DEFINING INFORMATION VISUALIZATION HEURISTICS BASED ON HEURISTIC GROUPING BY EXPERTS

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ABSTRACT

The visualization community has been done some efforts to construct a set of heuristics focused on the qualitative evaluation of a visualization (including usability issues, but not limited to them), which could be used in Heuristic Evaluations (HE). Despite these efforts, we could not find a consolidated (i.e. solid) set of visualization heuristics in use in our community. In this work, we present initial steps for defining a set of heuristics based on heuristics proposed by our community, aiming that such a set can be used in a visualization-focused Heuristic Evaluation and become consolidated after improvements. To develop this work, we started by collecting visualization heuristics and guidelines proposed by our community in papers related to HE; we also collected guidelines extracted from visualization books. A set of experts grouped these heuristics and guidelines using an online card sorting procedure. We summarized these groups in a set of eight heuristics to be used in a regular HE procedure. We assessed these new heuristics in an experiment with professionals and students with visualization background. These participants pointed out that they were able to use the proposed heuristics to identify problems related to visualization concepts in the systems they evaluated. In addition, most participants indicated that the set is well-defined, appropriate, and pertinent to each case found, which is a positive result towards the definition of a consolidated set of heuristics for visualization.

KEYWORDS

Information Visualization, Heuristic Evaluation, Heuristics

1. INTRODUCTION

Heuristic evaluation is a well-known inspection technique for assessing human-computer interfaces. It was proposed initially as a discount method for usability engineering (Nielsen, 1989), given that it can anticipate many relevant interface problems that a usability test would reveal, it is cheaper and faster than that kind of test, and its execution does not involve end users.

Many areas have been defining their own heuristics, such as human-robot interaction, software for children, smartphones, mobile devices and games (Oliveira, 2017). In particular, visualization is also part of this list. This research area has been proposing in the last two decades some sets of heuristics (e.g. the works of Forsell and Johansson (2010), Amar and Stasko (2004), Freitas et al. (2002), Scapin and Bastien (1997), Zuk and Carpendale (2006)), each one with its own concerns about which concepts to focus on and which construction strategy to follow. However, until now we could not perceive a consensual set of “visualization-specific heuristics” (in the terms of Tarrell et al. (2014)), i. e., a set of heuristics that are widely accepted by the visualization community to assess the quality of visualization systems. The opinion of the same authors is that the creation of visualization-specific heuristics would require “a concerted, community-wide effort to be most effective”.

Inspired on the need of widely accepted visualization-specific heuristics constructed and validated with the support of the visualization community, this paper presents a small set of heuristics for heuristic evaluation focused on relevant characteristics for information visualization (InfoVis) systems. This set was constructed with the support of InfoVis community members, and it groups 82 heuristics into 8 groups, which originated a new set of eight heuristics. This reduced set was preliminarily evaluated through an experiment with the participation of InfoVis community members, which provided positive feedback about the proposed heuristics.

This paper is organized as follows. We present in Section 2 some works related to the creation of visualization-specific heuristics. In Section 3, we describe our methodology for creating and evaluating our own set of heuristics with support of the InfoVis community. We discuss our results in Section 4, in which we highlight the description of our new heuristic set, the evaluation procedure, and the feedback of the evaluators that used our heuristics. The last section concludes the paper and points out future work.

2. RELATED WORK

As we pointed out in the beginning of this paper, the InfoVis area has been developing a list of heuristic sets for itself for at least twenty years (Freitas et al., 2002; Amar and Stasko, 2004; Zuk and Carpendale, 2006; Scapin and Bastien, 1997; Forsell and Johansson, 2010). Oliveira and Silva (2017) summarize the main contributions of these works. Developing such kind of heuristics is relevant, given that using visualization-specific heuristics would provide more effective assessment of visualizations than using usability heuristics (Tarrell et al., 2014).

Regarding some desired properties for InfoVis heuristics, Santos et al. (2018) argued that these heuristics should not be very specific, because this situation would have the potential to distract the evaluators from finding other, more general problems. Väätäjä et al. (2016) pointed out that the document that describes the heuristic set (in their case, the set of Forsell and Johansson (2010)) should include examples of heuristic violations, should group the heuristics according to a logical order, and should also shorten their descriptions. They also reported the need to include heuristics related to user interactions and aesthetics in that particular set. In a similar way, Santos et al. (2018) pointed out that some of the current proposed heuristics may be hard to use, and suggested that some heuristics could be rephrased and perhaps presented as exemplified guidelines.

Tarrell et al. (2014) and Oliveira and Silva (2017) presented distinct classifications of the approaches for developing heuristics. Tarrell et al. (2014) proposed three classes of approaches for creating visualization-specific heuristics: process-based approaches, in which the heuristics embrace all aspects of a visualization process; performance-based approaches, which propose a small set of heuristics that tries to cover most known problems; and framework-based approaches, which organize heuristics into categories. The authors argued that a framework-based approach would be better that the other two approaches. Oliveira and Silva (2017) defined two main classes of techniques for developing heuristic sets: techniques based on human resources, or based on literature review. In the first case, brainstorming meetings, answering questionnaires, and rating heuristics are some of the mentioned ways in which recruited people (users and/or experts) may help to define the heuristic set. In the second case, literature exploration, transformation of guidelines into heuristics, and derivation of heuristics from a set of problems are some strategies to define heuristic sets.

Apart from these classifications, it is worth noting that Tarrell et al. (2014) pointed out that the development of such set of heuristics is not straightforward, and it would require “a concerted, community-wide effort to be most effective”. They proposed that the community should work in a wide, asynchronous iterative task in which the proposed visualization guidelines could be commented on, voted on, and refined.

It is also relevant to consider how visualization-specific heuristics would complement (or be complemented by) other evaluation techniques. The work of Santos et al. (2018) compared problems found in usability tests and those found by heuristic evaluations. These evaluations used Nielsen’s usability heuristics (Nielsen, 1994) and the visualization heuristics proposed by Zuk and Carpendale (2006) and Forsell and Johansson (2010). The authors pointed out that usability tests may complement the list of problems found by these visualization heuristics (which is similar to what happens with Nielsen’s heuristics), according to their comparison.

Assessing the quality of a given set of heuristics is also a concern. Regarding this topic, Väätäjä et al. (2016) used a qualitative and quantitative methodology for assessing the explanatory quality of the heuristics of Forsell and Johansson (2010). The proposed methodology collects data from evaluators, after a heuristic evaluation session, about how well the heuristics explain the problems found by the evaluators, the usefulness of each heuristic, how easy (or not) was to do the evaluation procedure with these heuristics, and how to improve them. The authors perceived the need to provide better, more comprehensive definitions of these heuristics than those presented by Forsell and Johansson (2010), and these definitions were presented to the evaluators before the evaluation sessions. Väätäjä et al. (2016) concluded that the assessed heuristics have a good explanatory quality, because 65% of the reported heuristic violations gave a complete or fairly complete explanation of these violations to the evaluators. Väätäjä et al. (2016) also indicated that the lack of knowledge of the application domain by the evaluators may hamper the evaluation process.

As far as we know, the three last sets of heuristics presented in the InfoVis literature were the sets of Wall et al. (2019), Zhu and Gumieniak (2021), and Oliveira and Silva (2017) (whose work was partially complemented by Oliveira (2017)). Wall et al. (2019) presented a methodology called ICE-T. It comprises a set of 21 low-level heuristics, which are grouped into ten guidelines and further into components. These components (insight, confidence, essence and time) are supposed to represent the value of the visualization under evaluation. One step that differs ICE-T from other approaches is that the evaluators must provide a score for each heuristic, instead of associating problems with heuristics.

Zhu and Gumieniak (2021) proposed a computer-assisted heuristic evaluation method for data visualization. They exemplify some of the heuristics they considered; however, the complete list of heuristic rules they used is not available in their work. It is noteworthy that they argue that "Many heuristic rules are too abstract to be checked automatically", which enhances the need to have a human inspection of visualization systems.

The set of Oliveira and Silva (2017) and Oliveira (2017) was based on grouping of heuristics proposed by the following authors: Forsell and Johansson (2010), Shneiderman (1996), Amar and Stasko (2004), Freitas et al. (2002), Scapin and Bastien (1997), Nielsen (1994), and Zuk and Carpendale (2006). It is worth noting that Zuk and Carpendale (2006) also define "potential heuristics" based on theories and guidelines from the works of Bertin (1983), Tufte (1991), and Ware (2004). Oliveira and Silva (2017) grouped all these heuristics (a total of 62 ones) based on a matrix with pairwise similarity of heuristics. This matrix was reordered to group similar heuristics, aiming to help the visual identification of groups. They empirically defined the similarity level of each pair of heuristics as "not similar"; "somewhat similar"; "resembling, but not equal", and "equal". Visualizing this similarity matrix as a heatmap helped the authors to propose their groups of interrelated heuristics. After that, they defined each group as a new heuristic, which received a name and a description. They proposed a set of 15 heuristics. Oliveira (2017) conducted a preliminary HE with this new set of heuristics and collected a set of suggestions about how to improve it. Three evaluators conducted the evaluation of a visualization system from the electric power generation sector. They started with an individual session of assessment, followed by a consolidation session. The evaluation returned a set of problems to be solved in the assessed software. Oliveira (2017) pointed out that the empirical values of the similarity matrix could be a source of bias in the work, and that information visualization books could contribute with relevant concepts that possibly were not covered by the proposed heuristics.

3. METHODOLOGY

Our methodology comprises the following steps:

1. *Collecting sets of visualization heuristics published in previous papers*. This step is composed of bibliographic review about heuristic evaluation in visualization.
2. *Collecting a set of guidelines published in visualization books*. We consider this step necessary to fill in some possible gaps regarding visualization concepts that would not have been covered by the set of heuristics proposed in previous works. (Hereafter we will consider that guidelines can be understood as heuristics, and therefore we will use only the term "heuristics" to refer heuristics and guidelines).
3. *Generating groups of interrelated heuristics*. This step involves the participation of visualization experts to group the heuristics. Using the *card sorting* technique (Nielsen and Mack, 1994) supported by an online tool, each expert should individually create clusters of heuristics and provide a representative name to each cluster. It is worth noting the relevance of the participation of experts in this step, aiming to avoid bias.
4. *Creating a new set of visualization heuristics*, based on groups generated in the previous step. This step begins with a review and comparison of the (sometimes conflicting) groups of heuristics defined by each expert. The intermediate result of this process is a single set of groups of heuristics that tries to better represent the opinions of the experts. Based on this result, it is possible to define a new list of heuristics, one for each proposed group. Each heuristic must have a clear name and a description, based on the group of heuristics that the new heuristic represents.

5. *Evaluating the new heuristics*. The proposed preliminary assessing procedure comprises four steps.
   (a) First of all, it is necessary to define which systems will be evaluated by the proposed visualization-based HE. This choice may be guided by the experience of the research team regarding the perceived quality of visualization systems, and by the already known problems these systems present. The pre-selected systems are then inspected to search for problems related to each of the new heuristics, with the aim to find at least one problem per group of heuristics.
   (b) After selecting the systems to be assessed, it is necessary to invite a set of professionals and graduate students, with experience in visualization, to participate of a HE session. The first task of these professionals is to fill a short profile questionnaire; the questions are: highest academic level; formation area; working area; and years of experience with information visualization.
   (c) After filling the questionnaire, the authors must indicate that the participants should execute the individual step of a HE with the proposed visualization heuristics, in the set of systems defined by the authors. Each participant should briefly describe (and illustrate, if possible) the visualization problems they identified on each system. They should also link each problem to some of the new heuristics and to inform the reasoning behind the linking. It is noteworthy that the authors should not provide a set of tasks to guide the participants in exploring the systems in search of heuristic violations.
   (d) According to their own experience when executing the HE with the proposed heuristics, each participant should use a five-point Likert scale score, varying from 1 (completely disagree) to 5 (completely agree), to classify eight statements, one per heuristic. Each statement has the format "The heuristic *N*, "*name*" is suitable for evaluating visualization systems". *N* and *name* are respectively the number and name of the heuristic.
   (e) Besides, the participant should also write a brief analysis of the heuristic set, in which he/she should consider aspects such as suitability, pertinence, objectivity, and usefulness of the set of heuristics, and if the description of each heuristic is adequate.
   (f) The authors are then in charge of the analysis, comparison, and summarization of these results.

4. RESULTS

In this section we present and discuss the results we obtained by following our methodology. We split this section in two parts: definition (Section 4.1) and evaluation (Section 4.2) of the proposed heuristics.

4.1 Defining Heuristics

We summarize the results of the first steps of our methodology, from the selection of heuristics to the definition of a new set of heuristics:

1. *Collecting sets of visualization heuristics published in previous papers*: in this step, we considered as a starting point the papers already selected by Oliveira and Silva (2017), which surveyed works related to heuristic evaluation in visualization. Therefore, we chose the 62 heuristics they collected in their work.
2. *Collecting a set of guidelines published in visualization books*: in this second step, we complemented the selected heuristics with a set of 22 heuristics extracted from the books of Ward et al. (2015) and Mazza (2009). We chose these books due to our own perception about their easy-of-learning style and their
   coverage regarding the main aspects of the visualization area. Therefore, at the end of this step, we collected a set of 84 heuristics (this number includes the heuristics found in the Step 1).
3. *Generating groups of interrelated heuristics*: for this step, we invited a set of five researchers with background in visualization. We used the online tool Proven By Users (https://provenbyusers.com, accessed in August, 2020) to conduct this step. We inserted each of the heuristics from Step 2 into this tool as a card (except two of them, which were omitted due to a manual failure). During the use of the tool, the participants individually grouped the cards with heuristics, according to subjective similarity criteria. Therefore, at the end of this step, we had five distinct ways of grouping the set of heuristics.
4. *Creating a new set of visualization heuristics*: in this step, we compared the groups of heuristics defined by each of the five participants. First of all, we studied the co-occurrence of heuristics in groups.

For each pair (h_1, h_2) of heuristics, we defined a function $c(h_1, h_2)$ that counts how many groups have both heuristics. After that, we constructed a reorderable heatmap that represents this function; rows and columns represent heuristics, and the cells represent the values of the function *c*. We used a hierarchical clustering method (with average linkage criterion) to reorder and group the heuristics in the heatmap. Based on this reordered heatmap, we identified groups that could be considered as more consensual regarding the experts' grouping. We used these groups as a starting point to define a single set of groups of heuristics. Each of these groups was then considered as a new heuristic. Each new heuristic received a representative name and a description that includes the concepts of the heuristics that it embraces. The process of providing clear descriptions to each new heuristic motivated us to enhance the differences between them. Therefore, we made at this point a new review of the heuristic grouping, where some groups were merged. The final result of this step was the following new list of heuristics:

- **Heuristic 1. Help and error management.**
  - Prevent user errors;
  - Help users undo or redo one or more actions (for error correction or as part of an exploratory process);
  - Help users understand error messages using simple, code-free language;
  - Provide easy-to-find help for users.
- **Heuristic 2. Interaction and view transformation.**
  - Allow users to have an overview of the dataset, adjust the visualization focus (zoom resources), and dynamically select data (dynamic queries);
  - Allow users to get details about a data selection and browse those details, as well as extract selected items and selection parameters.
- **Heuristic 3. Action control and feedback.**
  - Users must receive feedback on the actions they executed on the system, in an appropriate manner and within a reasonable time.
- **Heuristic 4. Decreased visual effort.**
  - Avoid visual overload;
  - Use item grouping, and item distinction by format and localization appropriately;
  - Use proper graphic resources to get immediate users' attention when needed.
- **Heuristic 5. Decreased cognitive effort.**
  - Prevent users from having to remember information from one part of the dialog to another;
  - Use visualizations that are consistent with users' knowledge and experience (idiom, language, symbol understanding, expected order of how a system displays information, expected order to perform actions; and low or high computing or application domain experience).
- **Heuristic 6. Decreased motor effort.**
  - Provide accelerators to increase the interaction speed (such as shortcuts and control keys).
- **Heuristic 7. Ease of obtaining and deriving information.**
  - Provide resources to ease the creation, acquisition and transfer of knowledge or metadata about domain parameters;
  - Expose data uncertainties and their consequences;
  - Support the formulation and confirmation of hypothesis, as well as manual or automatic discovery of correlation models and constraints;
  - Allow users to visualize and understand relationships between data;
  - Add text to the visualization, in an integrated manner, when needed;
  - Use extra codification to help the perception of information elements (such as clusters);
  - Make easy to find information elements in the visualization, as well as understand the general disposition of information elements in the visualization.
- **Heuristic 8. Visual mapping**
  - Follow visual mapping guidelines that are consistent with the types of each variable of the dataset to be visualized (categorical, ordinal or quantitative), aiming to provide an appropriate precision level to the users' analysis task;
  - Consider limitations of the proposed mapping, such as space constraints to show a visualization, constraints on the number of marks and variables to be presented, and constraints of each graphic property regarding the number of elements it is able to represent;
  - Enable changes in scales;
  - Consider the semantic of colors in the source domain of the data, when relevant;

- Consider visual constraints related to accessibility (color blindness especially);
- Promote graphical excellence; do not use inadequate visual mappings that promote data misinterpretations; and present as much ideas as possible, in the lowest possible time, using the smallest amount of ink, using the smallest possible space.

4.2 Evaluating the New Heuristics

To prepare our preliminary evaluation procedure of our new heuristics, we started by selecting two systems to be evaluated: Gapminder's Bubbles (https://www.gapminder.org/tools) and DrasticData's Treemapping (https://www.drasticdata.nl/treemapping.htm) – hereafter mentioned as Gapminder and DrasticData, respectively, for short. These systems were initially selected due to previous experience of our research team using both systems in visualization classes.

We executed a preliminary inspection of these systems, based on our new list of heuristics, aiming to confirm that the systems have visualization problems related to most of these heuristics. We observed that Gapminder violates heuristics 1, 3, 5, and 7 (at least one violation per heuristic), and DrasticData violates heuristics 2, 4, and 8 (one violation per heuristic). We did not note violations to the heuristic 6. Therefore, we concluded that we could use these systems in our experiment.

After selecting Gapminder and DrasticData, we invited 9 people with experience in visualization to use our heuristics in a HE session. Their highest level of formal education is doctorate (4 participants), master's degree (3), MBA (1) and graduation (1). Their study area is "computing"; they used many different names for that, such as computer science, information systems, and systems analysis and development; some reported artificial intelligence and InfoVis. Four participants reported that their current occupation area is InfoVis, while other reported varied areas such as business intelligence, data science, information systems, systems analysis and development, computer science, machine learning, and software development. Four participants reported that they have 3.5 to 5 years of experience with information visualization, two participants reported 6 to 9 years, and three participants informed 10 to 12 years. Therefore, we can conclude that our HE was carried out by professionals who are mostly Ph. D. and masters in computing, work mostly with InfoVis and have an average of 7.3 years of experience in the area. These characteristics contribute to strengthen the analysis of the results that we will present.

Each participant performed a HE of the selected systems using our list of heuristics, as proposed in the methodology. Regarding the Gapminder visualization, the HE revealed a set of 17 violations of heuristics composed by the union of all violations reported by each participant. All heuristics were used at least one time, except the heuristic 5, which was not used. From the 7 problems that were reported by more than one participant, in 5 of them the participants cited the same heuristic to identify the problem (sometimes using a complementary heuristic to enhance the error description). Besides, from the 6 heuristic violations that we previously identified in Gapminder, the participants found 5 of them, and in 3 problems both the authors and the participant(s) classified the violation using the same heuristic.

In the HE performed over the DrasticData system, the union of the heuristic violations observed by the participants comprised 15 violations. In this case, all heuristics were used at least one time, with no exceptions. From the 6 problems reported by more than one participant, in 3 of them the participants identified the problem using the same heuristic (sometimes using a complementary heuristic to enhance the error description, as already happened in the Gapminder's HE). We had previously found only 3 problems in DrasticData, but we classified these problems with different heuristics than the participants, except in one case.

These results raise some considerations about the new heuristics. We can comprehend a heuristic evaluation as a process with two goals: helping to find errors, and helping to classify each of them. In our evaluation experiment, we observed that more errors were found than we expected; we can consider this as a normal situation, given the already known advice of having 3 to 5 evaluators in a HE session (Nielsen, 1994). Regarding the classification of errors, we noted that some errors were associated with more than one heuristic (sometimes by the same evaluator). We highlight that heuristic 7 (Ease of obtaining and deriving information) was reported for a same error than other heuristics were, such as heuristic 8 (Visual mapping) and 4 (Decreased visual effort). Some factors that may justify this situation are the novelty of these heuristics for the evaluators, and the complementarity of the heuristic 7 regarding other heuristics (e.g., a non-appropriate visual mapping can lead to a visualization in which is hard to obtain information). Besides, we did not a consolidation step in which evaluators could aggregated, discuss and refine the errors they found; such step could potentially reduce these multiple classifications.

	Participants										
Heuristics	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean**	**Std. Dev.**
H1	5	5	5	5	5	4	4	5	5	4.8	0.4
H2	5	5	5	5	3	4	5	5	5	4.7	0.7
H3	5	5	5	5	5	3	5	5	5	4.8	0.7
H4	4	5	3	5	3	4	5	5	4	4.2	0.8
H5	5	5	5	5	5	4	5	5	4	4.8	0.4
H6	3	5	5	5	5	2	2	5	4	4.0	1.3
H7	5	5	5	5	3	4	5	5	5	4.7	0.7
H8	5	5	5	5	3	4	5	5	5	4.7	0.7
Experience with InfoVis (years)	12	10	8	6	5	5	10	3.5	4		

Figure 1. Matrix with five-point Likert scale scores for questions related to each heuristic

Figure 1 presents a heatmap with the Likert scale scores given by each participant to the statements related to each heuristic. The color mapping follows a red-white-blue scale, in which bluish cells represent scores 4 or 5, white cells indicate score 3, and reddish cells represent scores 1 or 2. The overall bluish appearance of this heatmap and the mean scores indicate that in most situations the participants agreed that the heuristics are suitable for evaluating visualization systems.

The opinions provided by the participants about each heuristic revealed some possibilities of improvement for our heuristic set. We highlight the following improvements: enabling evaluators to better distinguish heuristics 2 and 7, and 4 and 8; splitting heuristic 7 into two or three heuristics; removing subjective terms in heuristics 3 and 4; and considering how essential is to add a heuristic related to shortcuts (heuristic 6). It is worth noting that the lowest mean scores of heuristics 4 and 6 are consistent with the problems pointed out in the comments.

Besides the heuristic-focused comments, the participants also provided overview comments about the heuristics. Most of them were positive. The participants made two suggestions: indicating filtering and sampling as visual scalability solutions (maybe as part of heuristic 4); and considering how suitable is the scale of values being used to represent the data space (including distortion aspects and possible interpretation problems).

We must highlight a set of limitations of our work, which need to be considered when trying to follow our methodology. First of all, given the absence of a control group in our experiment, we could not state that our heuristic set is more effective than others proposed by the InfoVis literature. We also cannot state that the results can be generalized to other types of visualizations, given that only two systems were evaluated. The small number of participants involved along the process may also limit this generalization; further research should evaluate more systems with more participants in order to verify this possible generalization. Besides, we believe that the work of Wall et al. (2019) points out a complementary view to our work, and we must consider this work before doing new experiments. We also did not collect data about the participants' previous experience with practical application of HE; their level of expertise could help to better group heuristics, or to better execute HE procedures.

5. CONCLUSIONS

This work presented a proposal of a new set of heuristics for assessing visualization software in a heuristic evaluation method. We created this set based on a process in which experts clustered heuristics which were available in InfoVis literature or were derived from InfoVis books. The proposed groups of heuristics were used as a basis for the proposition of our heuristics.

A set of evaluators with expertise in InfoVis used these heuristics to assess two visualizations available on web, with the goal of experimenting these new heuristics. The evaluators found a set of InfoVis-related problems in these systems, and classified them according to the violated heuristics. They also expressed their opinions related to the experience of using our InfoVis-related heuristics. The scores they provided pointed out that they agree, in average, that these heuristics are suitable for evaluating visualization systems. They provided very constructive comments about how to improve these heuristics, including the need of clarifying terms in some descriptions, adding some missing concepts, and helping to distinguish between some heuristics.

We understand that there is still a long way to reach a wide accepting of the proposed heuristics by the InfoVis community. Future work includes refining the proposed heuristics according to the received comments presented in this paper, as well as conducting more heuristic evaluations using these heuristics. We also plan to measure the coverage of these heuristics and to compare it to the coverage of other heuristics and other evaluation methods, so that we can better understand the pros and cons of using our heuristics to evaluate visualization systems.

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