalaut and Khandnor [8] presented a study about reverse engineering java code. The study aimed to compare byte code reverse engineering tools (decompiler) with UML reverse engineering tools (Altova UModel and Enterprise Architect). The input for this comparison is java source and java class files. They stated that the decompiler and the UML reverse engineering tools generate the same class structures. However, in our study, although the structure is about the same, the detail in class information and relationship is different if we compare reverse engineered class diagram based on the class file and java source file.

D. Akehurst et al [13] focused on providing solutions to the issues of mapping qualified associations and the UML 2.0 semantic variations of an association into the Java 5 programming. It presents a comparison of forward engineering functionality to examine the capability of some CASE tools. Our evaluation covered forward and reverse engineering of class diagram based on user view. Their paper is centered on how to generate code based on the design and our paper evaluates and compares the tools' capabilities on reverse engineer basic class information and relationships.

Andreas Boklund et al [17] present a comparative study of forward and reverse engineering in UML tools. The purpose of their study was to test a selection of selected modeling tools for a typical three-tier layered web service application. They tested four modeling tools and the evaluation was done based on UML-Modeling, UML-based Code Generation and Reverse Engineering UML-diagram from code. From their result, the evaluation was focused on code generation using the tools especially method generation and data type. On the other hand, we cover a wider area (attribute, method and relationship) on reverse engineering output from the evaluated tools. Not all tools that they have selected can be used in their test. For instance, the Rational Rose did not support forward and reverse engineering in C#. Furthermore, our selected tools are comparable in term of the tools capability and functionality.

Stefan Kearney and James F. Power [18] proposed a framework and automated tool for benchmarking UML CASE tools reverse engineering capabilities. The proposed framework is to show the most accurate and reliable CASE tools in reverse engineering capabilities. The automated tools presented in this paper tightly rely on the input from software metrics tools. The results of their tools are also based on this software metrics. Although we did our experiment semi automated, we present more information rather than concentrate only on software metrics. As shown in our result, to choose a reliable and accurate CASE tools for reverse engineering UML diagram is not only based on software metrics but also other element that able to be reconstructed by the CASE tools such as relationship and the capability of the tools to reverse engineer into multiple types of programming language.

For future work, we propose this evaluation to be extended to larger systems to evaluate the scalability and performance of the tools. Also, future research in reverse engineering should try to come up with abstraction mechanisms for leaving out details and emphasize important information from reverse engineered source code.

VIII. Conclusion

This paper has provided an assessment of the reverse engineering capability of seven CASE tools (6 commercial and two open source). We have assessed the tools by evaluating the reverse engineering features that are provided. Basically, all CASE tools are capable of performing reverse engineering from source code to class diagrams and package diagrams. Some of the tools can also reverse engineer sequence diagram, but need a little help from the user to do this. The tools also support various types of input formats other than source code, such as class or object file and executable file. Even though these input formats offer

additional options to the user, the resulting diagrams differ from the results from using source code as input.

Generally, there are not many differences between the capabilities of tools in reverse engineering into UML. Almost all the evaluated tools have relatively the same strengths and weaknesses: CASE tools do not completely show all class information and CASE tools are also not capable of correctly and completely presenting the class relationships – especially aggregation and composition.

With the state of the practice of current tools, details that are omitted from relations in class diagrams can lead to misinterpretations. The CASE tools providers could improve their reverse engineering capabilities by better identifying the association, aggregation and composition relationship. For user that consider using reverse engineering using CASE tools as a means of discovering their design should be aware of the weaknesses of these tools: Even though the tools result present a lot of UML diagrams, not all the result are correct or complete.

ACKNOWLEDGEMENT

We would like to thank all the CASE tools and the software metric tool providers for giving us the evaluation and academic license for this assessment purpose.

REFERENCE

[1] Fowler, M.: UML Distilled: A Brief Guide to the Standard Object Modeling Language, 3rd Edition Addison-Wesley, New York,(1997)

[2] http://www.uml-diagrams.org/

[3] Yann-Gaël Guéhéneuc and Hervé Albin-Amiot. Recovering Binary Class Relationships: Putting Icing on the UML Cake. In Doug C. Schmidt, editor, *Proceedings of the 19th Conference on Object-Oriented Programming, Systems, Languages, and Applications (OOPSLA)*, pages 301--314, October 2004.

[4] http://www.math-cs.gordon.edu/courses/cs211/ATMExample/

[5] C. Bennett, D. Myers, D. Ouellet, M.-A. Storey, M. Salois, D. German, and P. Charland. A survey and evaluation of tool features for understanding reverse engineered sequence diagrams, J.Softw. Maint. Evol.: Res. Pract., vol. 20, no. 4, pp. 291–315, 2008.

[6] Bruce E.Wampler. The Essence of Object-Oriented Programming with java and UML,1st Edition, Addison-Wesley, 2002.

[7] R. Kollmann, P. Selonen, E. Stroulia, T.Systa and A. Zundorf. A Study on the Current State of the Art in Tool-Supported UML-Based Static Reverse Engineering. Proc. IEEE Working Conference on Reverse Engineering, Richmond VA, pp. 22-32, 2002.

[8] Asit Kumar Gahalut, Padmavati Khandnor. Reverse Engineering : An Essence for Software Re-engineering and Program Analysis. International Journal of Engineering Science and Technology, Vol. 2, No. 06, 2010.

[9] B. Bellay and H. Gall. A Comparison of Four Reverse Engineering Tools. 4th Working Conference on Reverse Engineering, pages 2-11, The Netherlands, 1997.

[10] Jussi Koskinen, Tero Lehmonen. Analysis of Ten Reverse Engineering Tools. International Joint Conferences on Computer, Information, and Systems Sciences, and Engineering (CISSE) ,2008.

[11] http://www.sdmetrics.com/

[12] Elliot J. Chikofsky and James H. Cross II. Reverse Engineering and Design Recovery: A Taxonomy. IEEE Software 1990.

[13] D. Akehurst, G. Howells, K. McDonald-Maier. Implementing Associations : UML 2.0 to Java 5. Software and Systems Modeling, vol. 6, no. 1: 3-35, March 2007.

[14] Ariadi Nugroho, M. R. V. Chaudron. A Survey of the Practice of Design - Code Correspondence amongst Professional Software Engineers, Proceedings of the First International Symposium on Empirical Software Engineering and Measurement, p.467-469, September 20-21, 2007

[15] Timothy C. Lethbridge , Janice Singer , Andrew Forward. How Software Engineers Use Documentation: The State of the Practice, IEEE Software, vol. 20 no. 6, p.35-39, November 2003.

[16] http://www.liacs.nl/~hosman/Hafeez2011.pdf

[17] Andreaas Boklund, Stefan MankeFors-Christiernin, Christer Johansson, Hakan Lindell, A Comparative Study Of Forward and Reverse Engineering In UML Tools. IADIS International Conference Applied Computing 2007.

[18] Stevan Kearney, James F. Power, REM4j – A Framework for Measuring the Reverse Engineering Capability of UML CASE tools. 19th International Conference on Software Engineering and Knowledge Engineering, Boston, USA, pp. 209-214, 9-11 July, 2007.

Hafeez Osman received the BSc (2001) and MSc (2003) degrees in computer science from University Technology Malaysia, Malaysia. He spent 8 years in the IT Industry. Currently, he is a doctoral candidate at the Leiden Institute of Advance Computer Science, Leiden University, The Netherlands. His main research interests are software evolution, software architecture and design, UML, reverse engineering, and empirical research in software engineering.

Michel R.V. Chaudron received the MSc (1992) and PhD (1998) degrees in computer science from Leiden University, The Netherlands. He spent a couple of years working in the IT industry, after which he worked at TU Eindhoven. Currently, he is an associate professor at the Leiden Institute of Advanced Computer Science, where he heads the ICT in Business MSc program. His main research interests are software architecture, component-based software engineering, UML, and empirical research in software engineering. He has published more than 80 refereed papers in these areas and is an active participant in conferences in these areas.