

Custom Visualization without Real Programming



Kostas Pantazos
Software and Systems
IT University Of Copenhagen

A thesis submitted for the degree of
Philosophiae Doctor (PhD)

October 2012

To my parents.

Abstract

Information Visualization tools have simplified visualization development. Some tools help simple users construct standard visualizations; others help programmers develop custom visualizations. This thesis contributes to the field of Information Visualization and End-User Development. The first contribution of the thesis is a taxonomy for Information Visualization development tools. Existing taxonomies for Information Visualization are helpful, but none of them can properly categorize visualization tools from a user development perspective. The categorization of 20 Information Visualization tools proves the applicability of this taxonomy, and the result showed that there are no *Drag-and-Drop* tools that allow end-user developers as well as programmers to create custom visualizations. The results can be used by the End-User Development and the Information Visualization community to identify future avenues of research.

The second contribution is a new visualization development approach, the *Drag-Drop-Set-View-Interact* approach provided by the visualization tool uVis. In order to construct custom visualizations with uVis, end-user developers and programmers *drag and drop* controls, *set* formulas, *view* immediate results, and *interact* as end-users without switching workspace. This approach was possible by extending the uVis formula language with a development environment – the uVis Studio. As existing work in Information Visualization has overlooked end-user developers, and End-User Development has not explored visualization development, this thesis provides a starting point for End-User Development of Information Visualization. The results of this thesis show that with a modest amount of training, end-user developers can construct custom visualizations with the *Drag-Drop-Set-View-Interact* approach. Related work in Information Visualization regarding tools for custom visualizations has mainly focused

on supporting programmers with language tools. This thesis showed that programmers can construct custom visualizations faster with *Drag-Drop-Set-View-Interact*. Additional proof is provided through the development of two custom visualizations by an experienced user of uVis.

Acknowledgements

The last three years have been an unforgettable experience. Some days were good and productive, others were stressful and long. However, writing these acknowledgments makes you feel good. First, you are happy to write the last part of your thesis. Second, you go back in time to recall great memories.

First and foremost, I would like to thank my supervisor, Soren Lauesen. He is a devoted professor advising, encouraging, inspiring all the time. Having meetings with Soren has always been a pleasure, as these discussions brought back smiles lost in piles of papers and lines of code. I am grateful and lucky to work with and learn from him.

Second, I would like to thank the other members of the uVis project: Mohammad A. Kuhail, Soren Lippert, and Shangjin Xu. It has been a pleasure and great experience working together.

My colleagues in the Software and Systems Department made this long journey more enjoyable. I have enjoyed every moment of our discussion, collaboration and happy hours at the scrollbar. I would also like to thank Prof. Ben Shneiderman, Dr. Catherine Plaisant and the members of the Human-Computer Interaction Lab at the University of Maryland for the great experience.

Many thanks to MyClinic, Symmetric Consulting, Venereal Clinic and all the usability study participants. Also, many thanks to Mads B. Andresen and Nikolaj Setness for their contribution to the uVis project.

Words cannot express the gratitude I owe Arisa and my family. Arisa has been encouraging, inspiring, advising, and supporting me all the time, and I would not be the person I am today without my family's support.

Contents

List of Figures	viii
List of Tables	xiii
1 Introduction	1
1.1 Research Problems	1
1.2 Solution	3
1.3 The uVis Project	4
1.4 Research Approach	5
1.5 Contributions	6
1.6 Publications	7
1.7 Thesis Overview	8
2 Background and Related Work	10
2.1 Information Visualization	10
2.2 End-User Development	13
2.3 Existing Visualization Development Tools	17
2.3.1 A Review of Existing InfoVis Taxonomies	17
2.3.2 Visualization Tool Taxonomy	19
2.3.3 Analysis Approach	22
2.3.4 Tools and Toolkits	23
2.3.5 Results	42
3 Solution	45
3.1 uVis Formula Language	45
3.1.1 uVis Files	46

3.1.2	Controls	46
3.1.3	Properties	47
3.1.4	Formulas	47
3.1.5	Visualizations	49
3.1.6	Interaction	51
3.1.7	Special uVis Concepts	52
3.2	uVis Studio	54
3.2.1	Panels	57
3.2.2	Development Approach	67
3.2.3	Cognitive Supports	68
3.2.4	Performance	70
4	The Approach in Practice	72
4.1	The Process Completion Diagram	72
4.2	Visualizing the Evolution of Technologies	79
5	Usability Evaluation	82
5.1	Usability Factors	82
5.2	Measurement Techniques for Usability	83
6	Usability Study with Programmers	87
6.1	Procedure and Tasks	87
6.2	Results	91
6.3	Summary	104
7	Usability Study with End-User Developers	111
7.1	Procedure and Tasks	111
7.2	Results	114
7.3	Summary	126
8	Usability Study with Clinicians	132
8.1	Information Visualization in Healthcare	132
8.2	Usability Study	135
8.2.1	Procedure and Tasks	135
8.2.2	Results	138

8.2.3 Summary	141
9 Discussion	146
9.1 Visualization Tool Taxonomy	147
9.2 uVis	148
9.3 Usability Studies	148
10 Conclusions and Future Work	154
Appendix A A Custom Visualization with uVis Formulas	158
Appendix B Evaluation with Programmers - Documentation	163
Appendix C Evaluation with End-User Developers - Documentation	180
Appendix D Evaluation with Clinicians - Documentation	187
References	198

List of Figures

2.1	The evolution of user-centered design by Aigner et al.[2].	13
2.2	A scatter plot (top) and its graphical specifications (bottom) created with APT. Source: [60].	24
2.3	SAGE’s input and the result. Source: [87].	25
2.4	A visualization in SageBook (top), and SageBrush where visualizations are specified (bottom). Source: [25].	26
2.5	Visualizing financial information with DEVise in a step-by-step approach: select a schema, select a data stream, define mapping, and define visual links and cursors. The final output is shown on the right side, together with the pop-up window that shows details-on-demand. Source: [59].	27
2.6	A pie chart created with Processing. Source: [80].	28
2.7	GeoVISTA Studio: the Main window shows the visual objects and system options, the Design window (top) contains visual objects represented by icons and connected by lines, the Graphical User Interface (right) shows the visualization specified in the Design window (left), and the Property Editor (represented by the adapter wizard) used to customize a visual object. Source: [100].	29
2.8	A parallel coordinated visualization with InfoVis Toolkit. Source: [28].	30
2.9	A scatter plot created with Piccolo. Source: [9].	31
2.10	A multi-view coordination visualization in Improvise and the Controls editor. Source: [112])	32
2.11	An animated radial layout created with Prefuse. Source: [36].	33
2.12	The Job Voyager visualization created with Flare. Source: [30].	34

LIST OF FIGURES

2.13	An arc diagram created with Protovis in ProtoViewer. ProtoViewer consists of three parts: Data (left), Design (middle) and Code Editor (right). Source: [4].	35
2.14	A calendar view created with D3. Source: http://mbostock.github.com	36
2.15	A bar chart created with MS Excel. Source: [64].	37
2.16	A bubble chart created with Tableau. Source: [99].	38
2.17	Several visualizations of the same dataset created with Spotfire. Source: [97].	39
2.18	Several visualizations of the same dataset created with Omnisciope. Source: [71].	39
2.19	The Designer (left) and the Previewer (right) in Tom Sawyer Presentation. Source: [103].	40
2.20	A treemap in Code-Playground of Google chart Tools. Source: [32].	41
2.21	A map visualization in Many-Eyes. Source: http://www-958.ibm.com/	42
3.1	a. Vis-file, b. Vism-file	46
3.2	Visualizations created with uVis: a. Simple Pie Chart, b. Custom Pie Chart, c. Spiral Graph, d. SparkClouds, e. CircleViews, f. TreeMap, g. TileMaps.	50
3.3	uVis Studio v.1: 1. Toolbox, 2. Explorer, 3. Design Panel, 4. Property Grid, 5. E/R Model, 6. Error List, 7. Modes, and 8. Auto-Completion. Notice that the selected control is highlighted in dark-blue, and properties are shown in the <i>Property Grid</i> . In this case, the developer is specifying the Rows . The developer types the fields after the <i>group by</i> , but the <i>Auto-Completion</i> does not suggest <code>tblIntake</code> because it is not used.	55
3.4	uVis Studio v.2: 1. Toolbox, 2. Explorer, 3. Design Panel, 4. Property Grid, 5. E/R Model, 6. Error List, 7. Modes, 8. DataView, 9. Control-Data Hierarchy, 10. Auto-Completion, 11. Formula suggestions. The selected control is highlighted in light blue color in the <i>Design Panel</i> and <i>Control-Data Hierarchy</i> , as the selected property in the <i>Property Grid</i>	56

LIST OF FIGURES

3.5	The <i>Auto-Completion</i> in action showing suggestions of : 1. table names, 2. relationship names, 3. SQL keywords, 4. field names, 5. control names, 6. control Properties, 7. event properties, and 8. functions and control properties.	60
3.6	The first version of the <i>E/R Model</i> (left). The improved version of the E/R Model (right).	61
3.7	The <i>Formula Suggestions</i> in action showing suggestions of: 1. table names, 2. field names, 3. relationship names when the Rows property of the parent control is not specified, and 4. relationship names when the Rows property of the parent control is specified.	63
3.8	1. A developer attempts to map the field amount to the Top property. 2. A developer tries to map the rows of tblIntake to Top	63
3.9	The developer selected the error message in the Error List (left) and the wrong formula is highlighted in the Property Grid (right).	64
3.10	1. The <i>Interact-Mode</i> is set to designer mode and the developer has selected the barIntake control (top). 2. The <i>Interact-Mode</i> is set to end-user mode and the developer interacts with the timescale and tests the tool-tip.	65
3.11	The developer uses the <i>Data</i> to: enable the WYBIWYG (1) or disable it (2).	65
3.12	1. The <i>DataView</i> . 2. The Control-Data Hierarchy.	66
4.1	The evolution of the Process Completion Diagram (PCD). The final version visualizes the blood-test process from the medical domain. . . .	73
4.2	Three controls were dragged and dropped. The selected control and property are colored in light blue.	74
4.3	Creating the plot using two labels and two lines.	75
4.4	Two rectangles and a triangle to visualize the in-time, the late and the not-completed tests.	76
4.5	Shapes are bound to data and Height and Width are mapped to number of tests and duration.	77
4.6	“Interact with the Design Panel” end-user is enabled. The other panels are disabled.	78

LIST OF FIGURES

4.7	The final version of PCD.	78
4.8	1. The paper-based visualization that provides an overview of the process and details for each step of the process. 2. The Multi-Step Process Visualization (MSProVis) combines three views in a single presentation, allowing managers to explore process, steps, and actors' tests rapidly.	80
4.9	1. The original drawing visualizes 382 technologies. 2. The custom visualization created with uVis formulas and the Studio.	81
6.1	The bar chart and the E/R data model.	89
6.2	The LifeLines and the E/R data model.	90
6.3	Initial version of MSProVis.	90
6.4	Participant 1: Problem counts by type (left). Subjective ratings (right).	93
6.5	Participant 2: Problem counts by type (left). Subjective ratings (right).	95
6.6	Participant 3: Problem counts by type (left). Subjective ratings (right).	97
6.7	Participant 4: Problem counts by type (left). Subjective ratings (right).	99
6.8	Participant 5: Problem counts by type (left). Subjective ratings (right).	101
6.9	Participant 6: Problem counts by type (left). Subjective ratings (right).	103
6.10	Participants' rating for Task 1 and 2 (top). Minimum, Maximum and Average rating for Task 1 and 2 (bottom).	108
7.1	The bar-chart and the E/R data model.	112
7.2	The PCD, the simplified PCD used in this study, and the E/R Data Model.	113
7.3	Participant 1: Problem counts by type (left). Subjective ratings (right).	115
7.4	Participant 2: Problem counts by type (left). Subjective ratings (right).	116
7.5	Participant 3: Problem counts by type (left). Subjective ratings (right).	118
7.6	Participant 4: Problem counts by type (left). Subjective ratings (right).	119
7.7	Participant 5: Problem counts by type (left). Subjective ratings (right).	121
7.8	Participant 6: Problem counts by type (left). Subjective ratings (right).	122
7.9	Participant 7: Problem counts by type (left). Subjective ratings (right).	124
7.10	Participant 8: Problem counts by type (left). Subjective ratings (right).	126
7.11	Participants' rating for task 1 and 2 (top). Minimum, Maximum and Average rating for task 1 (bottom-left) and task 2 (bottom-right)	129

LIST OF FIGURES

8.1	Three different EHR systems from the Copenhagen region showing: 1. the patient's medicines. 2. the drug records for a patient. 3. the lab-test results for a patient.	133
8.2	1. Current presentation at the clinic, 2. A simple presentation patient lab-test results, 3. Presenting lab-test results on a time-line.	135
8.3	The LifeLines and the E/R data model.	136
8.4	The PCD, the simplified PCD used in this study, and the E/R Data Model.	138
8.5	Clinician 1 and 2: Problem counts by type (top). Subjective ratings (bottom).	140
A.1	(a) LifeLines visualization created with uVis. (b) The E/R model. (c) The formulas for each control, which are stored in a <i>Vis</i> file.	159

List of Tables

2.1	A taxonomy of visualization tools.	20
2.2	20 InfoVis tools mapped according to the taxonomy. Tools from industry are in bold. Boxes in yellow indicate the problems addressed in this research. Boxes in gray represent future research directions.	43
3.1	Performance measures. The first column shows the time spent when uVis Studio starts, but no visualization is opened. The other columns shows how the Studio performs when a visualization has: one control, 83 controls, 5,226 controls, and 50,000 controls.	70
6.1	Usability problems encountered in this study. They are grouped by root problem, and classified by type. For each problem I show who encountered it and potential solutions.	106
7.1	Usability problems recorded in this study. They are grouped by root problem and classified by type. For each problem I show who encountered it.	128
8.1	Usability problems encountered in this study. They are grouped by root problem, and classified by type. For each problem I show who encountered it.	143

Chapter 1

Introduction

1.1 Research Problems

Information Visualization (InfoVis) is an important topic in many domains: clinicians want a complete picture of patient data; project managers need to obtain an overview and identify the bottlenecks in a project; database analysts look for visualizations that can locate trends in large databases. Traditionally, visualization development is collaboration between domain experts and professional programmers. Both parties spend time and resources to iteratively design a good visualization. Usually, there are communication problems between users and programmers; users have the domain knowledge but no programming skills, while programmers do not have the domain expertise. Consequently, the process may require time and resources. From a management perspective, this collaboration can become very expensive.

The ideal solution to this problem would be to allow domain users to construct visualizations. As a result, the cost will be significantly reduced, and better visualization will be developed as users know their own demands better. However, this solution is difficult because few domain users have the required IT skills.

In the last decade, a new research discipline has emerged, called End-User Development (EUD). The main goal of this discipline is to empower end-user developers to create, modify and extend *software artifacts*, and as a result gain more control over their applications [56]. This thesis focuses on end-user development of visualizations.

In the thesis, I distinguish three kinds of users:

- *Simple users* have basic IT skills and can operate IT systems to accomplish basic tasks, but not programming skills.
- *End-user developers* are not programmers, but users who “may have little or no formal training or experience in programming” [72]. These users “have experience performing relatively sophisticated data organization and manipulation, using a combination of manual processing and limited amounts of programming or scripting” [37].
- *Programmers* have excellent developing skills and are experienced in software development and databases. They usually work in IT companies that provide domains with IT applications. Constructing custom visualizations is time consuming, but not difficult for programmers.

Rather than investigating InfoVis in itself, this work investigates visualization development tools from a user perspective, and more precisely for end-user developers and programmers.

Several InfoVis tools have been developed to help users with different IT skills develop visualizations – representations of abstract data that “has no inherent mapping to space” [20]. Some of them support users with predefined visualizations, and others with primitive visual objects that can be combined into visualizations. In order to compare visualization development tools and to what extent the visual mappings are predefined, I classify visualizations in two types:

- *Standard visualizations*: predefined visualization templates that combine, customize, or extend the templates in limited ways. For example, a bar chart in MS Excel uses a predefined bar chart template where only a few visual attributes of the chart (e.g. bar height) are assigned to data.
- *Custom visualizations*: combine visual objects into a complex visualization or use predefined visualization templates that can be combined, customized and extended in many ways. For example, a LifeLines visualization [79] is constructed by combining bars, triangles, labels, etc. Another example is a bar chart created with Prefuse. Users of Prefuse can assign all visual attributes of the bar chart to data attributes.

Commercial tools [64, 97, 99] allow simple users to create standard visualizations. Other tools [9, 13, 14, 28, 36], especially from research, focus more on supporting programmers with libraries to develop custom visualizations. As shown in a recent study [73], more tools are needed to help end-user developers (called savvy users [37, 73] in the InfoVis field) develop custom visualizations. Therefore, the main research question is:

Can end-user developers construct custom visualizations?

In addition to the main problem, this thesis also addresses the problem programmers face in visualization development. Programmers construct custom visualizations in a programmatic way. They write code in code editors and run the program to view data and test interactions. Consequently, this process affects their performance. Therefore, this research also addresses this sub-question:

Can programmers construct custom visualizations faster?

1.2 Solution

To allow end-user developers create custom visualizations, we developed uVis. uVis combines a simplified programming mechanism (the uVis formula language) with a development environment that provides aids to enhance cognitive abilities (uVis Studio).

The uVis formula language resembles a spreadsheet language. Each control (visual object) attribute has a formula. *uVis Studio* (or simply the Studio) is the development environment of uVis. Users of uVis *drag-and-drop* controls, *set* control properties using uVis formulas, *view* immediate results in the Studio, and *interact* with the visualization as an end-user without switching workspace. This development approach is called *Drag-Drop-Set-View-Interact* and differs from approaches of existing visualization tools, because they do not use a drag-and-drop approach.

The goal is to make a general-purpose visualization tool that supports construction of many types of visualization (e.g. time-oriented, tree, etc.) through property formulas. This means that visualizations such as LifeLines [79], Fisheye menus [8], SparkClouds [55], etc., can be constructed by defining formulas for the properties of controls. As an example, in uVis, the Bederson's Fisheye menu [8] can be constructed using a label for each menu item. The label's `Top`, `Left` and `FontSize` properties are formulas that compute distorted positions and sizes.

uVis supports a wide range of visualizations. However, with current version some custom visualizations may not be possible to implement. As an example, in cases of animation uVis falls short. Therefore, I would like to remind the readers that uVis is a general-purpose visualization tool that proves the idea, but still needs more features and controls.

1.3 The uVis Project

The research presented in this thesis is part of the uVis project started early 2008 in the Software and Systems Department of the IT University of Copenhagen. Prof. Soren Lauesen defined the goal and the scope of the project, the requirements and invented uVis, as described in [53]. uVis was inspired by MS Access, which was popular and nicely combined user interface and database. However, it was not powerful enough for custom visualizations. The idea was to allow properties to be powerful formulas and in that way develop user interfaces and visualizations without real programming. The design of the solution and the implementation is the joint intellectual work of Mohammad Amin Kuhail, Soren Lauesen, Kostas Pantazos, and Shangjin Xu (in alphabetical sequence). At the beginning, the project focused on developing the uVis formula language and made a proof of concept that user interfaces and visualizations can be created with property formulas written in a text editor. The second step of the project was to develop uVis Studio, the development environment of uVis, and evaluate the uVis formula language and uVis Studio with end-user developers and programmers. The contributions of the second step are described in this thesis.

Developing such a tool is a challenging task, as many engineering requirements should be considered. The requirements of uVis were defined by Soren Lauesen [52] and include many perspectives: usability, performance, security, simulated time, testing issues, etc. However, the theme of this thesis is not to elaborate on all perspectives. Rather, the main perspective is usability, aiming at answering the aforementioned research questions.

1.4 Research Approach

The research presented in this thesis does neither investigate existing visualizations, nor introduce novel ones. Rather, it focuses on the development process of visualization applications. The research presented in this thesis can be divided in three parts conducted in parallel. They are described in this section.

Review of Existing Visualization Development Tools

The purpose of the review was to identify existing related work on InfoVis development tools. 20 InfoVis tools (13 from research and seven from industry) were selected and investigated on how they support users despite their IT skills. As part of this, I developed a visualization tool taxonomy presented in Chapter 2 in detail.

Development of uVis Studio

Once we proved that it was possible to implement the formula language, I had to develop the development environment, which would make uVis easily accessible to end-user developers as well as programmers. The first version of the Studio was usability tested with programmers who have developed visualizations and user interfaces with other tools. Their feedback helped us to identify difficult concepts of the uVis formula language, usability problems with the Studio, and suggestions for improvement. The results of this usability study are presented in Chapter 6. The second version of uVis Studio introduced new panels, new features and several improvements. This version was evaluated with end-user developers. Results are reported in Chapter 7 and 8.

Usability Studies

I conducted three usability studies. The first study was conducted with six programmers using the first version of uVis Studio, and aimed at answering the research question: “*Can programmers construct custom visualization faster?*”. I decided to ask for programmers who are experienced in developing InfoVis and Human-Computer Interaction applications because they could compare the development approach applied in uVis with what they had used so far. Also, they had been using development environments and should be able compare the features of the Studio versus what they had used before. Using the second version of uVis Studio, I conducted the second study with

eight end-user developers and the third with two clinicians who are end-user developers. These two studies aimed at answering the research question: “*Can end-user developers create custom visualizations?*”. The purpose of the studies was also to identify usability problems in order to improve uVis.

1.5 Contributions

The research contribution of the uVis project is the visualization tool (uVis) that uses spreadsheet-like formulas (*uVis formula language*) and has a development environment (*uVis Studio*). The contributions of my thesis are:

- A visualization tool taxonomy for InfoVis: Existing taxonomies for InfoVis are useful in categorizing visualization techniques, identifying suitable visualizations for different data types, structuring the development of InfoVis, etc., but none of them can properly categorize visualization tools from a development perspective. The categorization of 20 InfoVis tools proves the applicability of this taxonomy, and the result showed that there are no *Drag-and-Drop* tools to create custom visualizations for end-user developers as well as programmers.
- A new *Drag-and-Drop* development approach with uVis, called *Drag-Drop-Set-View-Interact*: In order to construct custom visualizations, users of uVis *drag and drop* controls, *set* formulas, *view* immediate results, and *interact* as end-users without switching workspace.

Existing work in InfoVis has overlooked end-user developers. At the same time, the EUD literature has not investigated the involvement of end-user developers in visualization development. This work contributes to InfoVis and EUD with a new approach, which allows end-user developers to construct custom visualizations. The results of usability studies with end-user developers showed that with a modest amount of training they can learn and use uVis to construct custom visualizations.

Related work in InfoVis regarding development tools for custom visualizations mainly supports programmers with language tools. Direct manipulation, immediate feedback, switching workspace are some of the factors that can affect their performance in visualization development. This work also contributes with a new

development approach, which boosts programmers' performance. The results of a usability study with programmers who have programmed visualizations and user interfaces with other tools, indicated that uVis allows programmers develop custom visualizations faster than other tools. In addition, two custom visualizations were developed in a few hours with this approach by an experienced user of uVis.

During the PhD study, I made two more contributions:

- *De-identifying an Electronic Health Record (EHR) Database - Anonymity, Correctness and Readability of the Medical Record.*

Getting access to real data is difficult in every domain, but in healthcare it becomes more complicated due to patient confidentiality. As we needed real data to create visualizations and test the tool, I collaborated with a Danish EHR vendor and developed an algorithm to de-identify a full EHR database with 437,164 patients [74]. The de-identified database (323,122 patients) is adequate for supporting research, development and training. This is the first published study on de-identifying Danish health care records.

- *Exposing Delays in Multi-Step Processes by Retrospective Analysis.*

In 2011, I visited the Human-Computer Interaction Lab at the University of Maryland to evaluate uVis with programmers. In collaboration with Prof. Ben Shneiderman, Dr. Catherine Plaisant and Sureyya Tarkan I developed a visualization called the Process Completion Diagram (PCD) that aggregates medical event-logs into in-time, late and not-completed tests, and visualizes those using shapes, colors and positions [75]. The interactive Multi-Step Process Visualization (MSProVis) combines a number of PCDs to expose delays in multi-step processes, and support the comparisons between steps or between actors executing those steps. MSProVis was constructed with uVis. The formula language and the integrated development environment allowed us to rapidly create several visualization prototypes and led us to MSProVis.

1.6 Publications

I am the main author of the following publications:

- Pantazos, K., Kuhail, M., Lauesen, S., and Xu, S. **uVis Studio: An Integrated Development Environment for Visualization**, In Proc. of Visualization and Data Analysis, (2013).
- Pantazos, K. and Lauesen, S. **Constructing Visualizations with InfoVis Tools - An Evaluation from a User Perspective**, In Proc. of GRAPP/IVAPP 2012, (2012).
- Pantazos, K. **Engaging Clinicians in the Visualization Design Process Is It Possible?**, In Proc. Workshop on Visual Analytics in Healthcare (VAHC) in conjunction with IEEE VisWeek, (2011).
- Pantazos, K., Lauesen, S., and Lippert, S. **De-identifying an EHR Database-Anonymity, Correctness and Readability of the Medical Record**. In Studies In Health Technology And Informatics, (2011).
- Pantazos, K., Shollo, A., Staron, M., Meding, W., **Presenting Software Metrics Indicators - A Case Study**, In Proc. of the 20th International Conference on Software Product and Process Measurement (MENSURA), (2010)

1.7 Thesis Overview

Chapter 2 - Background and Related Work: This chapter introduces the reader to the End-User Development and InfoVis field. Next, the chapter presents visualization development tools used to categorize 20 InfoVis tools. The results of this study shows the current state-of-the-art regarding InfoVis development tools and identifies existing problems.

Chapter 3 - Solution: This chapter describes the proposed solution. At the beginning, the uVis formula language is presented introducing the principles and explaining how formulas set properties to bind controls to data, map fields to properties and refer to control properties. Next, the chapter describes the uVis Studio. Two versions were developed applying iterative development. The differences between these versions are explained as the Studio is described. After presenting uVis Studio, the development approach and cognitive supports of uVis Studio are presented. The chapter concludes with performance measures.

Chapter 4 - The Approach in Practice: This chapter presents uVis in practice using two real scenarios. The first describes the Process Completion Diagram and illustrates step by step how a custom visualization can be constructed applying the *Drag-Drop-Set-View-Interact* approach with uVis Studio. The second scenario shows another custom visualization that visualizes the evolution of technologies.

Chapter 5 - Usability Evaluation: This chapter presents usability as an evaluation method selected in this thesis. It describes the factors of usability and how they are measured. The chapter concludes with the approach applied in the usability studies presented in this thesis.

Chapter 6 - Usability Study with Programmers: This chapter reports on a study conducted with six programmers. Next, it presents the tasks, procedures and results from the study with programmers. At the end, this chapter reports on usability problems, subjective ratings, and a summary of the results.

Chapter 7 - Usability Study with End-User Developers: This chapter reports on a study conducted with eight end-user developers. After describing the tasks, procedures and results, the chapter concludes with the usability problems, subjective ratings, and a summary of the results.

Chapter 8 - Usability Study with Clinicians: This chapter presents a usability study with two clinicians, who are end-user developers. Initially, the need for better presentations of clinical data is depicted through three electronic healthcare record systems from the Copenhagen region. Next, the procedures, tasks and results are described. This chapter concludes with a list of usability problems, subjective ratings, and a summary of the results.

Chapter 9 - Discussion: This chapter discusses the results and the limitations of the research presented in this thesis.

Chapter 10 - Conclusions and Future Work: This chapter presents concluding remarks and discusses future work.

Chapter 2

Background and Related Work

This chapter presents the background and related work focusing on: Information Visualization and End-User Development. First, it presents the Information Visualization field and then introduces the reader to End-User Development. The chapter concludes with a review of existing visualization development tools.

2.1 Information Visualization

Information Visualization (InfoVis) is graphical presentation of abstract data; data that “has no inherent mapping to space” [20]. As an example from the medical area, abstract data are information stored in the database regarding a patient (e.g. name, age, treatment date, dose, intake, etc.)

InfoVis attempts to reduce the time and the mental effort users need to analyze large datasets [20, 96]. The InfoVis field has enabled development of visualization systems that enhance human cognitive processes by visually presenting abstract data [20]. Although, the InfoVis field emerged during the 1980’s with the availability of computers, InfoVis evidence can be tracked long before. Two well-known examples are Minard’s map and Florence Nightingale’s diagram. The map of Minard (a civil engineer) was drawn in 1869 to represent the marching of Napoleon’s army towards Moscow and their retreat [105]. Florence Nightingale’s diagram designed in 1858 shows the death rates in the hospital of Scutari, and how the rates reduce by the changes introduced by nurse Florence Nightingale [96]. Both diagrams allow viewers to get a clear picture of the situation, and derive results without any detailed explanation.

This corresponds to the primary task of InfoVis: “allow information to be derived from data” [96].

Several InfoVis applications have been developed to visualize time-oriented data. LifeLines [79] is an interactive visualization that presents an overview of a patient’s medical record. This visualization was the inspiration for LifeLines 2 [111], but it visualizes a collection of medical records, where users can explore the event-logs for temporal patterns. LifeFlow [116] provides an overview of event sequences by summarizing all possible sequences and visualizing the temporal space of events within sequences. Aigner et al. [3] provide an overview of 101 visualization techniques for time-oriented data. Among them are Arc Diagrams, Circle View, Circos, Flow Map, Perspective Wall, TimeTree, etc.

As the work presented in this thesis focuses on how users develop visualizations, I will not discuss further the work in visualization types (e.g. time-oriented, network, tree, etc.) or interaction techniques (e.g. such as filtering, zooming, focus+context etc.). The related work builds upon what a user can achieve with existing development tools from InfoVis field. As an example, a popular visualization tool from research is Prefuse [36]. This toolkit can support construction of a wide range of visualizations, from standard to custom visualization. I will not investigate the possible visualizations, but who is able to develop visualizations and how they do it with Prefuse. Before I surveyed the InfoVis development tools (section 2.3), I elaborate on the importance of engaging users in visualization development reflecting on existing work, followed by an introduction to the End-User Development field.

Users in Visualization Development

Considering the variety of data and user tasks, it is obvious that new visualizations are needed. However, developing new visualizations is not an easy task. Several InfoVis toolkits and tools [9, 14, 28, 30, 36, 64, 71, 97, 99] have been developed to improve visualization development and provide better presentation of data. Providing good data visualization is challenging as visualization creators should have a good understanding of the data, and then properly design representations that allow users to accomplish tasks effectively and efficiently. This is usually a problem according to Thomas and Cook [102], who say that: “Most visualization software is developed with incomplete

information about the data and tasks. New methods are needed for constructing visually based systems that simplify the development process and result in better targeted applications.”

To facilitate the visualization development process and ensure that visualizations provide complete information about the data and tasks, several InfoVis applications (e.g. [79, 81, 84, 92]) have been developed applying the user-centered method, where users participated during the entire development process. Norman[70] and Nielsen[68] describe user-centered design as the early and continuous involvement of end-users in the design and development process. Considerable work has been conducted by Slocum et al. [92], Robinson et al. [81], Roth et al. [84], and Koh et al. [49] to define the activities applied in the user-centered model for the design and implementation of InfoVis tools. For example, Robinson et al. [81] describe a six-stage user-center design process (work domain analysis, conceptual development, prototyping, interaction and usability studies, implementation, and debugging) where users are involved and provide input in each stage. Using this model [81], Roth et al. [84] present a modified user-centered design approach, which starts with prototyping, followed by interaction and usability studies, work domain analysis, conceptual development, implementation and ends with debugging. Although, the user-centered model helps producing better visualizations, still it is challenging to bridge the gap of knowledge between end-users and programmers. This gap can influence communication and create challenges such as: programmers should understand end-user needs, end-users should gain some knowledge regarding InfoVis, end-users should be devoted and actively participate in the process, etc. In their study Koh et al. [49] experienced similar challenges where simple users where more interested in the tool than on questions about their tasks and data. Also, when they tried the tool they found it limited compared to the prototypes defined during the process. The authors [49] suggested that an iterative approach may address these issues.

Although a user-centered method is a successful approach, researchers envisage approaches to facilitate visualization development and assure that visualizations provide complete information about the data and tasks. Aigner et al. [2] discuss how to support user-centered visual analysis that consists of three factors: the visualization, the analysis, and the user. Figure 2.1 illustrates how they view the past, the present of user-centered visual analysis, and suggest that future research should focus on these

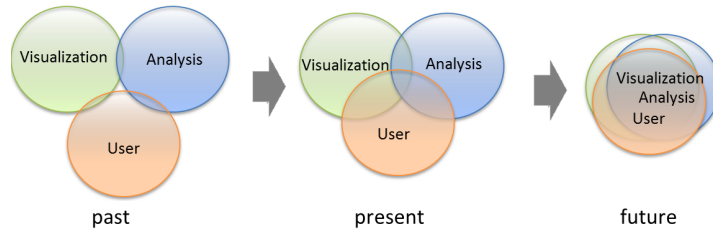


Figure 2.1: The evolution of user-centered design by Aigner et al.[2].

three factors and lead to the convergence of user-centered visual analysis. Their vision matches the universal usability challenge defined by Plaisant [78]. According to Plaisant [78] visualization tools should be accessible to diverse users that do not have the same background, technical knowledge, or personal abilities. Heer et al. [37] seek ways of introducing new audiences in InfoVis. They say that designing visualizations is not an easy task for users, but “we have to provide them tools that make it easy to create and deploy visualizations of their datasets” [37]. Pantazos and Lauesen [73] investigated how 13 InfoVis tools help users construct visualizations. The study concludes that present tools mainly help simple users construct visualizations using predefined templates and allow programmers to create custom visualizations. End-user developers (savvy users) are not well supported and need different visualization tools to create custom visualizations [73].

2.2 End-User Development

The End-User Development (EUD) field is a new research discipline that has emerged from research in Human-Computer Interaction, Cognitive Science, Requirements Engineering, Software Engineering, CSCW, Artificial Intelligence, Information Systems, and the Psychology of Programming [47]. As a relatively young discipline, the field is not mature when it comes to terminology, approaches and subject areas [47]. However, Lieberman et al. [56] define EUD as “a set of methods, techniques, and tools that allow users of software systems, who are acting as non-professional software developers, at some point to create, modify or extend a software artifact”. End-user developers are not professional programmers, but users who “may have little or no formal training or experience in programming” [72]. The main goal of EUD is to empower these users to create, modify and extend software artifacts, and as a result gain more control over

their applications. In old days there were a few end-user developers, but due to the increased use of computers, the number of these end-user developers is increasing. In 1995, Boehm et al. [12] estimated that by 2005, there would be 55 million end-user developers in the United States. In 2005, Scaffidi et al. [88] used and improved Boehm's method to estimate that in 2012 there will be 90 million end-user developers. They predicted that 55 million will be users of spreadsheets or databases. Some end-user developers are: system administrators, interaction designers, teachers, accountants, health care workers, managers, etc.

EUD takes a broader perspective and is not limited to programming when it comes to adjust application to users' needs [57]. Lieberman et al. [56] defines two types of end-user activities:

1. Program creation and modification: Activities that allow end-users to create or modify software artifacts. In this case, the application is called *adaptable* as it allows unanticipated changes.
2. Parameterization or customization: allow end-users to parameterize or customize their applications using the available presentations or interactive mechanisms. In this case, the application is called *adaptive* as it can be tailored to end-users needs in predefined ways.

In order to support program creation and modification, the system should be flexible and expressive enough (e.g. set parameters, compose objects, etc.) [56]. Simple changes are not difficult, but things become more complicated as programming is involved. MacLean et al. [61] suggested a "gentle slope" to reduce the level of complexity and support changes on different levels. However, in cases of extensive changes, a programming language must be used [61].

EUD also focuses on parameterization or customization. This means customizing, configuring and tailoring the application, but not direct changes in the source code [48]. Customizing, configuring and tailoring are performed beyond the stage of creating a new application, and take place after the application is implemented within its environment of use. Investigating customization, configuration and tailorable systems is beyond the scope of this work.

Development Techniques

As there is no EUD taxonomy that categorizes development techniques for end-user developers, several techniques from the psychology of programming are inherited by EUD researchers. Some of the main techniques are [57]: Scripting Language, Visual Programming, Spreadsheet and Programming by Example. As this thesis relates to Spreadsheet and Visual Programming, I elaborate more on these two development techniques. However, the purpose is not to discuss related work on Spreadsheet or Visual Programming tools, because this thesis only inherits the principles from these fields. For example, the uVis formula language resembles Spreadsheet formulas. Similarly, direct manipulation and immediate feedback, features of uVis Studio, are important factors that resemble Visual Programming.

1. **Visual Programming:** Employs diagrammatic representations to create applications through visual components that can be manipulated or to modify existing ones [17, 18, 93]. As they are perceived to be more natural, visual language researchers claim that end-user developers can benefit from it. Whitley’s review [114] showed that visual languages can provide better support for some tasks (e.g. data flow tracking), but it seems that they do not take away the burden for EUD.

Pygmalion, “a two-dimensional, visual programming system implemented on an interactive computer with graphics display” [93], is one of the first visual programming tools. Users of Pygmalion interact with visual entities (icons) in an interactive editor (the display screen). With Pygmalion, programming consists of creating a sequence of display frames, the last of which contains the desired information. Forms/3 [16] is another example of a visual programming tool. To create a program, a Forms/3 programmer applies direct manipulation to place cells on forms and specify a formula for each cell. Another tool is Prograph [26]. Prograph targets professional programmers and graphically shows “the main concepts of object oriented programming, classes, attributes and methods and how a method’s representation defines the semantics of its dataflow, data driven execution” [26]. Prograph can model parallelism, sequencing, iteration and conditional constructs. Another tool is Cocoa [94], which allows “programmers” (children) create games by defining rules. Rules are represented by graphical preconditions

and graphical postconditions. AgentSheets [57] is a simulation-authoring environment where end-users construct highly parallel and interactive simulations using autonomous agents to replace numbers and strings of spreadsheet. Similar to Cocoa, it supports development of simulation games, but on a web platform. LabView is developed by National Instruments, Inc. and is one of the most popular visual programming tools. It allows users to connect (through drawn wires) different function nodes with a block diagram. The result is a virtual instrument that has a front panel. Labview supports structured programming where users can develop their own functionalities. This application proved the superiority of visual to textual programming in the instrument field (C was used as the alternative) [7].

Direct manipulation is an important feature in visual programming. Considerable work [27] has been done on systems that support direct manipulation. According to Shneiderman [89] “direct manipulation systems offer the satisfying experience of operating on visible objects”. As an example, Forms/3 [19] supports programming of graphical objects through direct manipulation of objects instead of specifying formulas. Hundhausen et al. [40] investigated whether direct manipulation interfaces can lower the barriers to programming. Their results showed that “the direct manipulation interface promoted significantly better initial programming outcomes, positive transfer to the textual interface, and significant differences in programming processes” [40]. Further, the authors state that direct manipulation interfaces can introduce non-programmers to traditional textual programming. Therefore, direct manipulation interfaces should help end-user developers as well.

2. **Spreadsheets:** Initially developed as a domain-specific tool for accountants, which has become the most popular tool for end-user developers. The success can be explained by the fact that spreadsheets use formulas, which are specified in a free sequence, to process and analyze data. Kelleher and Pausch [46] present a survey that evaluated programming environments and languages for end-user developers (novice programmers). Their results showed that simplifying the mechanics of programming is a way to engage end-user developers in development [46]. Spreadsheets does this and it can also explain its popularity among users.

2.3 Existing Visualization Development Tools

In addition, the widespread use in industry through commercial tools and the research [16, 19, 44] has a positive impact on EUD.

These approaches have proven to be successful with a specific group of users [57], but in many cases, these tools are insufficient and programming is needed. EUD does not favor any development technique. Rather, according to Reppening and Ioannidou [57], EUD seeks tools that match the challenges posed by a development process to users' skills.

This thesis does not aim at providing a visual programming or a spreadsheet solution, but rather builds upon the successful principles of them such as formulas, direct manipulation, immediate feedback, etc. As the EUD community has not investigated EUD of custom visualizations, the purpose of this thesis is to develop a tool that empowers them to create and modify custom visualizations.

2.3 Existing Visualization Development Tools

To get an overview of existing work on visualization development, I surveyed InfoVis development tools. I investigated how existing tools help users with different IT skills construct visualizations. As no previous taxonomy from InfoVis and EUD can properly address this question, a new visualizations tool taxonomy was developed. First, I present the visualizations tool taxonomy and explain how it differs from other existing taxonomies. Second, I describe how I selected 20 InfoVis visualization tool, and provide a brief summary of each tool. Finally, I conclude the chapter with the categorization of 20 InfoVis tools, which highlights existing problems in EUD of InfoVis.

2.3.1 A Review of Existing InfoVis Taxonomies

The InfoVis community has developed several taxonomies and frameworks. Shneiderman [90] presented a task by data type taxonomy for InfoVis. This taxonomy classifies visualization data types (1D Linear, 2D Map, multidimensional, temporal, tree and network) and identifies the tasks (overview, zoom, filter, details-on-demand, relate, history and extract) that have to be supported. However, it does not provide insight on how users construct visualizations using visualization tools.

Chi and Riedl [24] developed a framework that uses operators and interactions in visualization systems. This framework allows programmers to explore and evaluate

2.3 Existing Visualization Development Tools

visualization operators, to identify operators that can be reused and to extend the systems using them. Also, this framework assists end-users to understand how to use a tool and analyze their tasks.

Chi [23] proposed taxonomy of visualization techniques that used the data state reference model. The taxonomy provides an overview of existing visualization techniques and shows that many techniques use similar operating steps. It also allows programmers to realize how InfoVis techniques are used more generally.

Amar and Stasko [5] presented a knowledge task-based framework that can be used for design and evaluation of InfoVis. Their framework addresses the analytic gap in visualizations and attempts to assist complex tasks (e.g. decision-making and learning). They identified two analytic gaps in present InfoVis tools: Rational Gap (“representing the gap between perceiving a relationship and expressing confidence in the correctness and utility of that relationship”) and Worldview Gap (“representing the gap between what is shown to a user and what actually needs to be shown to draw a representational conclusion for making a decision”) [5]. Further, they defined tasks for each gap that can be used in systematic design and heuristic evaluation of InfoVis systems to reduce the gaps. The purpose of the framework is not to analyze how users construct visualizations.

A high level taxonomy was presented by Tory and Moller [104]. This taxonomy categorizes visualization algorithms, and does not focus on data. The classification uses design models. Design models are assumptions on how algorithms present the data. These design models are categorized using their discretion or continuousness and attributes (e.g. time, color) used by the designer of the algorithm. This taxonomy supports users when they choose visualization techniques that satisfy their requirements, but does not analyze how users construct them.

Pfitzner et al.[76] took a broader perspective and presented a framework that considers data, task, skill, context, the input and output hardware, the software tools, and the user interactions and human perceptual abilities. More explicitly, it addresses five factors: (1) data type and data relationships, (2) task type, (3) interactivity type, (4) user skill, and (5) context of the InfoVis use. The purpose of this framework is to structure the development of InfoVis and reduce the gulf of execution and evaluation users face when they try to solve a problem using a tool.

2.3 Existing Visualization Development Tools

Lee et al. [54] describe task taxonomy for graph visualization. They defined a list of tasks (e.g. filter, sort, cluster, etc.) useful for programmers (designers) and users (evaluators). Programmers use these tasks to improve their tools, and evaluators utilize them to compare visualization tools.

Heer et al. [37] investigated how people can be engaged in InfoVis. Their study does not present a formal taxonomy of users, but they aim at an understanding of user skills, goals and data.

A recent taxonomy of interactive dynamics for visual analysis was presented by Heer and Shneiderman [38]. The authors have defined three categories, and four tasks in each: (1) *data and view specification*: visualize, filter, sort, and derive; (2) *view manipulation*: select, navigate, coordinate, and organize; (3) *analysis process and provenance*: record, annotate, share, and guide. This taxonomy aims at successful dialogues, and support users when they evaluate and create visual analysis tools, but it provides little insight on how users construct visualizations.

2.3.2 Visualization Tool Taxonomy

Although the existing taxonomies and frameworks are helpful in categorizing visualization techniques, identifying suitable visualizations for different data types, structuring the development of InfoVis, etc., none of them can properly categorize visualization tools from a user perspective and address these questions:

- What IT skills should users have to construct visualizations?
- What types of tool are available for visualization development?
- What types of visualization can users with various IT skills construct with these tools?

The proposed taxonomy aims at answering the aforementioned questions. The visualization tool taxonomy consists of three high-level categories: *user skills*, *tool types* and *visualization types*. Each category is divided into subcategories. Table 2.1 illustrates the taxonomy, and below I describe the categories and the subcategories.

1. Tool types

2.3 Existing Visualization Development Tools

Category	Subcategory
Tool Types	<ul style="list-style-type: none">• Language Tool• Wizard Tool• Drag-and-Drop Tool
User Skills	<ul style="list-style-type: none">• Simple User• End-User Developer• Programmer
Visualization Types	<ul style="list-style-type: none">• Standard Visualization• Custom Visualization

Table 2.1: A taxonomy of visualization tools.

As there are no visualization tool taxonomies defined in InfoVis or EUD, I searched for taxonomies from other fields, and more specifically in the Human-Computer Interaction field. Myers et al. [66] presented a study on how tools support users when they construct user interfaces. The authors have categorized the ways of constructing user interfaces in seven categories: windows managers, event languages, interactive graphical tools, component systems, scripting languages, hypertext and object-oriented programming languages. Inspired by Myers et al. classification and considering that some are almost the same approach, I decided to categorize the tools in three groups: *language tools* (include event languages, scripting languages, hypertext and object-oriented programming languages), wizard tools (correspond to the windows managers and component system), and drag-and-drop tools (correspond to the interactive graphical tools). As this category classifies InfoVis tools, I decided to utilize the reference information visualization model described in [20, 24]. The reference model defines the process in three sub-processes: *Data Transformation*, *Visual Mapping*, and *View Transformations*. Card et al.[20] say: “The core of the reference model is the mapping of data table to visual structures”. Therefore, this categorization focuses on how tools support visual mappings. This is how I define each category.

- *Language Tools*: users use event, scripting, functional, or programming languages to construct visualizations. The language is used to specify the visual objects and map data to visual objects. Prefuse [36], Protovis [13], D3 [14] are some of the tools of this category.

2.3 Existing Visualization Development Tools

- *Wizard Tools*: users construct visualizations by inputting data in one or more windows. Users interact in a step-by-step approach with windows to create visual object and bind them to data. A popular visualization tool is MS Excel [64].
- *Drag-and-Drop Tools*: users interact with an interface and apply a drag-and-drop approach to construct visualizations. Objects are visually created by drag and drop actions, and the visual mapping is realized through direct visual manipulation or concise specifications. Some of these tools are: Spotfire [97], Tableau [99] and Omiscope [71].

2. User Skills

Heer et al. [37] classified users based on their skills in three categories: novice, savvy and expert users. I use this categorization to classify users and their ability to construct visualizations. These terms may be ambiguous when ones considers the domain knowledge users have. For example in the medical area, some doctors may have no IT skills, but they have excellent domain knowledge and are experts of the domain. In addition, savvy users and end-user developers are the same group of people, but know with different names in InfoVis and EUD. With respect to the classification by Heer et al. [37], I decided to use the terms *simple user*, *end-user developer* and *programmer*.

- (a) *Simple Users* have basic IT skills and can operate IT systems to accomplish basic tasks, but not programming. [37]. Some of them are: project managers, salespersons, nurses, doctors, etc.
- (b) *End-User Developers* are not programmers, but users who “may have little or no formal training or experience in programming” [72]. These users “have experience performing relatively sophisticated data organization and manipulation, using a combination of manual processing and limited amounts of programming or scripting” [37]. Some of them are: doctors specialized in medical informatics, data analysts experienced with MS Access, researchers outside the computer science field, but fond of IT, etc.
- (c) *Programmers* have excellent developing skills and are experienced in software development and databases. They usually work in IT companies that provide

domains with IT applications. Constructing custom visualizations is time consuming, but not difficult for programmers. Some of them are: software engineers, researchers in computer science, etc.

3. Visualization Types

This category considers a high-level distinction of visualization types investigating the boundaries of existing tools to support users construct visualizations other than the predefined ones. The purpose of this categorization is not to explicitly investigate if a tool supports specific visualizations such as hierarchal, time-oriented, etc. Also, it does provide insights on interaction techniques (e.g. zooming, focus+context, etc.) Considering to what extent the visual mappings of a visualization are predefined, I define two visualization types.

- *Standard visualizations*: predefined visualization templates that combine, customize, or extend the templates in limited ways. For example, a bar chart in MS Excel uses a predefined bar chart template where only a few visual attributes of the chart (e.g. bar height) are assigned to data.
- *Custom visualizations*: combine visual objects into a complex visualization or use predefined visualization templates that can be combined, customized and extended in many ways. For example, a LifeLines visualization [79] is constructed by combining bars, triangles, labels, etc. Another example is a bar chart created with Prefuse. Users of Prefuse can assign all visual attributes of the bar chart to data attributes.

This taxonomy aims at providing an overview of development tools in InfoVis. Programmers can identify useful approaches and get inspired by existing work; researchers can use it to identify and pursue new research paths; newcomers in the InfoVis field can use it as a reference point to identify suitable tools based on their IT skills.

2.3.3 Analysis Approach

I used two popular sources, the ACM Portal and the IEEE website, to find InfoVis tools and toolkits. I searched for related work by combining these keywords: “information visualization”, “tool”, “toolkits”, “graphical user interface”. Initially, I ranked the

2.3 Existing Visualization Development Tools

results based on the total number of citations, and then I selected only the most promising ones by reading the abstracts. Next, I read all the papers and selected the most appropriate tools and toolkits. They are: APT [60], SAGE [87], SageBook [25], DEVise [22, 58, 59], GeoVISTA Studio [100], The InfoVis Toolkit [28], Piccolo [9], Improvise [112], Prefuse [36], Protovis and ProtoViewer [4, 13], and Data-Driven Documents (D3) [14]. During the process of reviewing the existing literature, I identified two more tools from research that were relevant to my investigation and decided to include them in my analysis, because of their popularity and approach. They are: Processing [80] and Flare [30]. In total, I selected 13 tools from the research area.

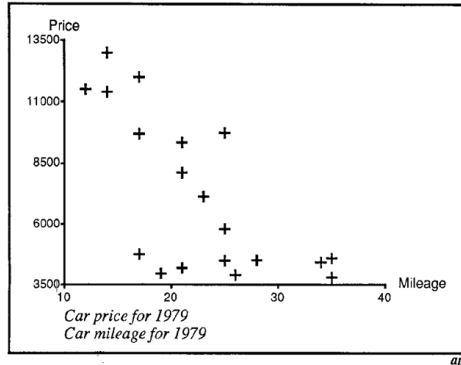
As I was reviewing the existing literature, I also found several industry tools that I decided to use. In addition, I searched the web for consumer InfoVis tools. At the end I selected seven popular tools: Spotfire [97], Tableau [99], Omniscube [71], MS Excel [64], Google Chart Tools [32], Tom Sawyer Presentations [103] and Many Eyes [108].

I chose only 20 tools and toolkits and I believe that the selected tools are a good sample that represents the wide-range of InfoVis tools and toolkits from research and industry. I did not include in my analysis tools that are similar to the selected ones. Some of them are: ComVis [63], Dave [110], PRISMA [31], Jazz [10], Visage [85], and Polaris [98].

The assessment of the tools from academia is based on the published papers, while the commercial tools were assessed using information from their web pages and using the trial or full versions available from their websites. Categorizing the tools in distinct categories it is not without challenges. Many tools span more than one category. When I was in doubt about a tool I discussed it with other members of the project and decided based on our judgment.

2.3.4 Tools and Toolkits

In this section I use the aforementioned taxonomy to categorize the selected tools. First, I present InfoVis tools and toolkits from research, and second, I describe the ones from industry. Note that the purpose of this categorization is not to analyze and compare implementation details, but to investigate the way users construct visualizations.



```

Encodes(VertAxis, [3500, 13000], ScatterPlot)
Encodes(HorzAxis, [10, 40], ScatterPlot)
Encodes(Points, Cars, ScatterPlot)
Encodes(Position(Points, VertAxis), Price(Cars), ScatterPlot)
Encodes(Position(Points, HorzAxis), Mileage(Cars), ScatterPlot)
    
```

Figure 2.2: A scatter plot (top) and its graphical specifications (bottom) created with APT. Source: [60].

APT

APT (A Presentation Tool) [60] is one of the earliest tools that automatically creates effective graphical presentation of relational data. Presentations are generated in a linear model where data are extracted, synthesized and then the tool handles the rendering process to create the final output. Programmers use predefined templates (e.g. bar charts, scatter plots or connected graphs) and write their graphical specifications (sentences of a graphical language that has exact syntax and semantics), and the tool creates the graphical presentation. Figure 2.2 shows an example. Programmers, and probably end-user developers, would be able to specify graphical designs, but still they cannot create graphical presentations other than the supported ones. The visual mapping is defined through APT specifications and automatically handled by the tool.

User Types: End-user developers and programmers.

Tool Types: Language tool.

Visualization Types: Standard visualizations.

2.3 Existing Visualization Development Tools

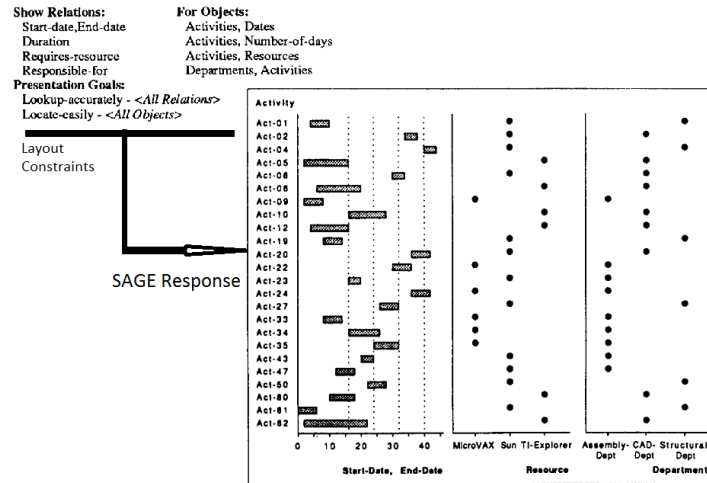


Figure 2.3: SAGE's input and the result. Source: [87].

SAGE

Early 1990's, Roth and Mattis [87] presented SAGE, “an intelligent system which assumes presentation responsibilities for other systems by automatically creating graphical displays which presents the results they generate” [87]. This tool uses graphical techniques to express the application data characteristics and fulfill the presentation needs. Users query the database, and the result is used by SAGE. Based on the data, SAGE automatically defines the visual mappings and generates the visualization. After a presentation is generated, users can adjust the visual mappings of the auto-generated visualization by setting layout constraints for the data. Figure 2.3 shows an example of layout constraints and SAGE response. SAGE can be used by programmers and probably end-user developers, but SAGE provides limited support for constructing custom visualizations.

User Types: End-user developers and programmers.

Tool Types: Language Tool.

Visualization Types: Standard visualizations.

SageBook

SageBook [25] allows users to sketch, search and customize visualizations. The user creates a sketch using SageBrush [86], and SageBook searches for suitable data-graphics in SageBook's library. The results (one or more data-graphics) are shown in the SageBook

2.3 Existing Visualization Development Tools

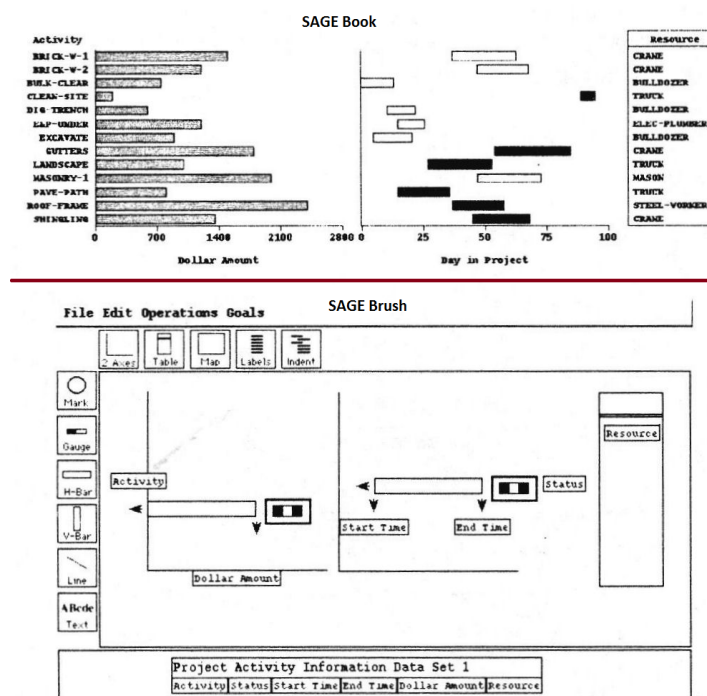


Figure 2.4: A visualization in SageBook (top), and SageBrush where visualizations are specified (bottom). Source: [25].

browser. This tool is accessible by all types of users. They can select a data-graphic and modify it in SageBrush (Figure 2.4), but the visual objects are not bound to data. Further, SageBook limits users to construct visualizations that match the data-graphic library.

User Types: Simple users, end-user developers and programmers.

Tool Types: Drag-and-drop Tool.

Visualization Types: Standard Visualizations.

DEVise

DEVise [22, 58, 59] allows users to create visualizations by creating, modifying or connecting visual objects (components). DEVise maps the data to visual objects and displays them in a view. At the end, the view uses the data and visual filters to draw the result in a window. DEVise users use a step-by-step approach to create visualizations: select an input, choose a file type for the input file, select an existing mapping or define a new mapping using *tcl* language expressions [113], select a view to display the

2.3 Existing Visualization Development Tools

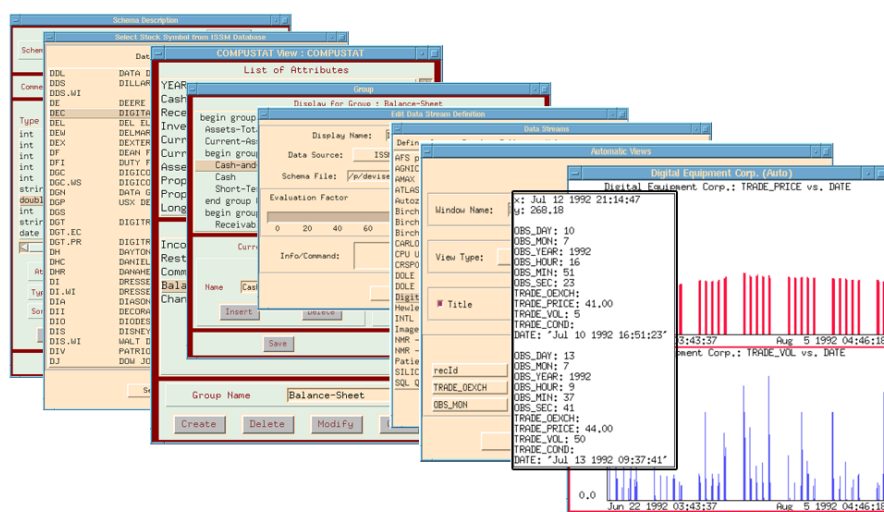


Figure 2.5: Visualizing financial information with DEVise in a step-by-step approach: select a schema, select a data stream, define mapping, and define visual links and cursors. The final output is shown on the right side, together with the pop-up window that shows details-on-demand. Source: [59].

data, select initial values for the visual filter, and finally select a window to display the view. Further, users can adjust visualizations. Figure 2.5 presents an example. In DEVise, users can create visualizations by combining and linking visual objects using the predefined visual mappings, but it is questionable if simple users can create new mappings. They have to use the *tlc* language, which may introduce some challenges even for end-user developers. The authors says that DEVise is a powerful exploration framework, “but to appreciate this power fully, one must work with the system or at least look at several applications in some details” [58].

User Types: Simple users (only standard visualizations), end-user developers and programmers.

Tool Types: Wizard Tool.

Visualization Types: Standard and custom visualizations.

Processing

Processing (Figure 2.6) was developed initially “to teach fundamentals of computer programming within a visual context” to newcomers, but it has grown into a more complete tool for constructing images, animations and interactions [80]. Processing has a development environment similar to a regular one. Programmers specify the

2.3 Existing Visualization Development Tools

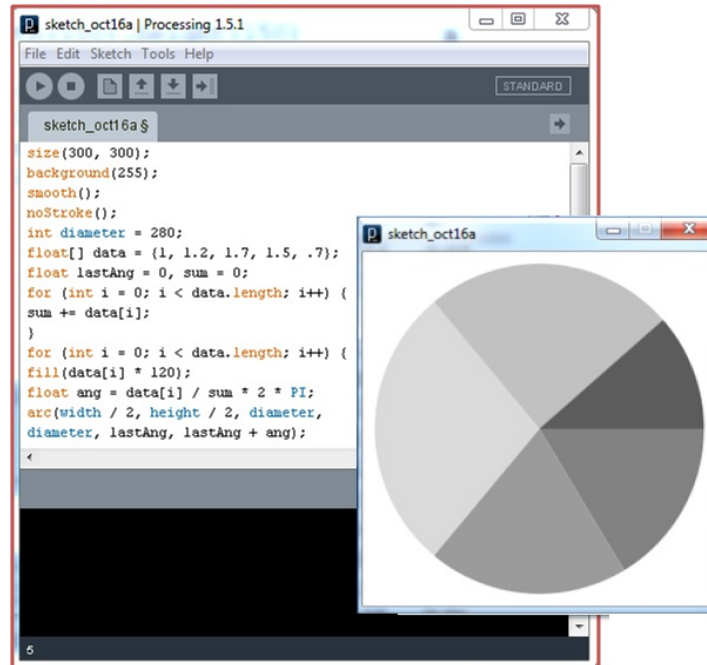


Figure 2.6: A pie chart created with Processing. Source: [80].

visual mappings by writing code in the code editor. They view the visualization in a new window after having executed the code. To create a visualization, users have to know another programming language, Processing. As a result, this tool is used only by programmers, or non-programmers who pursue a programmer carrier.

User Types: Programmers.

Tool Types: Language tool.

Visualization Types: Standard and custom visualizations.

GeoVISTA Studio

GeoVISTA Studio (Figure 2.7) is a development environment designed to support geoscientific data analysis and visualizations [100]. It is built in Java and uses JavaBeans technology. A visualization in GeoVISTA Studio is composed by connecting visual objects (implemented as Java beans components). GeoVISTA Studio consists of three windows: the *Main* window shows the menus and JavaBeans visual object palette; the *Design* window where visual objects are placed and connected; the *Graphical User Interface (GUI)* window shows “live” the output of the used beans. Programmers can

2.3 Existing Visualization Development Tools

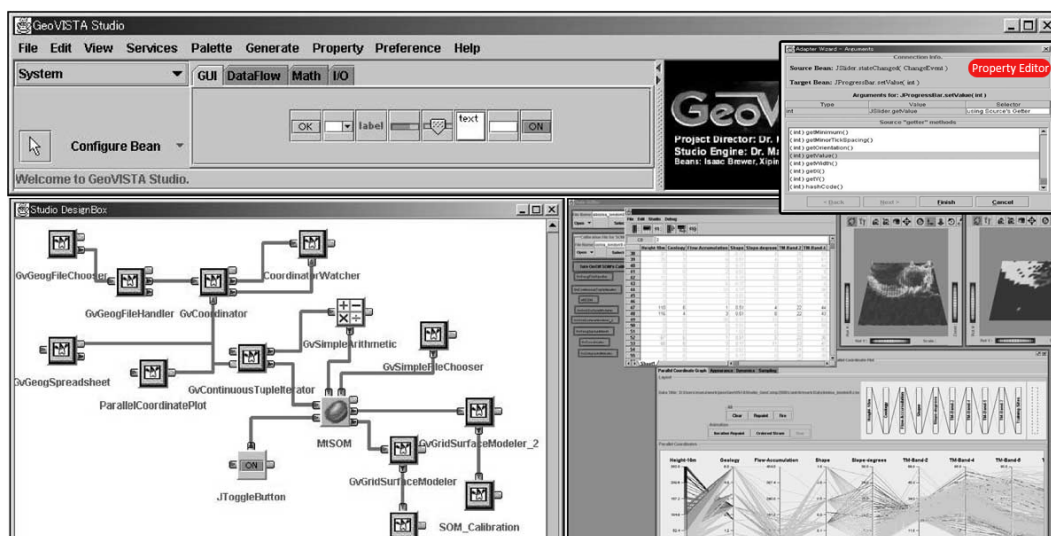


Figure 2.7: GeoVISTA Studio: the Main window shows the visual objects and system options, the Design window (top) contains visual objects represented by icons and connected by lines, the Graphical User Interface (right) shows the visualization specified in the Design window (left), and the Property Editor (represented by the adapter wizard) used to customize a visual object. Source: [100].

use the *Property Editor* to customize the appearance and behavior of a visual object. The application programmers (programmers and probably end-user developers) are the main users of the Studio, and they follow the following steps to construct an application: list the requirements, select the appropriate visual objects from the palette menu (new visual objects can be developed outside of the Studio and imported), place visual objects in the *Design*, link the visual objects to meet the requirements, customize a visual object using the *Property Editor*, and test the design in the *GUI*.

User Types: End-user developers and programmers.

Tool Types: Wizard Tool.

Visualization Types: Standard and custom visualizations.

The InfoVis Toolkit

The InfoVis Toolkit [28] is a Java based visualization toolkit that uses several interactive components to construct visualizations. This toolkit assists programmers in constructing standard and custom visualizations. They are specified programmatically. Figure 2.8 shows an example. It allows programmers to extend the toolkit with new compo-

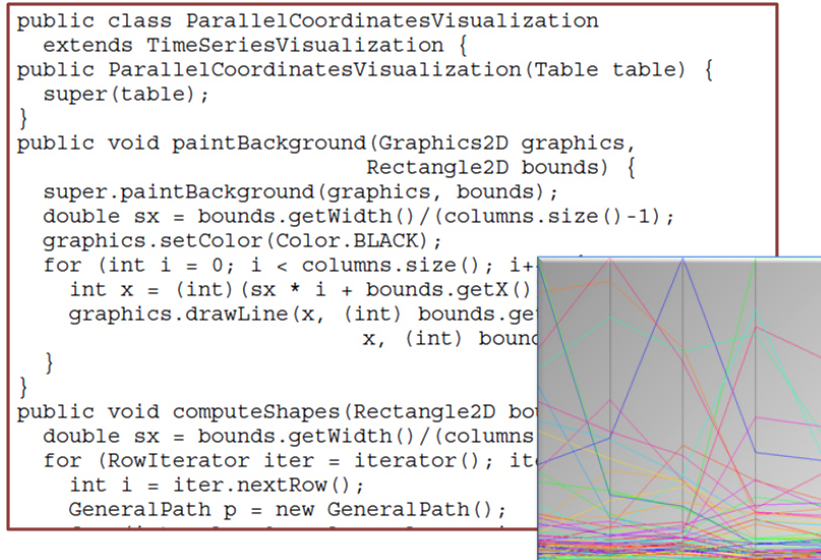


Figure 2.8: A parallel coordinated visualization with InfoVis Toolkit. Source: [28].

nents and to integrate visualization techniques into interactive applications. However, creating visualizations requires experienced programmers. Consequently, this toolkit is not appropriate for simple users and end-user developers. The InfoVis toolkit does not have a specialized development environment, but it can be integrated in a development environment such as Eclipse. This integration does not support features such as drag-and-drop, immediate feedback, and so forth.

User Types: Programmers.

Tool Types: Language Tool.

Visualization Types: Standard and custom visualizations.

Piccolo

Piccolo [9] is developed in Java and C#. This toolkit is mainly used for developing graphical applications with rich user interfaces. Piccolo supports the development of visualizations indirectly, as it does not support visualization techniques [36]. Nevertheless, novel visualizations such as LifeFlow [116] are based on this toolkit. Programmers can create visualizations in Java or C# and use visualization functionality and components, such as zooming, animation and range slider. Figure 2.9 shows an example. This toolkit can be used only by programmers, and the fact that it does not support

2.3 Existing Visualization Development Tools

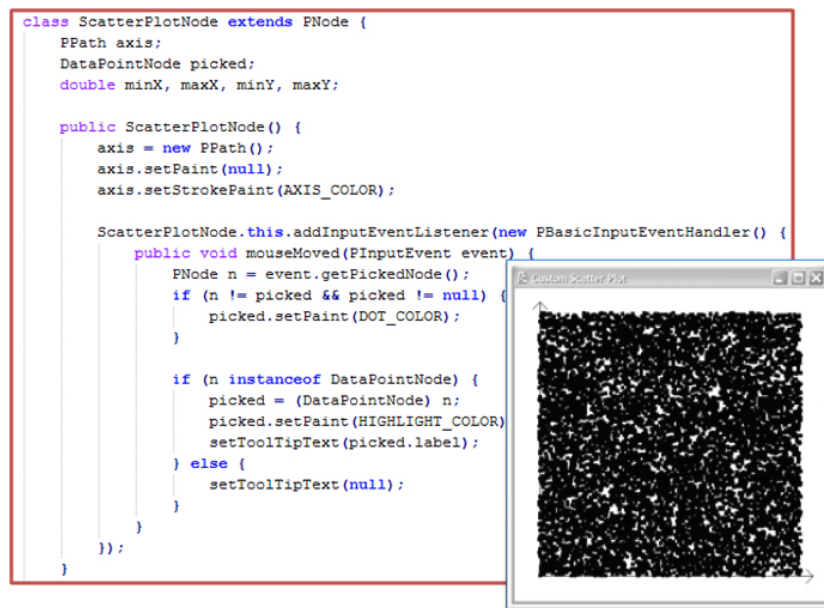


Figure 2.9: A scatter plot created with Piccolo. Source: [9].

visualization techniques directly, makes it challenging even for them. Similar to the InfoVis toolkit, Piccolo does not have a specialized development environment either.

User Types: Programmers.

Tool Types: Language tool.

Visualization Types: Standard and custom visualizations.

Improvise

Improvise [112] is a visualization toolkit for creating multi-view coordination visualizations for relational data. It is written in Java. Visualizations are created by specifying expressions for simple shared-object coordination mechanism. Shared-objects in Improvise, which are responsible for visual mapping, are graphical attributes such as color, font, etc. Improvise has a specialized development environment where users apply a step-by-step approach interacting with four editors and creating views by adding frames, controls, defining variables and attaching data using the lexicon work area (a central repository where information related to the data and database are saved). Users of Improvise can construct standard and custom visualizations based on the predefined controls. Programmers can create visualizations by specifying expressions for simple shared-object coordination mechanism. Although I believe that Improvise can be used

2.3 Existing Visualization Development Tools

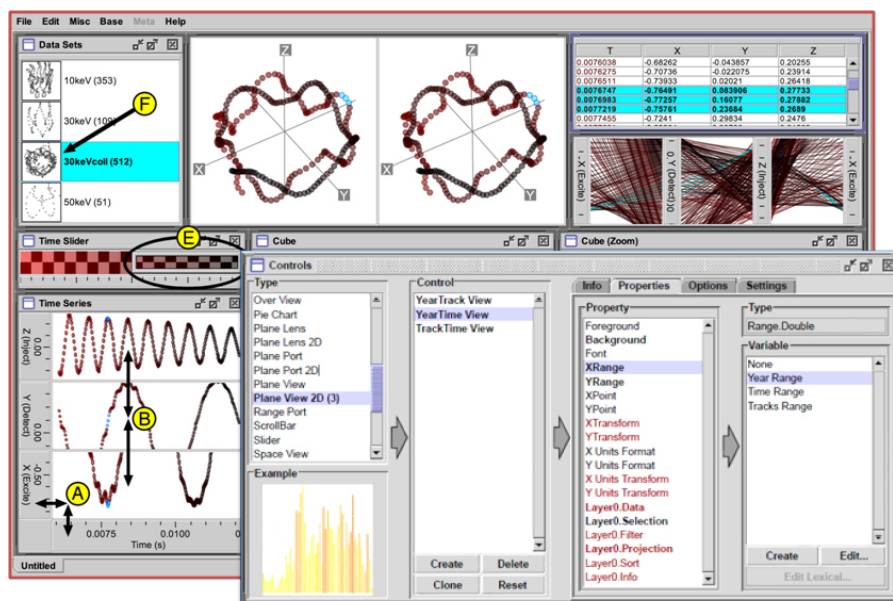


Figure 2.10: A multi-view coordination visualization in Improvise and the Controls editor. Source: [112])

by end-user developers, this has not been empirically evaluated. Further, this tool is specialized for coordinated visualizations that use predefined controls. Although it is a powerful tool, it is not obvious from [112] if Improvise can be extended and adapted to other than coordinated visualizations. Figure 2.10 shows a screen shot of Improvise.

User Types: End-user developers and programmers.

Tool Types: Wizard tool.

Visualization Types: Standard and custom visualizations.

Prefuse

Prefuse [36] is another toolkit developed in Java. Visualizations in Prefuse are written in Java, and programmers construct them using a set of fine-grained building blocks and specifying operators that define the layout and behavior of these blocks. Figure 2.11 shows an example. The purpose of this tool is to facilitate users' work who are skilled Java programmers. They can develop standard and custom visualizations programmatically. This toolkit can be integrated in development environments as the InfoVis toolkit does, but the integrated development environment provides them with limited cognitive support as visualizations are defined in the code editor.

2.3 Existing Visualization Development Tools

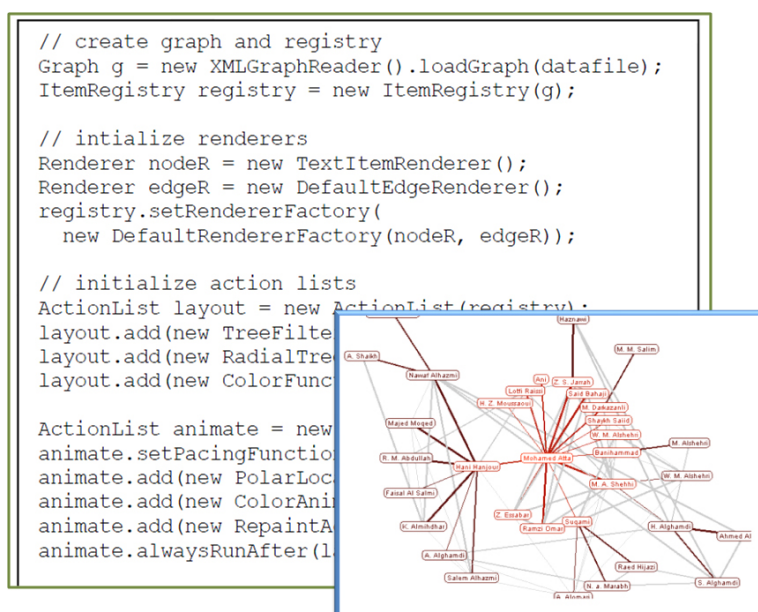


Figure 2.11: An animated radial layout created with Prefuse. Source: [36].

User Types: Programmers

Tool Types: Language Tool

Visualization Types: Standard and custom visualizations

Flare

This visualization toolkit [30] is a successor of Prefuse [36], but is written in ActionScript. Flare supports programmers with a number of standard and custom visualizations. To construct visualizations, programmers specify in ActionScript the properties of the visual objects and sequential commands. Figure 2.12 shows an example. Programmers can also define new operators and visual objects, but advanced programming knowledge is required. Flare can be integrated in Adobe Flex IDE and it does not come with a specialized IDE.

User Types: Programmers.

Tool Types: Language tool.

Visualization Types: Standard and custom visualizations



Figure 2.12: The Job Voyager visualization created with Flare. Source: [30].

Protovis and ProtoViewer

Protovis [13] is implemented in JavaScript and helps programmers construct visualizations using a domain specific language. They can combine primitive visual objects, called marks, bind them to data, and specify visual properties. Programmers can create simple and custom visualizations by specifying Protovis specifications. The authors of Protovis have compared the specifications for a simple pie chart in Protovis, Processing and Flare, showing that the visualization in Protovis is specified in fewer lines of code [13]. This shows the simplicity of Protovis language, which has a potential of engaging end-user developers in visualization development. Although I believe that Protovis can be used by end-user developers, there is no empirical evidence that proves it.

ProtoViewer [4] extends Protovis with a development environment. The screen (Figure 2.13) is divided in three parts: *Data*, *Design* and *Code*. Programmers choose a dataset, select a visualization template and automatically the code is shown in the *Code* editor. They execute the code to view the results in the *Design*. Programmers can either use predefined visualization templates, and the code is automatically shown in the *Code* editor, or start from scratch and write Protovis specifications to specify controls. Constructing custom visualizations by end-user developers in Protovis becomes even

2.3 Existing Visualization Development Tools

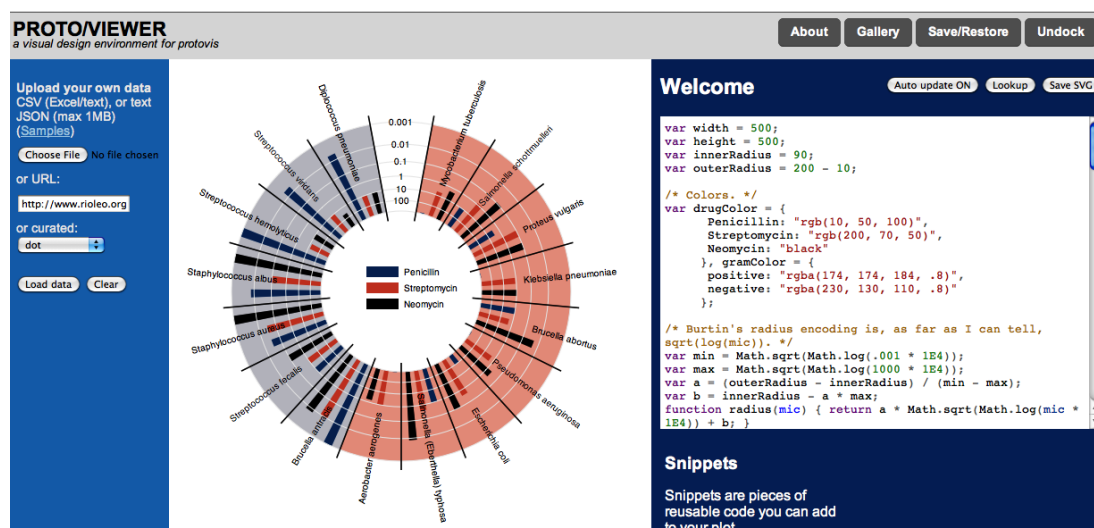


Figure 2.13: An arc diagram created with Protovis in ProtoViewer. ProtoViewer consists of three parts: Data (left), Design (middle) and Code Editor (right). Source: [4].

more realistic by means of its development environment – ProtoViewer. However, neither Protovis nor ProtoViewer has been evaluated with end-user developers.

User Types: End-user developers and programmers.

Tool Types: Language / Wizard tool.

Visualization Types: Standard and custom visualizations.

Data-Driven Documents: D3

Data-Driven Documents (D3) [14] is a successor of Protovis [13]. Visualizations are constructed using SVG, HTML 5 and CSS. In D3 the data transformation, the immediate evaluation and the browser’s native representation are handled in more effective and transparent way than Protovis, which uses more succinct specification for static presentations [14]. However, these improvements introduce an overhead for users: the knowledge of SVG, HTML 5 and CSS. D3 is a web-based library and can be integrated in existing development environments. Still, users have to use the code editor to create visualizations. This toolkit is suitable for programmers only. Figure 2.14 shows an example of D3.

User Types: Programmers.

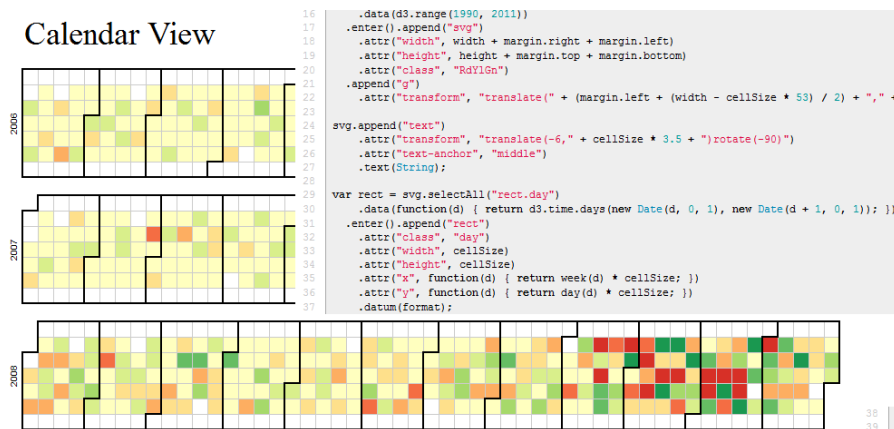


Figure 2.14: A calendar view created with D3. Source: <http://mbostock.github.com>.

Tool Types: Language tool.

Visualization Types: Standard and custom visualizations

MS Excel

MS Excel [64] is a spreadsheet program that allows users to analyze and visualize data. With simple steps, all kind of users can construct visualizations based on predefined templates (e.g. bar chart, pie chart, etc.) They select a visualization template (e.g. bar chart) and specify spreadsheet formulas or use standard widgets to map the data to the visual object in the worksheet area. Figure 2.15 presents an example. In MS Excel, the visual mapping is limited and users can set only predefined visual properties. Custom visualizations cannot be constructed by simple users or end-user developers. Programmers can program custom visualizations in Macros (Visual Basic scripts), which can be integrated into MS Excel.

User Types: Simple users, end-user developers and programmers

Tool Types: Wizard tool

Visualization Types: Standard visualizations

Tableau

Tableau [99] is a commercial visualization tool, a successor of Polaris [98] developed at Stanford University. Tableau allows users to construct visualizations by dragging and dropping fields onto axis shelves (vertical and horizontal areas) and using visual speci-

2.3 Existing Visualization Development Tools

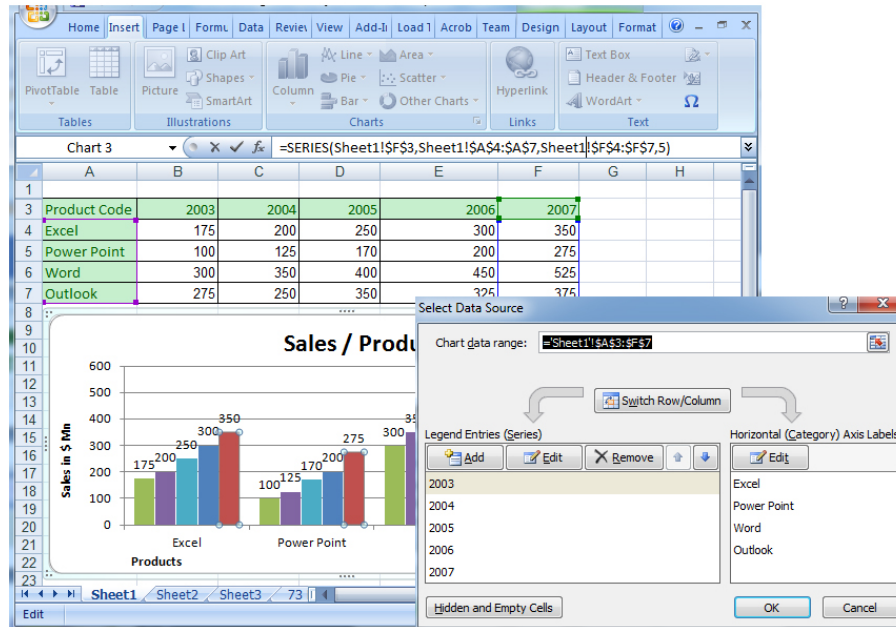


Figure 2.15: A bar chart created with MS Excel. Source: [64].

fications (Figure 2.16). This tool can be classified as the drag-and-drop tool due to its drag-and-drop features, but it can be considered as a wizard tool as well. Tableau uses VizQL [35], an algebraic specification language, to create views based on predefined templates and bind data to them. Further, it has a powerful interactive development environment where users can interact, filter, sort data and create interactive dashboards. The main users of this tool are simple users. Tableau is a “black box” system. Programmers do not have access to the kernel of the system and it is not possible to extend it. Therefore, constructing visualizations other than the supported ones is not possible.

User Types: Simple users, end-user developers and programmers.

Tool Types: Drag-and-drop / Wizard tool.

Visualization Types: Standard visualizations

Spotfire

Spotfire [97] is another commercial tool for data visualizations. It supports users, regardless of their IT skills, with a number of visualization techniques. Users, regardless their IT skills interact with the development environment and construct visualizations

2.3 Existing Visualization Development Tools

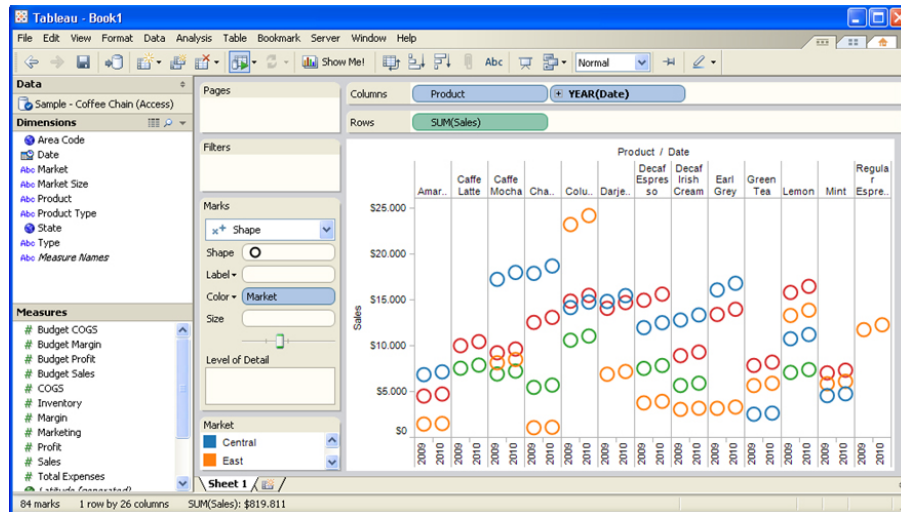


Figure 2.16: A bubble chart created with Tableau. Source: [99].

based on predefined ones. Once they select the data and choose a visualization template, the tool automatically generates the visualization. Users can sort, filter and re-arrange data by simply dragging and dropping fields in the design area. Users can also create dashboards, by combining different visualizations (e.g. bar chart, scatter plot, etc) in a single screen (2.17). As in Tableau, users can not create custom visualizations except for the standard ones.

User Types: Simple users, end-user developers and programmers

Tool Types: Drag-and-drop / Wizard tool

Visualization Types: Standard visualizations

Omniscope

Omniscope [71], shown in Figure 2.18, is in the same category as Tableau and Spotfire, and shares similar features such as interactive dashboard, drag and drop features, etc. Although it can be used by all types of users, the main scope of this tool is to support simple users in constructing standard visualizations, as Spotfire and Tableau do. Visualizations are constructed based on predefined templates. Custom visualizations cannot be constructed with this tool. Programmers can not extend the system with new controls or functionalities, as it is a “black box” system.

User Types: Simple users, end-user developers and programmers

2.3 Existing Visualization Development Tools

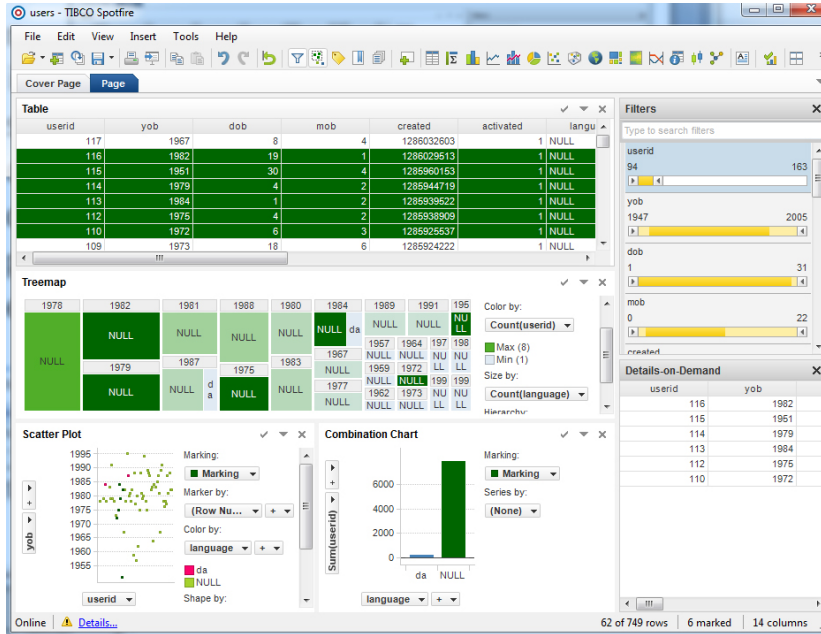


Figure 2.17: Several visualizations of the same dataset created with Spotfire. Source: [97].

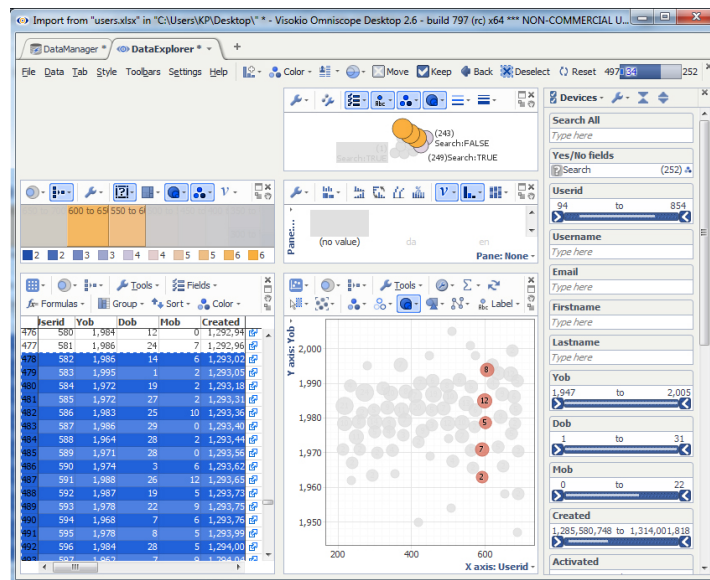


Figure 2.18: Several visualizations of the same dataset created with Omniscio. Source: [71].

2.3 Existing Visualization Development Tools

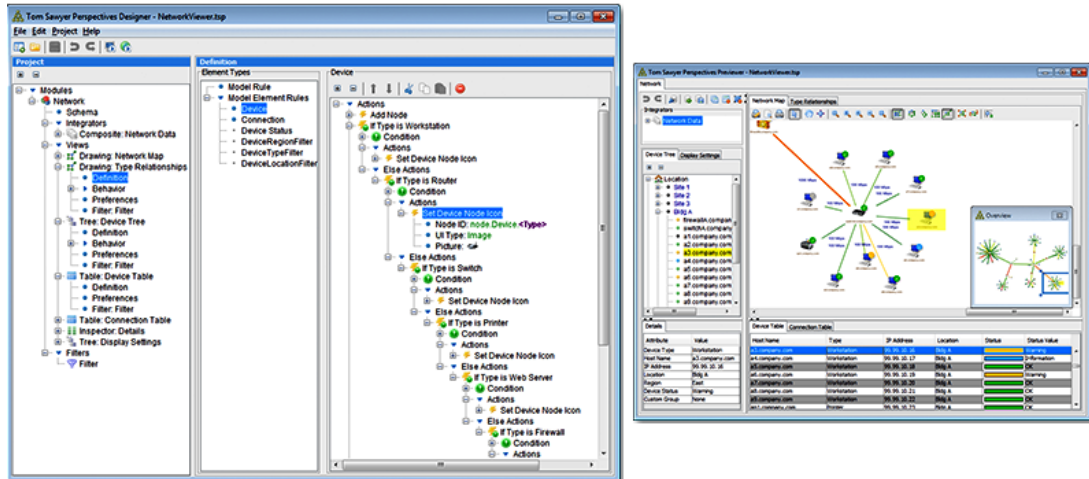


Figure 2.19: The Designer (left) and the Previewer (right) in Tom Sawyer Presentation. Source: [103].

Tool Types: Drag-and-drop / Wizard tool

Visualization Types: Standard visualizations

Tom Sawyer Perspectives

Tom Sawyer Perspectives is a software development kit that supports the construction of “enterprise-class data visualization and social network analysis applications” [103]. It has a development environment where users use the *Designer* to specify schema, data sources, bindings, and filters. They use the *Designer* to specify rules for the visual representation of the data, to add context menus and to define custom toolbars, tool-tips, and graphical viewing and editing behaviors. The results are presented on the *Previewer*. Although this tool supports quick development of visualization applications, constructing custom visualizations is not feasible because users are limited to using visualization models supported by the tool. As Tableau, Spotfire and Omniscope, extending this tool is not possible. Figure 2.19 presents a screen shot of the Tom Sawyer Perspectives.

User Types: Simple users, end-user developers and programmers

Tool Types: Drag-and-drop / Wizard tool

Visualization Types: Standard visualizations

2.3 Existing Visualization Development Tools

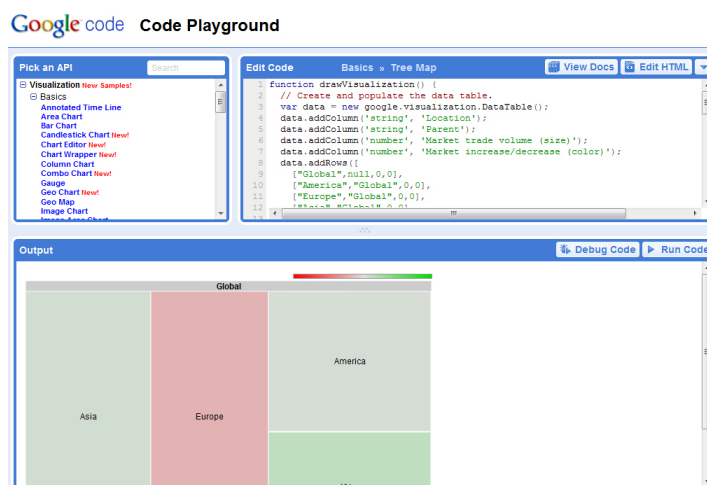


Figure 2.20: A treemap in Code-Playground of Google chart Tools. Source: [32].

Google Chart Tools

Google Chart Tools [32] is a library written in JavaScript that provides several predefined simple (line chart, scatter chart, etc.) and advanced chart types (Image multi-color bar chart, Motion Chart Time Formats, etc.) Visualizations can be constructed by programmers in the web-based development environment named Code Playground, illustrated in Figure 2.20. In addition, Google Chart Tools has another environment named Live Chart Playground, to test charts already created in the Code Playground. In Live Chart Playground, programmers can change some parameters and see how the visualization changes. These two environments increase the likelihood of attracting and engaging end-user developers to create visualization in JavaScript. However, programmers and end-user developers are limited to predefined templates and functions, because the kernel of the library is not available.

User Types: End-user developers and programmers.

Tool Types: Wizard / Language tool.

Visualization Types: Standard visualizations

Many Eyes

Many Eyes [108], developed at IBM Research Center, is a web-based visualization platform mainly for simple users. In Many Eyes, visualizations are implemented in Java

2.3 Existing Visualization Development Tools

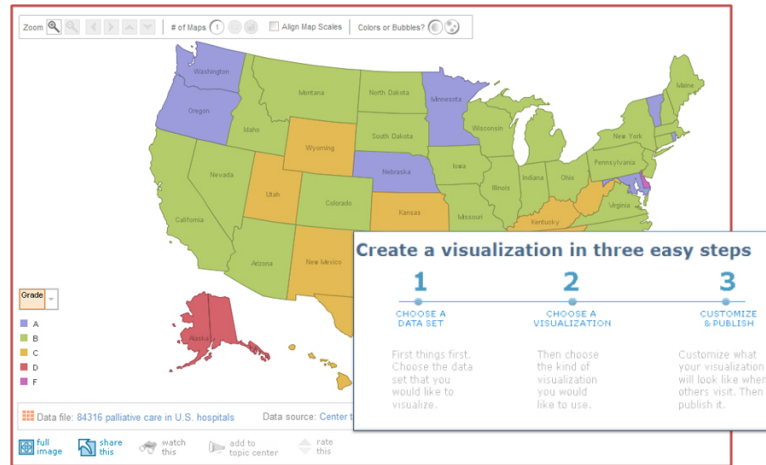


Figure 2.21: A map visualization in Many-Eyes. Source: <http://www-958.ibm.com/>.

Applets. Users construct visualizations in three steps: upload a dataset; choose a visualization template; customize and publish the visualization. Many Eyes automatically generates and shows the visualization on the screen. Custom visualizations are not supported. Figure 2.21 presents a screen shot of Many-Eyes.

User Types: Simple users, end-user developers and programmers

Tool Types: Wizard tool

Visualization Types: Standard visualizations

2.3.5 Results

Table 2.2 provides an overview of the results. The table shows that there is a tendency for researchers to focus on helping programmers to construct custom visualizations. In contrast, industry targets their products to simple users and helps them create standard visualizations. Although both communities can benefit from the engagement of end-user developers in constructing custom visualizations, end-user developers are neglected and not supported as simple users and programmers are. Further, the results show that only DEVis, GeoVISTA Studio, Improvise and Protovis/ProtoViewer may help end-user developers construct custom visualizations. However, to the best of my knowledge there is no empirical evidence that proves it. Surprisingly, InfoVis tools and toolkits are usually evaluated through case studies where impressive visualizations have been developed, and not through usability studies or experiments with potential

2.3 Existing Visualization Development Tools

	Constructing Visualizations					
	Standard Visualizations			Custom Visualizations		
	Language Tools	Wizard Tools	Drag-and-drop Tools	Language Tools	Wizard Tools	Drag-and-drop Tools
Simple Users		DEVise, MS Excel, Tableau, Spotfire, Omniscio, Tom Sawyer Perspectives, Many Eyes	SageBook, Tableau, Spotfire, Omniscio, Tom Sawyer Perspectives			
End-User Developers	APT, SAGE, Protovis, Google Chart Tools	DEVise, ProtoViewer, Improvise, GeoVISTA Studio, MS Excel, Tableau Spotfire, Omniscio Tom Sawyer Perspectives Google Chart Tools, Many Eyes	SageBook, Tableau, Spotfire, Omniscio, Tom Sawyer Perspectives	Protovis	ProtoViewer, Improvise, DEVise, GeoVISTA Studio	
Programmers	APT, SAGE, Protovis, Prefuse, Piccolo, Processing, Flare, D3, The InfoVis Toolkit, Google Chart Tools	DEVise, ProtoViewer, Improvise, GeoVISTA Studio, MS Excel, Tableau, Omniscio, Tom Sawyer Perspectives, Google Chart Tools, Many Eyes	SageBook, Tableau, Spotfire, Omniscio, Tom Sawyer Perspectives	Protovis, Prefuse, Piccolo, Processing, Flare, D3, The InfoVis Toolkit	ProtoViewer, Improvise, DEVise, GeoVISTA Studio	

Table 2.2: 20 InfoVis tools mapped according to the taxonomy. Tools from industry are in bold. Boxes in yellow indicate the problems addressed in this research. Boxes in gray represent future research directions.

2.3 Existing Visualization Development Tools

users. This indicates that the InfoVis community has to focus more on evaluation of the development tools with real users.

The results also show that simple users are supported with interactive development environments where they can use a step-by-step and/or drag-and-drop approach. These environments aim at handling the gulf of execution (*How do I do something?*) and evaluation (*What happened?*) identified by Norman [70] by allowing simple users to easily map data to visual objects in standard visualizations and obtain immediate feedback. The visual mapping of custom visualizations is mainly handled through code, with the exception of *Improvise*, *GeoVISTA Studio* and *DEVise*, which use a step-by-step approach.

Mapping InfoVis development tools according to this taxonomy gives research directions that the InfoVis community should investigate. First, end-user developers need more tools to create custom visualizations. Second, there is a need for *drag-and-drop* tools that allow users to create custom visualizations. Creating tools for users with different IT skills may address the universal usability challenge [78] and facilitate the process of introducing new audiences to InfoVis.

The research presented in this thesis focuses on EUD of visualizations and addresses the problem: *there are no Drag-and-Drop tools that allow users to create custom visualizations independently of their IT skills*. More specifically, this work targets end-user developers as well as programmers. The following chapter describes the proposed solution that uses techniques proven successful in other areas, e.g. formulas, drag-and-drop, etc.

Chapter 3

Solution

This chapter describes a *drag-and-drop* approach for visualization development. The proposed solution (uVis) consists of:

- *The uVis formula language*: supports visualization development by combining visual objects where each property can be a formula. uVis formulas are similar to spreadsheet formulas and can address relational data, other visual objects, and dialog data.
- *The uVis Studio*: a development environment for uVis that consists of several coordinated panels and features that help end-user developers and programmers create visualizations with a *Drag-Drop-Set-View-Interact* approach.

This chapter consists of two sections. The first section describes the uVis formula language and the second presents uVis Studio. In this chapter, for simplicity, instead of using the terms end-user developers and/or programmers I refer to them as developers.

3.1 uVis Formula Language

The scope of this section is not to present the uVis formula language in detail, but to provide knowledge needed to understand how uVis formulas are used to create visualizations and to follow the remaining chapters. A detailed explanation of the uVis formula language can be found in [53].

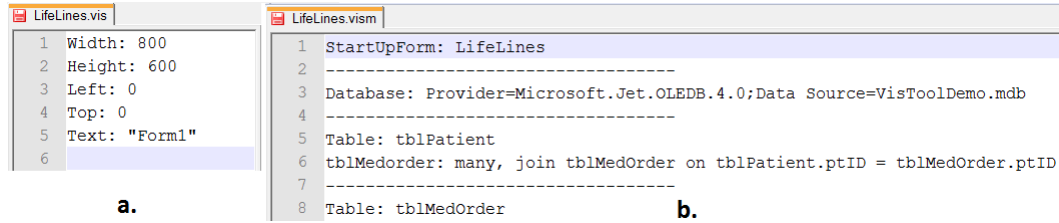


Figure 3.1: a. Vis-file, b. Vism-file .

3.1.1 uVis Files

A visualization created with uVis has two kinds of files:

- A visualization file (*Vis-file*) contains the formulas needed to generate a Windows form with data visualizations and simple controls. A *Vis-file* will normally be generated and edited through uVis Studio, but might also be created and edited outside uVis Studio. Figure 3.1.a shows an example of a *Vis-file* opened in notepad. A visualization might use several forms. In this case several *Vis-files* are used.
- A mapping file (*Vism-file*) contains information about the database. It lists the available tables and relationships in the database. A *Vism-file* is created by a database expert, or a uVis user who is able to specify the database connection and table relationships. Figure 3.1.b shows an excerpt of a *Vism-file*. Line 5 and 6 specify a one-to-many relationship between two tables: `tblPatient` and `tblMedorder`. The Vism-file also specifies the start-up form and initial development modes.

3.1.2 Controls

Developers construct visualizations by placing visual objects on forms and specifying uVis formulas for their properties. For instance, a bar-chart is created by binding a box control to data so that the box repeats itself and sets the heights according to data. Other visualizations are composed from several controls. To visually map controls to data and compose the visualization, developers specify uVis formulas for the control properties. uVis provides simple controls (e.g. label, textbox, triangle, box, etc.) but

also advanced ones (e.g. a `TimeScale` control that can show several periods of time with different zoom and align other controls accordingly).

3.1.3 Properties

Properties define the appearance and behavior of a control. A property has a formula that computes the value of the property, or defines it as a constant. Controls have three kinds of properties.

uVis properties: All controls have common properties such as `Top`, `Left`, `Width` and `Height`, and individual properties such as `Text`, `Radius` and `Angle`. A special property is `Rows`. Its formula computes a list of rows from a table or joined tables. uVis generates a control for each row.

Designer Properties: A developer may define a new property, a designer property. He may for instance write a complex formula in it. Other properties can refer to it. When the designer property has no formula it can contain a value and serve as a variable. In this case they have the same role as the dialog or session data in other programming languages.

Event Properties: Event properties do not have a formula but one or more statements that are performed when the event happens. As an example, the click event handler for a button may contain `Refresh()`, a uVis function that calls uVis to check for changed data and update all controls accordingly. The formula may also contain assignment statements, which can set designer properties and change database fields.

3.1.4 Formulas

The formula is the most important concept in uVis. To build a visualization you need controls, but formulas are the ones responsible for “gluing” these controls, defining their appearance and specifying their behavior. Formulas can refer to controls, control properties, tables and table fields in the database. In a *Vis-file*, a control consists of a block of formulas specified as plain text.

The uVis formula language combines several popular principles from programming languages, spreadsheets, relational databases and graphical user interfaces. For instance, it inherits the principle of referring to objects using the *dot* (`.`) operator as programming languages do. uVis uses almost the same algorithm that spreadsheets

use to calculate the formulas in the right sequence. However, controls (cells in spreadsheets) do not exist initially, but are created by formulas at run-time. This requires a more sophisticated algorithm. Formulas encapsulate complex logic such as SQL queries. As other tools, uVis has the usual math and string functions.

Access to control properties

A formula can refer to a control property. This is done with the *bang* operator (!), which addresses visual control elements. In case the formula refers to a property of the same control, the name of the property can be used without any prefix.

`Width: controlA ! Height` (*Refer to a property of another control.*)

`Width: Height` (*Refer to a property of the same control.*)

In principle, uVis could use a *dot* operator instead of the *bang* (!) or other operators described below. However, early in the project we noticed that these operators increased readability of the formulas. In addition, the operators resolve name ambiguities, for example between the `Height` property and a table field called `Height`.

Binding controls to data

uVis formulas can bind controls to rows of a table or joined tables. uVis controls have a special property called `Rows`. `Rows` specify how to compute a list of rows. uVis will generate an instance of the control for each row. An example is:

`Rows: tableA` (*tableA is a table in the database.*)

In this case, uVis compiles all formulas, collects information about the fields used, generates an SQL statement using the collected fields, executes it, retrieves the rows from `tableA`, and generates an instance of the control for each row. Each instance is bound to the corresponding row.

`Rows` formulas can join several tables, and the result is used to generate controls. To support this, uVis has join operators for *one-to-many* and *many-to-one* relationships: `-<` (left) join many, `=<` inner join many, `>-` (left) join one, and `>=` inner join one. uVis does not have join operators for *one-to-one* and *many-to-many* relationships. The *one-to-one* relationship can be replaced either by *one-to-many* or *many-to-one*. *Many-to-many* is not supported directly by databases, so uVis has no operator for it. A *many-to-many* relationship is normalized by introducing an extra table that has *many-to-one* relationships with the other two tables.

The join operators resemble the notation used in an Entity Relationship diagram. These operators denote the relationship cardinality using the Information Engineering cardinality style [62]. The join operators are used in the `Rows` property of a control, for instance:

```
Rows: tableA -< tableB
```

`tableA` and `tableB` exist in the database and have a *one-to-many* relationship. The database expert has defined this relationship and for simplicity given it the name `tableB` (Figure 3.1.b shows an example). The result of the formulas is: all `tableB` rows that relate to `tableA`. Fields from `tableA` are added to each row.

With this `Rows` property, the *dot* operator can access fields of the tables. For example, a formula defines the height of a control according to a field.

```
Height: tableA.fieldA (fieldA exists in this joined tables)
```

Formulas can also access properties and fields in the list of controls generated by `Rows`. Two examples are:

```
Width: controlA[5]!Height (Refer to Height of the fifth control instance.)
```

```
Height: controlA[5].FieldA (Refer to FieldA mapped to the fifth control instance.)
```

A `Rows` formula can have an SQL tail with `Where`, `Order By` and other SQL parts in any sequence. Examples are:

```
Rows: tableA -< tableB order by tableA.FieldA (rows ordered by FieldA)
```

```
Rows: tableA -< tableB group by tableA.FieldA (rows grouped by FieldA)
```

```
Rows: tableA -< tableB where tableA.FieldA = 1 (rows filtered by FieldA)
```

Finding a control based on data

Sometimes there is a need to “walk” from a row to a control bound to it. This is done with the *control join* operator (`-=`). It can for instance be used to align control instances. A real example is described in Appendix A.

3.1.5 Visualizations

uVis supports development of a wide range of visualizations. As proof of concept, several visualizations have been developed. Figure 3.2 shows some visualizations created with uVis formulas. Appendix A explains in detail how a custom visualization is created with uVis. In theory, uVis formulas could support all types of visualizations, such as time-oriented, hierarchal, geographical, animations, etc. However, at the current

3.1 uVis Formula Language

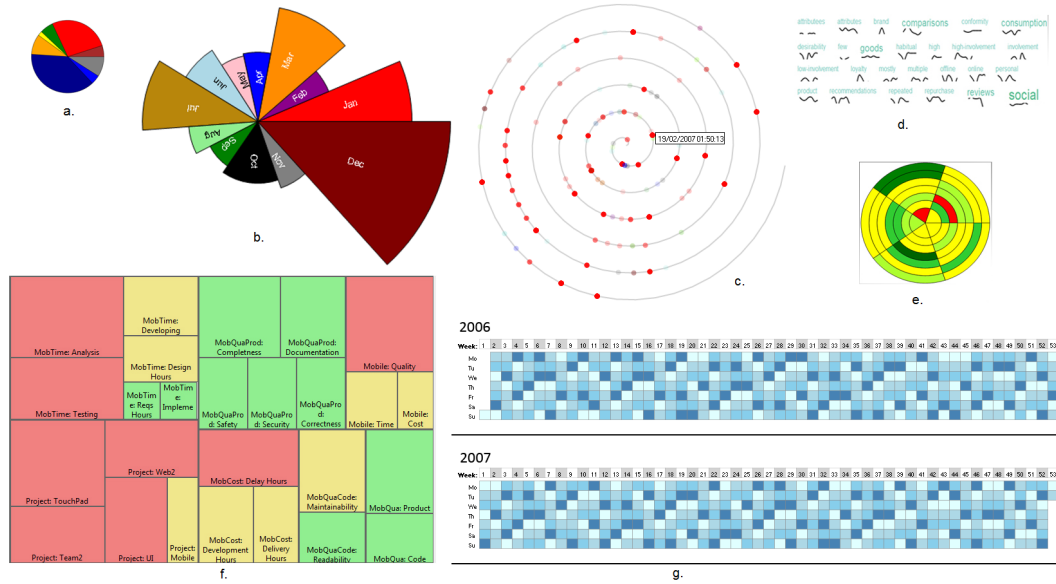


Figure 3.2: Visualizations created with uVis: a. Simple Pie Chart, b. Custom Pie Chart, c. Spiral Graph, d. SparkClouds, e. CircleViews, f. TreeMap, g. TileMaps.

stage, it is not possible to construct animations and geographical visualizations. In order to create these types, some additional visual object types are required. As an example, geographical visualizations can be constructed by introducing a geographical map object.

A great deal of research has been conducted in layout algorithms that automatically arrange visual objects to create novel presentations. TreeMap [11, 42] and Tag Cloud [41, 45, 65] are two popular layout algorithms. These two layout algorithms calculate the position and size of the visual objects. The Tag Cloud can easily be defined by uVis formulas. Figure 3.2.d shows a SparkClouds [55], a custom visualization that integrates SparkLines [106] in a Tag Cloud visualization. This visualization is created with uVis formulas.

However, in other cases (e.g. TreeMap), it is not possible to create the visualization with simple formulas. Such a visualization can be provided by a special Layout property. A developer creates a TreeMap visualization (Figure 3.2.f) using a box with these properties:

```
Box: treeMapBox
Rows: tableA
```



```
Layout: TreeMap()
Weight: tableA.FieldA
```

uVis creates a list of rows and for each row it creates a control instance. When creating a control instance, uVis checks if the `Layout` property is set and calls `TreeMap`. `TreeMap()` calculates and sets values of `Width`, `Height`, `Top` and `Left` according to the `TreeMap` algorithm. The `Width`, `Height`, `Top` and `Left` are read-only for any control having a `Layout` property.

3.1.6 Interaction

Interaction is an important aspect of visualizations. Without interactivity users would not be able to explore data. uVis supports interaction (e.g. details-on-demand, filtering) by means of event properties. The formula for an event property is a list of statements to be executed when the event occurs. As an example, to implement details-on-demand, the developer uses two box controls: `Box1` and `BoxDetails`. The developer defines an event handler property for the `Click` event in `Box1`. The event handler toggles the `Visible` property of `BoxDetails`. These are the formulas:

```
Box: Box1
Click: BoxDetails!Visible = Not BoxDetails!Visible, Refresh()
...
Box: BoxDetails
Rows: ...
Visible: Init false
Text: Me.Comments
...
```

When the end-user clicks `Box1`, uVis performs the actions (statements) in the click formula. As a result, the `Visible` property of `BoxDetails` is toggled. The statement `Refresh()` asks uVis to recompute all formulas and redraw controls where a property value has changed. As a result the `BoxDetails` will appear.

The uVis formula language is not mature enough to support complex interaction such as semantic zooming and focus+context. As an example, the `TimeScale` control supports zooming, but this feature is implemented inside the `TimeScale` control. Implementing this with formulas is difficult even for experienced uVis users.

3.1.7 Special uVis Concepts

Before I present uVis Studio, I describe some concepts used in the uVis formula language.

- **Bundle:** The `Rows` property creates a list of rows and creates a control for each row. These controls are called a bundle. As an example, the `Rows` formula is set to `tableA`, which has 23 rows. uVis evaluates the formula and creates a bundle of controls.

```
Box: Box1
Rows: tableA
...
```

In this case the bundle has 23 controls because there are 23 rows in `tableA`.

- **Index:** A control has an index inside the bundle. The first control has index zero, the second one, and so forth. As an example, `Left` is set to this formula.

```
Box: Box1
Left: Index * 20
...
```

uVis evaluates the `Left` formula for each control. As a result, the first control has `Left` 0, the second 20, the third 40, and so forth.

- **Parent:** This property creates a control instance for each instance of another control (the parent). Assume a developer wants to add a label (`Label1`) that appears next to each `Box1`. Instead of specifying the `Rows` property of the label, the developers makes `Parent` refer to `Box1`. As a result one label (`Label1`) will be generated for each `Box1`.

```
Label: Label1
Parent: Box1
...
```

The `Parent` can also be combined with join operators to define the `Rows` property of a control.

```
Label: Label2
Parent: Box1
Rows: Parent -< tableB
```

In this case, uVis evaluates the `Rows` formula for each *Parent* control (`Box1`) and creates a bundle of controls for the parent. The bundle is created according to the `tableB` rows reachable from the parent's row.

- **Canvas:** By default, a control is attached to the form and scrolls with it. However, the form may contain canvas controls. If the control has a `Canvas` property, it is attached to the `Canvas` control and scrolls with it. Assume a box control `Box1` is attached to a canvas control `Panel1`. The `Canvas` property of `Box1` is set to `Panel1`, as follows:

```
Box: Box1
Canvas: Panel1
...
```

- **Me:** Refers to the current control and data row bound to this control. `Me` is optional unless there is an ambiguous case that uVis cannot resolve. `Me` can also be used to refer to a specific control in the current bundle.

```
Box: Box1
Height: Me.FieldA
Left: Me[2]!Width (Go to the third control in my bundle)
...
```

- **Init:** Makes a property value changeable at run-time.

```
Textbox: txbID
Text: Init abc
...
```

In this example, the initial values is *abc*. An end-user can type something in the textbox and in this way change the value of `Text`. uVis uses the new value when evaluating formulas.

- **Conditional statements:** uVis supports conditional expressions in `C#` style. For example, the back color of a bar in the bar chart can depend on `Value`.

```
Box: Box1
BackColor: Value<10?"Green":"Red"
...
```

3.2 uVis Studio

uVis Studio (or simply the Studio) is the development environment of uVis. uVis Studio consists of 9 panels (Figure 3.4): *the ToolBox*, *the Explorer*, *the Property Grid*, *the Modes*, *the Error List*, *the E/R Model*, *the Design Panel*, *the Control-Data Hierarchy* and *the DataView*. All panels can be arranged by developers; they can resize, dock, hide, and open them as separate windows.

uVis Studio is written in C#, with a user interface in Windows Presentation Foundation (WPF). Two versions of uVis Studio were developed. Figure 3.3 shows the first version. Figure 3.4 shows the second version. The differences between the first and the second version (described later in this section) include two new panels (*Control-Data Hierarchy* and *DataView*), a new feature (*Formula Suggestions*), and several improvements (e.g. user-interface design, icons, *Modes* presentation, etc.) .

In the first version (Figure 3.3), the *Design Panel* shows a custom visualization inspired by LifeLines [79]. This visualization shows the medicine orders (white boxes aligned to the timescale) and intakes (colored bars inside the white boxes) for patient Lise B. Hansen. End-users interact with the timescale to zoom in and out. Further they select another patient by changing the value in the text box.

In the second version (Figure 3.4), the *Design Panel* shows a custom visualization of the evolution of technologies since 1985. The yellow column and row shows the total number of technologies per category and year respectively. The big black bars show the total number of technologies. Each box uses color-coding to show if there have been publications or not. The small bar inside a box illustrates the number of technologies per year. The first column aggregates the number of technologies for the years' range defined in the two text boxes. End-users can change their values and the visualization updates.

To create these visualizations, developers *drag and drop* controls from the *Toolbox* into the *Design Panel*, *set* formulas for control properties in the *Property Grid*, *view* immediate results in the *Design Panel* after the properties have changed, and *interact* as end-users (using *Modes*) to see how the visualization behaves.

The rest of this chapter describes the panels and features of uVis Studio, and in some cases it refers back to Figure 3.3 and 3.4. Next, the development approach and

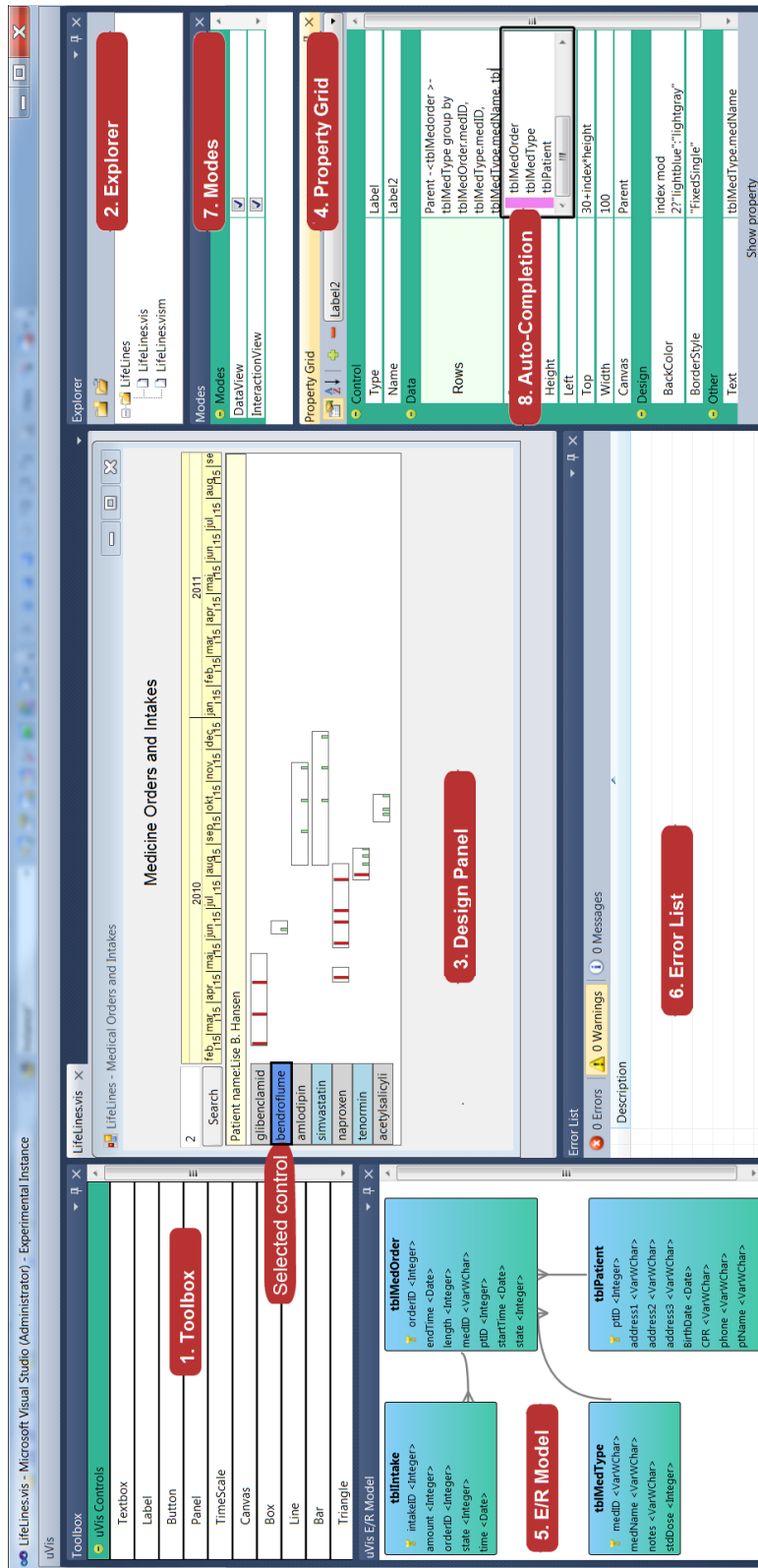


Figure 3.3: uVis Studio v.1.1: Toolbox, 2. Explorer, 3. Design Panel, 4. Property Grid, 5. E/R Model, 6. Error List, 7. Modes, and 8. Auto-Completion. Notice that the selected control is highlighted in dark-blue, and properties are shown in the *Property Grid*. In this case, the developer is specifying the **Rows**. The developer types the fields after the *group by*, but the *Auto-Completion* does not suggest **tblIntake** because it is not used.

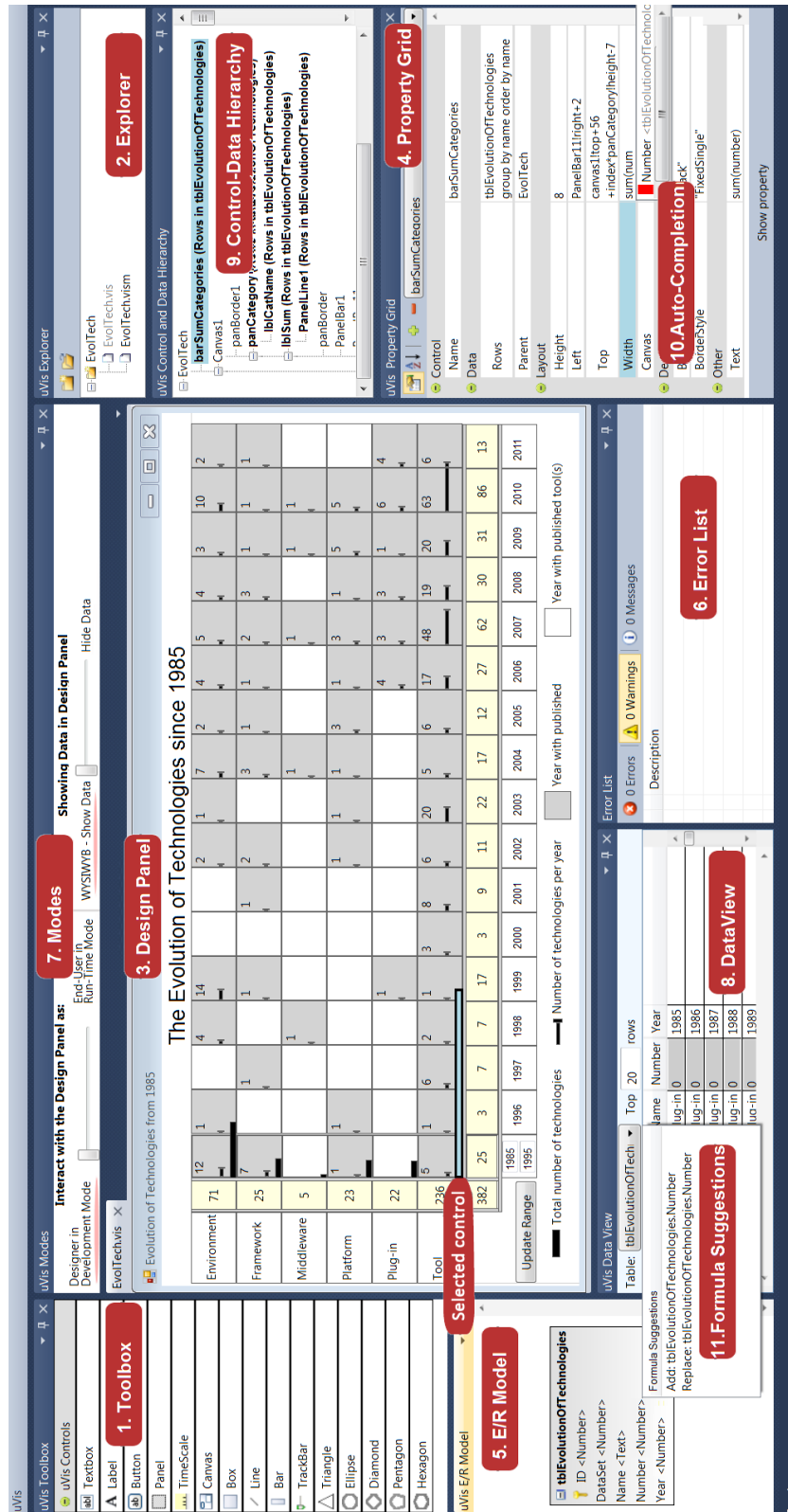


Figure 3.4: uVis Studio v2.0: 1. Toolbox, 2. Explorer, 3. Design Panel, 4. Property Grid, 5. E/R Model, 6. Error List, 7. Modes, 8. DataView, 9. Control-Data Hierarchy, 10. Auto-Completion, 11. Formula suggestions. The selected control is highlighted in light blue color in the *Design Panel* and *Control-Data Hierarchy*, as the selected property in the *Property Grid*.

the cognitive supports of uVis Studio are presented. The chapter concludes with some performance measures.

3.2.1 Panels

uVis Studio has nine panels to support the *Drag-Drop-Set-View-Interact* development approach. The design of uVis Studio was inspired by existing integrated development environments such as Visual Studio and Eclipse. Novel features of the Studio were elicited in the requirements document [52]. As an example, one of the requirements was that the user of the Studio should continuously obtain immediate feedback during development.

The Toolbox

The Toolbox (Figure 3.4.1) contains the control types that uVis supports, such as label, button, triangle, timescale, etc. A developer drags and drops a control into the *Design Panel* and the Studio sets the default property values. The developer may also select a control and draw it as a rectangle in the *Design Panel*. Icons for each control were added in the second version (Figure 3.4.1) to help developers distinguish them.

The Explorer

A developer creates and opens uVis folders with the *Explorer*. This panel (Figure 3.4.2) shows *Vis-files* and *Vism-files*. There are two icons on the top of this panel. The developer clicks on the right icon and uses a wizard to locate the folder where the *Vism-file* is stored. The *Vism-file* is written in advance by a database expert who can specify the database connection and table relationships. The developer clicks on the *Vism-file* and the visualization opens in the *Design Panel*.

The Design Panel

Visualizations are shown in the *Design Panel* (Figure 3.4.3). A developer drags and drops controls from *Toolbox*, moves and resizes them. However, it is not possible to move a control when it has a formula for the position (**Left** or **Top**). If the **Left** property of a control is bound to a table field, the developer can only change the position by changing the formula in the *Property Grid*.

When the developer drops a control or moves a control into a **Canvas** control, the **Parent** and **Canvas** property are automatically set to the **Canvas** control. However, the developer can change them manually in the *Property Grid*. When the developer adds a new control, the control formulas with default values are automatically set.

In the first version (Figure 3.3.3) the *Design Panel* was coordinated with the *Property Grid*. Whenever the developer selected a control, it became highlighted in dark blue and the corresponding formulas were shown in the *Property Grid*. The second version (Figure 3.4.3) uses a light blue color for the selected control because the dark blue is less readable. When a control is selected in the *Design Panel*, the control is also selected in the *Control-Data Hierarchy* and the *DataView* shows its row data.

Feature: What-You-Bind-Is-What-You-Get

The *Design Panel* is a “live” one. It supports direct manipulation and provides continuous feedback during development. When the developer has changed a formula, the *Design Panel* updates immediately. The developer does not need to execute the program to view controls bound to data. I call this feature *What-You-Bind-Is-What-You-Get*. For example, a developer specifies the **Rows** in the *Property Grid* to bind a label to the rows of *tableA*. This table has 23 rows. uVis creates 23 labels automatically, and the *Design Panel* shows them. As another example, the developer maps a field of a table to the **Text** property of a label and the field values are immediately shown in all of them.

The Property Grid

The *Property Grid* (Figure 3.3.4) shows the properties for the selected control. By default, it shows the properties of the form control. A row in the *Property Grid* consists of the *property-name* and the *formula*. Properties can be sorted alphabetically or shown in groups to help the developer find them faster. A change in the *Property Grid* is immediately reflected in the *Design Panel*. Also, a change in the *Design Panel* (e.g. moving a control) automatically updates the *Property Grid*. A developer can add and remove properties by clicking on the + and - button respectively.

Feature: Auto-Completion

Writing formulas can be challenging, as developers must remember the syntax, and it is common to misspell words. To help them, the *Property Grid* has an *Auto-Completion* feature that suggests what can follow. The suggestions can be available variables and functions of the formula language, but also suggestions for tables, table fields and relationships in the database.

Let us assume that a developer starts typing. The *Property Grid* sends to uVis what has been typed and receives information about what can follow. The *Auto-Completion* uses this information to create a list of suggestions. Suggestions are grouped in categories (e.g. property, table, field, etc.), sorted based on the typed letter(s), and are shown in a pop-up window. Color-coded icons are used for items of the same category to help distinguish the suggestions.

Figure 3.5 shows eight examples. Let us describe some of them. In the first example, the developer is typing a formula for the **Rows** property (light blue). The developer typed “tbl” and suggestions that start with these letters are shown. In this case, the *Auto-Completion* shows four table names (see the E/R Model in Figure 3.3). In the fourth example, the developer has typed the table name and pressed a *dot*. The *Auto-Completion* shows only the fields of this table. In the seventh example, the developer added a new property and started typing. A list with control property names, including the existing designer properties, is shown.

In the second version (Figure 3.4.10), I improved the algorithm to show more precise information, and solved bugs found during the first usability study. Descriptive tool-tips were added for each item in the *Auto-Completion*. In addition to the color-coding that denotes the category, I added the category name (in light gray). In this way, developers can directly see suggestions and their category.

The E/R Model

uVis uses the Vism file to extract table, field and relationship names from the database. The *E/R Model* uses this information and visually presents it as an Entity Relationship diagram (E/R) [21]. An entity represents a table in the database and shows the fields and field types. The connectors represent the relationships using the Information Engineering cardinality style [62]. Other cardinality styles are developed by Chen [21],

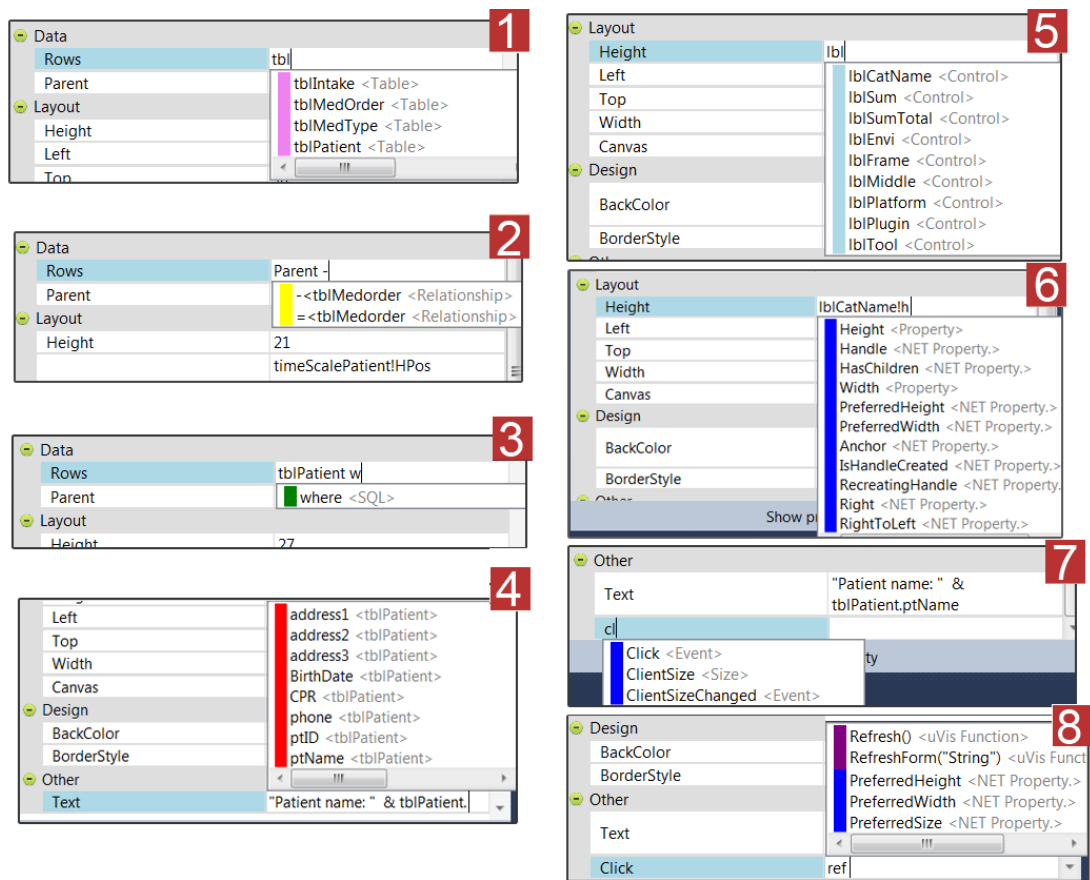


Figure 3.5: The *Auto-Completion* in action showing suggestions of : 1. table names, 2. relationship names, 3. SQL keywords, 4. field names, 5. control names, 6. control Properties, 7. event properties, and 8. functions and control properties.

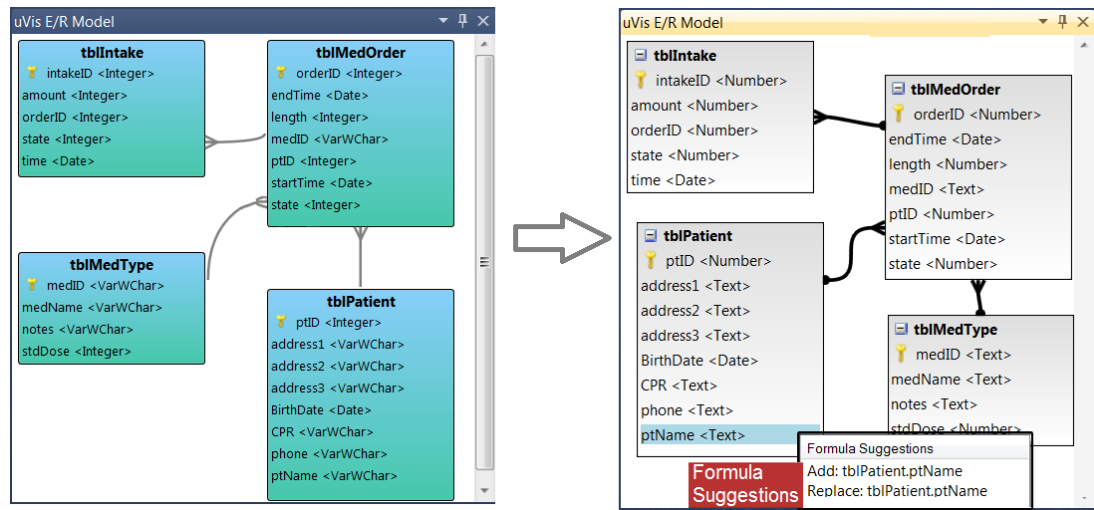


Figure 3.6: The first version of the *E/R Model* (left). The improved version of the *E/R Model* (right).

Bachman [6], etc. Choosing the right cardinality is challenging, and the decision can be debatable. From our personal experience with teaching *E/R* models, the Information Engineering cardinality style is the easiest to learn.

Developers can re-arrange the entities with the mouse. As the database may contain many tables, developers can expand or collapse table fields and detach the *E/R Model* panel from the Studio to enlarge it and get a better overview.

Figure 3.6 shows the two versions of the *E/R model*. In the second version, the *E/R Model* is more interactive, useful and readable. First, the developer selects a table or a field and views the data in the *DataView*. Second, I renamed the field types of the database to more comprehensible terms for end-user developers. For example, `VarChar` was replaced by `Text`. Finally, I changed the layout using more bright colors to avoid readability issues caused by the contrast.

Feature: Formula Suggestions

In the second version, the *E/R Model* has a new feature called *Formula Suggestions*. This feature aims at helping users specify easier data mapping formulas. A developer selects a property in the *Property Grid*, then right-clicks a table name, field name or relationship line to see formula suggestions in a pop-up window. There are two choices

for one suggestion. The developer can choose *Add* to append a suggested formula to the selected property, or *Replace* to replace the formula of the selected property with the suggested formula. As a result, the formula updates, and changes immediately reflect in the *Design Panel*.

Figure 3.7.11 shows *Formula Suggestions* in action. Below I describe a simple examples:

- A developer wants to set the **Text** of a label (bound to `tblPatient` rows) to:

```
"Patient Name: " & tblPatient.Name
```

- (1) Selects the **Text** property from the *Property Grid*.
- (2) Types “Patient Name:”.
- (3) Right-clicks over `ptName` field from `tblPatient` in the *E/R Model* panel. *Formula Suggestions* (pop-up window) is open.
- (4) Selects from the *Formula Suggestions* “Add: `tblPatient.ptName`”. The *Formula Suggestions* automatically inserts the “&” operator before `tblPatient.ptName`.

The algorithm used in the *Formula Suggestions* provides suggestions that follow the formula syntax, and automatically adds the correct operator in front of the suggestion. It also considers the **Rows** and the **Parent** of a control. For example, a developer tries to use a field from a table that is not included in the **Rows** property. The *Formula Suggestions* shows a message notifying the developer that this cannot be performed (Figure 3.8.1). The algorithm also checks the type of the formula versus the type of the property. For example, the developer selects the **Top** property and attempts to bind it to a table or a relationship. Again, no suggestions are shown, but a message says that a table or relationship is only used with the **Rows** property (Figure 3.8.2).

The Error List

The *Error List* shows a list of errors whenever a formula is wrong. Figure 3.9 shows an example when a developer misspelled the word “left”. The user double clicks on the error, and the wrong formula in the *Property Grid* is colored in red. Once the formula is corrected, the error list updates. In spite of the errors, the visualization is running all the time.

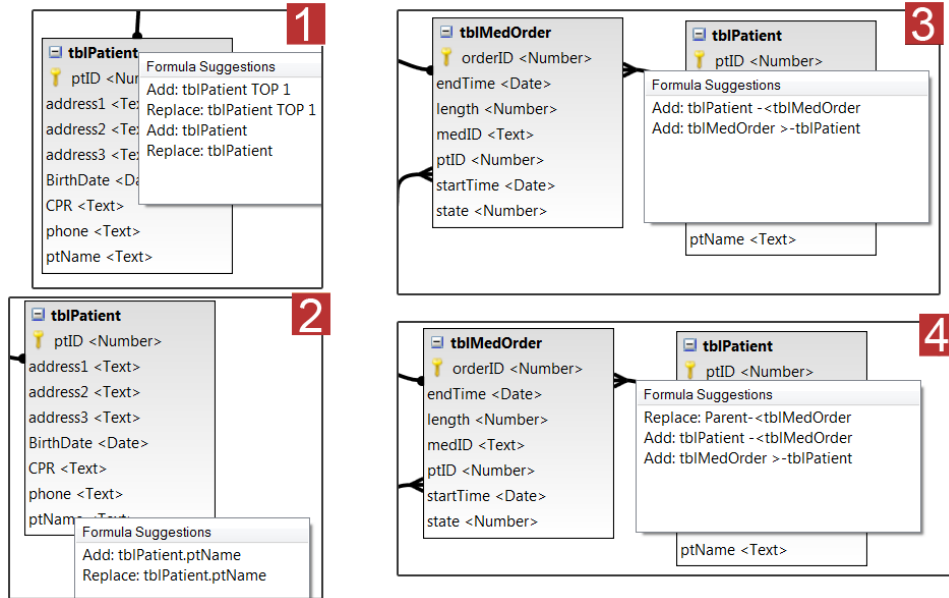


Figure 3.7: The *Formula Suggestions* in action showing suggestions of: 1. table names, 2. field names, 3. relationship names when the **Rows** property of the parent control is not specified, and 4. relationship names when the **Rows** property of the parent control is specified.

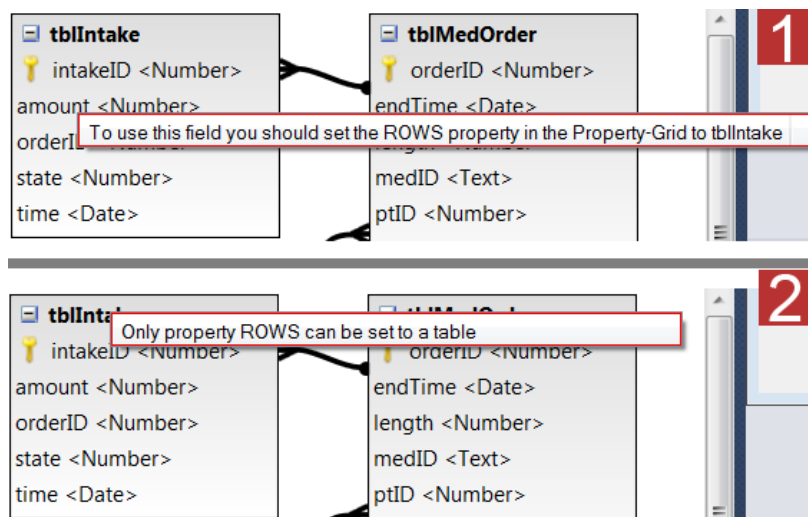


Figure 3.8: 1. A developer attempts to map the field `amount` to the `Top` property. 2. A developer tries to map the rows of `tblIntake` to `Top`.

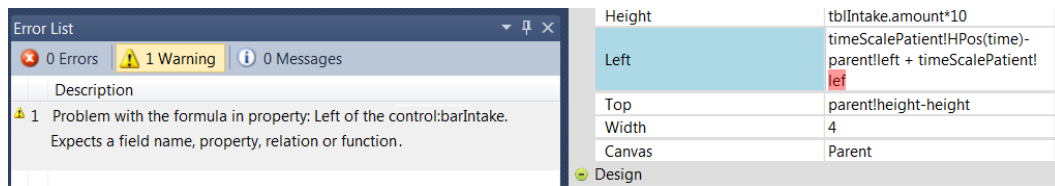


Figure 3.9: The developer selected the error message in the Error List (left) and the wrong formula is highlighted in the Property Grid (right).

In the second version, the content of the error messages improved as changes in the kernel were made. Also, the format of the message changed slightly. I removed some details that might be confusing for developers (e.g. the position and the line number).

The Modes

In the first version, the *Modes* used check boxes (Figure 3.3.7). In the second version (Figure 3.4.7), I re-designed the layout of the *Modes*, as they were not intuitive in the first usability study. The new presentation uses sliders, color-coding for the selected mode, and has descriptive text and tool-tips. In addition, the *Modes* panel is positioned over the *Design Panel*. These changes attempt to improve understandability and visibility of the *Modes*. This panel shows the *Interact-Mode* and *Data-Mode* (Figure 3.4.7).

- **Interact-Mode:** It enables interaction with the *Design Panel* as an end-user. Enabling the *Interact-Mode* through a slider might be considered as the *Run* button in traditional development environments. However in these environments, the developer has to wait for the result, which is shown in a different workspace. In Figure 3.10.1, the *Interact-Mode* is disabled, while in Figure 3.10.2 the developer moved the slider to enable it. In this way, the developer interacts with the timescale as an end-user.
- **Data-Mode:** It disables the *WYBIWYG* feature of the *Design Panel*. In Figure 3.11.1 the *Design Panel* shows controls bound to data. In Figure 3.11.2 the developer moved the slider to disable the *WYBIWYG* and the *Design Panel* shows only one instance. In this case, the screen is similar to the *Design Panel* in Visual Studio or Eclipse.

3.2 uVis Studio

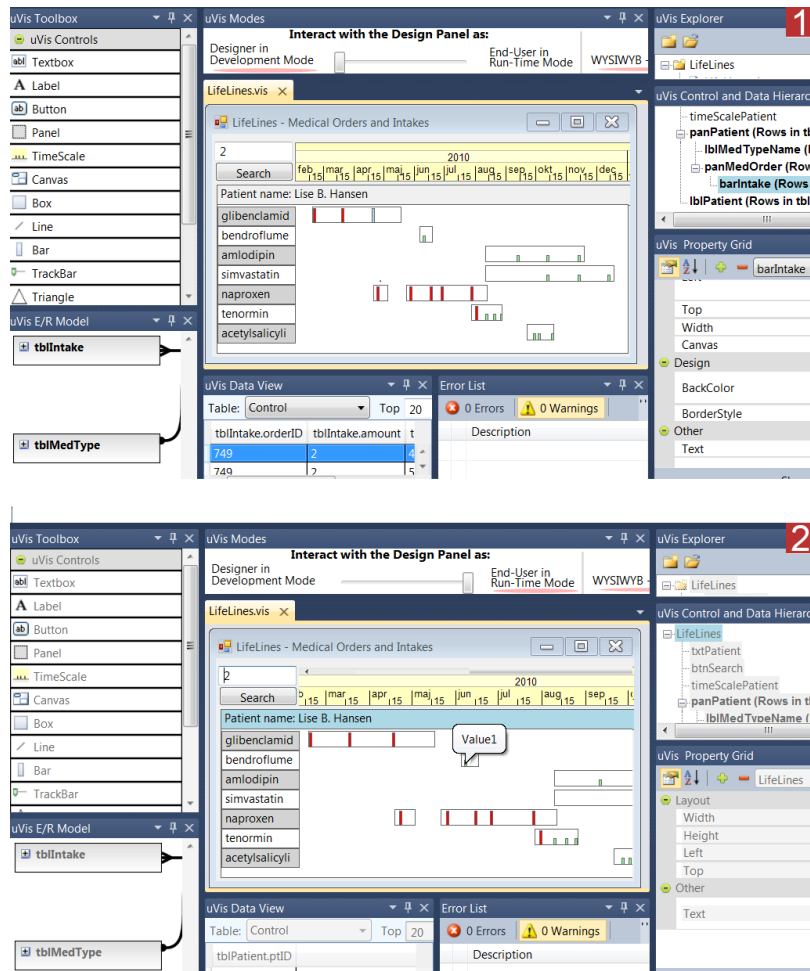


Figure 3.10: 1. The *Interact-Mode* is set to designer mode and the developer has selected the *barIntake* control (top). 2. The *Interact-Mode* is set to end-user mode and the developer interacts with the timescale and tests the tool-tip.

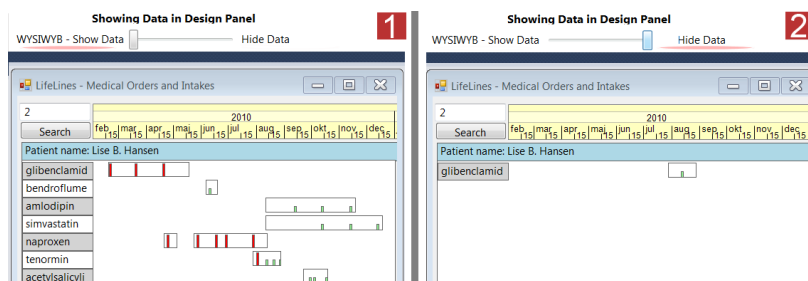


Figure 3.11: The developer uses the *Data* to: enable the WYBIWYG (1) or disable it (2).

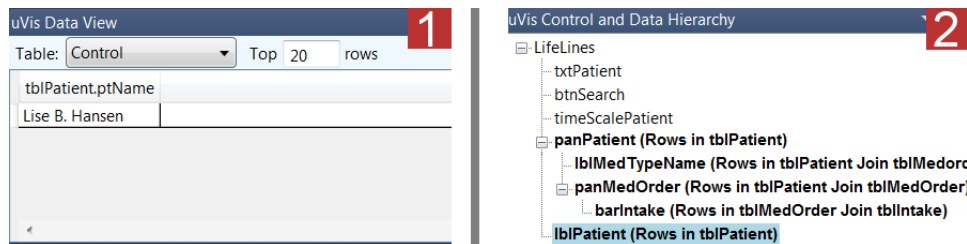


Figure 3.12: 1. The *DataView*. 2. The Control-Data Hierarchy.

The *DataView*

The *DataView* (Figure 3.4.8) was developed in the second version of the Studio and shows data from the database. This panel is coordinated with the *E/R Model*. A developer clicks a table in the *E/R Model* and the rows are shown. The developer may also click a field, and the column is brought to focus and highlighted. Next, the developer may order rows according to it; useful when exploring data. When the developer clicks a control that is bound to data, then the *DataView* shows the row-data. An example is presented in Figure 3.12.

The Control-Data Hierarchy

This panel (Figure 3.4.9) shows the control and data hierarchy of controls in the form. It was developed in the second version of uVis Studio in an attempt to improve understandability of the **Canvas** and **Parent** concept. The panel displays the control hierarchy as a tree. Each control is represented by a node and child nodes denote the nested controls. The data hierarchy is represented by the tree as well, but additional plain text is used to explain the data source. For example in Figure 3.12 the **panMedOrder** control resides inside the **panPatient** control. The plain text shows which table is used, but for information such as *where* and *group by* the developer has to check the exact formulas in the *Property Grid*.

When there are many controls, it is important to distinguish controls bound to data from others. Therefore, the text style is bold if the control or its **Parent** control is bound to data. An example is presented in Figure 3.12.

Developers can expand/collapse controls and detach the panel and view it separately. Finally, interactions with the panel reflect in the *Design Panel*, the *Property Grid* and the *DataView*.

3.2.2 Development Approach

In uVis Studio, visualizations are constructed with the *Drag-Drop-Set-View-Interact* approach. Developers *drag* and *drop* controls, *set* control properties using formulas, immediately *view* how controls are bound to data, and *interact* with the visualization as end-users without switching workspace. Below, I describe the approach and elaborate on how the Studio attempts to reduce the gulf of execution (how do I do it?) and evaluation (what happened?).

- Developers *drag* and *drop* controls. In uVis Studio, developers need minimal mental effort to create a control because drag-and-drop is a straight forward action. It is obviously easier than writing code.
- For each control, developers *set* control properties through the *Property Grid*. The *Auto-Completion* helps them with suggestions to write the correct formula. Also, developers view the data model in the E/R model, and bind controls to data and map fields to properties using the *Formula Suggestions*.
- Developers immediately *view* results in the *Design Panel*, and if needed adjust control properties again. They do not switch workspace to view what happened after changing a property. Developers view the mapping of the data to controls in the *Design Panel*, observe the properties in the *Property Grid*, and see the bound data in the *DataView*. To further improve the visual feedback, controls bound to data overlap partly because the Studio automatically set the `Left` property to a formula. Developers obtain continuous feedback and realize what happened, reflect on the formulas and understand how the mapping was done.
- Developers *interact* with the visualization as end-users without switching workspace. The *Design Panel* shows the visualization “live”, and developers can enable the *Interact-Mode* to interact as end-users. In this way, developers realize what happened as they interact.

Tanimoto [101] defined a taxonomy of development environments using the feedback to developers, known as the “liveness” taxonomy. This taxonomy has four levels of liveness:

1. *Informative*: Environments where developers can create, but not run a program.

2. *Informative and significant*: Environment where developers can create programs, and explicitly submit programs to execute.
3. *Informative, significant and responsive*: Environment where developers create programs, and any change causes computations without any explicit submission for execution.
4. *Informative, significant, responsive and live*: Environment where a program is “continually active, or potentially so” [101], and developers can edit programs at run-time; there is no need to stop or restart to view the changes.

Language tools such as Prefuse, Piccolo, InfoVis Toolkit, Flare, etc. can be integrated in development environments such as Eclipse. However, the development approach is language-based, where users of these tools write code. At the end, they execute the code to view the result. In wizard tools such as Improvise and Devise, users specify step by step a visualization using several windows. At the end, they are able to view the results. According to the “liveness” taxonomy, these tools fall in the second level – *informative and significant*.

uVis Studio falls somewhere between level three and four. The uVis Studio shows the “live” version of the visualization and developers can create and edit visualizations without explicitly asking for a compilation. Changes in the *Property Grid* are reflected immediately to the visualization when developers press **ENTER** or change focus.

3.2.3 Cognitive Supports

As Norman [70] says, “the real power come from devising external aids that enhance cognitive abilities.” uVis Studio resembles a traditional development environment, but it supports improved external aids – several coordinated panels and novel features.

Coordinated Panels

In uVis Studio, the coordinated panels aim at facilitating development by allowing developers to view different information simultaneously through different panels. Several panels are coordinated and changes in one reflect on others. The *Design Panel* is coordinated with the *Property Grid*, the *Data-View*, the *Control-Data Hierarchy*, and the *Error List*. The *DataView* is also coordinated with the *E/R Model*. As an example, a

developer can view the data bound to a control from the *DataView*, the formulas used for this control in the *Property Grid*, and where the control is positioned in the *Design Panel* and *Control-Data Hierarchy*.

Novel Features

uVis Studio has several novel features to enhance the development process: *What-You-Bind-Is-What-You-Get (WYBIWYG)*, *Interact-Mode*, *Auto-Completion* and *Formula Suggestions*.

1. **What-You-Bind-Is-What-You-Get (WYBIWYG)**: whenever a formula is changed the visualization is updated showing real data corresponding to the “live” version. This feature of the *Design Panel* allows developers to get immediate feedback and view controls bound to data without running the application. *WYBIWYG* enhances the visual mappings, and improves efficiency and correctness during development. Also, it may lead to discovery of novel presentations because of the immediate feedback on the screen.
2. **Interact-Mode**: changes the way the developer interacts with the *Design Panel*. This feature allows the developer to interact with the visualization in the *Design Panel* as an end-user or as a designer without switching workspace. As a result, it removes the step where the developer runs the program and waits for the result to show in a different workspace.
3. **Auto-Completion**: as the developer types a formula, a pop-up window in the *Property Grid* suggests what can follow. This feature of the *Property Grid* helps developers recognize rather than remember the syntax of the formula language, and write them correctly. Unlike the auto-completion in traditional IDEs, uVis provides suggestions for tables, table fields and relationships in the database.
4. **Formula Suggestion**: after selecting a property control in the *Property Grid*, the developer clicks on a table or a table field in the *E/R Model* and a pop-up window suggests what can be used to set the property. This feature of the *E/R Model* helps developers bind controls to data and map fields to properties.

	Time in milliseconds				
	Open uVis Studio	Visualization with 1 control	Visualization with 83 controls	Visualization with 5,226 controls	Visualization with 50,000 controls
Load E/R model	1	25	25	26	26
Load Property Grid	3	48	65	191	1093
Load Design Panel	3	121	242	898	7867
Load Control Hierarchy	1	5	12	16	16
Load Explorer	10	5	4	20	7
Load DataView	1	130	126	126	138
Load Toolbox	185	0	0	0	0
Load Modes	4	0	0	0	0
Load Error List	1	0	0	0	0
Add a control in Design Panel	N/A	109	213	827	7352
Delete a control in Design Panel	N/A	28	74	547	7547
Auto-Completion response-time on key pressed	N/A	18	55	131	240
Switch to Interaction Mode using Modes	N/A	6	6	8	8
Enable WYBIWYG using Modes	N/A	12	101	543	5198
Disable WYBIWYG using Modes	N/A	12	101	104	120

Table 3.1: Performance measures. The first column shows the time spent when uVis Studio starts, but no visualization is opened. The other columns shows how the Studio performs when a visualization has: one control, 83 controls, 5,226 controls, and 50,000 controls.

3.2.4 Performance

To evaluate uVis Studio performance from a user perspective, I measured the time uVis Studio takes to load visualizations with various number of controls, add and delete a control, switch modes, and the response time of *Auto-Completion*. I used an MS Access database that had 4 tables. I used a ThinkPad W510 with a 1.73 GHz Intel Core i7 processor and 4 GB RAM. I executed the same tests five times and show the averages.

Table 3.1 shows how uVis Studio performs when a visualization has: one control, 83 controls, 5,226 controls, and 50,000 controls. The time is measured in milliseconds. As shown in the table, uVis Studio spends more time to load the *Design Panel* compared to other panels. As the number of controls increases, the overall performance of the Studio is affected especially. This is caused by the uVis kernel which queries the database, and computes and renders controls. Adding and deleting a control is as fast as refreshing the screen. The response-time of *Auto-Completion* and *Interact-Mode* is neglectable from a user perspective. When the *WYBIWYG* is enabled or disabled, there is a difference in performance because the screen is refreshed. This difference relates to the number of controls in *Design Panel*.

The figures show that the Studio itself responds immediately from a user perspective, but the kernel takes time to open a form and refresh the screen. The kernel uses roughly 0.16 ms/control to compute and render a control. Additional performance measures can be found at [107].

Chapter 4

The Approach in Practice

This chapter shows how an experienced user of uVis develops custom visualizations. The chapter proves that it is possible to create custom visualizations without real programming using the *Drag-Drop-Set-View-Interact* approach. However, it does not prove that real end-user developers and programmers can do it. This will be subject of Chapter 6, 7 and 8.

4.1 The Process Completion Diagram

In 2011, I visited the Human-Computer Interaction Lab at the University of Maryland to evaluate the usability of uVis with programmers. During my stay, I met Sureyya Tarkan, a PhD student at the lab. Using a drawing tool, Sureyya had designed a novel representation, called the Process Completion Diagram (PCD) that aggregates event-logs of medical data into in-time, late and not-completed tests, and visualizes these using shapes, colors and positions. Although she has advanced programming skills, Sureyya had no time to implement a running prototype as it would have taken her approximately two weeks to develop. I was introduced to her work and we started collaborating. The goal of this collaboration was to create a running prototype based on her initial design. Sureyya provided me with a printed version of the visualization, but there were no available data. I created a sample dataset and developed the initial version of the visualization in five hours using the first version of uVis Studio. After I implemented the first version, in collaboration with Sureyya, Prof. Ben Shneiderman

4.1 The Process Completion Diagram

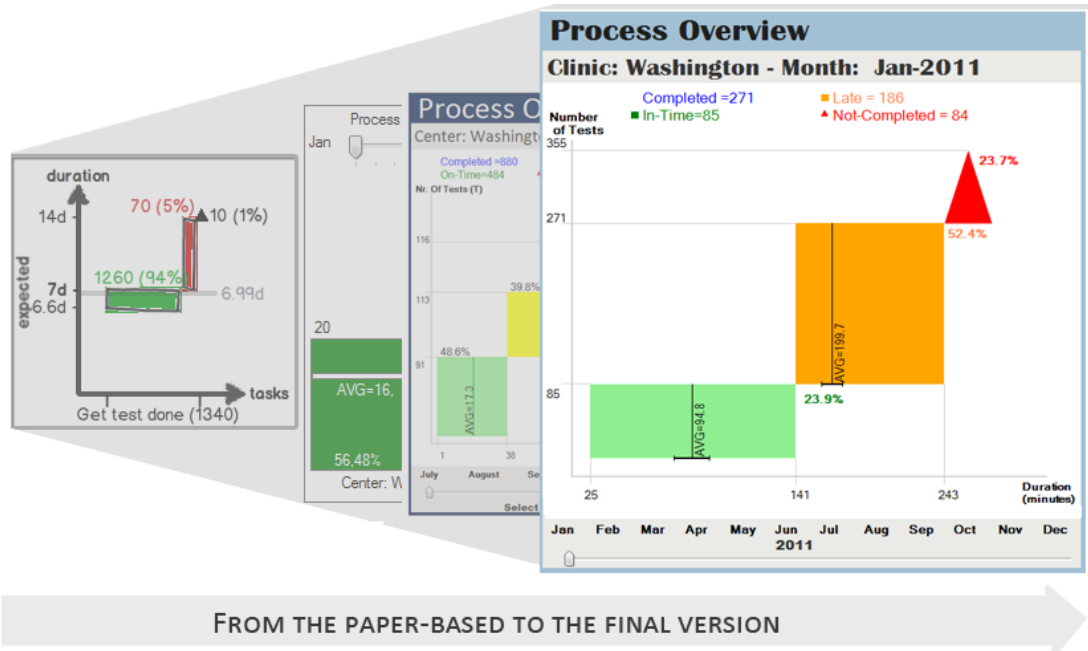


Figure 4.1: The evolution of the Process Completion Diagram (PCD). The final version visualizes the blood-test process from the medical domain.

and Dr. Catherine Plaisant, I iteratively improved the design of the initial version. Figure 4.1 shows the evolution of the PCD from the paper-based to the final version.

Figure 4.1 shows an example from the medical domain, and illustrates how 355 blood tests are presented using the PCD. It uses a green rectangle, an orange rectangle and a red triangle to represent the number of in-time, late, and not-completed tests. The PCD uses different shapes to help distinguish the completed from the not-completed tests. These three shapes are placed in a time series plot, where the X-axis shows the test duration and the Y-axis shows the number of tests. Figure 4.1 shows that there are 85 in-time, 186 late, and 84 not-completed blood tests. Classifying tests into in-time and late is realized using a threshold of lateness. Thresholds are defined by process managers.

The PCD also shows the minimum, average, and maximum duration for the in-time and late groups of tests. The in-time durations range from 25 to 141 minutes and the late durations range from 141 to 243 minutes. The PCD also presents a large amount of detailed information such as the threshold value, the standard deviation around each average (a small horizontal mark at the bottom of each rectangle), and the percentages

4.1 The Process Completion Diagram

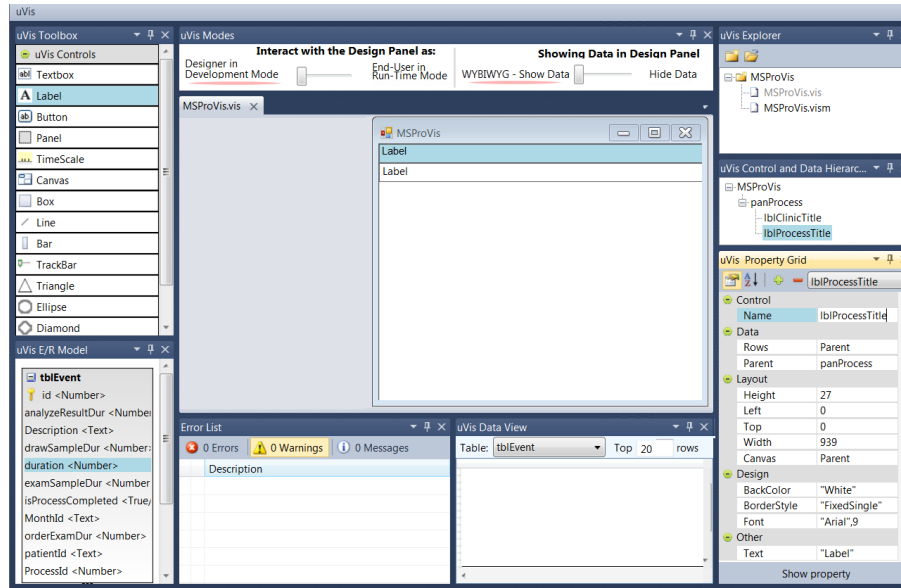


Figure 4.2: Three controls were dragged and dropped. The selected control and property are colored in light blue.

for in-time, late, and not-completed tests. At the top of the PCD there is a textual list of the absolute numbers of total completed, which is made up of the in-time and late tests. The textual list also presents the number of not-completed tests. Small colored shapes are placed close to each label, to link the texts with the shapes in the plot. End-users interact with the track-bar to compare performances of different months, and clicks on shapes to see details on demand.

4.1.1 Constructing the PCD

To construct this visualization, I use a database with one table (`tblEvent`) that contains blood-test data. First, I created the *Vism-file* outside the Studio, then I create a *Vis-file* with the Studio. I double-click on the *Vism-file* and an empty screen is shown in the *Design Panel*.

I drag and drop a panel control, which will contain all the other controls, then add two labels inside it. A selected control is highlighted in light blue color in the *Design Panel* and the *Control-Data Hierarchy*, and its properties are shown in the *Property Grid*. I select a property to write a formula. Figure 4.2 shows a screen shot.

I drag and drop four more controls to construct the plot: two lines and two labels.

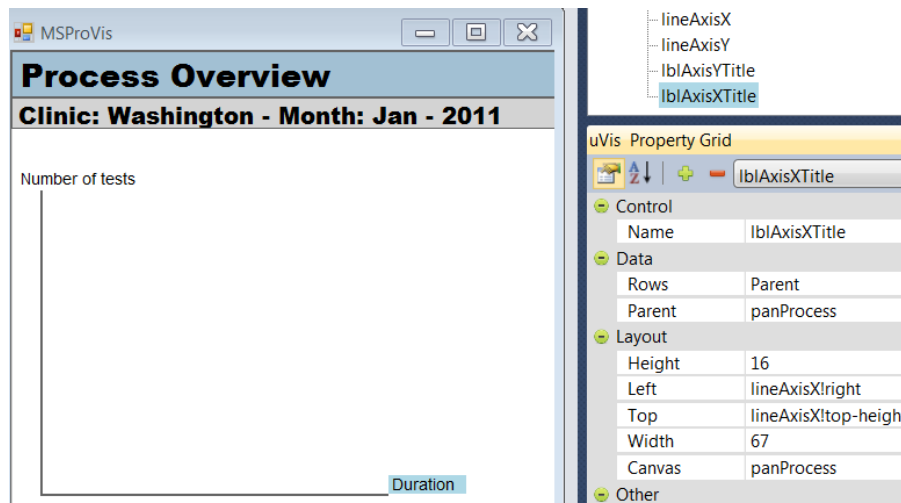


Figure 4.3: Creating the plot using two labels and two lines.

I rename the controls to meaningful names and “glue” them by means of formulas. For example, the position of `lblAxisXTitle` is set using these formulas:

```
Label: lblAxisXTitle
Left:  lineAxisX!Right (Refer to the Right of the lineAxisX)
Top:   lineAxisX!Top-Height
```

Likewise, I set the `Left` and the `Top` property of `lblAxisX`, `lblAxisY` and `lblaxisYTitle`. The Auto-Completion feature helps me write the correct formulas by providing suggestions. Figure 4.3 shows part of a screen shot.

Next, I drag and drop two boxes and one triangle. I change the `BackColor` property to light green, orange and red for the in-time box (`boxOvertime`), the late box (`boxLate`) and the not-completed triangle (`triNotCompleted`) respectively. Next, I set the `Top` and the `Left` property so that `triNotCompleted` and `boxLate` are placed at the right-top corner of `boxLate` and `boxOvertime`. Figure 4.4 shows the formulas for `boxLate`.

In the PCD, the size of the shapes is calculated by aggregating lab-test results from `tblEvent`, and grouping them in: in-time, late and not-completed. The height of the shapes corresponds to the number of tests in the table, and the width of the rectangles represents the test duration. As the not-completed tests do not have a duration time, the triangle’s width does not represent duration. In this case I set it to 40 pixels. I bind controls with the `Rows` property, and the *Auto-Completion* and *Formula Suggestions* helps me. For example, this is the formula for the `boxLate`:

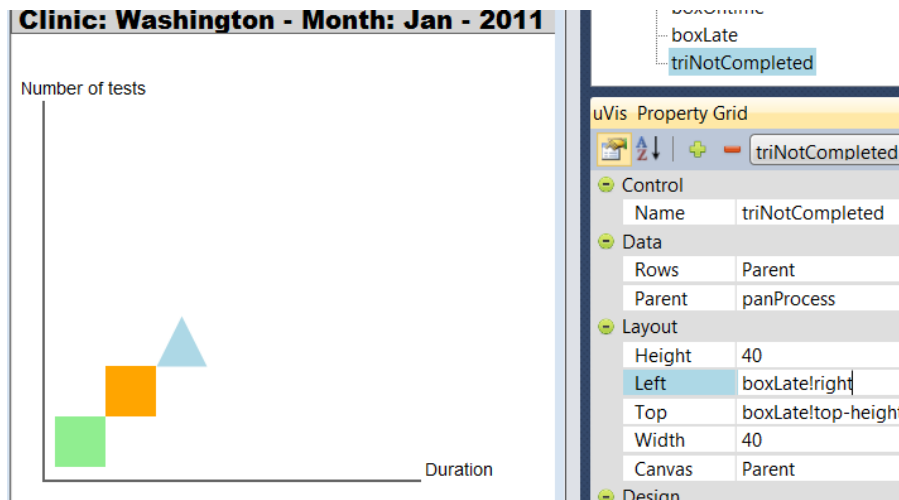


Figure 4.4: Two rectangles and a triangle to visualize the in-time, the late and the not-completed tests.

```
Rows: tblEvent where MonthId = 1 and duration > 100
      and isProcessCompleted = 1 group by ProcessId
```

This formula means: select and group the tests that were completed, had duration greater than 100 (corresponds to the threshold of lateness) and were performed in the January. To get the number of tests, the minimum duration and the maximum duration, I add four new properties for each shape and specify their names and formulas as follows:

```
MyCount: count(ProcessId)
MyMaxDuration: max(duration)
MyMinDuration: min(duration)
TotalNumber: lblAxisTitle!Text (contains the total number of tests for January)
```

This causes uVis to use a bit of math to set the `Width` and the `Height` property of each control, for instance Figure 4.5 shows a screen shot. Note that the *DataView* shows the data bound to this control. In the *Hierarchy* the text of this control becomes bold to show that it is bound to data, and the additional text tells which table is being used.

Next, I drag and drop a track bar (`TrackBarMonth`) and a label (`lblMonthName`). I set the `Minimum`, `Maximum` and `Value` of `TrackBarMonth` to 1, 12, and `Init 1` respectively. Setting the `Value` to `Init 1` allows end-users to change it at run-time as they

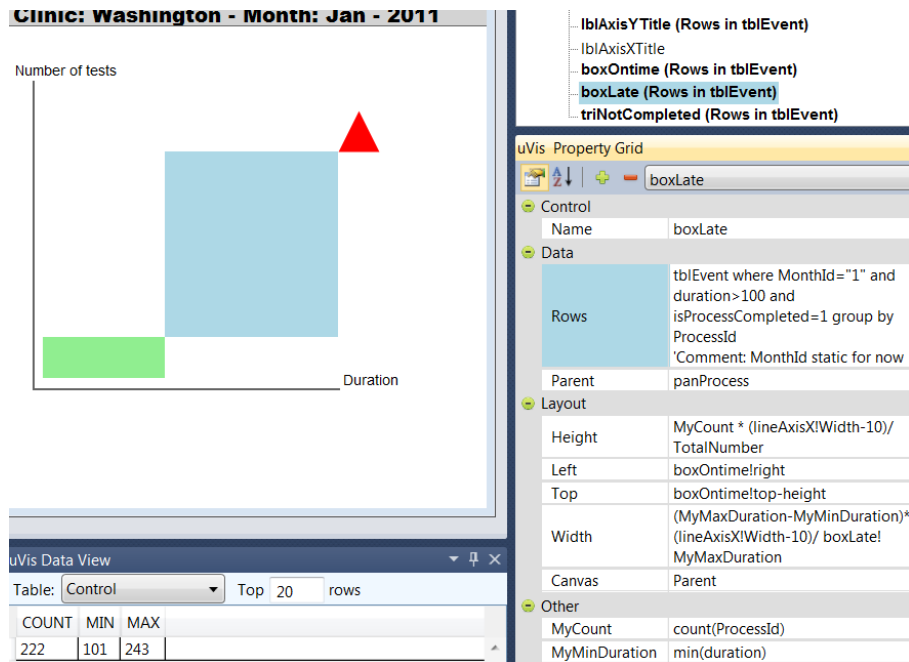


Figure 4.5: Shapes are bound to data and Height and Width are mapped to number of tests and duration.

interact with `TrackBarMonth`. I want to refer to the `Value` of `TrackBarMonth`. Therefore, I go to the `Rows` property of each control that uses the `MonthId` field in the *where* clause, and replace `MonthId = 1` with `MonthId = TrackBarMonth!Value`. Next, I set the `ValueChanged` property to this:

`ValueChanged: Requery()` (*Requery()* is a *uVis* function)

This means that every time an end-user interacts with `TrackBarMonth`, the PCD shows the data of the selected month. After implementing the interaction I enable the *Interact-Mode* to interact as an end-user. In this mode all panels are disabled, except for the *Design Panel* and the *Modes*. Figure 4.6 shows part of a screen shot.

The final version (Figure 4.7) was iteratively created and uses seven types of controls: the panel, the box, the triangle, the label, the line and the track-bar. Above, I summarized the steps that I followed to create it. However, it is not mandatory to follow this sequence. For example, an end-user developer or a programmer may drag and drop a box to visualize the in-time tests, bind that to data, and copy and paste it (and its formulas) to create another box. Next, the end-user developer or the programmer adjusts the formulas so it represents the late tests.

4.1 The Process Completion Diagram

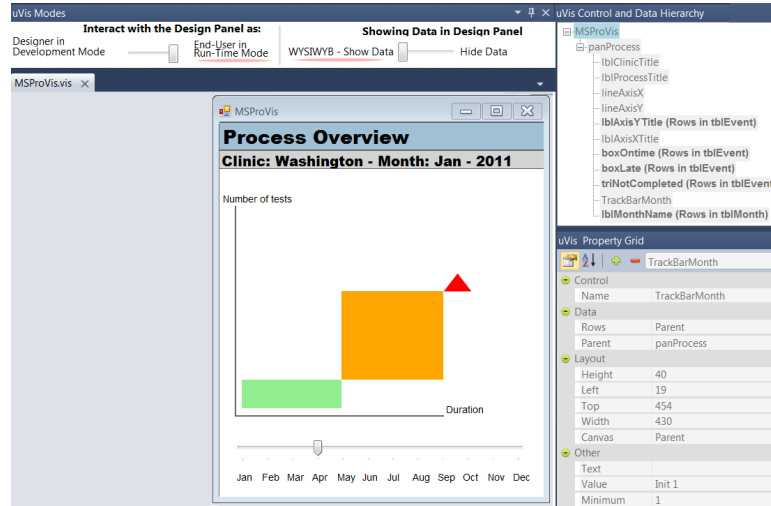


Figure 4.6: “Interact with the Design Panel” end-user is enabled. The other panels are disabled.

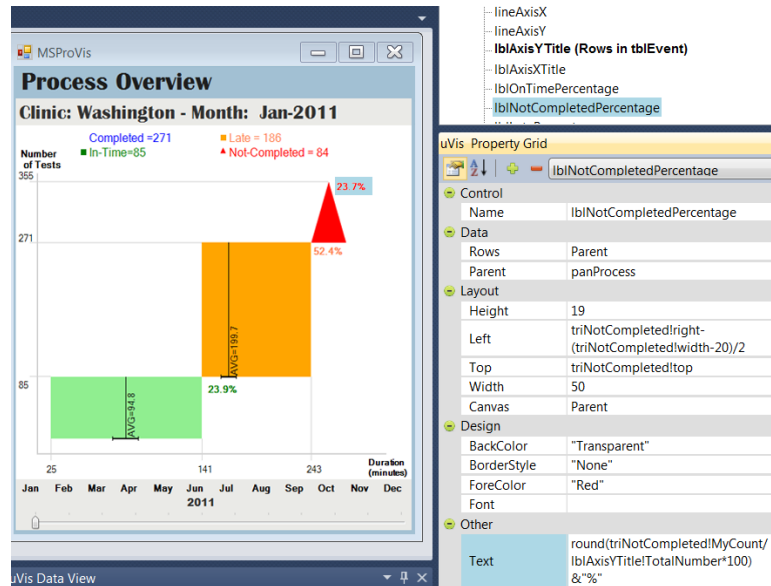


Figure 4.7: The final version of PCD.

The Multi-Step Process Visualization

I used the PCD visualization to create the Multi-Step Process Visualization (MSProVis). MSProVis is an interactive visualization composed of three main views: *Process Overview*, *Steps in Details*, and *Actors in Details*. It allows managers to review and compare series of PCDs at different levels of detail, allowing comparisons between steps or between actors executing those steps. This visual approach aims to facilitate retrospective analysis of the multi-step process.

The *Process Overview* and *Steps in Details* are the most interactive parts. In the Process Overview, the managers can interact with the slider and view historical data for different months. Automatically, the *Steps in Details* and *Actors in Details* views show steps and actors' tests for the selected month. MSProVis calculates initial predefined thresholds of lateness, and allows managers to adjust those thresholds interactively in *Steps in Details*. Threshold changes are also reflected in the *Process Overview* and *Actors in Details* view. Managers can view details-on-demand inside tool-tips by clicking on shapes. Figure 4.8.1 shows the initial version designed by Sureyya, and Figure 4.8.2 presents the final version of MSProVis constructed with uVis. The initial version of MSProVis (Figure 4.8.1) was developed in approximately five hours. The final version (Figure 4.8.2) was iteratively developed, but an experienced uVis user should be able to rapidly construct it.

4.2 Visualizing the Evolution of Technologies

In 2012, Paolo Tell, a PhD student at the IT University of Copenhagen, had conducted a systematic mapping study investigating the evolution of technologies from 1985. Although, his research focuses on global software engineering and is not related to information visualization, Paolo drew a custom visualization to present the results in a journal paper. During the revision of the paper Paolo had to change the drawing because of the data, and in a meeting we had, he expressed the frustration of having a drawing rather than an interactive visualization. As he already knew my research, Paolo asked if I could do something similar using the Studio. We started discussing his visualization and what the data were. After the meeting, I got a printed version of the visualization and the dataset.

4.2 Visualizing the Evolution of Technologies

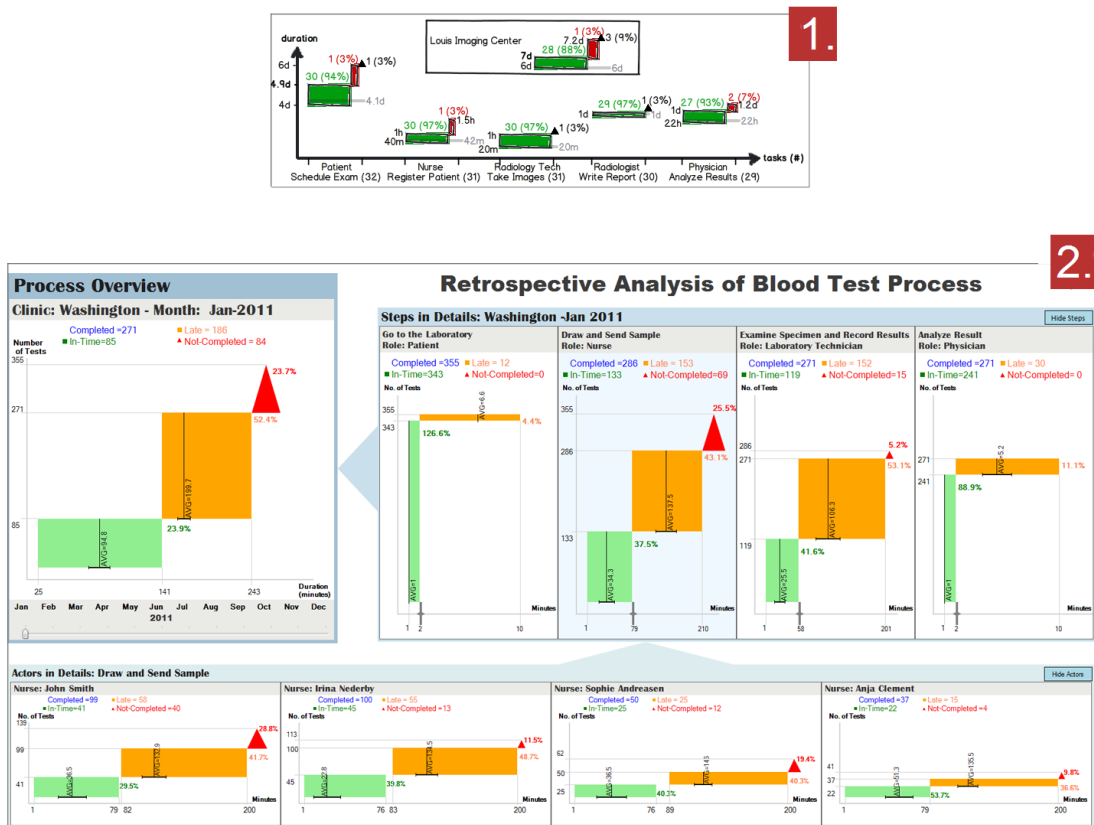


Figure 4.8: 1. The paper-based visualization that provides an overview of the process and details for each step of the process. 2. The Multi-Step Process Visualization (MSProVis) combines three views in a single presentation, allowing managers to explore process, steps, and actors' tests rapidly.

4.2 Visualizing the Evolution of Technologies

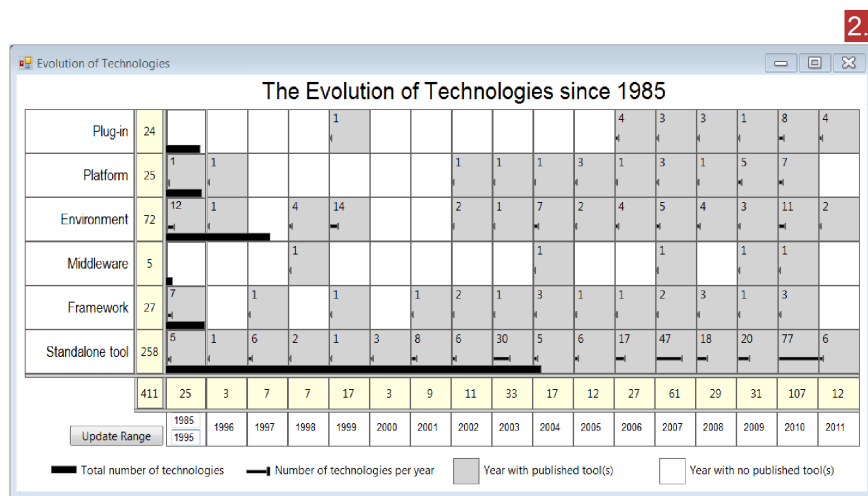
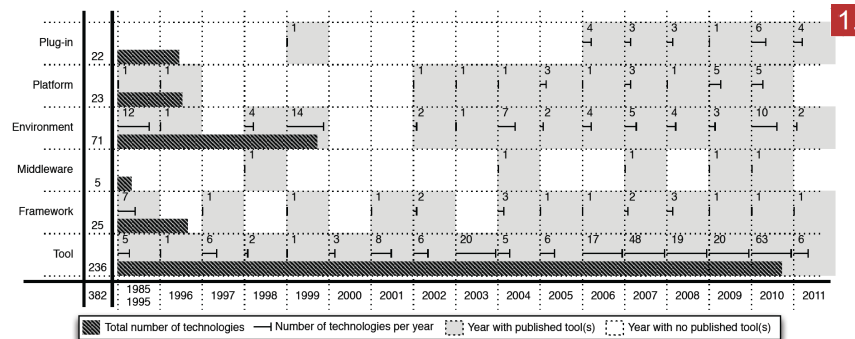


Figure 4.9: 1. The original drawing visualizes 382 technologies. 2. The custom visualization created with uVis formulas and the Studio.

In this visualization, the boxes in the yellow column and row show the total number of technologies for each category and year respectively. Using color-coding, the white boxes show year without publications. The gray boxes denote years with publication. Inside these boxes there are some small bars. The width of these bars illustrates the number of technologies. The first column aggregates the number of technologies for the years' range defined in the two text boxes. End-users can change these values and the visualization is updated. The big black bars show the total number of each technology. As an experienced uVis user, I developed this visualization in five hours. In these five hours, I had to understand the visualization, the data, and create the solution.

Chapter 5

Usability Evaluation

Conducting usability studies is a popular technique to evaluate a tool with users. I conducted usability studies to evaluate the uVis formula language and the Studio, and answer the research questions:

1. Can end-user developers construct custom visualizations?
2. Can programmers construct custom visualization faster?

The collected information will help us to improve uVis, so that it becomes more mature. Also, the results of the evaluation will serve as a starting point in investigating end-user development of information visualization. The rest of this chapter explains what usability consists of, how it can be measured, and the approach used in this thesis.

5.1 Usability Factors

Usability comprises many factors. I used the six factors defined by Lauesen [51]:

- Fit for use: “The system can support the tasks that the user has in real life.”
- Ease of learning: “How easy is the system to learn for various groups of users”
- Task efficiency: “How efficient is it for the frequent user?”
- Ease of remembering: “How easy is it to remember for the occasional user?”
- Subjective satisfaction: “How satisfied is the user with the system?”

- Understandability: “How easy is it to understand what the system does?”

I primarily measure the ease of learning, subjective satisfaction and understandability. Fit for use, task efficiency and ease of remembering were not addressed explicitly because they are hard to measure during development.

5.2 Measurement Techniques for Usability

Lauesen [51] defines six measurement techniques for usability: task time, problem counts, keystroke counts, opinion poll, score for understanding and guidelines. From the six measurement techniques, I used:

1. *Problems counts*: This measure is best for measuring ease of learning (but provides good indications for the other usability factors too) by observing users as they use the system in a think aloud manner. I used Lauesen’s classification [51] to classify usability problems identified in the studies:
 - (a) **Bug**: *The system fails to perform correctly.*
 - (b) **Missing Functionality**: *The system cannot support the user’s task.*
 - (c) **Task Failure**: *The user cannot complete the task on his own or he erroneously believes that it is completed.*
 - (d) **Cumbersome**: *The user complains that the system is cumbersome.*
 - (e) **Medium Problem**: *The user finds the solution after lengthy attempts.*
 - (f) **Minor Problem**: *The user finds the solution after a few short attempts.*
2. *Opinion Poll*: This technique measures user satisfaction by answering 5-point Likert scale questions.
3. *Score for understanding*: This technique measures understandability by asking questions about how the user believes the system works.

Problem counts and score for understanding are suitable during development. Opinion polls are less suitable, yet the best to measure subjective satisfaction [51]. The other measurement techniques (task time, keystroke counts and guidelines) require experienced users and a more finished system.

Problem Counts

Problem counts can be measured in many ways, including: cognitive walkthrough, heuristic evaluation, and thinking-aloud study.

- **Cognitive walkthrough:** is the procedure of evaluating a user interface by walking through the user tasks to identify the necessary functions [51]. According to Hertzum and Jacobsen [39], this method is appropriate before testing with users is possible. Also, the authors state that this method should be conducted with group of evaluators and can provide additional feedback to user testing when evaluators face problems in recruiting participants [39].
- **Heuristic Evaluation:** is an approach where usability specialists identify usability problems with a list of heuristic guidelines [51]. Any computer professional should be able to perform a heuristic evaluation, but “evaluator’s skills and expertise has a large bearing on the result” [39]. The involvement of usability specialists can positively affects the effectiveness of this method [67].
- **Thinking-aloud study:** is a popular method where users are asked to carry out a task using a system in a think-aloud manner[51]; thinking-aloud and observations on how a user performs, are used by the evaluator to identify usability problems. According to Hertzum and Jacobsen [39] there is no clear definition of this method, either for the procedure. A general practice is to have a facilitator (who administer the sessions) and an evaluator (records a list of usability problems), but the usability test can be perform from one who plays the same role [39]. This method can be used during development and the number of users is always questionable. Involving the right number of participants is always difficult to achieve. According to Nielsen and Landauer [69] and Virzini [109] the number of new usability problems decreases after the fifth study.

I decided to use the think-aloud study because it provides better feedback to developers and the system was not sufficiently mature and stable to consider other approaches. Also, the think-aloud approach is considered to be the most important approach to evaluate user interfaces [68]. During this approach, many suggestions for improvement may come up [91]. A limitation of the approach is that the measured time may increase because of verbalization [91]. However, in the usability studies I did

not plan to measure the time of small task steps (e.g. drag and drop a control, change the left position). Rather, I planned that each task should be accomplished in a certain time. The reason that I did not measure time of small steps, was because it requires users who are experienced with the tool. Measuring it would not provide any valuable information as all of them were new to the uVis formula language and the Studio. Also, the tool was a functional prototype, and the results may differ from a finished system.

I conducted all the usability studies, kept notes during the sessions as I was observing the participant and listening to his/her comments. As it was not possible to have a facilitator who knew uVis in the study, I decided to use a recording tools in order to avoid missing information. Whenever, participants were not able to proceed by themselves, I assisted them and recorded the usability problem as a task failure. When the system failed, I recorded it as a bug. Minor and medium problems were identified based on my observations. I recorded as cumbersome all those cases where the user complained verbally.

The goal of these studies was to evaluate the uVis formula language and the Studio in order to answer the research questions. I asked participants create a visualization rather than adjust an existing one, because this would provide more feedback about the tool. This means, that participants had to accomplish a difficult task as they had to learn the formula language, how the Studio works, and understand how visualizations are created with the tool. The first task was to create a simple visualization with guidelines. In the second task participants were asked to create a custom visualization. The procedure and documentation are discussed in detail at the beginning of Chapter 6, 7 and 8.

Opinion Polls and Score for Understanding

To measure opinion polls and score for understanding, I used questionnaires and interviews. According to Nielsen [68], questionnaires and interviews are not direct usability evaluation methods because they provide users' opinions rather than observable facts.

In order to provide additional data on subjective satisfactory, I asked users to answer a questionnaire after each task. I used a five point Likert scale and asked questions about the uVis formula language and uVis Studio. The questionnaire was inspired by the questionnaire for user interaction satisfaction (QUIS) developed by Shneiderman [91]. Only in the first study did I conduct a semi structured interview.

5.2 Measurement Techniques for Usability

A semi-structured interview has predefined questions, but it provides the flexibility of changing the focus of questions during the interview [82]. Robson [82] says that “biases are difficult to rule out”. To obtain unbiased data from interviews, the conductor has to be an experienced interviewer. Although the bias effect is present, interviews have a potential to provide useful information [82].

Chapter 6

Usability Study with Programmers

This chapter presents a usability study with six programmers. Although, all of them indicated that they are programmers, none of them are professional programmers who practice programming on a daily basis. This means that they probably do not have the skills of a professional programmer, but certainly, they are not end-user developers. Five of them have developed information visualization applications and one of them user interfaces. In addition, all of them have used an integrated development environment at some point in time.

I chose these subjects because they would be able to compare the development approach and the features of the Studio with what they had used before. In addition, they could compare the uVis formula language integrated in the uVis Studio with other development tools. Their feedback helped us identify usability problems, and provide suggestions for improvement.

6.1 Procedure and Tasks

No participant had prior knowledge of the uVis formulas or the Studio. Each usability test was conducted in three hours on average and consisted of four main parts: introduction to uVis, construct a bar chart, construct the LifeLines, and a semi-structured interview. I conducted the study, kept notes, and recorded the sessions. During the sessions, I assisted the participant whenever there were misinterpretations, confusions

or malfunctions of the system and recorded them as usability problems. Each problem was classified using the problem classification [51]. For instance, in cases that the system failed to perform correctly, I classified this problem as a *bug*. In other cases where participants could not complete a step on their own, I recorded this as a *task failure*. The documentation used in this study is presented in Appendix B.

Part 1: Introduction to uVis

This part took 30 minutes on average, where the participant was introduced to uVis. I had predefined a structure of the concepts I was going to explain, and used that as a guide to present the tool to the participant. I explained how visualizations are created in uVis, what the uVis formulas are, how to refer to control properties, tables and fields, etc. Also, I showed the participant the reference card for the uVis formula language. At the end, I opened the Studio and described it.

Part 2: Construct a Bar Chart

After introducing the tool theoretically, I practically showed to the participant how to create a bar chart using a simple MS Access database with three tables (Figure 6.1). While, I was creating it I explained what I was doing. After my presentation, the participant was asked to replicate what I did, and carry out the same task in a think-aloud manner. I also provided the participant with a reference card that showed the bar chart and the formulas of each control. Note that I used this simple bar chart to allow the participant to understand the uVis formulas more easily and become familiar with the Studio. Once the participant finished constructing the bar chart, I asked some questions on a 5-point Likert scale.

This session lasted 45 minutes on average. The purpose of this part was to allow the participant to create the bar chart using the uVis formula language and the Studio.

Part 3: Construct a LifeLines

I showed the participant an already implemented version of the LifeLines that used data from a MS Access database with 4 tables (Figure 6.2). I explained some advanced concepts (e.g. the control-join operator “-=” that aligns controls vertically, and the

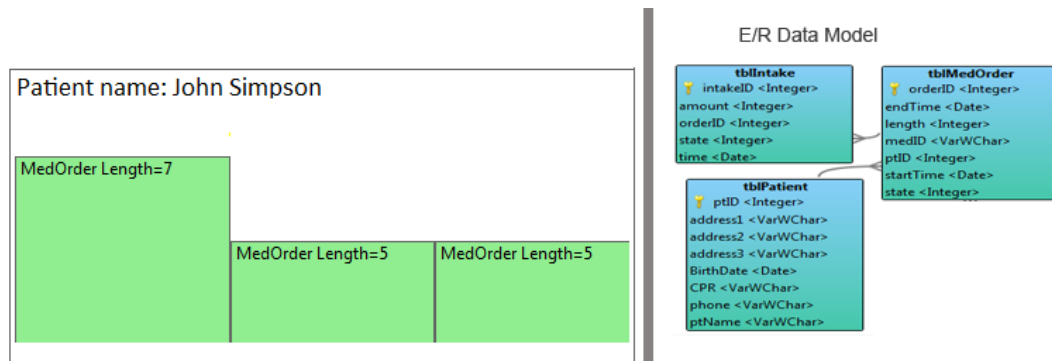


Figure 6.1: The bar chart and the E/R data model.

HPos function of the timescale that aligns controls horizontally, `init` and `Refresh()`). Then, the participant was asked to create the LifeLines, and think-aloud during the process. I provided the participant with the uVis reference card, a reference card where the visualization was showed without any formulas, and some hints in the second page. The hint page showed how to write a complex `Rows` formula with a *Group By*, how to align controls vertically and horizontally, how to convert a `String` to `Integer` type, and how to use the `Refresh()` function. At the end, the participant was asked to reply to the same questions as in part 2. This part of the study lasted one hour and 30 minutes on average and aimed at evaluating the uVis formulas and the Studio. In addition to part 2, the participant used the *Interact-Mode* to interact as an end-user with the visualization.

Part 4: Semi-Structured Interview

A 15 minutes semi-structured interview followed, where the participant was asked about the uVis formulas, the Studio, how different this approach is from what the participant has used so far, and if the participant believes that end-user developers can use the Studio to construct visualizations. Also, an early prototype of the MSProVis visualization (Figure 6.3) was shown, and the participant was asked to estimate the development time using the Studio and other tools. I applied a semi-structured interview in order to obtain better insights and identify how the uVis approach could be improved.

6.1 Procedure and Tasks

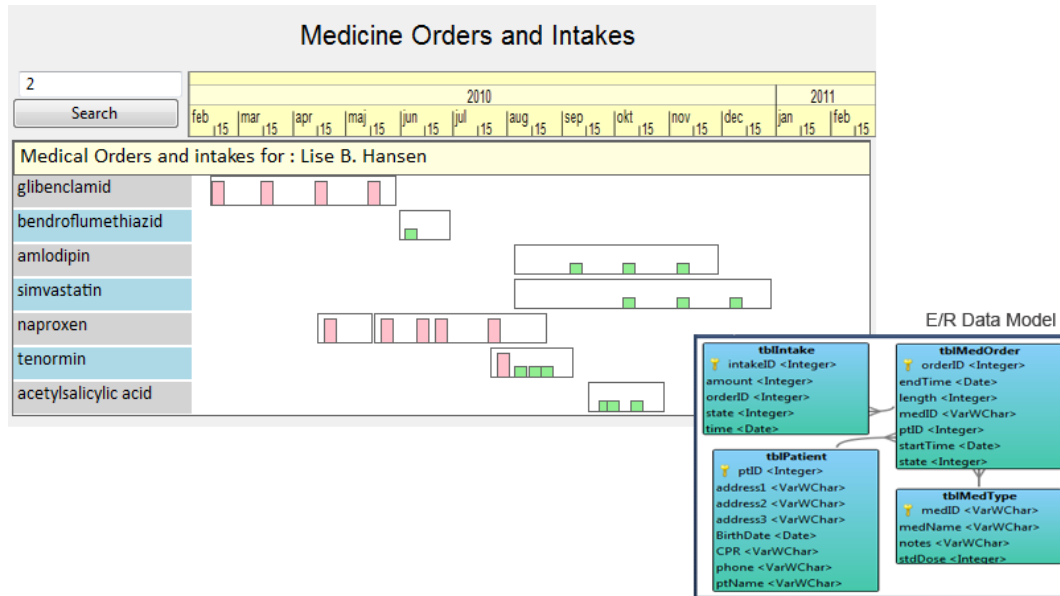


Figure 6.2: The LifeLines and the E/R data model.



Figure 6.3: Initial version of MSProVis.

6.2 Results

In this section I present the results of this study. For each participant I describe his/her background, report the number of observed problems categorized by type, subjective ratings, and participant's comments about the tool and their answers from the semi-structured interview. I conclude this chapter with a summary of the results.

Participant 1

Male; 30 years old; working as a PhD student in Computer Science from 2008; has been coding from 1999; has a very good knowledge of E/R databases; has a good knowledge of MS Excel spreadsheet formulas; has been working for the last two years with visualizations; has coded visualizations from scratch using Python, and has used Prefuse, and D3.

Problem Counts

In this usability test, the participant faced several problems. Two of them were task failures. The first problem relates to the **Parent** concept of the uVis formula language and the second was specifying a complex formula for the **Rows** property that used a *Group By*. There was no problem when the participant wrote a simple formula for **Rows**. In total, I observed 19 problems and Figure 6.4 shows the number of problems of each type. Below, I elaborate on these problems, and at the end of the chapter I present a summary of the problems observed in the usability study. For simplicity I will not elaborate in detail for the other participants, as I do here.

- **Create a bar chart:** The **Parent** and **Canvas** properties caused confusion, as the user assumed they were the same (*Problem:* Task Failure). Further, specifying the **Rows** property was hard, as the Left-Join operator ($-<$) was not intuitive to the user (*Problem:* Medium). However, the participant reflected and used the E/R model to solve it. The Studio used a top-down approach to position controls on the form (*Problem:* Minor). The user was more used to the bottom-up approach, and found the top-down approach cumbersome. While he was creating the visualization, he would have liked to see more details in the form (*Problem:* Missing Functionality). For example, showing a label over a bar that indicates

the bar was bound to data (`tblMedOrder`). One of the limitations in the Studio is that users are not allowed to change the control's position when the position is set to a formula (*Problem: Missing Functionality*). The user understood the reason, but suggested that the user should decide about that. In some cases the Auto-Completion did not perform as expected (*Problem: Bug*). It should not be removed when the typed word matched the suggestion (*Problem: Minor*). The Error-List window was not helpful, as the user found the errors confusing and would have liked to have more details (*Problem: Missing Functionality*), or a way to debug (*Problem: Missing Functionality*).

- **Create a LifeLines:** After several attempts, the participant specified the correct formulas for the `Rows` (*Problem: Medium*). The difficulties were caused by the `Parent` concept, and the Join-Left operator (`-<`). He was not able to specify a complex formula that joined 3 tables and used a `Group By` (*Problem: Task Failure*). As several controls were used to construct this visualization, the user would have preferred having a control hierarchy window (*Problem: Missing Functionality*) instead of the combo-box in the Property Grid (*Problem: Minor*). The error messages were not helpful to him as they were difficult to understand (*Problem: Cumbersome*). Once the system failed to respond, and we had to close and open the visualization (*Problem: Bug*). The user found the Modes useful, but as he commented later he would have liked to see it over the Design Panel (*Problem: Minor*). Also, better and more explicit names for the modes would have made them more understandable (*Problem: Minor*). At the end, he suggested that viewing the real data is important (*Problem: Missing Functionality*). Descriptive tool-tips could have helped him understand the Studio and its features better (*Problem: Missing Functionality*).

Questionnaires

The subjective ratings are presented in Figure 6.4. Looking at them, one may interpret them as follow: The uVis formula language provides good data binding, but the operators and the `Parent` concept are not intuitive enough. Further, the ratings indicate that the participant liked the immediate feedback of the *Design Panel*, the *Auto-Completion* and the *E/R Model*. In contrast, *Modes* and Error List were not appreciated.

Problem Type	No.	Question	Task 1	Task 2
Task Failure	2	How easy was it to use uVis formulas?	4	3
Medium	2	How easy was it to understand the uVis properties: Rows, Parent and Canvas.	2	4
Minor	5	How easy was it to use the uVis operators (., !, -<, -=)?	2	3
Cumbersome	1	How easy was it to bind controls to data?	4	4
Bug	2	How easy was it to use uVis Studio?	3	4
Missing Functionality	7	How useful was the Auto-Completion in the property grid?	3	5
		How useful was it to preview "live" the visualization in the Design Panel?	4	5
		How useful was it to interact with the Design Panel?	3	3
		How useful was it to see the E/R model?	5	5
		How useful was it to see the Error List window?	2	2
		How useful was to have the Modes?	N/A	3

Figure 6.4: Participant 1: Problem counts by type (left). Subjective ratings (right).

Debriefing

After the second task, I asked the participant some questions regarding uVis, the approach and the MSProVis. From his comments, the participant liked the Studio, and how he could interact, bind, and view the controls in the *Design Panel*. *Auto-Completion* was helpful, but in some cases failed to suggest correctly. He had used Prefuse [36] and D3 [14], but he had always transformed the data into a single table. The participant found it interesting and believes that it is important to allow users to access tables in a relational database. He added that accessing relational data may be challenging when it comes to join data from different tables, because of the knowledge the user should have about E/R databases. The participant said that viewing the E/R model facilitated his work, but he would have liked to see the real data as well. uVis operators and keywords such as `Parent` and `Canvas`, frustrated him and it took some effort to understand the concepts clearly.

Regarding the development process in comparison with other tools the participant has used, he said: “It is a different way of thinking, and may restrict the development as the visualization is bound to relational data. But, it is cool as well.” Also he said that “The Studio helps me see and keep the general goal. When I am programming, I go too deep in detail, and after a couple of hours I loose what I started with.”

At the end, I showed him the initial early version of MSProVis (Figure 6.3), and asked how much time it would take him to implement it in the Studio versus using other tools he knows. The participant looked at MSProVis, checked the *E/R Model*, and estimated that using other toolkits would take approximately 3 weeks, and from scratch around 5 weeks. Using the Studio he reported: “Assuming that I have all what

I need, like controls, proper errors, and a stable Studio, I think I would be able to do it in 6 hours. Also, I need to have some domain knowledge, meaning I should know what I am visualizing.”

Participant 2

Male; 23 years old; master student in Human Computer Interaction for the last 6 months; coding for the last 5 years; started using E/R databases some years ago, but does not have a strong background as he does not write his own SQLs; has barely used spreadsheet formulas in MS Excel; has not worked with visualizations, but has done work related to the Human Computer Interaction (HCI) field; has never coded a visualization.

Problem Counts

16 problems were identified with this participant and Figure 6.5 presents the number of problems of each type. Two task failures were identified. The first relates again to the complex formula for **Rows** that uses a *Group By*. The second one relates to binding a control to data that are not from the **Rows**. The participant thought that the binding was realized, but it was not. No medium problems were observed with this participant. Six minor problems relate to the operators of the formula language and the Studio. Four problems were recorded as missing functionalities (e.g. inherit Parent control properties and set a *Group By* automatically). One problem was a bug, as the system failed to delete a control. Three were cumbersome as the participant verbally commented on those, e.g. difficult to understand the error messages and the use of the control-join.

Questionnaires

The subjective ratings are shown in Figure 6.5. They indicate that the participant liked uVis Studio in general. The *Design Panel*, *E/R Model* and *Error List* seems to be useful panels. In contrast, uVis operators were hard and rated lower than others.

Problem Type	No.	Question	Task 1	Task 2
Task Failure	2	How easy was it to use uVis formulas?	4	4
Medium	0	How easy was it to understand the uVis properties: Rows, Parent and Canvas.	5	4
Minor	6	How easy was it to use the uVis operators (., !, -<, -=)?	3	3
Cumbersome	3	How easy was it to bind controls to data?	4	4
Bug	1	How easy was it to use uVis Studio?	4	4
Missing Functionality	4	How useful was the Auto-Completion in the property grid?	4	4
		How useful was it to preview "live" the visualization in the Design Panel?	4	4
		How useful was it to interact with the Design Panel?	5	4
		How useful was it to see the E/R model?	5	5
		How useful was it to see the Error List window?	5	5
		How useful was to have the Modes?	N/A	4

Figure 6.5: Participant 2: Problem counts by type (left). Subjective ratings (right).

Debriefing

The participant thinks that constructing visualizations using the uVis formulas is feasible, but prior proper training and useful documentation is required. Also, he said that “I would have liked simpler examples for explaining the Rows.” As he has been working with ActionScript, where `Parent` means `Canvas`, the participant found it difficult to understand the differences, saying: “The `Parent` is not intuitive.” The operators were not easy to understand, but he said: “Using the operators in 2-3 more cases, it would be ok for me.”

The participant liked the features of the Studio. His comments on the Studio were: “I have never seen a *Design Panel* that provides immediate feedback, that’s good. *Auto-Completion* is good as well, but in some cases failed. I like the *Interact-Mode*, you don’t need to run and compile, but a better way of showing the *Modes* is needed.” The participant thinks that the Studio helps him construct better visualizations, but more controls are needed where users have more control over them. For example, he wanted to have rounded corners in a control. Also he suggested that a more attractive design for the Studio should be considered.

Finally, I showed him the initial version of MSProVis, and asked if he would be able to construct it with the Studio and his tools, and estimate the time for both. The participant reflected and replied: “If I have a stable version of the Studio, I have used the operators a couple of times, I know the data, and know what to visualize, it would take me about an hour. I cannot estimate how much it would take to build it from scratch without using a toolkit; I do not know what toolkits exist. But, again I have never constructed visualizations, so it is hard to give precise estimates.”

Participant 3

Male; 31 years old; working as a PhD student in Computer Science for the last 7 years; has been coding for the last 12 years; started using E/R databases since 2009, but does not use it very often; started using spreadsheet formulas in MS Excel 8 years ago, but does not use them very often; took only a class on visualization, and has participated in several usability studies regarding visualizations; coded a TreeMap for his class using Piccolo.

Problem Counts

12 problems were identified with this participant and Figure 6.6 presents the number of problems of each type. Three task failures were identified; the same task failure problems encountered by participant 1 and 2. No medium problems were observed with this participant. I observed two minor problems. The first relates to the names of *Modes* and the second to the `Name` property in *Property Grid*. Three problems were recorded as missing functionalities (e.g. missing the Data-View panel to see the real data from the database). Three problems were bugs. In one of them, uVis failed to re-compute the properties properly. I observed one cumbersome problem as the participant verbally commented on the difficulty to understand the error messages.

Questionnaires

The subjective ratings are presented in Figure 6.6. They indicate that *Auto-Completion* and *Design Panel* were the most appreciated part of the tool. uVis formulas were not easy to use. *Error List* and *E/R Model* were not helpful.

Debriefing

uVis Studio supported only *top-down* approach to position controls, and the participant asked for the `Bottom` property. When I told him that currently the tool does not support it he said “I do HTML, so Top is fine.” The participant added a new property and the *Auto-Completion* helped him find the `Font` property rapidly. Also, the *Auto-Completion* assisted him to write a formula for the `Rows` property that used the join operator. His comment was: “I like this, because it shows me only what I can use.”

Problem Type	No.	Question	Task 1	Task 2
Task Failure	3	How easy was it to use uVis formulas?	2	3
Medium	0	How easy was it to understand the uVis properties: Rows, Parent and Canvas.	3	4
Minor	2	How easy was it to use the uVis operators (., !, -<, -=)?	4	4
Cumbersome	1	How easy was it to bind controls to data?	4	4
Bug	3	How easy was it to use uVis Studio?	3	3
Missing Functionality	3	How useful was the Auto-Completion in the property grid?	5	5
		How useful was it to preview "live" the visualization in the Design Panel?	5	4
		How useful was it to interact with the Design Panel?	5	5
		How useful was it to see the E/R model?	2	3
		How useful was it to see the Error List window?	2	3
		How useful was to have the Modes?	N/A	4

Figure 6.6: Participant 3: Problem counts by type (left). Subjective ratings (right).

Looking at the *Design Panel*, which provided him immediate feedback, he said: “Aha, this is nice.”

The participant looked at the visualization, and dragged and dropped all controls he needed. He renamed and positioned them referring to other control properties. Next, he looked at the E/R model and thought aloud: “Now, I have to figure out the Rows.” After completing the task the participant said: “I am still having problems understanding the Rows, but the layout is OK. This may be because of my background. I do a lot of HTML, but not SQL.”

The participant found the Studio similar to other IDEs, and believed that it helps him construct faster visualizations because: “I can see the results when I am creating it.” The *Auto-Completion* was helpful, especially when he specified the Rows. However, in a few cases he did not get any suggestions, and suggested that such minor issues should be corrected. The participant found the *WYBIWYG* feature of the *Design Panel* useful and, as the other participants, he did not disable it. Regarding the *Modes*, the participant said: “The *Interact-Mode* is helpful. The only problem that I have with the Modes is that I have to figure them out. The naming is not clear.”

The participant compared uVis with Piccolo saying that “I find it very convenient to directly map from data to the visualization. Piccolo does not have a similar concept, but it is also a more general toolkit.” He found the tool pretty powerful, as he could create a subset of the LifeLines in a short time. Furthermore, the participant believes that “uVis fills comfortably the space in the middle between MS Excel, where you can create fast simple visualizations, and the other toolkits used for more complex visualizations. I have noticed from my colleagues, who create visualizations, that first

they come up with the idea what the visualization should look like, and then look for tools to implement. So, I am curious how this tool will enable that.” According to the participant, this tool can be used by end-user developers who know SQL and can write a HTML page.

Regarding the development of the initial version of MSProVis, he said: “I cannot estimate how much time it would take to develop the visualization from scratch, as I have never done it. But, using a toolkit it would take me some weeks. While in uVis, assuming that it is stable, I think I can do it in less than a week. The only problem is that if something goes wrong, I have to know how to debug or read the errors.”

Participant 4

Female; 22 years old; graduated student in Computer Science; has been coding for the last 4 years; took a class in E/R databases in Spring 2011; has basic knowledge of MS Excel spreadsheet, but has not done something complicated; introduced to visualization area in summer 2011; coded a visualization using ActionScript in Flex, and has used Prefuse.

Problem Counts

14 problems were identified with this participant and Figure 6.7 presents the number of problems of each type. I observed one task failure when the participant was not able to specify a complex formula that used a *Group By*. No medium problems were observed with this participant. I observed five minor problems. All of them relate to the Studio (e.g. resize a control). Three problems of them were missing functionalities. For example, she would have liked to see the hierarchy of the controls. One problem was a bug as uVis Studio failed to set Parent and Canvas property automatically. I observed two cumbersome problem as the participant verbally commented on the difficulty to understand the error messages and keeping track of parent-child relationship.

Questionnaires

The subjective ratings are presented in Figure 6.7. From these ratings, one can see that the participant better liked the *Design Panel*, *Auto-completion* than *E/R model* and *Error-List*. uVis operators, data binding and *Modes* were also appreciated, but not to the same degree.

Problem Type	No.	Question	Task 1	Task 2
Task Failure	1	How easy was it to use uVis formulas?	2	3
Medium	0	How easy was it to understand the uVis properties: Rows, Parent and Canvas.	3	4
Minor	5	How easy was it to use the uVis operators (., !, -<, -=)?	4	4
Cumbersome	2	How easy was it to bind controls to data?	4	4
Bug	3	How easy was it to use uVis Studio?	3	3
Missing Functionality	3	How useful was the Auto-Completion in the property grid?	5	5
		How useful was it to preview "live" the visualization in the Design Panel?	5	4
		How useful was it to interact with the Design Panel?	5	5
		How useful was it to see the E/R model?	2	3
		How useful was it to see the Error List window?	2	3
		How useful was to have the Modes?	N/A	4

Figure 6.7: Participant 4: Problem counts by type (left). Subjective ratings (right).

Debriefing

At the end of task 1 the participant said: “I think I got how it works. But, I cannot keep track of the controls, and especially the *Parent*. I could not keep the hierarchy straight for this simple demo, and I definitely could not remember which module used what data source on top of all that. The interface automatically changes these things for you, which is great, but when I started to rename components, everything went out the window. Other than that, it was cool to see the thing I was building as I was writing the formulas.”

At the end of task 2, she said: “I never turned the data binding off, so I only imagine that the *Data-Mode* off would be helpful if you were making templates. Debugging in general seems pretty difficult, since there are so many references to this or that component. Again, showing, rather than making the user remember, the parent-child relationships would help a lot. Also, not being able to move the boxes after I specified one formula for, say, “left”, was a little clumsy.”

The participant liked the Studio and its feature. She said: “I all the time used the *Design Panel*, and it makes a difference with the immediate feedback.” She appreciated the *Interact-Mode*, but the naming and the position of the window confused her. Her comment was: “Modes make sense, but I would position the window over the *Design Panel*.”

She thinks that the uVis can assist users in developing visualizations faster, but it depends also on the type of visualization. The participant had developed a visualization that use some animations, and said: “For richer static visualizations this tool would

be better, but if you need a dynamic animation, I don't think so. I don't know how to make animations.”

The participant compared the development process she applied when she created her visualization with JavaScript with the one in the Studio. She could see similarities and reported that “I incrementally created the visualization adding JavaScript code, the more code I added the closer I got. The same applies for the Studio. I iteratively drag and drop controls and set formulas. But, with this tool I do not need to run the program.”

The participant believes this tool can be used by end-user developers to construct visualizations, saying: “I think that it would be ok for end-user developers since *Auto-Completion* tells you what you could use.”

Finally, I asked her if she could create the initial version of MSProVis using the Studio. Her comment was: “Yes, I think it will be significantly more difficult than the previous two as the debugging part is hard.” Also, keeping track of the **Parent** and the **Rows** was not easy for her, commenting that “If I could easily trace back to the **Parent** and the **Rows**, it might have helped me.” Assuming that the Studio is stable, and has the required functionalities, she could construct the visualization in approximately two hours, and one hour to make sure that everything worked fine. Finally, she added: “If I use a toolkit, it will take longer, because you are typing code, and you do not get immediate feedback. It is easier to debug, but still would be longer, but I am not sure how much.”

Participant 5

Male; 26 years old; working as a PhD student in Computer Science from 2007, has used E/R databases since 2004; has used spreadsheet formulas for the last 9 years; has been researching the visualization field since 2008; first uses Spotfire to construct a visualization, and if it is not possible he would code it.

Problem Counts

10 problems were identified with this participant and Figure 6.8 presents the number of problems of each type. I observed one task failure. The participant was not able to specify a complex formula that used a *Group By*. One medium problem was observed

Problem Type	No.	Question	Task 1	Task 2
Task Failure	1	How easy was it to use uVis formulas?	4	1
Medium	1	How easy was it to understand the uVis properties: Rows, Parent and Canvas.	4	3
Minor	4	How easy was it to use the uVis operators (., !, -<, -=)?	5	2
Cumbersome	1	How easy was it to bind controls to data?	2	1
Bug	2	How easy was it to use uVis Studio?	3	2
Missing Functionality	1	How useful was the Auto-Completion in the property grid?	5	5
		How useful was it to preview "live" the visualization in the Design Panel?	5	5
		How useful was it to interact with the Design Panel?	3	5
		How useful was it to see the E/R model?	5	5
		How useful was it to see the Error List window?	1	4
		How useful was to have the Modes?	N/A	5

Figure 6.8: Participant 5: Problem counts by type (left). Subjective ratings (right).

with this participant. After several attempts, the participant specified the correct formulas for the Rows. I observed four minor problems that relate to uVis operators and the Studio (e.g. names of *Modes*). One problem was missing functionality, which relate to missing details in the *Design Panel*. Two problems were bugs. The first was caused by the uVis kernel, which did not align controls properly. The second relates to *Auto-Completion*, which failed to provide suggestions. I observed one cumbersome problem as the participant verbally commented on the difficulty to understand the error messages.

Questionnaires

The subjective ratings are presented in Figure 6.8. The participant seems to like the Studio panels better than the formula concepts and operators. The *Design Panel* and *Auto-Completion* were appreciated more than others.

Debriefing

The participant compared uVis with Spotfire [97] saying that you can create similar visualization, like the LifeLines, but it will not look as good as in uVis. Also, he added that in Spotfire you are limited to implement and test interaction technologies and create custom visualizations.

The Studio reminds him of visual GUI software, and appreciated the *WYBIWYG* feature. He said: “It is cool. You don’t have to compile it, or do anything. It makes the development easier.” However, he added that the feedback could have been better when it comes to how many controls are generated, hidden, and what is not working.

Once, when he was specifying the formulas for the bar, he removed the value in the Width property. Automatically, uVis set the width to the default value, but this was not shown in the property-grid. This confused the participant saying: “Why does it not tell me that the value is set to default?” The participant also liked the *Interact-Mode* and commented: “The *Interact-Mode* was helpful as well, and I would like a keyboard shortcut for that.”

The participant thinks the Studio helps in constructing visualizations faster, but not sure what the limitations in this tool are. His comment was: “definitely it’s better than writing code, but there may be visualizations that might not be possible to implement, for example animations.” Regarding the end-user developers, his opinion was that the Studio can support end-user developers construct visualizations, but it needs better errors and warnings for the hidden instances. He stated: “Showing errors better and adding warnings that there are hidden instances, would make it easier.”

Regarding the development of the initial version of MSProVis, the participant said: “If everything works as it should, I would create it in one hour.” The participant has good knowledge of Spotfire, and commented: “Spotfire is my de-facto tool. For the people in the lab I am the expert.” He would create something similar using bar charts and stack-chart, as the following quote illustrates: “It would be three bar charts, and another view using the stack chart. But, it would not be the same.” Looking at the *E/R model* of the visualization, he commented: “to create a visualization using several tables in Spotfire, would not be easy. You can setup linking with tables but it becomes too complicated, and it is not like a relational database. It would not be as flexible as with the Studio.” Finally, he estimated that coding this visualization, would take him at least two weeks.

Participant 6

Male, 24 years old; PhD student in Computer Science for the last one and a half years; has been coding since 2006; started using E/R databases 1 year ago; has been using spreadsheet formulas in MS Excel; worked with visualization for 3 months while he took a class for his studies; created a visualization for his class project using JavaScript and D3 [14].

Problem Type	No.	Question	Task 1	Task 2
Task Failure	3	How easy was it to use uVis formulas?	3	2
Medium	1	How easy was it to understand the uVis properties: Rows, Parent and Canvas.	2	2
Minor	2	How easy was it to use the uVis operators (., !, -<, -=)?	4	2
Cumbersome	4	How easy was it to bind controls to data?	2	2
Bug	1	How easy was it to use uVis Studio?	3	3
Missing Functionality	1	How useful was the Auto-Completion in the property grid?	4	4
		How useful was it to preview "live" the visualization in the Design Panel?	3	4
		How useful was it to interact with the Design Panel?	4	4
		How useful was it to see the E/R model?	4	4
		How useful was it to see the Error List window?	5	4
		How useful was to have the Modes?	N/A	4

Figure 6.9: Participant 6: Problem counts by type (left). Subjective ratings (right).

Problem Counts

12 problems were identified with this participant and Figure 6.9 presents the number of problems of each type. Three task failures were identified; the same task failure problems encountered by participant 3. One medium problem was observed with this participant, which relates to specifying a *Rows* formula. I observed two minor problems. The first relates to the names of *Modes* and the second to the top-down approach of uVis Studio. One problem was recorded as missing functionality. The participant asked for a debugging feature. I observed a bug when *Auto-Completion* failed to provide suggestions. Four cumbersome problems were recorded and they were: refer to a control, the control-join operator, error messages content, and keeping track of Parent.

Questionnaires

The subjective ratings are presented in Figure 6.9. From these ratings, one can see that the participant found difficult to bind control to data. uVis formula concepts were less appreciated than uVis Studio.

Debriefing

The participant has been using Eclipse, but he prefers the *Design Panel* in uVis Studio. His comment was: “It is nice to see what I am making.” Regarding the *Interact-Mode*, he said that in more complicated cases it would be helpful, but in these small tasks, he could not really appreciate the feature. He added: “The E/R model helped me a lot in specifying the *Rows*, but still I have to think. It is difficult to handle databases for everyone, especially the joins.”

The Studio can help him make visualizations faster, but for standard ones such as a bar chart, he would use MS Excel. The participant commented on the D3 tool saying: “D3 is more for something from scratch, it is different from uVis.”

He believed that end-user developers can use uVis, and he thinks that the syntax is just a matter of time. Further, he commented: “the challenging part is the database. So, I think they should know some SQL.”

I asked the participant if he would be able to create the initial version of MSProVis with uVis Studio. His comment was: “considering that I know what I am visualizing, and I have the tool working, I think so, but I cannot estimate. Using other tools? I don’t know if there are any tools that would help me, but for sure I would search the web first.”

6.3 Summary

In this study, six programmers, who are not professionals, were asked to use uVis and create a bar chart and a simplified LifeLines. The results of this study shows that programmers can use uVis Studio and create faster custom visualizations with the *Drag-Drop-Set-View-Interact* approach. From my observations and their comments uVis Studio support better the development of custom visualizations than other tools because they interact with visual object and not code, and view immediate results as they progress.

Participants looked at the initial version of MSProVis and except for participant 6, they estimated the time it would had taken them to construct the visualization with the Studio versus other tools. Using other tools, they would have spent 2-3 weeks on average. While, using a mature version of uVis Studio, their estimations varied from one hour to less than a week. Although this has to be proven, it still indicates the perceived power of uVis formulas and the Studio. As some of them also said, some custom visualizations may not be possible to implement with the current version.

Below, I summarize the usability problems and the subjective ratings from the questionnaires. I conclude with a summary of my observations on the uVis formula language and uVis Studio.

Usability Problems

The participants constructed the visualizations and I assisted them whenever they were not able to complete a step or the system failed. Whenever I had to interfere, I recorded it as a usability problem and classified it. This version of uVis Studio corresponded to a functional prototype that failed several times. Although I followed the same procedure with each participant, some usability problems might have been caused by variations in my presentation.

I group the usability problems in two categories: those caused by the uVis Formula Language and those caused by uVis Studio. Table 6.1 shows a summary of the problems identified in this usability study. 38 different usability problems were identified. Some problems (e.g. specify a formula that used a *Group By* for the **Rows** property) were encountered by all participants, other problems (13 in total) by one (e.g. resize a control). Several problems were caused by uVis kernel bugs. For example, after specifying the *control-join* operator the kernel did not compile the formulas correctly and no error messages were shown in the *Error List* panel. As a result the participants had to close and re-open the visualization. Another bug was related with the algorithm that the *Auto-Completion* used. Some of the suggestions for improvement, which I implemented in the second version of the Studio are:

- A new feature that allows users to set properties from the *E/R Model*.
- A new panel that shows the control and data hierarchy.
- A new panel that shows the row-data from the tables. Also, it shows the data bound to a control, once the user selects a control.
- Improved user interface.
- Improved presentation and algorithm of the *Auto-Completion*.
- Improved interaction with the *Design Panel*.
- Improved presentation of the *E/R Model*.
- Improved error messages in the Error-List.
- Improved presentation of the *Modes*.

6.3 Summary

Area	Problem Type	Description	Participant	Possible Solutions	
uVis Formula language	Task Failure	The <i>Parent</i> and the <i>Canvas</i> concept	1,3,6	Better training. Investigating for solutions.	
	Minor	The <i>Dot</i> and the <i>Bang</i> difference	2,5	Improve the uVis Kernel, so it finds out which operator should be used, and automatically corrects the formula. Better training.	
	Minor	The use of double quotes	2	Better training	
	Medium	Specify a simple Rows formula	1,5,6	Introduce formula suggestions in the E/R model, and allow users to set a property from the E/R model.	
	Task Failure	Specify a complex Rows formula that uses group by	1,2,3,4,5,6	Introduce formula suggestions in the E/R model, and allow the user to set a property from the E/R model.	
	Cumbersome *, Medium **	The use of the Control-Join (-=) operator	2*, 6 *, 1**	Better training	
	Cumbersome	The use of the horizontal position function	2,6	Better training	
	Bug	Failed to align controls horizontally	3,4,5	Improve uVis kernel	
	Missing Functionality	Transfer the parent control's properties to a child control	2	Improve uVis kernel	
	Missing Functionality	Use <i>This</i> keyword instead of <i>Me</i>	2	Better training, and may be introduce <i>This</i> in uVis formula language	
	Cumbersome	Refer to a control property	2,6	Better training	
	Bug	Delete a control from the form	1,2	Improve uVis kernel	
	uVis Studio	Missing Functionality	Use the CSS paradigm for positioning controls	1,4	Implement the CSS paradigm
		Minor	Use the top-down approach to position controls	1,2,6	Improve uVis kernel and the Studio. Allow users to set the Bottom and Right property as well.
		Missing Functionality	Missing details in the Design Panel	1,5	Improve the Design Panel. Add tooltips that will show more information can solve this problem.
Missing Functionality		The position of a control when the position is set to a formula	1,3,4	A new algorithm that will check the references in the formulas, and allow users to move a control.	
Minor		Auto-Completion hides the suggestion that match the typed word.	1, 5	Change the algorithm of the Auto-Completion.	
Bug		In a few cases the Auto-Completion did not suggested anything	1,2,3,4,5,6	Improve the algorithm of the Auto-Completion.	
Minor		Double-click on an error in the Error-List	4	Automatically highlight incorrect formulas in the Property-Grid.	
Cumbersome		Understand the error-messages	1,2,3,4,5,6	Better error descriptions	
Missing Functionality		Debugging feature in the Studio	1,3,4,6	New panel in the Studio	
Missing Functionality		Control-Data Hierarchy window to show the Parent and Canvas hierarchy of controls	1,4	New panel in the Studio	
Minor		The combo-box in the Property Grid	1,4	The Control-Data Hierarchy window may solve this problem.	
Cumbersome		Keep track of parent-child relationship	4,6	The Control-Data Hierarchy window may solve this problem.	
Minor		The position of the Modes window in the Studio	1,4	Re-design the layout using a slider, and place it to top.	
Minor		Names of the modes in the Modes window	1,2,3,4,5,6	Re-design the layout using a slider, and place it to top.	
Minor		Setting automatically the Left property to <i>Index*2</i> was not enough to see that there were several controls	2	Set automatically the Left property to <i>index*5</i>	
Missing Functionality		Set the <i>Group By</i> automatically	2	May be group by primary keys from the E/R model using the formula suggestion feature. uVis Set <i>Refresh()</i> as default property when the control is created.	
Minor		Add <i>Refresh()</i> by default to the Timescale	2	Better training	
Minor		<i>Name</i> and <i>Text</i> in the Property were ambiguous	3	Better training	
Missing Functionality		Data-View window to show the row-data from the database	1,3	New panel in the Studio	
Bug		Some cases the Studio failed to set <i>Parent</i> and <i>Canvas</i> automatically	3,4	Improve the algorithm that sets the Parent and Canvas automatically in the Studio	
Minor		Find a control in the Toolbox	4	Add icons in for each control in the Toolbox	
Minor		Resize a control	4	Increase the offset when the user mouse-over and clicks on the borders of a control.	
Minor		<i>TAB-Key</i> to confirm a formula change in the Property Grid	5	Use the <i>TAB-Key</i> , and consider other cases based on other development environments	
Minor		Show default values of a property when the property is empty	5	Introduce a new column in the Property-Grid that shows the values.	
Task Failure		Bind controls to data not from the Rows property	2,3,6	Better training. The formula suggestion in the E/R model may help.	
Missing Functionality		Missing tooltips in the Studio	1	Add tooltips for all the panels, also for the suggestions in the Auto-Completion list.	

Table 6.1: Usability problems encountered in this study. They are grouped by root problem, and classified by type. For each problem I show who encountered it and potential solutions.

- Icons for controls in the *Toolbox*.
- Descriptive tool-tips in the Studio.

Some problems need more investigation to identify a good solution and implement it.

Questionnaires

After each task, participants were asked to fill a questionnaire. Figure 6.10 show the ratings for task 1 and 2, and the minimum, maximum and average ratings of each task. Note that in the first questionnaire they were not asked about the *Interact-Mode*, because they did not use the feature. Although the sample is small, the average values confirm my observations and their comments during the usability study and the interview. The ratings shows that features of the Studio (*WYBIWYG*, *Interact-Mode* and *Auto-Completion*) were useful to all of them. The uVis formula language was rated lower as some of them had difficulties understanding it.

uVis Formula Language

Participants could easily specify simple formulas that bind controls to data and map properties to table fields. In complicated cases, they were more skeptical on how to specify a formula that uses the special uVis operator ($-<$). Some of them solved the confusion by referring to the *E/R Model* and using *Auto-Completion*. This study showed that in order to use uVis Studio, users need to have some database knowledge, and understand SQL concepts such as: joining tables, *Group By*, etc. All of them appreciated the simplicity of the control-join operator. One of them looked at the operator and managed to figure out the algorithm. The others were more skeptical and I had to explain the operator.

Parent refers to another control so that the formulas can use its data row. **Canvas** means that the control is attached to the **Canvas** control and scrolls with it. These were not easily understood by the participants. Two of the participants suggested that a new panel that presents the **Parent** and **Canvas** hierarchy could improve understandability. This window would help them distinguish which controls were bound to what data, and which control contained what controls. Furthermore, improving the functionalities that automatically sets the **Parent** and **Canvas** property may reduce the confusion.

Question	Participant 1		Participant 2		Participant 3		Participant 4		Participant 5		Participant 6		Average	
	Task 1	Task 2	Task 1	Task 2	Task 1	Task 2	Task 1	Task 2	Task 1	Task 2	Task 1	Task 2	Task 1	Task 2
How easy was it to use uVis formulas?	4	3	4	4	4	4	2	3	4	1	3	2	3.5	2.8
How easy was it to understand the uVis properties: Rows, Parent and Canvas.	2	4	5	4	4	4	3	4	4	3	2	2	3.3	3.5
How easy was it to use the uVis operators (., !, <, ->)?	2	3	3	3	5	4	4	4	5	2	4	2	3.8	3.0
How easy was it to bind controls to data?	4	4	4	4	3	5	4	4	2	1	2	2	3.2	3.3
How easy was it to use uVis Studio?	3	4	4	4	4	4	3	3	3	2	3	3	3.3	3.3
How useful was the Auto-Completion in the property grid?	3	5	4	4	5	4	5	5	5	5	4	4	4.3	4.5
How useful was it to preview the live version of the visualization in the Design Panel?	4	5	4	4	5	5	5	4	5	5	3	4	4.3	4.5
How useful was it to interact with the Design Panel?	3	3	5	4	5	4	5	5	3	5	4	4	4.2	4.2
How useful was it to see the E/R model?	5	5	5	5	5	5	2	3	5	5	4	4	4.3	4.5
How useful was it to see the Error List window?	2	2	5	5	4	2	2	3	1	4	5	4	3.2	3.3
How useful was it to have the Interact-Mode?	N/A	3	N/A	4	N/A	4	N/A	4	N/A	5	N/A	4	N/A	4

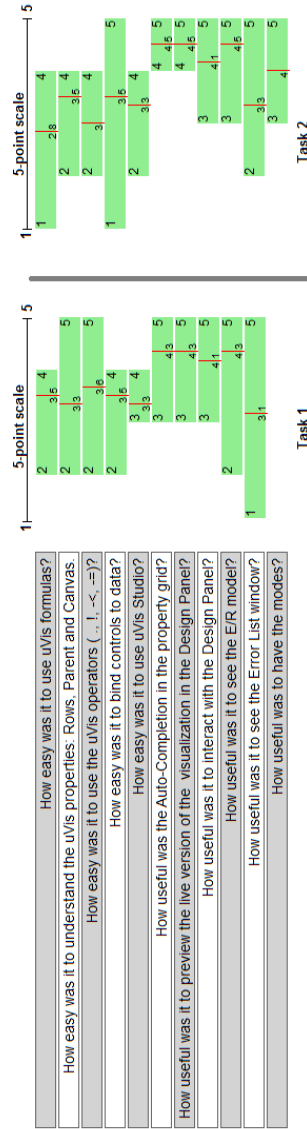


Figure 6.10: Participants' rating for Task 1 and 2 (top). Minimum, Maximum and Average rating for Task 1 and 2 (bottom).

Referring to control properties was easier. They could rapidly write the formulas using the **bang** and **dot** operator. One of them used the **dot** operator all the time, while another used only the **bang**. In both cases, uVis compiled the formulas correctly, but the participant had not clearly understood the difference. Making uVis correct the formula to **bang** or **dot**, might help.

uVis Studio - Features

What-You-Bind-Is-What-You-Get: All participants found the *WYBIWYG* feature of the *Design Panel* useful. They could drag-drop controls, bind them to data and get immediate feedback on the screen. From the observations and their comments, I can say that all participants were looking at the *Design Panel* while they changed formulas. Further, they had the possibility to turn this feature off but none of them did. This confirms that they found it useful. Some of the participants asked for more detailed information in the *Design Panel* (e.g. warning the user in case of hidden controls) and being able to move controls after they had specified a formula for their position.

Auto-Completion: From the observations and the participant's comments, the *Auto-Completion* assisted them in most of the cases. They appreciated the fact that it was showing what can follow, and this ensured them that they were writing the correct formula. The *Auto-Completion* reduced the cognitive effort participants had to remember the syntax. However, in some cases the *Auto-Completion* failed (e.g. no suggestions after a control function). Further, one participant suggested that introducing tool-tips on mouse over, could provide them a better explanation of the suggestions.

The *Interact-Mode*: Participants liked the *Interact-Mode* feature, although it was only used in the second task because of the simplicity of task 1. They were confused as the names (*InteractionView* and *DataView* at that time) were misleading. The names in the *Modes* should explicitly describe the states. One of them suggested using a slider rather than a checkbox, to improve understandability. Two of them suggested placing the *Modes* over the *Design Panel* to improve visibility.

uVis Studio - Coordinated Panels

The panels allowed them to view information from different perspectives. Changes in the *Property Grid* were immediately reflected in the *Design Panel*, and viewing the *E/R Model* helped them specify the formulas. They could identify the relationships, and

the *Auto-Completion* confirmed their assumptions. Two participants suggested that viewing the data in the database, would ensure them that the visualization showed the correct data. The *Error List* panel was less helpful than the other panels, because all participants found some of the errors hard to understand, and asked for better error messages. However, they appreciated the fact that they could select an error and see the wrong formula colored in red. In this usability study, the *Toolbox* contained a number of controls that allowed them to carry out the tasks. However, they commented that they might need more controls. Also, one participant suggested that small icons in the *Toolbox* would have helped her in locating the controls faster.

Chapter 7

Usability Study with End-User Developers

This chapter presents a usability study with eight end-user developers. No participant had prior knowledge of the uVis formulas or the Studio. The second version of uVis Studio was used in this study. The purpose of this usability study was to investigate if end-user developers can construct custom visualizations with the *Drag-Drop-set-View-Interact* approach. In addition, it aimed at identifying usability problems and providing suggestions for further improvement.

7.1 Procedure and Tasks

Each usability test was conducted in three hours and consisted of two tasks: construct a bar-chart following a video and construct the PCD. I conducted the study, kept notes, and used a recording tool for the sessions. The study was conducted at the IT University of Copenhagen, using a laptop connected to an external monitor. To avoid effects that might have been introduced through variations of the oral presentation, I decided to explain the uVis formula language and the Studio through a video. I used the same problem classification as in Chapter 6. I assisted the participant whenever there were misinterpretations, confusions or malfunctions of the system. Whenever I assisted them, I recorded it as a usability problem. The documentation used in this study is presented in Appendix C.

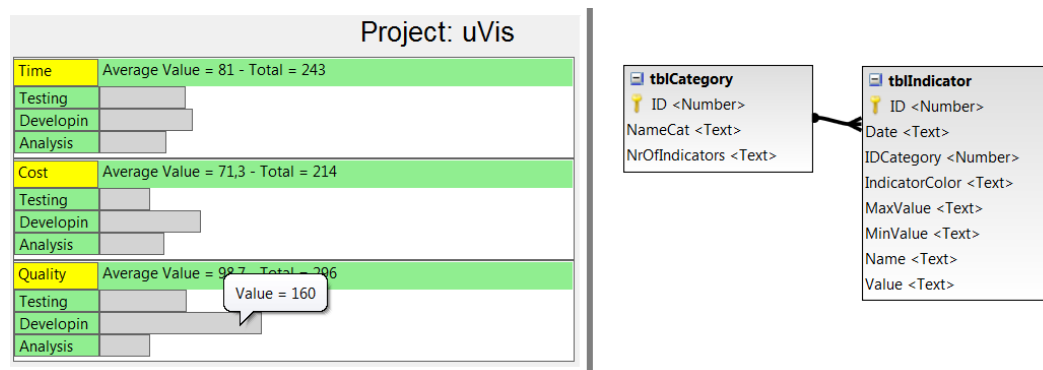


Figure 7.1: The bar-chart and the E/R data model.

Task 1: Construct a Bar-Chart

This task lasted no more than one and a half hours. In the first 20 minutes, I asked some background questions, briefly explained the participant the uVis formula language through the reference card, and showed the uVis Studio on paper.

Next, the participant followed a video (played on the laptop screen) and replicated the steps in the uVis Studio (opened in the monitor). The video showed step-by-step how to create the bar-chart shown in Figure 7.1. The video was 10 minutes long. It had no audio, but several call-outs to explain how to use the uVis formula and the Studio. More explicitly the call-outs explained: how to bind control to data, how to refer to properties, how to map a field to a property, where to view data, properties and the hierarchy, where to find the error messages, etc. The participant was informed from the beginning that he was allowed to stop the video, play it backwards and forwards.

I encouraged the participant to carry out the task in a think-aloud manner. At the end of this task, I asked the participant 20 questions regarding the uVis Formula, the uVis Studio and the uVis approach. 19 of them were questions on a 5-point Likert scale. Two of them were optional because the questions were related to the visualization development model, and the participant might not have the required knowledge to answer. The last question was about suggestions for improvement.

The goal of this task was to introduce the uVis formula language and the Studio with a video, identify usability problems and gather feedback.

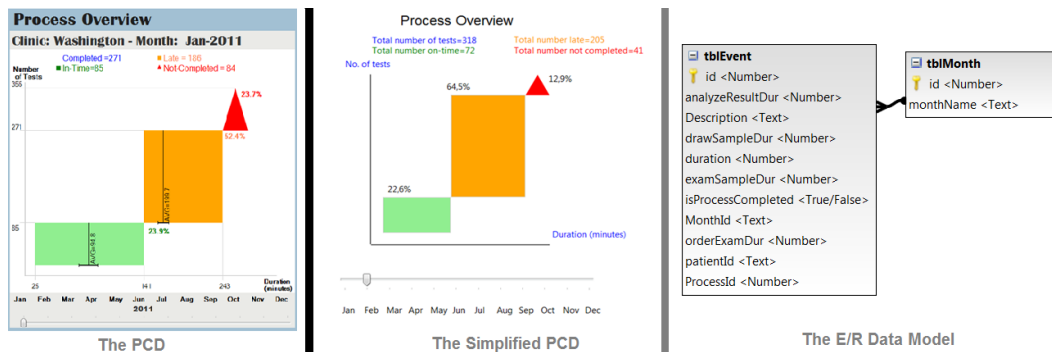


Figure 7.2: The PCD, the simplified PCD used in this study, and the E/R Data Model.

Task 2: Construct the Process Completion Diagram

I presented the Process Completion Diagram (PCD) using a scenario from the medical domain and explained how the event-log data are visualized. The participant was asked to create a simplified PCD. The simplified PCD (Figure 7.2) did not show the horizontal and vertical lines in the X-axis and the Y-axis, the average and the standard deviation. However, the steps involved in constructing the simplified PCD are representative ones (e.g. drag and drop control, refer to a property, bind a control to data, map a field to a property, view immediate feedback, check errors, try as an end-user, etc.) The participant would have been able to enrich it with the missing details, but I decided to use this version due to time constraints. The entire usability test was limited to three hours. The participant was asked to create the PCD thinking aloud.

The uVis formula language reference card, a reference card where the visualization was showed without any formulas, and some hints in a second page were given to the participant. The hint page showed them how to write a complex `Rows` formula with a `Group By`, how to use SQL aggregates (`Count()`, `Max()`, `Min()`), how to convert a `String` type to `Integer` type, and described the `Requery()` function. In addition, I gave the participant another reference card with the Studio shortcuts. The participant had one hour and 30 minutes to finish this task. At the end, the participant answered the same questionnaire as in task 1.

7.2 Results

This section presents the results of this study. For each participant I describe his/her background, report the number of problems categorized by type, subjective ratings, and summarize participants comments about the tool. I conclude this chapter with a summary of the results.

Participant 1

Male; 25 years old; holds a bachelor's degree in Economics and works as a project economist; has never developed a program by himself, but is able to read and edit Visual Basic code (last time was four months ago); has a good knowledge of E/R databases because in his previous work he was a database analyst, but as he said he is not an expert; has never used a development environment; used MS Excel spreadsheets a week ago; has never programmed a visualization, but has created standard visualizations with MS Excel.

Problem Counts

The first task was performed in 40 minutes and the second in one hour and 5 minutes. Figure 7.3 presents the number of problems of each type. In total, 11 problems were identified with this participant. Two of them were task failures: specifying a **Rows** formula that used a *Group By* and not noticing errors in *Error List*. No minor and medium problems were observed with this participant. Five bugs were observed (e.g. the **Rows** formula was not evaluated correctly). Two missing functionality were related with uVis Studio. The first relates to more drag-and-drop actions. The second has to do with moving a control when a formula is set for **Left** or **Top**. Two were cumbersome problems as the participant verbally commented on those: better error messages and specifying **Top** instead of **Bottom**.

Questionnaires

The subjective ratings are presented in Figure 7.3. These figures indicate that the participant found difficult the uVis formula language and appreciated better the Studio. *Auto-Completion*, interacting with the *Design Panel*, *Error List* and testing the

Problem Type	No.	Question	Task 1	Task 2
Task Failure	2	How easy was it to use uVis formulas?	3	2
Minor	0	How easy was it to understand uVis properties: Rows, Parent and Canvas.	3	4
Medium	0	How easy was it to use uVis operators (., !, -	4	3
Cumbersome	2	How easy was it to connect controls with data?	2	4
Bug	5	How easy was it to use uVis Studio?	3	4
Missing Functionality	2	How useful was the Auto-Completion in the property grid?	4	5
		How useful was it to preview the live version of the visualization in the Design Panel?	3	2
		How useful was it to interact with the Design Panel?	3	5
		How useful was it to have the Interact-Mode?	3	4
		How easy was it to use test the application as an end-user?	5	5
		How useful was it to see the E/R model?	3	2
		How useful was it to set formulas from the E/R model?	2	2
		How useful was it to see the Error List window?	5	4
		Were the errors understandable in the Error List?	4	5
		How useful was it to see the real row-data in the window Data View?	4	3
		How useful was it to see the controls in the window Control and Data Hierarchy?	4	4
		How much the formula language does facilitate visualization development?*	3	4
		How much the development environment does facilitate visualization development?*	3	5
		Do you think you could use uVis in your domain and create visualizations?	3	4

Figure 7.3: Participant 1: Problem counts by type (left). Subjective ratings (right).

application as an end-user are some of the most rated aspects of uVis. While, other features were found not less useful (e.g. *E/R Model*, setting the formulas from *E/R Model*, *DataView*, uVis operators).

Debriefing

At the end of the study he commented: “It will be really easy to create visualizations with this tool, but users need some IT and database knowledge. It makes sense why you asked for end-user developers. The formula language seems very dynamic. I would be able to use it more effectively but I need some practice. This is an easy way to show data, and MS Excel has some limitations. I had also difficulties with Excel although they try to make it very user-friendly.”

Participant 2

Female; 26 years old; graduated student in Communication and Informatics; currently enrolled in the master’s programme “Innovative Communication Technologies and Entrepreneurship” at the Aalborg University; has never programmed; worked once with E/R databases during her bachelor’s studies, six years ago; has used Eclipse 2-3 times, and last time was a month ago; has used MS Excel spreadsheets, but not extensively; has never programmed a visualization or created a visualization.

Problem Type	No.	Question	Task 1	Task 2
Task Failure	11	How easy was it to use uVis formulas?	5	4
Minor	2	How easy was it to understand uVis properties: Rows, Parent and Canvas.	4	4
Medium	2	How easy was it to use uVis operators (.. !, -	2	4
Cumbersome	2	How easy was it to connect controls with data?	5	4
Bug	5	How easy was it to use uVis Studio?	4	4
Missing Functionality	4	How useful was the Auto-Completion in the property grid?	4	5
		How useful was it to preview the live version of the visualization in the Design Panel?	4	4
		How useful was it to interact with the Design Panel?	4	4
		How useful was it to have the Interact-Mode?	4	5
		How easy was it to use test the application as an end-user?	4	5
		How useful was it to see the E/R model?	5	4
		How useful was it to set formulas from the E/R model?	5	4
		How useful was it to see the Error List window?	5	5
		Were the errors understandable in the Error List?	5	4
		How useful was it to see the real row-data in the window Data View?	4	5
		How useful was it to see the controls in the window Control and Data Hierarchy?	4	5
		How much the formula language does facilitate visualization development?*	4	4
		How much the development environment does facilitate visualization development?*	4	4
		Do you think you could use uVis in your domain and create visualizations?	5	4

Figure 7.4: Participant 2: Problem counts by type (left). Subjective ratings (right).

Problem Counts

The participant finished the first task in 50 minutes. The second task was performed in one hour and 20 minutes. She faced several problems with data binding and referring to control properties. My conclusion is that the participant had IT skills that correspond to a simple user and not end-user developer.

Figure 7.4 presents the number of problems of each type. In total, 26 problems were identified with this participant. 11 problems were task failure; they relate to data binding, **Parent** concept and not noticing the errors in the *Error List*. Two minor and two medium problems were observed and they relate to uVis formulas. Five bugs were observed (e.g. the **Rows** formula was not evaluated correctly). Four were missing functionality problems related with uVis formulas (e.g. using an SQL aggregate in **Rows**) and the Studio (e.g. moving a control when a formula is set for **Left** or **Top**). Two were cumbersome problems as the participant verbally commented on those: better error messages and specifying **Top** instead of **Bottom**.

Questionnaires

The subjective ratings are presented in Figure 7.4. One can notice that the ratings show a high level of appreciation, but they do not match participant's experience as I continuously helped her. This is also reflected in the below debriefing.

Debriefing

At the end of the usability test, the participant said: “I think I need more practice and database knowledge. The formulas were not easy to write, but I think the Studio helps you, especially the *Design Panel*.”

Participant 3

Female; 32 years old; holds a master’s degree in Communication and Informatics; currently is a PhD student at the Roskilde University investigating healthcare and IT; has programmed only during some courses in 2005; used E/R databases during her studies, and briefly in 2010 when she was working as business developer in a Danish bank; has used Dreamweaver to create a website in 2005; has good knowledge of MS Excel spreadsheets and used it 2 days ago; has never programmed a visualization but she has used MS Excel to create standard ones.

Problem Counts

The participant completed the first task in 45 minutes. The second task lasted one hour and 10 minutes. Figure 7.5 presents the number of problems of each type. In total, 15 problems were identified with this participant. Three of them were task failures. One of them relates to distinguishing the selected control by means of color. Two minor problems were recorded and they relate to the uVis formulas language. No medium problems were observed. Five problems were bugs (e.g. the uVis kernel failed to compute **Bottom**). Three were missing functionality problems: show always the control in the *Design Panel*, move a control when control position is set to formula, and move only one control instance. Two were cumbersome problems as the participant verbally commented on those: better error messages and specifying **Top** instead of **Bottom**.

Questionnaires

The subjective ratings are presented in Figure 7.5. From the ratings, it seems that the participant found difficult to understand the error messages and not helpful the *Error List*. Connecting to data using uVis operators, *Design Panel*, *Auto-Completion* and *Data-View* were appreciated more than others (e.g. *DataView*).

Problem Type	No.	Question	Task 1	Task 2
Task Failure	3	How easy was it to use uVis formulas?	5	4
Minor	2	How easy was it to understand uVis properties: Rows, Parent and Canvas.	5	5
Medium	0	How easy was it to use uVis operators (., !, -	4	4
Cumbersome	2	How easy was it to connect controls with data?	5	5
Bug	5	How easy was it to use uVis Studio?	4	4
Missing Functionality	3	How useful was the Auto-Completion in the property grid?	4	4
		How useful was it to preview the live version of the visualization in the Design Panel?	5	5
		How useful was it to interact with the Design Panel?	4	5
		How useful was it to have the Interact-Mode?	4	5
		How easy was it to use test the application as an end-user?	4	4
		How useful was it to see the E/R model?	5	5
		How useful was it to set formulas from the E/R model?	4	4
		How useful was it to see the Error List window?	2	3
		Were the errors understandable in the Error List?	4	1
		How useful was it to see the real row-data in the window Data View?	5	5
		How useful was it to see the controls in the window Control and Data Hierarchy?	5	4
		How much the formula language does facilitate visualization development?*	4	4
		How much the development environment does facilitate visualization development?*	4	4
		Do you think you could use uVis in your domain and create visualizations?	5	4

Figure 7.5: Participant 3: Problem counts by type (left). Subjective ratings (right).

Debriefing

At the end of the usability test, the participant said: “ It was a long time since I worked with databases. I had to do many things at the same time: recover my knowledge, figure out the panels and how to use the tool, focus on the video and relate the video to what I know. To find the right balance of the formula language is probably a delicate matter, but using the software for the first time was a bit too technical. If I had some more practice, things would have been better. With the second task it got a bit easier. It was fun but also challenging.”

Participant 4

Female; 28 years old; holds a master’s degree in Software Engineering and Management; working as a researcher in a Danish bank; has developed an MS Access program in 2005, and has edited code during her studies before 2008; has an understanding of E/R databases but has not used a database since 2008; used Visual Studio but not extensively during her studies; used MS Excel spreadsheets in 2009; has never programmed a visualization, but has created standard visualizations with MS Excel.

Problem Type	No.	Question	Task 1	Task 2
Task Failure	3	How easy was it to use uVis formulas?	4	3
Minor	2	How easy was it to understand uVis properties: Rows, Parent and Canvas.	4	3
Medium	0	How easy was it to use uVis operators (., !, -	5	5
Cumbersome	2	How easy was it to connect controls with data?	5	3
Bug	6	How easy was it to use uVis Studio?	4	4
Missing Functionality	6	How useful was the Auto-Completion in the property grid?	5	5
		How useful was it to preview the live version of the visualization in the Design Panel?	5	5
		How useful was it to interact with the Design Panel?	5	5
		How useful was it to have the Interact-Mode?	5	5
		How easy was it to use test the application as an end-user?	5	5
		How useful was it to see the E/R model?	5	5
		How useful was it to set formulas from the E/R model?	5	5
		How useful was it to see the Error List window?	5	4
		Were the errors understandable in the Error List?	5	5
		How useful was it to see the real row-data in the window Data View?	4	5
		How useful was it to see the controls in the window Control and Data Hierarchy?	5	5
		How much the formula language does facilitate visualization development?*	4	5
		How much the development environment does facilitate visualization development?*	5	5
		Do you think you could use uVis in your domain and create visualizations?	5	5

Figure 7.6: Participant 4: Problem counts by type (left). Subjective ratings (right).

Problem Counts

The participant completed the first task in 40 minutes. The second task lasted one hour and 5 minutes. Figure 7.6 presents the number of problems of each type. In total, 19 problems were identified with this participant. Three problems were task failures: using a *Group By*, not noticing the errors in Error List, and specifying a SQL aggregate. Two minor problems were recorded and they relate to the uVis Studio. No medium problems were observed. Six problems were bugs. One of the six bugs was caused by *Property Grid*. The formula was not updated properly and the participant had to confirm a change by pressing **Enter**. Six were missing functionality problems. The participant would have preferred to set properties from the *Control-Data Hierarchy* panel, move controls after setting the position of a control, etc. Two were cumbersome problems as the participant verbally commented on those: better error messages and specifying **Top** instead of **Bottom**.

Questionnaires

The subjective ratings are presented in Figure 7.6. The ratings indicate that the participant found the Studio better than the formula language. The *Design Panel*, *Auto-Completion*, *E/R Model* and *Control-Data Hierarchy* were appreciated more than uVis operators.

Debriefing

At the end of task 1 the participant commented: “It reminds me of Gemini, a tool I used in the bank in 2008. I was basically using the toolbox and property grid, but there were no *E/R Model* and *DataView*. This made my work difficult.” After finishing the second task she added: “the system is easy to use, but you need some practice. Constructing visualizations is difficult, because you should know the domain data, have a good knowledge of databases as well. I liked the panels, the drag and drop, and viewing the changes in the *Design Panel*. At some point, when I set a wrong formula for the **Rows**, the box disappeared, it should always be there. The *Auto-Completion* feature was a bit slow in some cases.”

Participant 5

Female; 24 years old; holds a bachelor’s degree in Information Technology; currently is enrolled in the master’s programme “Game Design” at the IT University of Copenhagen; has programmed only during some courses, and she did more editing than programming six months ago; used the SQL server three years ago during a bachelor course; has used Visual Studio, last time three years ago; has not used MS Excel spreadsheets since 2009, and at that time did simple and basic things; has never programmed a visualization but used SPSS to create standard one.

Problem Counts

The participant finished the first task in 45 minutes. The second task lasted one hour and 10 minutes. Figure 7.7 presents the number of problems of each type. In total, 21 problems were identified with this participant. Eight of them were task failure: mapping a field to a property, specifying interactions with `refresh()`, using a SQL aggregate, not noticing the error messages, etc. Three minor problems were recorded and one relates to uVis operators and two to the Studio. One medium problems was observed, which relates to aligning controls using `Index`. Five problems were bugs. One of the them was caused by the uVis kernel, which failed to compute **Rows** correctly. Two were missing functionality problems and they relate to the Studio. Two were

Problem Type	No.	Question	Task 1	Task 2
Task Failure	8	How easy was it to use uVis formulas?	4	3
Minor	3	How easy was it to understand uVis properties: Rows, Parent and Canvas.	5	4
Medium	1	How easy was it to use uVis operators (., !, -	4	5
Cumbersome	2	How easy was it to connect controls with data?	4	4
Bug	5	How easy was it to use uVis Studio?	5	3
Missing Functionality	2	How useful was the Auto-Completion in the property grid?	4	4
		How useful was it to preview the live version of the visualization in the Design Panel?	5	5
		How useful was it to interact with the Design Panel?	4	5
		How useful was it to have the Interact-Mode?	4	5
		How easy was it to use test the application as an end-user?	5	5
		How useful was it to see the E/R model?	5	5
		How useful was it to set formulas from the E/R model?	4	4
		How useful was it to see the Error List window?	4	4
		Were the errors understandable in the Error List?	3	3
		How useful was it to see the real row-data in the window Data View?	5	4
		How useful was it to see the controls in the window Control and Data Hierarchy?	4	5
		How much the formula language does facilitate visualization development?*	3	5
		How much the development environment does facilitate visualization development?*	5	5
		Do you think you could use uVis in your domain and create visualizations?	5	5

Figure 7.7: Participant 5: Problem counts by type (left). Subjective ratings (right).

cumbersome problems. The participant verbally commented on those. They are: better error messages and specifying Top instead of Bottom.

Questionnaires

The subjective ratings are presented in Figure 7.7. Overall, the ease of use for uVis formula language and the Studio were rated the same. Most of the features and panels of the Studio were rated higher.

Debriefing

At the end she added: “It looks like a program that is nice to use. The suggestions helped me a lot, but *Group By* is difficult. I need some more practice with the formulas, but I like that you can see what you are doing. Also, there are the errors which I did not notice several time, but they are pretty easy to see what the problem is.”

Participant 6

Male; 28 years old; PhD student at Copenhagen Business School, investigating the management of social business; graduated student in Information Technology; programmed during his studies, and last time was five years ago; used E/R databases for six month in 2007; has used Eclipse and Net-Beans five years ago; used MS Excel spreadsheets last week; has never

Problem Type	No.	Question	Task 1	Task 2
Task Failure	5	How easy was it to use uVis formulas?	4	3
Minor	2	How easy was it to understand uVis properties: Rows, Parent and Canvas.	3	4
Medium	0	How easy was it to use uVis operators (., !, -	2	4
Cumbersome	2	How easy was it to connect controls with data?	3	3
Bug	5	How easy was it to use uVis Studio?	4	4
Missing Functionality	3	How useful was the Auto-Completion in the property grid?	4	4
		How useful was it to preview the live version of the visualization in the Design Panel?	4	4
		How useful was it to interact with the Design Panel?	4	4
		How useful was it to have the Interact-Mode?	3	4
		How easy was it to use test the application as an end-user?	3	4
		How useful was it to see the E/R model?	3	5
		How useful was it to set formulas from the E/R model?	4	5
		How useful was it to see the Error List window?	4	3
		Were the errors understandable in the Error List?	2	4
		How useful was it to see the real row-data in the window Data View?	2	4
		How useful was it to see the controls in the window Control and Data Hierarchy?	4	4
		How much the formula language does facilitate visualization development?*	2	3
		How much the development environment does facilitate visualization development?*	3	3
		Do you think you could use uVis in your domain and create visualizations?	4	4

Figure 7.8: Participant 6: Problem counts by type (left). Subjective ratings (right).

programmed a visualization, but has created standard visualizations with MS Excel.

Problem Counts

The participant finished the first task in 40 minutes and the second task in one hour and 10 minutes. Figure 7.8 presents the number of problems of each type. In total, 17 problems were identified with this participant. Five task failures were observed. They relate to data binding, not noticing error messages and confusing the **Text** property with the **Name** property. Two minor problems were recorded and they relate to the Studio. No medium problems were observed with this participant. Five problems were bugs. One of the them was caused by the *Property Grid*, which failed to correctly update the name of a designer property. Three were missing functionality problems and they relate to the Studio. Two were cumbersome problems. The participant verbally commented on those. They are: better error messages and specifying **Top** instead of **Bottom**.

Questionnaires

The subjective ratings are presented in Figure 7.8. The *E/R Model* was the highest rated by this participant, in contrast to connecting control with data and *Error List*.

Debriefing

At end the participant commented: "Binding control to data is not easy, especially when you have to use a *Group By*. I would have preferred a switch rather than a slider. The errors should be more visible and should catch my attention. Error prompts should be as pop-ups as I never noticed them. It is a nice tool for a researcher, who does not have a strong technical background, to use and create their desktop dashboard such as Social Media Control Panels."

Participant 7

Male; 36 years old; graduated student in telecommunication; last time created a web page using Joomla two years ago; experimented with E/R databases for some months in 2010; used Visual Studio two years ago; is experienced with MS Excel spreadsheets; has never programmed a visualization, but has created standard visualizations with MS Excel.

Problem Counts

The participant performed the first task in 50 minutes. The second was performed in one hour and 10 minutes. Figure 7.9 presents the number of problems of each type. In total, 14 problems were identified with this participant. Three task failures were observed. The first two relate to data binding. The third was caused by *Error List* because he did not noticed the errors. Two minor problems were recorded. In the first he tried to refer to a property using the control name, and the second was caused by the double quotes. No medium problems were observed with this participant. Five problems were bugs. One of the them was caused by the *Auto-Completion* feature, which failed to provide suggestions. Two were missing functionality problems and they relate to the Studio. Two were cumbersome problems. The participant verbally commented on those. They are: better error messages and specifying Top instead of Bottom.

Questionnaires

The subjective ratings are presented in Figure 7.9. The rating can be interpreted as follow: the participant found uVis formula language difficult to use, and some parts of

Problem Type	No.	Question	Task 1	Task 2
Task Failure	3	How easy was it to use uVis formulas?	3	3
Minor	2	How easy was it to understand uVis properties: Rows, Parent and Canvas.	3	2
Medium	0	How easy was it to use uVis operators (., !, -	2	3
Cumbersome	2	How easy was it to connect controls with data?	4	3
Bug	5	How easy was it to use uVis Studio?	4	3
Missing Functionality	2	How useful was the Auto-Completion in the property grid?	5	5
		How useful was it to preview the live version of the visualization in the Design Panel?	4	5
		How useful was it to interact with the Design Panel?	3	4
		How useful was it to have the Interact-Mode?	4	4
		How easy was it to use test the application as an end-user?	5	5
		How useful was it to see the E/R model?	4	4
		How useful was it to set formulas from the E/R model?	3	3
		How useful was it to see the Error List window?	5	3
		Were the errors understandable in the Error List?	4	4
		How useful was it to see the real row-data in the window Data View?	5	5
		How useful was it to see the controls in the window Control and Data Hierarchy?	5	4
		How much the formula language does facilitate visualization development?*	N/A	4
		How much the development environment does facilitate visualization development?*	3	3
		Do you think you could use uVis in your domain and create visualizations?	5	5

Figure 7.9: Participant 7: Problem counts by type (left). Subjective ratings (right).

the Studio were highly rated (e.g. Auto-Completion, Design Panel, DataView) unlike others (e.g. *E/R Model* and Error List).

Debriefing

During the second task, the participant said “I have used *Group By* many years ago, but I am not sure if I remember it. Could you explain it?” I gave him an example and told him how *Group By* works. This clarified his concerns and helped him write the correct formulas. At the end he commented: “It is a good thing that it is at run-time, you do not need to do anything.”

Participant 8

Male; 33 years old; currently studying Information Management at Copenhagen Business School, and before has worked as a consultant in marketing; programmed last time when he was 16 years old; I explained briefly what an E/R database is because he had never used an E/R databases; no prior experience with a development environment; used MS Excel spreadsheets when he was a consultant, but has not practiced it since 2007; has never programmed a visualization, but has created standard visualizations with MS Excel and Google Spreadsheets.

Problem Counts

The participant performed the first task in one hour and the second in one hour and 20 minutes. The participant had many difficulties, especially with database concepts. During the first task I had to teach him some database concepts. Although I observed from the first task that the participant did not have the required IT skills, I asked him to carry out the second task as well. I wanted to see how much he could do. Therefore, from the beginning I told him “Try to do what you can, then I will help you.” The participant dragged and dropped all controls. He placed them and changed some properties so they looked similar to what I asked him to do. Then, he said “I’m not sure how to bind controls to data, that’s why I started with the visual part.” Together, we wrote the formulas for data binding.

Figure 7.10 presents the number of problems of each type. 20 problems were identified with this participant. 9 problems were task failure; they relate to data binding, **Parent** concept and not noticing the errors in the **Error List**. No minor problems were observed with this participant. One medium problem was recorded and had to do with the use of **index**. Four bugs were observed (e.g. the **Rows** formula was not evaluated correctly). Four were missing functionality problems related with uVis formulas (e.g. using an SQL aggregate in **Rows**, using a switch similar to iPhone for *Modes*) and the Studio (e.g. moving a control when a formula is set for **Left** or **Top**). Two were cumbersome problems as the participant verbally commented on those: better error messages and specifying **Top** instead of **Bottom**.

Questionnaires

The subjective ratings are presented in Figure 7.10. These subjective ratings indicate that the participant liked *Auto-Completion*, *Design Panel*, *E/R Model* and *Interact-Mode*. **Parent/Canvas** concepts, binding control to data and Error List were less appreciated. However, these ratings does not match his performance because he was continuously helped to complete the tasks.

Debriefing

At the end he commented: “I think there is a lot of potential for creating visualizations of this kind in this way. The interface and manipulation during the process is extremely

Problem Type	No.	Question	Task 1	Task 2
Task Failure	9	How easy was it to use uVis formulas?	5	4
Minor	0	How easy was it to understand uVis properties: Rows, Parent and Canvas.	4	3
Medium	1	How easy was it to use uVis operators (., !, -	4	5
Cumbersome	2	How easy was it to connect controls with data?	5	3
Bug	4	How easy was it to use uVis Studio?	4	4
Missing Functionality	4	How useful was the Auto-Completion in the property grid?	5	5
		How useful was it to preview the live version of the visualization in the Design Panel?	5	5
		How useful was it to interact with the Design Panel?	5	4
		How useful was it to have the Interact-Mode?	5	5
		How easy was it to use test the application as an end-user?	5	5
		How useful was it to see the E/R model?	5	5
		How useful was it to set formulas from the E/R model?	5	4
		How useful was it to see the Error List window?	5	3
		Were the errors understandable in the Error List?	4	4
		How useful was it to see the real row-data in the window Data View?	3	4
		How useful was it to see the controls in the window Control and Data Hierarchy?	5	4
		How much the formula language does facilitate visualization development?*	5	5
		How much the development environment does facilitate visualization development?*	5	5
		Do you think you could use uVis in your domain and create visualizations?	5	5

Figure 7.10: Participant 8: Problem counts by type (left). Subjective ratings (right).

well thought out. I managed to get through it as a total novice, therefore if I were to wish for any improvements it would be to have more drag and drop functionality. Also, I liked how the errors are highlighted, and the suggestions. The second task is excellent; it is a more complex task and clearly shows the utility of this tool.”

7.3 Summary

With proper training and knowledge most of them can probably create custom visualizations with *Drag-Drop-Set-View-Interact* approach in uVis. In spite of the improved tool, end-user developers faced several problems, particularly with data binding. Based on observations on the task failures I can say that they did not perform better than the programmers.

In task 1, participants were asked to create a bar chart following the video. Two participants (participant 2 and 8) could not understand how the controls were bound to data, and how to refer to control properties. From my observations, I conclude that their IT skills correspond more to a simple user than to an end-user developer. The other participants were better able to understand what the video was showing.

In task 2, participants did not use a video or watch the one used in task 1. During this task, two participants (2 and 8) had many difficulties in completing the task. I continuously assisted them to complete the task. With advanced training they might learn how to create visualizations with uVis. On the other hand, the other participants

performed better. However, none of them were able to finish all the tasks on their own. I helped them the first time to write a complex formula; the formula that used *Group By* and *where*. After the first time, they could reuse the formulas and adjust them properly.

I noticed that the video presentation helped users create the bar chart, but in several cases they were replicating without reasoning. This was reflected in the second task where they had difficulties specifying a *Group By*. On the other hand, they had to look at two screens, and this was cumbersome as they had to keep track of the video, play it back and forward. Identifying the correct training approach seems to be more difficult than I expected at the beginning, and some of the usability problems might have been caused by the selected approach.

Usability Problems

In this study, I identified 43 different usability problems: 12 task failure, two cumbersome, two medium, six minor, nine bugs, and 12 missing functionalities. I group the usability problems in two categories: those caused by the uVis Formula Language and those caused by uVis Studio. Table 7.1 presents the problems classified and the participant who encountered the problem. From this table, one can notice that binding controls to data is the most difficult part for end-user developers. In addition, the number of bugs and missing functionalities reflect on the maturity and stability of the tool. As shown in Table 7.1, 13 problems were unique, and the rest occurred with more than one participant.

Questionnaires

Figure 7.11 presents the subjective ratings of each participant and summarizes their ratings of each task where the minimum, the maximum and the average value are shown. These subjective ratings provide useful insights to identify what should be improved. Also, they hint at the advantages and disadvantages of this approach. For example, *Auto-Completion*, *Design Panel*, *Control-Data Hierarchy*, *Modes* were highly rated, in comparison to the uVis formula language and the *Error List* panel.

7.3 Summary

Area	Problem Type	Description	Participant
uVis Formula Language	Task Failure	Binding a control to a table	2,8
	Task Failure	Binding a control to data using group by	1,2,3,4,5,6,7,8
	Task Failure	Binding the rows of a table to a property	2,5,6
	Bug	Kernel failed to set the Bottom property of the triangle	1,2,3,4,5,6,7,8
	Bug	Highlighted all the formula instead of the problematic part in the Rows property	1
	Medium	Concatenating two words	2
	Task Failure	Specifying the Requery() function	2,5,8
	Task Failure	Referring to a property	2,8
	Task Failure	Understanding Parent concept	2,5,8
	Task Failure	Understanding the -< operator	2,8
	Task Failure	Map a field to a property without specifying the Rows property	2,5,7,8
	Minor	The Dot and Bang difference	2,6
	Missing Functionality	Using the SQL aggregate in the Rows property	2,8
	Bug	Kernel failed to report an error when a double quote was missing	2,3,5,7
	Minor	Double quotes in text	2,3,5,7
	Minor	Referring to a property using the name of the control only	3,7
	Missing Functionality	Asked for another syntax to specify aggregates (tblName.fieldName.Max)	4
	Missing Functionality	The control should never disappear even though the formula is wrong	3,4
	Task Failure	Specifying a SQL Aggregate	2,4,5,6,8
	Bug	Kernel failed to evaluate the Rows formula correctly	1,2,3,4,5,6,7,8
Medium	Aligning overlapping controls using Index	2,5,8	
uVis Studio	Task Failure	Errors were not noticed in the Error List	1,2,3,4,5,6,7,8
	Bug	The formula was not updated correctly when the focus was lost	1,2,3,4,5,6,7,8
	Missing Functionality	More drag and drop features	1,2,5,8
	Missing Functionality	The position of a control when the position is set to a formula	1,2,3,4,5,6,7,8
	Cumbersome	Specifying the Top property instead of Bottom	1,2,3,4,5,6,7,8
	Task Failure	Using the Name property instead of the Text property	2,5,6
	Missing Functionality	Control properties in the Hierarchy	2
	Missing Functionality	Asked to move only one control instance	3
	Task Failure	Light blue color of the selected control	3
	Minor	Resize a control	4,5
	Missing Functionality	Panels should be always enabled	4
	Missing Functionality	Set a property using the controls in the Hierarchy, instead of typing.	4
	Bug	Copying and pasting a control failed the first time	4
	Minor	Right-click on the table name, and relationship line	5
	Minor	Difference between Add and Replace in the Formula Suggestions	4,6
	Bug	Auto - Completion failed to correctly suggest	1,2,3,4,5,6,7,8
	Missing Functionality	Lines in the design panel when controls are moved	4
	Missing Functionality	Having a switch like the one in iPhone than a slider for the Modes.	6,7,8
	Bug	Property Grid failed to update the name of a designer property	6
	Missing Functionality	Pop-up window for errors	6
	Cumbersome	Better error messages	1,2,3,4,5,6,7,8
	Bug	Auto-completion had a slow response in some cases.	4

Table 7.1: Usability problems recorded in this study. They are grouped by root problem and classified by type. For each problem I show who encountered it.

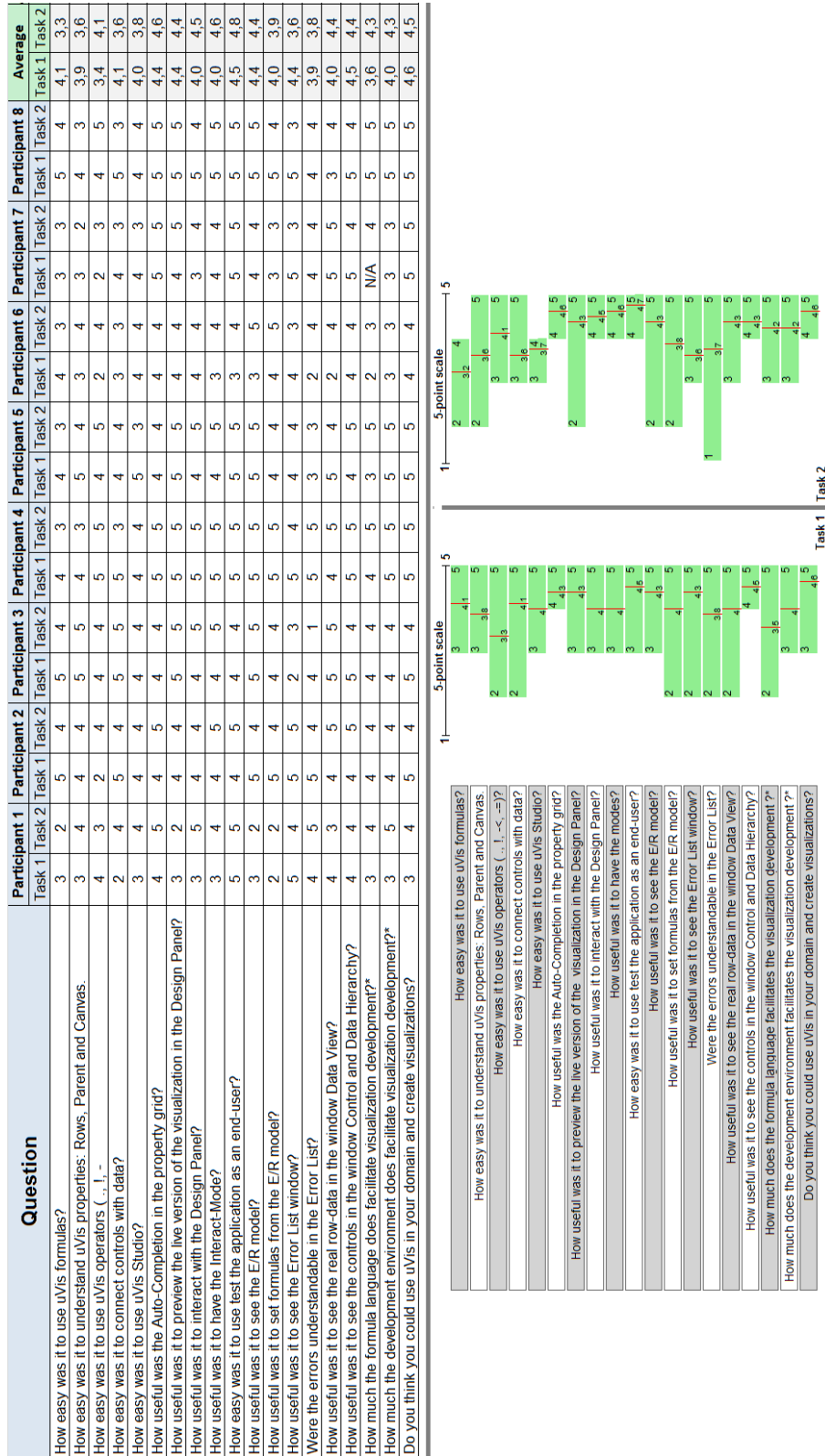


Figure 7.11: Participants' rating for task 1 and 2 (top). Minimum, Maximum and Average rating for task 1 (bottom-left) and task 2 (bottom-right)

uVis Formula Language

Binding a control to the rows of a table was understandable, but it was more challenging in the complex case where they had to use a *Group By*. Six of them had difficulties the first time because they could not recall how *Group By* worked. During the study most of them reasoned correctly, but they were not sure how to express it using the formulas. After the first time they could proceed on their own. Providing them with more examples, simple tutorials or video might improve their performance. Two of them had not the required knowledge and I had to assist them all the time.

Participants found this less complex than the data binding. Apart from the last participant, the others could easily refer to properties. Initially, some of them had difficulties remembering the syntax. With the help of *Auto-Completion* and by means of practicing, I observed that they became better.

uVis has several new keywords and operators. Some of them were familiar and quickly understood, others made them skeptical and confused. For example, some participants could not distinguish the difference between the *dot* and *bang* operator. The **Parent** keyword was not intuitive to some of them, and in several cases I had to explain the concept. Most of them could guess the left-join operator ($-<$), but in combination with the **Parent** keyword it made the formula non-intuitive. The uVis formula language uses these operators to provide simple formulas, but this has disadvantages as well. I noticed that they got better at the end of the study, and I believe that with more examples and practice, language barriers can be overcome.

uVis Studio - Features

WYBIWYG: Participants found the *Design Panel* useful. Interacting with visual objects was easy and their comments indicate that the *WYBIWYG* feature continuously helped them understand the formulas. They got immediate feedback and could reflect on the formulas. For example, it helped them observe how a change in the **Rows** property affected the visualization. In addition, viewing the result of a mathematical equation immediately helped them find out the correct equation. However, the participants suggested several features to improve the *Design Panel*, such as adding lines when a control is moved.

Auto-Completion: The *Auto-Completion* assisted them with correct suggestions. In a few cases when they misspelled a word and there were no suggestions, they stopped and checked what they had typed. In other cases, the feature was not suggesting all possibilities and this bug made some of them skeptical and wondered why there are no suggestions. Both cases shows that participants were not simply using the feature to avoid misspellings, but also to confirm that what they were typing followed the syntax.

Formula Suggestions: Participants found this feature helpful. They could easily bind controls to data and map fields to properties. However, some of them would have liked to automatically specify a *Group By* as well.

Interact-Mode: Participants found the *Interact-Mode* useful. They liked that they could test the visualization without switching context. In the second task, one of them dragged and dropped the track-bar and implemented the interaction. After that, he was continuously testing how the interaction changed the visualization. While the *Data-Mode*, which disables the *WYBIWYG* feature, was only used to test it. Although to most of them the sliders were understandable, some of them suggested using a switch as in iPhones.

uVis Studio - Coordinated Panels

uVis Studio provides several coordinated panels. Changes in the *Property Grid* were immediately reflected on the *Design Panel*, the *Control-Data Hierarchy*, the *Error List* and *DataView*. This allowed them to view the changes from different perspectives and better understand the formula language and the visual mapping. Although the error messages were not visible most of the time, participants liked that the *Error List* was coordinated with the *Property Grid*. They all appreciated that wrong formulas were colored in red. Supporting them with the *E/R Model* and *DataView* was also helpful. Several times before they wrote a formula, they consulted the *E/R Model* and viewed the data in the *DataView*. After setting a formula, they were able to view the data bound to the control. I observed several strategies of using these panels. Some of the participants used mainly *Control-Data Hierarchy* to navigate through controls and view their properties in the *Property Grid*. Others were using the *Design Panel*.

Chapter 8

Usability Study with Clinicians

This chapter presents a usability study with two clinicians. Before, I report on the study, I discuss InfoVis in healthcare and the importance of empowering clinicians in visualization development.

8.1 Information Visualization in Healthcare

Healthcare systems create and use a large amount of data and it is a challenge to present these data. According to Smith “*doctors in developed countries seem to be overwhelmed by the information provided for them. The amount of information is enormous and disorganized, and it is hard to find the answers to questions that arise in consultations.*” [95]. Based on their experience and knowledge, clinicians need easy and intuitive presentations that fulfill their needs [43, 77]. Researchers have created efficient visualizations such as LifeLines [79], Knave II [33], TimeLine [15], CareVis [1], LifeLines 2 [111], LifeFlow [116], etc. Roque et al. [83] compared 6 InfoVis systems (LifeLines [79], LifeLines 2 [111], KNAVE II [33], CLEF Visual Navigator [34], TimeLine [15], and AsbruView [50]). These tools allow clinicians to get an overview of the Electronic Health Record (EHR). Their results showed that these tools were not always designed with user feedback, and evaluations were not conducted in real clinical environments. They conclude that a closer collaboration with medical professionals would result in better systems.

Most EHR systems use mainly text and tabular presentation, and there is a need for visualizations where clinicians can get better overview. Figure 8.1 shows three EHR

8.1 Information Visualization in Healthcare

1

Start	Slut	Type	Lægemiddel	Vareform	Dosis	Dagndosis	Adm.vej	Info
13.07.06		Fast.Inf.	Cefuroxim 1500 ...	15 mg/ml inf.v...	1500 mg x 3	4500 mg	IV	
17.08.06		Fast	Furix	10 mg/ml inj.v...	40 mg x 2	80 mg	IV	
20.10.06		Fast.Inf.	Metronidazol "Bax...	5 mg/ml inf.v...	500 mg x 3	1500 mg	IV	
13.07.06		Fast	Selo-zok	100 mg depot...	100 mg x 1	100 mg	OR	
13.07.06		Fast	Laktulose SAD	667 mg/ml mi...	13340 mg x 1	13340 mg	OR	
13.07.06		Fast	Multivitamin mine...	tabletter	1 stk x 1	1 stk	OR	
03.10.06		Fast	Ibumetin	400 mg tablet...	400 mg x 3	1200 mg	OR	
03.10.06		Fast	Picolon	7,5 mg/ml ora...	10 drb x 1	10 drb	OR	
01.02.08		Fast	Pinex	500 mg filmov...	1000 mg x 3	3000 mg	OR	

2

Date	By	Preparation Name	Concentrat...	Medicament Desig...	Packing	L.	P.	Dos...	To date	A	C	P.	S.	L.	S.	D.	F	L
09-04-2008	set	Aeropax	40 mg	tyggetabletter	100 stk.	1	1	3,00	11-05-2008									
17-04-2008	set	Daonil	1,75 mg	tabletter	100 stk.	1	1	3,00	19-05-2008		C							
28-12-2005	dmo	Voltaren	50 mg	enterotabletter	20 stk.	1	1	2,00	12-12-2008		C							
12-03-2008	set	Zyprexa	10 mg	overtrukne tabletter	28 stk.	1	1	1,71	22-03-2008		A							
03-12-2008	set	Lucosil	500 mg	tabletter	48 stk.	1	1	0,00	03-12-2008		B							
18-01-2008	set	Novorapid FlexPen	100 IE/ml	inj.væske, opløsning	15 ml	1	1	0,00	19-09-2008		A							

3

BERGGREN,NANCY ANN Venerea 20. Jul 10 11:16 Primær behandlingsteam ikke tildelt

2512484916 25 Dec 1948 (61) Udgiver:FRIS JØRGENSEN,JARI

Parallell Diagnostik Medicin Rikvisitioner Kontrastmidler Doseringer DCC-Skema Laboratorie Resultater Læbka WWW Bakt Patoverb

Laboratorie Resultater

All Tests By Date

Laboratorieresultater -All Tests By Date - Seks Måned

Patient: Berggren Nancy Ann (CPR: 2512484916)
 Provesvar fra: EH Bispebjerg Hospital Provestatus: K
 Provetagningstidspunkt: 22-01-2010 10:36 Svar afsendt senest: 22-01-2010 03:00
 Svar oprettet i VistA: 26-02-2010 14:57 Svar opdateret i VistA: 26-02-2010 14:57

Analysenavn
 P-Human immundefektvirus 142(antistof4g)

Resultat
 0

Referencekommentar
 0

Status
 ENDELIGT RESULTAT

Patient: Berggren Nancy (CPR: 2512484916)
 Provesvar fra: EH Bispebjerg Hospital Provestatus: K
 Provetagningstidspunkt: 01-02-2010 09:10 Svar afsendt senest: 15-01-2010 03:00
 Svar oprettet i VistA: 26-02-2010 14:56 Svar opdateret i VistA: 26-02-2010 14:56

Analysenavn
 P-Hepatitis B virus c-antistof

Resultat
 1

Referencekommentar
 0

Status
 ENDELIGT RESULTAT

Figure 8.1: Three different EHR systems from the Copenhagen region showing: 1. the patient's medicines. 2. the drug records for a patient. 3. the lab-test results for a patient.

systems used in the Copenhagen region. In a department of Bispebjerg Hospital, the EHR system uses a tabular presentation to show medical orders (Figure 8.1.1). From this screen it is not easy to identify what medicines the patient is taking at the current time. Another EHR system supports clinics and hospitals with tabular presentations (Figure 8.1.2). In the Venereal Clinic of Bispebjerg Hospital, clinicians use the VistA EHR system to record patient's venereal diseases, also referred to as sexually transmitted infections. Lab-test results are presented using a text-based presentation (Figure 8.1.3). For each patient in the clinic, clinicians have to read a long text to see a simple result. When clinicians have to view several results, the complexity amplifies.

In the early phase of this research, I collaborated with clinicians of the Venereal Clinic, and in one of our meetings they said that it is difficult to distinguish if a lab-test result was negative or positive. In addition, the sensitiveness of this lab-test requires additional mental effort and they were afraid they missed some results when there were many of them.

In the plain text (Figure 8.2.1), clinicians identified the three most important variables (date, result and test name). These values were used to create a simple visualization (Figure 8.2.2) with uVis Studio. Further, Figure 8.2.3 shows how these data can be presented using a timeline. They found these ideas great, and asked if they could have something similar in their EHR system. Unfortunately, due to time, resource and database constraints, visualizations were not integrated into their system. This scenario confirms the need for better presentations and the importance of involving clinicians in the visualization process. It is difficult to visualize important variables from electronic health records without medical expertise.

This research aims at minimizing the collaboration with clinicians but empower the clinicians, whose IT skills correspond to end-user developers, with a tool that allows them to create effective visualizations.

At Bispebjerg hospital in Copenhagen, another department uses an MS Access system developed by one of the clinicians. Another clinician has been working as a surgeon for the last 30 years, and IT is his hobby. He has worked with IT for the last 20 years, and uses MS Excel, MS Access and Visual Basic. He developed an EHR system, which was used for a couple of years in his department. These two examples prove that in the healthcare environment there are clinicians with IT skills that correspond to end-user developers. They have the clinical domain knowledge and with the proper tool

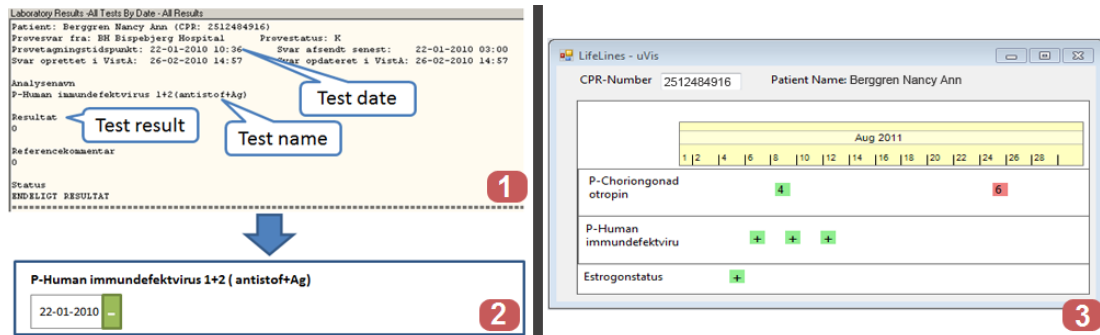


Figure 8.2: 1. Current presentation at the clinic, 2. A simple presentation patient lab-test results, 3. Presenting lab-test results on a time-line.

they might construct effective visualizations. Further, it will increase the possibility of developing novel visualizations for clinical data. Last but not least, clinicians without IT experience can collaborate with IT clinicians to create and adjust visualizations in the department or hospital.

8.2 Usability Study

I present a usability study with two clinicians who were asked to construct visualizations with the *Drag-Drop-Set-View-Interact* approach. As clinicians are hard to recruit for a usability study and have very low availability, I conducted only two usability tests. The first test was conducted in four hours and the second in two hours.

This study investigated if clinicians, who have IT skills at the level of an end-user developer, can construct custom visualizations using the uVis formula language and the Studio. In addition, the study focused on identifying potential usability issues and providing suggestions for further improvement.

8.2.1 Procedure and Tasks

This study was planned to run in four hours and consisted of three parts: introduction, construct the LifeLines, and construct the Process Completion Diagram.

The first usability test was conducted in two sessions of two hours, four days apart. In the first session the clinician performed task 1 and 2. In the second session, the clinician finished task 3. In this usability test, the Studio did not have the *Formula*

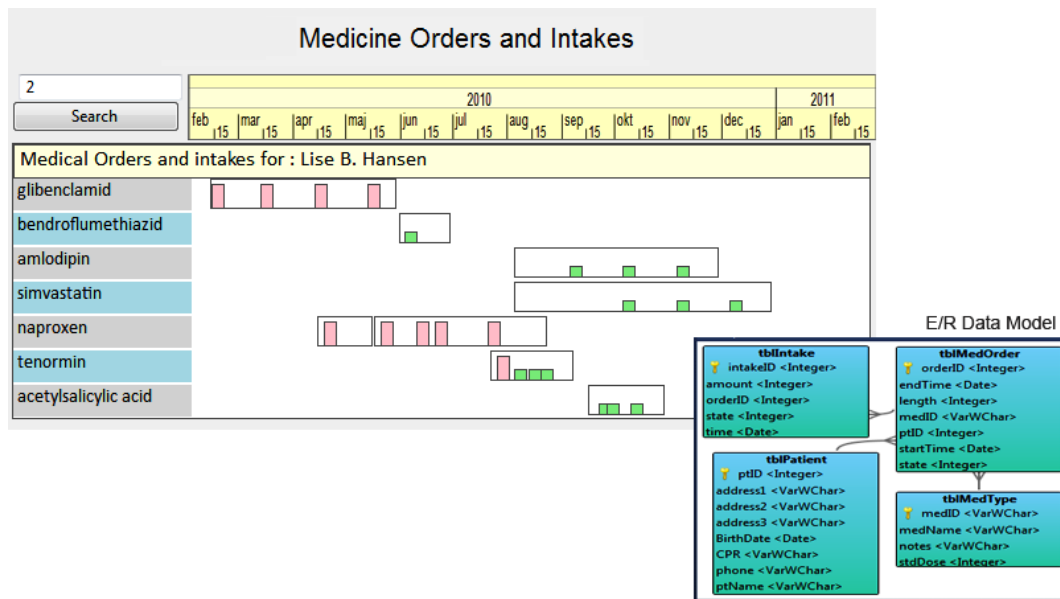


Figure 8.3: The LifeLines and the E/R data model.

Suggestions feature, because at that time it was under development. Due to clinician's availability, I had to run the study without this feature.

The second usability test was conducted in one session, lasted only two hours, and the clinician performed only the first two parts.

I conducted the study, kept notes, and recorded the sessions. During the sessions, I helped the clinician whenever there was a misinterpretation, confusion or malfunction of the system. These cases were recorded as usability problems. The documentation used in this study can be found at Appendix D.

Task 1: Introduction to uVis

This task lasted 30 minutes, where I described the uVis formula language and the Studio. I explained how visualizations are created, what the uVis formulas are, how to refer to control properties, to data, etc. I gave the clinician a list of tasks describing what he was supposed to do. I did not use the video because the time was limited, and the tasks were similar to the ones described in the video. I showed him the reference card for the uVis formula language. At the end of this part, I asked the clinician questions regarding the uVis Formula, the uVis Studio and the uVis approach. I used the same questionnaire as in Chapter 7.

Task 2: Construct the LifeLines

This task was also performed with a programmer (described in Chapter 6), but the first version of the Studio was used.

I showed the clinician an already implemented version of the LifeLines that used data from a MS Access database with 4 tables (Figure 8.3). I explained some advanced concepts (i.e. the control-join operator “==” that aligns controls vertically, and the `HPos` function of the timescale that aligns controls horizontally). Then, I asked the clinician to create the LifeLines and think-aloud during the process. I provided the clinician with the uVis reference card, a reference card where the visualization was showed without any formulas, and some hints in a second page. The hint page showed him how to write the complex `Rows` formula with a *Group By*, how to align vertically and horizontally, how to convert a `String` type to `Integer` type, and described the `Refresh()` function. At the end, the clinician was asked to reply to the questionnaire again as in task 1. This task was planned to last one and a half hours.

Task 3: Construct the Process Completion Diagram

This was conducted four days after the first session, but only with the first clinician. This task was performed with an end-user developer, as described in Chapter 7.

I showed him an already implemented version of the Process Completion Diagram (PCD) that used a MS Access database with two tables (Figure 8.3). I explained how the event-log data are visualized. The clinician was asked to create a simplified PCD. The simplified PCD (Figure 8.4) did not show the horizontal and vertical lines in the X-axis and Y-axis, the average and the standard deviation. However, the steps involved in constructing the simplified PCD are representative ones (e. g. drag and drop control, refer to a property, bind a control to data, map a field to a property, get immediate feedback, check errors, try as end-user, etc.) The clinician would have been able to enrich it with the missing details, but time did not allow. The clinician was asked to create the PCD thinking aloud.

The uVis reference card, a reference card where the visualization was showed without any formulas, and some hints in the second page were given to the clinician. The hint page showed them how to write the complex `Rows` formula with a *Group By*, how to use SQL aggregates (`Count()`, `Max()`, `Min()`), how to convert a `String` type to

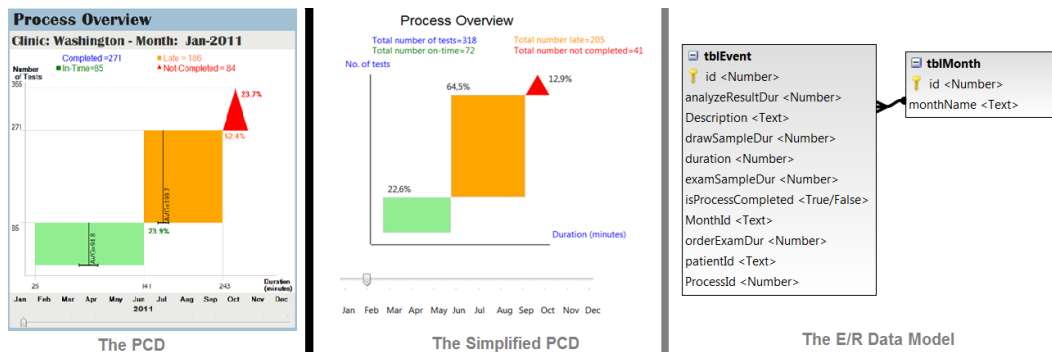


Figure 8.4: The PCD, the simplified PCD used in this study, and the E/R Data Model.

Integer type, and described the `Requery()` function. In addition, I gave the clinician a reference card with the Studio shortcuts. At the end, the clinician was asked to reply again to the same questions. This task was planned to last two hours.

The rest of this chapter presents the clinicians' background, the results from the study, the usability problems and the subjective ratings from the questionnaires.

8.2.2 Results

This section presents the results of the study. For each participant I describe his background, report the number of problems categorized by type, subjective ratings, and summarize participant's comments about the tool. I conclude this chapter with a summary of the results.

Clinician 1

Male; 64 years old; MD Surgeon and part-time PhD Student at the IT-University of Copenhagen; started working in Health Informatics in 1986; programmed for two months in 1978; used E/R databases in the period 1994-1995, and during the last month; has never used a development environment; regularly used MS Excel formulas since 1996; has designed visualizations using pencil and paper, but has never programmed one.

Problem Counts

The clinician is a member of the uVis project. He started practicing the uVis formula language a month before, only around one day a week. He had been using a simple

text-editor to write formulas and had never used the Studio.

The first task lasted 15 minutes, the second one and half hours, and the third task two hours. Figure 8.5 presents the number of problems of each type. In total, 30 problems were identified in this usability test. Eight of them were task failures: specifying a **Rows** formula that used a *Group By* and not noticing errors in **Error List**, etc. Four minor problems were recorded (e.g. using double quotes). Six medium problems were observed with this participant. They relate to data binding, aligning controls, and uVis operators. Four problems were bugs. One of the them was caused by the *Auto-Completion* feature, which failed to provide suggestions after a parenthesis. Five were missing functionality problems and they relate to uVis formulas (e.g. using an SQL aggregate in **Rows**) and the Studio (e.g. more shortcuts and color pallet). Three were cumbersome problems. The participant verbally commented on those. They are: better error messages, specifying **Top** instead of **Bottom**, and confirming a change with **ENTER**.

Questionnaires

The subjective ratings are presented in Figure 8.5. They indicate that the participant found less useful *DataView*. The *Design Panel*, *Modes*, E/R model and *Auto-Completion* and *Error-List* were rated higher.

Debriefing

At the end of the second task, he added: “the **bang** is confusing but I have to learn it; also, the uVis operators and the double quotes. This has to do with training as well. I have no suggestions how to improve the learning. I think having a feature on the E/R for mapping fields to properties would be helpful. A great thing of the Studio is the *Design Panel* placed in the center, where you can see the results as you work; also, the *Auto-Completion* tells you what you can write, this is great.”

At the end of task 3, he commented: “I think I could have done this even if you were not here, but it would have taken me more time. I was not thinking the right way at some parts, but I would have gone back and do it properly. And, it’s a good technique to refer to properties.”

Clinician 1		Clinician 2	
Problem Type	No.	Problem Type	No.
Task Failure	8	Task Failure	10
Medium	6	Medium	4
Minor	4	Minor	0
Cumbersome	3	Cumbersome	1
Bug	4	Bug	3
Missing Functionality	5	Missing Functionality	5

Question	Clinician 1			Clinician 2	
	Task 1	Task 2	Task 3	Task 1	Task 2
How easy was it to use uVis formulas?	4	4	4	3	2
How easy was it to understand uVis properties: Rows, Parent and Canvas?	4	3	4	4	2
How easy was it to use uVis operators (. , , -<)?	4	3	4	4	2
How easy was it to connect controls with data?	5	4	4	4	4
How easy was it to use uVis Studio?	4	3	3	2	2
How useful was the Auto-Completion in the property grid?	4	4	4	5	4
How useful was it to preview the live version of the visualization in the Design Panel?	5	5	5	4	4
How useful was it to interact with the Design Panel?	4	3	3	3	3
How useful was it to have the modes?	5	5	5	3	4
How easy was it to use test the application as an end-user?	5	5	5	4	5
How useful was it to see the E/R model?	4	4	4	5	5
How useful was it to set formulas from the E/R model?	N/A	N/A	N/A	4	4
How useful was it to see the Error List window?	5	5	5	4	5
How useful was it to see the real row-data in the window Data View?	2	2	2	5	4
How useful was it to see the controls in the window Control and Data Hierarchy?	4	4	4	4	3
How much the formula language does facilitate visualization development?*	4	4	4	4	5
How much the development environment does facilitate visualization development?*	4	5	5	4	5
Do you think you could use uVis in your domain and create visualizations?	4	5	5	4	5

Figure 8.5: Clinician 1 and 2: Problem counts by type (top). Subjective ratings (bottom).

Clinician 2

Male; MD Senior Surgeon; 57 years old; started using IT in 1985, and has used Visual Basic, JavaScript, and PHP; does not program often lately, last time was 1 month ago when he experimented with HTML 5; Has a good knowledge of E/R databases, and mostly uses MS Access and MySQL; used a database a week ago; borrowed Visual Studio from a friend, but never used it; barely uses MS Excel as he thinks it is too primitive; has created simple visualizations to show statistics using Google Spreadsheet and MS Excel.

Problem Counts

The clinician had no prior experience with the uVis formula language or the uVis Studio. This study was conducted in two hours because of his availability.

The first task was performed in 20 minutes and the second in one hour and one and half hours. Figure 8.5 presents the number of problems of each type. 23 problems were identified with this participant. 10 of them were task failures. Similar to the end-user developers, presented in Chapter 7, the clinician faced problems with data binding and

errors were not noticeable to him. No minor problems were recorded with this clinician. Four medium problems were observed. They relate to aligning controls, uVis operators, and using the **Name** property instead of **Text**. Three problems were bugs. One of them was caused by *Property Grid*, which failed to update the formula in after the focus was lost. Five were missing functionality problems. One relates to uVis formulas (e.g. using an SQL aggregate in **Rows**). The other four has to do with the Studio (e.g. map field to properties from *DataView* and hide panels in end-user mode). One was a cumbersome problems and it relates to better error messages.

Questionnaires

The subjective ratings are presented in Figure 6.4. These figures indicate that the clinician found difficult the uVis formula language (e.g. the **Parent** concept and the uVis operators) and appreciated better the Studio. The *E/R model*, *Auto-Completion* and *DataView* were rated higher than the *Control-Data Hierarchy* and *Modes*.

Debriefing

At the end of task 1, the clinician said: “I use databases because in MS Excel you cannot use SQL to access the database. This is another way, but I can understand it. Also, I can understand the properties as I have used them in Visual Basic.”

After the second task, he commented: “It is extremely important that we get some tools like this. But, I hope it would be for non-programmers as well. At present, users need to have some programming skills. I would prefer something that does not require any skills at all. I think there are a few clinicians who can use tools like this. But, it has to be more user-friendly.” He also said: “the database concepts make it challenging as most of clinicians are used to Spreadsheets and do not use databases. That’s why some assistance from the IT department is required.”

8.2.3 Summary

Assuming that clinicians obtain proper training and have IT skills at the level of an end-user developer, it is possible to engage them in development and allow them to construct custom visualizations. More practice, proper documentation and a more mature tool are needed to overcome the learning curve and improve their performance.

Both clinicians believed that uVis is a useful tool and it is possible to use it in their environments.

Usability Problems

Table 8.1 presents the problems and the clinician who encountered the problem. I group them in two categories: those caused by the uVis formula language and those caused by uVis Studio.

36 usability problems were identified in this study. 10 of them were task failures, but only seven were encountered by both. The other three were medium problems for the first clinician. This can be explained because the first clinician had some experience with the uVis formula language. Both clinicians asked for more drag and drop features. 18 problems were unique, where eight of them were missing functionalities. Clinicians encountered a few bugs as well. Most of them were caused by the Studio, which did not handle an exception properly.

Questionnaires

Figure 8.5 presents the subjective ratings of each clinician. They provide hints of the advantages and disadvantages of the uVis formula language and the Studio. For example, both clinicians liked the *Design Panel*, *Auto-Completion* and *Interact-Mode*. *DataView* was not useful for the first clinician. uVis operators were difficult to use for the second clinician.

uVis formula language

Clinicians had difficulties to bind controls to data. Both of them were unable to write the complex formula that joins three tables and uses a *Group By*. This was difficult even for programmers, as shown in Chapter 6. However, from their comments I noticed that they knew what should be shown, but were not sure how to express it with a formula. The *Group By* increased the level of complexity, and both clinician asked for a simple way to specify a *Group By*. In other cases, they were able to proceed on their own.

Clinicians easily referred to control properties. At the beginning of the study they were skeptical regarding the syntax, but as they progressed, referring to control properties became more intuitive.

Area	Problem Type	Description	Clinician
uVis Formula Language	Bug	Kernel failed to evaluate the Rows formula correctly	1,2
	Medium	Specifying the Requery() function	2
	Medium	Referring to a property	1
	Medium	Concatenating two words	1
	Medium	The Dot and Bang difference	1,2
	Medium	Aligning overlapping controls using Index	1,2
	Medium* , Task Failure**	Using the -= operator	1* , 2**
	Medium* , Task Failure**	Using Hpos() to align controls	1* , 2**
	Task Failure**	Aligning overlapping controls using Index	1* , 2**
	Minor	Double quotes in text	1
	Minor	Using conversion function (Cstr())	1
	Missing Functionality	Using the SQL aggregate in the Rows property	1,2
	Missing Functionality	Asked for SQL Aggregates without specifying group by	1
	Medium* , Task Failure**	Binding a control to a table	1*,2**
	Task Failure	Binding a control to data using group by	1,2
	Task Failure	Binding the rows of a table to a property	1,2
	Task Failure	Understanding Parent concept	1,2
	Task Failure	Map a field to a property without specifying the Rows property	1,2
Task Failure	Specifying a SQL Aggregate	1,2	
uVis Studio	Bug	Studio did not handle correctly an error	1
	Bug	Auto - Completion failed to correctly suggest the after a parenthesis	1,2
	Bug	The formula was not updated correctly when the focus was lost	1,2
	Cumbersome	Move a control when the position is set to a formula	1
	Cumbersome	Better error messages	1,2
	Cumbersome	Using Enter to confirm in some cases	1
	Medium	Using the Name property instead of the Text property	2
	Minor	Specifying the Top property instead of Bottom	1
	Minor	Using colors by name	1
	Missing Functionality	More drag and drop features	2
	Missing Functionality	Map fields to properties from DataView	2
	Missing Functionality	Hide panels in End-User mode	2
	Missing Functionality	Automatically generate Group by in the Formula Suggestions	2
	Missing Functionality	Copying and pasting some of the properties	1
	Missing Functionality	More shortcuts in the Studio	1
	Missing Functionality	Color pallet in the Property Grid	1
	Task Failure	Error messages not visible in the Error List	1,2

Table 8.1: Usability problems encountered in this study. They are grouped by root problem, and classified by type. For each problem I show who encountered it.

Using uVis keywords and operators was challenging for these participants as well. Although the first clinician had some prior knowledge of formulas, I observed that in several cases he was confused by the **bang** and **dot** operator. The **Parent** keyword was obscure to both of them. In one case, the first clinician ignored the **Parent**, and joined two tables using **tableA -<tableB** and a where clause. This shows that he had not understood the **Parent** concept correctly. On the other hand, he was able to bind the controls properly. They could guess what the join-left (-<) denoted using the *E/R model*, but using it in practice was difficult. They understood better as they used them a couple of times.

uVis Studio - Features

WYBIWYG: Clinicians found the *Design Panel* and the *WYBIWYG* feature useful. I had already shown them how to disable the feature, but they did not. Getting immediate feedback helped them reflect on formulas and adjust them properly.

Auto-Completion: This feature was appreciated and used all the time. At some point the first clinician commented “I noticed that Auto-completion is not suggesting anything. This is because I have to set the **Rows** property.” This case shows that the clinician was using it not only to avoid misspelling, but also to reflect on what he was doing.

Formula Suggestions: The first clinician explicitly asked for such a feature. The second appreciated the fact that it showed formula suggestions, notified him when a visual mapping was not possible, and allowed him to easily set control properties. He used the feature to set the complex formula that used a *Group By*. I noticed that viewing the *E/R model* and looking at the suggestion helped his reasoning. However, there was no suggestion about joining three tables in a single step. Therefore, he had to use the first suggestion and join two tables, then add the third table. Also, he asked for suggestions about *Group By* clauses as well.

Interact-Mode: They liked the *Interact-Mode* and the fact that they did not have to switch workspace to test interactions. One of them suggested that the panels in end-user’s mode should be hidden. On the other hand, the *Data-Mode* that disables the *WYBIWYG* feature was never used.

uVis Studio - Coordinated Panels

I observed that several times they got information from different panels to confirm what was visualized in the *Design Panel*. In other cases, it was enough to just look at the *Design Panel*. This allowed them to view the changes from different perspectives and understand the uVis formula language and the visual mapping more easily. I noticed that the first clinician used the *Control-Data Hierarchy* extensively, unlike the second clinician. The second clinician liked the *DataView* and used it in combination with the *E/R model*. The first clinician consulted the *E/R model*, but the *DataView* was used less. Clinicians could barely notice the error messages in the *Error List*, and I had to remind them several times to check the *Error List*. However, they found useful how they could navigate from an error message in the *Error List* to the wrong formulas in the *Property Grid*.

Chapter 9

Discussion

In this thesis, I introduce uVis that is based on the *Drag-Drop-Set-View-Interact* approach. uVis is a visualization tool that allows end-user developers as well as programmers to construct a wide range of custom visualizations. However, some custom visualizations may not be supported by uVis, because it needs more features and controls. As an example, animations cannot be created with uVis for the time being.

The purpose of this thesis was not to investigate and evaluate whether uVis supports all kinds of custom visualizations. Rather, the purpose of this thesis was to investigate and answer the research questions: “*Can end-user developers construct custom visualizations?*”, and “*Can programmers construct custom visualizations faster?*”. In order to answer these questions, I conducted three usability studies with programmers and end-user developers. The usability studies with end-user developers showed that they can construct custom visualizations with a modest amount of training. The usability study with programmers showed that they can create custom visualizations faster with the *Drag-Drop-Set-View-Interact* approach in uVis.

The collected information will also assist in improving uVis, so that it is easier to learn. In addition, the results of the evaluation serve as a starting point in investigating end-user development of visualizations. To the best of my knowledge there is no previous study that has investigated end-user development of visualizations.

During this research I developed a visualization tool taxonomy. It provides a high-level classification of InfoVis development tools investigating how users, despite their IT skills, develop visualizations. It consists of three dimensions: user skills (simple users, end-user developers and programmers), visualization types (standard and cus-

tom visualizations) and tool types (language, wizard and drag-and-drop tools). The categorization of 20 InfoVis tools proves the applicability of this taxonomy, and the results show that users need tools to create custom visualizations with a drag-and-drop approach. The result of this categorization also shows that InfoVis and EUD have to focus more on how to engage simple users and end-user developers in development of custom visualizations. To the best of my knowledge, none of the selected tools were empirically evaluated with potential users.

The remaining part of this chapter reflects and discusses the limitations of the work presented in this thesis. I start my discussion with the visualization tool taxonomy, the uVis and conclude with the usability studies.

9.1 Visualization Tool Taxonomy

The tool visualization taxonomy presented in this thesis was used to categorize 20 tools and prove taxonomy's applicability. I selected only 20 tools instead of all existing InfoVis tools, due to time constraints. Furthermore, the selected ones are representatives and many of them have contributed significantly in the InfoVis field.

To identify InfoVis tools I searched two popular sources IEEE and ACM portal up to 2012. InfoVis tools published in other sources such as Springer, Elsevier, Sage, etc., were not included.

Categorizing the tools in distinct categories it is not without challenges. Many tools span more than one category. The decision was based on the published papers, personal experience with the tools and in few cases where it was not clear I discussed with my colleagues and decided accordingly. However, neither my colleagues nor I have the knowledge that authors of these tools have, which would have facilitated the categorization process, might have avoided issues such as classifying a tool in more than one dimension, and possible miss-classifications.

Users of this taxonomy should be aware that it does not investigate visualization techniques. This was out of the scope of the taxonomy, as previous work (see Chi [23]) has presented a taxonomy of visualization techniques using the data state reference model.

9.2 uVis

uVis has several open issues. One issue is the variety of the supported custom visualizations. Although, uVis can support a wide range of visualizations (e.g. time-oriented, hierarchal, etc.), there are some that are not possible to be implemented. An example is animation. Furthermore, uVis supports development of existing custom visualization easily. However, this does not mean that users of uVis can invent custom visualizations. This work only focuses on constructing the visualization once the idea is present. Another open issue is related to interaction techniques. More work has to be done on the uVis formula language part in order to increase the number of interaction techniques. As an example, implementing focus+context is currently not possible with uVis formulas. Other open issues are the number of controls and visualization layout algorithms, platform dependency, etc.

uVis Studio is the development environment for the uVis formula language. uVis Studio makes the *Drag-Drop-Set-View-Interact* approach possible. There are practical issues that affect the implementation of uVis Studio, but they are outside the research scope of this thesis. Among these are more panels, features, and functionalities that users expect in modern tools. However, the current implementation of uVis Studio has several coordinated panels and introduces new features such as WYBIWYG. Furthermore, design choices can be debatable, but the decisions were made based on my previous experience with other tools, and the requirements [52] set from the beginning.

As mentioned earlier, the purpose of this thesis was not to investigate whether uVis supports development of all custom visualizations. Rather, it proves the *Drag-Drop-Set-View-Interact* approach can allow end-users to construct a wide range of custom visualizations, and at the same time helps programmers construct them faster than with other tools.

9.3 Usability Studies

To address the research questions, I conducted three usability studies. The studies have limitations in terms of generalizability, reliability and validity. Generalizability is concerned with whether the findings identified from this studies are applicable in other cases [82]. Reliability poses the question “will another evaluator obtain the same results if the test is repeated?”, and validity refers to the results related to the usability

problems the evaluator tested [68]. In this respect, I elaborate on several factors they may have affected generalizability, reliability and validity.

Evaluation Practices

In this thesis I used usability evaluation. Ideally, I would have liked to run a controlled experiment evaluation [78] where participants used uVis and existing tools to create custom visualizations. As a result, I would have been able to compare the *Drag-Drop-Set-View-Interact* approach of uVis against other tools. However, this was not feasible because I do not have the knowledge of other tools needed to train participants and evaluate the tools in the same way. Therefore, the study would have been biased. Ideally, another organization would run this study, but this was out of our control.

Another type of evaluation is case studies in real environments [78]. This type of evaluation requires a good collaboration with a company. At this time-frame, I did not had any collaborators that were willing to implement uVis and allow me conduct case studies.

Most of the existing tools have been evaluated through the functionality supported and theoretical frameworks. For example, one tool is *Improvise* [112]. According to the author's publications [112] and his PhD thesis, there are no evaluation with users. Rather, the author presents the proof of concept through various visualizations. Another example is *Protovis* [13] that was extended with a development environment called *ProtoViewer* [4]. Neither *Protovis* nor *Protoviewer* has been evaluated with potential users. To the best of my knowledge, there are no available data from empirical evaluations of other tools that can be used and compared with the studies of uVis.

Formative and Summative Evaluation

In the thesis I report the results from a formative evaluation. This evaluation provides useful information during development, but is different from the summative evaluation. The summative evaluation is useful when the product is released to ensure that usability is adequate and maybe competitive [68].

In the first formative evaluation, participants assessed the uVis formula language and uVis Studio. Although, I improved the tool in the second iteration, still the assessment of the first usability study with programmers could not provide useful insights for end-user developers. As a result, the findings of the first usability study do not assure

that the new version is appropriate for end-user developers. As an example, none of the programmers had a problem noticing an error, while all end-user developers had. This happened because they have different IT skills. Therefore, conducting a formative evaluation with end-user developers was more appropriate. In addition, ideally, I would have liked to conduct a summative evaluation as well, where the overall quality of the tool is assessed and would have provided more reliable data. However, this was not feasible in this time frame because the tool was not mature and stable enough. The number of bugs and missing functionality recorded during the usability studies indicate the uVis status as well. Therefore, a formative investigation was more appropriate at this stage.

A Functional Prototype

In these studies, I used a functional prototype. uVis Studio was iteratively developed, and the second version considerably changed from the first in terms of stability and supported functionalities. The fact that uVis was a functional prototype means that the results of the studies may change as uVis turns into a working system in a real environment.

Participants and Procedures

With valuable input from Prof. Soren Lauesen, Prof. Ben Shneiderman and Dr. Catherine Plaisant, I created a plan for each test, and decided to ask for specific target users.

In all three studies, I asked participants to create visualizations from scratch, rather than adjusting predefined ones. The first and the second study lasted three hours. The third study was conducted in four and two hours, due to clinicians availability. I used several techniques to obtain valid data: verbalization and observations during the study, which lead to usability problems, a questionnaire after each task and in the first study I conducted a semi-structured interview.

In the first study, I was explaining the principles of uVis. This may have affected the study, because of the variations in explanation. As a result, I decided to use a video in the second study. While in the third, due to time limitations, using a video was not possible. Therefore, I defined and used a list of tasks to introduce the tool to the clinicians. Identifying the correct training approach seems to be more difficult

than I expected at the beginning, and some of the usability problems might have been caused by the selected approach. For example, one of the participants complained that the video went too fast. Also, they had to keep track of the video, and in some cases they had to go back and forth.

The first study involved programmers from the HCIL at the Maryland University. They have experience in programming InfoVis and user interfaces. In the second study, when I recruited the participants I explicitly asked for specific IT skills. However, as the study showed, two of them did not meet the requirements, although they indicated so initially. For the last study, I was able to recruit two clinicians with the required IT skills. Unfortunately, it was not possible to recruit others as clinicians have limited availability.

The number of participants in the first and second study was fairly low. The third study was restricted to two participants, because recruiting clinicians is very hard. In the first usability study with programmers, I recorded 38 usability problems: three task failures, four bugs, five cumbersome, one medium, 15 minor and 10 missing functionalities. 13 problems were recorded only with one of the participants. Three problems were task failures, but only one was recorded with all participants. In the second study with end-user developers, I recorded 43 usability problems: 12 task failure, two cumbersome, two medium, six minor, nine bugs, and 12 missing functionalities. Three task failures were related with the uVis Studio and eight with the uVis formula language. Two task failures were identified only with the participants who had IT skills of a simple user. In the third study with two clinicians, I recorded 36 usability problems. 10 of them were task failures, but only seven were encountered by both. Nine were missing functionalities and four were bugs. 18 problems were unique, where eight of them were missing functionalities. The second clinician faced four task failures that were medium problems for the first clinician. Probably, this occurred because the first clinician had some knowledge on the uVis formula language. From these figures, I expect more usability problems with additional participants.

Direct comparison between programmers and end-user developers is not possible. However, some usability problems were present in each case despite their IT skills. Some examples are: all participants were not able to write a formula that used a *Group By*; binding a control to data not from the `Rows` property was a problem for two programmers and seven end-user developers; the `Parent` concept was a problem for

three programmers and five end-user developers; some of programmers and end-user developers asked for more drag-and-drop functionalities.

After each task, participants answered a questionnaire. The subjective ratings indicate what participants found useful and difficult. As an example, *WYBIWYG* of the *Design Panel*, *E/R Model* and *Interact-Mode* were rated higher by end-user developers than uVis operators, *Parent* concept, and *Error List*. However, as the number of participants is fairly low, it was not possible to make any statistical analysis when it comes to the questionnaire ratings.

Task Selection

Selecting appropriate tasks to use in a usability study is a difficult process. Nielsen says that task should be “as representative as possible to the uses to which the system will eventually be put in the field” [68]. In these studies, I decided to ask participants to create rather than modify an existing visualization. This decision was made because the system is meant to be primarily used for creating visualizations. Also, the creation process involves modification, as the *Drag-Drop-View-Interact* approach builds on incremental actions (drag and drop controls, set formulas, refine them till the expected result is achieved). This approach highlighted different usability problems with the formula language and the Studio. However, using another set of tasks might have highlighted other usability problems. Wilson presents two cases where the wrong set of tasks caused problems in the final product [115]. To address the issue of selecting wrong tasks, I discussed with my colleagues and decided to use the selected tasks.

Evaluator Effect

According to Hertzum and Jacobsen [39], the evaluator effect relates to “differences in evaluators’ problem detection and severity ratings.” The authors [39] state that “the question is not whether the evaluator effect exists, but why it exists and how it can be handled”. The evaluator effect also exists in my usability studies because usability evaluation is related with how the evaluator interprets the results [39]. In their study [39], the results showed that the evaluator effect between two evaluators can scale between 5% to 65%. These figures definitely pose the question how valid the data are. This is not related to the specific choice of usability evaluation method, but is related to the number of evaluators involved. Introducing more evaluator can reduce it, but

not avoid it completely [39]. Ideally, I would have liked to involve more evaluators in my studies, but this was not possible due to limited resources, budget and the required expertise in uVis. On the other hand, the judgments of evaluators on the severity of a usability problem is questionable, as “complete agreement among evaluators is unattainable” [39].

Questionnaires and Interviews

In the usability study with programmers, I asked questions regarding uVis, the approach, and to estimate the development time of an initial version of MProVis using the Studio and other tools. In addition, all participants in these studies answered to some 5-point Likert scale questions. Overall, the results of the interviews and questionnaires showed a high level appreciation of participants towards uVis. It should be noted that these results might have been biased by the conductor. This means that the participants might have overrated uVis due to my presence. According to Robson, this is difficult to avoid [82]. Therefore, the readers should interpret the result with caution.

Chapter 10

Conclusions and Future Work

Constructing visualizations is an important task in many domains: healthcare, financial, logistics, academia, etc. Previous research in InfoVis has focused on helping programmers construct custom visualizations with powerful toolkits, and allowing simple users to create standard visualizations. End-user developers (also known as savvy users) are overlooked. EUD investigates how to empower end-users developers to create, modify and extend software artifacts and gain control over their applications. Neither the InfoVis nor EUD literature has investigated whether end-user developers can construct custom visualizations. This thesis addresses the following research questions: “*Can end-user developers construct custom visualizations?*” and “*Can programmers construct custom visualizations faster?*”

In order to answer the above questions, I conducted a literature review and carried out usability studies with end-user developers and programmers. I reviewed existing literature to obtain an overview of existing InfoVis tools and how they support end-users developers and programmers. As part of this review, I developed a visualization tool taxonomy. This taxonomy, inspired by existing taxonomies, consists of three dimensions: *user skills*, *tool types* and *visualization types*. The results of this review showed that there are no *Drag-and-Drop* tools to create custom visualizations for end-user developers as well as programmers.

In response, I presented uVis that is based on the *Drag-Drop-Set-View-Interact* approach. Extending the uVis formula language with a development environment (uVis Studio) made this approach feasible. Instead of writing code and running the application to view the results, end-users and programmers *drag and drop* controls in the

Design Panel, set uVis formulas for their properties in the *Property Grid*, view immediate visual results in the *Design Panel*, and use *Interact-Mode* to *interact* as end-users with the visualization without switching workspace.

Initially, I made a proof of concept that this approach can be used in practice by an experienced user of uVis. Two custom visualizations were developed within a few hours. Further, I conducted a usability study with six programmers who were asked to create a standard and a custom visualization within three hours. Next, I conducted a usability study with eight end-user developers and one with two clinicians, who are end-user developers. These studies aimed at answering the research questions. The results of the usability studies have been presented in Chapter 6, 8 and 7. This was followed by a discussion of the results and limitations of this work in Chapter 9.

This thesis showed that end-user developers can construct custom visualizations using the *Drag-Drop-Set-View-Interact* with a modest amount of training. At the same time, programmers can construct custom visualizations faster with the *Drag-Drop-Set-View-Interact* in uVis. Additional proof is provided through the development of two custom visualizations by an experienced user of uVis.

EUD and InfoVis communities should consider this research as a starting point for end-user development of visualization. Based on the results of this work, I present some recommendations for researchers and tool developers.

1. As visualizations are all about data, visualization tools should have a *WYBIWYG* feature. This feature makes the visual mappings more transparent.
2. The development environment should allow developers to test end-user interaction without switching workspace. Switching the context from development to runtime is perceived as a barrier.
3. Auto-Completion is known for its usefulness, but introducing database related suggestions is a big improvement.
4. Drag and drop functionality is very important to all users, independent of their IT skills.
5. Usability test visualization development tools with users.

-
6. Constructing custom visualizations with simple visual objects allows high customization, but requires additional mental effort from end-user developers. Providing off-the-shelf controls that can be combined with simple ones should help end-user developers create custom visualization faster.

Future Work

During this research I have faced many limitations and came upon many ideas that were not possible to research within the time frame, but can be interesting for the future. Some of them are very technical and domain specific while others are broader. I present some of them below.

Improve uVis

During the studies, I observed several navigation patterns through the panels. However, identifying which panels were used mostly, navigation patterns and trends need further research. Conducting studies with eye-tracking devices can address these questions better. Future work will concentrate on investigating and identifying appropriate and relevant panels to visualization development. Several design choices were inspired by existing tools, personal experiences, and user feedback. Furthermore, choosing the right colors, fonts, and icons is a delicate matter and requires more investigation to obtain the right balance.

The **Parent** and **Canvas** were confusing to programmers as well as end-user developers. Adjusting the formula language so that the **Parent** is automatically handled by the kernel, and visible on-demand might help them. Yet, this needs more investigation.

Future work will also focus on error handling. A better way of showing error messages to end-user developers is needed. A potential solution is using pop-up windows, but this may affect user satisfaction as pop-up windows may become annoying. Also, the content of the error messages will be revised.

Finally, future work will focus on enriching uVis with more controls, built-in functions and layout algorithms, and addressing the usability problems.

Integrating uVis in Working Environments

This thesis investigated if end-user developers can create custom visualizations. Future work includes integrating uVis in working environments. This will allow us to conduct a summative evaluation with real users and tasks. As a result the overall quality of the tool will be assessed. This integration can investigate how end-user developers can tailor visualizations constructed with uVis. In addition, requirements perspective not addressed in this thesis, such as scalability, interoperability, security, etc., can be evaluated. uVis aims also at extending existing applications with visualizations. Future work should investigate different limitations (e.g. accessing data from an existing database, communicating with existing infrastructure) and identify proper solution.

Platform Independence

The current version of uVis uses the .NET Framework. uVis should be developed for other platforms. The project is currently focusing on how to migrate to the web and mobile platforms. This research aims at investigating how visualizations can be created in tablets and touch screen surfaces applying the *Drag-Drop-Set-View-Interact* approach. At the same time, this research will focus also on other challenging issues such as space efficiency, performance issues, touch-screen limitations, etc.

One Environment - Several Toolkits

Previous research has focused on encapsulating several Java based toolkits in a meta-toolkit called Obvious [29]. Future researchers can apply the same approach, and investigate how different toolkits can be integrated in a development environment. This can facilitate visualization development and allow users to choose a toolkit that takes advantage of the patterns as well as features implemented in each of them.

Simple Users in Development of Custom Visualizations

The InfoVis community has done considerable work to provide visualizations in different domains. Also, extensive work is conducted to improve user satisfaction. However, more work has to be done in order to introduce new audiences in development of custom visualizations. Future research should concentrate on developing new approaches and tools that allow simple users to construct custom visualization.

Appendix A

A Custom Visualization with uVis Formulas

Figure A.1.a presents a custom visualization, inspired by the LifeLines [79], constructed with uVis formulas. It shows the medicine orders and medicine intakes for a patient. Figure A.1 shows also all the controls and their formulas, and the E/R model. In this data model, a patient may have many medicine orders; a medicine order may have several intakes and relates to one medicine type. End-users can search for different patients by changing the patient id in the textbox control and view the medicine orders and intakes. To create this visualization we use 11 controls: one form, three labels, two panels, one timescale, one button, one textbox and one bar. In the following subsections, I focus on the most important concepts, and explain how to bind controls to data, map fields to properties, align controls, and implement interaction.

Bind controls to data

Using rows from one table

This visualization shows medical data for a single patient. The Rows of `panPatient` (Figure A.1.c.6) is this:

```
Rows: tblPatient where tblPatient.ptId = cint(txtPatient!text)
```

Notice that a formula refers to a control property using the *bang* operator(!). Because `ptId` in `tblPatient` is of type `Integer`, we use the function `cint()`, which converts a `String` to an `Integer`. The text property in `txtPatient` (Figure A.1.c.2) is initially 2 (`Init 2`). As mentioned earlier, `Init` allows end-users to change a value at run-time.

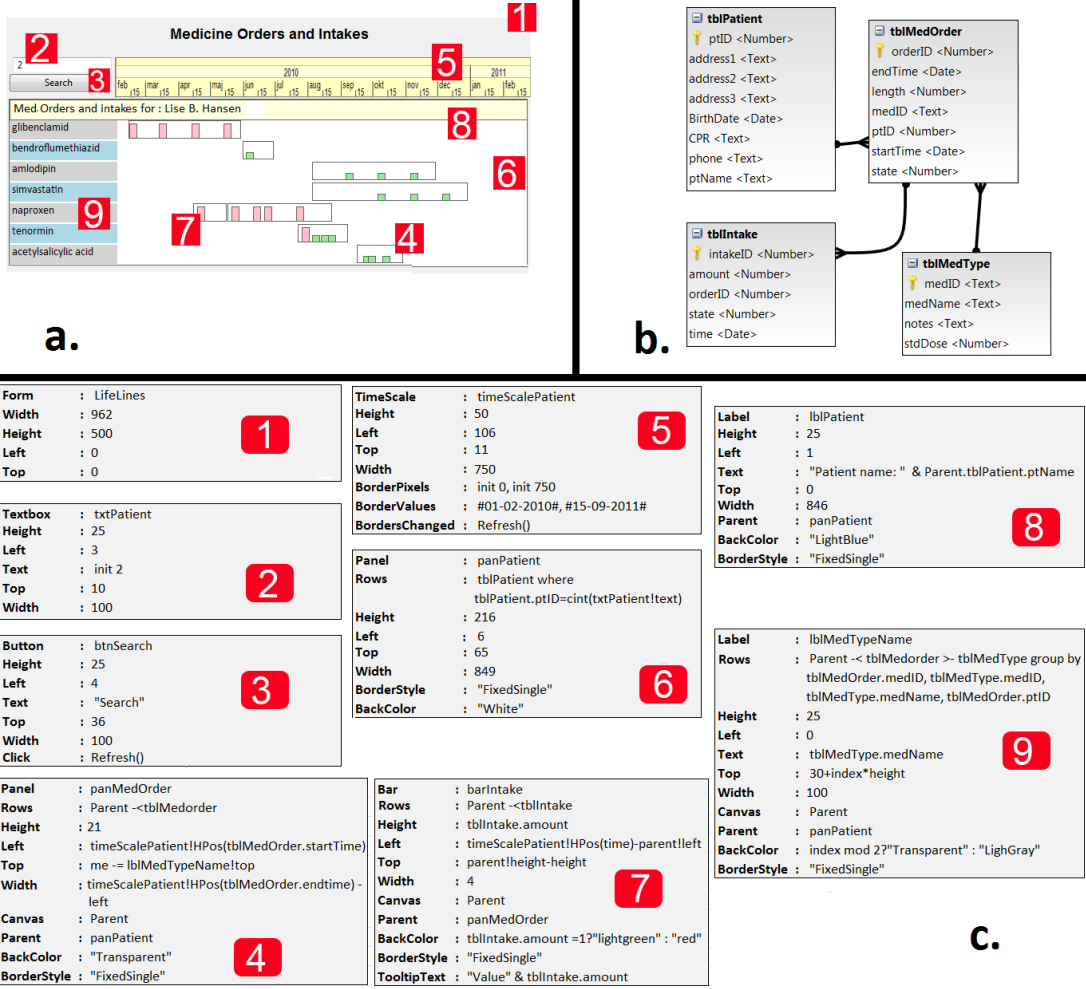


Figure A.1: (a) LifeLines visualization created with uVis. (b) The E/R model. (c) The formulas for each control, which are stored in a *Vis* file.

This formula is evaluated by uVis and translated into this SQL query:

```
Select ptId where ptId=2;
```

As a result, this control is bound to the data row with patient id equals to two.

Using rows from more than one table

To visualize the medicine orders of a patient, the join operator (-<) is used. The `panMedOrder` control is bound to data by means of these formulas for the `Rows` and `Parent` properties:

```
Panel: panMedOrder
Parent: panPatient
Rows: Parent -<tblMedOrder
...
```

The `Parent` formula means: make a bundle of controls for each parent control. The `Rows` formula means: from the parent row, walk to the related rows of `tblMedOrder`, and for each row create a control.

uVis compiles all the formulas, collects fields used (`startTime` and `endTime` used to map the `Left` and `Width` property). Then, generates and executes the SQL query, which corresponds to:

```
SELECT startTime, endTime
FROM tblPatient LEFT JOIN tblMedOrder
ON tblPatient.ptID = tblMedOrder.ptID
WHERE tblPatient.ptID = 2;
```

This complex SQL query, a common scenario in data access, highlights the power and simplicity of uVis. Similar SQL queries may be difficult to write and understand even by programmers, let alone end-user developers.

In this case, we could have specified the `Rows` property without using the `Parent` keyword, but the formula would have had a *where clause*:

```
Bar: panMedOrder
Rows: tblPatient -<tblMedOrder
      where tblPatient.ptId= cint(txtPatient!Text)
...
```

In the same way, the `Rows` property of `barIntake` is specified.

Map fields to properties

The formula language can map a field to a property, and also use the field's value in a conditional statement: For example, the back color of `barIntake` is defined as follows:

```
Bar: barIntake
BackColor: tblIntake.amount = 1 ? "lightgreen" : "red"
...
```

Align controls

To align controls horizontally, formulas use the predefined function of the `TimeScale`, `HPos()`. The `HPos()` function translates a point in time into the corresponding pixel position. The `Left` formula of `panMedOrder` uses this function to get the pixel position corresponding to the date-time field `startTime`. The `Width` formula uses the `endTime` field to calculate the width in pixels.

```
Panel: panMedOrder
Left: timeScalePatient!HPos(starttime)
Width: timeScalePatient!HPos(endtime) - Left
...
```

The formula language has a control-join (`-=`) operator that “walks” from a table row to a control bound to the same row. In this case, this operator defines the top of `panMedOrder` controls:

```
Panel: panMedOrder
Top: Me >- tblMedType -= lblMedTypeName!Top (or Me -= lblMedTypeName!Top)
...
```

This means: from my medicine order row, walk to the related `tblMedType` row; from it walk to the `lblMedTypeName` bound to the same row; then use its top. In this case, the `>-tblMedType` can be omitted because `uVis` can find the path on its own.

Implement interactions

When an end-user interacts with a control, an event is triggered. To implement a simple search function, the `Text` property of `txtPatient` and the `Click` property of `btnPatient` are specified as follows:

Textbox: txtPatient

Text: Init 2

...

Button: btnPatient

Click: Refresh()

...

Let us assume that an end-user changes the text value from 2 to 3, and clicks the button. The click event is triggered and **Refresh()** is called. This function asks uVis to recompute the formulas and check if the SQL has changed. If so it re-queries the database, and updates the form.

Appendix B

Evaluation with Programmers - Documentation

This appendix presents the documentation used during the first study. At the end it gives an example of a usability log for one participant.

Introduction to uVis

I explained the uVis principles and syntax to the participant referring to:

Controls

- .Net Controls
- uVis Controls

Properties

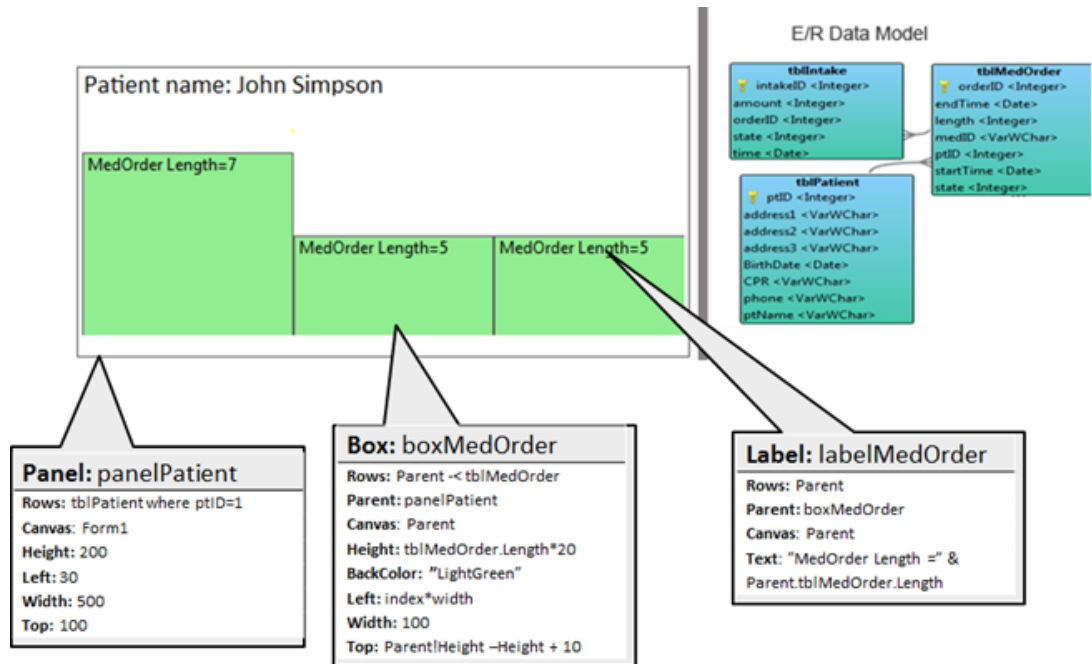
- uVis Properties
- Designer Property
- Event Properties
- Special property - Rows
- Special property - Parent
- Special property - Canvas

Formula Language

- Dot operator (.)
- Bang Operator (!)
- Join Operators (-<or >-)
- Control Join Operator (-=)
- Me
- Init
- Index
- Parent
- System
- SQL Keywords
- If-Statement
- String Type
- Date Type

Task 1

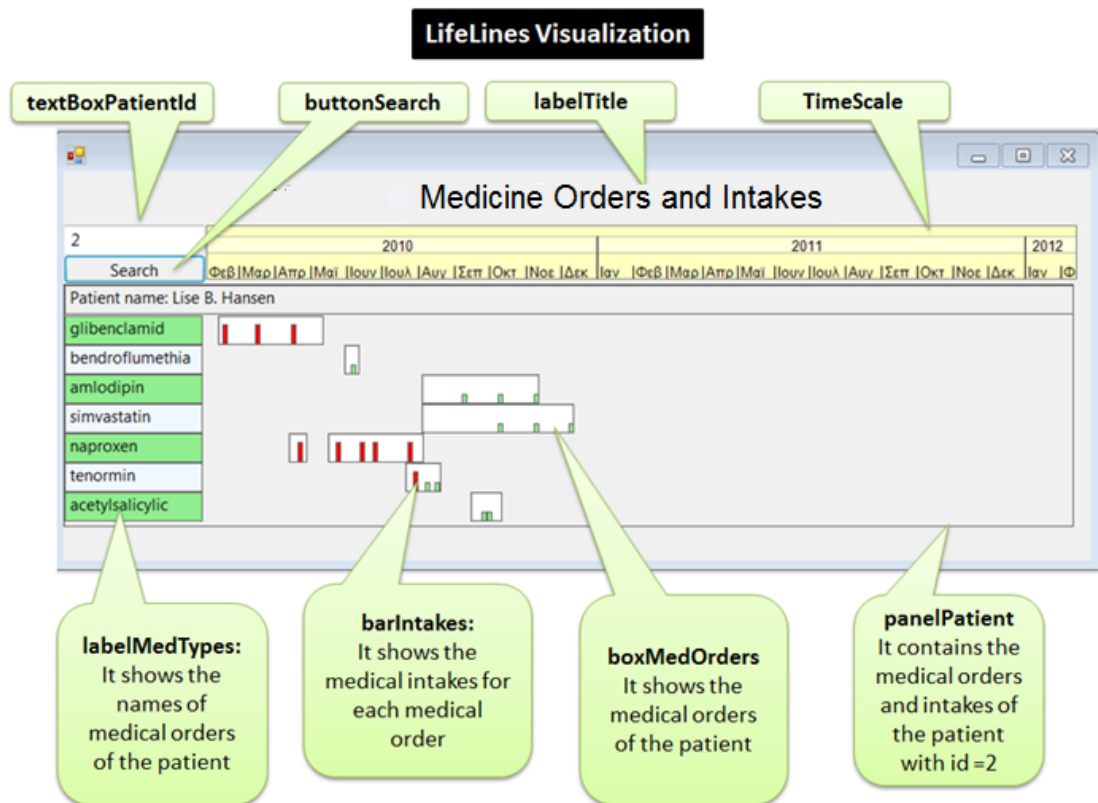
Create a simple bar chart as shown.



Scanned version of the original.

Task 2

You will have to create a simple version of the LifeLines, as shown.



Scanned version of the original.

Hint Page

Useful formula examples:

- Use the `-<` operator to join tables: e.g. `tblA -<tblB` or `Parent -<tblB`
- Use *Group By* to group the rows and obtain unique values: e.g. `Parent -<tblB >-tblC group by tblB.Id, tblC.Id`
- Use `Me` keyword and the `-=` operator to align a control vertically to another control: e.g. `me -= LabelA!Top`
- To convert a `Text` to a number use `cint(Text)`
- To convert a `Number` to `Text` use `cstr(Number)`
- Use `Init` to make a value changeable at run-time (e.g. `Text: Init 1`)
- To implement interaction in the `TimeScale`, set the property `BorderChanged` of the `TimeScale` to `Refresh()`. The `Refresh()` recomputes all the values of the controls in the form.
- To implement interaction and be able to search for patients, set the `Click` property of the `Button` to `Requery()`. The `Requery()` queries the database, and shows the results in the form.
- uVis Studio uses the Top-Down approach of placing the control. Set `Top` to `Parent!Top-Height`.

Scanned version of the original.

Semi-structured Interview

Background Questions:

1. Identification:
 - a. Name;
 - b. Title;
 - c. Profession;
 - d. Age;
 - e. Nr of years working in the current position.

Background:

2. How many years have you been coding?
3. How many years have you been using E/R databases?
4. Have you used spreadsheet formulas before? E.g. MS Excel formulas?
5. How long have you been working with visualization?
6. Do you create your visualizations from scratch? Do you use any toolkit or tool?

uVis - Other tools

7. With which tool/toolkits would you compare uVis, and why?

uVis Studio:

8. What do you think of the Studio? Could you compare it with other Development environments?
9. What do you think of the live design panel?
10. What do you think of the modes?
11. Would this help you in created better visualizations?
12. Would it help in the development process?

uVis visualization development process

1. How do you start (do you follow any steps) when you want to create a visualization?
2. How was the last task where you had no training?
3. How different is it from what you have been doing so far? Using building blocks and binding data to each block?
4. Do you think uVis facilitates the process?
5. Do you think uVis can engage user with limited programming skills to create advanced visualization, such as Lifelines?

Scanned version of the original.

Questionnaire

After each task the programmer replied to the questionnaire through Google Docs.

Question	Rate				
How easy was it to use uVis formulas?	1	2	3	4	5
How easy was it to understand the uVis properties: Rows, Parent and Canvas.	1	2	3	4	5
How easy was it to use the uVis operators (., !, -<, -=)?	1	2	3	4	5
How easy was it to bind controls to data?	1	2	3	4	5
How easy was it to use uVis Studio?	1	2	3	4	5
How useful was the Auto-Completion in the property grid?	1	2	3	4	5
How useful was it to preview the live version of the visualization in the Design Panel?	1	2	3	4	5
How useful was it to interact with the Design Panel?	1	2	3	4	5
How useful was it to see the E/R model?	1	2	3	4	5
How useful was it to see the Error List window?	1	2	3	4	5
How useful was to have the Interact-Mode?	1	2	3	4	5
Do you have any suggestion on how to improve uVis?					

Questions used in this usability study.

B.1 Usability Log

This is the present the usability log for the first participant. The other logs were recorded in the same way.

setting the background: ~~into~~ ~~with~~
 referring to the with

That's interesting!

Users wanted to use directly
~~Date~~ ~~Max~~, without specifying a group by

~~Task 2! Lifelines~~

→ Explorer: ~~why do you need to show it!~~

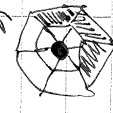

a) Open uVis Studio and the Lifelines
 b) Explain the controls used and the whole context.
 c) Explain what we want to visualise with ~~this~~ Lifelines
 d) Explain how the parent is used, the group by

Uvis: John

Recording: 1

~~Task 1~~

- ① Top Down Approach / Bottom up
- ② Labels for more information
- ③ Users wants to drag and drop a control even after specifying the formula
- ④ Properties should be ordered and put Name on the top
- ⑤ Users does not know the properties, he can use. He asked for a Border Color.
- ① Errors comparing
- ② keep suggestion in ~~bullet~~ ~~list~~
 → i.e. Top window should still be in the list

<p>→ Issue with the intelligence.</p>	<p>30 mins</p> <p>Min: 54 / (should create the Logos)</p>
<p>→ Users asked if he could use the limit instead of TOP Limit is M7SQL.</p> 	<p>→ Convers: don't understand it</p> <p>→ Changed the <u>perched</u> name and the label went out.</p>
<p>→ Live Version of the Design Panel. didn't understand it</p> <p>Live Preview →</p>	<p>→ Interaction Made / Date view</p> <p>made not on the top, at the left, users didn't noticed that</p> <p>→ <u>could reconfigure</u></p>
<p>e) Explain the vertical alignment and horizontal alignment</p> <p>→ User was confused with the</p>	<p>→ User used dot and <u>borg</u> both</p>  <p>→ A hierarchy of controls.</p>

Users confused with term "BANG"

Several bugs with

- a) with sense
- b) Refresh
- c) with renewing
- d) with selecting
- e) with

When users aligned the controls said "that's fancy, that means I did understand smth"

- wonder what happens if the time scale name changes.

= Difficult to understand the error

Users confused with term "BA"

Several bugs with

- a) with sense
- b) Refresh
- c) with renewing
- d) with selecting
- e) with

When users aligned the controls said "that's fancy, that means I did understand smth"

- wonder what happens if the time scale name changes.

= Difficult to understand the error

⇒ It's a ~~very~~ different way of thinking, and restrict it as the visualization is bound to data.

⇒ ~~Flexibility is not about~~

⇒ Wonder if you can group by twice?

"It's really cool"
—o—

~~Interview~~

- E/R ⇒ very good
- Speed ⇒ used, and good but not as in E/R.
- Vis: at least 2 years.

Tools: Java Sketch in Python, used D3, Prefuse.

Q. 1.

It helps the fact we see and keep the general goal, when I am fine tuning I go to deep in details, and after 10 hours I ~~got~~ look what I started out.

Q. 3

Little similarity in D3

In Prefuse and D3 you have the frame work.

Interview

Never used E/R in before and D3, always 1 table pre processing and then start

→ MSProvis, start looking and thinking on it.

It's cool to use E/R tables.

→ Needed the E/R model.

⇒ Needed to explain the domains

⇒ the join are difficult UML has several definitions

⇒ Uses tool kits, with toolkits 3-weeks

the "x" is an advantage if you have been taught like that.

⇒ From scratch, 5 weeks.

⇒ In the tool can do it in max 6 hours. Assume we

—o—

⇒ hit and operator frustrated me.

have a stable

⇒ ~~the notes~~

B.2 Test Report

This is the present the test report usability for the first participant. The other test reports were prescribed in the same way.

Background - Participant 1

Male; 30 years old; working as a PhD student in Computer Science from 2008; has been coding from 1999; has a very good knowledge of E/R databases; has a good knowledge of MS Excel spreadsheet formulas; has been working for the last two years with visualizations; has coded visualizations from scratch using Python, and has used Prefuse, and D3.

Task 1: Results

The `Parent` and `Canvas` properties caused some confusion, as the user assumed they were the same (*Problem: Cumbersome*). Further, specifying the `Rows` property was not easy to understand, as the Left-Join operator (`-<`) was not very intuitive to the user (*Problem: Medium*). On the other hand, he really liked the simplicity of the formulas where he could refer to properties and data-fields easily. In one case, he could change the back-color by simply referring to a data field and using the simplified version of the `IF-Else` statement, and view the result immediately. In his experience with other tools, sometimes he found himself wasting too much time trying to implement simple things by means of digging into the code.

The Studio used a top-down (specifying the `Top` property) approach for placing controls on the form (*Problem: Minor*). The user was more used to the bottom-up approach, and found the top-down approach a bit cumbersome. Also, while he was creating the visualization, he would have liked to see more details in the form (*Problem: Missing Functionality*). For example, adding a label that indicates the bar was bound to table `tblMedOrder`. One of the limitations in the Studio is that users are not allowed to change the control's position when the position is set to a formula (*Problem: Missing Functionality*). The user understood the reason, but suggested that the user should decide about that.

The user really appreciated the WYBIWYG feature of the Design Panel and kept the `DataView` Mode active. Also, the Auto-Completion was useful, but the user prefers

that the suggestion should not be removed when the typed word match the suggestion (*Problem: Minor*). Further, in some cases the Auto-Completion did not perform as expected (*Problem: Bug*). It was obvious that he found the E/R model useful as he referred to it while he was setting the **Rows**, and mapping properties to table fields. The Error-List window was not very helpful, as the user found the errors a bit confusing and would have liked to have more details (*Problem: Cumbersome*), or a way to debug (*Problem: Missing Functionality*). However, he appreciated that by double-clicking on the error, the wrong formula was colored in red in the property-grid.

Task 2: Results

The user faced some difficulties specifying the correct formulas for the **Rows** (*Problem: Medium*). The difficulties were caused by the **Parent** concept (*Problem: Cumbersome*), and the Join-Left operator ($-<$) (*Problem: Medium*). I noticed that the user had difficulties specifying a complex formula that joined 3 tables and used a group by (*Problem: Task Failure*).

The E/R Model, and the Auto-Completion assisted him in specifying the correct formulas. From my observation the Auto-Completion worked not only to suggest, but also to ensure the user that he was writing the correct formula.

As several controls were used to construct this visualization, the user would have preferred having a control hierarchy window (*Problem: Missing Functionality*) instead of the combo-box in the Property Grid (*Problem: Minor*).

The user was not able to understand the Control-Join ($-=$) operator initially, but after thinking-aloud and assuming how that would have been implemented, he managed to figure out the algorithm. He liked the idea, and found it useful. The error messages were not very helpful to him as they were difficult to understand (*Problem: Cumbersome*). Once the system failed to respond, and we had to close and open the visualization (*Problem: Bug*).

The user unchecked the *DataView* mode to test the mode. This action caused some problems in the following steps. He bound controls to data, but did not get any immediate feedback in the Design Panel. The user succeeded in implementing the interaction in the **TimeScale** control, and test it by dis-activating the *InteractionMode*. The user found the Modes confusing because he would have liked to see it over the Design Panel (*Problem: Minor*). Also, better and more explicit names for the modes would have

made them more understandable (*Problem: Minor*). At the end, he suggested that descriptive tool-tips could have helped him in understanding better the Studio and its features (*Problem: Missing Functionality*).

Semi-Structured Interview

The user liked the Studio, and how he could interact, bind, and view the controls in the Design Panel. Auto-completion was helpful, but in some case failed. He has been using the frameworks defined in Prefuse and D3, but always he had to pre-process the data into a single table. He found it very interesting and believes that it is important to allow users to access tables in relational databases directly. However, accessing relational data may be challenging when it comes to join data from different tables. The problem is related with SQL, and the knowledge the user has on E/R databases. He said that viewing the E/R model facilitated his work, but he would have liked to see the real data as well. uVis operators and keywords such as `Parent` and `Canvas`, frustrated him and it took some effort to understand clearly the concepts.

Regarding the development process, in comparison to other tools the user has used, he said: "It is a different way of thinking, and may restrict it as the visualization is bound to data. But, it is cool as well". Also he said that "The Studio helps me see and keep the general goal. When I am programming, I go to deep in details, and after a couple of hours I loose what I started at."

At the end, I showed him an early version of MSProVis, and asked how much time would take to him to implement it in the Studio versus using other tools he knows. The user looked at MSProVis, checked the E/R Model, and estimated that using other toolkits would take approximately 3 weeks, and from scratch around 5 weeks. Using the Studio he reported: "Assuming that I have all what I need, like controls, proper errors, and a stable Studio, I think I would be able to do it in 6 hours. Also, I have to have some domain knowledge, meaning I should know what I am visualizing".

Appendix C

Evaluation with End-User Developers - Documentation

This appendix presents the documentation used during the second study.

Task 1

Task 1: Introduction

Watch the video and replicate the steps with uVis Studio.

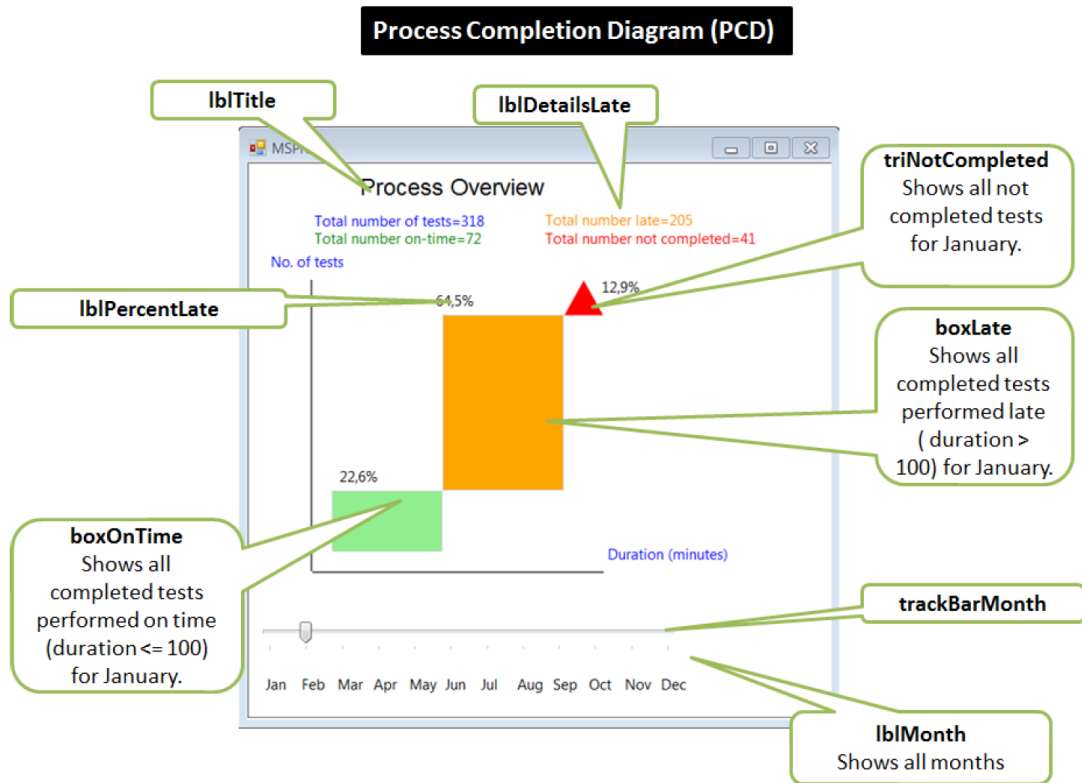
You can stop the video, move forwards and backwards.

Link: <https://dl.dropbox.com/u/5614860/Bar.avi>

Scanned version of the original.

Task 2: Create the Process Completion Diagram

You will have to create the Process Completion Diagram, as shown:



Scanned version of the original.

Hint Page

Useful example of formulas:

- You can use *Bottom* Property or you can compute it as `Top + Height`
- You can use *Right* Property or compute as `Left + Width`
- SQL Aggregate functions for control bound to rows:
 - `Min(fieldname)` to get the minimum value in a table column
 - `Max(fieldname)` to get the maximum value in a table column
 - `Count(fieldname)` to get the number of rows in a table
 - `AVG(fieldname)` to get the average value in a table column

NOTE: Use group by whenever you are using the SQL Aggragetes.

- Use `Init` to make a value changeable in runtime (i.e. `Value: Init 1`)
- To convert *Text* to a number use `cint(Text)`
- To convert *Number* to Text use `cstr(Number)`
- Use `Round(Number)` to round the number (i.e. `Round(1.2343)` will be rounded to `1.2`)
- Use `Requery()` for the `ValueChanged` on the Track Bar control.

Scanned version of the original.

Structured Interview

Background Questions:

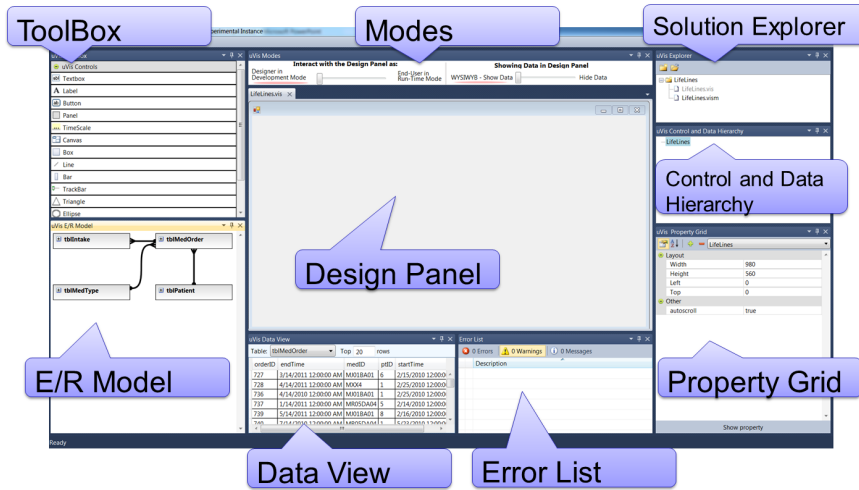
1. Identification:
 - a. Name;
 - b. Title;
 - c. Profession;
 - d. Age;
 - e. Nr of years working in the current position.
 - f. Degree (i.e. Bachelor/ Masters/ PhD)

Background:

2. Have you ever coded, and if so, how many years have you been coding?
3. When did you code last time?
4. Have you ever used E/R database, and if so, how many years have you been using E/R databases?
5. When did you use databases last time?
6. Have you ever used a development environment before? E.g. Visual Studio, Eclipse?
7. When did you use development environment last time?
8. Have you ever used spreadsheet formulas before? E.g. MS Excel formulas?
9. Have you ever designed a visualization?
10. Have you ever coded a visualization?
11. Which tools have you used?

Scanned version of the original.

uVis Studio and Reference Card



Scanned version of the original

© Soren Lauesen 2012

uVis Reference Card – Simplified Version v1.1

Paths in tables - Joins

Rows: tblA
Get tblA from the data map. Generate a control for each data row.

Rows: tblA Where id = 35
Get only the rows where the id field is 35.

tblA Where id = bcCtrlText
Get only the rows where the id field matches the text in the bcCtrl box.

tblA Group By name
Divide all tblA rows into groups according to their name. Calculate aggregates for each group according to the formula. The result has one row for each group.

tblA Where name = bcCtrlText AND age = tblAgeText
Get only the rows where the name field matches the text in the bcCtrl box, the age field matches the text in the tblAge box and groups them by the Fields.

tblA -> tblB
As join many, but for each A row without B rows, include an A row with nulls in the B fields.

tblA -> tblB Where tblB name="tbl" Group By tblA id
Get all B rows related to the A rows and include the A fields. Include only rows with name="tbl". Divide into groups according to tblA's id field.

SQL aggregate functions

Row group - Group By: SQL aggregate functions need a group by data source. Each row in the data source has a group of source rows. Aggregate functions count the rows in the group, sums them, etc.

Count(x) Number of rows in my row group, omitting rows with fields = null.

Min(x) Minimum of x fields in ...

Max(x) Maximum of x fields in ...

Avg(x) Average of x fields in ...

Sum(x) Sum of x fields in ...

Horizontal & Vertical alignment

tblScale (tblParent): Function: Call property function. Align the controls to the TimeScale tblScale where list the date.

Me -> tblID | Top Control walk: Walk to my related tblID box. Get its Top property.

Align the controls to the related control tblID using its top.

Entity Relationship (E/R) data model

```

    graph TD
      tblPatient --> tblMedOrder
      subgraph tblPatient
        pID
        address1
        address2
        address3
        BirthDate
        CPR
        phone
        pHName
      end
      subgraph tblMedOrder
        orderID
        endTime
        length
        medID
        pID
        startTime
        state
      end
    
```

Panel: panelPatient
Rows: tblPatient where pID=1
Canvas: Form1
Height: 200
Left: 30
Width: 500
Top: 100

Box: boxMedOrder
Rows: Parent -> tblMedOrder
Parent: panelPatient
Canvas: Parent
Height: tblMedOrder.Length*20
BackColor: "LightGreen"
Left: index*width
Width: 100
Top: ParentHeight - Height + 10

Label: labelMedOrder
Rows: Parent
Parent: boxMedOrder
Canvas: Parent
Text: "MedOrder Length = " & Parent.tblMedOrder.Length

Paths from Parent

Parent.pID Field in my parent's data row.

Parent! Top Property in my parent control.

Rows: Parent -> tblB ParentJoin For each parent control, generate a bundle of child controls. The bundle contains a control for each related B row.

Refer to Control and Data Field

ControlA! Top Refer to Property, Top in ControlA. NOTE: The Bang is used.

Top or Me! Top Refer to Property of the same control. NOTE: Me means this control.

Refer to a table's field id or Me - id Refer to a field in my data row. NOTE: The DOT is used.

tblA id Refer to a field with table prefix. NOTE: The DOT is used.

Supported Types

1 Number
"Letter to..." Text
"John" & "Smith" Text
Concatenate two tests in one: "John Smith"

True, False Booleans

#24-12-2011# Date
Correspond to 24th Dec 2011

Conversion Functions

CInt("3") = 3, omitting prefix.
Convert a text to a number

CSInt(23) = "23": No preceding space.
Convert a number to a text

Round(2.123) = 2.1 (Double)
Rounding a number.

uVis Functions for Event Handling

Refresh() Recalculates all controls in the Form.

Requery() Execute the query specified at ROWS property and recalculates all controls in the Form.

Operators and IF-Else

* Multiply, Result type is Integer, Double, etc.

/ Divide, Single or Double result, 5/2 = 2.5

\ Integer divide, result truncated, 5/3 = 1

Mod Modulus (remainder), 5 Mod 3 = 2

++ Add and subtract

& Concatenation, String result

A ? B : C If A is true, B else C.
Simplifies IF-ELSE statement

Scanned version of the original.

uVis Studio Shortcuts

Action	Mouse and Keys combinations
Delete a control	CTRL + Delete
Copy a control	CTRL + C
Paste a control	CTRL + V
Undo	CTRL + Z
Redo	CTRL + Y
Call Refresh	CTRL + F5
Select a control	Mouse Click
Select the underlying control	CTRL + Shift + Mouse Click

Scanned version of the original.

Appendix D

Evaluation with Clinicians - Documentation

This appendix presents the documentation used during the second study. At the end it presents a detailed usability log for one participant.

Task 1 - Introduction to uVis

You will create a simple bar chart with the uVis formulas and the Studio. You should follow the steps described below.

1. Drag and drop a *Canvas* in the middle of the Design Panel.
2. Move the canvas to the *Top* of the Design Panel using the mouse.
3. Move the canvas to the *Left* of the Design Panel using the Property Grid.
 - a. Set *Left* property to 0.
4. Bind the Canvas to the first row of a table in the database.
 - a. Set the *Rows* Property, for example, to `:tblPatient where ptID=2`
5. Can you view the data in the Data View window?
6. Set the *BackColor* property to "White". **NOTE:** the double quotes are required.
7. Add a *Bar* control inside the *Canvas*.
8. *Parent* Property of the Bar is set to Canvas. This means that the Bar refers to the rows of Canvas. In our case it refers to `tblPatient where PtId=2`
9. Set the *Rows* to `Parent-<tblMedOrder using` the E/R Model Window .

Right-click on the relationship line and select the suggestion.

NOTE: This formula allows us to join two tables.

In plain text it means: Join the Parent rows (in this case= `tblPatient` where patient id is 1) with the rows in `tblMedOrder` where patient id is 2.

In SQL means : `SELECT ptID FROM tblPatient JOIN tblMedOrder ON tblPatient.ptID = tblMedOrder.ptID WHERE tblMedOrder.ptID = 2;`

10. Set *Left* to "index*width"
11. Set *Top* to `Parent!Height-Height`.

NOTE: The (0,0) coordinates start from the top of the Canvas not of the Form. The position of a control inside a canvas is relative to the canvas.

OR: you could rename the TOP property to Bottom.
12. Click on the Bar. Can you view the data in the Data View?
13. Can you find the field *length* in the E/R Model?
14. Set the *Height* Property of the Bar to the field *length*.
 - a. You can type it, or
 - b. You can go to the E/R Model, right click over the field *length*, and select Replace: `tblMedOrder.length`

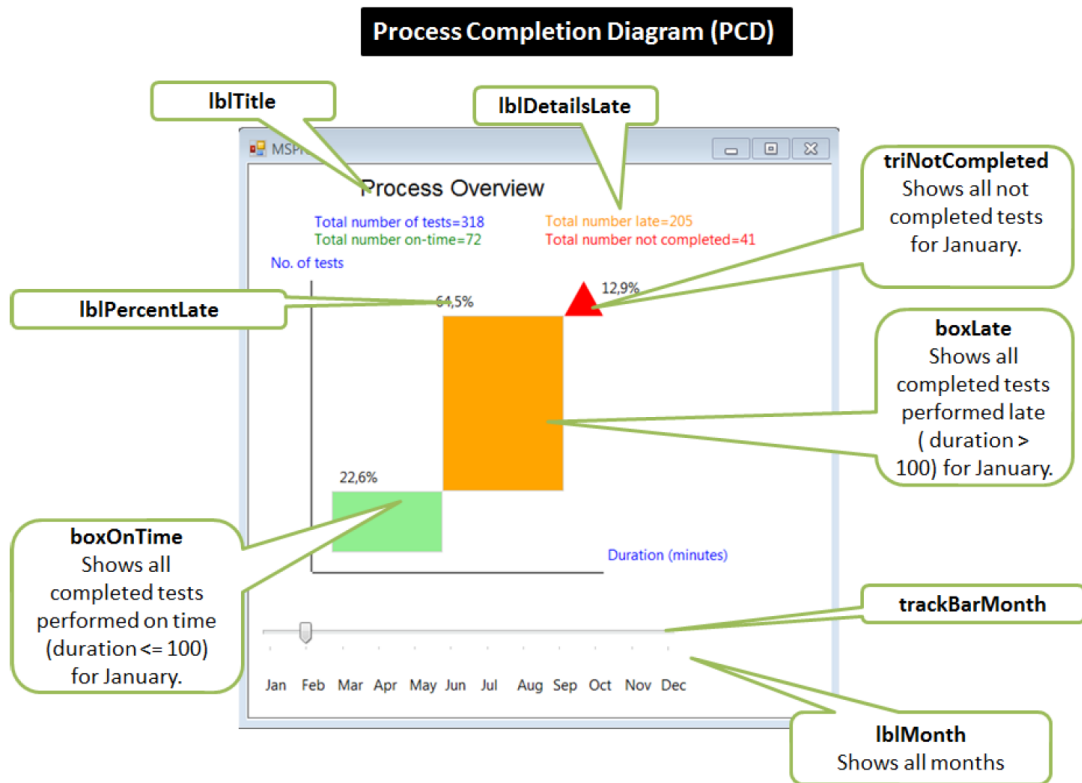
Scanned version of the original.

-
17. Set the formula of the *Tooltiptext* to "Length = " & length
 - a. This means that a tooltip is added to the bar, and will show the length value when we click on the bar.
 18. Move the slider in the **Interact with the Design Panel in Modes** window to *End-User in Run-Time Mode*
 19. Click on the bar to try the ToolTip.
 20. Move the slider in the **Showing data in Design Panel in Modes** window to hide data. Can you understand what happened?

Scanned version of the original.

Task 2: Create the Process Completion Diagram

You will have to create the Process Completion Diagram, as shown:



Scanned version of the original.

Useful example of formulas:

- You can use *Bottom* Property or you can compute it as `Top + Height`
- You can use *Right* Property or compute as `Left + Width`
- SQL Aggregate functions for control bound to rows:
 - `Min(fieldname)` to get the minimum value in a table column
 - `Max(fieldname)` to get the maximum value in a table column
 - `Count(fieldname)` to get the number of rows in a table
 - `AVG(fieldname)` to get the average value in a table column

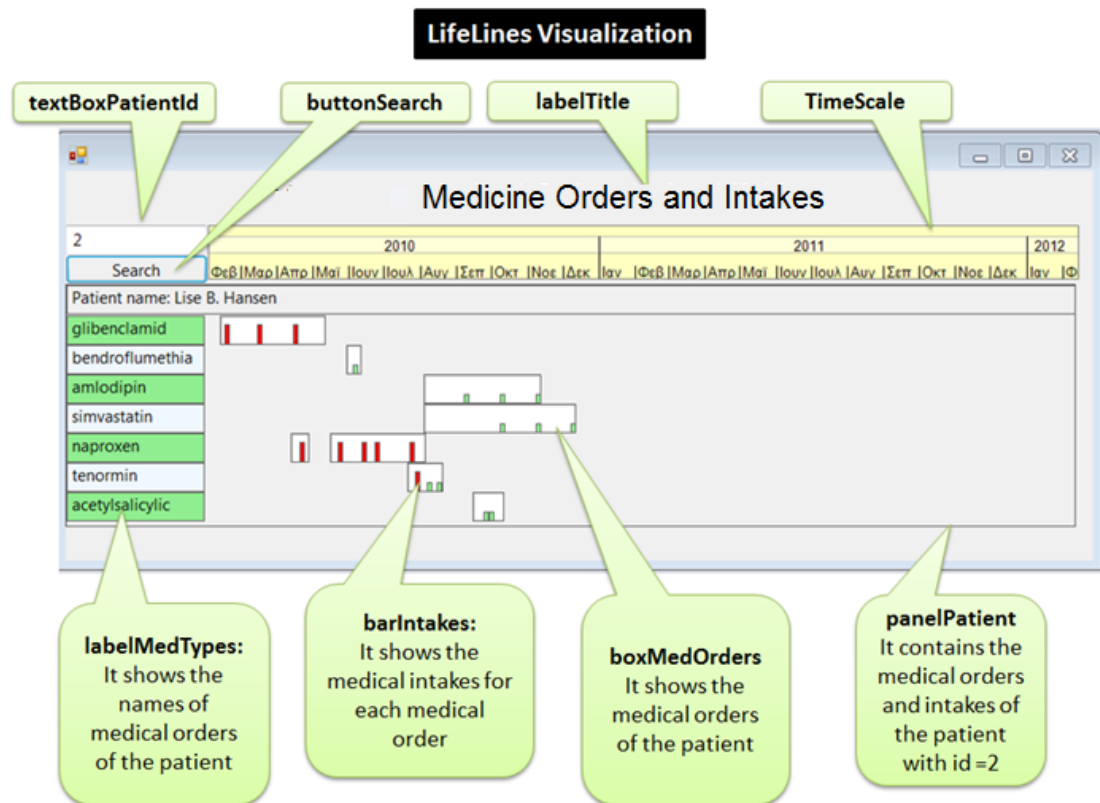
NOTE: Use `group by` whenever you are using the SQL Aggragetes.

- Use `Init` to make a value changeable in runtime (i.e. `Value: Init 1`)
- To convert *Text* to a number use `cint(Text)`
- To convert *Number* to Text use `cstr(Number)`
- Use `Round(Number)` to round the number (i.e. `Round(1.2343)` will be rounded to `1.2`)
- Use `Requery()` for the `ValueChanged` on the Track Bar control.

Scanned version of the original.

Task 3 - Create the LifeLines

You will have to create the LifeLines, as shown.



Scanned version of the original.

Useful formulas examples:

- Use the `-<` operator to join tables: i.e. `Parent -< TblMedOrder`
- Use **Group By** to group the rows and obtain unique values: i.e.
`Parent-<tblMedOrder>-tblMedType group by
tblMedOrder.MedId, tblMedType.MedId, tblMedOrder.PtId,
tblMedType.MedName`
- Use **me** keyword and the `-=` operator to align a control vertically to another control:
i.e. `me -= LabelA!Top`
- To convert *Text* to a number use `cint (Text)`
- To convert *Number* to Text use `cstring (Number)`
- Use `Init` to make a value changeable in runtime (i.e. `Text: Init 1`)
- Use `Refresh()` for the `BorderChanged` in the `TimeScale`
- Use `Requery()` for the Click on the `Button`.
- uVis Studio uses Top-Down approach of placing the control. Set `Top` to
`Parent!Height - Height (as used in Task 1)`

Scanned version of the original.

Structured Interview

Background Questions:

1. Identification:
 - a. Name;
 - b. Title;
 - c. Profession;
 - d. Age;
 - e. Nr of years working in the current position.
 - f. Degree (i.e. Bachelor/ Masters/ PhD)

Background:

2. Have you ever coded, and if so, how many years have you been coding?
3. When did you code last time?
4. Have you ever used E/R database, and if so, how many years have you been using E/R databases?
5. When did you use databases last time?
6. Have you ever used a development environment before? E.g. Visual Studio, Eclipse?
7. When did you use development environment last time?
8. Have you ever used spreadsheet formulas before? E.g. MS Excel formulas?
9. Have you ever designed a visualization?
10. Have you ever coded a visualization?
11. Which tools have you used?

Scanned version of the original.

Questionnaire

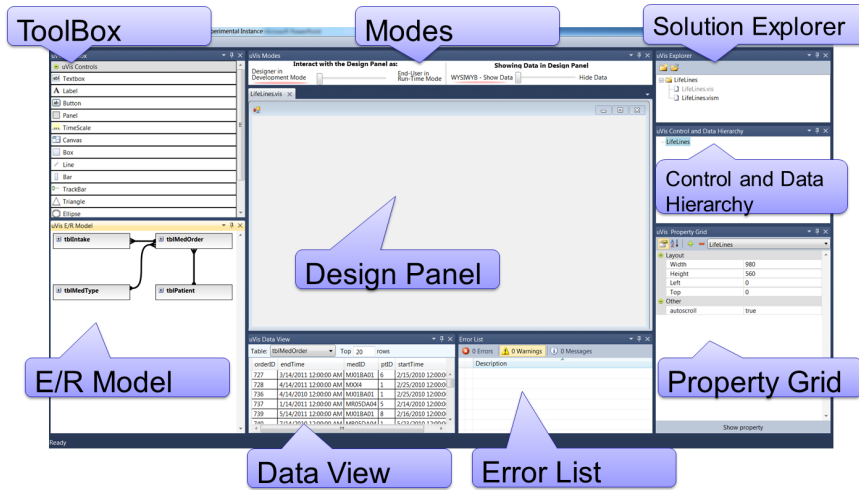
After each task the clinician replied to the questionnaire through Google Docs.

Question	Rate				
How easy was it to use uVis formulas?	1	2	3	4	5
How easy was it to understand uVis properties: Rows, Parent and Canvas.	1	2	3	4	5
How easy was it to use uVis operators (., !, -	1	2	3	4	5
How easy was it to connect controls with data?	1	2	3	4	5
How easy was it to use uVis Studio?	1	2	3	4	5
How useful was the Auto-Completion in the property grid?	1	2	3	4	5
How useful was it to preview the live version of the visualization in the Design Panel?	1	2	3	4	5
How useful was it to interact with the Design Panel?	1	2	3	4	5
How useful was it to have the modes?	1	2	3	4	5
How easy was it to use test the application as an end-user?	1	2	3	4	5
How useful was it to see the E/R model?	1	2	3	4	5
How useful was it to set formulas from the E/R model?	1	2	3	4	5
How useful was it to see the Error List window?	1	2	3	4	5
How useful was it to see the real row-data in the window Data View?	1	2	3	4	5
How useful was it to see the controls in the window Control and Data Hierarchy?	1	2	3	4	5
How much does the formula language facilitates the visualization development model?*	1	2	3	4	5
How much does the development environment facilitates the visualization development model?*	1	2	3	4	5
Do you think you could use uVis in your domain and create visualizations?	1	2	3	4	5
Do you have any suggestion on how to improve uVis?					

*Optional

Questions used in this study.

uVis Studio and Reference Card



Scanned version of the original

© Soren Lauesen 2012

uVis Reference Card – Simplified Version v1.1

Paths in tables - Joins

Rows: tblA
Get data from the data map. Generate a control for each data row.

Rows: tblA Where id = 35
Get only the rows where the id field is 35.

tblA Where id = bcCritText
Get only the rows where the id field matches the text in the bcCrit box.

tblA Group By name
Divide all tblA rows into groups according to their name. Calculate aggregates for each group according to the formula. The result has one row for each group.

tblA Where name = bcCritText AND age = tblAgeText
Get only the rows where the name field matches the text in the bcCrit box, the age field matches the text in the tblAge box and groups them by the Fields.

tblA -> tblB
As join many, but for each A row without B rows, include an A row with nulls in the B fields.

tblA -> tblB Where tblB name="tbl" Group By tblA id
Get all B rows related to the A rows and include the A fields. Include only rows with name="tbl". Divide into groups according to tblA's id field.

SQL aggregate functions

Row group - Group By: SQL aggregate functions need a group by data source. Each row in the data source has a group of source rows. Aggregate functions count the rows in the group, sums them, etc.

Count(x) Number of rows in my row group, omitting rows with fields = null.

Min(x) Minimum of x fields in ...

Max(x) Maximum of x fields in ...

Avg(x) Average of x fields in ...

Sum(x) Sum of x fields in ...

Horizontal & Vertical alignment

tblScale (tblParent): Function: Call property function. Align the controls to the tblScale tblScale where list the data.

Me -> tblID | Top Control walk: Walk to my related tblID box. Get its Top property.

Align the controls to the related control tblID using its top.

Entity Relationship (E/R) data model

```

tblPatient
├── pID
├── address1
├── address2
├── address3
├── BirthDate
├── CPR
├── phone
└── pName

tblMedOrder
├── orderID
├── endTime
├── length
├── medID
├── pID
├── startTime
└── state
    
```

Label: labelMedOrder

Rows: Parent

Parent: boxMedOrder

Canvas: Parent

Text: "MedOrder Length = " & Parent.tblMedOrder.Length

Panel: panelPatient

Rows: tblPatient where pID=1

Canvas: Form1

Height: 200

Left: 30

Width: 500

Top: 100

Box: boxMedOrder

Rows: Parent -> tblMedOrder

Parent: panelPatient

Canvas: Parent

Height: tblMedOrder.Length*20

BackColor: "LightGreen"

Left: index*width

Width: 100

Top: Parent.Height - Height + 10

Paths from Parent

Parent.pID Field in my parent's data row.

Parent! Top Property in my parent control.

Rows: Parent -> tblB ParentJoin For each parent control, generate a bundle of child controls. The bundle contains a control for each related B row.

Refer to Control and Data Field

ControlA! Top Refer to Property, Top in ControlA. NOTE: The Bang is used.

Top or Me! Top Refer to Property of the same control. NOTE: Me means this control.

Refer to a table's field id or Me - id Refer to a field in my data row. NOTE: The DOT is used.

tblA .id Refer to a field with table prefix. NOTE: The DOT is used.

Supported Types

1 Number

"Letter to" Text

"John" & "Smith" Text
Concatenate two tests in one: "John Smith"

True, False Booleans

#24-12-2011# Date
Correspond to 24th Dec 2011

Conversion Functions

CInt("3") = 3, omitting prefix.
Convert a text to a number

CSInt(23) = "23": No preceding space.
Convert a number to a text

Round(2.123) = 2.1 (Double)
Rounding a number.

uVis Functions for Event Handling

Refresh() Recalculates all controls in the Form.

Requery() Execute the query specified at ROWS property and recalculates all controls in the Form.

Operators and IF-Else

* Multiply, Result type is Integer, Double, etc.

/ Divide, Single or Double result, 5/2 = 2.5

\ Integer divide, result truncated, 5/3 = 1

Mod Modulus (remainder), 5 Mod 3 = 2

-- Add and subtract

& Concatenation, String result

A ? B : C If A is true, B else C.
Simplifies IF-ELSE statement

Scanned version of the original.

uVis Studio Shortcuts

Action	Mouse and Keys combinations
Delete a control	CTRL + Delete
Copy a control	CTRL + C
Paste a control	CTRL + V
Undo	CTRL + Z
Redo	CTRL + Y
Call Refresh	CTRL + F5
Select a control	Mouse Click
Select the underlying control	CTRL + Shift + Mouse Click

Scanned version of the original.

References

- [1] Aigner, W., and Miksch, S. Carevis: Integrated visualization of computerized protocols and temporal patient data. *Artif. Intell. Med.* 37, 3 (2006), 203–218. 132
- [2] Aigner, W., Miksch, S., Müller, W., Schumann, H., and Tominski, C. Visual methods for analyzing time-oriented data, Jan. 2008. viii, 12, 13
- [3] Aigner, W., Miksch, S., Schumann, H., and Tominski, C. *Visualization of Time-Oriented Data*, 1st ed. Springer Publishing Company, Incorporated, 2011. 11
- [4] Akasaka, R. Protoviewer: a web-based visual design environment for protovis. In *ACM SIGGRAPH 2011 Posters*, SIGGRAPH '11, ACM (2011), 85:1–85:1. ix, 23, 34, 35, 149
- [5] Amar, R., and Stasko, J. A knowledge task-based framework for design and evaluation of information visualizations. In *Proceedings of the IEEE Symposium on Information Visualization*, INFOVIS '04, IEEE Computer Society (Washington, DC, USA, 2004), 143–150. 18
- [6] Bachman, C. W. Data structure diagrams. *DataBase* (1969), 4–10. 61
- [7] Baroth, E., and Hartsough, C. Visual object-oriented programming. Manning Publications Co., Greenwich, CT, USA, 1995, ch. Visual programming in the real world, 21–42. 16
- [8] Bederson, B. B. Fisheye menus. In *Proceedings of the 13th annual ACM symposium on User interface software and technology*, UIST '00, ACM (New York, NY, USA, 2000), 217–225. 3
- [9] Bederson, B. B., J., G., and J., M. Toolkit design for interactive structured graphics. *IEEE Trans. Softw. Eng.* 30 (2004), 535–546. viii, 3, 11, 23, 30, 31
- [10] Bederson, B. B., Meyer, J., and Good, L. Jazz: an extensible zoomable user interface graphics toolkit in java. In *Proceedings of the 13th annual ACM symposium on User interface software and technology*, UIST '00, ACM (New York, NY, USA, 2000), 171–180. 23

REFERENCES

- [11] Bederson, B. B., Shneiderman, B., and Wattenberg, M. Ordered and quantum treemaps: Making effective use of 2d space to display hierarchies. *ACM Trans. Graph.* 21, 4 (2002), 833–854. 50
- [12] Boehm, B., Clark, B., Horowitz, E., Westland, C., Madachy, R., and Selby, R. Cost models for future software life cycle processes: Cocomo 2.0. In *Annals Of Software Engineering* (1995), 57–94. 14
- [13] Bostock, M., and Heer, J. Protovis: A graphical toolkit for visualization. *Visualization and Computer Graphics, IEEE Transactions on* 15, 6 (nov.-dec. 2009), 1121–1128. 3, 20, 23, 34, 35, 149
- [14] Bostock, M., Ogievetsky, V., and Heer, J. D3 data-driven documents. *IEEE Transactions on Visualization and Computer Graphics* 17, 12 (Dec. 2011), 2301–2309. 3, 11, 20, 23, 35, 93, 102
- [15] Bui, A., Aberle, D., and Kangarloo, H. Timeline: Visualizing integrated patient records. *Information Technology in Biomedicine, IEEE Transactions on* 11, 4 (july 2007), 462–473. 132
- [16] Burnett, M., Atwood, J., Walpole Djang, R., Reichwein, J., Gottfried, H., and Yang, S. Forms/3: A first-order visual language to explore the boundaries of the spreadsheet paradigm. *J. Funct. Program.* 11 (2001), 155–206. 15, 17
- [17] Burnett, M. M. Visual programming. *Encyclopedia of Electrical and Electronics Engineering* (1999). 15
- [18] Burnett, M. M., and Baker, M. J. A classification system for visual programming languages. Tech. rep., Corvallis, OR, USA, 1993. 15
- [19] Burnett, M. M., and Gottfried, H. J. Graphical definitions: expanding spreadsheet languages through direct manipulation and gestures. *ACM Trans. Comput.-Hum. Interact.* 5, 1 (1998), 1–33. 16, 17
- [20] Card, S. K., Mackinlay, J. D., and Shneiderman, B., Eds. *Readings in information visualization: using vision to think*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 1999. 2, 10, 20
- [21] Chen, P. P.-S. The entityrelationship model toward a unified view of data. *ACM Trans. Database Syst.* 1, 1 (1976), 9–36. 59
- [22] Cheng, M., Livny, M., and Ramakrishnan, R. Visual analysis of stream data. In *Proceedings of SPIE / The International Society for Optical Engineering*, vol. 2410 (1995), 108–119. 23, 26

REFERENCES

- [23] Chi, E. H. A taxonomy of visualization techniques using the data state reference model. In *Proceedings of the IEEE Symposium on Information Visualization 2000*, INFOVIS '00, IEEE Computer Society (Washington, DC, USA, 2000), 69–. 18, 147
- [24] Chi, E. H.-h., and Riedl, J. An operator interaction framework for visualization systems. In *Proceedings of the 1998 IEEE Symposium on Information Visualization*, INFOVIS '98, IEEE Computer Society (Washington, DC, USA, 1998), 63–70. 17, 20
- [25] Chuah, M. C., Roth, S. F., and Kerpedjiev, S. Intelligent multimedia information retrieval. MIT Press, 1997, ch. Sketching, searching, and customizing visualizations: a content-based approach to design retrieval, 83–111. viii, 23, 25, 26
- [26] Cox, P., Giles, F., and Pietrzykowski, T. Prograph: a step towards liberating programming from textual conditioning. In *Visual Languages, 1989., IEEE Workshop on* (oct 1989), 150 –156. 15
- [27] Cypher, A., Halbert, D. C., Kurlander, D., Lieberman, H., Maulsby, D., Myers, B. A., and Turransky, A., Eds. *Watch what I do: programming by demonstration*. MIT Press, Cambridge, MA, USA, 1993. 16
- [28] Fekete, J.-D. The infovis toolkit. In *Proceedings of the IEEE Symposium on Information Visualization 2004* (2004), 167 –174. viii, 3, 11, 23, 29, 30
- [29] Fekete, J.-D., Hemery, P.-L., Baudel, T., and Wood, J. Obvious: A meta-toolkit to encapsulate information visualization toolkits — one toolkit to bind them all. In *Visual Analytics Science and Technology (VAST), 2011 IEEE Conference on* (oct. 2011), 91 –100. 157
- [30] Flare. <http://flare.prefuse.org/>. Accessed August, 2011. viii, 11, 23, 33, 34
- [31] Godinho, P. I. A., Meiguins, B. S., Meiguins, A. S. G., Casseb do Carmo, R. M., de Brito Garcia, M., Almeida, L. H., and Lourenco, R. Prisma - a multidimensional information visualization tool using multiple coordinated views. In *Proceedings of the 11th International Conference Information Visualization, IV '07*, IEEE Computer Society (2007), 23–32. 23
- [32] Google. <http://code.google.com/apis/chart/>. Accessed October, 2011. ix, 23, 41
- [33] Goren-Bar, D., Shahar, Y., Galperin-Aizenberg, M., Boaz, D., and Tahan, G. Knave ii: the definition and implementation of an intelligent tool for visualization and exploration of time-oriented clinical data. In *Proceedings of the working conference on Advanced visual interfaces, AVI '04*, ACM (2004), 171–174. 132
- [34] Hallett, C. Multi-modal presentation of medical histories. In *Proceedings of the 13th international conference on Intelligent user interfaces, IUI '08*, ACM (2008), 80–89. 132

-
- [35] Hanrahan, P. Vizql: a language for query, analysis and visualization. In *Proceedings of the 2006 ACM SIGMOD international conference on Management of data*, SIGMOD '06, ACM (2006), 721–721. 37
- [36] Heer, J., Card, S. K., and Landay, J. A. prefuse: a toolkit for interactive information visualization. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, CHI '05, ACM (2005), 421–430. viii, 3, 11, 20, 23, 30, 32, 33, 93
- [37] Heer, J., Ham, F., Carpendale, S., Weaver, C., and Isenberg, P. Creation and collaboration: Engaging new audiences for information visualization. In *Information Visualization*, A. Kerren, J. Stasko, J.-D. Fekete, and C. North, Eds., vol. 4950 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, 2008, 92–133. 2, 3, 13, 19, 21
- [38] Heer, J., and Shneiderman, B. Interactive dynamics for visual analysis. *Commun. ACM* 55, 4 (Apr. 2012), 45–54. 19
- [39] Hertzum, M., and Jacobsen, N. E. The evaluator effect: A chilling fact about usability evaluation methods. *Int. J. Hum. Comput. Interaction* 13, 4 (2001), 421–443. 84, 152, 153
- [40] Hundhausen, C. D., Farley, S. F., and Brown, J. L. Can direct manipulation lower the barriers to computer programming and promote transfer of training?: An experimental study. *ACM Trans. Comput.-Hum. Interact.* 16, 3 (2009), 13:1–13:40. 16
- [41] Jaffe, A., Naaman, M., Tassa, T., and Davis, M. Generating summaries and visualization for large collections of geo-referenced photographs. In *Proceedings of the 8th ACM international workshop on Multimedia information retrieval*, MIR '06, ACM (New York, NY, USA, 2006), 89–98. 50
- [42] Johnson, B., and Shneiderman, B. Tree-maps: a space-filling approach to the visualization of hierarchical information structures. In *Proceedings of IEEE Conference on Visualization* (1991), 284–291. 50
- [43] Johnson, C. M., Johnson, T. R., and Zhang, J. A user-centered framework for redesigning health care interfaces. *J. of Biomedical Informatics* 38, 1 (2005), 75–87. 132
- [44] Jones, S. P., Blackwell, A., and Burnett, M. A user-centred approach to functions in excel. *SIGPLAN Not.* 38, 9 (Aug. 2003), 165–176. 17
- [45] Kaser, O., and Lemire, D. Tag-cloud drawing: Algorithms for cloud visualization. vol. abs/cs/0703109 (2007). 50
- [46] Kelleher, C., and Pausch, R. Lowering the barriers to programming: A taxonomy of programming environments and languages for novice programmers. *ACM Comput. Surv.* 37, 2 (June 2005), 83–137. 16

REFERENCES

- [47] Klann, M., Patern, F., and Wulf, V. Future perspectives in end-user development. In *End User Development*, H. Lieberman, F. Patern, and V. Wulf, Eds., vol. 9 of *Human-Computer Interaction Series*. Springer Netherlands, 2006, 475–486. 13
- [48] Ko, A. J., Abraham, R., Beckwith, L., Blackwell, A., Burnett, M., Erwig, M., Scaffidi, C., Lawrance, J., Lieberman, H., Myers, B., Rosson, M. B., Rothermel, G., Shaw, M., and Wiedenbeck, S. The state of the art in end-user software engineering. *ACM Comput. Surv.* 43, 3 (Apr. 2011), 21:1–21:44. 14
- [49] Koh, L. C., Slingsby, A., Dykes, J., and Kam, T. S. Developing and applying a user-centered model for the design and implementation of information visualization tools. *2011 15th International Conference on Information Visualisation* (2011), 90–95. 12
- [50] Kosara, R., and Miksch, S. Metaphors of movement: a visualization and user interface for time-oriented, skeletal plans. *Artif. Intell. Med.* 22, 2 (May 2001), 111–131. 132
- [51] Lauesen, S. *User Interface Design: A Software Engineering Perspective*. Addison-Wesley Longman Publishing Co., Inc., Boston, MA, USA, 2005. 82, 83, 84, 88
- [52] Lauesen, S. Requirements of uVis. Available on demand, 2009. 4, 57, 148
- [53] Lauesen, S. Vistool for unified data visualization. IT University Of Copenhagen, www.itu.dk/people/slauesen/S-EHR/UnifiedDataVisualization.pdf, 2009. 4, 45
- [54] Lee, B., Plaisant, C., Parr, C. S., Fekete, J.-D., and Henry, N. Task taxonomy for graph visualization. In *Proceedings of the 2006 AVI workshop on BEyond time and errors: novel evaluation methods for information visualization*, BELIV '06, ACM (2006), 1–5. 19
- [55] Lee, B., Riche, N. H., Karlson, A. K., and Carpendale, S. Sparkclouds: Visualizing trends in tag clouds. *IEEE Transactions on Visualization and Computer Graphics* 16, 6 (2010), 1182–1189. 3, 50
- [56] Lieberman, H., Patern, F., Klann, M., and Wulf, V. End-user development: An emerging paradigm. In *End User Development*, H. Lieberman, F. Patern, and V. Wulf, Eds., vol. 9 of *Human-Computer Interaction Series*. Springer Netherlands, 2006, 1–8. 1, 13, 14
- [57] Lieberman, H., Paternò, F., and Wulf, V. *End User Development (Human-Computer Interaction Series)*. Springer-Verlag New York, Inc., Secaucus, NJ, USA, 2006. 14, 15, 16, 17
- [58] Livny, M., Ramakrishnan, R., Beyer, K., Chen, G., Donjerkovic, D., Lawande, S., Myllymaki, J., and Wenger, K. Devise: integrated querying and visual exploration of large datasets. In *Proceedings of the 1997 ACM SIGMOD international conference on Management of data*, SIGMOD '97, ACM (1997), 301–312. 23, 26, 27

-
- [59] Livny, M., Ramakrishnan, R., and Myllymaki, J. Visual exploration of large data sets. In *Proceedings of SPIE / The International Society for Optical Engineering* (1996). viii, 23, 26, 27
- [60] Mackinlay, J. Automating the design of graphical presentations of relational information. *ACM Trans. Graph.* 5, 2 (Apr. 1986), 110–141. viii, 23, 24
- [61] MacLean, A., Carter, K., Lövstrand, L., and Moran, T. User-tailorable systems: pressing the issues with buttons. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '90, ACM (New York, NY, USA, 1990), 175–182. 14
- [62] Martin, J. *Information Engineering: Planning and Analysis*. Prentice-Hall, Inc., Englewood Cliffs, NJ, USA, 1990. 49, 59
- [63] Matkovic, K., Freiler, W., Gracanin, D., and Hauser, H. Comvis: A coordinated multiple views system for prototyping new visualization technology. In *Proceedings of the 2008 12th International Conference Information Visualisation, IV '08*, IEEE Computer Society (2008), 215–220. 23
- [64] Microsoft Excel. <http://office.microsoft.com/en-us/excel/>. Accessed August, 2011. ix, 3, 11, 21, 23, 36, 37
- [65] Milgram, S., and Jodelet, D. Psychological maps of paris. *Environmental psychology* (1976), 104–124. 50
- [66] Myers, B., Hudson, S. E., and Pausch, R. Past, present, and future of user interface software tools. *ACM Trans. Comput.-Hum. Interact.* 7, 1 (Mar. 2000), 3–28. 20
- [67] Nielsen, J. Finding usability problems through heuristic evaluation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '92, ACM (New York, NY, USA, 1992), 373–380. 84
- [68] Nielsen, J. *Usability Engineering*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 1993. 12, 84, 85, 149, 152
- [69] Nielsen, J., and Landauer, T. K. A mathematical model of the finding of usability problems. In *Proceedings of the INTERACT '93 and CHI '93 conference on Human factors in computing systems*, CHI '93, ACM (1993), 206–213. 84
- [70] Norman, D. A. *The Design of Everyday Things*. Doubleday Business, 1990. 12, 44, 68
- [71] Omnisciope. <http://www.visokio.com/>. Accessed August, 2011. ix, 11, 21, 23, 38, 39
- [72] Pane, J., and Myers, B. More natural programming languages and environments. In *End User Development*, H. Lieberman, F. Patern, and V. Wulf, Eds., vol. 9 of *Human-Computer Interaction Series*. Springer Netherlands, 2006, 31–50. 2, 13, 21

-
- [73] Pantazos, K., and Lauesen, S. Constructing visualizations with infovis tools - an evaluation from a user perspective. In *GRAPP/IVAPP*, P. Richard, M. Kraus, R. S. Laramee, and J. Braz, Eds., SciTePress (2012), 731–736. 3, 13
- [74] Pantazos, K., Lauesen, S., and Lippert, S. De-identifying an ehr database - anonymity, correctness and readability of the medical record. *Studies In Health Technology And Informatics 169* (2011), 862–866. 7
- [75] Pantazos, K., Tarkan, S., Plaisant, C., and Shneiderman, B. Promoting timely completion of multi-step processes - a visual approach to retrospective analysis. Tech. Rep. HCIL-2012-27, University Of Maryland, Human Computer Interaction Lab, 2012. 7
- [76] Pfitzner, D., Hobbs, V., and Powers, D. A unified taxonomic framework for information visualization. In *Proceedings of the Asia-Pacific symposium on Information visualisation - Volume 24*, APVis '03, Australian Computer Society, Inc. (Darlinghurst, Australia, Australia, 2003), 57–66. 18
- [77] Pieczkiewicz, D. S., Finkelstein, S. M., and Hertz, M. I. Design and evaluation of a web-based interactive visualization system for lung transplant home monitoring data. *AMIA Annual Symposium proceedings AMIA Symposium AMIA Symposium 2007*, 598–602. 132
- [78] Plaisant, C. The challenge of information visualization evaluation. In *Proceedings of the working conference on Advanced visual interfaces*, AVI '04, ACM (2004), 109–116. 13, 44, 149
- [79] Plaisant, C., Mushlin, R., Snyder, A., Li, J., Heller, D., Shneiderman, B., and Colorado, K. P. Lifelines: Using visualization to enhance navigation and analysis of patient records. In *In Proceedings of the 1998 American Medical Informatic Association Annual Fall Symposium* (1998), 76–80. 2, 3, 11, 12, 22, 54, 132, 158
- [80] Processing. <http://www.processing.com/>. Accessed August, 2011. viii, 23, 27, 28
- [81] Robinson, A. C., Chen, J., Lengerich, E. J., Meyer, H. G., and MacEachren, A. M. Combining usability techniques to design geovisualization tools for epidemiology. *Cartography and Geographic Information Science 32*, 4 (2005), 243–255. 12
- [82] Robson, C. *Real World Research - A Resource for Social Scientists and Practitioner-Researchers*, second ed. Blackwell Publishing, Malden, 2002. 86, 148, 153
- [83] Roque, F. S., Slaughter, L., and Tkatšenko, A. A comparison of several key information visualization systems for secondary use of electronic health record content. In *Proceedings of the NAACL HLT 2010 Second Louhi Workshop on Text and Data Mining of Health Documents*, Louhi '10, Association for Computational Linguistics (Stroudsburg, PA, USA, 2010), 76–83. 132

REFERENCES

- [84] Roth, R. E., Ross, K. S., Finch, B. G., Luo, W., and MacEachren, A. M. A user-centered approach for designing and developing spatiotemporal crime analysis tools. *geovistap-suedu*, Norman 1988 (2009). 12
- [85] Roth, S. F., Chuah, M. C., Kerpedjiev, S., Kolojechick, J. A., and Lucas, P. Toward an information visualization workspace: combining multiple means of expression. *Hum.-Comput. Interact.* 12, 1 (Mar. 1997), 131–185. 23
- [86] Roth, S. F., Kolojechick, J., Mattis, J., and Chuah, M. C. Sagetools: an intelligent environment for sketching, browsing, and customizing data-graphics. In *Conference companion on Human factors in computing systems*, CHI '95, ACM (1995), 409–410. 25
- [87] Roth, S. F., and Mattis, J. Automating the presentation of information, 1991. viii, 23, 25
- [88] Scaffidi, C., Shaw, M., and Myers, B. Estimating the numbers of end users and end user programmers. In *Visual Languages and Human-Centric Computing, 2005 IEEE Symposium on* (2005), 207 – 214. 14
- [89] Shneiderman, B. Direct manipulation: A step beyond programming languages. *Computer* 16, 8 (1983), 57–69. 16
- [90] Shneiderman, B. The eyes have it: A task by data type taxonomy for information visualizations. In *Proceedings of the 1996 IEEE Symposium on Visual Languages*, VL '96, IEEE Computer Society (Washington, DC, USA, 1996), 336–. 17
- [91] Shneiderman, B., and Plaisant, C. *Designing the User Interface: Strategies for Effective Human-Computer Interaction*, 5. ed. Pearson Addison-Wesley, Upper Saddle River, NJ, 2009. 84, 85
- [92] Slocum, T. A., Cliburn, D. C., Feddema, J. J., and Miller, J. R. Evaluating the Usability of a Tool for Visualizing the Uncertainty of the Future Global Water Balance. *Cartography and Geographic Information Science* (Oct. 2003), 299–317. 12
- [93] Smith, D. C. *Pygmalion: a creative programming environment*. PhD thesis, Stanford, CA, USA, 1975. AAI7525608. 15
- [94] Smith, D. C., Cypher, A., and Spohrer, J. Kidsim: programming agents without a programming language. *Commun. ACM* 37, 7 (July 1994), 54–67. 15
- [95] Smith, R. What clinical information do doctors need? *BMJ British Medical Journal* 313, 7064 (1996), 1062–1068. 132
- [96] Spence, R. *Information Visualization: Design for Interaction (2nd Edition)*. Prentice-Hall, Inc., Upper Saddle River, NJ, USA, 2007. 10, 11

REFERENCES

- [97] Spotfire. <http://spotfire.tibco.com/>. Accessed August, 2011. ix, 3, 11, 21, 23, 37, 39, 101
- [98] Stolte, C., and Hanrahan, P. Polaris: a system for query, analysis and visualization of multi-dimensional relational databases. In *Information Visualization, 2000. InfoVis 2000. IEEE Symposium on* (2000), 5–14. 23, 36
- [99] Tableau. <http://www.tableausoftware.com/>. Accessed August, 2011. ix, 3, 11, 21, 23, 36, 38
- [100] Takatsuka, M., and Gahegan, M. Geovista studio: a codeless visual programming environment for geoscientific data analysis and visualization. *Comput. Geosci.* 28, 10 (Dec. 2002), 1131–1144. viii, 23, 28, 29
- [101] Tanimoto, S. L. Viva: A visual language for image processing. *J. Vis. Lang. Comput.* 1, 2 (June 1990), 127–139. 67, 68
- [102] Thomas, J. J., and Cook, K. A. A visual analytics agenda. *IEEE Comput. Graph. Appl.* 26, 1 (2006), 10–13. 11
- [103] Tom Sawyer Perspectives. <http://www.tomsawyer.com/products/perspectives/index.php>. Accessed August, 2011. ix, 23, 40
- [104] Tory, M., and Moller, T. Rethinking visualization: A high-level taxonomy. In *Proceedings of the IEEE Symposium on Information Visualization, INFOVIS '04*, IEEE Computer Society (Washington, DC, USA, 2004), 151–158. 18
- [105] Tufte, E. R. *The visual display of quantitative information*. Graphics Press, 1986. 10
- [106] Tufte, E. R. *Beautiful Evidence*. Graphis Pr, 2006. 50
- [107] uVis. Performance details. <https://dl.dropbox.com/u/5614860/Performance.xls>, 2009. 71
- [108] Viegas, F. B., Wattenberg, M., van Ham, F., Kriss, J., and McKeon, M. Manyeyes: a site for visualization at internet scale. *IEEE Transactions on Visualization and Computer Graphics* 13 (2007), 1121–1128. 23, 41
- [109] Virzi, R. A. Refining the test phase of usability evaluation: how many subjects is enough? *Hum. Factors* 34, 4 (1992), 457–468. 84
- [110] Vrachnos, E., and Jimoyiannis, A. Dave: A dynamic algorithm visualization environment for novice learners. In *Proceedings of the 2008 Eighth IEEE International Conference on Advanced Learning Technologies, ICALT '08*, IEEE Computer Society (Washington, DC, USA, 2008), 319–323. 23

REFERENCES

- [111] Wang, T. D., Plaisant, C., Quinn, A. J., Stanchak, R., Murphy, S., and Shneiderman, B. Aligning temporal data by sentinel events: discovering patterns in electronic health records. In *Proceedings of the twenty-sixth annual SIGCHI conference on Human factors in computing systems*, CHI '08, ACM (2008), 457–466. 11, 132
- [112] Weaver, C. Building highly-coordinated visualizations in improvise. In *Proceedings of the IEEE Symposium on Information Visualization*, IEEE Computer Society (2004), 159–166. viii, 23, 31, 32, 149
- [113] Welch, B. B. *Practical programming in Tcl and Tk (2nd ed.)*. Prentice-Hall, Inc., Upper Saddle River, NJ, USA, 1997. 26
- [114] Whitley, K. Visual programming languages and the empirical evidence for and against. *Journal of Visual Languages & Computing* 8, 1 (1997), 109 – 142. 15
- [115] Wilson, C. Taking usability practitioners to task. *Interactions* 14, 1 (Jan. 2007), 48–49. 152
- [116] Wongsuphasawat, K., Guerra Gómez, J. A., Plaisant, C., Wang, T. D., Taieb-Maimon, M., and Shneiderman, B. Lifeflow: visualizing an overview of event sequences. In *Proceedings of the 2011 annual conference on Human factors in computing systems*, CHI '11, ACM (2011), 1747–1756. 11, 30, 132