Cartesian vs. Radial – A Comparative Evaluation of Two Visualization Tools

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Abstract. Many recently developed information visualization techniques are radial variants of originally Cartesian visualizations. Almost none of these radial variants have been evaluated with respect to their benefits over their original visualizations. In this work we compare a radial and a Cartesian variant of a visualization tool for sequences of transactions in information hierarchies. The Timeline Trees (TLT) approach uses a Cartesian coordinate system to represent both the hierarchy and the sequence of transactions whereas the TimeRadarTrees (TRT) technique is the radial counterpart which makes use of a radial tree, as well as circle slices and sectors to show the sequence of transactions. For the evaluation we use both quantitative as well as qualitative evaluation methods including eye tracking.

1 Introduction

Many radial visualizations can be produced by transforming a visualization from a Cartesian coordinate system into a radial coordinate system. For example, a rose diagram and a pie chart are radial variants of bar charts, and a star plot [1] is a radial variant of a parallel coordinates visualization [2], see Figure 1. Hierarchical data is also represented in many different ways, for example in a node-link and layered icicle approach. Not surprisingly, radial node-link visualizations have been developed [3] and the layered icicle technique has also been "radialized", for example in Information Slices [4].

Furthermore, several recently developed visualization techniques combine radial visualizations, e.g. hierarchical edge bundles [5] combine radial icicles and radial trees, and Stargate [6] combines radial icicles and parallel coordinates.

Looking at all these examples, the question arises what is the effect of the radial transformation on the useability. Radial visualizations are more difficult to implement and often look nicer than their Cartesian counterparts. But it remains an open question whether they better support users to comprehend data and extract knowledge.

In this paper, we present two empirical studies comparing two visualization tools – a Cartesian one and its radial variant. The tools were developed for the visualization of sequences of transactions in information hierarchies.

The rest of this paper is organized as follows. In Section 2 we discuss related work. Section 3 briefly introduces both visualization tools. Next, we present the

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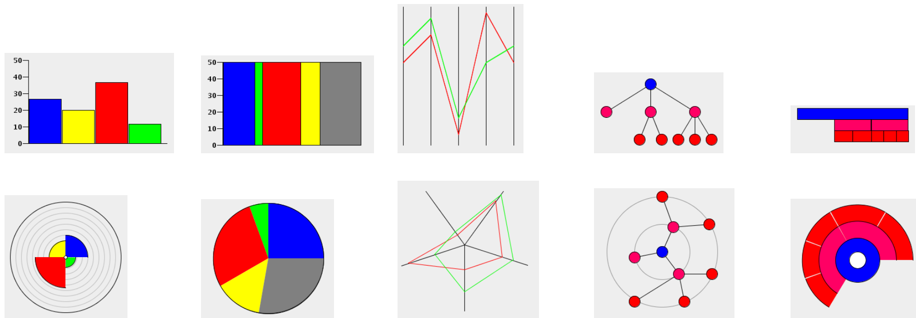

Fig. 1. Some radial visualizations and their Cartesian counterparts

design, results and limitations of our eye tracking study in Section 4. Finally, we draw some conclusions from our study in Section 5.

2 Related Work

The pros and cons of radial visualizations have mostly been discussed by their developers but rarely evaluated in a user study. An informal user study has been organized for the hierarchical edge bundling approach [5] for example. But the researchers did not evaluate if the radial layout would be better than a non-radial one. The developers of this system just found that the participants could gain insights in the adjacency relations in a hierarchical structure. They did not compare their different layouts against each other.

Stasko et al. [7] compared the Sunburst technique to Treemaps [8] by evaluating the effectiveness and utility of both tools. They conducted two empirical studies for the two space-filling visualizations of the hierarchical data namely file and directory structures. The participants had to perform search tasks with both the rectangular Treemap method and the radial Sunburst technique. The authors found that the participants better understood the hierarchical structure with the radial tool.

Four different tree representations are compared in [9]. The author examined in a user study that different tree layouts lead to the fact that users uncover different and sometimes complementary insights in the given data. He compared a treemap, a baloon layout [10], a hierarchical node-link, and – most important in the context of this paper – a radial tree layout.

There has been a lot of work on visualizing information hierarchies using node-link diagrams [11], radial [12], or space-filling techniques like Treemaps [8], Information Slices [4], or Sunburst [13], but only few researchers have developed methods to visualize transactions between elements of a hierarchy [14,15,16,17].

The goal of this paper is to present the results of a comparative study of two tools – a Cartesian [18] and a radial one [19] – for visualizing sequences of transactions in information hierarchies.

3 Description of the Tools

Information hierarchies exist in many application domains, e.g. hierarchical organization of companies, or file/directory systems. In addition, there are relations between elements in these hierarchies. For example, employees are related if they communicate with each other, or files are related if they are changed simultaneously. Through these relations the participating elements together form a transaction. Often, we are not interested in a single transaction, but in a sequence of transactions that occur over time.

In the following we explain the details of the two tools compared in the study: Timeline Trees (TLT) [18] which uses a Cartesian representation to visualize sequences of transactions in an information hierarchy, and TimeRadarTrees (TRT) [19] which is able to represent the same kind of data but in a radial style. Both tools can be separated into three views:

The tree view as a traditional node-link diagram: The TLT approach places the information hierarchy on the left hand side of the whole view whereas the TRT visualization makes use of a radial tree that represents the leaves of the hierarchy on the circle circumference and the whole tree on top of the timeline view. Trees can be collapsed or expanded to an interactively selectable level in both tools.

The timeline view with a space-filling approach: In TLT the sequence of transactions is visualized as sets of boxes, that are drawn from left to right in the diagram. We refer to this sequence of boxes as a timeline – in many applications time provides a natural order on the transactions. Each box represents one member element of a transaction and is positioned in the same column as the other members of this transaction and in the row of the according item. The TRT approach uses circle slices and circle sectors instead of rectangular boxes. The time axis starts in the circle center.

The thumbnail view: In TLT thumbnails are displayed for every item or collapsed node at the right side of the tree diagram. They show the transactions from the perspective of the according node, such that only those transactions the node is member of are represented in the thumbnail using the selected color code, whereas the remaining transactions are only drawn as gray boxes. Thumbnails are a good tool for identifying correlations between nodes though they are very small. The TRT visualization uses radial thumbnails that are located outside the circle to avoid an overlap with the timeline view.

4 Eye Tracking Study

To attract participants to our study, we decided to use a data set related to soccer. The reason for choosing this kind of data is that soccer is well-known and easy to explain. Furthermore it is a real and an adequately representative data set.

We found that a data set representing the number of ball contacts of players in a sequence of moves contains all the features that we need for the visualization

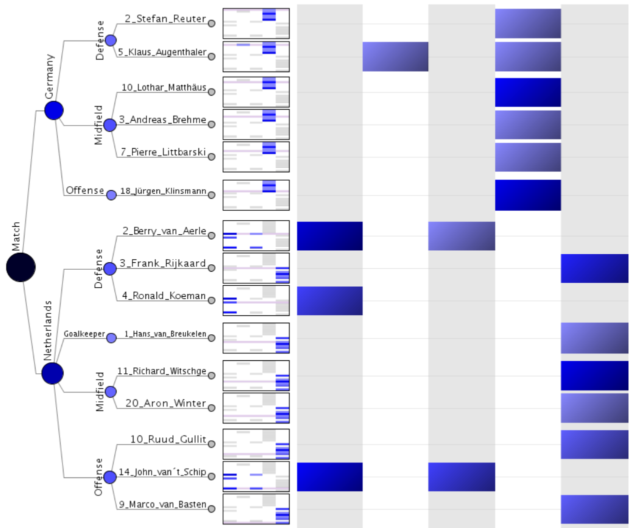

Fig. 2. TLT representation of a soccer data set

tools. First of all, each soccer match is hierarchically organized in the following manner: One match consists of two teams which build the first level of the hierarchy. It is then further subdivided into team parts – the goalkeeper, the defense, the midfield and the offense.

A move in the match is the set of players that have one or more ball contacts until the opposite team wins the ball possession. The number of ball contacts of each player in each move is recorded and is an indication for the weight of each player in that move. Two players of different teams can also be in the same move in a special kind of event when both players are ejected from the match simultaneously, for example, because of a red card or a substitution. In this way the whole match can be separated in a sequence of moves. A move corresponds to a transaction in the more general terminology of the visualization tools.

We base our experiment on a real data set which was manually recorded from a soccer match between the national teams of Germany and the Netherlands in the World Cup Championships in 1990 played in Italy. It was the round of the last sixteen teams that Germany won 2 to 1.

4.1 The Population

The population that performed the evaluation consisted of 35 students (18 males, 17 females). The participants were split randomly into Group TLT (17 participants: 9 males, 8 females) and Group TRT (18 participants: 9 males, 9 females). All test persons participated voluntarily in the evaluation. Before the actual experiment the participants had to fill in a short questionnaire about their mathematical background, video gaming skills, and soccer interests. As we can see in

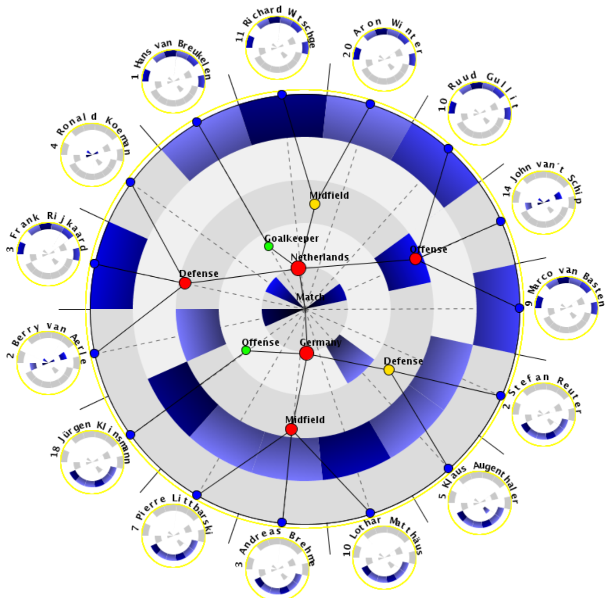

Fig. 3. TRT representation of a soccer data set

Table 1, both groups were relatively balanced with respect to their interest in soccer, but Group TRT had slightly better mathematical skills and Group TLT slightly more experience in video gaming.

Table 1. Population

	TLT	TRT
Participants		
- total	17	18
- male	9	9
- female	8	9
Mathematical skills (1 very good, 6 very bad)		
- in school (∅)	2,76	2,47
- estimated current skills (∅)	3,35	3,11

	TLT	TRT
Soccer interests		
- not at all	4	5
- some	8	10
- very interested	4	3
- plays soccer	2	2
3D-game playing (hours/week)	0,82	0,67

4.2 The Experiment

After finishing the initial questionnaire, the participants were asked to read a printed tutorial text about the visualization technique (either TRT or TLT). At the end of the tutorial text there were some initial questions for them to check whether they understood how to read the visualizations. The participants had 10 minutes for the tutorial.

The actual experiment took 15 minutes and was performed with an eye tracking system (Tobii x50) that uses corneal reflection of infra-red light to locate the position and movement of the eye. The questions and visualizations were shown on a computer screen and two cameras mounted on the screen recorded

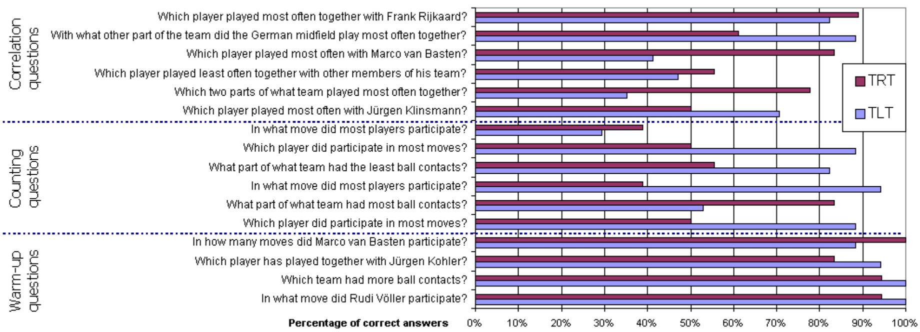

Fig. 4. Correctness of answers for both groups

the eye movements at a frequency of 50 Hz, i.e. an image is taken every 20 ms. The visualizations were single screenshots of the TRT and the TLT tool showing between 13 to 157 transactions and between 8 to 22 leaf nodes. No interactive features were available.

For the analysis of the recorded eye tracking data we used heatmap visualizations. To produce the heatmaps, points of fixations of several test persons have been combined. A fixation was registered by the system when a test person gazed at an area of 30 pixels radius at least for 100 ms.

4.3 Results

In this experiment the participants had to answer 18 questions. The last two of these questions were open questions, while the first 16 questions had clearly determined correct answers. These 16 questions and the overall results are shown in Figure 4. They can be grouped into three categories: warm-up questions, counting questions and correlation questions.

Warm-up Questions. For the warm-up questions we see, that these questions have been answered correctly by more than 90 percent, sometimes even 100 percent, of the participants.

Counting Questions. This type of question focuses on counting and summing items in different scenarios. As shown in Table 2, TLT outperformed TRT with respect to correctness of answers as well as with respect to response time for correct answers. Moreover, these two results are statistically significant[1].

By examining the heatmaps we found that the participants did not use the thumbnails when answering these questions. This was expected because the main purpose of the thumbnails is the detection of relationships.

Correlation Questions. For correlation questions, that ask about relations between items, the participants could answer more questions correctly when using TRT, as shown in Table 2. Unfortunately, this result is not statistically significant.

[1] In the tables we have set the error probability of all statistically significant results ($p < 0.05$ with Bonferroni-Holm correction) in bold face.

Table 2. T-test analysis

	Number of correct answers				Response time for correct answers			
	Mean (TLT)	Mean (TRT)	T-Value	P-Value (2-sided)	Mean (TLT)	Mean (TRT)	T-Value	P-Value (2-sided)
- all 16 questions	11.83	11.06	-1.089	0.284	16.69	21.55	3.060	**0.004**
- counting questions	4.35	3.17	-3.436	**0.002**	17.40	23.07	2.511	**0.017**
- correlation questions	3.65	4.17	1.037	0.520	21.74	23.23	0.840	0.407

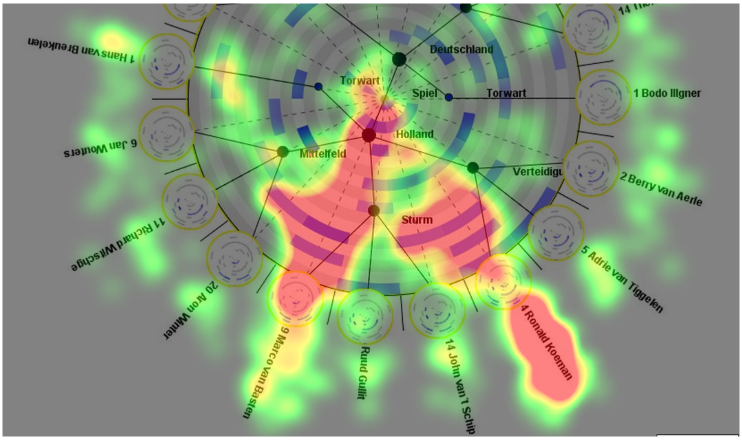

Fig. 5. Heatmap for TRT (Correlation question)

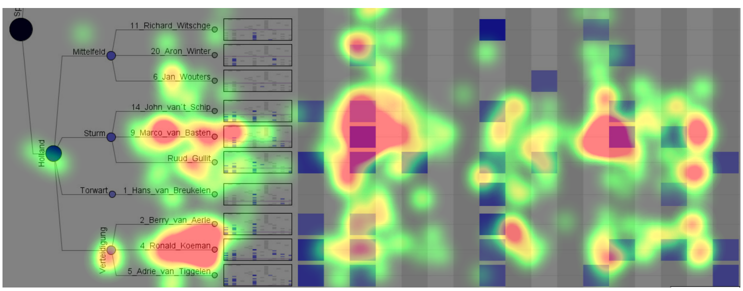

Fig. 6. Heatmap for TLT (Correlation question)

After examining the heatmaps of the correlation questions we found that the participants using TRT looked at the thumbnails more intensively than those using TLT. For example, Figure 5 and Figure 6 show the heatmaps for "Which player played most often with Marco van Basten?". In the TLT heatmap, one can easily see that there was almost no fixation on the thumbnails, whereas in the TRT heatmap there was a strong fixation at the thumbnail of Marco van Basten and another one at the thumbnail of Ronald Koeman – the correct answer for this question. When looking at the heatmaps of those participants using TLT who answered correlation questions incorrectly, we often found that they did not make much use of the thumbnails.

Open Questions. All of the previous questions could be answered automatically with relatively simple database queries and no visualization at all. We think that the most important contribution of visualization tools is for exploration of large data sets, where we do not know what to look for in advance. For this, we also showed the participants the visualizations and asked the very general question "Can you detect any trends or anomalies?". In both groups a test person mentioned on average about 4.3 observations. But the observations varied between the two groups. For example, 14 participants using TRT found that two players (Rudi Völler and Frank Rijkaard) only took part in moves at the beginning of the visualized time period[2], but only 6 participants using TLT detected this anomaly.

Looking at the heatmap shown in Figure 7 we realized that the participants using TLT did not inspect the periphery of the visualization, i.e. they did not fixate any of the four corners of the computer screen. Figure 7 shows that for TRT due to its radial layout this "blinders effect" did not occur.

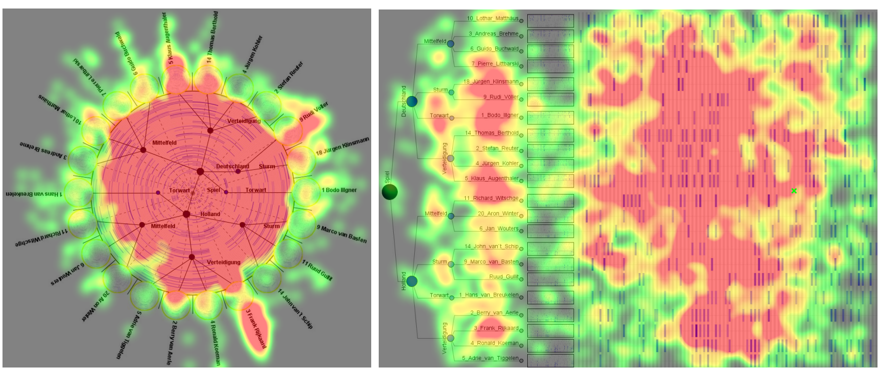

Fig. 7. Heatmap for TRT and TLT (Open question)

4.4 Threats to Validity

There are various factors that limit the validity of the results of these kinds of studies. These include for example the choice of the data set, the choice of the questions, and the size of the data set for each question. Furthermore, while the eye tracker used is not very distracting (compared for example to a head-mounted one), it still restricts the user not to move his or her head.

[2] Both players have actually been ejected from the match.

Finally, TRT does not exploit one of the alleged advantages of radial displays, the possibility to put detailed information in the center and context information in the periphery. Thus, we could not evaluate this feature.

5 Conclusion

While the overall performance of the participants using TLT was better than the performance of those using TRT, the interpretation and thus effective use of the thumbnails worked better in TRT. One reason for this might be that it is easier to distinguish and remember locations in the radial layout.

Radial visualizations are fancy, and for some tasks they may even be superior to their Cartesian counterparts. At least, in our empirical study the radial visualization could not keep up with the Cartesian one. Although TLT outperformed TRT overall, there is still some hope: The eye tracking experiment showed that the radial visualization did not lead to the "blinders effect", and that the radial thumbnails were more useful than the Cartesian ones.

The study presented in this paper should only be considered a first step towards answering our initial question of whether radial visualizations better support users to comprehend data and extract knowledge.

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