Radial vs. Cartesian Revisited: A Comparison of Space-Filling Visualizations

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ABSTRACT
Radial visualization continues to be a popular design choice in information visualization systems, due perhaps in part to its aesthetic appeal. However, it is an open question whether radial visualizations are truly more effective than their Cartesian counterparts. In this paper, we describe an initial user trial from an ongoing empirical study of the *SQiRL* (*S*imple *Q*uery *i*nterface with a *R*adial *L*ayout) visualization system, which supports both radial and Cartesian projections of stacked bar charts. Participants were shown 20 diagrams employing a mixture of radial and Cartesian layouts and were asked to perform basic analysis on each. The participants' speed and accuracy for both visualization types were recorded. Our initial findings suggest that, in spite of the widely perceived advantages of Cartesian visualization over radial visualization, both forms of layout are, in fact, equally usable. Moreover, radial visualization may have a slight advantage over Cartesian for certain tasks. In a follow-on study, we plan to test users' ability to create, as well as read and interpret, radial and Cartesian diagrams in SQiRL.

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: User Interfaces, User-centered design

General Terms
Radial Visualization

INTRODUCTION
Radial visualization is a frequently-recurring motif in the design of information visualization systems. We define *radial visualization* as a visualization which "arranges data in an elliptical fashion" [7], and *Cartesian visualization* as any visualization "based on a dominating rectangular structure" [6].

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Recent work [1, 2, 3, 6] has been concerned with evaluating the relative effectiveness of radial and Cartesian visualization schemes, but these comparisons have usually been between visualizations generated by disparate software systems, or by comparing users' ability to perform abstract tasks. There have been very few studies that evaluate radial and Cartesian layouts within a single visualization system. To fill this gap, we designed an empirical study of *SQiRL*, a visualization system that supports both radial and Cartesian layouts. This paper describes a preliminary study in which participants evaluated (static) radial and Cartesian graphics generated by SQiRL. In a future study, we will measure users' performance when interacting directly with SQiRL in both radial and Cartesian modes.

RELATED WORK
The practice of using radial charts in statistical graphics dates back to at least the 19th century. Oft-cited examples include the hand-drawn charts of William Playfair [12] and Florence Nightingale [11]. For a more complete history and discussion of radial visualization as a distinct design metaphor, please see the survey by Draper et al. [7].

Radial vs. Cartesian
In the past three decades, there have been a few attempts to evaluate the effectiveness of radial and Cartesian visualizations, with inconclusive results. As early as 1984, Cleveland observed that humans have difficulty judging the magnitude of angles [4]. More recently, Burch et al. [2] also compared various layouts for tree structures, and found that radial layouts were less effective for the specific task they evaluated. In contrast, a study by Stasko et al. [13] found that users generally preferred a radial layout over a Cartesian one for browsing filesystem hierarchies. Kriglstein et al. [9] implemented two separate but complementary visualizations, one radial and one Cartesian, for rendering entity-relationship diagrams. Their study found both representations to be useful and there was no specific conclusion as to which was "better."

A recent empirical study by Diehl et al. [6] suggests that, for many general tasks, Cartesian interfaces outperform their radial counterparts. This study has been

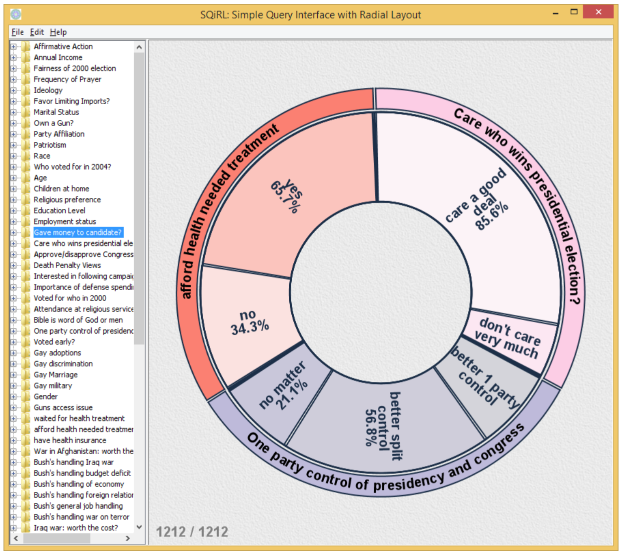

Figure 1. SQiRL's user interface. The canvas is dominated by a donut chart (the "ring"), onto which attributes can be added and removed by dragging to/from the panel on the left.

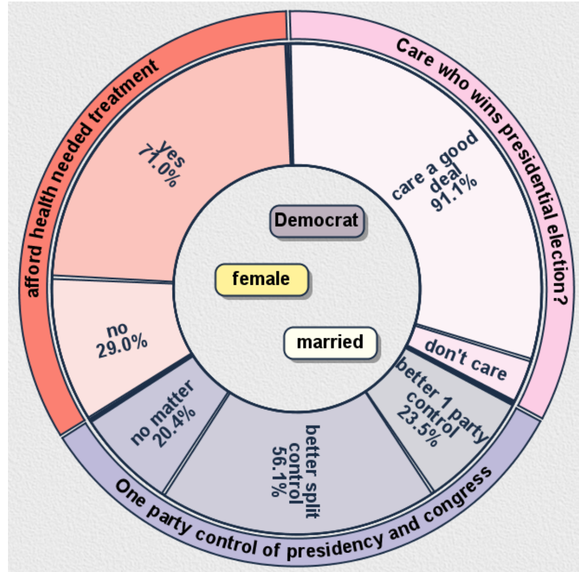

Figure 2. To limit the query to a specific subpopulation, the user drags attributes into the ring's interior.

cited [5, 14] as a reason for de-emphasizing radial visualization in favor of Cartesian layouts. Nonetheless, new visualization systems employing radial layouts continue to be introduced, and this trend does not appear to be slowing down anytime soon [3]. Whatever its strengths or weaknesses may be, radial visualization continues to be a popular design metaphor.

Many of the studies cited above compare radial and Cartesian renderings of node-link diagrams; these were often generated by disparate software systems. In contrast, we evaluate whether or not there is a significant difference in users' ability to read and interpret "space filling" diagrams, specifically the Cartesian stacked bar chart and its radial counterpart, the pie or donut chart. All the graphics used in our study were rendered by a single software system, SQiRL.

SQiRL

SQiRL is an open source research prototype for performing and visualizing queries on tabular data sets.

Due to space limitations, we do not give a full description of SQiRL's functionality here; instead we refer the reader to the original paper by Draper and Riesenfeld [8]. The workspace, or canvas, is dominated by a radial diagram as shown in Figure 1. (The screenshots used in this paper were prepared using an instance of SQiRL loaded with the ANES 2004 election data set [10].) Each sector of the diagram represents a different attribute of the population. The angular magnitude of each sector is proportional to the number of entities in the population that exhibit that attribute. The user can add or remove sectors to see different attributes of the population. Rather than employ a traditional pie chart, SQiRL uses a donut chart in which the space inside is reserved for user-specified independent variables. For example, in Figure 2, we see that among married women who are Democrats, most can afford health care, a slim majority prefer power to be split between political parties, and a vast majority care who wins the presidential election.

Early versions of SQiRL used radial visualization exclusively. For this study, we implemented an alternate Cartesian interface to SQiRL. Users can toggle between radial and Cartesian modes via a menu option. The mode of operation in SQiRL's Cartesian interface is analogous to the original radial interface. The central ring widget has been replaced by a block of contiguous stacked bar charts. The space inside the ring has been replaced with a rectangular "tray" directly underneath the chart. The screenshot in Figure 3 shows the same query as Figure 2, but in the Cartesian layout.

In most other studies comparing radial and Cartesian visualizations, the visualizations being evaluated were generated by separate programs. To our knowledge, ours is the first study to evaluate a visualization system that produces equivalent radial and Cartesian charts for the same query.

METHOD

Our initial hypothesis, based on the results of Cleveland [4] and Diehl et al. [6], was that Cartesian charts would outperform their radial counterparts in terms of both the speed and accuracy with which users interpret them.

In order to evaluate this hypothesis, we conducted a preliminary user study involving 48 participants. Like

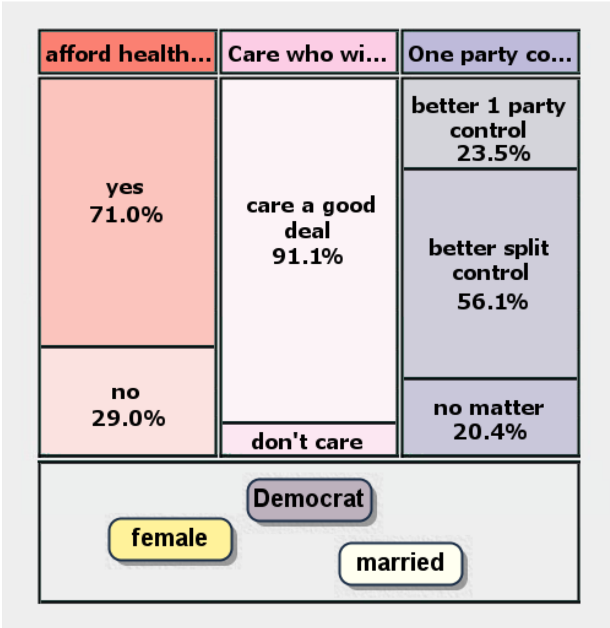

Figure 3. In Cartesian mode, the user places the query terms below the stacked bars, instead of inside the ring.

Diehl et al.'s study [1], participants viewed static screenshots rather than directly interacting with the SQiRL system. In the next phase of our study, we intend to measure users' performance when using the SQiRL system itself. To further simplify the present experiment, we intentionally selected charts containing a single attribute.

For the purposes of the present discussion, we use the standard term "sector" to refer to the different segments of a radial chart. Following Cleveland's terminology [4], we use the term "division" to refer to the individual segments of a stacked bar chart.

The format of the study is as follows. Once the participants were at their workstations, the facilitator launched a quiz program which presented the users with a series of 20 charts showing the results of queries executed in SQiRL. Of these 20 charts, 10 were radial and 10 were Cartesian. The quiz program alternated between radial and Cartesian charts. Half of the participants (24 out of 48) were shown a radial chart first, while the other half were shown Cartesian first. In either case, the data in the charts were the same for all users.

As shown in Figures 2 and 3, SQiRL normally prints the percentages in the sectors (for radial charts) and in the divisions (for Cartesian charts). These quantitative labels were removed for the purposes of the user study. The charts varied in complexity; the simplest had just 2 sectors (or divisions) while the most complex had 6.

For each of the 20 images, the user was given two tasks:

Table 1. Users' speed and accuracy for "Task 1": estimating magnitude of sectors/divisions

	Radial	Cartesian
Average difference between the actual percentage and users' estimates	±1.71%	±1.90%
Standard deviation	6.70%	8.36%
Average elapsed time	17.15 sec	18.08 sec

Table 2. Users' speed and accuracy for "Task 2": selecting the larger of two sectors/divisions

	Radial	Cartesian
Accuracy	88.45%	86.75%
Average elapsed time	11.68 sec	10.69 sec

Task 1. Estimate the magnitude of a given sector (or division), as a percentage of the whole. Users entered their responses as freeform text.

Task 2. Compare the relative magnitudes of 2 sectors (or divisions) and select the one that is greater. Users entered their responses via a checkbox.

The quiz program measured the elapsed time and the accuracy for each task. We did not collect any personal information (such as age or gender) from the participants, other than their names on the university-required consent forms. Participants received no monetary compensation for their participation in this study.

RESULTS

Our findings are summarized in Tables 1 and 2.

For Task 1 (estimating the size of a sector or division), the users' estimates for the radial charts averaged within ±1.71% of the correct percentage, with a standard deviation of 6.70%. In contrast, users' estimates for the Cartesian charts were, on average, ±1.90% of the correct percentage, with a standard deviation of 8.36%. Thus, while the *mean* accuracy for both charts was quite similar, the standard deviation was higher for the Cartesian charts, suggesting that some users had more difficulty guessing the size of the divisions in the Cartesian charts. In addition, the average elapsed time to complete each "Task 1" task was 17.15 seconds for radial, and only slightly higher (18.08 seconds) for Cartesian.

For Task 2 (examining two sectors or divisions and deciding which has the greater magnitude), users chose the correct answer 88.45% of the time for the radial charts, but only 86.75% of the time for the Cartesian charts. Interestingly, users' response times were slightly faster for the Cartesian charts, with an average response time of 10.69 seconds for Cartesian, and 11.68 seconds for radial.

In summary, users' responses were somewhat *more* accurate with the radial layout for both tasks. Users responded faster with the radial charts for Task 1, but slower for Task 2. In contrast to our initial hypothesis, our results suggest that the advantages of Cartesian over radial are not as clear-cut as we had believed. For certain applications, radial visualizations may be slightly easier to read and interpret than Cartesian visualizations.

DISCUSSION AND FUTURE WORK

This work contributes to the growing body of knowledge regarding the merits of both radial and Cartesian visualization techniques. Our results seem to suggest that the differences between these two styles are more cosmetic than utilitarian. However, we emphasize that this is a preliminary study, and that it is difficult to draw definitive conclusions at this point. The "radial vs. Cartesian" question is far from closed; more work is needed to determine which application domains are better served by which form of visualization.

The two primary limitations of the present study are:

1. each participant completed the same tasks in the same order; there was no randomization in the presentation of the charts, and
2. the participants evaluated static screenshots rather than interacting with the SQiRL software directly.

In the next phase of our work, we will address these limitations by allowing participants to respond to a randomized sequence of tasks by building queries directly in SQiRL, using both the radial and Cartesian interfaces. By measuring users' speed and accuracy to perform these tasks, we hope to gain some insight as to the merits and shortcomings of these two visualization styles, not merely as "read-only" charts, but as part of a complete interactive system. We also intend to conduct additional statistical analysis (e.g. ANOVA, t-tests) on the data to better understand variations in users' performance.

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