Making Distortions Comprehensible

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Abstract

This paper discusses visual information representation from the perspective of human comprehension. The distortion viewing paradigm is an appropriate focus for this discussion as its motivation has always been to create more understandable displays. While these techniques are becoming increasingly popular for exploring images that are larger than the available screen space, in fact users sometimes report confusion and disorientation. We provide an overview of structural changes made in response to this phenomenon and examine methods for incorporating visual cues based on human perceptual skills.

Keywords: Distortion viewing, visual comprehension. perceptual skills

1 Introduction

Although communication is a central purpose of graphical interfaces, visual comprehension issues often take a back seat to such concerns as functionality, speed of interaction and efficiency of user performance. This paper approaches graphical interfaces from a visual languages perspective, which suggests that human abilities to perceive should play a significant role in designing visual information displays. In particular, we explore a class of viewing techniques (multi-scale/distortion) that have been developed to display detail in context. This is achieved by magnification of the areas of an image where detail is desired, in exchange for compression of the remaining context.

Over the past fifteen years a great variety of techniques has been developed (for surveys see [13, 18, 25]). Initially, they were called *fish-eye views* by analogy to a fish-eye camera lens that presents an image with radially increasing compression. Current techniques, which admit a greater variety of resulting views, are called *distortion viewing*, *multi-scale viewing* and *detail in context views.*

These techniques strive to provide increased information comprehension, ease of navigation and effective use of screen space. However, users have made comments about confusion and disorientation. It would appear that in approaching an alternate solution to the screen usage problem, some new comprehension difficulties have arisen. Because of the potential benefits of multi-scale viewing, it seems important to address the problem of making these distorted images understandable. The user should be able to comprehend at a glance which sections are magnified/compressed with at least an approximate notion of degree.

2 Motivation

This section defines detail in context viewing and notes the comprehension issues that motivated research in this area. Detail in context interfaces are particularly interesting to discuss in terms of visual communication because their initial motivation came from comprehension issues. While they present a reasonable solution to the initial issues they addressed, new comprehension issues are raising questions as to usefulness of this approach.

The phrase *detail in context* is defined as the ability to see simultaneously, for some chosen aspect of the information, sufficient local detail set in overall global context. While there is considerable support for the importance of this idea, it is not achievable in the current screen real estate paradigm. With windows, icons, panning and zooming the desire to examine details often conflicts with the ability to maintain global context. Zooming out of or compressing the data to fit within the space of the screen can result in its becoming too dense to discern detail. Zooming into or magnifying a region will result in the loss of context. Magnifying a subsection in place, obscures local context. By using multiple images, global structure can be displayed in one while another can hold the required detail, however, the visual connectivity has been lost. The single situation where one can obtain a detail in context view is when the entire image will fit on the screen at once.

Research into detail in context displays started from a desire to create a more intuitive interface. Spence and Apperley framed their discussion in terms of navigation and proposing the bifocal display [25] as method to combat user disorientation in large information spaces. Subsequently Furnas' [4]

studies across a great variety of subject areas (geography, workplaces, history, and newspapers) revealed that people naturally retain and present information in a manner that utilizes detail in context. This insight into human information handling led to considerable effort to translate these ideas into an interface approach.

Not surprisingly this motivation is echoed in psychology and cognitive science literature. Detail in context viewing supports the human potential for visual gestalt, reduces cognitive effort needed for re-integration of separate views, and accesses spatial reasoning for navigation problems.

The point stressed in this paper is that from the beginning this stream of research has been motivated by the desire to increase the ease of information access. The ensuing research has indicated that a growing variety of types of distortion can create detail in context viewing tools. In fact, studies [9, 24] indicate increased user performance for path finding tasks. However, as research continues points continue to be raised concerning users comprehension of the multi-scale displays that detail in context techniques create. The advice from the literature can be summed up as follows:

- Avoid all occlusion if possible [3].
- Keep focal points in at least approximately the same location as in the initial layout [9].
- Smoothly integrate the focal point into its context [23].
- Use a familiar distortion curve (hemisphere) [22].
- Preserve the mental map by maintaining orthogonality, proximity and topology [15].
- Animate transitions between views [1].

3 Comprehension Issues

While there is considerable support for the idea of distortion viewing we do not want to create a new method of viewing information that brings with it new types of confusion. From observations, discussions and comments in the literature it seems that there are two basic comprehension issues arising with the use of distortion viewing tools: recognition and interpretation.

3.1 Recognition

When the choice of focal sections changes in emphasis, location or number, a distortion viewing tool creates a new view of the same information representation. It is apparent that users cannot always recognize that they are actually looking at the same information.

When we layout or display information on a computer screen we choose different types of representations depending on the characteristics of the information. While there are times when changing from one representation to another is desirable, sometimes it is the particular representation and the relationships it reveals that is of interest. This paper addresses exploration of the information through a given representation. In this situation it should be evident that the information is undamaged by changing the view. For example, rotating an object provides different views of the same information representation, similarly when stretching and distorting an image we want to be aware that what is changing is merely the view.

3.2 Interpretation

Recognition that we are still examining the same information does not automatically mean that we are able to interpret or understand the new view. Can items that are displayed in different or even varying scale be compared? The extensive discussions [27] on the possible ways that mis-interpretations occur in visual representations might indicate that distortion viewing is fraught with danger if not bound to failure. The question is can we simultaneously retain the advantages that seem to accrue through distortion tools and make them understandable? What kind of support can be included to make them more readable? Will visual support be enough? If the idea of presenting detail in context views is to be truly useful a user must be able to interpret the information in its distorted form, and be confident that distortions do not cause the information itself to be misunderstood.

4 Types of Information Representations

The basic problem is that a distorted image can be difficult if not impossible to read. However, this is not true to the same degree for all types of images or all types of distortions. Let us look at examples from the extremes.

4.1 Information Representation Styles that Obscure Distortions

Distance encodes meaning: There are many ways to use position or Euclidean distance within the display to encode some aspect of the information (see [2]). For example, in maps distances are a scaled representation of actual distances in the information, and in graphs node size can been used to encode some aspect of the data. Figures 1 and 2 each hold a bank of three images, one undistorted and two distorted views, in no particular order. For a personal experiment, examine them before reading the captions. While comprehension is important for all types of images there is a particular point to be made for those where distance or size is used to encode information. In our culture, interpreting maps assumes that distance is to scale and that scale is clearly indicated. A distortion view will create an image of the map containing sections of different scale as well as sections of varying scale. As seen in Figures 1 and 2 it would seem just as feasible to read the distorted image as if it were a different section of coastline or another part of the surface of Mars.

Unfamiliar layouts: The inability to tell whether or not a view has been distorted increases as familiarity with the information decreases. The examples in Figure 2 are most likely unfamiliar images. On the other hand user disorientation has been reported in cases when the map was familiar [23]. We suggest that this disorientation results from the discrepancy between the information provided by the distorted map and what the users feel they know to be true

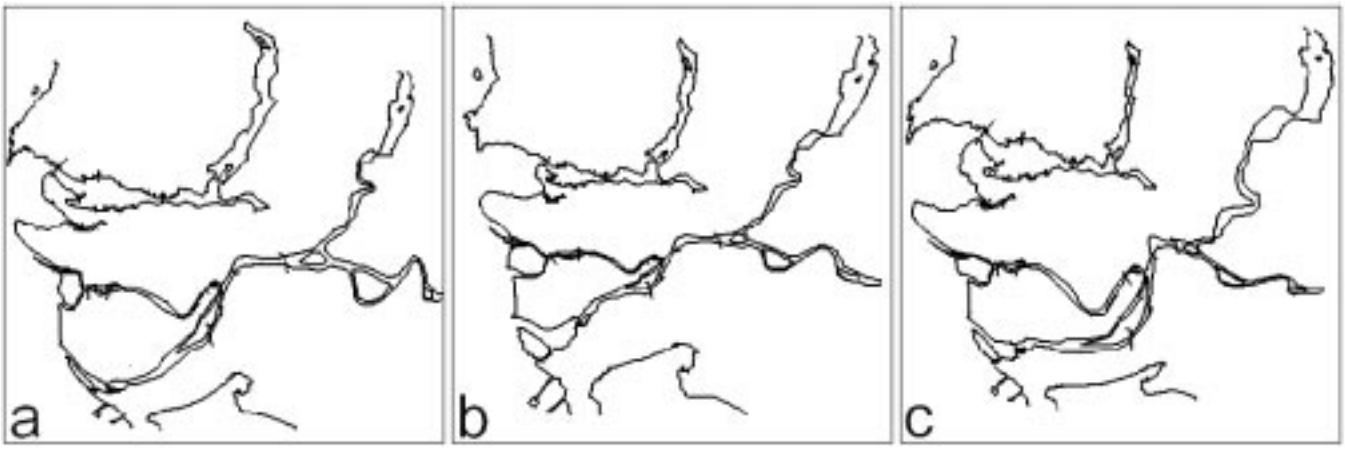

Figure 1: Map of the Vancouver coastline: a) with three focal points; b) undistorted; c) with four focal points

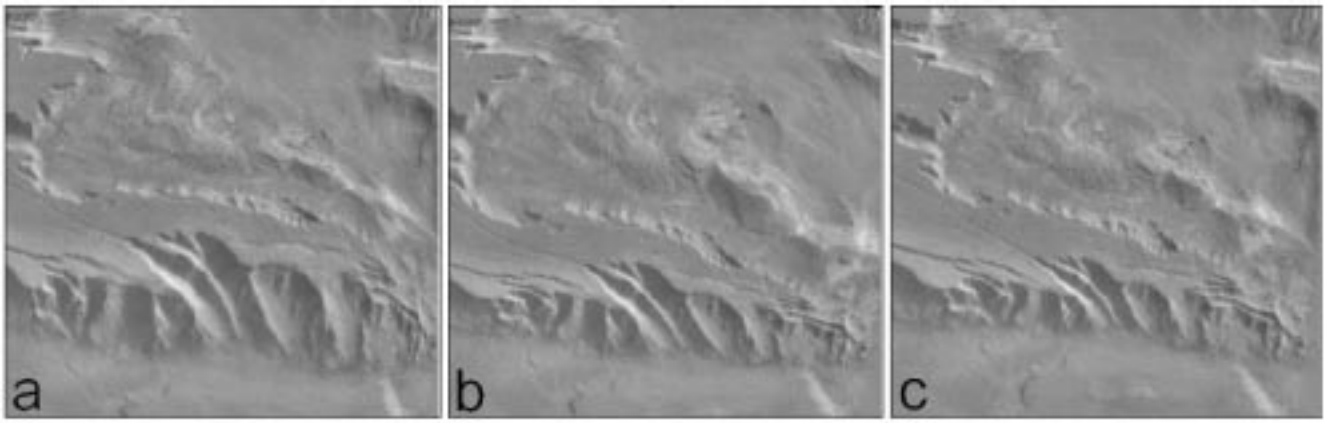

Figure 2: Photograph of the surface of Mars: a) with two focal points; b) with three focal points; c) undistorted

about the original map. This effect parallels what Tufte [27] discusses extensively as 'lie factors'. In this case previous knowledge is protecting the user from assimilating false information. In unfamiliar information spaces there is a greater chance of being misled.

Sparse layouts: In sparse and irregular layouts even familiarity does not help very much. For example in Figure 1 even for those of us to whom this coastline is very familiar the sparse and irregular nature of the information make it very difficult to discern the location of focal points. Even if focal points can be located it is hard tell much about them, for instance, the degree of magnification, or how far the distortion extends into the image.

4.2 Information Representations Styles that Reveal Distortions

Regular layouts: When the information display is very regular, changes in its pattern will define the distortions. Figure 3 shows a grid graph where the distortions are so readable it seemed unnecessary to include the undistorted image for comparison, and the text example in Figure 4 also shows how regularities in the layout make the distortion explicit.

Familiar layouts: Figures 4 and 5 show examples of a typical text field and a more sparse use of text, respectively. In Figure 4 our familiarity with text and the regularities in the layout combine to make very readable distortions. With the more sparse use of text in Figure 5 it is our recognition of changes across the word Columbia that reveal the distortion. However, as noted earlier distorted views of the familiar are uncomfortable. This was handled in Document Lens [21] by 'greeking' the distorted text to make it less irritating.

5 Towards a Solution

Paralleling the distinction between recognition and interpretation we separate the discussion along the lines of the structure, inter-view transition and the visual cues that are used to support distortion comprehension. Though there is overlap, the factors discussed under structure of distortions

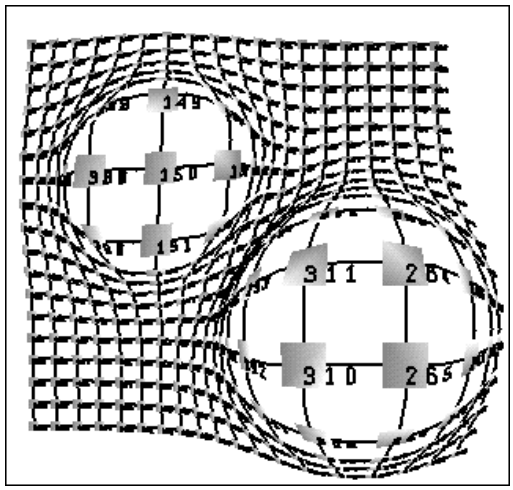

Figure 3: Regular layout a grid graph with two focal points

Figure 4: A text file with two focal points

(Section 6), and the transitions between distorted views (Section 7) predominately address the issue of recognition while the use of visual cues (Section 8) chiefly clarifies interpretation issues.

6 Structure of the Distortions

The actual structure of the distortions can significantly affect how easy it is to recognize the information from one view to the next.

6.1 Limiting the distortion

A very simple but significant idea in maintaining recognition is to limit the distortion. All previous approaches spread the distortion to the very edges of the image. Some [10, 16, 22, 23] are based on an asymptotic mathematical curve and achieve in "the ability to display infinitely large images at the expense of infinitely crumpling the edges" [15]. When the extent of the distortion is constrained portions of the image remain intact and each distorted area can be bounded,

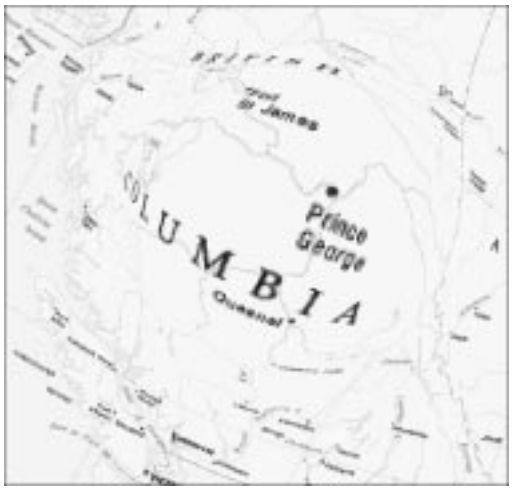

Figure 5: Sparse text, B.C. map, with one focal point

providing a good deal of undistorted background frame or edge information (Figure 6 (c) and (d)).

6.2 Magnification to scale

From our familiarity with use of scale in maps and now with zooming on a computer, it seems that we have little trouble if all that changes is the scale factor. It is important to provide the possibility of arbitrarily shaped focal regions that the user is aware are scaled only. In addition we add the option of interactively extending the scaled only section [3]. Figure 6 (b) shows a magnified only focal section and Figure 6 (c) shows both a constrained distortion (intact background) with a scaled only focal section; the distorted regions merely forming a visual connection between the two differently scaled sections.

6.3 Smooth integration

Sarkar's [22] suggestion to smoothly integrate the focal point into its context is extended to include also smoothly integrating the distorted region into its context. Figure 6 (a) shows smooth integration between focal area and background.

6.4 Distortion control

It has been noted that use of a distortion curve like a hemisphere [22] might be familiar enough to make the resulting views less disturbing. Extending this to include the possibility that certain types of distortions might be more appropriate for certain types of information, we introduce the notion of distortion control [3]. In every distorted view is a trade off between how much each foci is magnified and the degree of compression in distorted sections. Distortion control puts the space allocation decisions in the hands of the user, allowing for many different distortion patterns. All the images in Figure 6 show different variations in distortion control.

6.5 Minimize reorganization

While some of the initial fisheye approaches [9] did not keep focal points in the same location as in the initial layout, most recent ones do respect the existing layout. The exceptions such as Noik's [17] use detail in context techniques to create layouts, in contrast to adjusting an existing layout. This idea

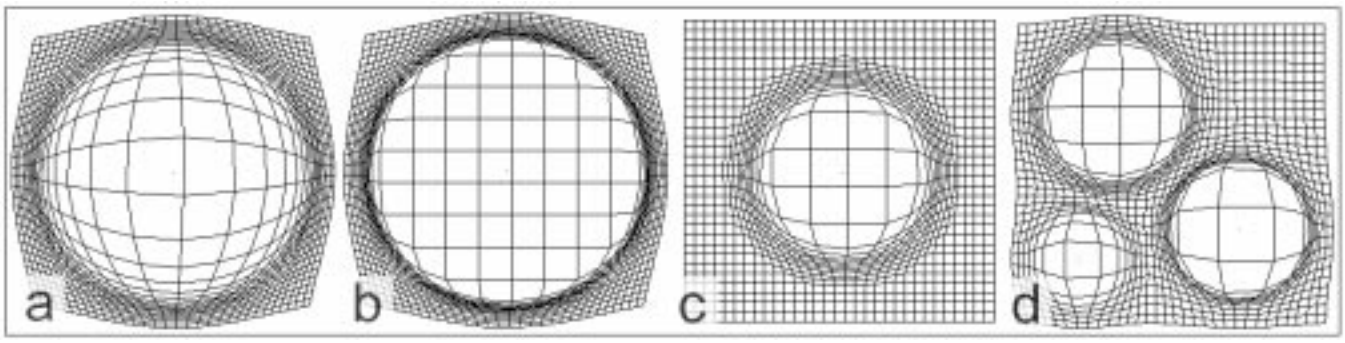

Figure 6: Grid graph, variation in distortion control: a) smooth focal integration; b) uniform scaling across focal region; c) constrained distortion; d) multiple foci

of respecting the original display is taken much further in the following point.

6.6 Mental Map

Misue et al. [15] discuss the possibility of aiding users in recognizing distorted views by preserving what they term a *mental map*. They suggest that maintaining three spatial properties may aid in preserving a user's mental map thus helping information recognition. The factors proposed are: orthogonality, that objects maintain relative right/left up/down positioning; proximity, that adjacent objects remain adjacent; and topology, that containment relationships are preserved. This is further discussed in [16, 23, 26] noting a distinction between orthogonal and radial distortion. The orthogonal distortion preserves orthogonal relationships in the display but creates new, perhaps artificial, clusterings. A radial approach is better at preserving proximity relationships which may be more important in some situations. Storey and Müller [26] declare that a choice must be made between them.

However, by using a radial approach in three dimensions 3DPS [3] provides the advantages of preserving proximity and topology relationships in the projected or top view while maintaining orthogonal relationships in the side view without the attendant problems of new clusterings and extraneous foci. Orthogonal relationships that are adjusted slightly in the 2D perspective projection, are maintained in the 3D form. While this is not quite an all in one solution (the user must adjust the viewing angle), the fact that the original information has just been stretched is quite apparent.

This discussion about preserving our mental map is at the heart of identifying those aspects about the layout which should be preserved. However, presently it is not clear what we actually do hold as a mental map of an image. While it is probable that we do spatial thinking in some manner that is akin to visual observation [7], it is not clear to what extent we maintain a visual image. It is possible that the disorientation that users mention occurs when the modified visual image conflicts with their own prior mental memory representation of the image. Since we assume that a user's mental representation is not a photocopy of the retina, it is reasonable to assume that there may be some set of distortions and/or support for the distortions that will allow users to maintain an accurate mental representation. This involves both recognition and interpretation.

7 Transitions

Perhaps the most important factor in recognition is how the transition between views is made. We recognize the importance of the observation in [1] that these transitions be visually continuous and suggest that it may be equally important that these transitions be reversible.

7.1 Continuous Transitions

A sudden transition between an original view and its subsequent distorted view can leave a user unsure about what information the display contains. It seems possible that the user may be looking at an entirely new set of information. Some techniques have such abrupt transitions [9] and some even entirely reorganize the display [17]. The need for continuous visual transitions was recognized and provided in [1, 3, 10, 12, 21]. Actually seeing the distortion created is very explanatory. However, this only applies at the time of transition.

7.2 Reversible Transitions

If the intention is to create a distortion browsing environment where one can visually explore information. Incorporating support for the user to learn about the distortions, ideally will create a situation where a user can become increasingly familiar with the viewing paradigm. One possibility is to make all distortions readily reversible. Colloquially one is aware that backtracking is used when learning. More emphaticly Piaget [19] explains that in order to know an object, a person must act upon that object. This action can vary from simple pushing and pulling to more "sophisticated intellectual operations, which are interiorized actions, carried out mentally (e.g. joining together, putting in order, putting in one to one correspondence), knowledge is constantly linked with actions or operations, that is, with transformations." He goes on to say that "Knowledge then... neither arises from the

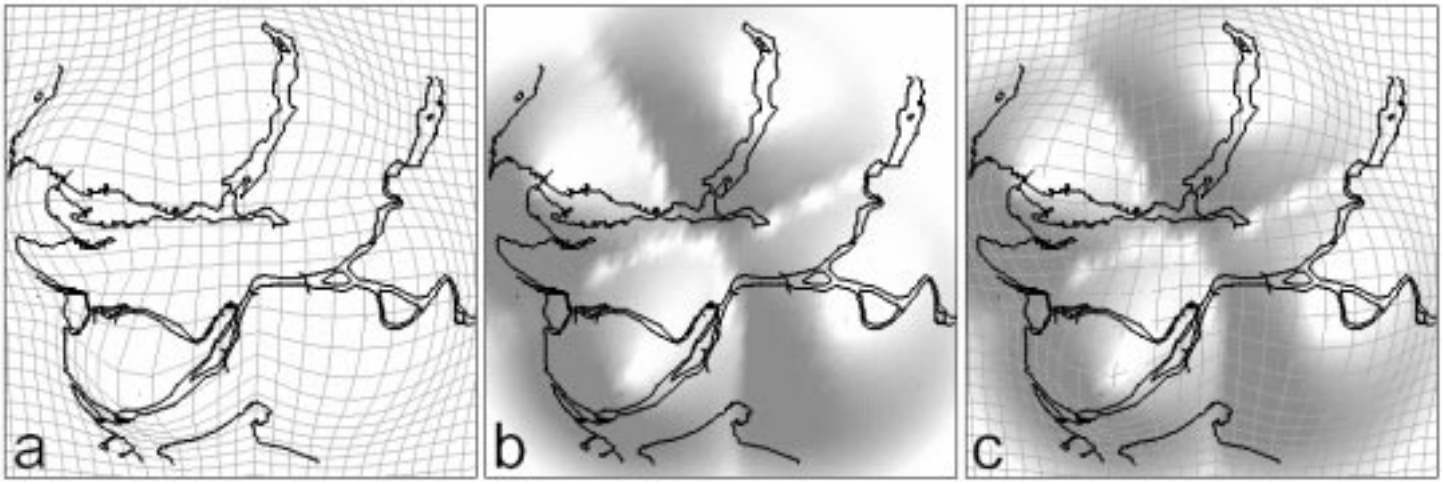

Figure 7: Map of the Vancouver coastline with same four foci as in Figure 2(b): a) grid; b) shaded; c) with grid and shading

objects nor the [person]... but from the interactions." Taking this advice seriously, it is apparent that it is important to create an interactive environment.

Piaget has a notion of two stages that someone goes through in developing understanding that he calls "revertability" and "reversibility." Revertability is the idea that two different states are somehow connected, and that one can get from one to the other and back again. Reversibility is the understanding that the two stages are in some way equivalent (more of an internal understanding than something external). An example of this is a young child's understanding of volume. Initially, a child will think that there is more milk if the glass is taller. Next, they develop the notion that you can get it back, that is, if you pour the milk from the wider glass back into the taller glass, you somehow "get back the bigger amount of milk." With time through observing this revertability the child develops an understanding of a separate notion (volume) that stays the same no matter what shape the glass. If possible this is exactly the type of deeper understanding we wish to enable. We wish to create an environment where the user can interactively push and pull, stretching into sections of the information with actions that allow visual exploration but leave the user confident the information they are exploring remains consistent.

We suggest that the fact that previous (or original) states of the image are readily available is very significant. Foci can be created, moved and removed, in each case the image reverts to its original layout. The important points are:

- Reversibility is closely connected to comprehension.
- The original undistorted image should be recoverable.
- Reversible distortions allow reference to the original topology.

Pulling and pushing should have equal and opposite effects. As a focus is moved through an area there is no residual effect of its passing. This should both make the tool more understandable with increased use.

8 Visual Cues

Thus far we have discussed how aspects of the structure of a distortion can affect comprehension, and the important nature of inter-view transitions. These both primarily address the issue of recognition. There remains the heart of the interpretation issue. That is, given that one can recognize that the information being examined is the same through successive distorted views, can one read the information's relationships in the distorted view without being mis-informed?

Visual representations of information ideally make certain relationships inherent in the information apparent; type of vegetation in a location, amount of rainfall that supports this vegetation, or how air moves over an obstacle. In many of these instances positional information plays a significant role in the reading. For example, a tight curve in air flow may represent a sudden change in direction, magnifying this section to check on the presence of any extra details will also spread the curve. One must be aware of this change in local scaling so as not to be mis-informed.

Our intention is to provide sufficient support to makes these changes in scale visually explicit. To this end we will examine the use of visual cues. The term visual cue is used to indicate any aspect of the display that has been added for human perceptual reasons, such as attracting attention, creating emphasis, or adding explanation, rather than to directly represent some aspect of the information.

In considering possible visual cues one direction to take is to utilize Bertin's notion of visual variables [2]. However, these variables were identified for printed graphics and were intended to be used as part of the mapping between the information and its representation. While they are proving useful in designing computational displays they are not en-

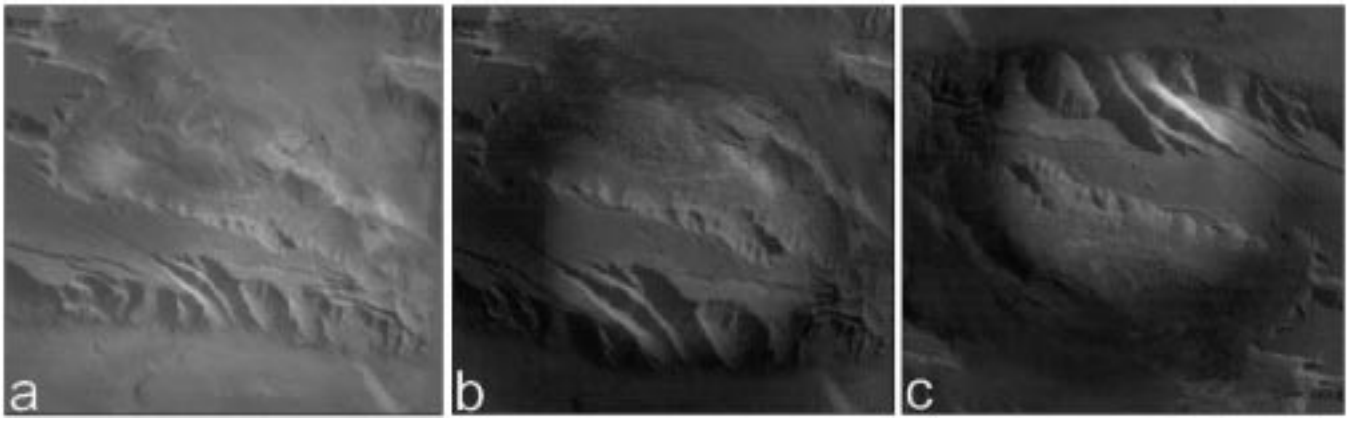

Figure 8: Topographic image of the surface of Mars: a) undistorted; b) with one focal point and the lights in agreement; c) same image as center rotated 180 degrees putting the lights in opposition

tirely applicable [28]. Another approach is to examine the capabilities and limitations of graphical computational displays. However specific attributes might be hard to define since computational capabilities and display technologies are still evolving rapidly. An alternative direction is to consider human perceptual capabilities, however once again this is an evolving research field. In the face of this dynamic research we have found it useful to identify different approaches to creating visual cues and their advantages and disadvantages of each. Four types of visual cues are discussed and applied to distortion viewing (3DPS [3]).

8.1 Constructions

These types of visual cues are created to fit the particular information representation and the task to be accomplished. While these may well be the most effective because they are individually tailored to the situation, they will usually be unfamiliar and as such definitely require explanation. It also may not be immediately apparent how to create a useful construction.

Application: The Surface

For users to build an interpretation of a representation they must connect it in their minds with something they already understand. In other words, for a given representation to be interpreted, it must stand for some object. The information representation stands for the data it symbolizes. However, in the users perception what does the distortion represent? The distortion can be a created by relatively complex mathematical function. A user may not know that this function exists, nor its details, and may not actually want to, and yet they need to understand how their information has been manipulated. To provide a method by which one can make distortions visually explicit, the information can be placed on a surface [3]. This yields a method of revealing the distortions even if some sections of the information representation are sparse. This provides several advantages:

- The resulting technique will not be tied to any particular kind of information layout.
- If the visual cues are provided about the surface, distortions will still be readable even when there are gaps in the information layout.

The 2D information can be thought of as lying on a planar surface. This surface is manipulated in an analogous manner to which one may manipulate a piece of fabric. In folding or re-arranging a piece of fabric one has no doubts as to whether the manipulations are interfering with anything that is printed on the surface. This pliable surface is a construction that does not represent any aspect of the information itself. Instead in provides a metaphor by which the distortions can be understood.

Application: Outlines

Once the image is a complex combination of distorted and untouched areas, it is useful to be able to see where one starts and the other stops. Optional outlining of scaled areas of magnification and the extent of the distorted area may be provided. In many viewing situations it is useful to be able to delineate the focal sections that have been magnified clearly separating sections of uniform scale from the distorted sections which link them maintaining context and position. This is a simple construction, but unless it is explicitly stated there is no indication of what these lines actually mean.

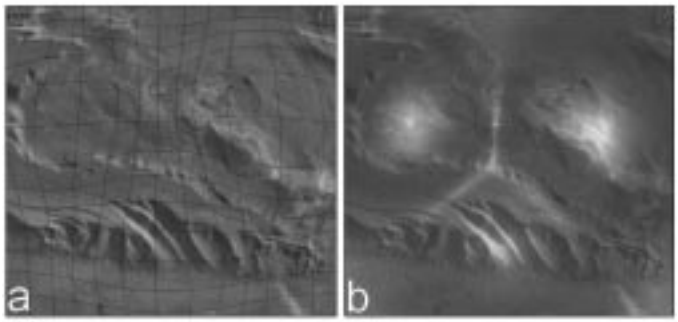

Figure 9: Topographic image of the surface of Mars: a) grid; b) with shading

8.2 Visual Formalisms

The term *visual formalism* was introduced by Harel [8] in connection various types of graph layout. We use the term more boardly to include other types of visual constructions such as charts, diagrams, as well as use of colour that assumes predefined meaning (e.g. red for stop, green for go). These can be thought of as constructions that are in common enough use within given communities such that it is reasonable to expect them to be understood. However, as these aspects have been learned they will be culturely tied. When making use of this type of visual cue it is important to consider who will find it easy to read, who will need help learning it and whether it will misinform some communities. Colour is a good example of the last point as it means many different things in many different cultures. In fact, the example about red and green above may not agree with all readers. Some of these formalisms may have become so familiar for certain groups of people that they may even prefer them to the more intuitive precognitive skills still, these preferences will be culturally tied and therefore need to be used with care.

Application: The Grid

The grid is a visual formalism borrowed from cartography and is familiar to those whose experience includes reading maps where lines representing longitude and latitude are used to explain relative scaling. Similarly grids can be used to reveal the nature and extent of the magnification and compression in a distortion view.

Overlayed across the entire information representation, a grid provides relative compression and magnification information. Figure 7 shows the four focal image from Figure 1(a). Figure 7(a) explained with a grid, (b) with shading and (c) with both.

Issues: The Grid and Topographic Images

When the grid is applied to a topographic image it has the effect of somewhat flattening the relief. For example in Figure 9 one can still see the ravines but the overlaying of the grid has diminished their impact. Here the use of shading (section 8.4) to reveal the focal areas is more effective and creates less interference.

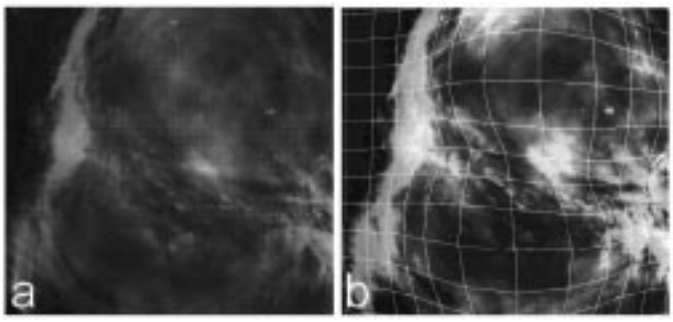

Figure 10: Orion nebula with two focal points: a) shaded; b) with the grid

8.3 Fundamental Perceptual Skills

In this group we include perceptual skills that current research indicates, though not decisively, may be precognitive. For example, there is an interesting discussion as to the nature of our ability to read perspective. While some argue that this is precognitive there is some indication that it is culturally tied. Stories [6] exist of people from other cultures following a perspective diagram on planting and ending up with convergent rows. In utilizing skills from this grouping it is possible that the advantages listed under precognitive skills (Section 8.4) may accrue; however, one must be aware that this cannot be assumed.

Application: Perspective

One of the more successful metaphors employed to date in distortion viewing is the use of three-dimensional space [3, 5, 14, 21]. These distortions are created using perspective to provide magnification and the resulting 3D image to provide visual information about how context has been distorted. Not only do we understand how a three-dimensional world incorporates more than one apparent scale, the natural action of bringing objects of interest closer in order to see them better can form the basis of an intuitive interface metaphor.

This approach provides two useful metaphors. One involves the actions performed to create the distortions. The action of pulling a section forwards to see it better, or in this case actually magnify it, seems like a natural action and response. The second metaphor involves the over all appearance. The end result of a multi-focal view can be seen as a curved 'landscape' with hills and valleys. Viewing this surface from above causes those areas that are closer to appear larger and those further away or tilted to be compressed.

The grid lines reveal the shape of the distortions by accessing two human depth cues: perspective information (without requiring edges) and texture gradient.

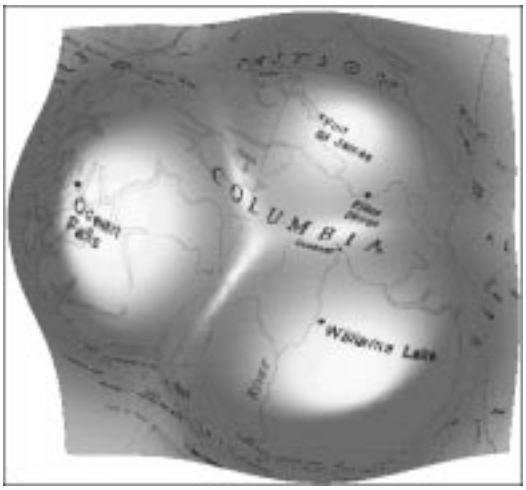

Figure 11: Map of B.C. with three foci, here the shading clearly reveals the soft surface

8.4 Precognitive Perceptual Skills

A perceptual skill is called precognitive if it is thought that it does not require conscious processing. It is believed that such skills have been with us for a long time evolutionarily.

The possibility of using such skills as visual cues is very appealing because:

- Processing should be virtually instantaneous.
- They should interfere very little with other conscious cognitive work.
- They should be readable to all humans. A truly low level skill will not be culturally tied.
- They should require little or no learning to be understood [28].

All this seems too good to be true, and that may be the case because in pursuing this path several problems arise. First, cognitive science research is still actively in the process of discovering what these skills are; and there are several for which arguments can be made both for and against declaring them as precognitive. Second, even given that we could agree on a list of such skills, these are very unusual aspects on which to base a design. For the purposes of research we consider those visual perceptual skills about which there seems to be fairly solid agreement in the literature as precognitive skills.

Application: Shape from Shading

As the desire is to utilize precognitive skills where possible, a first choice is to use shading. "The human visual system is capable of quickly and accurately establishing three dimensions from variations in luminance [shading] only" [20]. Although the retinal image is two dimensional, humans are capable of deriving an awareness of form and depth from shading [11]. It is probable that this ability to recognize shape from shading is one of the most primitive. One reason for this belief is the fact that many animals use counter-shading as part of camouflage colouring [11]. The prevalence of this is thought to indicate the significance of shade in detecting form. Ware [28] points out that distinguishing shape from shading is part of what he terms a sensory language, that bridges cultures and does not have to be learned. Such a low level visual routine is perfect for our purposes and may even provide an aspect of the interface that requires no learning. Studies [11, 20] also indicated that the extraction of shape from shading seems to assume a single light source. If objects next to each other are lit from opposite directions one will be read as concave and the other as convex. There is also an assumption that the light comes from above. These basic assumptions are easy to comply with, giving us a method that will do exactly as desired in making the distortions explicit. By making use of shape from shading we ensure that it is precognitive abilities that are being accessed instead of possibly increasing cognitive load. Note however that while shading is very effective in providing comprehension about the resulting 3D form, in some cases the shading itself is dark enough to obscure information. Shading should be optional and adjustable both in direction and intensity.

Issues: Light Position for Shading

As noted in the discussion above, for the best reading of shape from shading the light needs to appear to be coming out of either the upper right or upper left corner. For images that have no shading themselves this is no problem. However, when the image itself has shading care must be taken. If the lighting in the image comes from the same direction as the lighting being used as a visual distortion cue then they complement each other and both the distortion and the topology are readable. If the lighting comes from an opposing direction the eye will resolve the image with its preference for an upper off center light source dominating. The effect this has is to turn concave topology into convex or vica-versa. Figure 7 shows a topographic photograph of the surface of Mars with a single focal point. In the image Figure 7(c) the photograph has been rotated 180 degrees. This places the lights in opposition and reverses the concavity reading.

Issues: Shading and Colour

Colour is composed of hue, saturation and value. Shading operates on value. For images of diffuse colour it is easy to read the shading as simply darker colours (Figure 10). In this situation it does little to disambiguate the distortions. However, the grid is still effective. Notice how in Figure 11 the shading is perfectly effective on a coloured image. This is probably due to two factors: the use of colour in the map of B.C. is very simple while the colour in the nebula is diffuse and complex, and the image of the Orion nebula is less familiar than that of a simple map.

9 Conclusions

We have discussed the distortion viewing paradigm from the perspective of user comprehension. We identify two important aspects to this problem, recognition and interpretation, and provide an overview of how different factors concerning recognition have arisen and been addressed through structural changes. While these structural changes are significant, the fundamental problem persists. It must be possible for the user to interpret the distorted images.

In following general visual information presentation guidelines, one important question to be addressed is; 'does the resulting display distort the information?' In the distortion viewing paradigm the answer is obviously yes. However, if one re-examines the design guideline it is apparent that the real issue is whether or not the user is led to false conclusions about the information itself. We suggest that if the user can understand the distortions they will still be able to accurately interpret the information.

Through the use of the soft surface as an example, a metaphor is described that is understandable from a user's point of view. Further, to actually make this metaphor readable we examine visual skills to gain a better understanding of how to draw on aspects of the world that are already understood. The simple groupings of:

- Precognitive perceptual skills
- Fundamental perceptual skills
- Visual formalisms
- Constructions

offers several useful directions. It provides pointers for

places to look for relatively well-understood visual cues. It helps us identify which aspects of our interfaces may be cross cultural. It allows us to make use of cognitive science research without having to wait for definitive answers. Choosing cues in this manner lets us be aware of what types of explanations our display will need. Furthermore, taking advice from human potential not only does not tie us to what has already been done, but allows us to take small steps towards developing the computer as a medium in its own right.

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