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Short Paper

CompaRing: Reducing Costs of Visual Comparison

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Abstract

Comparison is a frequent task when analyzing data. In visualization, comparison tasks are naturally carried out based on a visual representation of the data. Visual comparison allows us to gain insight where plain computations of numerical differences alone cannot grasp the complex interdependencies in the data. Yet, visual comparison also comes at a cost. There are costs when interpreting the visual representation and costs when interactively carrying out the comparison. We present techniques to reduce some of the costs associated with visual comparison. We address cognitive costs for comparing objects that are spread across a visual representation and interaction costs for selecting and navigating between objects to be compared. Our techniques are illustrated by the example of comparing geographic regions in choropleth maps.

Categories and Subject Descriptors (according to ACM CCS): H.5.2 [Computer Graphics]: Information Interfaces and Presentation—User Interfaces—Interaction Styles

1. Introduction

Visual data analysis sessions typically include comparison tasks [GAW*11]. Starting from a general overview of the data, users identify relevant objects to be compared. The actual comparison aims to detect similarities and dissimilarities among the objects, eventually leading to higher-level findings such as the detection of clusters or trends.

Visual comparison is particularly beneficial in situations where purely computational approaches fail to capture the complex relationships in the data. Interactive visual comparison employs human cognitive abilities for flexible insight generation. Yet, interactive visual approaches always involve costs on the side of the user [PW06, Lam08]. These costs are attributed to interpreting the visual representations of the data and to interacting with them.

Our goal is to ease visual comparison tasks by reducing the associated costs. To this end, we develop a conglomerate of automatic, interactive, and visual methods that is inspired by previous work on radial visualization [DLR09], exploration techniques for graphs [MCH*09, BKA*15], visualization of off-screen locations [GBGI08, FD13], and fluid interaction [EMJ*11].

The key idea is to dynamically relocate the objects to be compared to form an in-situ juxtaposition. Reducing the distance between the objects makes the visual comparison cognitively easier [PW06]. The relocated objects serve to trigger automatic navigation to an object's original position in the visualization. This spares the user manual navigation steps and enables easy data-driven exploration. Animated visual feedback helps the user understand the re-arrangements and the automatic navigation. We also include a mechanism for automatic selection of comparison candidates, which further reduces the interaction costs. We apply our techniques to compare areas of a zoomable choropleth map. Designed as general lightweight on-demand tools, our techniques can potentially be useful in combination with other visualization techniques as well.

2. Comparison Tasks

Given data values p and q (or subsets P and Q), a *comparison task* is defined as the search for a relation $\mathfrak{r}$ such that $p\ \mathfrak{r}\ q$ (or $P\ \mathfrak{r}\ Q$) [AA06]. Of great practical relevance are order relations $\mathfrak{r} \in \{<, \leq, =, \geq, >\}$. Elementary comparison tasks are often direct predecessors to more complex tasks. For example, ranking several data objects requires that every pair of them be compared. It is also common to derive quantitative statements about the compared data to capture their degree of relatedness. A related notion is that of similarity (or dissimilarity), which plays an important role for higher-order data features such as clusters.

The computer can effectively and efficiently solve comparison tasks that boil down to determining the difference between two numbers. Yet in visualization scenarios, comparison is typically not that simple. Users have to make comparisons visually based on potentially complex representations of information-rich data objects.

In the process of visual comparison, users have to deal with three main difficulties. First, users have to compile and maintain a set of comparison candidates. The definition of comparison candidates is a dynamic process, because the user's interests are subject to change as new insight is generated during the exploration of the data. Interestingly, what to compare next is likely related to the immediate context of the objects being compared.

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Second, depending on the underlying visualization, the objects to be compared are not necessarily arranged in a way that facilitates comparison. Quite the contrary, with most standard visualization approaches, the objects are arranged according to some layout algorithm or to some naturally given mapping (e.g., geographic positions). However, with larger distances between objects, it becomes more difficult to compare them visually. The eyes have to look frequently back and forth between multiple objects and the short-term memory has to store not only the locations of objects, but also their visual appearance.

Third, when studying larger data, it is usually necessary to focus the analysis around subsets. Zoomable visualization interfaces enable the user to examine parts of the data in detail and to go back to an overview in an iterative fashion [Bed11]. When zoomed in, however, it is not guaranteed that all relevant objects are visible. When looking at an overview, some data features might be indiscernible, rendering detailed comparison difficult. As a consequence, users have to carry out manual navigation steps in order to successfully accomplish a comparison task.

3. Related Work

A large variety of existing techniques aims to support visual comparison tasks. Gleicher et al. [GAW*11] list more than 100 approaches. Recent examples include multi-scale comparison of execution traces [TDT13], the SimilarityExplorer for climate data [PDW*14], and comparison of event sequences with MatrixWave [ZLD*15]. Gleicher et al. identify three categories of approaches to support visual comparison: superposition, juxtaposition, and direct encoding. Superposition is about overlaying the objects to be compared, whereas juxtaposition creates side-by-side arrangements. For direct encoding, differences between objects are visualized directly.

Gleicher et al.'s three categories have individual pros and cons. Superposition and juxtaposition create layouts that make comparison task easy to carry out. Yet the layouts might not correspond to the user's mental map of the data or might even violate any natural layout inherent in the data. Direct encoding has the advantage that differences in the data can be read off with ease. Yet, the visualization of differences might be in conflict with the visualization of the actual data. In other words, what should the visualization present to the user, the data, the differences, or both?

Gleicher et al. also acknowledge the importance of interaction for visual comparison. Standard graphical user interfaces are predominant in most of the existing techniques. There are few works that study advanced interaction to support dynamic rearrangements to suit comparison tasks. Isenberg et al. [IC07] describe methods for comparing trees on interactive surface displays. Spindler et al. [STSD10] introduce *tangible views* that can be arranged physically for side-by-side comparison. Interaction techniques that mimic natural comparison behaviors of humans are discussed by Tominski et al. [TFJ12]. Common to all techniques is that they do not impose a fixed permanent layout on the data objects, but enable the user to flexibly create layouts as needed.

We conclude from this discussion that an ideal comparison technique would provide the user with (i) the original data layout and a suitable layout for comparison as well as (ii) a visual encoding of the original data values and one of the differences. Further, the technique would be flexible in the sense that the user can adjust it to what best suits the current analytic situation. However, many of the existing approaches are static in that they offer only one specific layout or encoding. We aim at a more dynamic and lightweight approach that can be applied on demand on top of an existing visualization.

4. Reducing Comparison Costs

Our approach is a combination of automatic, interactive, and visual mechanisms that locally affect a base visualization and provide visual feedback to help users carrying out visual comparison tasks. From a general perspective, our design goal is to narrow Norman's gulfs of execution and evaluation [Nor13]. According to the above discussion, more specific objectives are:

- Reduce costs for visually comparing the objects
- Reduce costs for selecting objects to be compared
- Reduce costs for navigating between the objects

4.1. Dynamic Rearrangement for Comparison

Generally, one cannot make any assumptions with regard to the position of the objects to be compared. A likely scenario though is that users select objects that are spread across the visual representation. Moreover, in a zoomable visualization, the objects can have different degrees of visibility: overview, detail, or off-screen. The consequence for comparison tasks is that users have to perform a number of zoom and pan operations until they have acquired sufficient information to draw a conclusion.

The goal now is to reduce the manual visitations of objects to be compared. Following previous work [BCC*03, KFA*04, MCH*09], the idea is to automatically *bring* the objects of interest to the user. To this end, an additional view is injected into the visualization, the so-called *CompaRing*. It follows the *ring pattern* [DLR09] and, as such, bears resemblance to many other designs, including radial menus [CHWS88], ring maps [ZFH08], and necklace maps [SV10].

The central visual element is a circular arrangement of n slots. As detailed comparison is possible only for a limited number of objects [PW06], the user will typically want to set $n < 10$. Each slot shows an object to be compared. Placing the objects of interest in the ring slots effectively creates a local overview based on which comparison tasks can be carried out more directly and more easily. Figure 1 illustrates a CompaRing with eight slots.

Yet, by relocating objects we disrupt their spatial embedding in the base visualization. To maintain residue of the object's original location, the slots show *indicator arcs* that communicate direction and distance of the individual objects. The arcs point in the direction where objects are located. Wide arcs (max. 90°) represent greater distances, whereas narrow arcs (min. 10°) indicate objects that are close. As an additional visual cue, objects are brought to their slots using fly-in animations. All objects fly at constant speed, so their arrival time depends on their distance to the CompaRing. Objects that are close arrive earlier than objects that are remote.

The CompaRing is an instance of a juxtaposition technique for visual comparison. Our goal is to support direct encoding of differences as well. To this end, the indicator arcs are enhanced by a color encoding of differences. When hovering a slot, the pairwise differences to all other slots are computed and visualized. Restricting the direct encoding of differences to the selected objects allows us to make even subtle variations visible, which is usually hardly possible with the global encoding of the base visualization.

A problem that remains to be solved is the overlap of the CompaRing with the base visualization. On the one hand, occlusion should be avoided, but on the other hand, a sufficient visual separation is necessary. A standard approach is to use transparency to let occluded information shine through. Yet, we came across situations where the base visualization interfered too much with the objects shown in the slots. To remedy this, we additionally blur the ring background to filter out high-frequency visual stimuli. This way, foreground and background are better separated, while still allowing baseline information to pass through.

With the CompaRing, we have designed a tool that provides an on-demand juxtaposition of the objects to be compared. Additional visual cues encode subtle differences visually and hint at the objects' original locations. The benefit for the user is that it is no longer necessary to *go* to each object and collect and memorize data characteristics. Instead, the CompaRing *brings* the required information to the user, which naturally reduces the costs for carrying out visual comparison tasks.

4.2. Automatic Selection of Comparison Candidates

For static non-interactive visualizations (e.g., prints), much of the costs for comparison are related to memorizing where objects are located and what data characteristics they exhibit. Interactive selection enables the user to mark and highlight interesting objects [Wil96], effectively off-loading costs for memorizing to the computer. We complement this standard approach with an automatic selection mechanism. The idea is to reduce the entirely manual selection of n objects to a manual selection of only one object plus an automatic selection of $n-1$ objects.

The utility of our idea largely depends on defining a semantically meaningful automatic selection. A sensible approach in the context of comparison tasks is to rank data objects according to their similarity. In other words, when the user selects a first object, $n-1$ most similar objects are added to the selection automatically. A simple way to compute similarity is to use basic Euclidean distance. In cases where the similarity of complex objects must be captured, it makes sense to extend to multidimensional or subspace measures [TMF*12].

As an alternative to similarity-based automatic selection, one could consider degree-of-interest (DOI) functions [vHP09, AHSS14] or mechanisms that traverse the internal (graph) structure of the data [MCH*09].

Irrespective of the method being employed to drive the automatic selection, the benefit for the user is that a single click (or tap) is enough to create a selection of n objects. Of course, manual refinements can be necessary to fine-tune the automatic selection.

4.3. Navigation Shortcuts

With the CompaRing, users compare objects that are detached from their surroundings. Yet it is often necessary to understand objects in their original context. This need is addressed by providing navigation shortcuts with the CompaRing's slots, which is similar to the idea of *Bring & Go* [MCH*09] and edge-based traveling [TAS09].

Each slot can be clicked to trigger an animation that takes the user (and the CompaRing) to an object's original position. Manual navigation steps are thus reduced to a minimum. In combination with the automatic selection mechanism an interesting novel way of data-driven navigation becomes possible. The user can use a navigation shortcut to visit the context of an object of interest. From the context one can select a new object and the automatic selection will bring *related* objects to the user's attention. Each of the newly brought objects can then be used as a destination to continue the data exploration. As indicated before, *related* can mean *similar* objects, but other meaningful interpretations are possible and useful as well (e.g., subspace similarity, graph topology).

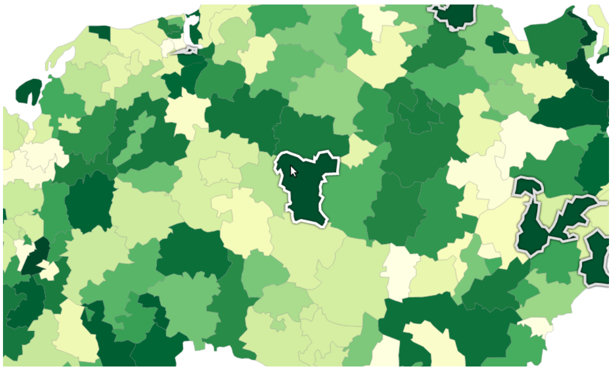
5. Approach Walkthrough

To illustrate the utility of our approach, we apply it to a choropleth map. A green-to-yellow color scale [HB03] is used to encode high-to-low data values. A darker green area in the center of the map attracted our attention. In Figure 1(a), we zoomed in onto that region. We are interested in comparing that region to other regions with a similar data value. With a single click, we select the region and the seven regions that are most similar are selected automatically as well (bright contours). Yet, it happens that not all automatically selected regions are visible on screen.

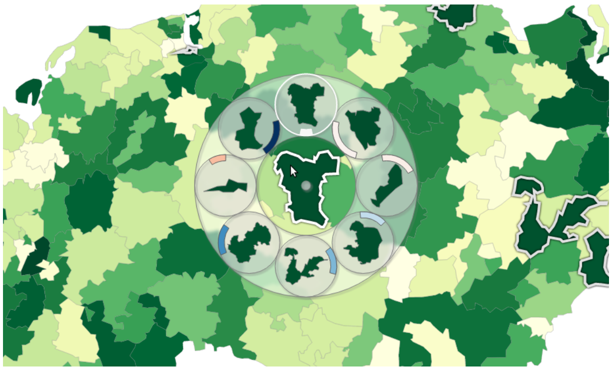
We activate the CompaRing, which brings the off-screen regions to the view as shown in Figure 1(b). The fly-in animations made close regions arrive earlier, whereas remote regions arrived later. In our simple example, we see that the colors of the regions are all similar as expected. The indicator arcs, visualize direction and distance of the regions' original positions. They also encode the similarity among the regions with a blue-white-red color scale (white for similar, blue and red for negatively and positively dissimilar, respectively). This way, the indicator arcs make clear that there are subtle differences, which we could hardly discern from the original encoding.

With the ComparRing, we can easily compare the regions of interest. But how does their immediate context look like in the map? To answer this question, we have to visit the regions' original locations. We choose to visit the second region in the ring, counting clockwise from the top. This region's indicator arc suggests that the region is located south-west from the current view (angle of arc) at a rather large distance (extent of arc). With a simple click, we trigger an animated transition that takes us there.

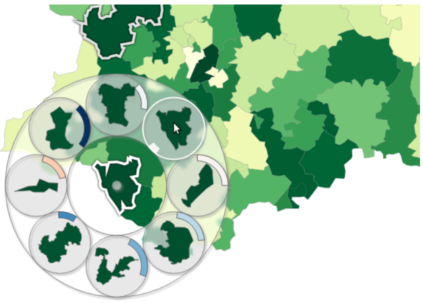
In Figure 1(c), we see that the map and the CompaRing have been automatically centered on the desired region. The corresponding indicator is now narrow and points directly at the region. There is also another selected region just partly visible at the top. We can now go on navigating to that region, go back to where we started with a click on the top-most slot, or dismiss the CompaRing and continue with other data exploration activities.



(a) Zoomed-in view.



(b) The CompaRing with indicator arcs.



(c) After automatic navigation.

Figure 1: *Using the CompaRing on a choropleth map.*

6. Preliminary User Feedback

The previous sections introduced several ideas that aim at reducing the costs of visual comparison tasks. Existing studies on visual comparison suggest that objects being close to each other can be easier to compare [LB98, PW06]. We expect this to be true for the CompaRing as well. The mechanisms for automatic navigation and selection clearly reduce the need for manual interaction. A formal user study to confirm these expectations is still to be conducted.

Yet, preliminary feedback has been acquired in a hands-on session with several visualization experts. Next, we will briefly report on the experts' feedback, indicate design alternatives, and discuss limitations of the developed approach.

The generally positive feedback supports our hypothesis that the CompaRing can be a useful tool for comparison tasks. Several ideas for improving the approach came up in the discussion with the visualization experts. One suggestion was to consider alternative layouts. Spirals, circle packings, linear lists, and matrices were mentioned in addition to laying out slots according to object directions. These alternatives have a direct impact on the number of objects that can be compared and on the degree of occlusion of the base visualization.

The indicator arcs received some degree of controversial discussion. Several experts shared the opinion that remote objects should be indicated with *narrow* arcs, while others found it perfectly suitable to use *wide* arcs. This prompts us to offer both alternatives and give the users the freedom to choose which best suits their needs.

The idea of automatic selection was welcomed, but the current implementation is limited to similarity-based selection only. Some experts expressed concerns regarding the scalability of the approach. Yet, as comparison tasks typically comprise only a few objects ($n < 10$), this is only a matter of efficient processing of the underlying data, but none of the visual and interaction design of the CompaRing. Therefore, we think it makes sense to further invest in easy-to-use and meaningful automatic selection.

The automatic navigation was considered useful. Yet, it was suggested to include mechanisms to easily go back (and forward) along the path previously taken during navigation. This also includes some form of visual feedback to indicate the path. Further, some experts mentioned it could be useful to dim the CompaRing to reduce occlusion of the immediate context of the navigation target. Alternatively, one could consider the actual geometric features of the context and dynamically adjust the layout accordingly.

7. Conclusion & Future Work

In this work, we presented a novel approach to visual comparison. The primary design goal was to reduce the costs of comparison tasks. To this end, we combine automatic, interactive, and visual mechanisms. We applied the mechanisms to a basic geovisualization. A prototype implementation is available at `http://goo.gl/AHwJkT`.

A natural next step for future work would be to quantify the reduction of costs achievable with our approach. A controlled user study could use the zoomable map visualization as a baseline against which the novel techniques can be compared in terms of accuracy of the comparison and the time needed to carry it out. Ideally, the basic choropleth map would be extended to a multivariate data display, for which comparison tasks are generally more demanding. However, as recent studies show [LPA15], designing such a controlled study is a formidable research challenge.

With the aforementioned expert feedback being incorporated into our solution, we hope that it can be generally applicable to other visualization settings. Graph visualization appears to be an area that could be worthwhile to explore next. Another promising direction would be to apply our work to wall-size visualizations, which are becoming increasingly relevant.

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