Comparison of Circle and Dodecagon Clock Designs for Visualizing 24-Hour Cyclical Data

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Abstract. Radial visualization is an important technique to depict serial periodic data. Circle clock design is intuitive to encode 24-hour cyclical data. However, the biggest limitation of the design is the accuracy of reading time points on circle. Dodecagon is another way to represent time series data. We empirically evaluated the effectiveness of circle and dodecagon clock design in perceiving specific points in time. A post-testing interview was also conducted to understand participants' strategies to read the times. Results show that dodecagon is more accurate than circle in terms of reading time points. Dodecagon was voted as a powerful approach to read the time points and circle was regarded as a better beautiful visualization method.

Keywords: Quantitative evaluation · Time series data · Radial designs

1 Introduction

Visualizing human mobility patterns has been a hot research topic with widespread applications in information visualization domain. Time series data are sets of values taken by a variable changing over time. Representing and analyzing the hourly trends in time series data is one of the most important research problems in this field. The primary role of time series visualization is typically to convey temporal information easily and accurately to users and help detect patterns and trends in the data. Circular layout has been widely used to encode time series and identify cyclic patterns in a day. Due to the traditional clock metaphor, it is intuitive to comprehend temporal information from a circular layout.

Circle design uses circular layout to encode temporal data with periodic structures in a compact way. It is particularly effective to model cyclic behaviors. Recently, many researchers have paid attention to the benefits and drawbacks of circle design, however, few work have presented effective strategies to improve circular diagrams with respect to answer times quickly and accurately. The accuracy of reading time points is the biggest limitation of circle clock design. Therefore, Guo et al. [1] proposed to use dodecagon instead of circle to visualize 24-hour cyclical data. 24 h are equally divided into 12 segments on the dodecagon. The segments enable users to recognize time values based on the positions of time points and lengths of lines.

This paper is mainly focused on the legibility of circle and dodecagon clock designs. Researchers conducted an experiment to compare the time and accuracy of

A. Marcus and W. Wang (Eds.): DUXU 2017, Part III, LNCS 10290, pp. 54–62, 2017.
DOI: 10.1007/978-3-319-58640-3_5

these two different designs on identifying time values in a circular layout. We then discuss the implications of the experimental results and contribute a discussion on metaphoric glyph designs that will help to further our understanding of visualization designs for serial periodic data.

2 Related Work

Radial visualization is used to describe any interactive system that lays out data with an elliptical style [2]. Radial visualization contains many forms such as pie charts, star plots, sociograms, and polar plots. Concentric Circles Technique was used to visualize periodic patterns [3]. A set of concentric circles were arranged to reflect quantitative histories. Some researchers presented a spiral data layout to map serial periodic data and each period filled one lap of the spiral [4]. The Event Tunnel system adopted a disconnected ring pattern to visualize event streams. Each unit of time was encoded as a ring and multiple rings were stacked as a cylindrical tunnel to represent sequences of events. Calendar based visualization has been proposed to identify patterns and trends in daily, weekly, or yearly data [5]. A fisheye calendar interface was designed to visualize more complex tasks with longer time periods [6].

Moreover, techniques such as Ringmaps [7], Spiral Graph [8], SpiraClock [9], and ClockMap [10] map time series in a 24-hour clock. The 24-hour clock metaphor is an intuitive approach to represent 24-hour cyclical data; however, it also has its disadvantages. A big limitation of the clock design is the accuracy of recognizing the time points and time intervals. The quality of data reading from radial visualization is determined by angles' reading and relevance accuracy. Pie chart is much better to estimate the proportions of the whole when providing at least five anchors – 0%, 25%, 50%, 75%, and 100% [11]. Making comparison of visual elements by angles and areas is less effective and accurate than by line lengths [12]. Furthermore, anchors usually provide natural references to facilitate the estimation of numerical values [13, 14]. As a result, tick marks, labels, axis lines and gridlines are usually added to facilitate value reading. These features maximize the data-ink ratio without changing the core meaning of a graph [15].

The goal of data visualization is to help users understand insights in the way of being graphical, readable and notable. The accuracy of reading quantitative information depends on visualization methods. The most effective parameter of perceptual tasks in visualization is position, then line length, angle, area, and volume [16]. Perceptual tasks require not only being more accurate but also being faster. Preattentive processing is regarded as one of the most common tests on the aspect of speed in perceptual level of visualization [11]. However, previous studies on preattentive processing do not necessarily apply to polygon shape recognitions.

Additionally, researchers have investigated different techniques to evaluate radial visualizations. Some researchers conducted a controlled experiment to compare the Radar chart with flower charts and concentric radial space filling circles for composite indicator visualization [17]. The circles method was inferior for trend identification and item comparison. Researchers found that Start Glyph and Clock Glyph were better than Line Glyph in terms of detecting a particular temporal location [18]. They also stated that the clock metaphor increased users' chronological orientation [18]. Participants argued that the clock metaphor may help them locate certain points in time on radial glyphs. Another work evaluated different data glyph designs based on a systematic review of research papers and indicated the usefulness of metaphoric glyph designs [19]. However, the past studies about metaphoric design were limited because of the type of metaphors and type of data.

3 Circle and Dodecagon Clock Designs

The daily routine is a continuous cycle of everyday lives. Everyone has to live on the 24-hour daily circle. The activity patterns vary at different times; however, it can show remarkable similarities across different people. One of the advantages of radial visualization is to simply gain insights in the relations and make comparisons through the circular layout. Many researches employ the clock metaphor to depict the time series data since it is tempting to use analogies to visualize the cyclical nature of daily time. A circular layout looks aesthetically appealing to visualize 24-hour cyclical data. 24-hour circle typically shows 24 h clockwise, with midnight at the top, 6:00 o'clock at the right, 12:00 o'clock at the bottom, and 18:00 o'clock at the left (Fig. 1 left). The time point is encoded as an orange dot located on the circle (Fig. 1 left). We can estimate the time on the circle is between 2 am and 4 am in Fig. 1.

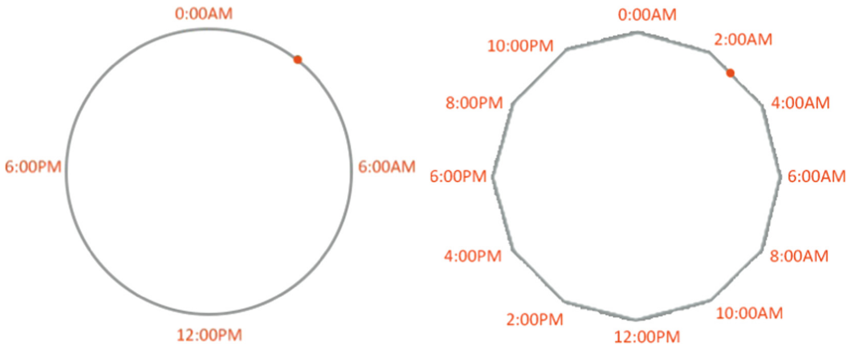


Fig. 1. Left: 24-hour circle clock design. Right: 24-hour dodecagon clock design. The time data is located on the two shapes as an orange dot. (Color figure online)

However, 24-hour circle clock design may not be the most appropriate and accurate way to perceive specific points in time. It is hard to recognize the position of the data point on the circle. Due to the limitation of 24-hour circle, Guo et al. [1] suggested to use dodecagon to represent a 24-hour clock. The 24 h are equally divided into 12 segments on the dodecagon. Each segment represents 2 h (Fig. 1 right). It enables audiences to estimate time based on positions and lengths of lines. The time point is also represented as an orange dot on the dodecagon. We can easily tell it is about 2:30 am to 3 am.

According to Tufte's design principles [15], visualization design should reduce non-data ink, avoid redundancy, and reduce ambiguity. Clock metaphor is closely related to serial periodic data. Nevertheless, few studies have been conducted to compare the effectiveness of metaphoric data glyph designs and generate design suggestions for clock metaphor approaches. As a result, we conducted an experiment to compare the time and accuracy of circle and dodecagon clock designs.

4 Experiment

4.1 Objectives and Research Questions

The goal of this experiment is to compare the visualization effectiveness of circle and dodecagon on identifying time values with 24-hour clock metaphor. The objective is to understand if dodecagon outperforms circle in regards to fewer errors and less completion time. The hypothesis is as follows:

H_1: With respect to 24-hour clock metaphor graphs, dodecagon would result in more accurate time reading than circle.

H_2: With respect to 24-hour clock metaphor graphs, dodecagon would result in faster time reading than circle.

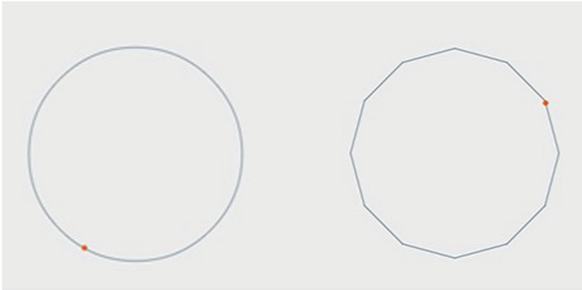
4.2 Design and Tasks

We set up an experiment to measure completion time and errors of identifying time values with dodecagon or circle. Subjects were required to complete the task shown in Fig. 2.

The task used a one-way ANOVA to compare the legibility of circle and dodecagon. The within-subjects design required participants to do 24 tests in the two different conditions – circle and dodecagon. We ran a series of two independent questions 12 times. All the time points for each question were generated randomly. Participants were required to read the time points as accurately and quickly as possible. Figure 2a shows an example of the first round of tasks. We used red color to encode the time. In particular, we asked the users to answer the following question for the presented graph:

- Please identify the time of the red dot and pick the related hours and minutes on the next page.

The survey notified subjects of how many questions were left after each round. We recorded the user's answers, the correctness of the answers, and the completion time. There was no time limit for answering each question. Participants were instructed to glance at the diagram, click on the next button, and choose the correct answer from a drop down list of hours (0–23) and a drop down list of minutes (0–59) in the next page. Both the perceived hours and minutes were logged. The reading time was recorded after the next button was clicked. Participants were not allowed to go back to review the graph or modify the submitted result.



(a)

(b)

Fig. 2. Screenshots of the task. (a) Task: identify the time of the red dot on the dodecagon or the circle; (b) Images for the post-testing interview. (Color figure online)

4.3 Post-testing Interview

At the end of the survey, we conducted a short interview with participants. We showed participants two images and asked them to pick which one they prefer, circle or dodecagon, in terms of aesthetic and legibility (Fig. 2b). Their strategies to read the times and comments to the designs were documented.

4.4 Participants and Instruments

We recruited participants who were not aware of the experimenter's hypothesis in order to minimize the possibility of demand characteristics. There were 55 persons (39 males, 16 females) who participated voluntarily with age between 15 and 45 years. Except for one participant, all were from our university and had a broad range of academic backgrounds – 23 Computer Graphics Technology graduate students, 13 undergraduate Engineering students, five Art and Design graduate students, and other undergraduate and graduate students from Building Construction Management, Chemistry, Aviation Technology, Audiology, and Linguistics.

The study was conducted in a laboratory environment where researchers were able to provide detailed instructions. Participants used a mouse to perform the tasks on a computer with 24 inch LED monitor and 1600 * 900 pixel resolution. The average duration of the survey was about 15 min per participant.

4.5 Results

We eliminated data of seven participants who withdrew from studies before they finished it. We ended up with 48 remaining participants (13 females, 35 males) with a mix of different backgrounds. The total trails for the task were 1152. The overall average error across variations was 26.20 min with the standard error 1.22 min for the circle, and 16.13 min with the standard error 1.22 min for the dodecagon. ANOVA showed that there was a significant effect of the shape on errors ($F(1, 1151) = 43.03$; $p < .0001$). A noticeable mean difference was visible across the two shapes with $p < .0001$. A closer pairwise comparisons showed that dodecagon was significantly more accurate than circle ($p < .0001$). Therefore, we can conclude that H1 is accepted and there was a significant mean difference between circle and dodecagon in respect of time reading errors. There was a high probability that dodecagon was more accurate for reading compared with circle.

The results also show that dodecagon may perform slightly better with the average completion time of 12.68 s and the standard deviation of 13.45 s. The mean completion time for circle is 14.22 s and the standard deviation is 17.62 s. However, ANOVA didn't show that there was a significant effect of the completion time on errors ($F(1, 1151) = 1.04$; $p = .3730$). The F Value and p-value, respectively, tested the null hypothesis that the completion time did not explain a significant proportion of the shape variance. Therefore, we can conclude that there was not a significant mean difference between circle and dodecagon with respect to reading speed. There was a comparatively small probability that dodecagon would result in faster time reading than circle.

The interview result showed that 66% of the participants preferred circle in terms of aesthetics, while 34% chose dodecagon. 82% of the participants chose dodecagon in terms of legibility, while 18% preferred circle. Thus, dodecagon was voted as a powerful approach to read the time points and circle was regarded as a better beautiful visualization method.

5 Discussion

5.1 Participant Feedback

After the survey, participants provided comments on their reading strategy. Most of them identified the time points based on adding up intervals or counting lines on the dodecagon. At first they counted how many sides the figure had and related the vertices to the hour markings on the clock to help them get a reference. Thus, they were able to use percentage of the line in between the two vertices as the percentage of minutes have transpired in that hour.

As we can see, it was easier to tell what time value fell where on the polygons because people can use each point to signify the hour. However, it was very interesting to notice that many participants always defaulted to the thinking that the glyph started in AM. They used the bottom of the glyph as 6:00 o'clock and the far left was 9:00 o'clock and the far right was 3:00 o'clock. Although we told the participants that one circle or one dodecagon represented 24-hour a day, they still mentally marked 12 and 6 as being the top and bottom vertices instead of using 0 and 12. Here we borrowed a term called anchoring from psychology to describe people's intuitive estimation [20]. Anchoring refers to the cognitive bias that influence the way human beings intuitively make decisions. Human have a tendency to use the initial piece of information to interpret information. 12-hour time and clock are commonly used in daily life. Since people rely heavily on the initial time information stored in their brain, it would be difficult for them to convert it into 24-hour format.

Except for the time used in the military and hospital, the 12-hour clock rule is much more common in the U.S. and Canada. The infoVis researches using 12-hour clock consider that it matches people's mental model of analog clock and makes it easier to decode time with the spatial layout. But the 12-hour approach needs to draw two circles on the clock to represent one day, and confusion will take place. Some researches insist on the 24-hour approach since there is no need to specify the time is AM or PM. Furthermore, this approach can reduce non-data ink, avoid redundancy, and reduce ambiguity. The pros and cons of both approaches point to the need for further research to compare their effectiveness.

5.2 Design Suggestions for Visualizing 24-Hour Cyclical Data

We provided two design options and conducted an empirical study to evaluate their performances. Our study showed that dodecagon is more accurate than circle in terms of reading time points on the shapes. Participants were significantly more confident with the dodecagon clock designs. Our feedback also shows that circle is more appealing to audiences but its legibility is low. Although 12-hour clock metaphor matches human's mental model of analog clock, we still suggest to use 24-hour clock because 12-hour clock increases the cognitive load of the design by adding another circle in the graph. All in all, using dodecagon to represent 24-hour cyclical data is the most appropriate and accurate way to visualize 24-hour cyclical data.

5.3 Limitations and Challenges

In the visual context, clustered shapes are very common to describe the distribution of the data. By dividing data into groups, humans are capable to identify daily routines or abnormal events in serial periodical data. The first limitation of the study is that it doesn't consider the other design parameters such as clustered glyphs, glyph sizes, widths, and line spacing. In order to inform more completed visualization design, we need to evaluate tasks including selecting similar time on clustered diagrams, reading time points on diagrams with different sizes, choosing preferable diagrams with different line widths and line spacing, and picking center points of circle and dodecagon.

The second limitation is related to bias pattern in proportion judgment. Spence [21] found there was a four-cycle pattern that produced a pattern of overestimation and underestimation of proposition with pie charts and stacked bar graphs. It stated that with tick marks at .25 intervals, a bias cycle occurred around different proportions. People have the tendency to overestimate proportions less than .25 as well as those between .50 and .75. On the contrary, proportions between .25 and .50 as well as greater than .75 were intent to be underestimated. In our test, we didn't consider these bias patterns. Either the quadrant angles or the points on the edges of the polygon provided reference for participants and helped them perceive the time more accurately. So there may be fewer errors around the 0:00, 6:00, 12:00 and 18:00 clock position. If the position of the time point was closer to the tick mark position, the error may become very small.

6 Conclusion

This paper presented two visual designs to support the 24-hour cyclical data visualization. We compared the effectiveness of the two different shapes – circle and dodecagon through the empirical study. The results of the study indicate that dodecagon outweighs circle with respect to accuracy and speed. Although we were able to demonstrate the effectives of the two shapes on reading time points, we found that people used different strategies to comprehend the information. We are interested in how different strategies would influence their performance. People may use different strategies to read time points and time intervals, thus it is necessary to measure the effectiveness of reading time intervals on circles and dodecagons. Our future study will focus on testing people's performance on identifying time intervals and then compare the results with our current work. In this way, we are able to provide more accurate, faster, and appealing visualization to improve the radial time series visualization.

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