EXPLORATIVE UML MODELING
Comparing the Usability of UML Tools

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Abstract: UML tools are used in three main ways: (1) to exploratively sketch key system components during initial project stages; (2) to manage large software systems by keeping design and implementation synchronized; and (3) to extensively document a system after implementation.

Professional tools cover (3) to some extent, and attempt to cover (2), but the vast number of languages, frameworks and deployment procedures makes those tasks all but impossible. By aiming at these two goals, tools must enforce formal UML language constructs more rigorously and thus become more complicated. They can become unsuitable for (1).

This paper looks at explorative modeling with the leading UML tool Rational Rose and the open-source sketching tool UMLet. We define usability measures, assess both tools' performance for common UML design tasks, and comment on the consequences for the application of UML tools.

1 INTRODUCTION

The Unified Modeling Language (UML) (Booch et al., 2005) has become the standard graphical notation in software engineering. Different diagram types support most phases and workflows of the software process, including requirement engineering, design, implementation and deployment. UML is supported by a variety of tools trying to deliver on the elusive promise of computer-aided software engineering (Eichelberger, 2002).

In practice, UML is applied in three main scenarios. First, UML is the notation of choice when creating early drafts of requirement specifications, and software or database designs. Use case diagrams and design sketches are often created from scratch and modified over several iterations. The diagrams do not have to adhere to the strict UML standards; they are used in an explorative way (Rumbaugh et al., 2004).

Second, in large-scale software engineering environments, software design and implementation are kept in sync using sophisticated round-trip engineering tools (Medvidovic et al., 1999). These are capable of generating code stubs from design blueprints, of generating diagrams from existing code, and of propagating changes from one artifact to others. The models and diagrams must conform to formal criteria; only in this way are the tools able to handle the relations between diagrams and code.

Finally, such round-trip engineering tools are also able to effortlessly generate UML documentation from large existing code bases. This is an easy way to provide clients with a seemingly vast amount of system documentation, which is often required by contract but seldom maintained consistently during a project's lifetime.

This paper looks at the first application scenario—UML sketching—, and more precisely at tools supporting the sketching process. We argue that UML is applied differently in that scenario, and that tools aimed at providing formal UML support and complex round-trip-engineering might be inadequate to cover it. We compare the commercial UML tool Rational Rose to the open-source tool UMLet (Auer et al., 2003) and quantitatively assess the tools' usability for explorative sketching. Rational Rose was chosen because it is the leading UML modeling tool in large-scale industrial environments. UMLet, on the other

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hand, provides a low-complexity user interface and thus a baseline for our comparison.

We assess the tools' usability by measuring the complexity of 16 common UML modeling patterns, or *use cases*. Examples for such use cases are changing class attributes, modifying dependencies, or adding messages in a UML diagram. The applied usability measures rely on concepts outlined in (Raskin, 2000).

The remaining paper is structured as follows: Section 2 provides links to related work. Section 3 gives a short introduction to Rational Rose and UMLet, highlighting their user interface principles and features. Section 4 discusses the three usage types of UML tools. Section 5 gives an overview on the method and use cases on which our evaluation is based. Section 6 discusses the results. Section 7 concludes and gives an outlook on further research.

2 RELATED WORK

UML (Booch et al., 2005) was originally developed by Grady Booch, James Rumbaugh, and Ivar Jacobson in 1994. The main reason was to standardize the many existing graphical notations like Booch, OMT, or ERM, and to provide a unified way of describing different software artifacts (classes, components, packages, etc.) arising in different software environments (object-oriented platforms, real-time systems, state machines, etc.). Typical types of UML diagrams are use case, class, or activity diagrams (Fowler, 2003). UML has become a de-facto standard since then. The Object Management Group (OMG), a non-profit industry consortium, is responsible for defining and maintaining the UML language specification (The Object Man Group, 2006). As of early 2006, the various parts of UML are being upgraded to version 2.0.

UML has been applied in many different areas of software engineering. Evans and Wellings (Evans and Wellings, 1999) report on the application of UML in real-time systems. Kohler et al. (Kohler et al., 2000) use a subset of UML in describing a decentralized production control system. Astesiano and Reggio apply UML in the context of distributed systems; they rely on the language's standardized extension features to adapt it to their specific domain. UML is also being taught in many software engineering courses; for an experience report please refer to (Dagdeviren et al., 2004).

Many tools attempt to provide UML support, e.g., IBM's Rational Rose (http://www.ibm.com/software/rational), Artisan's Real-Time Studio (http://www.artisansw.com), or Borland's Together (http://www.borland.com/together). These tools provide round-trip-engineering capability, i.e., they can produce code stubs from diagrams, diagrams from existing source code, and ways to keep them in sync when one artifact changes. Other tools, e.g., UMLet (http://www.umlet.com) or Violet (http://www.horstmann.com/violet/) focus on the fast creation of UML sketches (Chen et al., 2003; Auer et al., 2003). An extensive overview of UML tool features is available at http://www.jeckle.de.

User interface design (Raskin, 2000; Tidwell, 2005) is not a strictly quantitative engineering discipline: it requires intuition of users' habits and environments, common sense, an understanding of graphical representations and their effects, and attention to psychological processes during user tasks. An ubiquitous aspect of user interfaces—used widely in any windows-based operating system—are so-called *modal* dialogs. Such dialogs are windows that pop up to request a user input, while freezing input to the rest of the application. These disruptive dialog windows are described by Quan et al. (Quan et al., 2003) as follows: "Dialog boxes that collect parameters for commands often create ephemeral, unnatural interruptions of a program's normal execution flow." Many developers, too, seem to become aware of this intrusive effect; several well-known applications, like Microsoft's suite of development tools or the Firefox Web browser, for example, now rely on non-modal windows or unobtrusive task bars to provide document search functionality.

For applications with a largely graphical user interface, Moran et al. (Moran et al., 1997) implemented and refined an alternative user interaction approach—a pen based gesture recognition. While the gesture-based approach requires some initial learning effort, the authors report that users found it understandable and easy to use. Chen et al. (Chen et al., 2003) apply a whiteboard approach to the creation of UML diagrams in early project stages. Auer et al. (Auer et al., 2003) describe a text-based user interface to modify the graphical representation of UML diagrams. Several other authors report on possible user interface improvements for UML tools (Tenzer, 2004; Zhang and sho Chen, 2005; Lahtinen and Peltonen, 2003).

It is notoriously tricky to quantify how good a user interface is. Users with different background, experience levels, and goals can't possibly agree on a single "best" user interface. Yet several user interface guidelines attempt to provide formal criteria that should at least minimize bad interface choices and provide some cross-platform standardization (Apple Computer Inc., 1992).

Other authors, most notably Raskin (Raskin, 2000), attempt to provide metrics to measure the quality or usability of user interfaces. Indeed, a whole family of so-called GOMS methods (goals, operators, methods, selection rules) try to measure usability. For example, KLM-GOMS relies on 6 primitive operations (pressing a key, moving the mouse pointer, dragging the mouse pointer, mental preparation, moving hands, and waiting for command execution), and empirically determined execution times. This paper uses a similar, simplified approach to evaluate how two UML tools perform some fundamental UML design workflows.

3 EVALUATED UML TOOLS

3.1 Rational Rose

Rational Rose is one of the leading UML tools used in large-scale software development environments. Rational Rose is no longer sold as a stand alone application, but it is integrated into a number of CASE software products offered by IBM.

Rational Rose is not intended to be used as a simple sketching tool—it aims at providing assistance in designing large software systems. It relies on a formal, internal object model that allows one to view the design from different model perspectives.

Rational Rose was originally developed in 1992 at Rational Software Labs, using ADA and later Smalltalk. Version 1.0 supported the Booch notation only, since it was based on a tool developed by Grady Booch that created graphical representations of ADA program structures. Version 2.0 was released in 1993, supporting Microsoft Windows. After James Rumbaugh joined Rational, version 3.0 supported the OMT notation and featured some of the first round-trip engineering capability for C++. In 1996, Rose 4.0 was released, including Ivar Jacobson's use cases, improved round-trip engineering, and basic support for Visual Basic. Rose 98 featured UML notation, activity diagrams, and Java support. Rose 2000 shipped with an HTML generator and increased UML conformity. Rose 2001 supported J2EE and IBM's VisualAge for Java. Rational Software was acquired by IBM in 2003.

Model Views and Round-Trip Engineering

Rational Rose uses a formal model framework to store all design elements and their relationships. This way, Rational Rose can create different views of the design and ease the transformation of one diagram type to another. As an example, if the user changes the name of an element in one diagram view, it changes consistently in all other diagrams.

Rational Rose allows one to create a model from scratch or to start from a set of predefined models. Users can select from model templates like Java, VC-MFC, VB, etc. Figure 1 shows Rose's model browser. It is used to navigate through the model, and to add and delete diagrams, entities and relationships.

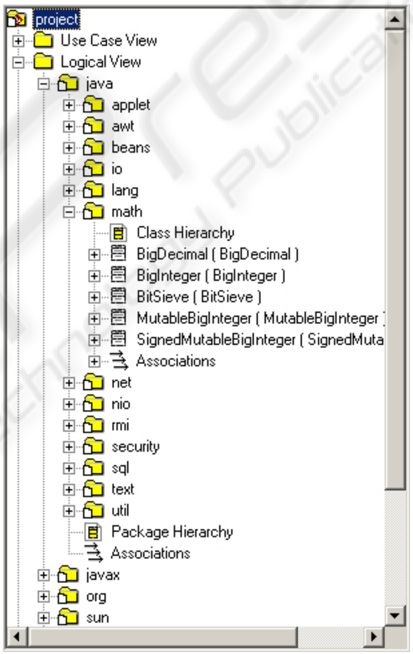


Figure 1: Rational Rose's model browser.

A key feature of Rational Rose is its round-trip engineering capability which allows one to generate source code from the model and model elements from source code. Round trip engineering consists of two parts:

- *Forward Engineering*: Changes to the UML model are translated into source code changes.
- *Reverse Engineering*: Changes to the source code are updated in the model's elements.

In our own experience, and based on reports from several fellow IT managers, this round-trip engineering process is not flawless. Large-scale industrial IT projects involve several different programming languages, operating systems, databases, class frameworks and batch scripts, in addition to a version control system, a code documentation tool, etc. This diversity alone makes keeping these systems and artifacts in sync a complex challenge.

3.2 UMLet: Lightweight UML Modeling

UMLet is a small UML sketching tool. It aims at early life-cycle UML modeling and UML education. It is distributed as open source tool under the terms of the GNU General Public License. Since it is developed in Java it is operating system independent. UMLet may also be used as a plug-in within the integrated development environment Eclipse to better integrate UML models with a project's source code artifacts.

UMLet was originally developed in 2001 at the Vienna University of Technology. The first versions were designed to run as an applet in a browser, with diagrams being stored on a central server. The setup of this client/server solution proved too tedious for average UML users and students; the following versions were therefore released as a stand-alone Java application. Several features were added in the following years: versions 1 to 3 provided export capabilities, integration in the Eclipse IDE, and user-defined element palettes. Versions 4 to 7 added new UML diagram types and user-defined UML elements via on-the-fly Java compilation. The main user interface concept remains the text-based UML element description.

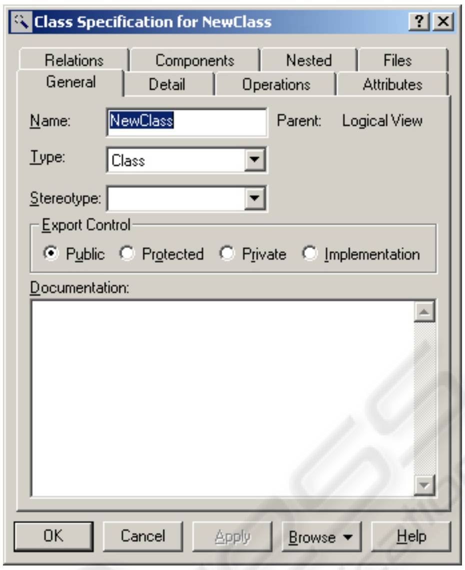
Text-Based Modeling

UML tools usually treat UML elements as visual objects, whose appearance can be edited by changing their attributes. This is mostly done through pop-up dialog boxes. See figure 2 for an example of Rose's dialog to edit a UML class element and its attributes. The dialog contains 8 tabs, and approximately 40 user interface elements.

UMLet's user interface is different: it allows users to define the look of a UML element by editing a textual description of it. For example, the UML class element in figure 3 is defined by the following lines:

```
MyClass
--
id: Long
ClassAttribute: Long
--
MyClass(i: int)
someOperation(): Object
```

The double dash denotes the lines that are separating class title, attributes and methods. Changing the title, or adding and removing new attributes and methods is done by editing the textual description of the class.



Class Specification for NewClass

Name: NewClass Parent: Logical View

Type: Class

Stereotype:

Export Control: ● Public ○ Protected ○ Private ○ Implementation

Documentation:

Figure 2: Rational Rose: Class Specification Dialog.

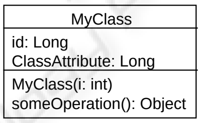


Figure 3: Class element.

Not only simple UML elements like classes can be modified like this. UMLet also provides more complex diagram types entirely defined by a text grammar. The sequence diagram of figure 4, for example, is defined as follows:

```
title: Sequence Diagram
_alpha:A_|_beta:B_|_gamma:G_
1->>2:1,2
2-/>1:async Msg.
3->>>1:1,3
1.>3:1,3:async return Msg
1->1:1:self
iframe{:interaction frame
2-/>3:2,3:async Msg.
iframe}
```

When the textual description of a UML element is edited by the user, the element's graphical representation is updated in real time—no separate dialog or confirmation is necessary. The text editor also provides standard copy/paste functionality, which is useful, for example, when adding several private attributes and corresponding get/set-methods to a class.

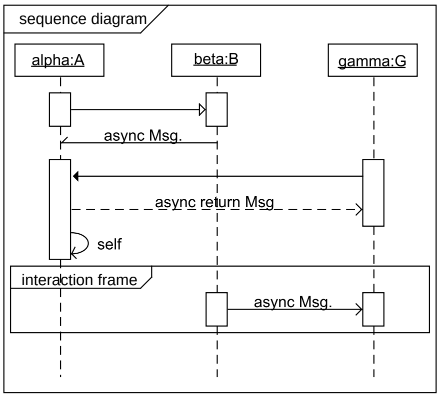
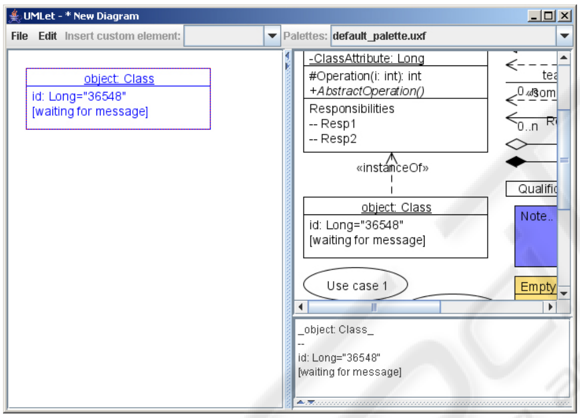


Figure 4: Sequence diagram using a simple grammar.

Figure 5 shows the user interface's three main parts: diagram panel, element palette panel and the text panel to edit the UML element attributes.



```
_object: Class_
--
id: Long="36548"
[waiting for message]
```

Figure 5: UMLet's user interface.

UMLet's element palettes are normal UML diagrams: they show the available diagram elements in real size rather than as tiny, abstract icons. The users can quickly identify the elements without having to interpret icons or navigate menus; see figure 5. And as a palette is just another UML diagram, it can be rearranged or modified to show the most useful elements or element configurations for a given environment.

4 UML TOOL USAGE

This section describes the three main usages of UML tools: explorative UML sketching, round-trip engineering, and system documentation. To perform the complex round-trip engineering and documentation, tools must enforce formal language constructs more rigorously. They can thus become unsuitable for simple explorative sketching.

Explorative UML modeling is the fast creation of UML sketches. Those sketches often do not have to be precise or final or completely UML compliant. The goal of explorative sketching is to play and experiment with the model, to reach a better idea of the design iteratively, and to discuss the model with colleagues and other stakeholders in the requirements analysis phase. Explorative sketching may also be used in UML education—UML examples can focus on key language elements while disregarding distracting details. A simple and fast modification of the diagram and its elements is crucial.

Round-Trip engineering aims to keep the design and the actual implementation of the software project synchronized. This should guarantee that the high-level abstraction and the low-level implementation both remain valid over the project's lifetime. This is important, for example, if changes to an application's overall software architecture should be made—the abstract design view is the natural starting point for such a refactoring effort. If the design view, however, does no longer represent the actual implementation, the refactoring must start on the implementation level and it becomes less transparent and more tedious.

Documenting existing artifacts is another major application for UML tools. It is often motivated by the fact that large projects require extensive system documentation. Unfortunately, a common measure for the quality of the documentation is its size, as precision and understandability are difficult to assess. An easy way to create massive amounts of documentation is to reverse-engineer diagrams from existing code. These generated diagrams are often very hard to interpret since, unlike hand made diagrams, they can't hide unnecessary details or make use of the elements' spatial orientation.

This paper focuses on the first application of UML tools, UML sketching. This is a fundamental UML tool application—every design tool, at several points in a project's life cycle, is likely to be used as a UML sketchpad. If it is too cumbersome to use, users will turn away and settle for improvised PowerPoint graphs or scanned notes.

5 TESTING SCENARIOS AND RULES

There are several methods to examine the usability and ergonomics of user interfaces. The most straightforward method might be to examine user behavior while they execute well defined use cases. This method can be combined with video recordings or even eye tracking recordings. Examinations like this, however, are very time consuming and expensive.

Raskin (Raskin, 2000) discusses an alternative method for quantifying user interface usability: GOMS (Goals, Operators, Methods, and Selections rules). GOMS, developed by Stuart Card, Thomas Moran and Allen Newell, evaluates a user interface by analyzing elementary actions like pointing and clicking with the mouse, or typing on the keyboard. These elementary actions are weighted with time factors.

We simplify this method by concentrating on mouse clicks and combined keyboard inputs, while disregarding mouse movements or individual key presses. We also do not weight the elementary actions, and only count the number of actions needed to complete a given use case.

The following list gives a set of representative use cases which are typical to the creation of UML diagrams. We concentrate on class diagrams and sequence diagrams, since the creation and modification of other UML diagram types is very similar.

1. **Create a simple class:** Starting from an empty diagram we create a simple class element without defining any attributes or operations.
2. **Extend a simple class with attributes:** Extend the simple class with one attribute without specifying special characteristics.
3. **Extend a simple class with operations:** Extend the (simple) class with one operation without specifying a special return value or input parameters.
4. **Modify an attribute's characteristics:** Modify the attribute; define it to be protected and specify its type as *Object*.
5. **Duplicate a class:** Make a copy of the class.
6. **Add an aggregation to a two-class diagram:** Add an aggregation dependency between two classes.
7. **Modify an aggregation to a generalization:** Change the aggregation dependency to a generalization dependency.
8. **Change the direction of a generalization:** Change the direction of the generalization, so the specialized class becomes the parent class.
9. **Delete one class:** Remove one class from the diagram.
10. **Undo class delete:** Undo removing one class from the diagram.
11. **Create a simple class diagram:** Create a slightly more complex class diagram. The composite design pattern—consisting of 4 classes and three different relationship types—is implemented.
12. **Create a simple sequence diagram:** Create a simple sequence diagram consisting of two objects. Object *One* sends a synchronous message to object *Two*.
13. **Change the message direction:** Change the direction of a message in a sequence diagram.
14. **Change the message type:** Change the message type from synchronous to asynchronous.
15. **Add a message to the sequence diagram:** Add a named message to the sequence diagram from object *One* to object *Two*.
16. **Create a sequence diagram:** Create a sequence diagram of the process of browsing with a Web browser to a Web site. The involved objects are *User*, *Browser*, *Web server*, *DNS*. Object types and message types are not specified.

As an example, these are the individual user interactions required for use case 1, with Rational Rose and UMLet:

Create a simple class:

Starting from an empty diagram we create a simple class element without defining any attributes or operations.

- Starting point: An empty diagram

- Goal: A diagram with a simple class element

User interactions required by UMLet: 2

1. Create the class by double clicking on the simple class on the palette.
2. Rename the class to "`MyClass`".

User interactions required by Rational Rose: 4

1. Select the class element by clicking on the class icon on the tool bar.
2. Place the class element by clicking in the diagram window.
3. Rename the class to "`MyClass`".
4. Click into the diagram window to complete the naming operation.

For an extensive description of all use cases, please refer to (Auer et al., 2007).

6 DISCUSSION

The results of the test are summarized in table 1 and figure 6. It shows that UMLet requires substantially fewer user interactions than Rational Rose; there are only a few tasks that can be executed faster in Rational

Table 1: Results.

#	Use Case	# UI UMLet	# UI R.Rose	Abs. Diff.	Rel. Diff.
1	Create a class	2	4	+2	100%
2	Extend class with attributes	5	4	-1	-20%
3	Extend class with one operation	5	4	-1	-20%
4	Modify an attribute	5	10	+5	100%
5	Duplicate a class	1	11	+10	1000%
6	Add an aggregation	4	2	-2	-50%
7	Modify an aggregation	1	5	+4	400%
8	Change a generalization	1	5	+4	400%
9	Delete a class	2	3	+1	50%
10	Undo class delete	2	2	+/-0	0%
11	Simple class diagram	39	48	+9	23%
12	Simple sequence diagram	4	29	+25	625%
13	Change message direction	3	11	+8	266%
14	Change message type	3	5	+2	66%
15	Add a message	3	4	+1	33%
16	Create a sequence diagram	12	49	+37	308%
				Median Relative Difference	83%

UI = number of user interactions

Rose. To complete simple but frequent tasks when creating UML sketches, users are required to perform about 80% more interactions with Rational Rose than UMLet.[1]

Surprisingly, duplicating a class element (use case 5) in Rational Rose is an extremely cost intensive task. It requires 11 interactions in Rose, and just one in UMLet. Apart from use case 5, use case 16 shows the maximum performance advantage of all tested use cases. The reason is UMLet's special grammar for sequence diagrams. It especially frees the user from the task of placing and resizing the various sub-elements' graphical representations. In order to keep the grammar's syntax simple, UMLet makes some trade-offs and does not support the full functional range of the UML sequence diagram. UMLet does provide support for creating such diagrams conventionally, using individually placed elements. In this case, however, UMLet's advantage shrinks.

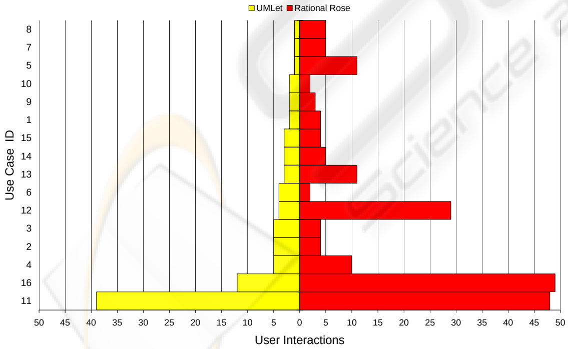


Figure 6: Results.

As documented in table 1, operations like changing the direction of dependencies (use case 8) or changing the type of dependencies (use case 7) are very simple using UMLet. Rational Rose's way of dealing with this is more time-consuming. In theory, this seems to be o.k.—after all, a dependency's direction or type seems to be so fundamental that changing it does not make sense in most cases. We found, however, that these use cases actually occur quite often when sketching diagrams, especially if the wrong relation was inadvertently added to the diagram, if the classes responsibilities change, or if inheritance structures are broken up and changed to looser class relations.

Although not covered by our test, even the simple task of adding multiplicities can turn out to be a struggle. Rational Rose offers two ways of adding multiplicities to a relation. Either the user selects it from a list box in one of the tabs of the specification dialog (requiring 6 user interactions), or the user selects the multiplicity type from the context menu (requiring 3 user interactions). The problem is that the user then often realizes that the multiplicity was added at the wrong side of the relation. So he is often forced to delete the multiplicity and re-add it. Mistakes like these occur in UMLet, too, but the correction can be done in a single user interaction using the text-based attribute specification, whereas Rose requires the entire process to be repeated.

The comparison of the two tools should not determine a "better" UML tool—after all, the tools have widely different aims. UMLet, in this paper, should merely denote a baseline, a low-complexity approach to which Rational Rose, one of the leading UML tools, can be compared with respect to fast UML sketching. Our comparison indicates that Rational Rose, on average, requires almost two times as many user interactions as necessary.

Is this merely the consequence of the fact that Rational Rose has many more features, and has to enforce more formal UML standards? Or, more generally, do tools dealing with complex demands necessarily become more complex?

We don't think so. A good example is Microsoft's suite of integrated development environments, Visual Studio. While offering an astonishing array of options and features, the basic functionalities of programming—typing, searching, looking up object members—continue to be very easy to use. The search functionality was actually improved over time (it is now non-modal, and offers a history of searches) without sacrificing usability; the object member lookup still hides complex functionality behind an unobtrusive and efficient user interface.

Tools thus are able to both tackle complex requirements, and to provide intuitive base functionality. In the quest to offer ever-more features, this goal should not be neglected.

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[1] The sign test rejects the null hypothesis of a zero median difference; it is significant at the 5% level.

7 CONCLUSION AND FURTHER RESEARCH

This paper compares two UML tools with respect to their suitability for explorative UML sketching. Several common UML design tasks were tested to determine the number of required user interactions.

The large, standard-conforming and -enforcing Rational Rose was found to require substantially more user interactions than UMLet. As Rational Rose's design goals have to accommodate a wide range of requirements, fast and explorative UML sketching becomes less intuitive and more tedious. This is assessed by comparing Rational Rose to UMLet, a tool specifically tailored to creating UML sketches.

We argue that as tools get more complex, developers must make sure to avoid compromising on important base functionality—otherwise, a tool will cover more requirements, but important ones less well.

Further research will focus on

- aspects of tool complexity and integration, especially on ways to integrate separate interactive and highly graphical applications;
- refined user interaction measures, that take into account not just the number of user interactions, but their type and complexity (like decoding an icon's meaning, or clicking on small, scattered buttons).

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