Rose Charts: Area or Length Encoding for Fill Level of Circle Sectors?

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Abstract

This paper examines the accuracy of value estimation from the fill level in circle sectors of rose charts, a circular chart type where all sectors share the same angle and encode values through either radius or area. But which encoding yields more accurate estimates? We conducted a user study comparing different sector configurations and chart sizes as well as the estimation errors of rose versus bar charts. Our findings indicate that both area and radius influence estimation accuracy. For values below 65%, area dominates as a visual cue, whereas for larger values, a transition to length perception can be observed. Based on these insights, we propose a transfer function to correct for average estimation errors and provide practical guidelines for the effective use of rose charts.

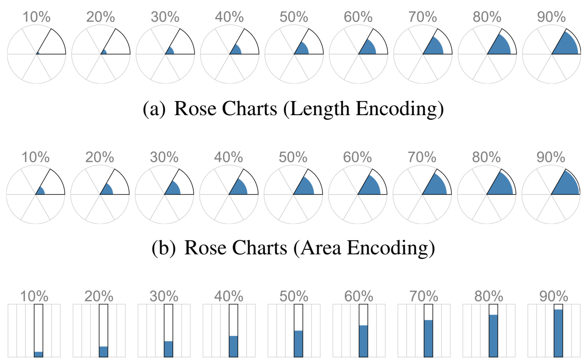
CCS Concepts

• ***Human-centered computing*** → *Visualization design and evaluation methods;* ***Empirical studies in visualization; Visualization theory, concepts and paradigms;***

1. Introduction

Circular designs are a common sight in visualization contexts, used to depict time series data [FFM*13, WDG*19], but also multi-attribute data [KMJF22]. A common one, the rose chart, consists of sectors with the same angle but varying radii. There are two encodings: either the respective attribute value is mapped linearly on the radius (as the majority of the found examples) or on the area of the slice (see Figure 1 (a) vs. (b)). This ambiguity means that viewers may misinterpret values in a rose chart if no clear indication of the encoding method is given. No guidelines exist on which encoding aligns better with human perception. Estimates could rely on radius by comparing the radius length with the length of the whole sector along its edges, or on area through part-to-whole comparisons. In fact, we would expect both to influence perception. Other factors, like sector sizes that change the sector's shape and the sector orientation that might introduce perspective distortion, might also bias the estimation. There is no question that the size of the chart affects the value estimation, but how small can you get without losing too much accuracy? As of yet, these questions remain unanswered.

Thus, we performed two studies investigating human perception and presentation factors for estimating values in rose charts. Presentation factors included (1) chart size, (2) number of sectors, and (3) sector orientation. A comparison with bar charts connects our results to known research. Our results provide clear indications that value estimation relies on both cues: first area, then transitioning to radius from about 65% on. Thus, we provide a transfer function that maps a data value to a radius along the range of all tested values (in 5-95%), which significantly improves estimation errors.



(a) Rose Charts (Length Encoding)

(b) Rose Charts (Area Encoding)

(c) Bar charts (Length Encoding)

Figure 1: *Comparison between rose charts and bar charts.*

2. Related Work

The rose chart we are dealing with in this paper (Figure 1 (a)+(b)) is also called a circular bar chart, radial column chart, radial histograms [amC24], Coxcomb Chart, or Polar Area Chart. The most important historical example that uses proportional filling of circle sectors is the "Diagram of the Causes of Mortality in the Army in

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the East" by Florence Nightingale – part of a letter [Nig58] sent to Queen Victoria on October 11, 1858. Similar visualization designs vary the shape of the sectors; sometimes they are disjointed and shaped as bars or columns [Rib24]. Some of the sectors start right in the center (as with our version) or have a small inner circle [Rya16]. Others have large center areas, empty or used for additional information [Ori24]. A third variable was the existence (or nonexistence [SDG20]) of an outer ring expressing an outer maximum that frames the sectors.

Cleveland and McGill [CM84] (and Heer and Bostock [HB10]) showed that linear encodings outperform angle and area. This affects the reputation of pie charts, which use angle encoding and are estimated via area [Kos19a], or the arc length [SK16]. So far, the area is seemingly the most important cue. Pie charts are particularly suitable for part-to-whole comparisons [Kos19b].

Several studies investigate the estimation of bar charts. Diaz [DMPV18] found that boxes surrounding each bar have a positive effect. Talbot [TSA14] investigated distances between bars, alignment, and absolute value estimation. Xiong [XSB*21] showed that viewers are best at comparing spatially close and aligned bars.

3. Pilot Study

The pilot study provided a first glance at the distribution of errors when estimating values in a rose chart sector, especially regarding what conditions might affect these results. The first condition is the **number of sectors** because the number of sectors defines the sectors' size and shape. We hypothesize that area recognition is active for wide sectors, while length recognition is active for narrow sectors. We chose charts with **5** and **8 sectors** that also have different symmetrical characteristics to compare charts with multiple symmetry axes against charts with only one symmetry axis. Our second condition is the **sector orientation**. Is the value estimation in a horizontal or vertical sector different from a sector that has some other orientation? Bar chart studies like Diaz et al. [DMPV18], Cleveland and McGill [CM84], or Talbot et al. [TSA14] use vertically or horizontally oriented bars, and we have not found any study that investigates bars with other rotations.

The pilot study was conducted with **7 volunteers** (colleagues, computer scientists) having at least a master's degree. It was presented as a series of websites resembling the paper card approach of Cleveland and McGill [CM84], but showing a single rose chart from which a single sector's value had to be estimated and entered into a text field (see Figure 2). The estimated values (percentages) range **from 5 to 95** in steps of 5 (19 different values) and were mapped linearly to the radii of the rose charts, e.g., we used a length encoding. The number of test cases per participant was **247 test cases** ((5 + 8 sectors) × 19 values). The test cases were randomized within the number of sectors. Neither the same sector nor the same value appeared twice in a row. The order of the number of sectors remained the same for all participants because no learning effect across the number of sectors was expected. The actual test pages were complemented by three pages of introduction, a survey page, and finally, one page showing the average error and time for this test run. The test pages included a timer, starting with the first task to give temporal orientation and adding a bit of pressure to prevent spending too much time on a chart and trying to "calculate" the values. A progression bar served as an additional orientation. Because the study was conducted online, actual screen densities and pixel sizes are beyond our control. Therefore, we use a calibration setup that requires adjusting a bar on the screen to the length of the shorter side of a debit/credit card, to ensure the same size of the chart on all screens.

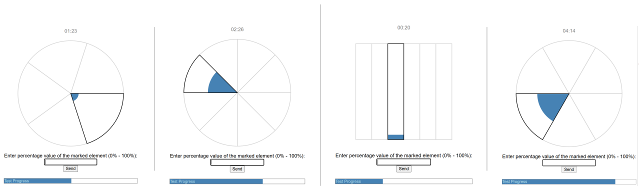
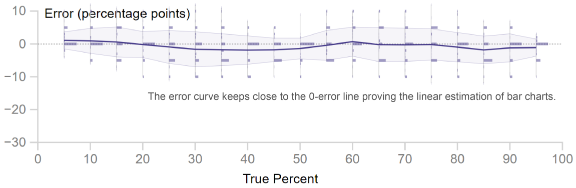


Figure 2: *Screens as seen by the participants: two sample pages of the pilot study (left, 5 sectors and 8 sectors) and two sample pages of the main study (6 bars and 6 sector circle).*

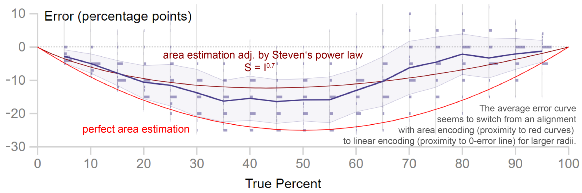
Several **findings** can be reported: **(1)** Even though the participants have not been instructed to round to **5 or 10 percent steps**, most of them did so anyway. This is in line with Talbot et al. [TSA14]. **(2)** Using the length encoding, the average error shows a tendency to underestimate the shown values (5 sectors, M=-8.10, SD=4.10) (8 sectors, M=-7.35, SD=2.90). The absolute error grows with growing values to its largest extent between 40% and 50% and then gets smaller again for larger values. This is interesting because Talbot [TSA14] found bar charts to get overrated for small values and underrated for large values. Rose charts do not seem to follow this rule. Using an area encoding, participants overestimated the values (5 sectors, M=9.21, SD=3.17) (8 sectors, M=10.20, SD=2.58). **(3)** A two-sided paired sample t-test between the 5-sector condition and the 8-sector condition did not reveal significant differences, $t(9)=-0.99$, $p=0.36$. Contrary to our expectations, the number of sectors does not significantly influence the estimability of rose charts – at least between 5 and 8 sectors and for our 7 test persons. **(4)** Additionally, a one-way ANOVA with repeated measures did not provide any evidence that the different orientations of the sectors affect the estimation (5-sector case, $F(4,24)=0.75$, $p=0.57$), (8-sector case, $F(7,42)=0.74$, $p=0.64$). The pilot study showed no significant influence of sector orientation or number of sectors (5-8) – this may be due to the low number of participants and should be treated with caution. However, it showed that the perceptual mechanism to estimate fill level in circle sectors works differently from that for bar charts.

4. Main study

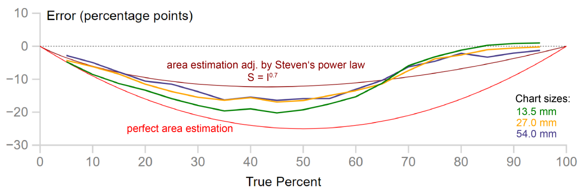
In the main study, we wanted to derive the shape of the error curve and compare the estimation errors of a rose chart to a comparable bar chart. Additionally, we are interested in the effect of the size of the chart on the estimation error. Rose charts are often used as glyphs, and as such, in smaller sizes. We wanted to determine the dependency of the estimation error on the **chart size**. Thus, we used diameters of **54.0 mm, 27.0 mm, 13.5 mm** (100%, 50%, and 25% of the shorter side of the regular debit card used for calibration). The largest size is typical for a single rose chart visualization, while the smallest size matches small glyph representations. As in



(a) Bar Chart (Size: 54.0 mm)



(b) Rose Chart (Size: 54.0 mm)



(c) Rose Charts (All sizes)

Figure 3: *Histograms, average, and standard deviation of the absolute estimation errors for rose and bar charts with 6 sectors assuming a linear radius encoding. The red lines show the error of perfect area estimators (dark red: taking Stevens' power law into account, light red: without compensation).*

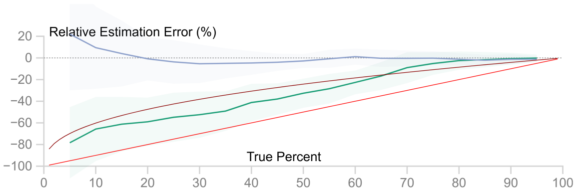


Figure 4: *Average and standard deviation of the relative estimation errors for rose charts (green) and bar charts (blue) with 6 sectors. Again, the red lines show the error of perfect area estimators (dark red: taking Stevens' power law into account, light red: without compensation).*

the pilot study, we used values from **5 to 95 in steps of 5**. We vary the chart type between **rose and bar charts**. In our design, both diagrams consist of **6 sectors** and make optimum use of the same space. This way, the height of the bar chart is slightly less than the diameter of the rose chart, but the effective length for estimation – because the rose charts use radius and not diameter to encode the value – is almost twice as large. In a small-multiples visualization, bar charts would need the extra space surrounding the chart to separate themselves from each other. The closed nature of the circular rose charts does not require any additional separation. In our within-subject study, the number of test cases per participant amounted to 114 test cases (3 sizes × 19 values × 2 chart types). The test cases within the chart type and the chart types were randomized. We chose to vary the sector in the presentation so that participants cannot use the former values as a direct reference.

We reused the interface of the pilot study, except for showing two examples for both chart types (0% and 100% to not prime the participants as to which encoding is used) and adding a pause screen after half-time to avoid fatigue, as some participants reported for the pilot study. As in the pilot study, we use a calibration setup that requires adjusting a bar on the screen to the length of the shorter side of a debit/credit card, to ensure the same size of the chart on all screens. We recruited **100 participants** (mean age of 34.06 (SD = 12.20), frequency of use of visualizations (0-3) 1.06 (SD = 0.96), 64% used rose charts before) from the crowd-sourcing platform Prolific. All participants reported having normal or corrected-to-normal eyesight and had at least a high school diploma. The participants were compensated with the recommended 9 GBP per hour, amounting to 2.25 GBP for the study.

Results: Figure 3 (a) and (b) show the absolute estimation errors per true percent for rose and bar charts, assuming that the true value for rose charts is a linear radius-based estimate. Each plot shows the average error as a blue line, the standard deviation as a light blue area, and histograms of the measured error per true percent regarding a length encoding. A length-based estimate would show a mean error curve along the x-axis, as seen in Figure 3 (a) for bar charts. As in Talbot et al. [TSA14], low values tend to be underrated by less than 3 percentage points. The error curve for rose charts shows much higher error rates, indicating that linear radius encoding does not align with human perception. We added two reference curves to the plot to determine whether the error pattern corresponds to estimations based primarily on area. The dark red curve represents the expected errors if participants perfectly estimated based on area according to Stevens' power law with an exponent of 0.7 [Ste57]. The light red curve reflects a pure area-based estimation without this correction. Notably, our blue **average error curve falls between these two references**. The references and the error curve show a similar shape for two-thirds of the diagram up to about 65%. The general underestimation of values from rose charts with radius coding could therefore exist because the area rather than the radius serves as a reference point for smaller values. After 65%, the slope increases, and starting with 70/75%, the error curve becomes almost linear. It seems that there is a shift in perception from area to length. Participants might have estimated the distance between the outer border of the sector and the start of the filled region for values above 75%.

The estimation error, especially between 40% and 50%, lies close to 15% for a length encoding. An area encoding with Stevens' power law applied would reduce the error to about 5%. Figure 1 exemplifies rose and bar charts for different values and illustrates the mismatch between the encoded true percent and the perceived ones when using length encoding. If we look at the relative estimation errors made per true percent for both chart types (see Figure 4), the large error when using length encoding in rose charts becomes obvious: on average, participants underestimated values below 20 by 60 to 80%! An area encoding corrected by Stevens' power law reduces the error to below 20% (distance between the blue aver-

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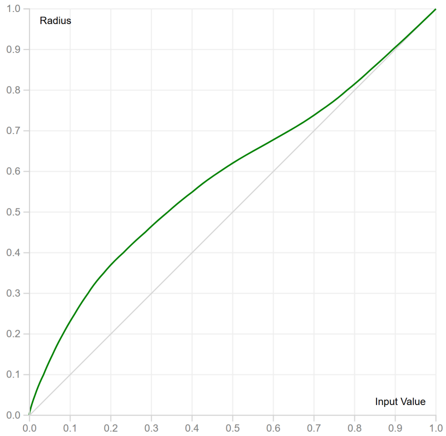

Figure 5: *The transfer function (green line) maps input values to fragments of the maximum radius for rose charts such that the resulting estimation error is minimized.*

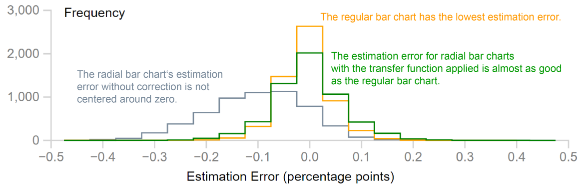

Figure 6: *Absolute error histograms of the estimation errors before (gray) and after (green) applying the transfer function. With the transfer function applied, the estimation error becomes close but is still worse than the bar chart's estimation error (orange).*

age and the dark red line). A bar chart only shows relative errors between 15% over- and 5% underestimation.

The influence of the chart size on the estimation error is evident in our data (see Figure 3 (c)). An ANOVA with repeated measures confirms that there are significant differences in the mean values of the sizes (rose charts, $F(2, 198)=31.4$, $p = 1.5E-12$; bar charts, $F(2, 198)=4.4$, $p=0.01$). T-tests between the individual sizes reveal that the mean error only increases significantly when reducing the size from 27.0 mm to 13.5 mm (rose charts, $t(99)=5.9$, $p=5E-08$; bar charts, $t(99)=2.9$, $p=0.005$). So it seems that a size of 27.0 mm is large enough on an average screen to fully assess the information from the plot, while a plot of 13.5 mm increases the estimation error considerably.

Error Compensation: Our comparison between rose and bar charts highlights the need for a compensation function to reduce estimation errors. While Stevens' power law for areas mitigates underestimation in radius-encoded charts (see especially Figure 4 (a)), it fails to capture the S-shaped curve. Instead, we model a piecewise linear filter function using 21 linear segments fitted via a sliding window approach (window size: 20%). Each point considers three to five linear values, weighted by their distance to the window center, ensuring a smooth curve. This method achieves an r^2 score of 0.96 (see Figure 5, green curve). The function's values are available as a CSV in the supplemental material. Figure 6 shows that the transformation reduces the average error to zero.

5. Discussion, Guidelines and Future Work

The two studies yielded several insights: (1) the number of sectors – at least between 5 and 8, and for our small sample size – does not have a significant influence on the estimation error, (2) the sector orientation – at least for 5 and 8 sectors and for our small sample size – does not have a significant influence on the estimation error, (3) the estimation error increases for chart sizes less than 27.0 mm, (4) the estimation of values from rose charts seems to be based on a mixture of area and length estimation, (5) the overall estimation error inside circle sectors using length encoding is surprisingly large. An average participant in the main study would underestimate an encoded 50% by about 15%, concluding that the chart must show only 35%! (6) An area encoding applying Stevens' power law already reduces the error significantly. (7) Our piece-wise transfer function reduces the average estimation error to zero over the entire range of values.

Regarding the size of the chart, we found that decreasing it below 27.0 mm hurt the estimation error. A follow-up study should determine the exact size at which the effect begins and how the error increases when further reducing the size. Also, we only studied the effect of 5, 6, and 8 sectors. Even though these did not show a significant difference, we would hypothesize that large numbers of sectors (>20) and very few (<4) would affect the estimations, because the visual primitives degenerate to either very thin bars or large, beveled pie slices. In our test, all sectors remained empty except for the chart's test sector. We intentionally did this to evaluate perception without distractors in this study. It is an obvious next step to add distractor sectors as conditions and evaluate their influence on the estimates.

Our results provide guidelines for the use of rose charts. The most important message is to use bar charts instead, whenever possible. Their linear length encoding makes for the best estimates. If you, however, need to use them – to match a certain aesthetic, to make the chart more memorable [BVB*13], to show patterns in a spatial embedding, or to depict a progression of time – be aware of the large estimation errors especially for small values when using a radius encoding and apply measures such as the following: (1) Implement a grid: grid lines have been shown to enhance the estimability of any plot type and will lead to considerable improvements here [BS11]. (2) Leave space in the center of the plot: the center of the plot produces the largest relative error; it is likely – however, not tested yet – that starting from a certain radius will reduce the estimation error for smaller values. For chart sizes above 27.0 mm, according to our study, area encoding adjusted by Stevens' power law for areas (exp=0.7) performs quite well. Our derived transfer function, shown in Figure 5, performs best for the investigated chart sizes, but could be fitted to specific radii to perform even better.

Acknowledgments

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