Recommender System to Support Chart Constructions with Statistical Data

Taissa Abdalla Filgueiras de Sousa[1,2] and Simone Diniz Junqueira Barbosa[1]

[1] Departamento de Informática, PUC-Rio, Rio de Janeiro, RJ, Brazil
[2] IBGE
{tsousa,simone}@inf.puc-rio.br

Abstract. Research on statistical data visualization emphasizes the need for systems that assist in decision-making and visual analysis. Having found problems in chart construction by novice users, we researched the following question: *How can we support novice users to create efficient visualizations with statistical data?* To address this question, we proposed ViSC, a recommender system that supports the interactive construction of charts to visualize statistical data. It explores a visualization ontology to recommend a set of graphs that help to answer information-based questions related to the current graph data. By traversing the recommended graphs through their related questions, the user implicitly acquires knowledge both of the domain and of visualization resources that represent the domain concepts of interest well. We report here a qualitative study conducted to evaluate ViSC using two methods: the Semiotic Inspection Method (SIM) and a Retrospective Communicability Evaluation (RCE). We first analyze how the questions influence the users' traversal through the graph and then address the broader question. We concluded the questions were important to generate efficient visualizations and thus, an efficient solution to help novice users in chart constructions.

Keywords: Statistical data visualization, recommender systems, semiotic engineering, human-computer-interaction.

1 Introduction

The goal of visualization is to aid understanding of data, leveraging the ability of the human visual system to identify patterns, detect trends and discrepancies [15]. Visualizations can be an effective means of communication when it takes advantage of human perception and cognition [22], esp. the human ability to recognize visual patterns [23]. However, chart creators or designers can confuse the reader either by selecting misleading graph types or by distorting representations. Tufte [27] describes methods to create well-designed charts, but also common techniques that obscure the reader's understanding, such as lack or forgetfulness of scale; omission of the initial value, which should be always zero (otherwise it may cause disproportion between the compared values); and comparison between part and the whole (comparisons between the past whole year with the current one). Thus, an efficient visualization can help in comprehension, memory and decision-making. On the other hand, inadequate visualizations can confuse the user, causing misinterpretation of data.

M. Kurosu (Ed.): Human-Computer Interaction, Part I, HCII 2014, LNCS 8510, pp. 631–642, 2014.

To promote an adequate interpretation and to avoid mistakes, students need not only perceptual experience but also mathematical knowledge [12]. Chart interpretation requires specific knowledge of graphic systems, which are not easy to learn [4, 13]. This problem is aggravated in countries with high rates of functional illiteracy and cultures that promote information absorption without questioning.

Computational systems that allow users to interact with charts can also influence to the data interpretation and the graphic system understanding. These systems aim to improve the user experience in data visualization and motivate his interest. Among the visualization tools to present statistical data in the Web, we find:[1] Manyeyes, GapMinder, Worldmapper, Statplanet, Google Public Data, several multimedia atlas, SIDRA, and Statistical Series. There are also several available toolkits that allow chart creation, such as: [2] Flare, Silverlight, JavaScript InfoVis toolkit and ivtk. However, many tools for novice users restrict users to a single visualization, and toolkits usually need additional programming to make the operations to the visualization creation, i.e., they target expert users [10].

Mackinlay *et al.* state "all analysts have knowledge about their problems domain, but only few have skills to design effective graphic presentations of information", and "people need systems of visual analyses that automatically present data using the best practices of graphic design" [19]. Sousa reached a similar conclusion when she analyzed problems of chart construction and interpretation through a qualitative research evaluation with some Web visualization tools [25].

Sousa also verified that the phrasing of the information-seeking question is a central step for reading and designing charts [1]. To help novice users in creating efficient visualizations, we created ViSC ─ Visualization with Smart Charts ─, a visualization tool for displaying statistical data that helps users to explore the information visualization space by recommending related visualizations based on typical information-seeking questions.

In the next section, we list some internet visualization tools and explain why they do not meet users' requirements for visualizing statistical data. Section 3 describes ViSC, our visualization tool. In section 4, we report a study to evaluate ViSC. Finally, section 5 presents concluding remarks and discusses future work.

2 Related Work

Our work draws on research on graphic systems, visualization techniques for interactive systems, automatic presentation techniques and tools.

---

[1] http://www-958.ibm.com/software/analytics/manyeyes/; http://www.gapminder.org/; http://www.worldmapper.org/; http://www.sacmeq.org/interactive-maps/statplanet/StatPlanet.html; http://www.google.com/publicdata/directory?hl=en_US&dl=en_US#; http://www.sidra.ibge.gov.br/; http://seriesestatisticas.ibge.gov.br/

[2] http://flare.prefuse.org/; http: //www.silverlight.net/; http://thejit.org/; http://ivtk.sourceforge.net

With regard to the rules of reading and constructing charts, we followed Bertin's semiology of graphics [1] and the Few's guidelines [11]. According to Bertin [1], the basic problem of chart construction is the selection of representation, which depends on the evaluation of specific properties and efficiency of each language. Heer and Shneiderman [16] describe three design solutions for data visualization. The first solution uses chart typology, a palette of available visualizations for analysts to show their data. Despite its simplicity and familiarity, especially to spreadsheet users, this approach may become cumbersome when trying out different visualizations with the same data. The second solution consists of using data-flow graphs, in which the visualization process is composed of a set of operators to enable tasks like data import, transformation, layout, coloring, etc. It allows flexible combination of systems and more design variations, but it also requires more effort than chart typologies. The third and last solution involves formal grammars for building visualizations. These grammars are high-level languages that describe how data should map onto visual features. Some examples of this type of solution are toolkits, such as: *ggplot for the R statistical analysis platform*,[3] Protovis [2] for HTML5, and Google Chart Tools.[4] However, as described before, toolkits require some programming skill. As these methods are not mutually exclusive, ViSC uses chart typology and formal grammar. However, our grammar is used only internally by a recommender system, and thus ViSC does not require programming skills from the user.

Tableau[5] and Explorations Views (EV) [10] are recent visualization tools developed for both novice and expert users. Show me [19] is an integrated set of interface commands that add automatic presentation in Tableau, a commercial system designed to be used by novice and expert users to create effective visualizations based on Bertin's semiology of graphics [1] and on the algebra of APT [20]. The Show Me panel consists of a dialog of choices with tooltips that describe conditions for a choice to be available. Exploration Views (EV) is still a prototype but also suggests charts and templates to create dashboards by novice users.

The next section describes ViSC, the proposed tool whose design draws on Bertin's and Few's rules and guidelines, as well as on the methods of automatic presentations used in Tableau and EV.

3 The ViSC Tool

Results of a qualitative user evaluation study of visualization tools [25] also influenced the design of ViSC interface. Similar to both EV and Tableau, ViSC generates visualizations of aggregated multidimensional data from selecting only two variables, while assigning default initial values to the remaining variables. As part of the process of information seeking, ViSC differs from the others because includes a knowledge-based recommender system [3]. Based on ViSC's ontology [24], the interface recommends charts to help meet user needs. From the selected data and visualization, ViSC attempts to infer questions the user might want to answer at each moment.

---

[3] `http://had.co.nz/ggplot2/`
[4] `https://developers.google.com/chart/interactive/docs/index`
[5] `http://www.tableausoftware.com/`

ViSC's ontology [24] was inspired on the ontology of the Visko project [28], the visualization ontology of UK National e-Science Center [21] and the data taxonomy of Tory *et al.* [26]. It has five high-level classes: data, display attribute, visualization, task and transformation.

The ontology associates eight kinds of visualization ─ clustered columns, multiple columns, stacked columns, time series, multiple time series, stacked series, scatterplot and table ─, questions related to these visualizations and characteristics of the selected data such as type of component and nature. The questions were classified according to the taxonomy of Amar *et al.*, which covers a set of ten task related to specific questions of a user may ask while work in a set of data [1]. The covered tasks are: retrieve value, filter, compute derived value, find *extremum*, sort, determine range, characterize distribution, find anomalies, cluster and correlate. In ViSC, the questions are dynamically generated based on templates stored at the database, such as:

- How many <persons> with <10 years of study> are in <Rio de Janeiro>? (task: retrieve value)
- What is the average of <grade average> in <disciplines> of the selected set? (task: compute derived value)

The relation between data characteristics and display attributes defines preconditions to map variables onto display attributes. We have also attributed scores (from 1 to 5) to the relation data-question-visualization. Therefore, besides data characteristics, the ontology presents selection conditions according to the number of selected elements at each dimension.

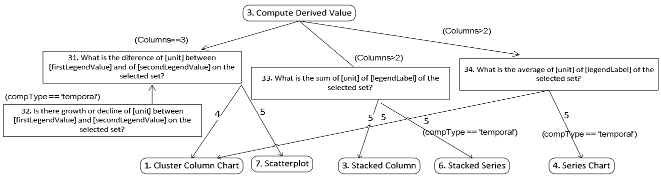


Fig. 1. Ontology fragment related to the task Compute Derive Value

Figure 1 presents a fragment of the ontology relating the task Compute Derived Value, its questions, conditions and effective visualizations. You can see that, regarding question 31, which calculates the difference between two quantitative values, the selection condition is to have 3 columns among the selected data. To answer this question, our visualization shows the scatterplot as the most highly rated (score equal to 5), so it is the most efficient between the options.

Figure 2 presents the ViSC main user interface. Area 1 displays the menu of elements to each dimension. Area 2 provides the visualization menu, whose items are enabled and disabled according semantic characteristics of the selected data (preconditions). Area 3 presents buttons to sort the data into the displayed chart. Area 4 is the main area, where the system displays charts. Finally, area 5 shows the related questions to recommend different visualizations.

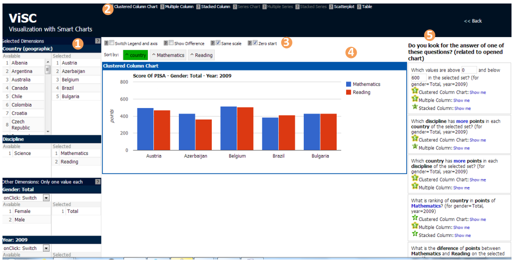


Fig. 2. ViSC Interface

The questions are generated by the user's interaction with the system in the following way: after the user selects the data, ViSC presents questions related to the current displayed visualization and recommends other efficient visualization to a different set of questions related to the selected data.

The questions aim to enable a user-system dialog in close-to-natural language, so that the user traverses through other visualizations related to the answer he seeks. For each interaction, the displayed questions can be changed or highlighted at the user interface, to reflect their relevance to the selected data. Thus, the system guides the user in searching for an effective visualization to answer her question. All visualizations related to the question are displayed at the interface sorted by score in decreasing order. The score is shown at the interface inside the star icon beside the name of the chart.

According to Semiotic Engineering, the user interface is a metacommunication artifact through which the designer sends to users a *metamessage* of why and how the users can and should use the system 9. From previous studies we defined the following ViSC metamessage: "*I think you are a student or a professional from a field related or not to statistics and need to create efficient visualizations. As you may not have total domain about the graphic system, you would like to have an interface that, with little interaction, creates a chart. From this chart you would like to easily change selected values or representation. You also want to be able to compare the displayed chart with other visualizations. Thus, we designed a system that, from the selection of the theme and two more variables, displays a chart with some dimensions selected automatically by default. You need only to include or switch the pre-defined values and select by one of the avialable visualizations. In order to help you to choose the most efficient visualization, the interface recommends visualizations based on questions you may want to answer. You can select the visualization through options of menu or through the questions. By selecting this kind of interaction you only need to find the sought question and to choose one or some among the recommended visualizations. The interface shows how to obtain the answer and highlight it in the chart. Each recommended visualization also has a score related to your selection and to a question you may want to answer. The interface displays these scores to help in your choice. You can also try other options to improve your chart such as switch axis, include difference, change scales, remove zero or sort values.*"

The main difference between ViSC and the other tools is exactly the dialog ViSC exchanges with the user through the related questions. Thus, we have aimed to contribute to the Human-Computer-Interaction (HCI) field through this proposal of interaction based on recommendation for visualization tools in order to solve problems of chart construction and interpretation by novice users.

4 ViSC Evaluation

We conducted a user evaluation study to answer the following question: “How do the related questions influence the task performance and the generated visualizations?” In this study, we compared ViSC with Tableau Public,[6] to understand the chart construction process with and without the interface questions. We selected two qualitative methods to triangulate results: the Semiotic Inspection Method (SIM) [6] and a method we named “*Retrospective Communicability Evaluation* (RCE)”, which involves user observation, Retrospective Think Aloud (RTA) [14] and the tagging step of the Communicability Evaluation Method (CEM) [8].

4.1 Methodology

SIM [6] is the proposed method by Semiotic Engineering [9] to analyze the diversity of signs and sign systems that compose the metamessage. After inspecting the metalinguistic signs (found in the system documentation and in natural language messages), static signs (composed of images, icons, colors, etc.) and dynamic signs (animations and generated behaviors from events), we compare the designer-to-user metamessage generated in each previous inspection and, finally, analyze the quality of the overall metacommunication. The *Retrospective Communicability Evaluation* consists of three main phases: 1) user observation, 2) retrospective think aloud (RTA) and 3) tagging. The observation phase consisted in observing and recording the user interacting with the tools and taking notes about relevant occurrences. The second phase (RTA) consisted in observing, recording and later transcribing each users’ speech while he was watching the recording created in the previous phase. Based on CEM [7], in the tagging step we identify breakpoints of communication, and then we map these breakdowns onto HCI problems and rewrite the semiotic profile with the general metamessage emitted by the system. For each breakdown, we assign one of the thirteen tags proposed by Semiotic Engineering, which are common expressions at the human communication and they are: “Where is it?”, “What now?”, “What’s this?”, “Oops!”, “Where am I?”, “What happened?”, “Why doesn’t it?”, “I can’t do it this way.”, “I can do otherwise.”, “Thanks, but no thanks!”, “Looks fine to me.”, “Help!” e “I give up.” Later, at the interpretation stage, with the tagged material, the evaluator aims to identify the main metacommunication problems, analyzing the frequency and context of each type of tagging, the existence of sequence of patterns to each type of tagging, the level of the analyzed problem and the communicability problems that caused the observed breakdowns.

[6] `http://www.tableausoftware.com/public`

We defined a scenario with two tasks with similar difficulty: one performed with ViSC and the other with Tableau Public. In order to reduce the learning effect of the evaluation results, we used the Latin square method [18] to distribute tasks and tools between the two groups of users. The tasks were the following:

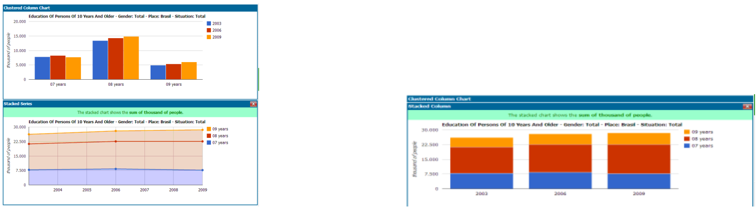
1. Show whether the education level of Brazilian students between 7 and 9 years old increased in the period from 2003, 2006 and 2009.
2. Analyze the average of grades in the PISA exam from Brazil, Canada and Australia in 2003 and 2009, and then identify the country with highest increase.

The participants had to have some skill in reading graphs but not be professional statisticians, journalists or data analysts, nor have previous experience in using Tableau. We recruited six students (undergraduate and graduate) in engineering, informatics, and computer science. In order to assess their initial skills and compare the results, we asked them to perform two tasks with pen and paper before the test sessions.

4.2 Findings

SIM and RCE were effective methods to help us find HCI problems in ViSC. Through SIM, we reconstructed the ViSC metamessage and checked that it was consistent with the designer's metamessage (described in section 3). However, this method revealed inconsistencies and ambiguities in some signs, meaning that the users could misunderstand them. RCE allowed us to understand the processes of user's reasoning and formulation of hypotheses, related to both the tools and the generated visualizations; to evaluate how the questions influenced the results; and to understand, through the reconstruction of the received metamessage, the signs actually misunderstood by the user.

Task 1 asked the user to show if there the total number of students between 7 and 9 years of schooling in 2003, 2006 and 2009 has increased. The first one, as a summation could be answered with both the stacked column (Figure 3b) and the stacked series (second chart of Figure 3a) in ViSC and the stacked bars in Tableau. All of the three users of ViSC used questions to perform the task and all generated efficient visualizations. The first one created a composite of two charts including the stacked series and the others created the stacked column chart.



(a) (b)

Fig. 3. (a) Result of the first user, cluttered column chart and stacked series; (b) Result of the second user, stacked columns

One of the HCI problems we analyzed with both methods was the selecting of the field difference (checkbox), because in some conditions it did not return any feedback. The RCE allowed us to find even more breakdowns, because the users sought a functionality not developed to the tool. Two of the three users who performed task 1 with ViSC tried to gather the three colors in a column with only one color. The users also did not understand well the sorting buttons. One of them tried to reorder variables by removing and including elements in the new order. We concluded that the sorting buttons did not emit a clear message to the user. RCE allowed finding other problems and HCI features that fumbled the user, such as: lack of understanding due to lack of metadata; and the need to relate the displayed graphics with the selected item in the graphic menu.

Regarding the features that helped the user, we verified, through explicit comments, that questions had major influence and led the user to efficient results. According to the first user, the questions were crucial for him to find the desired response. His answer about satisfaction with the result is consistent with the given explanation during the RCE and show that he really compared visualizations to achieve the given result: "*I decided to show the two graphs because I thought it would be more complete.*"

Other users employed the questions to check whether the graphic was correct. According to the second user, the questions were neutral to the obtained result. However, we assess that they had a higher importance because when he compared his chart to the recommended chart, he stopped seeking the consolidated sum, which expedited the completion of the task. According to him, his first impulse would always try to draw the graphic. Furthermore, when asked about other recommended alternative, he said: "It was interesting because I don't know if I would have thought to draw stacked series".

Despite having developed the same reasoning, intending to build a graphic that the tool did not allow (with the total sum), the third user chose the recommended solution. For him, as well as speed, this strategy also returned a better result than the one he had thought. These two users' statements show that some learning may have taken place during interaction with the system.

In order to evaluate the users' understanding of the questions, we asked them to explain how they thought the questions were generated and what they understood about the scores. The first user explained: "I honestly do not know how they are made, but it seems to have the information available to you and recommend some related information. (...) Either based on the chart or based on information. It shows what can be cool for you to show." The second user explained : " (...) So, at the first moment, I didn't realize that they were facilitators (...) I just realized it later when I got to click on the chart I've made". The third one said: "I knew it was going to show questions related to what I had. (...) So that was what helped me."

About sorting through scores, only the third user said he had seen it: "It has also influenced. For example: I looked at first at visualizations with score five." For the second user, it was not noticeable. "I saw it but I didn't understand what the star was."

Two users demonstrated awareness they did not create the most efficient chart but considered the task as complete. Although Tableau allowed more interaction than

ViSC and was apparently more attractive to users, the produced charts were considered less satisfactory, and the tool was considered more difficult. Between the two tools, one of the users stated he wanted thumbnails of graphics in ViSC as in Tableau.

Task 2 asked the user to observe the average grade on the PISA exam from Brazil, Canada and Australia in 2003 and 2009, and to identify the country where the increase was higher. The recommended visualizations were scatterplot (with score five) and clustered column chart (with score three).

The first two users used the questions to help in performing the task. However, none of them created the chart with the highest score. Two of them created the clustered column chart (Fig. 4a) and the other one, series chart (Fig. 4b).

Fig. 4. (a) Clustered column chart with the column difference; (b) series chart

Among the most serious problems encountered with the RCE we found the usage of questions to navigate without reading the questions. We also verified a problem in the ontology. The second user selected an equivalent question but the system opened a different option, the time series chart. This was not a good option to answer this question because the line was not very slanted (Fig. 4b).

Although the first user knew he already had an answer, he used the questions to try to find something better: “I understood they were many ways to show the information and I could filter sometimes. But I didn’t want to filter. I wanted to find the better visualization. First I looked for a line chart. I found a chart that I didn’t want (scatterplot).” He claimed to not have noticed the scores next to the visualizations and said they were useful because they opened the graphic to him.

The second user also used the questions and stated he accepted the first system recommendation and did not try other possibilities. He understood the questions and added that they were important to him: “They worked as a shortcut if you had something in mind to generate. I saw it was smart enough to see the data I wanted to analyze and match the questions with these data. For me it was helpful. I clicked here and I went straight to the answer. It just missed to improve the scale a little better, but it was just what I wanted. I thought it was important. It saved me a lot of time.”

The third user did not interact with the questions because, according to him, there was too much text. When questioned about the influence of the language (English), he stated that if the questions were in his native language he probably would have read them.

4.3 Discussion

In task 1, we verified that the questions motivated the data analysis, and could also have promoted learning for two users. All the users of ViSC interacted with the questions and understood how they worked. Although it was not clear to them how the questions were generated, they noticed their changes and considered them an important functionality to achieve their results.

In task 2, the questions had an important value to the second user, even though the presented result was not very efficient. In this task, he was the only one who really understood how the questions work. The first user used them in an inadequate way and the third user did not use them.

In the interviews, users stated that the questions in ViSC and the way to filter charts make the task easier. Among ViSC difficulties, we found some HCI problems, but only one user mentioned the questions as potentially causing difficulties, because, in his opinion, they can create ambiguity.

All users understood that the questions are dynamically generated and help them to create efficient visualizations. However, the scores were not understood by everyone.

We observed four different behaviors regarding interaction with the questions: (1) users who found in questions an opportunity to accomplish the task more quickly; (2) users who were not so satisfied or had doubts about the given solution and resorted to questions as a way to validate or to improve the result; (3) the user who used the questions as links to charts but who has not really read them; and (4) the user who did not interact with them.

Thus, we can answer how the questions influence the users' traversal through the charts. We observed that their influence was positive or neutral in all interactions. Regarding the task, we had some cases in which the questions sped up the process, working as a facilitator and, in other cases, they were important to check the result. Among the generated visualizations, users who used the questions created efficient graphs, except by the case in which we observed a problem with the ontology. Even in this case, the user understood the tool and performed the task quickly. We also verified one case which the user corrected the first generated graph with the recommended graph. In other two cases, the questions reinforced the option of the generated graph because they brought the same one. For those who examined the recommended options to choose from, we observed that recommendations have increased their confidence in the resulting chart and some learning may have taken place. Among those who did not use the question or used them as links to open the graph, their influence was neutral. None of them reported that the questions hindered the task performance.

5 Conclusions

The goal of this research was to create and evaluate a solution to support novice users to create efficient visualizations with statistical data.

Academic studies about information visualization, interactive graphs and evaluation with visualization tools were the bases to design and develop a visualization ontology and a knowledge-based chart recommender system called

ViSC, Visualization with Smart Charts. In ViSC, we sought to solve HCI issues we found in previously investigated tools. The most important point, however, was the inclusion of recommendations through common questions that users may want to answer about the data with efficient visualizations. The recommendations guide the user through charts related to the selected data during the interaction.

We evaluated ViSC using the Semiotic Inspection Method (SIM) and the Retrospective Communicability Evaluation (RCE). We explored how users understood the recommended questions and how the questions influenced users in performing the tasks and achieving their results. Five out of six users employed the questions, and four of them were able to obtain efficient results through their use and considered them important. Therefore we believe our main contribution to support efficient chart construction by novice users was achieved. In addition, some users analyzed more than one of the recommendations and compared them to the previous chart made by themselves, learning more about chart construction in the process.

Besides gathering some feedback for refining ViSC and its ontology, this research raised questions that require additional studies. First, we would like to conduct a longitudinal study to evaluate what kinds of learning take place. Second, we would like to better understand when and why users would not use the questions. Finally, we would like to evaluate how ViSC supports novice users who do not have a well-defined question and who want to check for new information through a process of knowledge discovery.

Acknowledgements. The authors thank the study participants for their valuable time and insights. Taissa Sousa thanks IBGE and Simone Barbosa thanks CNPq (process #308490/2012-6) for the support to her research work.

References

1. Amar, R., Eagan, J., Stasko, J.: Low-Level Components of Analytic Activity in Information Visualization. In: IEEE Symposium on Information Visualization 2005, USA (2005)
2. Bertin, J.: Semiology of Graphics: Diagrams, Networks, Maps (1918), ESRI 1st edn. (2011)
3. Bostock, M., Heer, J.: Protovis: A Graphical Toolkit for Visualization. IEEE Transactions on Visualization and Computer Graphics, InfoVis 2009 (2009)
4. Burke, R.: Knowledge-based recommender systems. Encyclopedia of Library and Information Science. Department of Information and Computer Science. U. of California, Irvine
5. Clement, J.: Misconceptions in Graphing. In: Proceeding of the 9th Annual Meeting of the International Group for the Psychology of Mathematics Education, pp. 369–375 (1985)
6. Cubrarnic, D.: Polstar: Assisted navigation for exploring multi-dimensional information spaces. In: Human-Computer Information Retrieval, HCIR (2008)
7. de Souza, C.S., Leitão, C.F., Prates, R.O., da Silva, E.J.: The Semiotic Inspection Method. In: Proceedings of the VII Simpósio Brasileiro de Fatores Humanos em Sistemas Computacionais, IHC 2006, pp. 148–157 (2006)

8. de Souza, C.S., Leitão, C.F.: Semiotic Engineering Methods for Scientific Research in HCI. Morgan & Claypool Publishers (2009)
9. de Souza, C.S., Leitão, C.F.: A method for evaluating the communicability of Users Interface. Morgan & Claypool Publishers (2009)
10. de Souza, C.S.: The semiotic engineering of human-computer interaction, Capítulos 1, 2 e 4. The MIT Press, Cambridge (2005)
11. Elias, M., Bezerianos, A.: Exploration Views: Understanding Dashboard Creation and Customization for Visualization Novices. In: Campos, P., Graham, N., Jorge, J., Nunes, N., Palanque, P., Winckler, M. (eds.) INTERACT 2011, Part IV. LNCS, vol. 6949, pp. 274–291. Springer, Heidelberg (2011)
12. Few, S.: Show me the numbers. Designing tables and graphs to enlighten. Analytics Press, Oakland (2004)
13. Goldenberg, E.P.: Mathematics, metaphors, and human factors: Mathematical, technical, and pedagogical challenges in the educational use of graphical representation of functions. The Journal of Mathematical Behavior 7(2), 135–173 (1988)
14. Gomes Ferreira, V.G.: Exploring Mathematical Functions Through Dynamic Microworlds, 353 f. Thesis (Education). Institute Education, Universidade de Londres (1997)
15. van den Haak, M.J., Jong, M.D.T., Schellens, P.J.: Retrospective vs. concurrent think-aloud protocols: testing the usability of an online library catalogue. Behaviour & Information Technology (2003)
16. Heer, J., Bostock, M., Ogievetsky, V.: A Tour Through the Visualization Zoo. Communications of the ACM (2010)
17. Heer, J., Shneiderman, B.: Interactive Dynamics for Visual Analysis. A taxonomy of tools that support the fluent and flexible use of visualizations. ACM Queue (2012)
18. Heer, J., Viégas, F.B., Wattenberg, M.: Voyagers and voyeurs: Supporting asynchronous collaborative information visualization. In: Proc. of the Conference on Human Factors in Computing Systems (CHI), pp. 1029–1038
19. Gao, L.: Latin Squares in Experimental Design. Michigan State University (2005), `http://www.mth.msu.edu/~jhall/classes/mth880-05/projects/latin.pdf` (last access in July 2013)
20. Mackinlay, J.D., Hanrahan, P., Stolte, C.: Show Me: Automatic Presentation for Visual Analysis. IEEE Trans. on Visualizations and Computer Graphics 13(6) (November/December 2007)
21. Mackinlay, J.D.: Automating the design of graphical presentations of relational information. ACM Trans. on Graphics 5(2), 110–141 (1986)
22. National e-Science Center. Visualization Ontologies, `http://www.nesc.ac.uk/talks/393/vis_ontology_report.pdf` (last access in November 2011)
23. Pinker, S.: A theory of graph comprehension. In: Freedle, R. (ed.) Artificial Intelligence and the Future Testing, pp. 73–126. Erlbaum, Hillsdale (1990)
24. Shah, P., Carpenter, P.A.: Conceptual limitations in comprehending line graphs. Journal of Experimental Psychology: General 124(1), 43–61 (1995)
25. Sousa, T.: Semantic characterization of visualization mechanisms. Tech. Report 16/12, PUC-Rio (2012)
26. Sousa, T.: How signification and communication systems influence the interpretation of statistical data by users with specific information needs. Tech. Report 15/12, PUC-Rio (2012)
27. Tory, M., Möller, T.: Rethinking Visualization: A High-Level Taxonomy. In: Proceedings of the IEEE Symposium on Information Visualization, INFOVIS 2004, pp. 151–158 (2004)
28. Tufte, E.R.: The Visual Display of Quantitative Information (2001)
29. Visko Visualization Knowledge, `http://trust.utep.edu/visko/dl/` (last accessed in November 2011)