The Aesthetics of Diagrams

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Abstract: Diagrammatic representations are omnipresent and are used in various application domains. One of their major goal, in particular for information visualization, is to make data visual in a way that a spectator can easily understand the graphical encoding to finally derive insights from the data. As we see, there are various different ways to visually depict data by using visual features in various combinations. In this paper we come up with some thoughts about existing diagram styles, for which we first discuss the benefits and drawbacks of each of them focusing on aesthetics based on readability. Additionally, we describe some initial results on the aesthetics of diagrams which we recorded in a web-based experiment. In this, we asked participants to vote for one of two given diagrams of a given repertoire of 70 of them covering all examined aspects which focuses more on aesthetics in the sense of beauty, not readability. The major result of this experiment unhides a trend towards colored, 3D, and radial diagrams which stands somewhat in contrast to readability user studies in information visualization oftentimes tending towards 2D and Cartesian diagrams for data exploration.

1 INTRODUCTION

Nowadays, there are various diagram types occurring in different styles combining several visual features into a single representation. The major goal of those diagrams is to graphically depict data or scenarios in some intuitive way. In particular, for information visualization, those should represent abstract data in a meaningful, intuitive, readable, and understandable way as described by Bertin (2010) and Tufte (1983, 1990). Moreover, the visualization should be as compact and space-filling as possible serving as a good overview of as much data as possible. When talking about these aspects, we refer to diagram readability aesthetics. Aesthetics in the sense of beauty oftentimes plays a second role.

But on the other side, the second kind of diagram aesthetics also plays an important role since 'good looking' visualizations much more attract users' attention and consequently, those might be used from a broader field of data analysts and in particular, by laymen which oftentimes only know diagrams from newspapers and magazines. These assumptions make diagram aesthetics an important topic worth discussing and studying.

In this paper we discuss the benefits and drawbacks of diagrams by looking at them from different perspectives. As a first attempt we come up with a very flat categorization in which we subdivide a diagram type depending on one visual feature it is based on. These features are in particular, if they are old ones or developed recently, if color is used or not, if they represent data in 2D or 3D, if they use animation or depict the data statically, if they are mapped to a radial (circular) or to a Cartesian coordinate system, if they are space-filling or not, or in which research field those are used more frequently, i.e. either in information visualization or scientific visualization. Typically, many more categories can be found, but to this end, we only explore this list to get some ideas for future directions.

To get a hint about user preferences on diagram aesthetics in the sense of beauty we conducted an uncontrolled web-based experiment in which we let people vote for exactly one of two represented diagrams chosen from a preselected repertoire of 70 of them. In this preliminary study we found that people tend more to colored, radial, and 3D diagrams which are considered as being not that readable and explorable as for example 2D diagrams mapped to a Cartesian coordinate system making them more space-filling and space-efficient. Colored diagrams were considered more aesthetically appealing than non-colored diagrams which is beneficial because using colors is important for both, readable as well as aesthetically appealing diagrams.

It may be noted that this work is just a very first step towards understanding diagram aesthetics. There

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are too many parameters serving as independent variables in a user experiment that much more empirical research must follow to come closer to solutions of this problem.

2 RELATED WORK

The international conferences on the theory and application of diagrams, held every two years, built a platform to discuss recent developments in diagram research, of which the last twelve years are surveyed by Purchase (2014). But also the traditional visualization conferences and journals provide various approaches including diagrammatic aspects focusing on producing effective visualization techniques.

From this point of view, we can subdivide existing diagram types into several categories of which we know that this is by far not a complete list. Based on these categories, a discussion on benefits and drawbacks can be started to get more insights on which ones are more suitable for readability tasks and which of those look more aesthetically pleasing in the sense of beauty. The best diagrams, at least in our opinion, are those which fulfill both aesthetics criteria.

In general, the term 'aesthetics' comes from the field of philosophy which contains aspects such as the general nature of art, beauty, and taste. In a scientific sense it can be more understood as the study of sensory-emotional values by judging applying sentiment and taste as described in Zangwill (2008). The definition of this kind of aesthetics is consequently not driven by a specific user task as information visualizers would understand it.

In contrast to that, diagram aesthetics in the sense of readability and effectiveness is more based on design principles such as the reduction of chart junk described in Bateman et al. (2010), a balanced lie factor illustrated by Tufte (1983), and a reduction of visual clutter as discussed in Rosenholtz et al. (2005). In particular, in the field of graph visualization, graph drawing aesthetics are important to produce readable node-link diagrams which is researched by Harel (1997) and Ware et al. (2002). For example, Bennett et al. (2007) discuss the aesthetics of graph visualization but they define aesthetics more in the sense of readability which they evaluate in a comparative user study. It is not clear if a viewer also finds the presented graph beautiful, i.e. aesthetically appealing. There are some user studies which indicate that participants might find node-link diagrams with acute crossing angles not that nice as node-link diagrams with angles close to ninety degrees which was investigated in an eye tracking study by Huang (2007).

van Wijk (2005) discussed the value of visualization. He measured the value of it by using effectiveness and efficiency. Based on this he discusses why visualizations are used in practice and why not. Finally, he explores two views on diagrams by looking at them as art or as scientific discipline. As a good example for aesthetics in the sense of beauty and in the sense of readability and explorability of data, van Wijk discusses the work of Kleiberg et al. (2001) on botanical trees. Those are inspired by the metaphor of 3D trees in nature for visualizing hierarchical datasets.

In our work we try to subdivide diagram types into several categories based on visual features. Those categories are then used to discuss benefits and drawbacks and finally, we ask a larger population how they judge the aesthetics of them. This may help to generalize the beauty of diagrams and to compare them with results of typical existing empirical user studies on diagram readability aesthetics.

3 CATEGORIZATION OF DIAGRAMS

Diagrams come in a variety of forms combining all imaginable visual features to produce depictions of data that benefit from a high degree of readability. Consequently, they allow to detect visual patterns which can lead to derive insights when those can be remapped to the original data.

In this section we propose a list of possible categories in which a diagram can fall in. These categories are used as basis to discuss benefits and drawbacks concerning insight detection as well as diagram aesthetics in the sense of beauty.

- **Old vs. New.** This reflects if a diagram appears before the invention of the computer (before 1941 as illustrated in Rojas (1998)) or after it. Consequently, diagrams of the first type are either hand-drawn or produced mechanically, see Bertin (2010). Diagrams of the second type are generated with computer aid, i.e. either by using a classical visualization tool which reads in datasets or by manually composing the diagram of graphical primitives.
- **Colored vs. Non-colored.** By these categories we subdivide diagrams into those types that only depict data as colored or non-colored images.
- **2D vs. 3D.** Diagrams might also be categorized if they make use of 3D, i.e. if they use a third dimension to project data on or not. This makes in

particular sense for data that already has an inherent spatial dimension but it is more questionable for data with an abstract 2D structure.

- **Animated vs. Static.** 'Animation is used for presentation, static displays for exploration' is oftentimes heard when dealing with this aspect of visual representation. We base one categorization on the fact if data is shown in an animated fashion or not.
- **Radial vs. Cartesian.** Some diagrams might be mapped to polar coordinates making them to radial (or circular) representations whereas others are mapped to a Cartesian coordinate system.
- **Infographic vs. Traditional Diagram.** Infographics are typically used in newspapers and magazines making a diagram more attractive to the readership. Traditional diagrams are those that are used in scientific research which typically avoid visual ornaments.
- **Space-filling vs. Non-space-Filling.** The display space might be used efficiently by avoiding empty spaces in which no data is encoded. In this case one might speak of a space-filling diagram whereas a non-space-filling diagram is the result in the second case.
- **Scientific vs. Information Visualization.** Diagrams can also be categorized by the research field in which they are used most frequently. Scientific visualization more frequently uses 3D visualizations since the analyzed data there has typically an inherent spatial dimension and is of continuous nature. In contrast, information visualization typically deals with discrete (non-continuous) and abstract data.

4 DIAGRAM READABILITY AESTHETICS

Although there are many diagram types it is often questionable which diagram is best suited for a given scenario and task to be solved. In the sense of readability aesthetics, comparative user studies can be conducted focusing on finding a good candidate for a certain purpose. The intent of this section is to briefly discuss diagram readability aesthetics and the benefits and drawbacks when diagrams of a certain category described in Section 3 are used to visually support a data analyst.

- Old diagrams typically use simple shapes and simple geometrical primitives. In many cases, the used color codings cannot compete with those of today's high-resolution displays. Consequently, we expect that those old-fashioned diagrams are not that useful for readability. Moreover, interaction techniques as we understand them as computer users are missing in such diagrams and they do not scale to large datasets. Examples of such diagrams are those designed by Bertin (2010).
- Colored diagrams have one great advantage over non-colored diagrams. They have an additional visual dimension on which a data attribute can be visually encoded. But due to perceptual issues we cannot use that many colors in a diagram as illustrated in the book on perception for design by Ware (2000), which can also be challenging for people suffering from color deficiencies and color blindness.
- Typical negative aspects such as occlusion effects and visual clutter come into play when an analyst is dealing with 3D diagrams. Interaction techniques such as rotation are a meaningful concept to achieve more readable 3D diagrams. This is for example also discussed in Heinrich et al. (2014) who described the use of 1D, 2D, and 3D visualizations for molecular graphics. They came to the conclusion that in this specific field researchers tend more to the 3D representations. Compared to them, only a few number of 2D candidates exists. In the field of software engineering, instead, various 2D visualizations are used but 3D as in software cities as described in Wettel and Lanza (2007) is rarely applied.
- In particular, in fields which have to deal with time-varying data, the question arises if it is displayed as a natural time-to-time mapping (animation) or as a time-to-space mapping (static). For example, in dynamic graph visualization, there exist these two concepts as surveyed in Beck et al. (2014). Animated diagrams soon lead to problems to preserve the mental map, in particular when subsequent diagrams have to be compared to explore them for time-dependent visual patterns. This is much easier in static displays for dynamic data but there, visual scalability problems might occur. Moreover, the application of interaction techniques is difficult in animated diagrams. An interesting discussion on these aspects is described in the work of Tversky et al. (2002).
- Bar and Neta (2006) found out that humans rather tend to prefer visual objects when they contain curved shapes. This aspect speaks in favor of radial or circular diagrams as surveyed by Draper et al. (2009). But Burch et al. (2011a, 2013) evaluated in an eye tracking experiment that radial

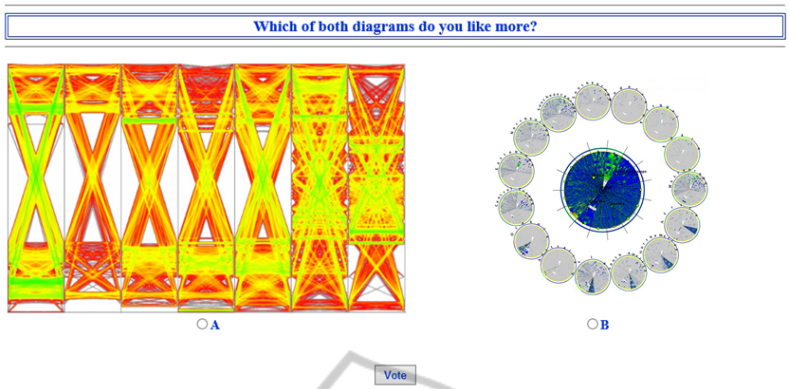

Figure 1: Our voting framework for recording diagram preferences: A dynamic graph visualization with applied edge splatting by Burch et al. (2011b) received 41.7 percent of the votes (58th place) (Left). A dynamic graph visualized as TimeRadarTrees by Burch and Diehl (2008) received 58.9 percent of the votes (9th place) (Right).

tree layouts cause twice as long completion times and more complicated visual task solution strategies as when traditional Cartesian tree layouts are used. Consequently, it seems as if radial diagrams are aesthetically appealing but from a readability and space-efficiency point of view they are rather questionable.

- Infographics typically use visual ornaments to make the data depiction more aesthetically appealing. In traditional diagrams those ornaments are regarded as chart junk which are not needed to make data explorable. In many cases the viewer has to inspect more visual elements in Infographics until he can derive insights. Infographics typically display statistical data and cannot handle large data sets as information visualizations can do.
- If a diagram is space-filling it can display a larger amount of data into a single view, i.e. an overview of a large amount of that data is visible as a starting point for further explorations. But also non-space-filling diagrams have their benefits. If we think of hierarchy visualizations like treemaps or node-link diagrams, the treemaps are more space-filling but the hierarchical organization in node-link diagrams becomes more apparent.
- Typical diagrams in SciVis have to deal with continuous, three-dimensional, and time-varying data. This makes the corresponding SciVis diagrams more complex to design and generate. Consequently, more complex algorithms are used to compute visualizations which can compete with the vast amount of data. In contrast to that, in InfoVis, diagrams are typically 2D representations and visually encode discrete data by using simpler algorithms.

5 AESTHETICS STUDY

The focus of this study is not on diagram readability aesthetics but more on the fact if a diagram is aesthetically appealing in the sense of beauty. To find this out we asked people in a web-based experiment to vote for one of two given diagrams. The goal of this crowdsourcing experiment was to get an impression about how the mass of people decides when it comes to aesthetics judgments for diagrammatic representations.

5.1 Diagram Collection and Stimuli

We collected 70 diagrams by using the image search functionality of Google. We strategically looked for diagrams of all categories, i.e. we integrated diagrams which are static as well as animated, are 2D as well as 3D, are radial as well as Cartesian and so on. It may be noted that a diagram can contain several of those visual features, i.e. a 3D pie chart is three-dimensional, radial, static, and is frequently used in information visualization but less frequently in scientific visualization.

All images were of high resolution and were scaled to fit to the horizontal and vertical display space. The question 'Which of both diagrams do you like more?' is clearly visible above both diagrams all the time, see Figure 1. We use animated gifs to visually depict animated diagrams in an endless replay scenario. Each participant can vote for exactly one of both diagrams by selecting either A or B and by confirming this decision by a mouse click. After that a new voting scenario was created, i.e. two different diagrams were randomly selected and displayed in a similar way.

5.2 Participants

Our study particpants were recruited by posting a link to the experiment on an author's web page. To take part, a login and a password are required. We did not record any additional information such as the participant's professional level, age, or gender, because we do not want to discourage people from taking part in the experiment. After two weeks, 127 people have taken part voluntarily in the experiment which voted 6,744 times in total. We also recorded the timestamp of the voting and how long it took them from seeing the diagrams and confirming the vote.

5.3 Study Design and Procedure

We ran the voting experiment for exactly two weeks. The web-based experiment could be let run in each standard browser by just logging in and using the corresponding URL. The voting web page was implemented in PHP. Technical problems during the experiment could be reported but fortunately, nobody reported one.

The single task for the participants was to vote for exactly one of two displayed diagrams. For this, they had as much time as they wanted. The data was recorded and stored in a text file which was later used for evaluation of the study results.

5.4 Results

We counted how often a participant voted for a specific diagram and how often the diagram was involved in a voting. This gives for each diagram a ratio of positive votes and the number of total votes for that diagram, giving a percentage value expressing the diagram aesthetics in the sense of beauty.

We base the ranking of all displayed diagrams in our experiment on these percentages and computed a decreasing order. Somewhat surprisingly, the 3D pie charts (the only ones that we showed) were on places one and two with 68.34 percent and 67.33 percent, respectively. The diagram on the third place is again a 3D diagram, but it is a very colorful three-dimensional bar chart (Cartesian) representing quantities in the plane (64.11 percent). This lets us assume that colored and 3D diagrams tend to be more aesthetically appealing to the viewer.

An also interesting phenomenon is the fact that simple and well-known diagrams seem to be preferred by the viewer, i.e. pie charts and bar charts as well as weather maps with an animated hurricane on it (64.10 percent). A metro map (63.42 percent) also belongs to the higher ranked diagrams.

Node-link tree diagrams, for example, of which we showed eight, are only ranked lower than 53th place and got an average percentage of only 38.59. The lowest only got 32.95 percent. All the non-colored diagrams are ranked very low which indicates that colorful diagrams might be more attractive and more beautiful.

What we also found interesting is the fact that treemaps are ranked very low. A general treemap only achieved 34.96 percent, which makes a 67th place in the ranking. The cushion treemap is even worse, getting only 29.37 percent at a 69th place. It seems, as if there are two many rectangular shapes in a space-filling representation, although the presented treemaps are very colorful. Our assumptions might go in the right direction if we inspect bubble treemaps, being less space-efficient, but using circular shapes. Those bubble maps are ranked on a 6th place with a percentage of 62.91.

Infographics are not considered that nice, all of them are ranked in the second half in the ranking. Maybe the color coding is responsible for that.

In summary, we can say that 3D, colored, and radial diagrams perform better in the study. Also animated diagrams are typically not ranked very low but those are also not the winners in this experiment.

5.5 Threats to Validity

It may be noted that this is an uncontrolled experiment, i.e. we know the login data from the participant but we do not know who is actually taking part in the study and we also do not know how much attention and importance the participant is given to this study. Consequently, we must be careful with the recorded results and just present the results as a very preliminary step towards the direction of investigating diagram aesthetics. Many more studies must follow, also in a controlled user study setting, maybe also by using eye tracking techniques.

What is also problematic in this study is the missing comparability of the diagrams. This means, we randomly show diagrams which depict different kinds of data. A scenario showing different diagrams for the same dataset would be beneficial but then we cannot compare, for example, diagrams for hierarchical datasets with those for multivariate data. Moreover, we only tested a limited number of diagrams. Since there are various of them, it is nearly impossible to test all of them. We tried to find a 'good' candidate for many of them and to show them as representative diagram for this class of diagrams in the study.

The evaluation of differences between user groups, i.e. male vs. female, young vs. old, expe-

rienced data analyst vs. layman etc. would also be worth investigating. But in this study this is problematic due to the uncontrolled web-based setting.

6 CONCLUSION AND FUTURE WORK

In this paper we presented a discussion on the use of diagrams in the field of information visualization, in particular we described benefits and drawbacks by categorizing them based on the visual features they are based on. Apart from having a look at the usefulness for specific data analysis tasks we look more on the aesthetics of the diagrams. To obtain better judgments on such aesthetics and to strengthen or weaken our subjective impressions of diagram types we conducted a preliminary web-based user experiment. Participants are confronted with two diagrams and have to vote in favor of one diagram. The major result of this uncontrolled comparative aesthetics study is that our participants find 3D, radial, and colored diagrams more aesthetically appealing than for example 2D, Cartesian, and non-colored representations.

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