The Inspector
A Cognitive Artefact for Visual Mapping

Mohammad A. Kuhail, Soren Lauesen and Kostas Pantazos
Software Development Group, IT University of Copenhagen, Rued Langgaards Vej 7, Copenhagen, Denmark

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Abstract: Existing custom visualization tools provide cognitive artefacts that can reduce the cognitive barriers designers encounter in *visual mapping*, mapping data to visual primitives (e.g. ellipse, rectangle) and their properties (e.g. colour, size.) However, our experience with designers shows that the existing artefacts are insufficient. In particular, designers struggle to understand the relationship between visual primitives, their properties, and data. Moreover, it is hard to verify the correctness of the visual mappings. In response, we developed a new cognitive artefact, *the inspector*, that explicitly shows the data behind visual primitive and their properties. We evaluated the impact of the inspector on usability with seven designers. The result shows that the inspector reduced usability problems and helped designers verify the visual mappings.

1 INTRODUCTION

Visual mapping is important for achieving visualization expressiveness, showing the facts in the data and no other facts (Sears and Jacko, 2007). Yet it remains problematic for designers, particularly novice ones when they implement standard visualizations (Grammel et al., 2011). They find it hard to map data to visual properties (Heer et al., 2008).

No similar study has been carried out to investigate problems designers encounter in implementing visual mappings of *custom visualizations*, visualizations that use position, size, shape, colour, and orientation to show data. However, unlike standard visualizations (e.g. bar chart), custom visualizations cannot be created by selecting predefined visualization templates and mapping data to the templates. They are tailored to a specific need.

Despite our attempt to assist designers in visual mapping with the Uvis tool (Lauesen, 2009), usability studies with Uvis show that designers struggle to understand the link between the visual structures and the data behind. As an example, some designers could not learn how to make a visual property represent data. Others could not confirm that their mappings were correct. We believe such obstacles could result in inappropriate visual mappings. In turn, this could hinder analysis and result in misleading conclusions. This problem is not addressed by present visualization tools.

As a solution, we developed *the inspector* on top of Uvis, a data grid that shows the data behind visual objects. Further, it shows the data values of the visual properties and sub-expressions used to specify the properties. To evaluate the inspector, we conducted a preliminarily evaluation to study the impact of the inspector on usability with seven *savvy designers*, designers without advanced IT skills. The results show that the inspector reduced usability problems and helped designers verify the correctness of their solutions. Further, it improved task completion time and visualization quality.

2 RELATED WORK

For the purpose of comparison, we look at how visualization tools of two categories (standard and custom) address visual mapping.

2.1 Standard Visualization Tools

One of the most famous tools for creating standard visualizations (e.g. bar charts) are charting tools such as MS Excel and Google spreadsheets (Spreadsheets, 2012). They are easy to use, and designers can create visualizations that correspond to pre-defined templates with a few clicks.

Visual mappings are made by selecting the data

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cells to be visualized and choosing a visualization that shows it. Designers do not have full control over how visual objects show data. It is automatically handled by the system.

Charting tools allow designers to view the underlying data of a visualization. For instance, when the designer selects a visual object, the underlying data get highlighted. However, the designer cannot view a particular data item behind a particular visual object.

Some data analytic tools such as Spotfire (Spotfire, 2012) and Tableau (Tableau, 2012) allow more data exploration than charting tools. They provide more visualization templates and functionalities. For instance, they allow conditional colouring and sizing.

Like charting tools, visual mappings are made by selecting predefined visualizations for selected data, but also changing some settings for selected visual objects such as "Size by" or "Colour by". Designers can see a connection between the visual objects and the data by adding a data sheet tab. The highlighted rows correspond to the selected visual objects.

To sum up, standard visualization tools can show the connection between visual objects and the underlying data. However, since designers are not supposed to create their own visual mappings, the tools do not provide information about the calculations behind the visual mappings. For instance, a bar in a chart shows data, but the tool does not show how mathematically this calculation was made, nor the concrete values of the bar heights.

2.2 Custom Visualization Tools

The research community has produced several visualization toolkits that support custom visualizations. Examples include InfoVis (Fekete, 2004), Improvise, Prefuse (Heer et al., 2005), Flare (Fla, 2009), Protovis, D3 (Bostock et al., 2011), and Uvis. Only a few of these tools (Improvise, Protovis, Uvis) use development environments that assist designers in visual mapping. The tools with development environments use declarative expressions for visual mapping despite some differences in approach. The expressions can be mathematical, logical, conditional, or a combination, and can refer to elements of data (e.g. fields) to make visual properties show data.

Improvise is a visualization system that mainly supports coordinated visualizations. Improvise assists designers in creating the expressions. For instance, designers choose possible sub-expressions (e.g. logical, mathematical, data fields) from combo boxes and lists. As a result, the expression is shown as a tree. Furthermore, Improvise provides a *visual feedback*. The changes in expressions are immediately reflected on the visualization.

Protovis is a JavaScript-based visualization toolkit that can be extended with a development environment called Protoviewer (Akasaka, 2011). Protoviewer allows designers to view the to-be-visualized data (arrays). Like Improvise, Protoviewer provides a visual feedback. The visualization is updated as a result of changing visual mappings. Furthermore, designers can select a visual object, and view the values of position visual properties.

Uvis is a visualization tool that allows designers to combine visual objects and specify their properties with spreadsheet-like expressions (formulas).

Uvis environment assists the designers in visual mapping. The environment consists of six panels (Figure 1) : toolbox, property grid, visualization form, data model, error list, and table view. The *toolbox* is a list of the available visual objects. The *property grid* shows the properties that control the appearance of the visual objects. The *visualization form* is the visualization the designer builds. The *data model* is the structure of the raw data (that data the designer wants to visualize.) The *error list* shows the problems with the visualization specifications. The *table view* is a feature that allows designers to view a sample of the raw data on demand. To view a table sample, the designer clicks a table box in the data model. This feature helps designers getting familiar with the data they want to visualize.

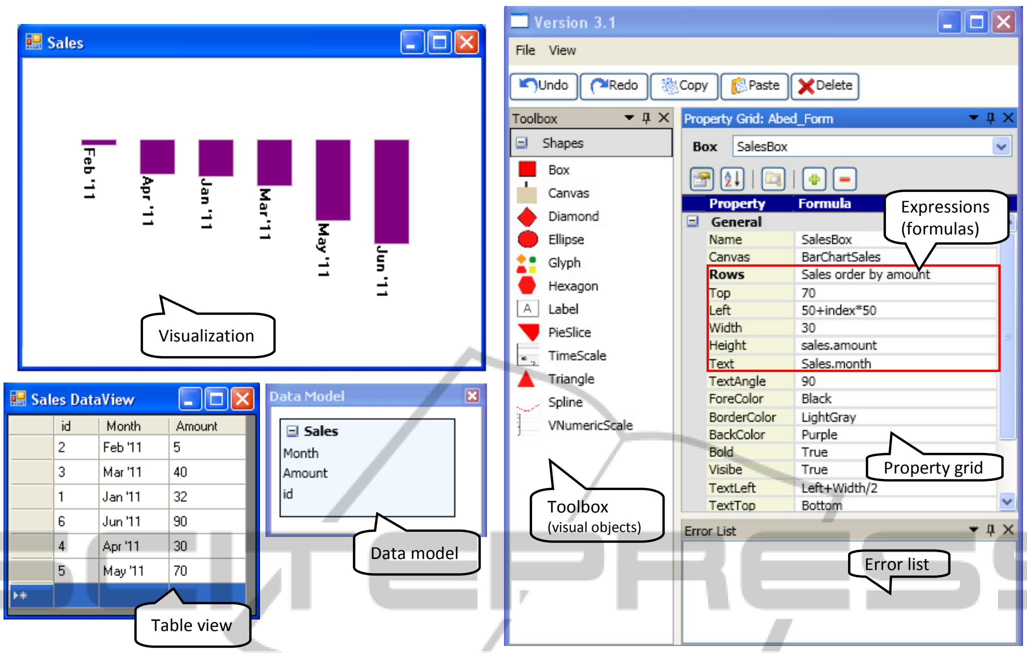
Figure 1 shows a snapshot of creating a bar chart with Uvis environment. The formulas in the property grid bind the bars to data and specify the height. More details about Uvis formulas and the environment can be found at (Kuhail and Lauesen, 2012; Kuhail et al., 2012; Pantazos et al., 2013).

To sum up, Improvise, Protoviewer, and Uvis assist designers in two ways: First, they provide designers with data they need to create an expression (e.g. available data fields, available properties.) Second, they provide a visual feedback. However, none of the tools explicitly shows the relationship between data, visual objects, and its properties.

3 USABILITY STUDIES

Prior to designing the inspector, we usability tested the development environment of Uvis to identify usability problems relevant to visual mappings. The results revealed a few problems not addressed by present tool environments.

This section briefly presents the usability study settings, and provides a summary of the qualitative and quantitative results of the studies.



id	Month	Amount
2	Feb '11	5
3	Mar '11	40
1	Jan '11	32
6	Jun '11	90
4	Apr '11	30
5	May '11	70

Property	Formula
General	
Name	SalesBox
Canvas	BarChartSales
Rows	Sales order by amount
Top	70
Left	50+index*50
Width	30
Height	sales.amount
Text	Sales.month
TextAngle	90
ForeColor	Black
BorderColor	LightGray
BackColor	Purple
Bold	True
Visibe	True
TextLeft	Left+Width/2
TextTop	Bottom

Figure 1: Uvis environment.

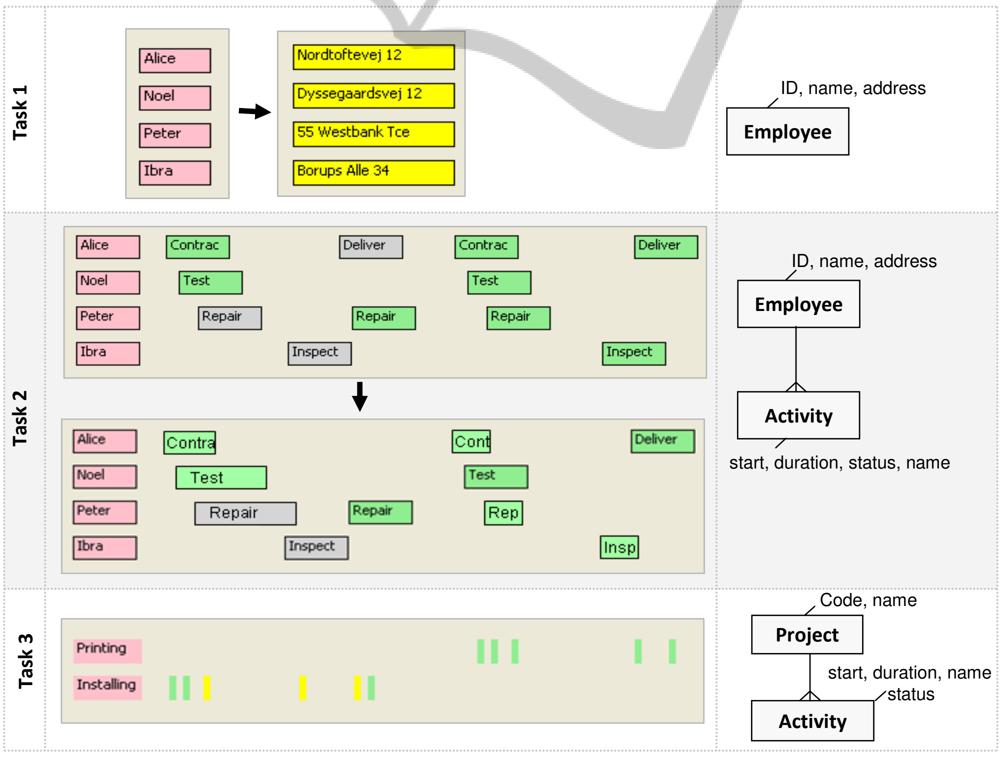


Figure 2: Usability test tasks.

3.1 Participants' Background

We recruited five participants. All of them, except for one, were non-programmers. The skills of the non-programmers varied from bare knowledge of IT (e.g. knowledge of MS Word) to some knowledge of spreadsheet formulas. The participants did not have prior knowledge of the Uvis approach and had never used the environment.

Although testing with five participants does not give statistical significance, it reveals the usability problems that most users will encounter (Lauesen, 2005). This *"formative evaluation"* is claimed to improve the tool (Nielsen, 1993).

3.2 Procedure and Tasks

We trained the participants using a textual tutorial, and asked them to carry three tasks out while thinking aloud. The data sets in the real tests were different from the ones shown to them. They were told the visualizations shown to them in the task are just examples.

One of the authors noted the observed usability problems. The documentation of the usability studies can be found at (Studies, 2012).

The tasks evaluate basic visual mapping techniques such as showing data by shape, text, size, etc.

Figure 2 shows the task as well as the data tables behind them.

- **Task 1.** The pink vertical list shows employee names. Make the list show their addresses instead and make the list yellow.
- **Task 2.** The visualization shows the employee activities in a certain period of time (See data model). Make the activities width represent the activity duration, also show the planned activities in green, and the cancelled ones in grey.

  Task 3. Create a visualization that shows the projects and their activities. The activities are positioned according to a time scale, and the projects they belong to. Change the task colour based on its status. If the status is done, make the task green. Otherwise, make it yellow.

In order to check the participant's understanding of visual mappings, we asked them the following questions after they finished working on the tasks:

- **Question 1** - *asked after task 1*: What data are the employee labels showing? Where do the data come from?

  Concept Checked. The question checks whether the participants understand the relationship between a visual object and the data row it is representing.
- **Question 2** - *asked after task 2*: Can you explain how the width of the activity represent the activity duration?

  Concept Checked. The question checks whether the participants understand how a visual property is calculated.

Table 1: Usability test tasks. T=Time measured in minutes, Q= Quality of the solution on a 0-10 scale.

	Participants					Summary	
	1	2	3	4	5	Time (m)	Quality (0-10)
Task 1	T: 10 Q: 10	T: 7 Q: 10	T: 2 Q: 10	T: 9 Q: 5	T: 8 Q: 5	μ : 7.3 σ : 3	μ : 10 σ : 4.1
Task 2	T: 15 Q: 8.5	T: 13 Q: 10	T: 8.5 Q: 9	T: 9 Q: 5	T: 15 Q: 10	μ : 12 σ : 3.1	μ : 1 σ : 2.2
Task 3			T: 8 Q: 5			μ : 10.4 σ : 4.4	μ : 9.6 σ : 0.5

- **Question 3** - *asked after task 1,2, and 3*: Can you confirm that your solution is correct?

  Concept Checked. The question checks whether the participants can verify their visual mappings (the expressions they defined to make visual properties show data).

3.2.1 Quantitative Results

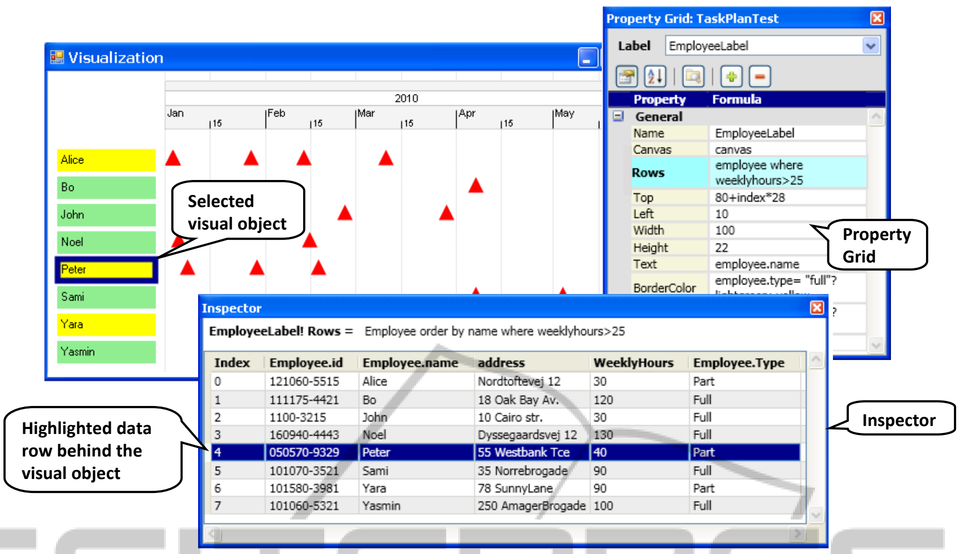
Table 1 shows the completion time (T) as well as the solution quality (Q) for the tasks. The quality of the solution was measured by taking the average of the following two measurements: The specifications of the solution compared against the optimal specifications, and the solution visual outcome compared against the required visual outcome.

Only one participant made it to task 3. The rest just carried out two tasks. The majority of the participants, particularly the non-programmers, did not perform well in the tasks.

3.2.2 Qualitative Results

We summarize the qualitative results based on the participants' thinking aloud and the answers to understanding questions as well as the observations we made while they carried out the tasks.

- **Problem 1: Understanding the Connection between Visual Objects and Data.** Although it was explained in the tutorial, many participants could not precisely understand the relationship between visual objects and data. For instance, one participant said in answering question 1, "the visual objects come from the table somehow. I do not know exactly how".
- **Problem 2: Specifying Visual Objects One by One.** Most participants thought they needed to type the field value for each visual object rather than specifying a reference (connection) from the visual objects to the data fields.
- **Problem 3: Understanding How Visual Properties are Calculated.** Most participants could



Property Grid: TaskPlanTest

Label: EmployeeLabel

Property	Formula
General	
Name	EmployeeLabel
Canvas	canvas
Rows	employee where weeklyhours>25
Top	80+index*28
Left	10
Width	100
Height	22
Text	employee.name
BorderColor	employee.type= "full"?

Inspector

EmployeeLabel! Rows = Employee order by name where weeklyhours>25

Index	Employee.id	Employee.name	address	WeeklyHours	Employee.Type
0	121060-5515	Alice	Nordtoftevej 12	30	Part
1	111175-4421	Bo	18 Oak Bay Av.	120	Full
2	1100-3215	John	10 Cairo str.	30	Full
3	160940-4443	Noel	Dyssegaardsvej 12	130	Full
4	050570-9329	Peter	55 Westbank Tce	40	Part
5	101070-3521	Sami	35 Norrebrogade	90	Full
6	101580-3981	Yara	78 SunnyLane	90	Part
7	101060-5321	Yasmin	250 AmagerBrogade	100	Full

Figure 3: The inspector showing the relationship between a visual object and a data row.

not exactly describe how a visual property could show the data.

- **Problem 4: Inability to Check the Visualization Correctness.** The participants were not confident about what they were doing. Surprisingly one participant came up with the right expression for task 2 but changed her mind because she did not see a visual difference. Hence, she undid her solution and ended up writing up the wrong solution.

We believe an important cause of this problem is that the participants had to imagine the relationship between the visual objects and the data. Things were not made explicit for them. They had to work out the connection themselves.

4 SOLUTION - THE INSPECTOR

The main purpose of the inspector is to reduce the problems we identified in the usability studies. Prior to designing the inspector, we thought we could solve the problems with better explanation. We usability tested again with a better tutorial. This improved the designer performance slightly but the problems remained. Hence, we decided an additional cognitive artefact was needed to support the designers. We iteratively designed the artefact. Some ideas were proposed and abandoned because they did not improve the designer's performance. For instance, we added a third column in the property grid that allows the designer to see the data behind a single visual object.

Gradually with the help of designers, the *principles* of the inspector shaped up. The principles are explained using examples in the following sections.

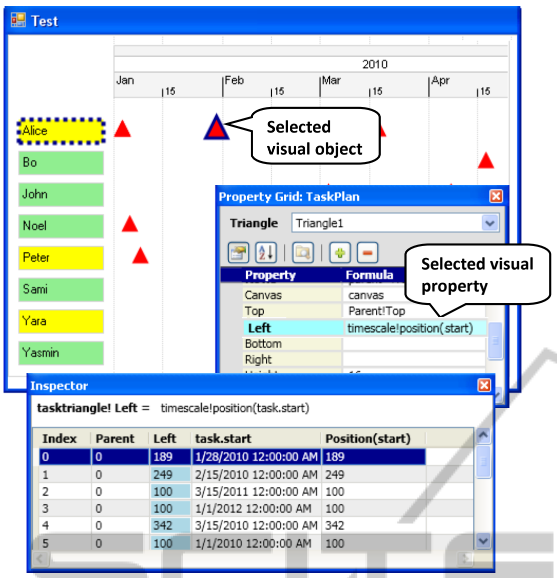
4.1 Connection between Visual Objects and Data

Figure 3 shows a visualization in Uvis environment. For space reasons, we only show three parts of the environment: the visualization, the property grid, and the inspector. The visualization shows tasks of employees in the period of time from 1st January 2010 to 30th May 2010. The visualization consists of a time scale on the top, a set of employee labels on the left, and the employee tasks as triangles mapped to the time scale.

The designer selected (clicked) a label showing employee Peter (Figure 3). The inspector highlighted the data row behind the label.

According to the expression connecting the labels to data (Rows property), only employees who work more than 25 hours per week should be shown. To confirm that the expression is correct, the designer can sort (click) the `WeeklyHours` field in the inspector to check if there are values less than 25.

Principle. The inspector allows the designers to view the relationship between a visual object and the underlying data. Selection can be done both ways. Designers can select rows in the inspector and the corresponding visual objects are highlighted and vice versa. When the underlying data changes (due to a change in the expression connecting the visual objects to data), the data in the inspector is updated immediately.



Property Grid: TaskPlan

Triangle: Triangle1

Property	Formula
Canvas	canvas
Top	Parent!Top
Left	timescale!position(start)
Bottom	
Right	

Inspector

tasktriangle! Left = timescale!position(task.start)

Index	Parent	Left	task.start	Position(start)
0	0	189	1/28/2010 12:00:00 AM	189
1	0	249	2/15/2010 12:00:00 AM	249
2	0	100	3/15/2011 12:00:00 AM	100
3	0	100	1/1/2012 12:00:00 AM	100
4	0	342	3/15/2010 12:00:00 AM	342
5	0	100	1/1/2010 12:00:00 AM	100

Figure 4: The inspector showing the relationship between a visual property expression and data.

To help designers find abnormal data in a large data set, the designers can sort on any column in an ascending or descending manner.

4.2 Connection between Visual Properties and Data

Figure 4 shows that the designer has selected (clicked) a triangle (`TaskTriangle`) representing Alice's task on 28th January 2010 and the Left property that positions the triangle according to the time scale.

The Left property of the `TaskTriangle` visual object is defined by an expression (`timeScale!Position(Task.Start)`).

The inspector breaks the expression down into two sub-expressions: `Task.Start` and `timescale!Position(Task.Start)`, and shows the values of the sub-expressions as well as the index of each `TaskTriangle` object in the bundle. 0.15cm
Principle. The inspector allows the designer to view the details of the visual property mappings and the data behind them. This has a potential of improving the designer's understanding of how visual mappings are calculated based on data.

4.3 Problematic Data Values

Figure 5 shows ellipses representing charity marathon runners. The size of the ellipses represent the runners age. The Left formula results in negative values for the first two instances. As a result, the instances could be fully or partly out of view. Hence, the inspector shows the values in yellow as a warning. If the designer did not intend for this to happen, a visual feedback would not help. Only concrete values can reveal such a problem.

The Height and Width formulas are identical, and they refer to field `Age`. For runner Laura, the value is null. The default values for Height and Width in this case are 0, but the inspector shows the null value in red so that the designer is aware. 0.15cm
Principle. In the world of programming, values such as null and division by zero can be problematic. This applies to the visualization world, and the inspector highlights these values in light red (erroneous values). We we also consider values that could cause visual objects to be out of view or invisible such as negative values for position and size properties. These values are highlighted in yellow (warning). The highlighting colours can be changed by the designer.

5 EVALUATION

We provide two evaluations for the inspector, a theoretical one based on relevant dimensions of cognitive dimensions of notations (CDs) (Green, 1989) , and an experimental one based on a preliminary evaluation study with seven designers.

5.1 Theoretical Evaluation

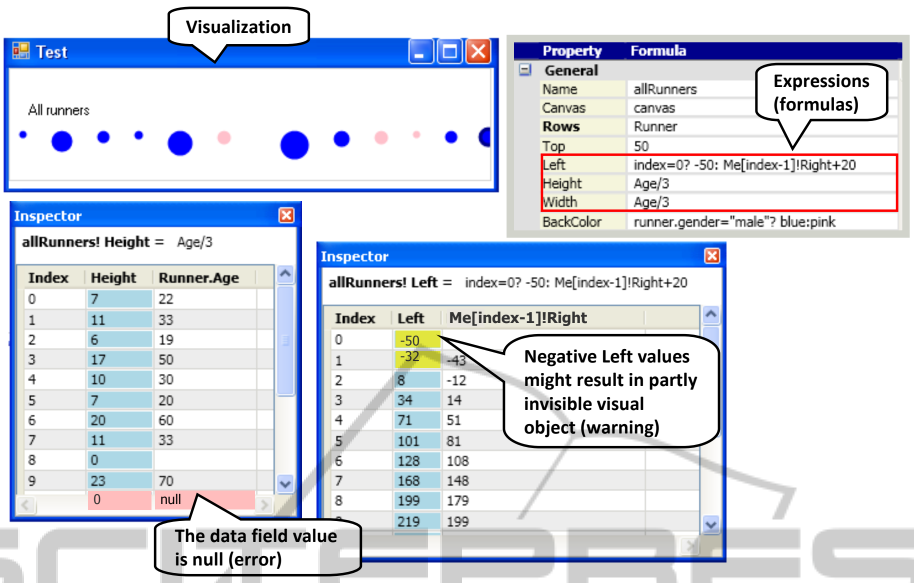
We selected the dimensions of hidden dependencies, progressive feedback, and visibility to evaluate the inspector. The selected dimensions are considered important for exploratory tasks (Green and Blackwell, 1998). The task of implementing custom visualizations is exploratory because the designer is not often sure about the desired end. It is a combination of modifying and adding to an existing visualization.

According to Green, it is desirable to have few hidden dependencies, high progressive evaluation and visibility for exploratory tasks (Green and Blackwell, 1998).

- **Hidden Dependencies.** The hidden dependencies dimension assesses whether dependencies between entities are hidden or visible.

  The inspector explicitly shows which particular visual property depends on which field, and which visual object depends on which data row. As a result, the inspector reduces hidden dependencies between the visual objects, their properties and the mapped data.

- **Progressive Evaluation.** The progressive evaluation dimension assesses how easy it is to evaluate


Visualization
Test
All runners
Expressions (formulas)
Negative Left values might result in partly invisible visual object (warning)
The data field value is null (error)

Property	Formula
General	
Name	allRunners
Canvas	canvas
Rows	Runner
Top	50
Left	index=0? -50: Me[index-1]!Right+20
Height	Age/3
Width	Age/3
BackColor	runner.gender="male"? blue:pink

Inspector

allRunners! Height = Age/3

Index	Height	Runner.Age
0	7	22
1	11	33
2	6	19
3	17	50
4	10	30
5	7	20
6	20	60
7	11	33
8	0	
9	23	70
	0	null

Inspector

allRunners! Left = index=0? -50: Me[index-1]!Right+20

Index	Left	Me[index-1]!Right
0	-50	
1	-32	-43
2	8	-12
3	34	14
4	71	51
5	101	81
6	128	108
7	168	148
8	199	179
	219	199

Figure 5: The inspector showing irregular values in red and yellow.

and obtain feedback on an incomplete task.

Although custom visualization tools provide visual feedback (WYSIWYG), it can be insufficient in some cases. For instance, cases where some visual objects are out of view. Hence, the inspector can bridge that gap with concrete values behind the visual objects and properties.

- **Visibility.** The visibility dimension assesses the ability to view a component easily. The inspector improves the visibility since it makes more information visible to the designer. For instance, the data and values behind visual objects and properties can be needed when the designer is verifying the visualization.

5.2 Experimental Evaluation

We carried out a preliminary evaluation study with seven designers to evaluate the effect of the inspector on the ease of learning of visualization creation.

5.2.1 Participant Background

All the participants were non-programmers. They had no prior knowledge of the Uvis formulas, and had never used Uvis environment. Table 2 shows the participant skills.

5.2.2 Procedure

Each evaluation study lasted 2 hours on average. The studies were carried out at a lab. The participants were divided into two groups: participants 1, 2, 3 and 4 belong to group A while participants 5, 6, and 7 belong to group B. Participants in group A used Uvis with the inspector while participants in group B used a Uvis version that did not have the inspector. Each participant viewed two screens. One screen showed a power-point based step-by-step tutorial available , and the other showed the Uvis environment. The tutorials for both groups were identical except that the group A tutorial explained about the inspector. Each designer was asked to view the tutorial, do what it says. The tutorial is divided into sections, at the end of which,

Table 2: The participant skills.

Profile	Participants						
	1	2	3	4	5	6	7
Age	28	22	22	60	18	27	29
Position	volunteer	student	student	businessman	student	student	Loan manager
Know what a database table is	✓	✓	✓	✓	✓	✓	✓
Familiar with ER models	✓					✓	✓
Familiar with basic algebraic equations	✓	✓	✓	✓	✓	✓	✓
Familiar with basic math sequences	✓	✓	✓	✓	✓	✓	✓
Familiar with basic spreadsheet formulas (e.g. +, *)	✓	✓	✓	✓	✓	✓	✓
Familiar with advanced spreadsheet formulas (e.g. SUM, MAX, AND)			✓				
Familiar with logical expressions	✓		✓				
Knows how to interpret simple visualizations (e.g. line chart, pie chart)	✓	✓	✓		✓	✓	✓

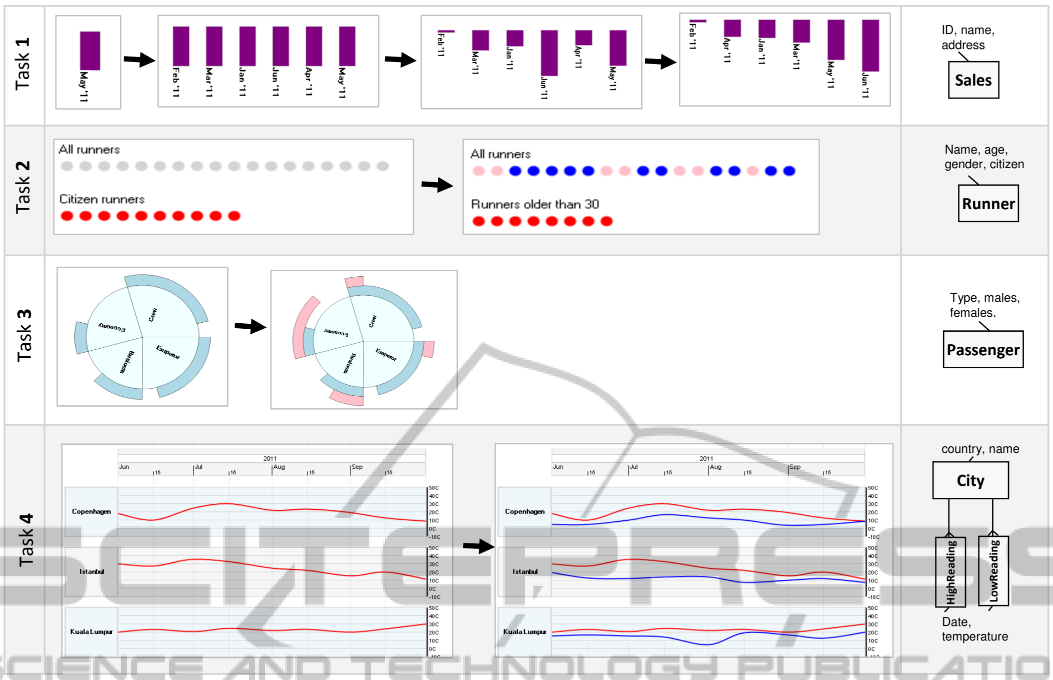


Figure 6: The evaluation tasks.

designers were given a task to work on their own, but they could go back to the tutorial and/or example solutions.

To evaluate the impact of the inspector on usability, we observed the usability problems in both groups and tested the understandability with questions. Further, we measured completion time (T) and the quality of the solution (Q). The quality of the solution was measured in the same way it was measured in the usability studies.

The documentation can be found at (Evaluation, 2012).

5.2.3 Tasks

The tasks were designed to meet three criteria: First, the visual tasks should cover different custom visualizations. Second, all the tasks should vary in complexity. Third, together with the evaluation study, the tasks should not take more than two hours.

- **Task 1.** The bars (on top of each other) show a company's monthly sales. Position bar charts representing monthly sales like a horizontal list, make the bar heights represent the monthly sales, and order them based on the sales.
- **Task 2.** The ellipses on the top show all runners in a marathon. The ones on the bottom show runners that are citizens. For the ellipses on top, make the male runners blue, and the female ones pink. For the ellipses on the bottom, show only runners older than 30.
- **Task 3.** A pie chart shows several classes of passengers (e.g. crew, emperor, etc.). The male passengers are shown on the top as light blue pie slices. Show female passengers on the top as pink pie slices.
- **Task 4.** The red curves represent the high readings of the weather in three cities in a period of time. Show the low readings as blue lines.

5.2.4 Questions

The questions were designed to collect qualitative information about the usefulness of the inspector.

- **Questions that were Asked to Both Groups:**
  - **Question 1** - *asked after all tasks*: Are you confident that your solution produce the expected outcomes described in the tasks?
  - **Question 2** - *asked after tasks 1 and 2*: Can you explain where the data in the visualization come from?
  - **Question 4** - *asked after task 3*: Can you explain how the curve position has been calculated?
- **Questions that were Asked to Group A:**
  - **Question 5** - *asked in the end of the study*: Did you find the inspector helpful? Why?

	GA Participants (with the inspector)				GB Participants (without the inspector)			Summary			
								Time (m)		Quality (0-10)	
	1	2	3	4	5	6	7	GA	GB	GA	GB
Task 1	T: 12.4 Q: 10	T: 5.5 Q: 10	T: 7.6 Q: 10	T: 14 Q: 7	T: 25 Q: 7	T: 23 Q: 4	T: 25 Q: 7	μ : 9.8 σ : 3.9	μ : 24.3 σ : 1.2	μ : 9 σ : 1.5	μ : 6 σ : 1.7
Task 2	T: 8.3 Q: 8	T: 4 Q: 10	T: 4.7 Q: 9	T: 8.1 Q: 5	T: 14 Q: 5	T: 12 Q: 8	T: 14 Q: 5	μ : 6.2 σ : 2.2	μ : 13.3 σ : 1.2	μ : 8 σ : 2.2	μ : 6 σ : 1.7
Task 3	T: 6.6 Q: 10	T: 15.3 Q: 9	T: 9.3 Q: 10	T: 23 Q: 4	T: 14 Q: 5	T: 12 Q: 2	T: 14 Q: 5	μ : 13.5 σ : 7.2	μ : 13.3 σ : 1.2	μ : 8.3 σ : 2.9	μ : 4 σ : 1.7
Task 4	T: 4.6 Q: 9	T: 7.6 Q: 9	T: 6.4 Q: 10	T: 11 Q: 5	T: 13 Q: 9	T: 12 Q: 2	T: 13 Q: 9	μ : 7.4 σ : 2.7	μ : 12.7 σ : 0.5	μ : 8.3 σ : 2.2	μ : 6.7 σ : 4

Figure 7: Evaluation Quantitative results. T=Time, Q=Solution quality, GA=Group A, and GB=Group B.

– **Question 6** - *asked in the end of the study*: How often did you use the inspector on average per task?

5.2.5 Results

Quantitative Results. Figure 7 provides an overview of the quantitative results of the evaluation. In all tasks, participants in group A (participants that used the inspector) had better solution quality than participants in group B (participants that did not use the inspector). Except for task 3, participants in group A completed their tasks in shorter time than participants in group B. In task 3, most group B participants gave up before they could come up with a complete solution.

Qualitative Results. The qualitative results can be summarized as follows:

- Participants in group A found the inspector helpful as it gave them feedback and confirmation of their solution. Our observations show that the participants looked at the inspector whenever the visual mappings changed.
- When asked after the end of each task about whether they are confident about their solution, two participants in group A looked at the inspector first to check the visual mappings and answered ”yes”. The participants in group B were hesitant to say yes. Instead the answers were ”I guess so” and ”Maybe so”.
- Group B participants found it hard to explain the relationship between data, visual objects, and visual properties. On the contrary, group A participants could easily use the inspector to explain the relationship. For instance, they pointed at a selected visual object (e.g. ellipse) and the underlying row in the inspector.

6 CONCLUSIONS AND FUTURE WORK

In this paper, we showed that there is a gap in custom visualization tools, the connection between visual objects, properties, and data is not explicit. We argued that the inspector bridges that gap by explicitly showing data behind the visual objects and the properties. Our theoretical evaluation shows that the inspector reduces hidden dependencies and improves progressive evaluation and visibility. Our preliminary evaluation with designers shows that the inspector helps designers verify the visual mappings and improves time completion and solution quality.

We plan on evaluating the inspector with more participants. Furthermore, we plan on testing the impact of the inspector on more cases. For instance, visual objects showing hierarchical data (e.g. graphs), visualizations with data that has problematic values (e.g. null values).

We also plan on evaluating the scalability of the inspector using visualizations of large data sets. If the current version of the inspector does not scale, what additions are needed to accommodate a large number of data? Could showing data in several pages suffice? Do we need to integrate a search mechanism? This needs to be investigated in depth and evaluated with designers.

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REFERENCES

(2009). Flare - data visualization for the web. URL: http://flare.prefuse.org/. Accessed September, 2012.

Akasaka, R. (2011). Protoviewer: a web-based visual design environment for protovis. In *ACM SIGGRAPH 2011 Posters*, SIGGRAPH '11, pages 85:1–85:1, New York, NY, USA. ACM.

Bostock, M., Ogievetsky, V., and Heer, J. (2011). D^3 data-driven documents. *IEEE Trans. Vis. Comput. Graph.*, 17(12):2301–2309.

Evaluation (2012). URL: http://itu.dk/people/moak/Inspector/EStudies.PDF. Accessed September, 2012.

Fekete, J.-D. (2004). The infovis toolkit. In *INFOVIS*, pages 167–174.

Grammel, L., Tory, M., and Storey, M.-A. D. (2011). Erratum to "how information visualization novices construct visualizations". *IEEE Trans. Vis. Comput. Graph.*, 17(2):260.

Green, T. and Blackwell, A. (1998). Cognitive dimensions of information artefacts: a tutorial. *T.R.G. Green and A.F. Blackwell*, 1(2).

Green, T. R. G. (1989). Cognitive dimensions of notations. In *Proceedings of the fifth conference of the British Computer Society, Human-Computer Interaction Specialist Group on People and computers V*, pages 443–460, New York, NY, USA. Cambridge University Press.

Heer, J., Card, S. K., and Landay, J. A. (2005). prefuse: a toolkit for interactive information visualization. In *CHI*, pages 421–430.

Heer, J., van Ham, F., Carpendale, S., Weaver, C., and Isenberg, P. (2008). Creation and collaboration: Engaging new audiences for information visualization. In Kerren, A., Stasko, J., Fekete, J.-D., and North, C., editors, *Information Visualization*, volume 4950 of *Lecture Notes in Computer Science*, pages 92–133. Springer Berlin / Heidelberg.

Kuhail, M. A. and Lauesen, S. (2012). Customizable visualizations with formula-linked building blocks. In *GRAPP/IVAPP*, pages 768–771.

Kuhail, M. A., Pandazo, K., and Lauesen, S. (2012). Customizable time-oriented visualizations. In *ISVC (2)*, pages 668–677.

Lauesen, S. (2005). *User Interface Design: A Software Engineering Perspective*. Addison-Wesley.

Lauesen, S. (2009). Uvis for unified data visualization. URL: http://www.itu.dk/people/slauesen/S-EHR/UnifiedDataVisualization.pdf. Accessed August, 2012.

Nielsen, J. (1993). *Usability Engineering*. Academic Press, Inc.

Pantazos, K., Kuhail, M. A., Lauesen, S., and Xu, S. (2013). uVis Studio: An Integrated Development Environment for Visualization. In *Proc. SPIE, Visualization and Data Analysis 2013*, number 8654-21.

Sears, A. and Jacko, J. A. (2007). *The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications*. CRC Press.

Spotfire (2012). URL: http://spotfire.tibco.com/. Accessed July, 2012.

Spreadsheets, G. (2012). URL: http://www.google.com/google-d-s/spreadsheets/. Accessed September, 2012.

Studies (2012). URL: http://itu.dk/people/moak/Inspector/UStudies.PDF. Accessed September, 2012.

Tableau (2012). URL: http://www.tableausoftware.com/. Accessed July, 2012.