Evaluating Usability of Information Visualization Techniques

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Abstract. Several information visualization techniques have been developed in the last few years due to the need of representing and analyzing the huge amount of data generated by several applications or made available through the World Wide Web. These techniques are usually interactive and provided as part of a graphical user interface. Information visualization techniques are usually reported showing their use in experimental situations, employing some kind of analysis. Nevertheless, few studies have specifically addressed the evaluation of such techniques. This paper reports our results towards the definition of criteria for evaluating information visualization techniques, addressing evaluation of visual representations and interaction mechanisms.

1. Introduction and motivation
In the last few years the increasing volume of information provided by several applications, different instruments and mainly the Web has lead to the development of techniques for selecting among a bulk of data the subset of information that is relevant for a particular goal or need. Research on visual query systems, data mining and interactive visualization techniques has resulted in a wide variety of visual presentation and interaction techniques that can be applied in different situations.
However, although there is a great variety of models and techniques for information visualization [Card et al. 1999], each application requires a particular study in order to determine if the selected technique is useful and usable. The type of data that should be represented and the user tasks or analysis process that the visualization should help or support usually guides these studies. By observing several applications it has become evident that we cannot separate the visual aspects of both data representation and graphical interface from the interaction mechanisms that help a user to browse and query the data set through its visual representation. Moreover, it is clear that evaluating these two aspects is an important issue that must be addressed with different approaches including, of course, empirical tests with users. Potential users of information visualization often have their own analysis tools (statistical ones, for example) and are not aware of the benefits of visualization techniques as a first phase in the data analysis process.

Besides visual representation characteristics and interaction mechanisms, a third aspect should concern the use of an information visualization technique as the core of an application interface: data usability.

Usually, usability is a term employed to describe the quality of use of applications by end-users [Bevan 1995]. In the context of interfaces for information visualization users not only interact with widgets on the interface but also with data supporting decision-making, which could be affected by the way information is presented. Due the nature of gathering or processing data, noise could be included in the data set affecting original data. In addition, a huge amount of information must be cut and summarized to be useful for supporting decision-making; even though the kind of information processing could alter the quality of original data set. These problems are not related to interaction mechanisms provided by the interface but with the data processing itself. That is why we use the term data usability to describe quality of information or quality of data in the context of information visualization applications. Data usability can be associated to three principles:

a) data reliability, which describes the feasibility of the gathering data process as well as the confidence level, including interval for errors, etc. that can cause distortion between reality and model (reality represented by the system);

b) minimal impact on data changing, i.e., the system must avoid changing the information and it must allow recovering original information whenever it is needed. However, in practice, this data stability is not feasible because frequently data must have to be adapted to visualization constraints such as the reduction of dimension when presenting n-dimensional data in a 2D or 3D visualization, for example. This 2D or 3D representation breaks down the usability of original data. It is clear that we cannot avoid some changes during the visualization process but we can try to reduce their impact; and

c) support decision-making, which means that data representation should be understandable by end-users and help them to make decisions.

Since information visualization is intended to provide insight from data, it becomes clear that both visual representation and interaction techniques must not affect the ways the user needs to use the data in a variety of analysis procedures.

Based on the above discussion, we separate usability issues in three main categories: i) visual representation usability, referring to the expressiveness and quality
of the resulting image; ii) interface usability, related to the set of interaction mechanisms provided to users so they can interact with data through the visual representation; and iii) data usability, devoted mainly to the quality of data for supporting users’ tasks.

Our approach is to link interface usability knowledge, concepts and methods with evaluation of the expressiveness, semantic content, and interaction facilities of visualization techniques. The first step was to define criteria for the evaluation of visual representations and interaction mechanisms provided by different techniques. We are investigating classical techniques employed for evaluating user interfaces (for example, usability inspection methods and user testing) in order to select an adequate framework for a methodology of usability testing at all the three levels mentioned above. At present, we have empirical evidences collected from case studies suggesting that we can distinguish these three categories.

The paper is organized as follows. Section 2 presents a further discussion on usability methods and a framework for classifying information visualization techniques. Section 3 addresses the set of criteria that should be considered when evaluating information visualization techniques, whereas section 4 reports a case study on the evaluation of a specific visualization technique. Finally, section 5 discusses our contribution when compared to other reports on the issue of evaluating visualization techniques, and concludes stating what should be done next in order to advance towards a usability method tailored to information visualization techniques.

2. Usability methods and information visualization techniques

Usability evaluation methods have been developed for many years in order to evaluate the efficiency, interaction flexibility, interaction robustness, and quality of use of user interfaces. Most methods are based on user testing [Rubin 1994] where usability is measured by observation of users interacting with the interface. Other usability evaluation methods are based on the inspection of interfaces by an expert, which is able to recognize usability problems [Nielsen and Mack 1994]. The main aim of usability evaluation is to identify problems that avoid/interfere with users’ tasks, causing stress or reducing user performance. These techniques are quite efficient for evaluating usability in interface when concrete tasks are considered. However it is much harder to evaluate usability when abstract tasks such as “understand data” or “make decision based on information” are considered. In addition, interfaces for information visualization include a set of 2D and 3D structures (such as 3D objects, polygons, scenarios and virtual worlds) that are unusual in most WIMP interfaces. As a consequence, it is much more difficult to describe and to identify usability problems on this kind of interface than in WIMP ones. The absence of criteria for evaluating information visualization interface is another great barrier since most metrics used to evaluate usability such as accomplishment of tasks and user performance are less important for such interfaces where the most important goal could be measured by the effective usage of information.

While most traditional evaluation methods fail to provide useful results on usability evaluation of interfaces for information visualization there are only a few experiences trying to evaluate aspects of this kind of interface. Recently the naming time method, a special kind of usability evaluation method based on user testing, was used to evaluate the effect of the reduction of quality of 3D images and the quality of
information provided [Watson et al. 2000]. That study has demonstrated the use of some cognitive aspects of visual representation quality and user performance related to the time spent for identifying objects and understanding information. Some other related works are discussed in Section 5.

In order to establish a framework either for facilitating the understanding of information visualization or for evaluating, and consequently comparing and choosing among different techniques, several authors have distinguished classes of information visualization techniques [Shneiderman 1996; Card and Mackinlay 1997; Chi and Reidl 1998]. We can separate techniques regarding their facilities to display and allow interaction with one-dimensional, two-dimensional, three-dimensional or multidimensional data, as well as temporal, hierarchical or multilinked data.

In this work, we follow Freitas et al. (2001) and distinguish information visualization techniques in two broad groups: i) techniques for displaying data characteristics and values and ii) techniques for displaying data structure and relationships. Both groups use visual representations dependent on the data that should be displayed.

In the first group, we include all the traditional function graphs, icons and glyph displays, pseudo-color, contour lines and vector maps, useful either for displaying entity-related data and spatial data. The second group is actually the class of techniques that deployed the area of information visualization. The display of linear structures (documents, texts, temporal data, etc.) was the motivation for techniques like Bifocal Display [Spence and Apperley 1982] and Perspective Wall [Mackinlay et al. 1991]. Hierarchies and graphs can be displayed using geometric objects implementing different metaphors [Robertson et al. 1991; Tesler and Strasnick 1992], space-filling approaches like Treemaps [Johnson and Shneiderman 1991] and Information Slices [Andrews and Heidegger 1998], and node-edge diagrams [Lamping et al. 1991; Munzner 1997].

When we turn our attention to the needs of interacting with the data through visual representations, we find three main classes of interaction mechanisms that should be considered: help and orientation mechanisms, browsing and searching/querying tools, and data reduction functions. We are not concerned here in describing which reported technique presents which interaction functions but in identifying characteristics that can be used to evaluate and compare techniques by means of interface usability methods.

3. Evaluation of information visualization techniques

The evaluation of information visualization techniques should be based in both testing the visual representation and the interaction mechanisms. For example, usual and critical aspects of visual representations are object occlusion and visual disorder, while visual disorientation is caused by changes in the visual representations due to some user action. Thus, there are situations when one aspect (interaction) affects the other (visual representation). All such characteristics should be verified in order to evaluate a specific visualization technique.

Our approach is to establish two sets of criteria, with associated metrics: the first being for usability testing of visual representations and the second one, for evaluating interaction mechanisms. Two initial sets were defined based on case studies with
different visualization techniques. Then, those two sets were refined taking into account characteristics found mainly in information visualization techniques, thus excluding many scientific data visualization techniques. The resulting two sets are examined in the following sections.

3.1. Visual representation criteria

Figure 1 presents a diagram depicting criteria for evaluating visual representations. They are commented in the following paragraphs along with examples of metrics, when appropriate.

![Diagram of criteria for the evaluation of visual representations of information visualizations techniques.](attachment:image)

The semantic contents of the data to be displayed may be affected by limitations, which are geometric or visual constraints like size of the display or maximum number of data elements, imposed by the visual representation as well as by its cognitive complexity. Moreover, the cognitive complexity of an image can be measured by data density, data dimension and by the relevance of the displayed information. For example, the number of points in a graph can measure data density, while data dimension is related to the number of dimensions simultaneously displayed.

Spatial organization is related to the overall layout of a visual representation, which comprises analyzing how easy it is to locate an information element in the display and to be aware of the overall distribution of information elements in the representation. Locating an information element can be hard if some objects are occluded by others, and if the layout does not follow a “logical” organization depending on some characteristics of the data elements. So, degree of object occlusion and logical order are characteristics to be measured in the visual representation. The spatial
orientation, which contributes for the user being aware of the distribution of information elements, is dependent on the display of the reference context while showing a specific element in detail.

Additional codification of information is another aspect one can use for evaluating visualization techniques. Besides the mapping of data elements to visual elements, the use of additional symbols or realistic characteristics can be used either for building alternative representations (like groups of elements in clustered representations) or to aid in the perception of information elements.

Finally, an important aspect of information visualization techniques is the result of rebuilding part or the entire visual representation after a user action. The time the technique takes to do that and the changes in spatial organization of the resulting image are important factors that can affect the perception of information.

3.2. Interaction mechanisms criteria

The set of criteria for evaluating interaction mechanisms is represented in Figure 2 and ultimately comprises functions that support common user tasks. The analysis of interaction mechanisms provided by an information visualization technique corresponds to a usability test of the tool that implements the technique.

![Figure 2. Criteria for the evaluation of interaction mechanisms.](image)

Functions like support for the user to control level of details, redo/undo of user actions and representation of additional information (for example, the path a user followed while navigating in a complex structure) define help and user orientation features, for which usability should be evaluated.

Considering navigation and querying features, techniques should be analyzed regarding the possibilities and easiness of selecting a data element, changing the user point of view, manipulating geometric representations of data elements, searching and querying for specific information, and expanding clustered/hidden data elements.

A last subset of criteria is related to the data set reduction features provided by the technique. Filtering allows reduction of information shown at a certain moment, leading more rapidly to adjustment of the focus of interest, and clustering allows
representing a subset of data elements by means of special symbols, while pruning simply cuts off information irrelevant for the understanding of a visual representation.

4. Case study: evaluation of the Bifocal Browser

We have investigated the benefits of our criteria by means of a case study. In the following subsections, we describe shortly an information visualization tool called Bifocal Browser and then we show how the criteria presented above were used for its evaluation.

4.1. Bifocal Browser: a short description

The Bifocal Browser [Cava and Freitas 2001] is an alternative way to explore large hierarchies in a node-edge diagram, incorporating some features borrowed from space-filling approaches [Johnson and Shneiderman 1991; Andrews and Heidegger 1998] and the hyperbolic browser [Lamping et al. 1991]. The technique is based on the focus + context approach, and uses two foci instead of one. In this technique, the hierarchy is represented as a node-edge diagram separated in two connected sub-diagrams, defining separate areas in the window: a detail area, which shows the node of interest and its subtree, and a context area, that displays its parent and siblings subtrees. Although it is not based on the hyperbolic geometry, the technique has similar characteristics. In Figure 3, the hierarchy is anchored on two main nodes called the context and detail focus, displayed at the center of the context and detail areas, respectively. The central rectangle in the right (Figure 3b) represents the detail focus at a certain moment, i.e., a node of interest, while the left one (Figure 3a) is the context focus. Thus, at the same time that it provides information on hierarchical relationships, the technique shows a detailed view of the subtree containing the node of interest.

Both context focus and detail focus are located side by side separated by an arbitrary (and parameterized) distance, defining separate circular areas in the window. Once the user indicates a node as the point of interest, the whole subtree of this node is shown in the right area of the window, while its parent node and all other subtrees are displayed in the left half of the window. Each subtree is displayed in a radial layout, with the selected node at the center of a circle, and its descendants distributed in concentric circles depending on their level in the structure. In order to avoid occlusion among objects, each subtree is actually displayed in a circle sector.

Nodes are displayed as rectangles with the size depending on their location in relation to the focus point. A node that is distant from the focus is shown with less detail than nodes nearer the focus, while nodes beyond a certain distance are not shown. This strategy was adopted to avoid displaying and manipulating elements that are far from the point of interest, based on the idea that a user browses a structure until reaching a specific node. Moreover, due to the reduced size these nodes would have if displayed near the border of the circle, the user probably would not point at them.

A different color is used to display the subtree that has recently occupied the detail area. Also, the root node is always displayed in red, in order to keep the user aware of what level in the hierarchy is currently in the context focus. This intends to minimize a possible disorientation that might happen due to rotations and translations applied to the subtrees when the user selects another node.
Distribution of nodes around the root node takes into account the number of leaf nodes in each subtree. Therefore, the subtree with more leaf nodes occupies the largest sector in the circle. This rule is applied recursively to each subtree in the structure. On the other hand, in the detail area, the goal is to provide the representation of the hierarchical relationships by means of a tree with the interest node as root. To achieve this goal, nodes at the first level are uniformly distributed around the inner circle. Their subtrees, however, are displayed in sectors with size proportional to the number of leaf nodes, following the same rule applied in the context area. This difference in the layout is more evident in unbalanced trees.

The selection of a node is the main interaction mechanism provided to the user; it can be applied to any node in order to bring to the detail focus the node along its subtree. This operation imposes a translation of the subtree to the detail area, as well as a rotation in the structure displayed in the context area.

![context area](a) ![detail area](b)

**Figure 3. A hierarchy with 760 nodes.**

### 4.2. Evaluating the Bifocal Browser

A first analysis of the Bifocal Browser was conducted to verify the completeness and applicability of the proposed evaluation criteria. Several hierarchies were used, the larger one being a 1000-nodes hierarchy.

Following a checklist containing objective questions related to criteria presented in section 3, we inspected the visual representations and performed common browsing and selection tasks. The major task in performing the analysis was to determine the metric for each criterion, since it depends both on data type and visual representation type.

**Limitations:** Geometric and visual constraints are not evident, except for the display area that is divided into two, for showing context and detailed information.
Upper bound for depth is 10; deeper hierarchies are shown with pruning of elements beyond that limit. Clustering limits were not used because there is no clustering function in the Bifocal Browser.

Cognitive complexity: the metrics were both the number of nodes, for data density, and a qualitative measure of legibility, in terms of occlusion of nodes. Although a large hierarchy with 1000 nodes was used, the pruning mechanism and the good distribution of elements in both areas guaranteed low occlusion and adequate legibility.

Spatial organization: Analysis of spatial organization was done using qualitative measures of the easiness in locating an object and the awareness degree users have with respect to the information space. The logical order was measured in terms of user's orientation in the information space, distribution of elements in the layout, for precision and legibility, efficiency in space usage and distortion of visual elements. Occlusion of objects was calculated in terms of the percentage of nodes shown in relation to the total number of nodes in the hierarchy. The spatial orientation that directly affects awareness of the information space was measured in terms of the possibility and easiness of specifying which nodes should be displayed in the context area and which ones should appear in the detail area. In the Bifocal Browser, when a node is selected, it is moved to the detail focus and the user does not have direct control over what is displayed in the context area.

Codification of additional information into visual attributes: this is practically absent in the Bifocal Browser because of the simplified representation of nodes; the only distinction between nodes is the colors used for the root node and the detail focus. No realistic techniques like shading or transparency are used for improving perception, mainly because that is not appropriate for 2D representations. There is no explicit clustering based on nodes content, but pruned subtrees are represented by a different symbol.

State transition characteristics: Transitions between two consecutive representations can be done with or without animation in the Bifocal Browser. Both were rapid mainly because no huge hierarchies were used. Immediate transitions can cause a temporary spatial disorientation because the two areas, context and detail, change entirely with the new distribution of subtrees. Since the technique is not based on hyperbolic geometry, animation is accomplished by rotations and translations, which appear rather discrete.

As for interaction mechanisms, usability tests conforming to some methodology were not performed. However, in a checklist style of evaluating a user interface, the criteria guided an analysis that checked the availability or absence of each feature in the browser as well as the possibility of its implementation if it is absent.

Help and user orientation: The browser allows control of the level of detail since the user can select a node and see its entire subtree in the detail area. Undo operation is not directly implemented and the user needs to select the last visited node to rebuild the previous display. This is facilitated by the display of that subtree in a different color to minimize spatial disorientation that might happen when the focus changes.

Navigation and querying: all the features needed for browsing are implemented except for search and query. Nodes can be selected by pointing at them, which causes
an automatic change in the user viewpoint as well as expansion of subtrees that might be previously pruned.

Data reduction features: the Bifocal browser does not have filtering nor content-based clustering functions. Pruning (that would be better classified as structure-based clustering, in our case) is automatic when the depth of a subtree that have to be displayed is beyond 10.

5. Discussion and final comments

Evaluating user interfaces is usually accomplished to detect design problems in the layout as well as in the interaction. The evaluation of image quality in computer graphics applications can be done through visual inspection by experts. In information visualization techniques, interface usability issues, expressiveness of visual representation (image semantic quality) are both as important as a third issue – data usability, since the main concern in this applications are to give insight to expert users regarding data they are analyzing.

Our case study, although brief, demonstrates the benefits of our criteria as an important aid to the task of evaluating information visualization techniques. We have performed inspections on the Bifocal Browser based on the criteria defined in Section 3 and we could find some potential problems concerning representation and interaction usability. The main problems detected in the visual representation are the occlusion of nodes in the context area in large hierarchies and the disorientation produced by the change in the overall layout, when one selects a different node as the interest node. Although the first one is a well-known problem in node-edge diagrams, pruning and clustering (with a good symbol design for representing clusters) will for sure minimize it. The disorientation associated to state transition is overcome by animation, as mentioned earlier. Regarding interaction mechanisms, some features like filtering are missing, and the identification of nodes to point at one of them is only performed based on the name of the node. An additional attribute can be associated with color (for example, file extension, if the hierarchy is a file tree) but this is hard-coded in the current implementation and not a user-defined mapping, which would be more useful.

Our approach in evaluating information visualization techniques considering criteria, which are up to now categorized by visual representation characteristics and interface usability, addresses larger issues than those reported in recently published literature. Wiss et al. (1998) describe the evaluation of three visualization techniques (Cam Trees, Information Cube and Information Landscape) based on the tasks defined by Shneiderman (1996). The authors implemented the three mentioned techniques and analyzed them in terms of which tasks they support. Brath (1997) proposes quantitative metrics to evaluate the efficiency of 3D static representations, basically graphs, thus not addressing interaction mechanisms. For each display, he measured the number of data points (for data density), number of dimensions (for cognitive complexity), occlusion rate, and identifiable data points. We included Brath's metrics in our set under the Cognitive Complexity and Spatial Organization criteria. Different visual representations provided by NIRVE (the NIST Information Retrieval Visualization Engine) have also been the subject of evaluation by Cugini et al. (2000). Usability experiments were carried out to verify completion of tasks and difficulties in interaction using selected visual representations for a query result. Their goal, however, was not to set a
framework for evaluating visualization techniques but to specifically test design features adopted in the alternative visual representations in relation to the cognitive load.

We defined criteria which more directly relate to the usability of information visualization techniques and our criteria has been shown useful to discuss usability issues at the information visualization scenario in a broader sense. These can be used to clarify the notion of usability, which has been relatively inadequate in this domain. In so doing, we have addressed two important aspects, namely, (a) an extensive list of criteria to guide the design of usable information visualization software; and (b) an organization for structuring these criteria which can be easily extended to account for other properties or guidelines.

Next step includes to thoroughly testing the criteria with non-hierarchical information, such as spatial data and virtual reality environments. Later on, different usability methods will be experimented to establish which ones are more appropriate in each situation and why.

References


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