

On the truthfulness of petal graphs for visualisation of data

Frode Eika Sandnes

Faculty of Technology, Art and Design
Oslo and Akershus University College of Applied Sciences

Abstract

A petal graph is an aesthetically attractive and applauded tool for visualising parameter sets. For instance, petal graphs are often used by Norwegian policy makers and decision makers in higher education as the Ministry of Education and Research relies on petal graphs in their reports. This study argues that petal graphs are prone to misinterpretation. It is challenging to interpret a petal graph in general, it is hard to compare two or more petal graphs and this study demonstrates that the physical characteristics of petal graphs can be incorrect in terms of the parameters on display. This study concludes that the use of petal graphs should be abolished and that other visualisation techniques to be used instead. Several alternatives are suggested.

1 Introduction

Radial visualisations are popular, but the choice of such visualisations are often based on intuition rather than scientific arguments [4]. The literature on the effectiveness on radial visualisation techniques is limited [1] and has mostly focused on a limited set of specialised set of visualisation techniques — most of which are surveyed by Draper et al. [6]. Other visualisation techniques such as the petal plot remain unexplored and are thus the focus of this study. A petal graph is a type of radial graph which exploits a flower metaphor where groups of data are clustered into petals. For example, a dataset with four classes of data might be organised into four differently coloured petals. Each petal is constructed from parameters represented by radial lines. The end points of these lines are connected making up the petal area (see Figure 1).

A petal graph can be classified as a type of radar graph, also known as a star graph. Radar graphs are radial line plots of parameter sets that are popular for eye-catching presentations, but criticised for being hard to understand and providing little or no useful information. Polar plots are also a type of radar graphs, but these usually represent data in some linear relationship, for instance measurements as a function of angle or time. A polar plot could for instance represent the sensitivity of an omnidirectional microphone, or the load of a server during 24-hour cycles.

By inspecting a petal graph one easily notice individual parameters that stand out as large, strong areas and weak areas. Strong areas are represented by large petals and weak areas become small petals.

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Figure 1: A petal graph (blomst) representing institutional parameters for HiOA (Oslo and Akershus University College of Applied Sciences) from Database for Statistics on Higher Education.

Since 2009 the Ministry of Education and Research has published annual data in the form of interactive petal graphs on the website of the national Database for Statistics on Higher Education (DBH)¹. One example of such a petal graph is shown in Figure 1. These graphs are commonly used by senior administration staff and leaders in the Norwegian higher education sector. The petal graphs are used to visualise snapshots of the state of institutions such as education quality, research performance, internationalisation, regional contact, etc, and are intended to easily allow institutions to compare and benchmark their performance with other institutions. The Ministry of Education and Research is responsible for the Norwegian education system and their data and reports therefore carry much weight, are assumed to be of high quality and are trusted. Their petal graphs frequently appear in boardroom PowerPoint-presentation and written reports.

By viewing the petal graph in Figure 1 it is obvious that the institution-size petal is large and the regional contact petal is small, the research petal is quite small, the internationalisation petal and education petals are medium sized. In other words, the overall impression conveyed by the graph is a large institution with little regional contact. Apart from this impression the graph does not really say much else, besides the fact that the viewer can inspect the individual parameters.

Making comparisons is a key activity when viewers analyse charts. It is relatively easy to compare neighbouring objects, but it can be hard to compare the magnitude of

¹http://dbh.nsd.uib.no/styringsdata/velg_bloomst.action

two non-neighbouring parameters that are further apart — especially in radial graphs. Comparison is also more difficult when comparing parameters across two or more charts. The eyes have to move back and forth between the various plots and this process may lead to incorrect readings and misinterpretations. Another issue is the detection of change for time-varying diagrams. However, time-varying diagrams are beyond the scope of this study.

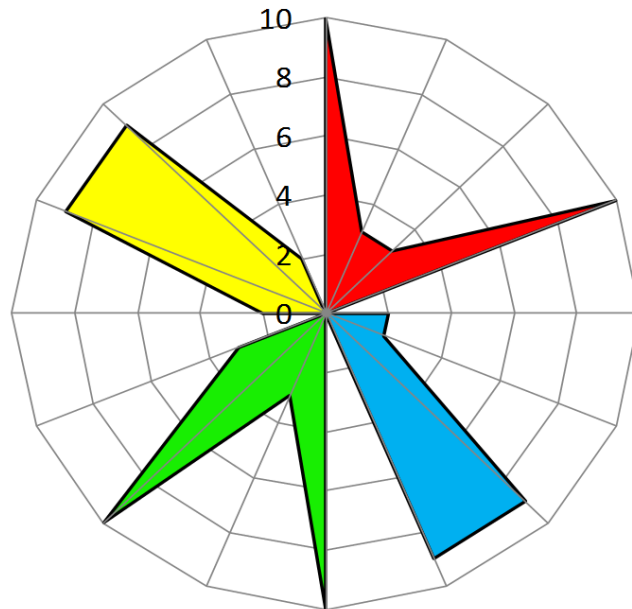


Figure 2: Misleading petal plot.

2 Physical properties of petal graphs

Figure 2 illustrates a petal graph with four petals with the colours red, blue, green and yellow going in clockwise direction starting at the top right. This colour convention will be used throughout this text. Which petal is the largest? It might be hard to assess, but some observers would perhaps point out that the yellow and the blue petals are the largest — and for good reason, as these petals have the largest physical area. The yellow petal is the largest with an area of 22.4 square units, the blue petal is the second largest with an area of 19.7 square units, while the green petal is the second smallest with an area of 17.2 square units and the red petal is the smallest with an area of 13.2 square units.

However, this is a misleading representation of the actual parameters as the two smallest red and green petals have the largest parameters, and the two largest petals have the smallest parameters. The red and the green both represent the same parameters 10, 10, 3 and 3, while the yellow and the blue both represent the parameters 9, 9, 2 and 2. The area of the smallest petal with large parameters is only 59% of the area of the largest petal with the small parameter set. The reason why identical parameters can give different results and larger parameters give a smaller area than small parameters is the sequence in which the parameters are presented. The impact of parameter sequence is explored in the following sections.

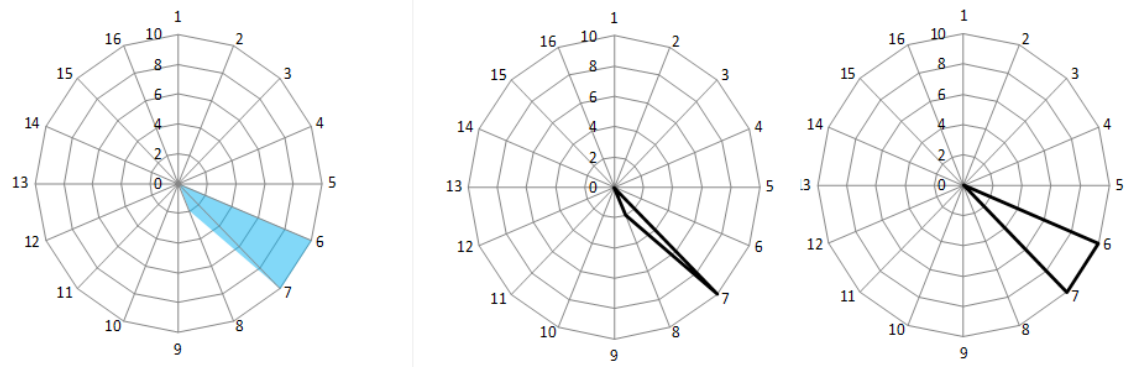


Figure 3: A petal constructed from two triangles.

Imagine q parameters organised into w petals. The parameters in each petal C_i , $i \in [1..w]$ are denoted by p_1, p_2, \dots, p_N where N is the number of parameters in the petal. Each petal is constructed from $N - 1$ triangles originating at the origin as shown in Figure 3. The area of such a triangle is given by

$$A = \frac{1}{2}ab \sin z \quad (1)$$

where a and b are the lengths of the two sides of the triangle leaving the origin and z is the angle of the triangle at the origin, given by

$$z = \frac{360}{q} \quad (2)$$

It is assumed that the parameters are equally spaced around the circle. The area of the entire petal is thus given by

$$A_{total} = \frac{1}{2} \sum_{i=1}^{N-1} p_i p_{i+1} \sin(z) \quad (3)$$

Since this discussion is concerned with the relative differences in area we can ignore the constant factor $\sin(z)/2$ and thus have the sum of parameter products given by:

$$T = \sum_{i=1}^{N-1} p_i p_{i+1} \quad (4)$$

As indicated by the example above, the order of the parameters affects the size of the area. If the parameters are organised such that pairs of large parameters are multiplied, that is, placed next to each other, it follows that the area will be large. However, if the largest parameters are multiplied by the smallest parameters it follows that the area will be smaller. Moreover, the first parameter p_1 and the last parameter p_N in the petal are only a factor of one product, while all others are used twice. Therefore, whether the largest or the smallest parameters are used in the first or last position will also affect the results. A maximum area is obtained if the parameters are organised in decreasing order and distributed with the largest parameters in the middle and the smallest at the ends, that is at the first and the last position, or more formally:

$$T_{max} : r_N, r_{N-2}, \dots, r_3, r_1, r_2, r_4, \dots, r_{N-3}, r_{N-1} \quad (5)$$

where r_i represent the i -th largest parameter in the petal. This sequence ensures that the large parameters are multiplied resulting in larger products. Similarly, a minimum area is obtained by arranging the largest elements at the ends and multiplying them with the smallest parameters, and then continuing with the sequence by forming products of the remaining smallest and largest parameters, or more formally:

$$T_{min} : r_1, r_N, r_3, r_{N-2}, \dots, r_{N-3}, r_4, r_{N-1}, r_2 \quad (6)$$

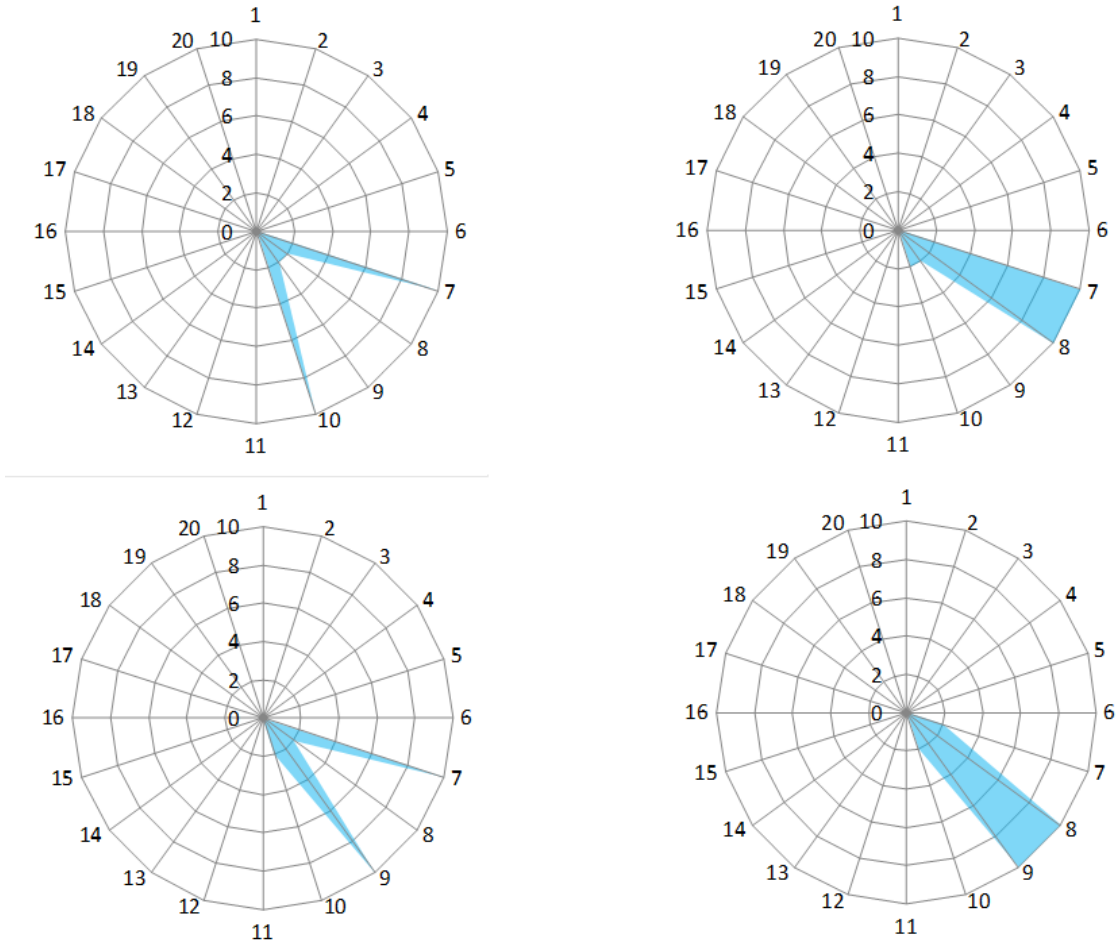


Figure 4: Parameter order affects the area of the petal.

Figure 4 shows an example of the effect of ordering. The example has two long L and two short S parameters, which can be organised into the following unique permutations $LSSL$, $LLSS$, $LSLs$ and $SLLS$. The areas of the four permutations become:

$$T_{LSSL} = LS + SS + LS \quad (7)$$

$$T_{LLSS} = LL + LS + SS \quad (8)$$

$$T_{LSLS} = LS + LS + LS \quad (9)$$

$$T_{SLLS} = LS + LL + LS \quad (10)$$

An LS term can be removed from all sequences since the triangles are compared relatively, and when compared

$$T_{LSSL} \leq T_{LSLS} \leq T_{LLSS} \leq T_{SLLS} \quad (11)$$

since

$$SS + LS \leq LS + LS \leq LL + SS \leq LL + LS \quad (12)$$

Clearly, the only scenario where the different sequences result in identical areas is when $L = S$, that is, when all the parameters are identical.

In conclusion, the physical characteristics of petal graphs are sensitive to the presentation order of the parameters. This can lead to problems since parameters often have no particular order and arbitrary presentation orders are chosen.

3 Perceptual properties of petal graphs

There is a vast literature on the perception of numbers, length and area [3, 5, 10, 11]. Humans are better at comparing one-dimensional lengths than areas spanning two dimensions. When humans observe two dimensional shapes one is likely to look at one dimensional features. This is the reason bar graphs are effective. Petal graphs are constructed from single spikes or bars which are quite similar to traditional bars in bar charts. However, unlike the bar chart where all the bars start at the same line and are aligned in the same direction, the spikes in petal graphs are oriented in different orientations. It is thus harder to compare the individual spikes. The ends of the spikes are connected with lines and the areas are filled in. These areas therefore become the dominant feature of petal graphs.

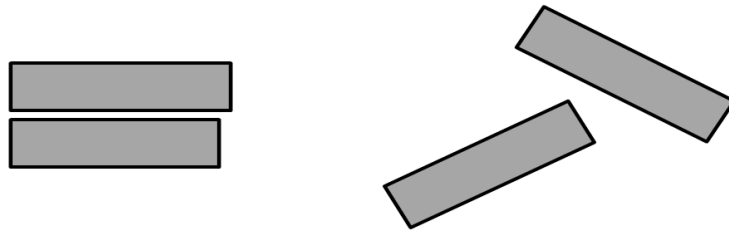


Figure 5: Comparing bars of different lengths: aligned (left) and arbitrary position (right).

Figure 5 illustrates the effect of alignment when comparing two bars with different length and same widths. The short bar is 95% the length of the long bar. This difference is relatively small. When the bars are aligned and have the same orientation it is easy to distinguish the longer from the shorter. However, when the same bars are not aligned and pointing in different directions it is harder to distinguish the lengths of the two bars. The advantage of aligning objects visually follows from the gestalt laws of common fate and continuity as viewers are searching for structure when perceiving visual stimuli. Moreover, the ability to spot differences can also be explained by Weber's law, that is, that the just noticeable difference between two stimuli is proportional to the magnitude of the stimuli. That is, if the two bars are long, the difference must be long for it to be noticed compared to two short bars. The literature also report perception effects that can give viewers an incorrect impression of line length such as the famous Ponzo illusion,

Muller-Lyer illusion and the horizontal-vertical illusion. Common to these illusions are that the lines have different orientations.

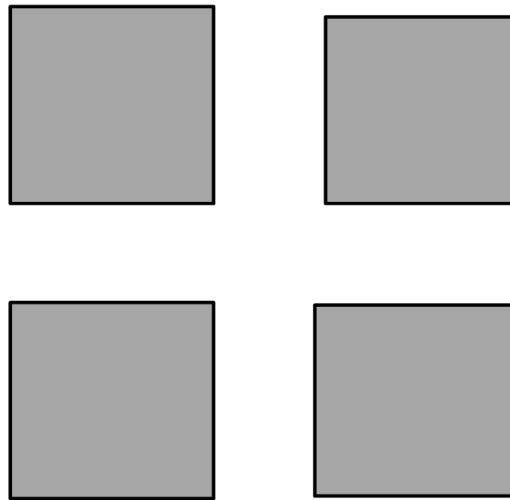


Figure 6: Comparing areas. Left top and left bottom: original square, top right square: 95% shorter sides, bottom right square: 95% less area.

Figure 6 illustrates how judging area is more difficult than judging length. The top left diagram shows the original square and the top right a square where the both sizes are reduced to 95% of the sides of the original square. The right square is clearly smaller than the left square, but the difference is less obvious than for the bar in Figure 5 where the length is much longer than the width. The bottom squares illustrates what happens if the reduction is measured in terms of area. The bottom left square is the original and the bottom right square has an area which is 95% of the original square. This square is more difficult to distinguish from the original square, because the sides are more similar, that is, 97.5% of the original. This is because the sides of the reduced square are equal to the square root of the 95% smaller area. Furthermore, if the squares are not aligned and have different orientations the task of distinguishing the squares is even more difficult.

A general polygons is not square, but rather have a blob-like shape making the judgment of dimensions and area more difficult. The disk is a polygon with infinite number of sides and Figure 7 illustrates that it is hard to assess small differences in disk dimensions. The right disk on the top row has a diameter 95% of the left disk. Although the difference in size is perceivable it is not obvious. The bottom right disk has an area 95% of the left disk, that is the diameter is just 97.5% of the left disk. It is much harder to assess the difference between these two shapes although they are aligned. Obviously, the orientation is irrelevant for the perception of disks. The effects of assessing the areas of disks versus squares has been addressed in the literature [5] and the results show that observers tend to underestimate the area of disks compared to squares.

The examples in Figures 2 and 4 where petals with larger parameters appear smaller than petals with smaller parameters are consistent with the classic study of perception of shape area by Smith [11]. Smith constructed 30 images with shapes of identical areas constructed from squares. A perception study showed that the subjects classified long and narrow shapes as having less area than the compact and dense shapes. In the examples in Figures 2 and 4 the large parameter petals have a thinner V-like shape while the smaller parameter petals have a more bulky condensed shape thus appearing to have larger area.

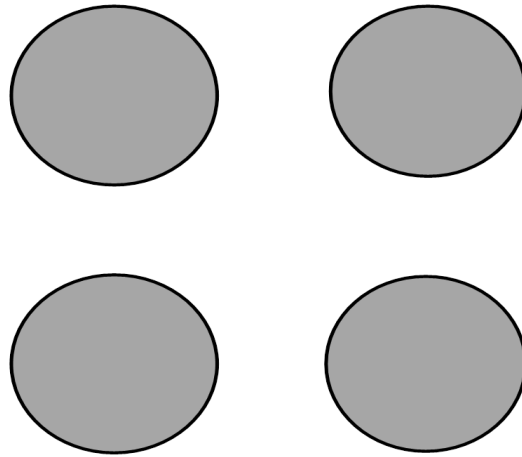


Figure 7: Comparing the differences between disks with different areas. Top: the diameter of the smaller (right) is 95% of the larger (left), bottom: the area of the smaller (right) is 95% of the larger (left).



Figure 8: Two shapes with identical area (34 squares) inspired by Smith [11]. The long and thin shape (left) is perceived to have a smaller area than the compact and dense shapes (right).

Figure 8 illustrates the different perception of area according to Smith's study.

4 Alternative visualisation techniques

As implied in the previous sections the petal graphs embody certain characteristics which render them unsuitable for the visualisation of parameters. Another visualisation technique that is used for the same purposes are sunburst diagrams, also known as radial bar diagrams and polar area diagrams [6]. A sunburst diagram is a radial diagram with bar graphs, or rays, originating from one central point and dispersing out in all directions. The length of the ray suggests the magnitude of its parameter. Moreover, the sunburst rays spread out in the shape of triangles. Thus, the larger the bar, the wider one end is. Sunburst graphs are for instance used in the European U-map initiative² hosted by the Center for Higher Education Policy Studies (CHEPS) which purpose is to classify European higher education institutions. An example of a u-map sunburst diagram is shown in Figure 9. Sunburst diagrams are also used for the visualisation of document contents [2] and multivariate analysis [9].

Figure 10 illustrates the visual difference between two sunburst beams as used in sunburst graphs. It is relatively easy to spot that there is a difference between the two beams on the right, and it is even easier to spot the difference when these beams are

²<http://www.u-map.eu/>

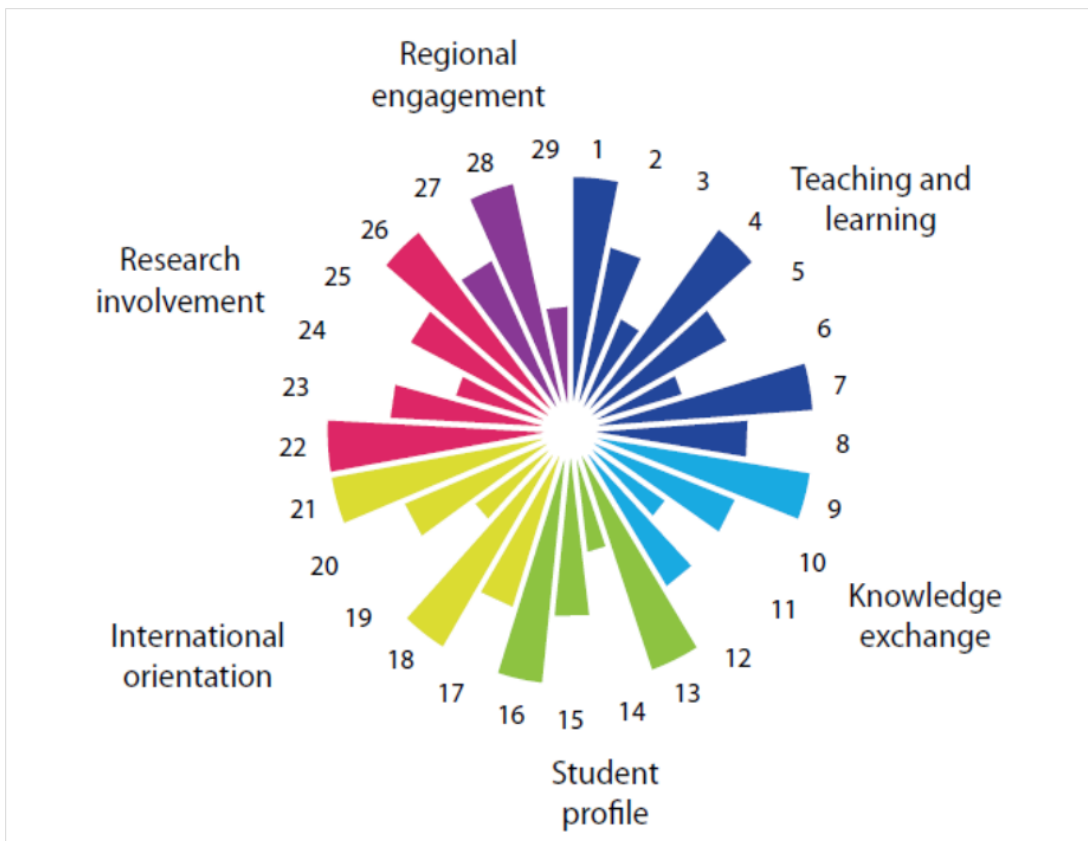


Figure 9: A sunburst diagram as used in U-map: A University Profiling Tool. 2011 Update Report.

aligned around a central point. In both cases the length of the smaller beam is 95% of the longer beam. The beams are effective as the width of the wide end increases linearly with the length of the beam providing the viewer with a secondary redundant visual cue.

Sunburst graphs are clearly not prone to the area problem faced by the petal graphs, and the perceptual characteristics of the beams make it is less difficult to assess parameter magnitude irrespective of orientation. Moreover, sunburst graphs are aesthetically striking and very suitable for attention grabbing presentations.

However, several visualisation experts argue for the proven and established no-nonsense visualisation tools — in particular Cartesian bar graphs [7, 8]. Most viewers are familiar with bar graphs and have some experience reading them. On the downside, it is harder to draw attention and generate excitement with Cartesian bar graphs.

Figure 11 shows a petal graph, sunburst graph and a traditional Cartesian bar graph based on the same parameters and the ones used in the first example in this text. As discussed, it is hard to make any sensible assessment of the petal plot as the smallest petals appear the largest. The sunburst plot is not ambiguous in terms of magnitude as each parameter has its own petal. A visual inspection of the sunburst plot reveals that the yellow and the blue parameters are smaller than the red and the green parameters. However, because of the rotations it is hard to make further analysis. The bar chart is probably the least visually impressive and aesthetically pleasing of the three alternatives. However, from the bar plot is easy to identify that the blue and the yellow parameters are smaller than the red and the green parameters. Furthermore, it is quite easy to spot

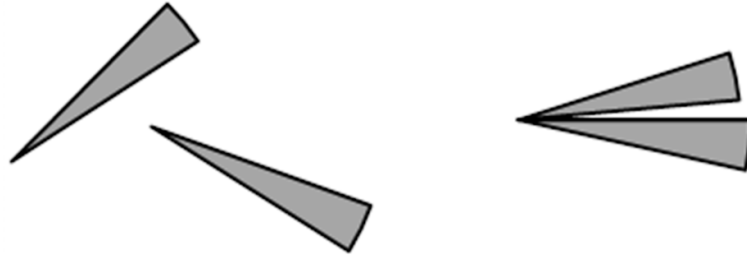


Figure 10: Assessing the difference between sunburst beams. Arbitrary positioned (left) and radiating from origin (right).

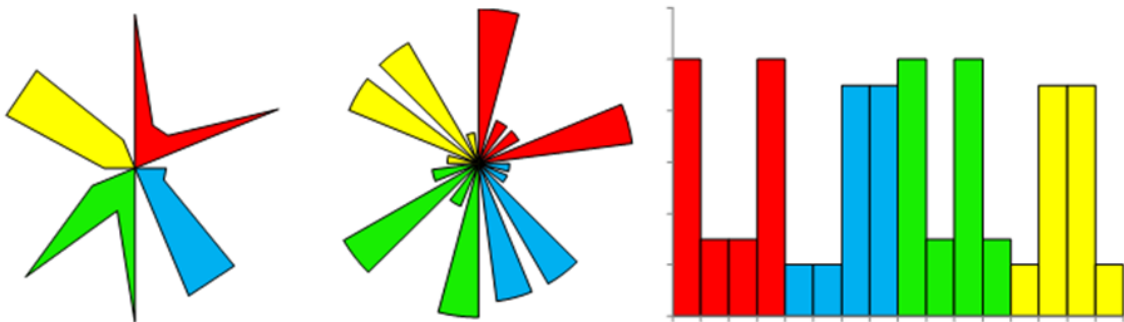


Figure 11: Comparison of a petal graph, a sunburst graph and a traditional Cartesian bar graph using the same set of parameters as in Figure 2.

that these data within the two groups have the same magnitude. These observations are consistent with the results reported in the literature. User studies have uncovered that for certain radial graph types and their Cartesian counterparts the Cartesian plots leads to better results while the radial plots are more effective as small thumbnails [1]. It has also been pointed out that it is easier to remember positions on a radial graphs, compared to Cartesian graphs [1] and that it is easier to remember outer or border cells than inner and non border cells [4]. Users also tend to need shorter time deciphering Cartesian plots than radial plots and that there is a positive effect of reading directions in Cartesian plots [4].

5 Conclusions

Although petal graphs are visually striking and attractive for making striking presentations this study argues that petal visualisation are prone to misinterpretation. The sequence order used is usually arbitrary and this study has shown that the parameter ordering affects the physical area of the petals. Moreover, the problems with petal graphs are supported by classic studies on perception of area where long and thin shapes are perceived as smaller than more concentrated and bulky shapes even when these shapes have similar area. The petal graph also suffers from the same problems as other radial visualisation approaches as reported in the literature. In particular, it is hard to compare the relative magnitude of each parameter, and it is difficult to compare parameters across different plots. It is recommended that petal plots are replaced by sunburst diagrams or preferably traditional Cartesian bar graphs despite the fact that the latter are less visually exciting. This conclusion echoes the recommendation posed in the literature, that is, not to choose radial visualisation approaches unless there is a very good reason to do so [4]. Moreover,

trusted organisations with a strong impact on society such as the Ministry of Education and Research should take special care to ensure quality in their official visualisations.

6 Acknowledgement

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