Visual composition of graphical elements on non-rectangular displays

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ABSTRACT

Graphical user interfaces are composed of varying elements (text, images, etc.) whose visual arrangement has been relatively well established in the context of rectangular interfaces. The advent of non-rectangular displays questions this knowledge. In this paper we study how traditional content layouts can be adapted to fit different non-rectangular displays. We performed a first qualitative study where graphic designers fitted text and images into different non-rectangular displays. From the analysis of their output we generalize and adapt ten composition principles that have been proposed in the literature for rectangular displays. We evaluate the revised principles through a paired comparison questionnaire where 57 participants compared pairs of layouts. Using the Bradley-Terry-Luce model to analyze our data we show that some results contradict current conventions on visual design for rectangular displays. We then extracted the most interesting cases and conducted a follow up study with additional shapes to investigate how the principles generalize. From these results we propose a set of guidelines for designing visual content for non-rectangular displays.

Author Keywords

Freeform display; non-rectangular display; visual design guidelines.

INTRODUCTION

Emerging technologies allow for the creation of non-rectangular displays with unlimited constraints in shape[i]. These displays can be applied to a wide variety of usage contexts, ranging from in-vehicle [18] and wearable displays [1] to public displays [31]. In these applications non-rectangular displays meet different needs for which traditional displays are not well-suited at. For instance, a single non-rectangular display can replace current instrument panels on car dashboards. Non-rectangular displays will also facilitate inserting displays on non-rectangular objects, furniture and/or urban architecture. In the context of mobile computing, non-rectangular displays can adopt shapes which will better fit wearable devices or replicate existing jewellery These applications correspond to a market in expansion that could impact millions of users in the near future [9,19]. With this eminent adoption comes the urgent challenge of rethinking the way we present content on non-rectangular displays [31].

Presenting content on rectangular displays is, in contrast, reasonably well understood. For instance Galitz [15] proposed ten aesthetic composition guidelines extracted from tacit knowledge that visual designers have accumulated over years of experience (e.g. balance, proportion or unity). There is also strong evidence to support the role of aesthetics in interface design and especially how they impact perceived usability [8,21,32] and visual search performance [30].

However non-rectangular displays challenge these fundamental composition principles. Recent work [31] demonstrated that different ways of presenting text on non-rectangular displays affect usability (reading performance and subjective preference). We therefore postulate that it will also be the case for presenting more complex content types combining images and texts, such as online newspapers. Our goal is thus to investigate if the established composition principles for traditional displays generalize to non-rectangular displays, and if not how they can be adapted for designers to create the layout of the next generation of display content.

To this end, we first performed a qualitative study that consisted in asking graphic designers to map traditional web content onto non-rectangular shapes. The analysis of the results showed that graphic designers' inner sense for composing layouts matches existing composition principles (simplicity, sequentiality, economy and unity) but that some revisions (balance, regularity, proportion, predictability) are needed; for these, we discuss how they can be generalized to non-rectangular displays and propose a set of hypotheses.

We then performed a pairwise experiment with 57 participants to test the revised composition principles. Using a Bradley-Terry-Luce model to associate subjective

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metrics to different visualizations we found that vertical symmetry is significantly better than with other axes. Among other results we found that adapting the grid orientation to the shape (radial for circle, oriented for triangle) makes the layout visually more pleasing. And placing the menu at the bottom of some shapes (e.g. circle) is better.

We also performed a follow-up pairwise experiment with additional shapes to investigate how the principles generalize. The study confirmed our findings on grid layout (adapting the layout to the shape can improve its clarity), on element shapes (shaping elements to the shape of the display is visually attractive) and on menu position (menu on top of the display is not always preferred).

Our contributions are (1) a set of visual composition guidelines for non-rectangular displays that extend existing guides on rectangular displays using webpage productions gathered in a qualitative study with graphic designers; (2) a pairwise experiment which assesses these guidelines; (3) a follow-up pairwise experiment investigating how the principles generalize to other shapes.

RELATED WORK

Our work relates to page layout, visual design principles and visualizations on non-rectangular interfaces.

Page layout guidelines

In graphics design, *page layout* consists in arranging visual elements on a page. Page layout has deeply evolved with printing and editing technologies [25]: physically assembling characters in letterpress printing (Renaissance), gluing papers in paste-up techniques to create pages that are later photographed (mid-20th century), and finally using Wysiwyg publishing software with the advent of computers. All these stages have influenced page layouts, which are most often based on rectangular grids [12,26].

Page layout involves design elements and choices, such as margins, images size and position. In grid design, these choices are based on predominant grid styles that have evolved over time, and on principles of page construction. These principles apply rules, such as the golden section [17], to divide a page in pleasing proportions. These rules are generally implemented in modern editing software. Using these rules, theoretical work in the field of graphic design has analyzed the proportioning systems of works of art, buildings or products with diverse shapes [11].

Visual Design principles

Visual layout guidelines have been to a large extent based on Gestalt Laws [10,16]. These laws mainly describe how visual elements are perceived as grouped based on principles of Proximity, Similarity (color, shape and size), Common fate, Good Continuation and Connectedness. These principles have been widely appreciated in various fields including architecture but also widely used in GUI design and information visualization [13,14,20,37].

Galitz [15] proposed 10 visually pleasing composition guidelines for GUI design: Balance, Symmetry, Regularity, Predictability, Sequentiality, Economy, Unity, Proportion, Simplicity, and Groupings. These principles summarize tacit knowledge developed by graphical designers over decades of practice. These principles encompass many page layout and visual perception principles (e.g. Gestalt).

Ngo et al. [27,28] proposed to use the 14 aesthetic features inspired from Galitz [15] and to associate a metric. However the work only focuses on a few aspects defined by Galitz while leaving out others. E.g. the authors did not consider the color or the shape of the elements, which are known to have an impact on the way we look for information. There are also inconsistencies in some metrics. E.g. Galitz defined "sequentially" as a way to arrange elements to guide the eye through a UI (e.g. bigger, colored saturated before small, black and white, unsaturated). However Ngo's metric measures if most of the big elements are in the upper part (vs. bottom and lower right). For these reasons our work uses Galitz' [15] principles because they clearly define and encompass all the important factors.

Interface aesthetic and usability

Norman, a father's of *usability design*, argued "good design means that beauty and usability are in balance" [29]. Work by Kurosu et al. [21] on the influence of aesthetics on usability showed a strong correlation between the two [21]. The results were confirmed by other studies [8,32]. Later work has investigated the effect of aesthetics on inherent usability, i.e. performance [30, 35]. Van Schnaik et al. [35] discovered that aesthetically pleasant web pages reduce error rate. Brewster et al [30] evaluated some of Ngo's aesthetic metrics [27,28] and demonstrated their effect on search performance. In our work, we perform the first evaluation of non-rectangular layouts using aesthetic measures such as beauty, clarity and symmetry [15].

Non-rectangular interfaces

Previous work on tabletop interfaces explored the use of non-rectangular graphical widgets to avoid hand occlusion or improve user collaboration. For example Cotting et al [6] proposed mapping rectangular widgets into bubbles having physical properties and that can be elastically deformed. Their work mostly focused on these elastic properties and how to adapt the content by using display warping.

Work has been carried on specific interfaces for round smartwatches. Xu et al. presented two different prototypes based on the use of LEDs around the bezel [36]. The first prototype used 4 LEDs to render four applications while the second one used 12 LEDs to show time and app data. Commercial round smartwatches use different approaches to present information. Apple Watch uses a circular honeycomb grid to present applications. This grid uses a fisheye view to provide context and focus: only items in the center can be tapped. What we learn from the above work and current interfaces, is that significant effort is needed to adapt UIs from rectangular to circular shaped displays.

Recently, Serrano et al. investigated text legibility on non-rectangular displays [31]. They presented scenarios in which non-rectangular displays reveal useful information.

They also conducted four studies to assess ten hypotheses on reading performances of text displayed on free-form displays. Their work shows that text reading performance is affected if not carefully designed for, and the authors provides a number of guidelines for text justifications based on display shapes [31]. Our work builds on these previous studies on non-rectangular displays and investigates more complex content types combining images and texts.

ELICITATION STUDY

To begin our exploration on the visual composition of graphical elements on non-rectangular displays, we first captured how graphical designers tacitly organize visual layouts. We gathered qualitative probes that we could use to generate new hypotheses for the visual composition of elements on free-form displays. We asked five graphic designers to compose webpages on non-rectangular shapes. This task relies heavily on creativity and thus we designed this study to be in the form of homework. Designers had a week to do the task wherever they wanted, thus avoiding us to interfere with any creative processes that might emerge from their environment. We then analyzed the productions to better understand which choices they made.

Design task

We gave participants a webpage with all associated content. We asked them to fill this content into four shapes: a circle and a triangle, with or without hole (see Figures 1, 2 and 3). These shapes come from prior work [35] and are based on geometrical shapes, which will make it easier to classify or extend our results.The initial rectangular area and the target non-rectangular shape had the same area (450cm2), to ensure all content could fit. To facilitate the task and ensure that all designers had the same working environment, we gave designers a vector file ready to use: the webpage content (text, images, colors) was ready to be manipulated and the four final shapes were included in the file.

We choose a news webpage as it combines a variety of graphical elements. To limit the length of the task and increase the results quality we picked a subset of shapes based on previous studies revealing that they could be used in upcoming scenarios [31] (e.g. free-form displays on road signs, circular pocket mirrors, non-rectangular coffee tables or in vehicles as well as displays with holes such as embedded displays in cooking hobs).

Participants

We recruited 5 professional graphic designers, aged 27.8 years on average (SD=6) from 3 different countries (USA, France and UK). They worked on graphic design for 6 years on average (SD=3). Their areas of expertise were print (5/5), web (4/5), and UI (2/5) design. We offered a 50£ voucher prize to a randomly chosen participant.

Procedure

We first informed designers about the project. Designers were given one week to complete their task. They could take all the time needed to perform it. They could use their preferred tool: all of them used Illustrator.

Collected data

We collected all resulting graphical designs. We also asked them to fill a questionnaire to gather information such as the time they took or if they had any specific strategy.

Questionnaire results

Designers completed the task in 90 min (SD=37). We asked them how satisfied they were on a 5-point Likert scale. They rated between neutral and positive the results on the circle, rather neutral with the triangle without hole, but were not satisfied with designs on the triangle with hole. These results are in line with the perceived difficulty. All designers found that shapes with hole were more difficult to fill. D4 stated that the triangle with hole "lacked symmetry". D3 argued, "shapes with holes are more difficult as you hardly can place a unit of content". D1 said, "much space was lost with the hole", even though all shapes had the same area. (4/5) designers agreed that the easiest shape was the circle without hole. D4 suggested, "circular shapes could actually be an advantage in creating an interesting layout". D3 preferred the triangle without hole as she felt "you can separate icons from content".

Productions results

We choose to perform their analysis in the next section to correlate our observations with previously established principles on rectangular displays.

GENERALISATION OF COMPOSITION PRINCIPLES

We present in detail the composition principles proposed by Galitz [15] and discuss how the definition can be adapted to non-rectangular displays. We use the productions of the elicitation study as probes and highlight hypotheses that we evaluate in the studies presented in the rest of the paper.

1. Balance/Symmetry

Original definition [15]: Balance (stability) means providing an equal weight of elements on each side of the horizontal or vertical axis. Heavier elements are the larger ones, with dark colours or unusual shapes. Galitz does not explicitly mention what regular shapes are. Our assumption is that rectangular topologies (including rounded corners) are implied because they represent most of the current GUI layouts. Symmetry is a subcase of Balance where the Balance is respected for both horizontal and vertical axis.

Generalization: There are two aspects that can change the way we define Balance when moving to non-rectangular displays: (1) the symmetrical axes of the display and (2) the definition of a "regular" shape. We have no reason to think that other aspects of the original definition should change (for the color and the size of the elements).

For the symmetrical axes, it is tempting to say that the balance should use natural axes of symmetry of the displays (e.g. medians in triangle) rather than the horizontal/vertical axes. However, examples produced by our designers suggest that balance should follow the vertical axis (Fig.1). This may stem from the fact that in Western cultures we read from left to right. The only example deviating from this is shown in Figure 2-left. We can see that designer (D1) used a radial composition, however we can note that s(he) used circular shapes for the components as well, thus emphasizing the Balance with the shape of element.

Figure 1. Balance: productions tend to follow a vertical symmetry axis with only one exception for the case of the hollow circle shown in Figure 2-left.

Most element shapes in the productions were rectangular except for the designs show in Fig.2. In these two designs the elements shapes were directly related to the shape of the display (the designed cut the elements in circle or triangle). For the circular designs it could also mean a desire to copy the shape of the hole itself. None of the productions are fully symmetrical, although there is rather a strong trend for vertical symmetry. Thus we do not think that full symmetry necessarily needs to be followed. This corroborates principles on rectangular displays where it is often advised to “break” the symmetry.

Figure 2. Balance: although most elements were rectangular, two examples use different shapes, but their topologies are directly related to the shape of the display.

Summary: In summary Balance should not change much from the original definition. The balance should still be done around a horizontal symmetry and should be done for all the difference color, size and shape of elements. We can hypothesize that:

- *H1. Balance using vertical axis is better than using some of the natural axes of symmetry.*
- *H2. Balance using vertical axis is better than using all of the natural axes of symmetry.*
- *H3. Balance using natural symmetry axes is better if element shapes follow display or hole shapes.*

2. Regularity

Original definition [15]: Regularity (consistency) means providing consistently spaced horizontal and vertical alignment points and spacing, as well as using similar element sizes, shapes and colors overall.

Generalization: Similar to Balance, there are two aspects that can potentially change the way we define Regularity when moving to non-rectangular displays: (1) the alignment axes which can be more than just horizontal/vertical and (2) the definition of a “regular” shape. We do not have reasons to believe that the second part of the definition should change (similar elements sizes and colors).

Concerning the alignment axes, it is possible to imagine different layouts and to deviate from the rectangular grid. In fact only 10/20 productions used a rectangular grid, 4 used a radial alignment and 6 used a tangential alignment (aligned with one or more edges of the screen). Interestingly the 4 designs using a radial alignment (Fig.2) had a hole suggesting using the hole as part of the design. Also the 6 using tangential alignment are triangles (Fig.3) suggesting that using the edges of the display shape as alignment point is not only obvious but also a good technique. E.g. D4 said “I tried to use the shape to my advantage in terms of following the lines. Also keeping a grid pattern made it easier to place items”. We did not observe any design using more than one concentric alignment (e.g. 2 concentric circles in the circular display or smaller triangles inside the triangular one). This may be due to the size and amount of elements we provided (not enough elements to use two concentric alignments), so we cannot conclude anything. However, we note that on the design with circles, the designer choose to decenter the elements to avoid a vertical symmetry. This corroborates the fact that full symmetry is not necessarily desirable.

Figure 3. Regularity: designs following a tangential alignment are made on triangular shapes only.

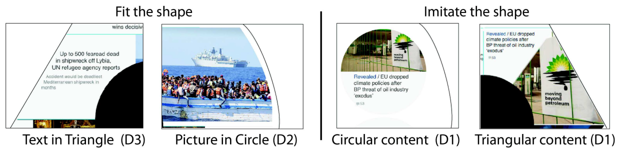

Figure 4. Designers reshaped content elements to fit the shape (left) or to enhance aesthetics by imitating the shape (right).

Concerning the regularity of element shapes we observed that designers reshaped the elements for two main purposes: to fit the shape and for aesthetics. Note that, in our instructions, we did not suggest that elements (images, text) could be reshaped, as we did not want to influence the designers’ creativity and the resulting designs. To fit the shape, designers aligned text with the shape bezel and/or cut the images (Fig. 4-Left). Out of the four designers, one never reshaped content (D4) and kept the original rectangular shape of texts and images. One of the designers, D1, reshaped content to imitate the shape: texts and images were made circular in the Circle shapes, and triangular in the Triangle shape (Fig. 4-Right). While this approach allows filling the Triangle efficiently, it seems to be mainly aesthetical in the case of the Circle. It is possible that, although images are cut, the regularity is preserved thanks to perception clues (e.g. Gestalt continuity).

Summary: Regularity should differ from the original definition regarding the alignment and the regularity of the shape of elements. We hypothesize that:

- *H4. It is better to keep regularity via a rectangular grid than via different grid shape.*
- *H5. It is better to keep regularity over keeping shape aspect (rather cutting it on the edges).*

3. Predictability

Original definition [15]: Predictability (conventions) means providing conventional orders or arrangements to ensure that viewing a screen (or part of it) enables one to predict how another will look (or the rest of it). Predictability is also enhanced through design Regularity.

Generalization: This guideline rather links the way several pages are designed and thus we have no reason to think that this should change with the shape of the device. To a large extent we can also couple this definition with some of Nielsen's guidelines of "consistency across platform", e.g. the fact that headers and menus are always at the top of a webpage. While all designers decided to keep the regular menu position at the top of the shape for the Circles (Fig. 1-2 left), most of them inversed the position for the Triangles (Fig. 1-2 right). This change is rather surprising, given that it goes against traditional web page layouts.

Summary: In summary the predictability should stay the same than for rectangular display except for the placement of the main elements such as menus. We hypothesize that:

- *H6 Menus should be placed at the widest horizontal portion.*

4. Proportion

Original definition [15]: Proportion means using aesthetically pleasing proportions for components of the screen. E.g. some rectangular shapes are more aesthetically pleasing than others [24] (square, square root of two, golden rectangle, square root of three or double square). Other guidelines also recommend using non-regular grids that follow a golden number layout [15].

Generalization: Common sense would favor the use of the same pleasing ratio for other shapes than the rectangle, e.g. golden ovals. More interestingly it is interesting to see how the golden number layout would match with non-rectangular content. Figure 7 illustrates how it would work with a circle and a triangle. Interestingly none of the productions seem to use such a layout but this may be due to the fact that they had to reshape an existing interface with a specific number of items. It would be interesting to see how they perform with a non-given interface (free to choose which elements to place).

Summary: The pleasing proportion for elements should not change but it could change for the overall layout that could for instance follow the golden number ratio. We could hypothesize that "using a golden number layout is better than a random one if Regularity and Simplicity are kept similar". However we will not investigate this issue further as it is hardly applicable to an informational webpage design and rather fit to more artistic content.

5. Simplicity

Original definition [15]: Simplicity (opp. complexity) means optimizing the number of elements on a screen, within limits of clarity, as well as minimizing the alignment points, especially horizontal or columnar. Several researchers have proposed to use information theory to provide a metric to this principle [1,33,34].

Generalization: We do not think that the definition should change with the number of elements, however the measure of alignment points should change to better reflect the fact that the element could be aligned differently (as already explained earlier in Regularity). Instead of using row and column we could thus use radial and tangential alignment.

Summary: We postulate that Simplicity should only be slightly different from the original definition regarding the alignment lines count. We could hypothesize that "the smaller the number of alignment points the better, whether these points are aligned on a grid or on a radial/tangential form". However, it is obvious that this guideline will have an impact on visual search (as the number of on screen elements increases) and thus we will not investigate it.

6. Sequentiality

Original definition [15]: Sequentiality means arranging elements to guide the eye through the screen in an obvious, logical, rhythmic, and efficient manner. The eye tends to be attracted by certain features (brighter, isolated or bigger elements, graphics, highly saturated colors) and then move to others. Sequentiality is enhanced through Grouping.

Generalization: We have no reason to believe that this should change. The definition of "unusual" or irregular shape could corroborate what had already been defined for Balance, i.e. those regular shapes are either rectangular or similar to the shape of the displays and/or the holes.

7. Economy

Original definition [15]: Economy means providing few styles, techniques, and colors in order to deliver the message as simply as possible (e.g. no ornamentation).

Generalization: This principle is straightforward and true for all UIs. We have no reasons to believe this should change. Designers' productions did not show any major removal or addition of elements.

8. Unity/Grouping

Original definition [15]: Unity (coherence) and Grouping means using similar sizes, shapes, or colors for related information as well as leaving less space between elements than the space left at the margins. With unity, the elements seem to belong together.

Generalization: We have no reason to believe this should change. The productions did not show any new tendencies in term of groupings apart from using different shapes (triangles or circles) for elements. D3 did not identify a particular strategy to place content. D1's strategy was to keep the content associations: images with text, text with icons. D2 and D4 agreed to put the most important content first (pictures): "Picture were given priority. I wanted to make sure the main focus of the picture wasn't cut out or disturbed." (D4); "I prioritize the photos to catch the eyes" (D1). D4 added, "I gave the icon a hierarchy of which would be most important to the audience; and then made sure they were placed in prominent positions or made larger".

CHOICE OF EXPERIMENTS

To evaluate the differences between the composition principles we opted for paired comparison experiments that are typical to gather Quality of Experience (QoE) feedback. They consist in asking participants to choose between two conditions, here two layout visualizations. The experiment is designed so that each participant rates each pairs of visualizations. Here, we explain why this experimental design is adapted to our research question.

Confound variables in performance based studies

Quantitative controlled experiments are assumed to be the best tool to demonstrate UI efficiency. But they are only useful when it is possible to test counterbalanced variables without introducing confounds. With our research question we could not find an experimental setup following this rule. E.g. in readability study (e.g. [38]), the issue is that we know text presentations affect readability [31]. Thus any effects observed could also be a result of the text presentations that change according to the conditions (confound variables). One solution is to remove the need for text and use visual search tasks. But complex images, including photos, have the same issues than text (confound variable) because different brightness, color, saturation and content affect perception [15]. The other recourse is to use symbols like in [30]. But the task is becoming abstract and ecologically distant from the initial question on page layout.

Paired comparison vs. Mean opinion score

A way to get participants' input is to use subjective judgement. Estimating preferences based on subjective judgements is a critical step in psychological experiments with applications in many fields such as marketing, environmental sciences and health economics [5]. In particular pairwise experiments have been widely used. In such studies, two conditions are presented to participants who then indicate one alternative over the other. Pairwise comparison ratings have been proven to produce more realistic results than asking for individual rankings (e.g. using a Likert scale) [39]. In particular there are powerful mathematical model, such as the Bradley-Terry-Luce [23] that can deduce an "ability" metric from the data as well as perform classical statistical hypothesis testing.

Crowdsource vs. not

Paired comparison experiments are also used in crowdsourced experiments. In such cases participants generally only rate a subset of all possible combination of conditions but only a subset. Although several models have been proposed to accommodate these reduced amounts of data [6], having all possible combinations increases the statistical power of the results and it is possible to compute an individual and group consistency (see results).

PAIRWISE EXPERIMENTS

The goal of this experiment is to validate or invalidate the hypotheses laid out in the previous sections.

Task

We asked participants to compare pairs of layout visualizations and say which one was nicer (i.e. visually pleasing), clearer (i.e. not confusing) and more symmetric (aesthetics term proposed in [22]). Participants could give three answers for each question: Visualization-1, Visualization-2 or Both.

Shapes

We used the same shapes as in the qualitative study, i.e. a circle and triangle, with and without a hole (C, T, CH, TH).

Design

We gave one general survey to the participants but it comprises four sub-surveys matching different hypotheses. For each survey, we compared visual compositions among shapes, but not between shapes. In each survey, the order of the trials for one shape was counterbalanced. The order of the sub-surveys was always the same (H123, H4, H5, H6). Our study was composed of 60 + 24 + 4 + 12 = 100 pairs.

- *Sub-survey 1. Balance and symmetry (H1, H2 and H3)*: we studied 3 symmetry axes (vertical, shape and all) and 2 element shapes (rectangular or matching display shape). Overall, we had 15 pair comparisons for each shape × 4 shapes = 60 pair comparisons (Fig.5).

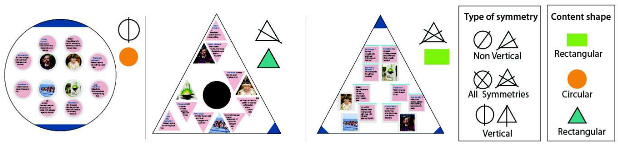

Figure 5. Conditions to test H1, H2 and H3 and three examples: a) vertical symmetry with circular content; b) non vertical symmetry with triangular content; and c) all axes of symmetry with rectangular content.

- *Sub-survey 2. Regularity (H4):* we studied four grid layouts (regular, radial, oriented and random). Overall, we had 4 pair comparisons for each shape × 4 shapes = 24 pair comparisons (Fig.6).

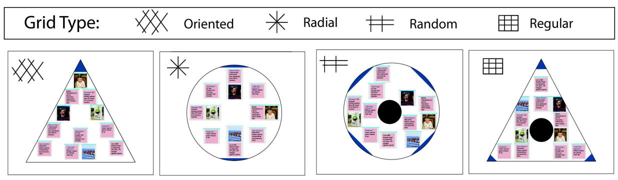

Figure 6. Conditions to test hypothesis H4.

- *Sub-survey 3. Regularity (H5):* We tested whether it was better to follow the regularity but have elements cut by the display shape or to break the regularity by having the elements fit the shape. We tested 2 conditions (elements out or in). Overall, we had 1 pair comparison for each shape × 4 shapes = 4 pair comparisons (Fig.7).
- *Sub-survey 4. Predictability (H6):* We changed the position of the menu. We tested 3 positions for the menu (top, bottom and following the shape). Overall, we had

3 pair comparisons for each shape × 4 shapes = 12 pair comparisons (Fig.8).

Figure 7. Conditions to test hypothesis H5. Left: elements fit in the display by breaking their regularity. Right: elements are cut to preserve their regularity.

Figure 8. The 3 menu positions explored in our study (H6): bottom, shape and top.

Participants

57 participants (16 female) from 8 different countries completed the study. Participants were aged 22.4 on average (SD=6). 49 of them were university students and the rest worked in academia as engineers (2), professors (2) or researchers (4). We removed results from 4 participants due to their low consistency (see step1 below).

Collected data

We collected 100 pairs × 3 questions = 300 answers per participant so a total of 300 × 57 users = 17100 answers.

RESULTS

Our analysis consists in three steps based on [5].

Step 1: Individual consistency checking

We computed the Transitivity Satisfaction Rate (TSR), which quantifies the consistency of a participant's judgments over multiple questions. E.g. if A is found more restrictive than B, and B more than C, then we should have A more restrictive than C. We implemented the algorithm found in [5] in Python. We removed 4 participants whose TSR was below 0.8. The mean TSR for all other users was 0.92 (SD = 0.05) and at least over 0.8 for all of them, thus denoting that they paid full attention to the study [5].

Step 2: Overall consistency checking

To test the overall consistency across participants we checked the stochastic transitivity properties or computed Kendall's µ-coefficient [5]. For each participant, we computed a list of rankings of visualisations and used the kendalltau Python library to produce a coefficient for each pair of participants, computed as a percentage (100% means all participants perfectly agreed, 0% they perfectly disagreed). Our results show that the mean Kendall's µ-coefficient is above 50% for all conditions.

Step 3: Model the data

The individual and overall consistencies were confirmed, so we proceeded to model the data. We used the Bradley-Terry-Luce model [4,23], which associates an "ability" metric to each condition that have been paired-compared as well as the p-value for each pair comparisons (BradleyTerry2 R package). The results are presented below for each comparison set. Note that the Bradley-Terry-Luce model computes a p-value that express how the visualizations compare to one specific visualization only, which serves as reference and is a parameter of the formula. We thus performed several tests to compute the significant level for each comparison. To counteract the problem of making multiple comparisons tests we used a Bonferroni correction for each result described below.

For sake of clarity, our figures only represent the results for the shape without holes. As results are similar for both types of shapes (with and without hole), we detail in the text any differences between them. We add all the figures corresponding to the conditions with a hole to the Annexe of the paper, as well as all details regarding the significance of our results (p-values) for each pair of conditions compared in our survey (adding it to our figures would make them unreadable). Each of the following figures shows the results representing the metric of each visualization computed via the Bradley-Terry-Luce model [4,23]. The metric gives a value between 0 and 1, where the lowest condition equals 0 and the highest 1. We also indicate the standard error values given by the model. We now detail the results for each hypothesis.

Display shapes are abbreviated as C circle T for triangle, CH for circle with a hole and TH for triangle with a hole.

Results for Balance and symmetry (H1, H2, H3)

Type of symmetry

Visualizations with vertical symmetry were deemed nicer, more symmetric and clearer than the ones with symmetry around a non-vertical axis or around various axes (except when using all axes with triangular content on T, which was no different than a vertical symmetry with rectangular content). The conditions involving symmetry around the shape axis were always rated worse than the others (for C we used vertical/horizontal axes).

Content shape

Overall the results of layout visualization with rectangular or shaped content are similar, but in cases the visualizations with shaped content was deemed nicer than the ones with rectangular content (Figure 9): on C for any type of symmetry; and on T when using all axis of symmetry. On the contrary, the layout visualizations with rectangular content were perceived as clearer than the ones with shaped content (with symmetry around the shape axis on T). Interestingly, the shape of the content sometimes influenced the perception on symmetry: for T, when the content was triangular, it was rated as more symmetric than when it was rectangular with the symmetry around the shape or all axes; and clearer with the symmetry around vertical and shape axes.

Display shape

The main difference between C and T was that on C, circular content was rated nicer than rectangular content (for the same type of symmetry), while on T, triangular content was rated as clearer and more symmetric than its rectangular counterpart (for the same type of symmetry). This illustrates that shaping the content to imitate the display can have different effects on user perception.

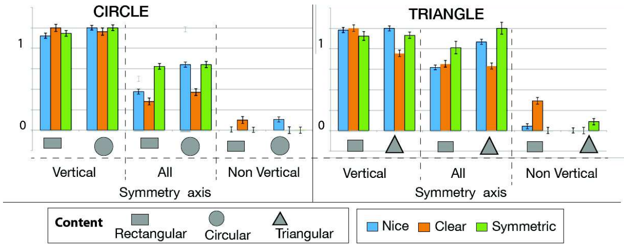

Figure 9. Results on H123 for the displays without hole. The Y-axis represents the mean rating for pair comparisons: blue for nice, orange for clear and green for symmetric.

Summary

These results validated H1 (*balance using vertical axis is better than the Shape axes),* H2 *(balance using vertical axis is better than using all axes)* and partially H3 *(balance using all axes is better if the elements follow the shape of the displays*): results show that all symmetry axis with shaped content is nicer on C, and more symmetric on T.

Results for Regularity and proportion (H4)

Grid type

An interesting finding is that the regular grid, which we expected to be preferred, is not always rated best (Figure 10): for C, the radial grid was nicer, clearer and more symmetric; for T, the oriented grid was nicer, although there was no difference on the other measures. As expected, the random grid was the least preferred across all display shapes, along with the Oriented grid on the Circle display.

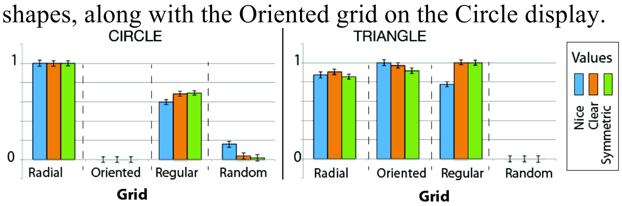

Figure 10. Results for H4 for the displays without hole.

Display shape

There was an interesting difference in how grids were rated between C and T: in C, the radial grid was rated as nicer, more symmetric and clearer than the other types of grids, which is not the case in T. This result suggests that the choice of a particular grid depends on the type of display, and that it should match the display shape (for instance, radial for C). We found an effect of the hole in displays: in TH, the oriented grid was always rated better than the radial grid (no difference on T between radial and oriented).

Summary:

Our results invalidate H4 (*better to keep regularity via a rectangular grid than different grid shape*). We found no differences between grid types on T but an effect for radial grid on C suggesting that grids need to match display shape.

Results for Regularity (H5)

In both C and T, with and without holes, not cutting the content (i.e. breaking the regularity of the elements to make them fit in the display) was rated nicer and clearer than cutting it (Figure 11). We found no difference on symmetry except for CH, which interestingly was found more symmetric when the regularity was preserved (i.e. content is cut).

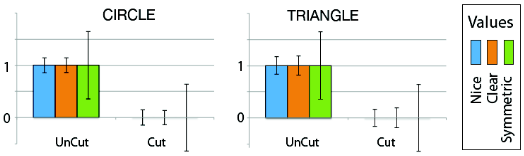

Figure 11. Results for H5.

Summary

This result invalidates H5: it is better to break regularity, than cutting content on the edges.

Results for Predictability (H6)

Menu position

Overall, the Bottom menu and the Top menu were deemed nicer, clearer and more symmetric than the Shape menu (Figure 12).

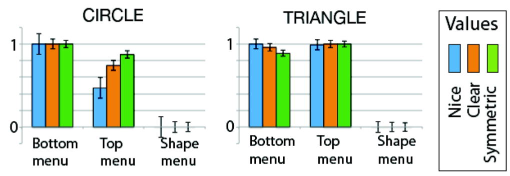

Figure 12. Results for H6.

Display shape

For C, using the Bottom menu was deemed nicer and clearer than the Top menu. We found no difference on the symmetric measure. For T, we found no difference between Top and Bottom menus. Interestingly, when on TH, the Top menu was deemed nicer, clearer and more symmetric than the Bottom menu. This result seems to indicate that the choice of the position of the menu depends on the display's shape: bottom for C, top for TH.

It is also interesting to note that C is horizontally symmetric (as opposed to T), and thus bottom and top menus are equivalent from a geometrical point of view (on T, the bottom menu is larger and the top menu is narrower). Participants preferred the bottom menu, which goes against conventions of placing the menu at the top of the display.

Summary:

We cannot validate or invalidate H6 (*menus should be placed at the widest horizontal portion of the display).* We further explore this hypothesis with more shapes next.

FOLLOW-UP PAIRWISE EXPERIMENT

The goal of this follow-up study was to analyze how previous findings generalize to more diverse shapes. We picked the most interesting composition revealed in the first study and conducted an experiment with four new shapes.

Shapes

We systematically explored shapes with increasing number of edges: triangle (3), trapezoid (4), pentagon (5) and hexagon (6). We also included an inversed triangle to see if the orientation of the shape had any effects.

Design

As before, we only compared visual compositions among shapes. We focused on the most interesting hypotheses (i.e. those related to the display shape) and removed the worst conditions (random grid in H4, shape menu in H6).

- *Sub-survey 1. Regularity* (H4): we studied three grid layouts (regular, radial and oriented) and 2 elements shapes (rectangular or as display), as seen in Figure 13. Overall, we had 15 pair comparisons for each shape x 4 shapes = 60 pairs.
- *Sub-survey 2. Predictability* (H6): We tested 2 positions for the menu (top and bottom). Overall, we had 1 pair comparisons for each shape x 4 shapes = 4 pairs.

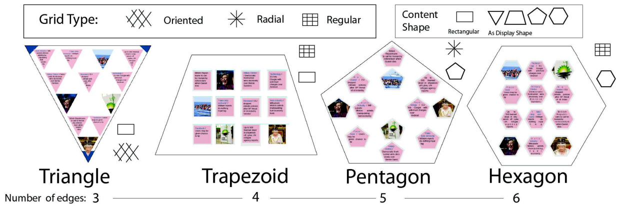

Figure 13. Shapes studied in our follow-up experiment.

Participants

In total 20 participants (5 female) from 7 different countries completed the four surveys. Participants were aged 29.8 on average (SD=5.1). 9 of them were university students, 6 worked in academia as engineers (1), professors (2) or researchers (3), and the rest had various professions.

Collected data

We collected 64 pairs × 3 questions = 192 answers per participant so a total of 192 x 20 users = 3840 answers.

Results

Step 1: Individual consistency checking

The mean TSR for all users was 0,93 (SD = .05). Individual consistency was at least over 0.8 for all users

Step 2: Overall consistency checking

Results show that the mean Kendall's u-coefficient is above 50% for all conditions (H4 nicer 66.8%, clearer 61.6%, symmetric 68.2% and H7 nicer 74%, clearer 56.6%, symmetric 71.6%).

Step 3: Model the data

The individual and overall consistencies were confirmed, so we proceeded to model the data as in our previous survey.

Results for Regularity:

On the Hexagon, Pentagon and Trapezoid, the Radial Grid was rated best with some exceptions: the Regular Grid on the Trapezoid was rated as clear as the Radial Grid (Figure 14). The Oriented grid was rated worst on these three displays. This was particularly true when the Oriented grid was combined with rectangular content, which had the lower ratings. Overall, shaped content looked nicer than rectangular content, which confirms the results of the previous survey.

Results were different for the Triangle: the Regular Grid was rated as nicer and more symmetric than the Radial and Oriented Grids. When the Regular Grid was combined with rectangular content, it was also rated as clearer. Interestingly, these results on the Triangle are also different from the results of the previous survey, where we found no difference between Regular and Oriented Grids. This means that the orientation of a shape (i.e. triangle vs. inversed triangle) changes the user preference on the grid layout.

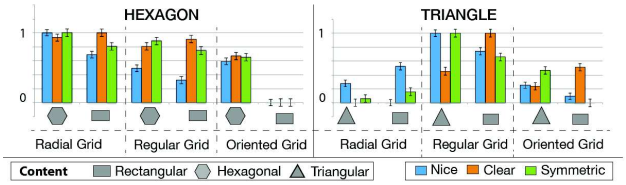

Figure 14. Results for Regularity (H4) on the Hexagon and Triangle displays.

Results for Menu position:

We only found a difference between Top and Bottom menus on the Hexagon and on the Triangle: on both shapes the Top menu was found nicer and clearer. This result on the inversed Triangle is different than the one from the previous survey, where no difference was found between Top and Bottom menus on the regular Triangle.

One hypothesis for this difference is that on the inversed Triangle, the Top area combines the fact of being the traditional location with a large area. Instead, on the regular Triangle, the Top was narrower, and thus participants were torn between the traditional menu position (top) and the larger area (bottom). This would also explain that no position preference emerged on the Pentagon and Trapezoid: on both shapes the top area is narrower.

Summary:

These results confirm the non-validity of H4 for other shapes except for the inversed Triangle (It is better to keep regularity via a rectangular grid than via different grid shape). Again, we cannot validate or invalidate H6 ("*Menus should be placed at the widest horizontal portion of the display"),* although results seem to indicate that the width of the menu along with the predictability of its position influence user's preference.

DISCUSSION

Guidelines for designing content for non-rect. displays

Based on our findings we propose a set of guidelines for designers on the use of symmetry axis, content shape, grid layout, regularity and menu position for non-rectangular displays. Some of these design guidelines contradict current conventions on rectangular displays.

Symmetry axis: The symmetry axis should be vertical to ensure that the final design is nice, clear and symmetric.

Content shape: Instead of using the traditional rectangular boxes for text or images, designers can reshape the content to fit the display (circular on circle, triangular on triangles, etc.). This reshaping will have different effects depending on the display shape: it will look nicer with circular content, or more symmetric with triangular content. However designers should be aware that sometimes reshaping content might make it appear less clear (such as in our triangle condition).

Grid layout: While using the traditional regular grid works well for certain shapes (regular and inversed triangles), using a grid with the same shape as the display shape can make the overall design look pleasing, clear and symmetric (as with radial grids in circle, pentagon and hexagon displays). A non-regular grid can benefit from non-rectangular content, as it better fits the shape of the grid (triangular content in oriented grid for instance).

Breaking content: To solve the problem of content not fitting exactly on the display, designers should favor breaking the regularity of the grid and making all content fit, rather than cutting elements by trimming the edges.

Menu position: While placing the menu at the traditional position on top of the interface works best for triangle and hexagon displays, designers could place it at the bottom in certain cases: this is a position that is nicer, clear and symmetric for a circular display, and that is equivalent to the top position for certain shapes (pentagon and trapezoid).

Generalization to other shapes

Since this work is the first exploration on how visual composition principles apply to non-rectangular displays, we decided to adopt a context-independent approach. We chose to study the generic properties of layout design instead of focusing on a given interface for a given application. The reason is that we wanted to provide generalizable findings rather than narrow in on specific guidelines that would be only valid for a specific case.

Our choice of shapes was based on usage scenarios envisioned for non-rectangular displays [31] and on an exploration of shapes with varying number of edges, which can also be found in [31]. Some of our results seem to be consistent across shapes, such as the fact that "shape-like" content looks better than a rectangular content, suggesting that they are probably valid for other shapes. Other results seem to depend on the display shape, such as the layout grid: while a radial grid is best for most display shapes (circle, hexagon, pentagon and trapezoid displays), a regular grid is better on triangular displays. In the future we plan to explore how these principles can be applied to specific usage contexts, which will imply a precise shape and display size, such as hand-held or in-vehicle displays. The size of the display can have an influence too, particularly when considering very small non-rectangular displays. We plan to study the size factor in the future.

Data collection from graphic designers

In our work we gathered non-rectangular designs created by 5 graphic designers, which informed our revision of traditional visual composition principles. Our designers had mostly experience in print and web design, and it could be interesting to explore how results would differ with other expertise. Also the task was to fit the content (image, text, icons) from an existing webpage to a non-rectangular display of the same area. If we had asked designers to create a visual layout composed of images, text and menus, without giving them the actual content, maybe results could differ. In our case, we wanted to ensure that all designers used the same content. One designer for instance stated that he usually works in team. Future work will further investigate the influence of designer's background and of task instructions.

Limitations and future work

Beyond the previously cited propositions concerning the shapes and the design task, we would like to conduct a larger study with more graphic designers. However having access to professional designers is not simple, and their experience may bias their designs on unconventional displays. Instead we plan to contact design students, whose visual creativity is still being developed.

Another limitation of our studies is that we did not test all possible combinations between conditions, given the huge number of parameters influencing visual composition. In the future we plan to further study the combinations between the factors that proved to have an effect on user preference, such as between layout grid and menu position.

Last, we really want to know what we could learn by using an eye-tracking setup on our experimental conditions. We want to explore two points in this regard: 1) visual saliency of non-rectangular displays, i.e. which regions of the shapes are most salient [3]; and 2) visual path used by the eyes when searching for a specific information on non-rectangular displays. Search paths follow well-known patterns on rectangular websites, such as Z or E patterns [7], but these may differ according to the display shape.

CONCLUSION

We studied how traditional content layouts can be adapted to fit different non-rectangular displays. We first ask graphic designers to fit the content of a newspaper webpage (text, images and icons) into different non-rectangular displays. We use their output to generalize and adapt existing composition principles for rectangular displays.

We evaluated the revised principles through two paired comparison questionnaires where participants compared pairs of layouts. The first survey explored Symmetry, Regularity and Predictability. The second survey extracted other interesting cases and applied them to additional shapes. Using the Bradley-Terry-Luce model to analyze our data we discuss the differences between the different compositions and propose a set of visual design guidelines for non-rectangular displays.

Although there are many other directions to study we believe that our work is a first step toward defining new guidelines for the design of free-form displays and it also has valuable application in the field of information visualization.

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