

Intercept Graph: An Interactive Radial Visualization for Comparison of State Changes

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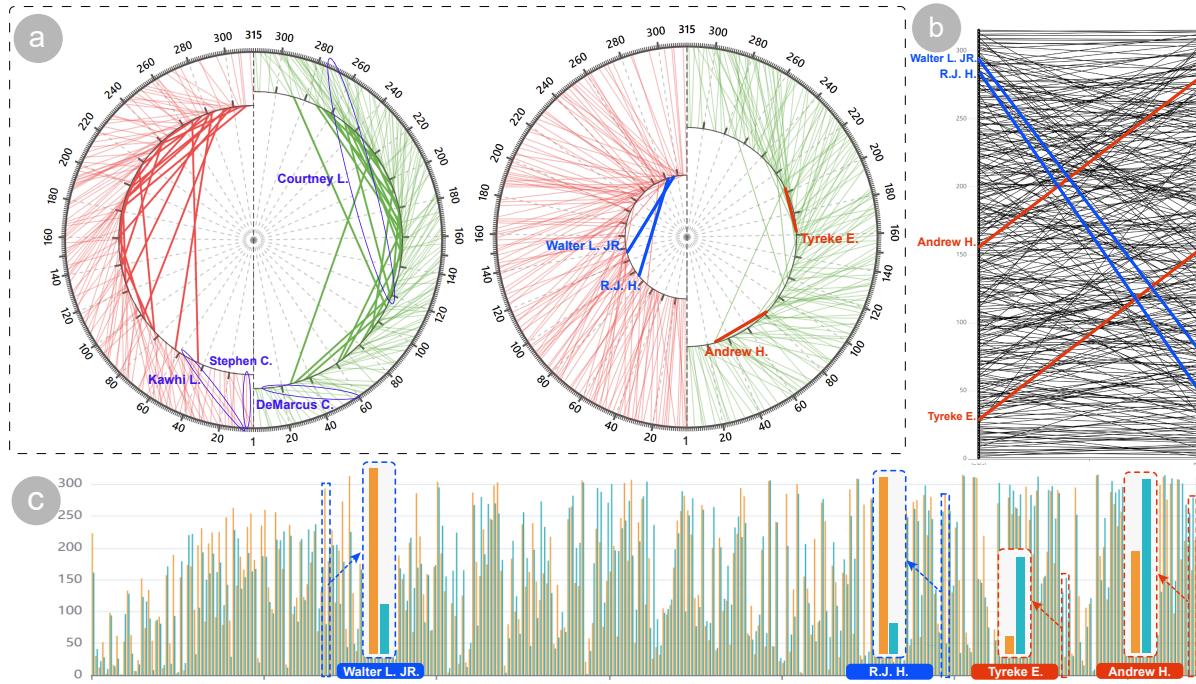


Figure 1: Comparison of a *Intercept Graph*(a) and other existing visualization tools for state change comparison, i.e. slope graphs (b) and grouped bar charts (c), representing the Points per Games (PPG) changes of 321 players across two seasons from a basketball statistics. The changes of PPG in two seasons before and after are indicated by intercepted line segment, line slopes and clustered bars' differences of (a), (b) and (c), respectively. (a)(left) accentuates players with top 30 PPG changes of the rising (left semi-circle, red) and dropping (right semi-circle, green) trends.

ABSTRACT

State change comparison of multiple data items is often necessary in multiple application domains, such as medical science, financial engineering, sociology, biological science, etc. Slope graphs and grouped bar charts have been widely used to show a “before-and-after” story of different data states and indicate their changes. However, they visualize state changes as either slope or difference of bars, which has been proved less effective for quantitative comparison. Also, both visual designs suffer from visual clutter issues with an increasing number of data items. In this paper, we propose *Intercept Graph*, a novel visual design to facilitate effective interactive comparison of state changes. Specifically, a radial design is proposed to visualize the starting and ending states of each data item and the line segment length explicitly encodes the “state change”. By interactively adjusting the radius of the inner circular axis, *Intercept Graph* can smoothly filter the large state changes and

magnify the difference between similar state changes, mitigating the visual clutter issues and enhancing the effective comparison of state changes. We conducted a case study through comparing *Intercept Graph* with slope graphs and grouped bar charts on real datasets to demonstrate the effectiveness of *Intercept Graph*.

Index Terms: Visual representation design—Interaction—State change comparison—Radial visualization;

1 INTRODUCTION

State change comparison is one of the most commonly used methods for quantitative analysis [17]. People need to compare the state changes of multiple data items and explore their initial and final states. For example, NBA league will compare all players’ progress and give the NBA Most Improved Player award to the player with the biggest progress compared to the regular season. Also, daily new case numbers of coronavirus are used to evaluate the latest regional disease situation worldwide. Visualization has been proved a powerful tool for data exploration. However, very few visualizations have been specifically designed for effectively visualizing and comparing multiple state changes.

According to our survey, slope graphs and grouped bar charts are often used to show and compare state changes due to their simplicity and accurate representation of the contexts (i.e. initial and final

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states). Slope graph (**Figure 2a**) is a line graph that connects the initial and final states of each data item along two vertical axes, and the state changes are directly encoded by the line slopes. Meanwhile, grouped bar charts (**Figure 2c**) often use two adjacent bars to display the initial and final states of a data item, and multiple data items are shown along the x-axis. The state changes are implicitly encoded by the height differences within the grouped bars.

Both slope graphs and grouped bar charts suffer from two major issues in supporting state change comparison. Their first major limitation comes from the effectiveness of their visual encodings for state changes. Slope graphs use *slope* to indicate state changes. However, slope has been proven as a less accurate visual encoding channel than other encoding channels (e.g., *length*) [5, 6, 7]. Grouped bar charts display state changes through the height differences of adjacent bars, but prior perception studies [4] have shown that people perform badly on the comparison of height differences of grouped bars. The second major limitation of slope graphs and grouped bar charts is the visual clutter issue. With the increase of the visualized data items, slope graphs will suffer from severe visual clutters, as shown in Figure 1b. For grouped bar charts, the bars will become thin and even difficult to recognize (Figure 1c), and it becomes difficult to compare the height difference [13], especially such a comparison is distracted by various short and tall bars [21]. Thus, when the amount of data items exceeds the scalability of slope graphs and grouped bar charts, people are even forced to adopt data tables alternatively to represent the dataset [23].

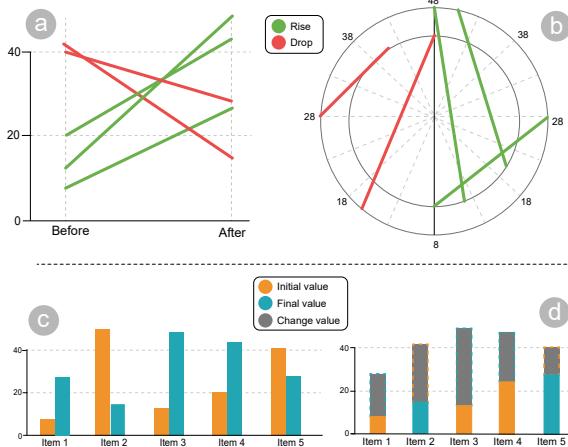


Figure 2: Existing visual designs and *Intercept Graph* encoding the same data. (a) Slope graph (b) *Intercept Graph* (c) Grouped bar chart (d) Stacked bar chart

To address the above two major issues, we propose *Intercept Graph* (**Figure 2b**), a novel radial visual design to facilitate effective comparison of state changes across multiple data items. Specifically, it allows a context-aware change comparison with the length of the line segments, which is proved as a more effective channel over slopes and bar differences. Also, with an increasing number of data items, *Intercept Graph* facilitates the change representation to support quick and smooth accentuation of large state changes and effective comparison among relatively similar state changes via introducing intuitive interactions.

We have released our approach as a publicly-available JavaScript library called *interceptgraph*¹, which enables a quick comparison of multiple state changes.

The major contributions can be summarized as follows:

- We propose *Intercept Graph*, a novel radial visualization tool for effective visual comparison of multiple state changes, which leverages the line segment length to directly encode the state changes, and intrinsically enables smooth interactions for filtering large state changes of user interest and amplifying the difference of similar state changes for an accurate comparison.
- We conducted case studies and compared *Intercept Graph* with slope graphs and grouped bar charts to evaluate its performance. The results demonstrate the usefulness and effectiveness of *Intercept Graph*.

2 PRELIMINARY SURVEY

There are few prior studies specifically investigating the visualization of state changes. Thus, to identify what visualizations have been applied to visualizing state changes, we conducted a preliminary survey to determine the mostly used visualization types for statistical change comparison. Following the methodology used by Segel and Heer [20], we first gathered figures from existing research papers that need to compare multiple state changes. We used the permutation of “state”, “change”, “comparison” as search keywords and manually harvested 100 top query results from Google Scholar. Since each study may include multiple figures for state change comparison, we further split them into 156 individual figure units. We then categorized all figure units into the five main groups (Table 1) introduced by Borkin et al. [2]. Note that the *Heatmap* category is designed to visualize changes with regard to spatial information such as the physical position, which is beyond the scope of our study and thus excluded from our survey.

	Category	Percentage
Bar	Grouped Bar Chart	44.9%
	Stacked Bar Chart	0.6%
Line	Slope Graph	28.2%
Circle	Pie Chart	3.8%
	Donut Chart	0.6%
Grid & Matrix	Heatmap	19.9%
Points	Scatter Plot	1.9%

Table 1: Categories of figure units and respective percentages collected from related research papers.

3 RELATED WORK

The related work of this paper can be categorized into two groups: state change visualization and radial visual design.

3.1 State Change Visualization

According to the preliminary survey shown in Table 1, we finally decide to target grouped bar charts and slope graphs due to their dominance in our harvested data set.

Slope graph [22] (Figure 2a) is an appropriate visual design when the nature of the task is to compare state changes across items based on comparing their line slope in time. A positive value of the slope implies that the dependent variable increases, while a negative value implies that the variable decreases. Grouped bar chart [1] (Figure 2c) is another approach to display state changes with the context of initial and final values, which encodes the initial and final values by respective categorical bars within each group. However, distractors between two target bar groups inevitably affect graphical perception when the amount of items exceeds its scalability [13, 21], grouped bar chart is the most common method to show state changes.

¹<https://www.npmjs.com/package/interceptgraph>

Stacked bar chart [10] (Figure 2d) is the most straightforward solution when we previously interviewed domain experts, which indicates change counts by the stacked sub-bars on lower sub-bars denoting a context state. However, if the data set includes data items of both rise and drop trends, the representation may suffer from visual complexity with an increasing number of items, which would significantly affect the human perception. Also, viewers can not determine relative bar height accurately on such unaligned bar chart variants [7]. As shown in Table 1, researchers rarely utilize this visualization type to compare state changes.

In this paper, the state changes are encoded by the *lengths* of different line segments, which is more accurate than *height difference* (for grouped bar charts) and *slopes* (for slope graphs) [5, 6, 7]. Also, intuitive interactions are enabled in *Intercept Graph* to support a comparison of state changes with better graphical perception.

3.2 Radial Visual Design

Visual representations of data that are based on circular shapes are referred to as radial visualizations [3]. Draper et al. [11] provided a comprehensive survey on radial visualization and categorize it into three visual themes: *Polar Plot*, *Space Filling* and *Ring Based*. The earliest use of a radial display in statistical graphics was the pie chart, which was proposed in William Playfair's 1801 treatise, the Statistical Breviary [19]. After that, radial visualization is becoming an increasingly pervasive metaphor in information visualization. Radviz [14] is a typical radial visualization-based approach to cluster multidimensional data. Hacialiefendioğlu et al. [16] developed a radial technique that allows elaborate visualization of the interplay between different violence types and subgroups. Additionally, prior studies further discussed the strengths and weaknesses of radial visualization through various methodologies [9, 15].

According to the taxonomy presented by Draper et al. [11], *Intercept Graph* belongs to the subtype *Connected Ring Pattern* under *Ring Based*. Accordingly, *Intercept Graph* preserves the advantages of radial visualization and further extends static radial methods via flexible interactions, making it available to compare items more accurately and effectively.

4 VISUAL DESIGN

We describe the composition of *Intercept Graph*, the approach of adjusting the radius of the inner circular axis, and the user interaction.

4.1 Visualising an Intercept Graph

Intercept Graph uses line segments to facilitate the comparison of state changes across multiple data items. The inner and outer circular axes are used to locate “initial” and “final” states respectively. Note that *Intercept Graph* is not an intact dual-circle design, since the left and right semi-circular axis are separated apart intrinsically, which are used to visualize data items with drop and rise trends of state values respectively.

Line segments (e.g., *Line AB*, *Line CD*, *Line EF* in Figure 3a) are a set of lines generally drawn from the inner circular axis to the outer circular axis, which are used to implicitly encode the change quantity of each item. The central angle between radii representing initial and final values is proportional to the state changes as the scale of both inner and outer circular axes are linearly distributed. For example, suppose that there are two data items. One data item changes from 33 to 35 and the other from 37 to 40. Then the ratio of the central angles of *Intercept Graph* is 3:2 as shown in the angles α and β subtended to line segments *AB* and *CD* in Figure 3a. Also, following the Laws of Cosines, the line segment *c* is determined as follows in terms of θ :

$$c = \sqrt{r^2 + R^2 - 2 \cdot r \cdot R \cdot \cos \theta} \quad (1)$$

where constants r, R denote the radii of the inner and outer circular axis respectively (as shown in the line segment *EF* in Figure 3a).

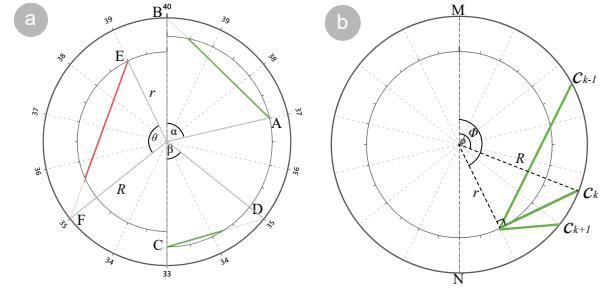


Figure 3: (a) An example showing that state changes are linearly encoded by central angles. (b) Analytic geometry diagram of *Intercept Graph* for the calculation of the radius of inner circular axis.

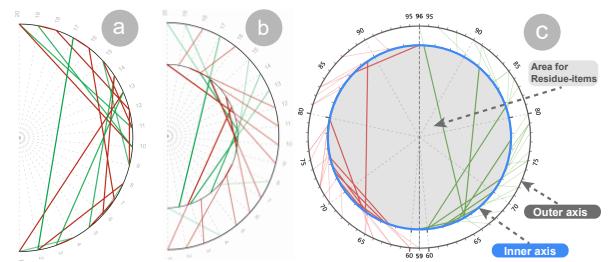


Figure 4: Alternative designs of *Intercept Graph*. (a) A draft with lines in the same semi-circular axis. (b) Extending (a) by introducing the inner circular axis for item filtering. (c) The final visual design.

$\theta \in [0, \pi]$ denotes the central angle subtended to the line segment. Equation 1 is monotonic increasing in terms of θ , which indicates that the central angle of *Intercept Graph* is correlated positively with the line segment length. So, according to the two conclusions illustrated above, the line segment length is positively correlated with the change quantity.

Axis range is determined by the minimum and maximum of the “initial” and “final” states of all the data items. With such a setting, *Intercept Graph* can have more space to highlight the state changes, facilitating an easy comparison of different state changes. As shown in Figure 4c, both the left and right parts of *Intercept Graph* have a fixed radius of outer circular axis and adjustable radius for the inner circular axis.

Residue-items are the remaining data items indicated by the line segments who intersect with the inner circular axis, as shown by the line segments with a bold portion in Figure 4c. The set of *residue-items* varies according to the adjustment of the radius of the inner circular axis, which serves as a filter which keeps only the items with a relatively large change. More specifically, the smaller the inner circular axis, the fewer *residue-items*. Otherwise, more data items with relatively small state changes will also be kept.

Alternative designs: Before we come up with the current design, we also considered several alternative designs (Figures 4a and b). Figure 4a can visualize the initial and final states of multiple data items, but they cannot support interactively filter data items with a large change. Figure 4b enables interactive filtering of *residue-items*, but still suffers from serious visual clutter. *Intercept Graph* is preferred, as it mitigates the visual clutter by plotting increasing and decreasing data items in the left and right circular axes, respectively.

4.2 Radius of the Inner Circular Axis

With the decrease of radius of the inner circular axis, all the data items with a smaller state change will be excluded from the residue items, i.e., *the state changes of all the residue-items are always larger than those excluded from the residue-items*. Figure 3b provides an intuitive illustration for this. As introduced in Section 4.1, the line segment length is positively correlated with the change quantity. Suppose we decrease the inner circular axis outward until it is tangent to *Line* c_k , which corresponds to the data item with k -th largest state changes. Then, *Line* c_{k-1} (representing the $k-1$ largest state changes) should always be included in the *residue-items*, while *Line* c_{k+1} (representing the $k+1$ largest state changes) is already excluded from the *residue-items*.

Given the above properties of the radius of the inner circular axis, users can interactively adjust the radius of the inner circular axis to focus on the data items with higher state changes. Also, we provide an automated way to help users quickly filter the data items with top- k state changes by automatically determining the corresponding radius of inner axis. As shown in Figure 3b, the corresponding radius of inner circular axis r can be calculated as follows:

$$r = R \cdot \cos(|\Phi - \phi|) \quad (2)$$

where $\Phi, \phi \in [0, 2\pi]$ denote the angles between the vertical separating line *MN* and the corresponding radii indicating the initial and final states of the data item with the k -th largest state change.

4.3 User Interaction

The user interaction extends *Intercept Graph* from static radial visualization. Specifically, two features called *large change accentuation* and *close change magnification* are proposed to supports more advanced features over the basic nature plotting change counts.

Large change accentuation allows quick filtering for the data items with large state changes of user interests. For example, through shrinking the radius of the inner circular axis, items with larger change counts would be more likely to be filtered (the flow is shown from Figure 4a to Figure 4b). Otherwise, all data items will turn into *residue-items* when the inner circular axis radius is equivalent to that of the outer circular axis. This feature performs well with an increasing number of data items.

Close change magnification enhances the human graphical perception of state change comparison through amplifying the difference of similar change quantities interactively (as shown in pairwise items highlighted in dark blue and crimson in Figure 1). Through shrinking the inner circular axis inward, the ratio of pairwise line segments will be magnified, which makes the comparison of relative state changes more effective.

5 CASE STUDIES

We conduct a case study on a basketball dataset to demonstrate the effectiveness of our proposed visual design. It contains 321 NBA player statistics, who are active players in both Season 2018 and 2019. We adopt the application as evaluating the progress of players is of great importance in the league, which is attributed to the foundation of the annual award Most Improved Player [18]. Following the methodology proposed by Dumitrescu et al. [12], we use a rank-based statistical category Points per Game (abbreviated as PPG) instead of raw data to address the discrepancy between players' performance and the highly-aggregated PPG records.

The preceding conventional designs, such as slope graph (Figure 1b), shows a PPG trend story by connecting two PPG states of Season 2018 and 2019, while another target design grouped bar charts (Figure 1c) plots items with 321 clustered bars. Apparently, both designs have limitations to visualize PPG changes. First, they encode changes by ineffective visual channels. For slope graphs (Figure 1b), line slopes across different players are difficult to be compared, especially there are distractors between two target lines. Also, as shown

in the detailed view of Figure 1c, bar height differences indicating PPG changes can not be perceived effectively. Furthermore, both designs are beyond their respective visual scalability to plot over 300 items. Specifically, for grouped bar charts, the perception suffers from the visual clutter in terms of the narrow width of bars and a variety of distractor bars. For slope graphs, serious line overlapping makes it hard to distinguish different lines and compare line slopes.

On the contrary, the proposed visual design *Intercept Graph* improves state comparisons in terms of better graphical perceptions. Figure 1a-left is used to visualize the top 30 players of rise and drop PPG changes by setting the *residue-item* number to 30 interactively. It is clear that the 30 *residue-items* for both rise and drop trends are arranged sparsely within the inner circular axes, which mitigates visual clutter issues significantly. If, instead, the user is interested in sets of top 10 candidates of MIP selection, simply setting the *residue-item* number to 10 will fulfill the needs (Figure 1a-right). Also, based on the length mapping of state changes, it is apparent to recognize that Kawhi Leonard (Line *Kawhi L.*) has a larger PPG progress than Stephen Curry (Line *Stephen C.*), both of which are plotted as red line segments due to the decrease of the rank values (e.g., from the third to the first), which actually indicates an improvement of their PPGs. Also, the PPG of Courtney Lee (Line *Courtney L.*) drops much more than that of DeMarcus Cousins (Line *DeMarcus C.*) due to the longer line segment length.

More interesting findings can be revealed by *Intercept Graph*. Here, we introduce a statistical measure *percentage difference*, according to a prior study [8], to reflect differences of two lengths of intercepted line segments. As shown in Figure 1b and Figure 1c, Line *Walter L. JR.* and Line *R.J. H.* (highlighted in dark blue annotations) have a percentage difference of slopes and bar height differences of 8.9% (213 and 234 places risen respectively) due to the linear visual mapping. However, our approach (Figure 1a-right) magnifies the length ratio of intercepted line segments to 18.3% (100.9 pixels to 123.4 pixels) through image software measurement. Another pair of target players *Andrew H.* and *Tyreke E.* for drop trend of PPG ranking (highlighted in crimson annotations) have the percentage differences of 8.1% (114 and 124 places dropped) and 19.2% (54.8 pixels to 67.8 pixels) for two preceding designs and our *Intercept Graph* respectively. It is clear that both results magnify the original linear mapping over two times, which makes the original linear mapping apparent enough to make judgments.

6 CONCLUSION

In this paper, we present a novel visual design *Intercept Graph* for context-aware comparison of state changes. Instead of focusing on visualizing the exact change quantities, *Intercept Graph* is mainly designed for facilitating the *comparison* of state changes across multiple data items via more effective interaction. We compared *Intercept Graph* with widely-used established tools (i.e., slope graphs and grouped bar charts). A case study on a two-season basketball dataset shows that our design can quickly filter large state changes and amplify the difference of similar state changes for an accurate comparison through smooth interactions. In future work, we plan to conduct more case studies and user studies on real datasets to further evaluate the effectiveness of *Intercept Graph*. Also, it would be interesting to explore how to *automatically* determine the optimal default inner circular radius for more efficient comparison of state changes.

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