Chapter 6

Making Distortions Comprehensible

Taking advantage of a computer's elastic presentation space involves considerable use of distortion. However, there is a basic comprehension problem in that a distorted image can be difficult if not impossible to read. Though this is not true to the same degree for all types of images or all types of distortions, it is important for users to be able to trust that the presentation will provide the necessary support to allow them to correctly interpret the information they are examining. Presentation research has always been motivated by a desire to make more understandable, easier to use presentations. However, in solving the comprehension issues that were first identified, new comprehension issues have arisen.

The history of presentation research has been an iterative process fueled by comprehension factors and continuing to identify new comprehension issues as it progresses. A problem identified early in the process was that the windows display paradigm interfered with readability, in that accustomed support for detail-in-context readings was missing, and with navigation, in that accessing large information spaces through a small window gave rise to the notion of being "lost in computer space" [105].

Readability in terms of detail-in-context was initially discussed from the perspective of knowledge extraction and knowledge retention and presentation. Greater facility for knowledge extraction has been attributed to the visual representation of information [13, 160, 157]. Printed information graphics offer the advantage of easy recognition of non-linear relationships. For example, looking at a map reveals direction as well as distance between cities. This type of advantage requires the ability to see both cities in a single presentation. The size of a computer's display space coupled with the available resolution results in the ability to present only relatively small images in full resolution. The prevalent windowing paradigm, with separate views, panning, scrolling and zooming, requires users to build relationship information in a piecemeal fashion. The ability to see the full visual representation is important to support relational readings.

Also, it appears that knowledge is naturally retained and presented in a manner that sets a subject of current interest with enough of the related information to provide context. Furnas' [52] studies across a great variety of subject areas and situations (geography, workplaces, history, and newspapers) provide evidence of this. For instance, a person will know the town they live in very well but may only know the names of neighbouring towns.

Furthermore, when looking at a large information space through a relatively small display it can be difficult to navigate. For instance, when looking at a map of North America through a display that is currently only showing Boston, is San Francisco directly west? Finding location in unknown information spaces is even harder.

The primary response to the comprehension problems of readability and navigation has been to develop detail-in-context techniques, with their attendant distortion and/or filtering. These techniques have achieved their goal of creating detail-in-context presentations, and there is evidence that these presentations do help in readability [157] and navigation [70, 141, 45, 154]. However, detail-in-context presentations have not been widely accepted. While detail-in-context presentations appeared successful in creating solutions for the comprehension problems they set out to address, new problems have arisen. People using detail-in-context presentations can become disoriented from one presentation to the next. We call this the problem of *recognition*. Suggestions that have been made to address the recognition problem can be summed up as providing animated transitions between presentations [5] and limiting the nature of the distortions [107]. However, it still seems that there are remaining comprehension problems with detail-in-context presentations. Recognition that the new presentation contains the same information as the previous one does not automatically mean that users are able to interpret or understand the information in the new presentation. We have identified this as an *interpretation* problem.

All the identified comprehension problems remain as issues. In other words the screen real estate limitations of a computer still need addressing. The ability to recognize the fact that the information is not damaged by changes in presentation remains a factor, as does the importance of being able to interpret the information as it is presented. We explore the possibilities of providing enough visual support to make a the full range afforded by the computer's elastic presentation space comprehensible.

This chapter is organized as follows. Section 6.1 defines the distinctions between the recognition and the interpretation problems of comprehending distorted images. Section 6.2 notes the responses in the literature to the recognition problem. Section 6.3 discusses how the interpretation problem varies across different representation types. In Section 6.4 we identify and discuss three methods that can be used to address these issues, namely: structure of the distortion, nature of the transitions and use of visual cues. Section 6.5 discusses how the structure of the distortion affects comprehension. The importance of transitions between presentations is discussed in Section 6.6. Section 6.7 examines the use of visual cues to disambiguate the distortions. Section 6.8 discusses ongoing comprehension problems.

6.1 The New Comprehension Issues

As a first step in considering the problem of making distortion presentations understandable we distinguish between recognition and interpretation. Clarifying this distinction has proved useful in making elastic presentations comprehensible. While some methods contribute to solutions for both of these problems, this is not necessarily the case. In fact, some methods provide solutions for one but exacerbate the other.

6.1.1 Recognition

When the choice of focal sections changes in emphasis, location or number, a distortion viewing transformation creates a new presentation. Users cannot always recognize that they are actually looking at the same information. We define the recognition problem as the ability to recognize that subsequent distortion presentations are still displaying the same information, from presentation to presentation it should be evident that the information depicted by the representation is undamaged by the change. For example, rotating an object provides different views of the same representation. Similarly when stretching and distorting an image it is important to be aware that only the presentation is changing; that is, that a presentation operation is a view operation.

6.1.2 Interpretation

Recognition that we are still examining the same information does not automatically mean that we are able to interpret or understand the new presentation. Can items that are displayed in different or even varying scale be compared? The extensive discussions [160] on the possible ways that misinterpretations occur in visual representations might indicate that distortion viewing is fraught with danger if not bound to failure. In both the information design community and the cartography literature there has been extensive discussion about how distortions in information presentation can misinform people [160, 77]. For example, many people who are used to the Mercator projection of the map of North America, think that Canada is much bigger than it is. The distorted projection has in a manner of speaking lied to them. If it is to be possible to take advantage of the type of screen usage distortion viewing affords, this issue must be addressed.

The question is, can we simultaneously retain the advantages that seem to accrue through distortion viewing 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. We call this the interpretation problem.

6.2 Previous Advice in Regards to the Recognition Problem

The following list summarizes the advice from the literature concerning the recognition problem.

1. *Use domain knowledge.* When knowledge about the information is known it can be used to create appropriate distortion transformations [52, 157]. For instance, if which aspects of the context are most important is known, this can be used to ensure that they are visible in the presentation [52] or if minimal usable scale is known, this can be adhered to [166]. While the use of domain knowledge is significant, as this framework is being developed independently of an application further discussion on this issue is not included in this thesis.

2. *Maintain spatial constancy.* In the physical world people remember where objects are spatially. For instance, when looking for a book the approximate location that it was last seen will be remembered [147]. To maintain spatial constancy the advice is to respect the position of items by moving them as little as possible during the distortion transformations. In particular, if possible use only changes in scale.

3. *Maintain focal position.* As a subset of spatial constancy it is particularly important to maintain the location of the focal region [70].

4. *Avoid information reversal.* The information reversal is the changing of spatial ordering (left/right, up/down, in/out). This is another noted subset spatial constancy that can be particularly disorienting in a presentation transformation [138].

5. *Preserve the mental map.* Misue et al. [107] suggest that preserving orthogonality, proximity and topology will allow the user to maintain their mental map. Points 2, 3, and 4, all of which concern the maintenance of spatially constancy, are formally summarized in this idea. If orthogonality, proximity and topology are preserved, there will be no information reversal and at least the relative location of the foci will be preserved. These ideas maintain spatial constancy by placing limits on the nature of the distortion transformation. Approaches which follow these directions were discussed in Section 2.2.1 under compressed contexts. In particular, the preservation of orthogonality leads to characteristic visual patterns with distinct regions of differing scale that are merely visually adjacent.

6. *Integrate context smoothly.* It may be important that the focal region still appear to be part of the context [138]. Being merely visually adjacent may not be sufficient. Approaches that follow this advice endeavour to integrate their context smoothly with their foci and tend to use non-linear distortion. These type of transformations provide good visual integration between regions. This may provide better support visual gestalt [35] but tends to violate orthogonality.

7. *Use familiar distortions.* Prompted by user complaints of disorientation with distorted presentations, Sarkar and Brown [137] suggest that a familiar distortion, for instance a hemisphere for maps, might be less disturbing.

8. *Provide animated transitions.* Animating the transition from one presentation to the next informs the user about the transformation [141]. The importance of animated transitions has been widely accepted. 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 they may be looking at an entirely new set of information. Some techniques have abrupt transitions [70] and some even entirely reorganize the display [116]. The continuous visual transitions are provided in [7, 83, 90, 132]. However, animations do not address the issues of how to interpret the new presentation once it has stopped moving.

6.3 On the Interpretation of Distortions

In some cases it is immediately obvious that an image is distorted, in others it seems virtually impossible to identify a distorted image. The ability to interpret distortions varies across different types of representations and across different types of distortions. This section examines how different representation types make detail-in-context distortions more or less apparent.

6.3.1 Representations Styles that Reveal Distortions

Familiar Representations. Figures 6.1 and 6.2 show examples of a typical text field and a more sparse use of text, respectively. In Figure 6.1 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 6.2 it is our recognition of changes across the word “Columbia” that reveal the distortion. However, distorted presentations of a representation as familiar as text can be uncomfortable to look at. This was noted in Document Lens [132] and handled by ‘greeking’ or replacing the actual text with an intentionally illegible representation. The thought was that since trying to read distorted text can be distracting and even cause eye strain, replacing it with representative lines would be less irritating.

Figure 6.1: A text file with two focal points

Figure 6.2: Sparse text, B.C. map, with one focal point (for map credit see Appendix C.2)

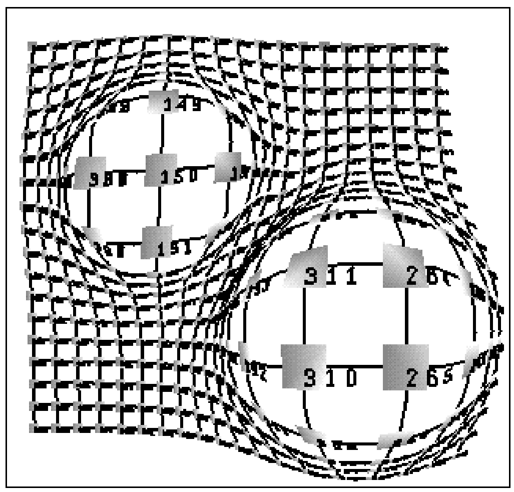
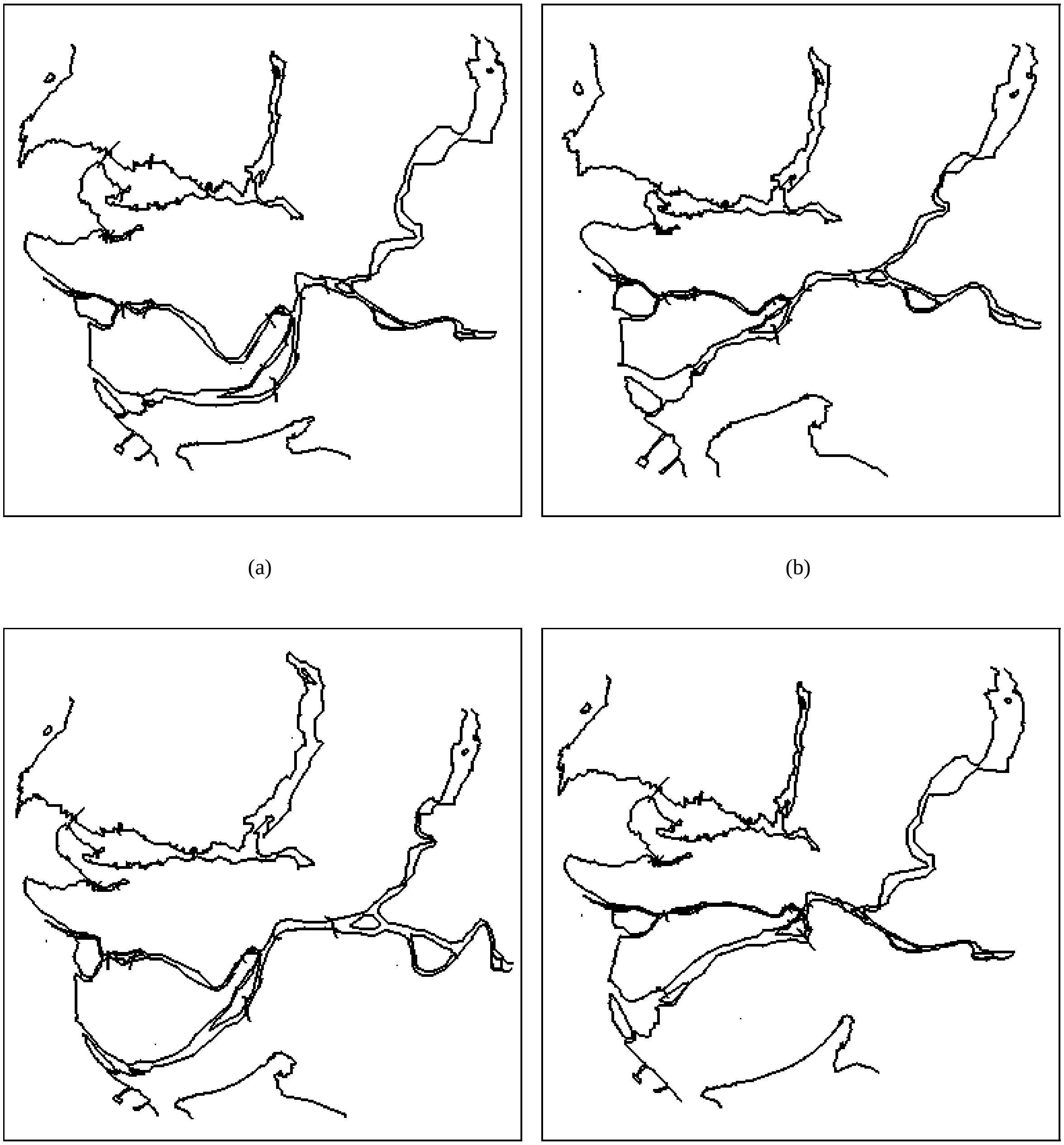


Figure 6.3: Regular layout of a grid graph with two focal points

Regular Representations. When the representation layout is very regular, changes in its pattern will define the distortions. For example, Figure 6.3 shows a grid graph with very readable distortions. Note that part of the readability of the distortions in Figure 6.1 also comes from the regular layout.

6.3.2 Representation Types that Obscure Distortions

Figures 6.4 and 6.5 each contain four images, one undistorted and three distorted views, in no particular order. For a personal experiment, examine them before reading further.



(a) (b)

(c) (d)

Figure 6.4: Four presentations of a map of the Vancouver coastline. It is hard to tell which of these is the normal presentation (for map credit see Appendix C.6)

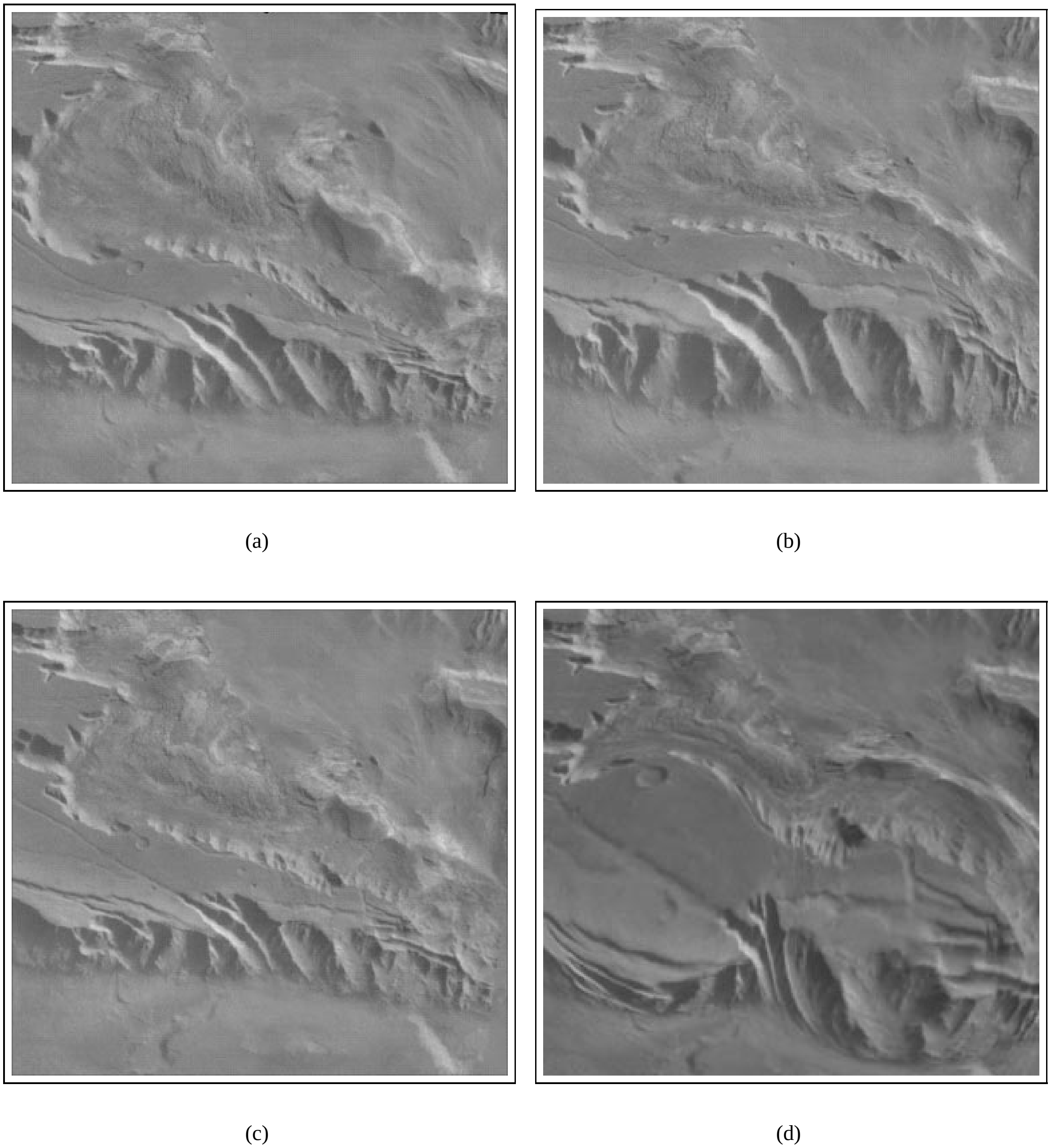
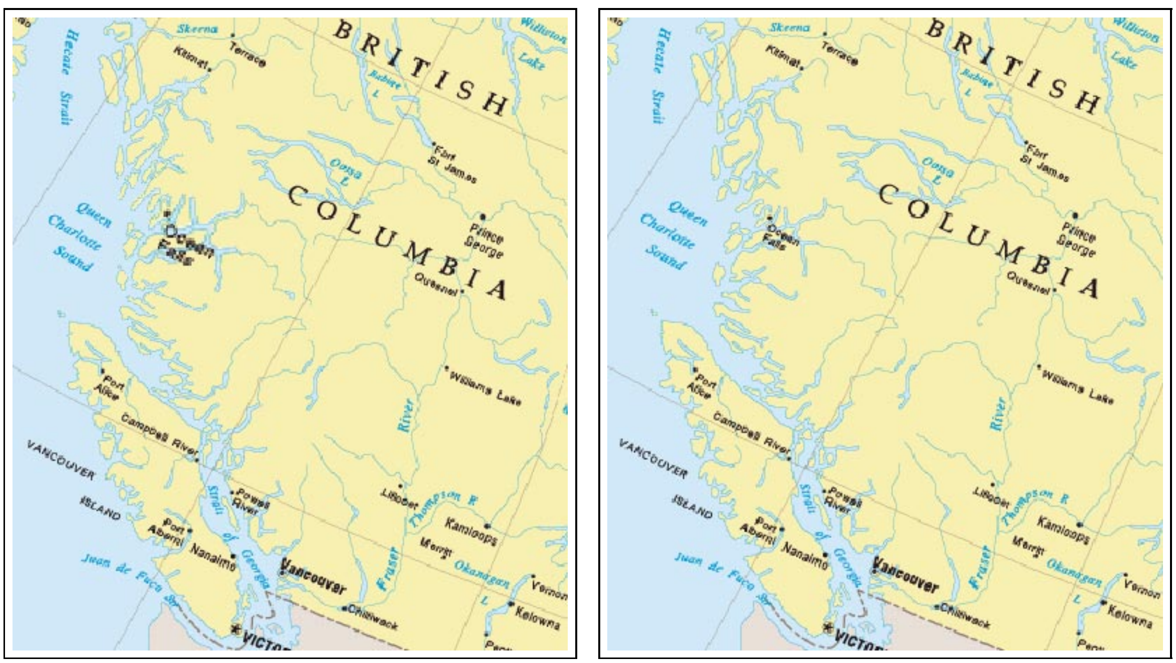


Figure 6.5: These photographs show a section of the surface of Mars (for image credit see Appendix C.4)

Sparse Representations. In sparse and irregular layouts even familiarity does not help very much.

For example in Figure 6.4 the sparse and irregular nature of the coastline of Vancouver make it very difficult to discern the location of focal points. Even if foci 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. Figure 6.4(a) has three focal regions; Figure 6.4(b) is the map in normal presentation; Figure 6.4(c) has four focal regions and Figure 6.4(d) has three focal regions.

Unfamiliar Representations. The inability to tell whether or not a presentation has been distorted increases as familiarity with the information decreases. The examples in Figure 6.5 of the surface of Mars are most likely unfamiliar images. In the case of a familiar image previous knowledge will, at least to some extent, protect the user from assimilating false information. In unfamiliar information spaces there is a greater chance of being misled. Figure 6.5(a) has three focal regions; Figure 6.5(b) has two focal regions; Figure 6.5(c) is the normal presentation; and Figure 6.5(d) has two focal regions.



(a) (b)

Figure 6.6: One of these two presentations of British Columbia contains a focal region. For explanation see text 6.3.3 (for map credit see Appendix C.2)

6.3.3 When Spatial Properties Encode Meaning

There are many ways to use spatial properties to encode some aspect of the information (see [13]). 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 such as relative importance. 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 6.4 and 6.5 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.

Figure 6.6 shows two maps of British Columbia. Which map has been distorted? Though there is text on the image, the structure of the distortion is such that looking for distorted text does not help much. The distortion in this case is small with a scaled-only focal region. This type of distortion is a useful one for viewing maps. It does not disturb very much of the map, it is smoothly integrated into its context and the focal region itself is not distorted but scaled. If the user is familiar enough with British Columbia to know that Ocean Falls is a much smaller city than Vancouver, they will know the location of one focal point (Figure 6.6(a)). If the information displayed in the image is not familiar, there is nothing to stop the user from thinking that Ocean Falls is a fairly large city. In this example, where the size of the text relates to the size of the city, the user can actually be misinformed through use of a distortion lens.

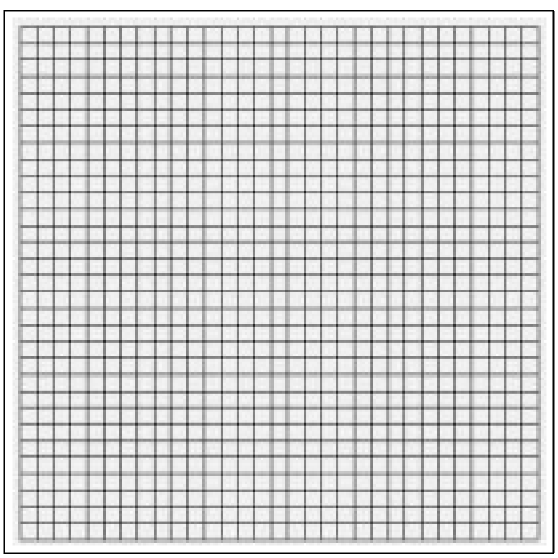
6.4 Towards an Interpretation Solution

In looking for solutions it is important to consider the comprehension problems that led to the creation of detail-in-context presentations as well as those that have arisen with the research. Research towards the development of detail-in-context methods has concentrated on *visual capabilities*, for instance, the number and type of foci and the degree of magnification.

We identify three distinct methods that can be used to increase the comprehension of distortion presentations: the structure of the distortions, the nature of the transitions between presentations, and the addition of visual cues. The structure of the distortion is reflected in the pattern of magnification and compression that results. It is the structure of the distortion that we have been using images of regular grids to reveal. Where and to what degree a region is compressed has significant effect on whether the resulting presentation is comprehensible. Section 6.5 discusses the effect of the structure of the distortion. Controlling the structure of the distortion can aid and aggravate both recognition and interpretation. Section 6.6 discusses transitions between presentations which chiefly address the recognition problem. Section 6.7 discusses visual cues which are added to support interpretation of a static distorted presentation.

6.5 Comprehensible Distortion Structure

Changing the structure of a distortion effects both recognition and interpretation. A change in the structure is a change in the placement and in the degree of the distortion. If the structural change alters all aspects of the representation this can make recognition difficult. This in turn can effect how difficult the presentation is to interpret. Sometimes, using a structure that makes it easier to tell that the information is the same from one presentation to the next makes it hard to tell that the image is distorted. The techniques to obtain variations in distortion structure were discussed in Chapter 3. This section utilizes illustrations with a simple grid to best show the changes in distortion pattern, and with the map of British Columbia to show the effect on an image. Figure 6.7 shows both the



(a) The undistorted grid

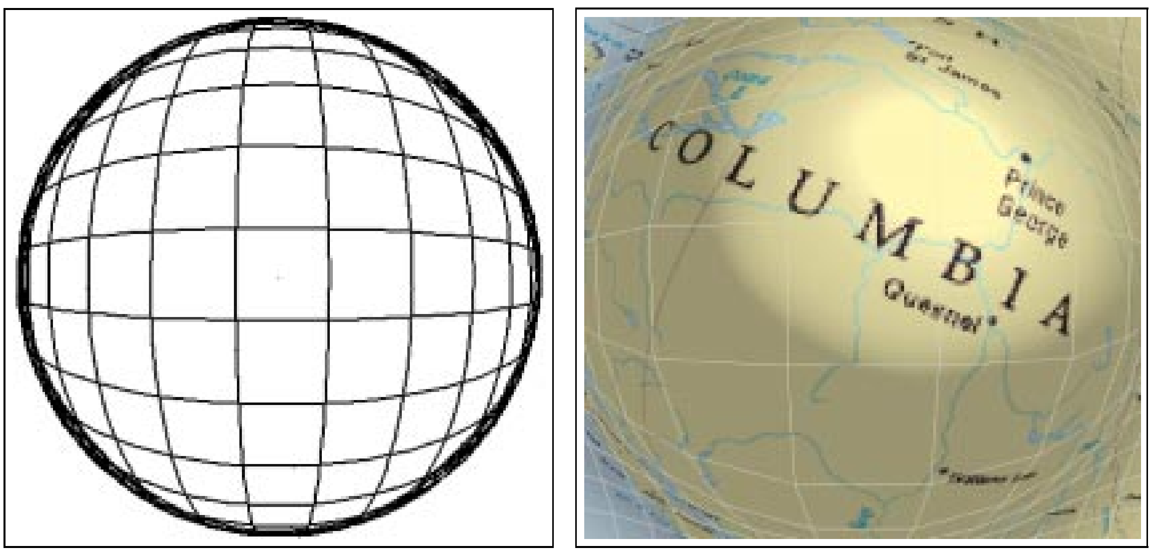
(b) The undistorted map of British Columbia (for map credit see Appendix C.2)

Figure 6.7: The normal presentations of a grid and a map of British Columbia

undistorted grid and the undistorted map of British Columbia.

6.5.1 Minimize Reorganization

While some of the initial detail-in-context approaches did not keep focal points in the same location as in the initial layout, most recent ones do respect the spatial organization of the normal presentation in some manner. The exceptions, such as Noik's [116], use detail-in-context techniques to create layouts, in contrast to adjusting an existing layout. In other words these techniques start from a representation that does not yet have a visual organization. The idea of respecting the original presentation, can be achieved by either constraining the distortion, excluding distortion from the focus, or adhering to the ideas expressed in preservation of the mental map (Section 6.5.4).



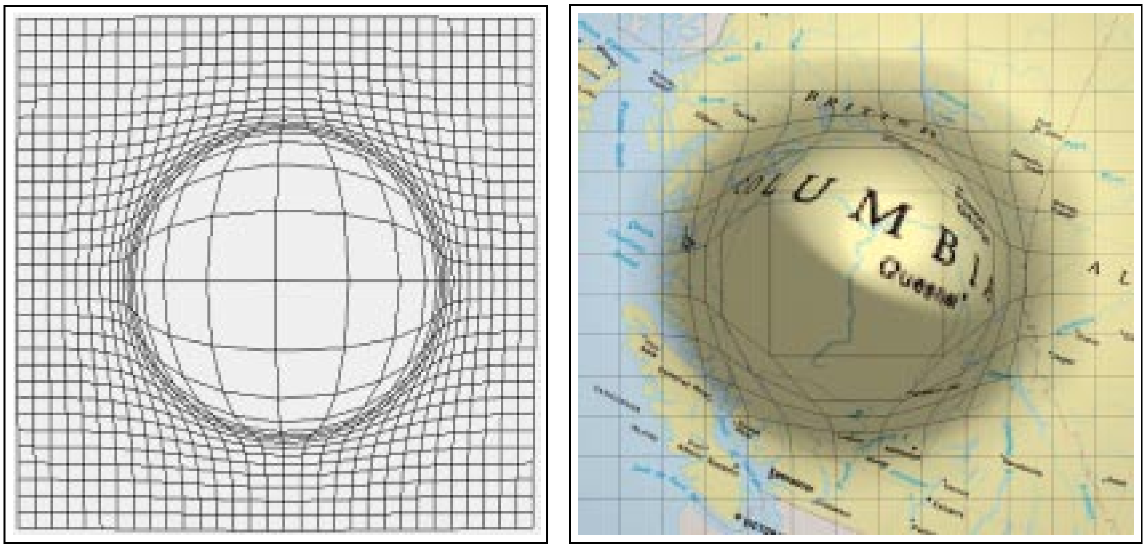
(a) The grid with extreme global distortion that severely compresses the edge of the image

(b) A globally distorted map of British Columbia. This distortion is not as extreme as the one with the grid alone but the features around the edges of the images are still unreadable (for map credit see Appendix C.2)

Figure 6.8: Global distortions

Constrained Distortions

In all previous work, the entire available display space other than that reserved for focal regions was either compressed, distorted or both, creating a *global distortion*. One good reason for using global



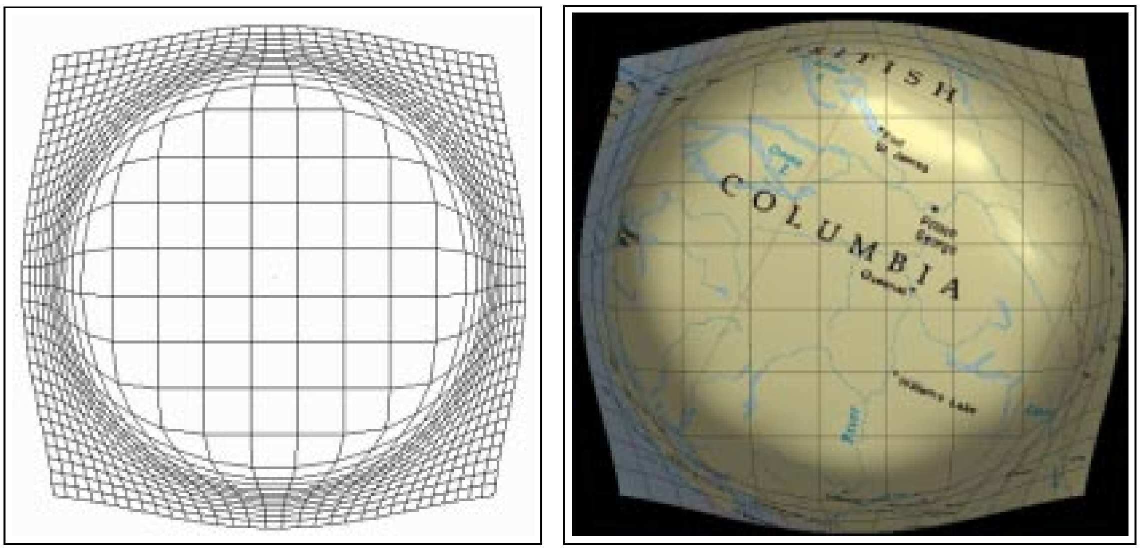
(a) (b) (for map credit see Appendix C.2)

Figure 6.9: Constrained distortions showing large regions of image in normal presentation

distortion is that it spreads the distortion and/or compression out as much as possible. Another is that compressing all of the remaining area will make the maximum amount of space available for magnification of a focus.

However, there are also problems with this approach. Some distortion approaches [83, 108, 137, 138] are based on an asymptotic mathematical curve and achieve “the ability to display infinitely large images at the expense of infinitely crumpling the edges” [107]. Figure 6.8 shows examples of extreme edge compression through use of global distortions. The grid compression at the edges of the grid (Figure 6.8(a)) is sufficiently extreme so as to bring into question whether context is being preserved. The compression in the image of BC (Figure 6.8(b)) is less extreme but at the edges of the image but it is still barely discernible. This contributes to the recognition problem. A very simple but significant idea in maintaining recognition is to limit the *spread* or the distance from the centre of the focal region that the distortion extends into the context. Limiting the spread creates *constrained distortions*. Basically, the idea behind using constrained distortions is to provide, when possible, unaltered regions of image to aid in recognition. Figure 6.9 shows constrained distortions; the outer area of both the grid and map are not distorted. Constrained distortions are also helpful in interpretation.

When the extent of the distortion is constrained, portions of the image remain undistorted. The image now has a focal region, a region of distortion and compression which connects it to its undistorted context. Constraining the distortion can allow for edges of the representation to be relatively undisturbed. This maintains the visual frame of the image.



(a) (b) (for map credit see Appendix C.2)

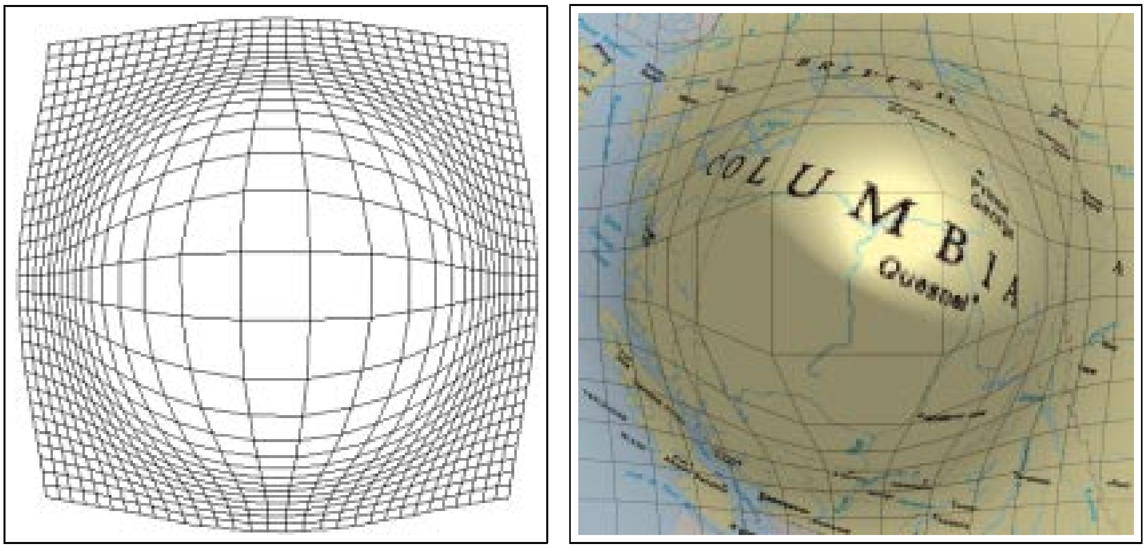
Figure 6.10: These presentations have a large focal region of magnification to scale

Excluding Distortion from the Focus

In general, it is much easier to read information that is not distorted but has only changed in scale. Just as the distortion can be limited from spreading to the edges of the context, focal regions that have changed in scale only can be provided. Figure 6.10 shows the grid and map of BC where the distortion has been excluded from the focus.

6.5.2 Smooth integration

Discussion in the literature [138] has indicated that more visually integrated patterns are preferred. Figure 6.11 shows a very smooth connection between the focus and its immediate surroundings, with regions adjacent to the focus magnified almost as much as the focus. This is a visually integrated distortion presentation where focal regions blend into context. It is smooth integration that provides



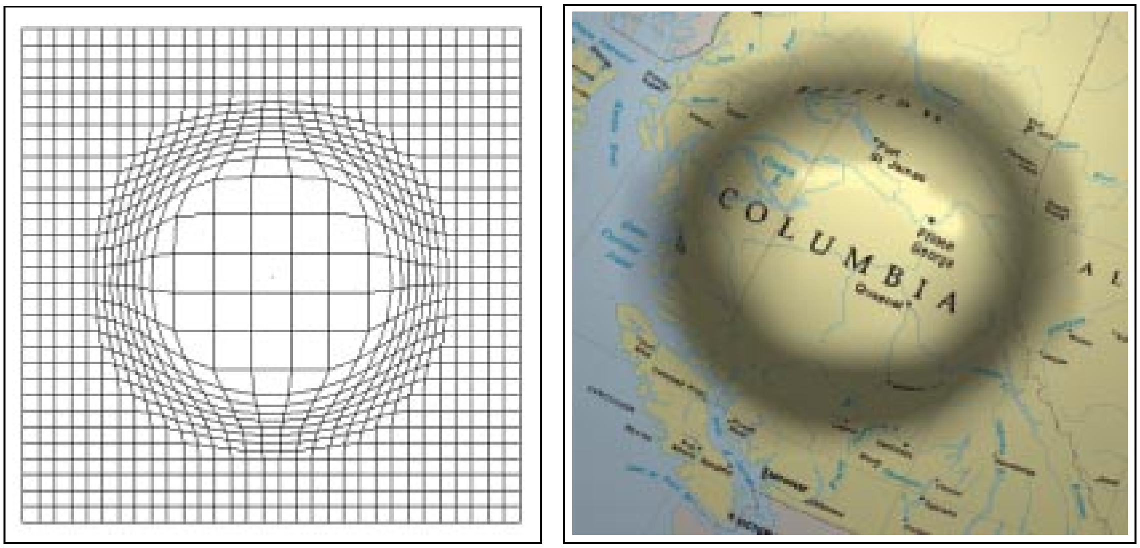
(a) (b) (for map credit see Appendix C.2)

Figure 6.11: Smooth visual integration of the focus, the compression and the context

the most effective unity of visual impression, or visual gestalt. While this provides perception of the image as a single event, it can lead to interpretation problems. Smooth integration tends to spread the distortion and make the divisions between regions less clear, such as where scaled-only areas end and distorted areas start. Simple visual continuity provides this information readily.

6.5.3 Distortion control

In every distorted view there is a trade off between how much each focus is magnified and the degree of compression that results. There are also choices to be made in regards to the relative spread or extent of the distortion and/or compression and to the type of visual connections between regions. Distortion control puts the space allocation decisions in the hands of the user, allowing for many different distortion patterns. Figure 6.12 shows a constrained lens with a scaled focal region. There are many possible variations of distortion (see Section 4.1). The best combination will be a function of the information representation, the task at hand and the preferences of the user.



(a) (b) (for map credit see Appendix C.2)

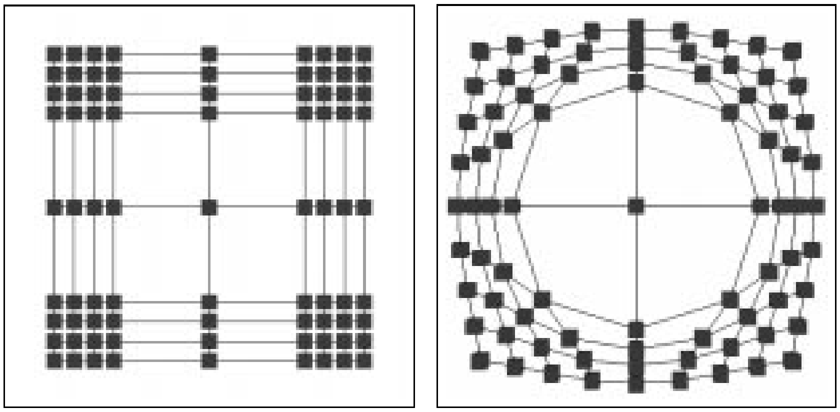
Figure 6.12: A constrained distortion with a region of scaled magnification in the focus creates a detectable division between the focal region, the compressed region and the remaining context

6.5.4 Mental Map

While there is considerable discussion in the cognitive science literature in regards to the nature of our mental models [35, 113] it does seem to be a useful concept to consider. In the distortion literature the question of preserving the *mental map* has been used to identify those aspects of a layout which should be preserved. Misue et al. [107] suggest that maintaining three spatial properties may aid in preserving a user's mental map, thus helping information recognition:

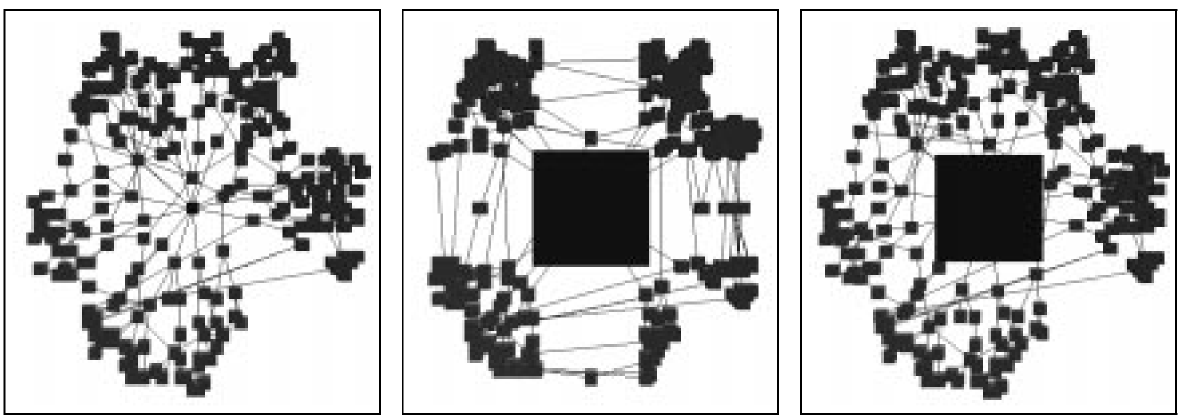
- *orthogonality* - objects maintain relative right/left, up/down positioning,
- *proximity* - adjacent objects remain adjacent, and
- *topology* - containment relationships are preserved.

However, presently it is not clear what is held as a mental map of an image [113]. While it is probable that we think spatially in some manner akin to visual observation [58], it is not clear to what extent a visual mental image is maintained. It is possible that the disorientation that users mention occurs when the modified visual image conflicts with their own prior mental representation



(a) Orthogonal displacement (b) Radial displacement

Figure 6.13: Orthogonal and radial displacement

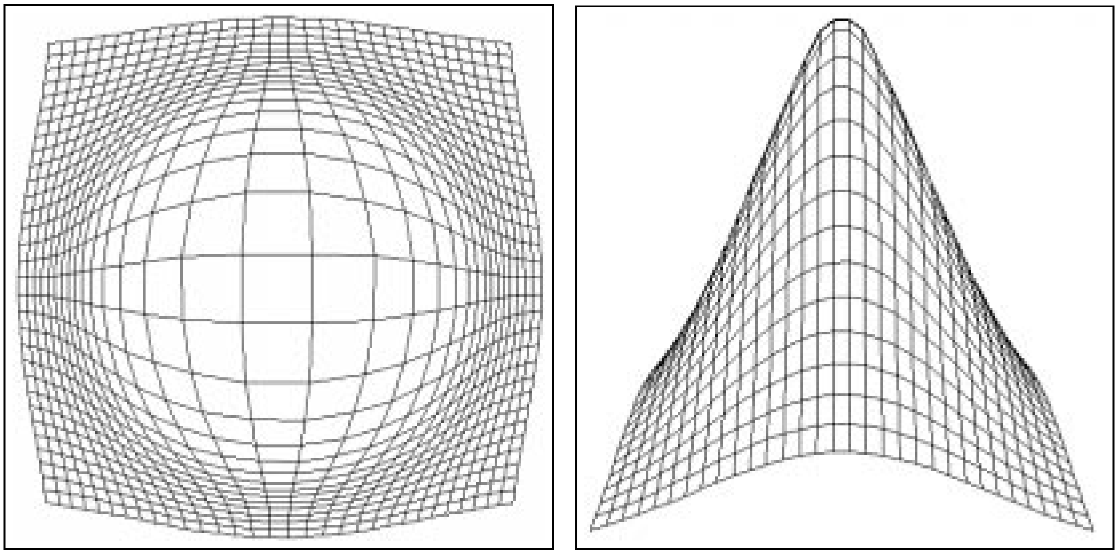


(a) Graph in normal presentation (b) Graph with step orthogonal distortion (c) Graph with step radial constrained distortion

Figure 6.14: The basic configuration of the graph layout in 6.14(a) is better preserved in 6.14(c)

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.

Preserving the mental map is further discussed in [107, 138, 150] where a distinction between orthogonal and radial distortion is noted. Figure 6.13 shows orthogonal displacement on the left and



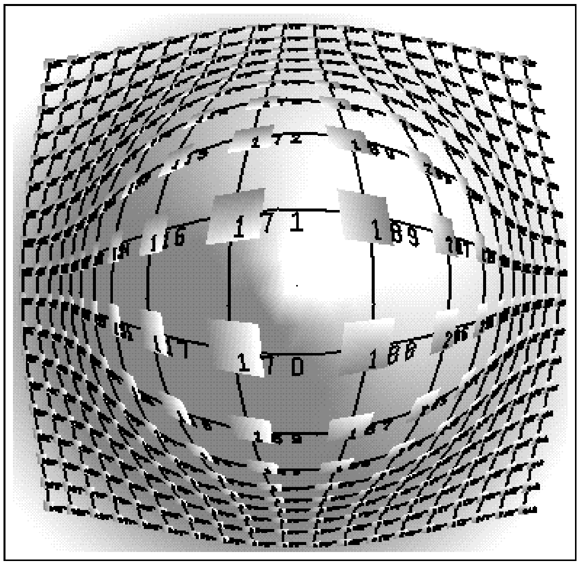
(a) 3D radial distortion, top view. Note the curve lines showing that orthogonal relations are not preserved in this view

(b) 3D radial distortion, side view. Note the straight lines indicating the preservation of orthogonality in this view

Figure 6.15: 3D distortions

radial displacement on the right. Note how the orthogonal displacement clearly preserves orthogonal relationships but creates new, perhaps artificial, clusterings. A radial displacement is perhaps better at preserving proximity relationships which may be more important in some situations [150]. Note these two displacements applied to a graph (Figure 6.14). Both create space for the magnification of the focal node. The similarities between the undistorted graph and the radially distorted graph are more clearly apparent. However, the distortion of the context is more subtle, making it a more difficult to interpret how the graph has been transformed.

Examining the radial layout with a simple grid (Figure 6.15(a)), one can see how the grid lines curve, so that a point at the top edge of the grid that was to the left of a central point on the same line is, in the distorted view, to the right. This violates orthogonality. However, this radial distortion has been created in our framework by manipulating a surface in three dimensions and viewing it through perspective projection. The image on the right in Figure 6.15(b) shows the same distortion from the side view. Note how the lines that appeared curved in the projected view are straight in the side view. Orthogonality has been preserved in the surface manipulation. It is perspective projection from the reference viewpoint that creates the appearance of a radial distortion.



(a) 3D radial distortion, shaded top view. Can one tell that orthogonality relationships are maintained but on a curved surface?

Figure 6.16: Question of orthogonality in 3D distortions

Using a three-dimensional distortion provides the advantages of preserving proximity relationships in the projected view while maintaining orthogonal relationships in the side view without the attendant problems of new clusterings (Figure 6.16). The question that arises is that since all the relationships of orthogonality, proximity and topology are preserved in the three-dimensional form, can this three-dimensional form be made evident to the user in a manner that supports this interpretation?

6.6 Comprehensible Transitions

Perhaps the most important factor in recognition is the transition between presentations. We recognize the importance of visually continuous transitions [7] and suggest that it may be equally important that these transitions be reversible.

6.6.1 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 [70] and some even entirely reorganize the display [116]. The need for continuous visual transitions was recognized and provided in [7, 20, 82, 90, 132]. Actually seeing the distortion created is very explanatory. However, this only applies at the time of transition.

6.6.2 Reversible Transitions

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.

Piaget has a notion of two stages that someone goes through in developing understanding that he calls "revertability" and "reversibility" [29, 121]. 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 focal regions revert to its original layout. The important points are:

- reversibility is closely connected to comprehension;
- the original undistorted image should be recoverable; and
- 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.

6.7 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 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 misinformed?

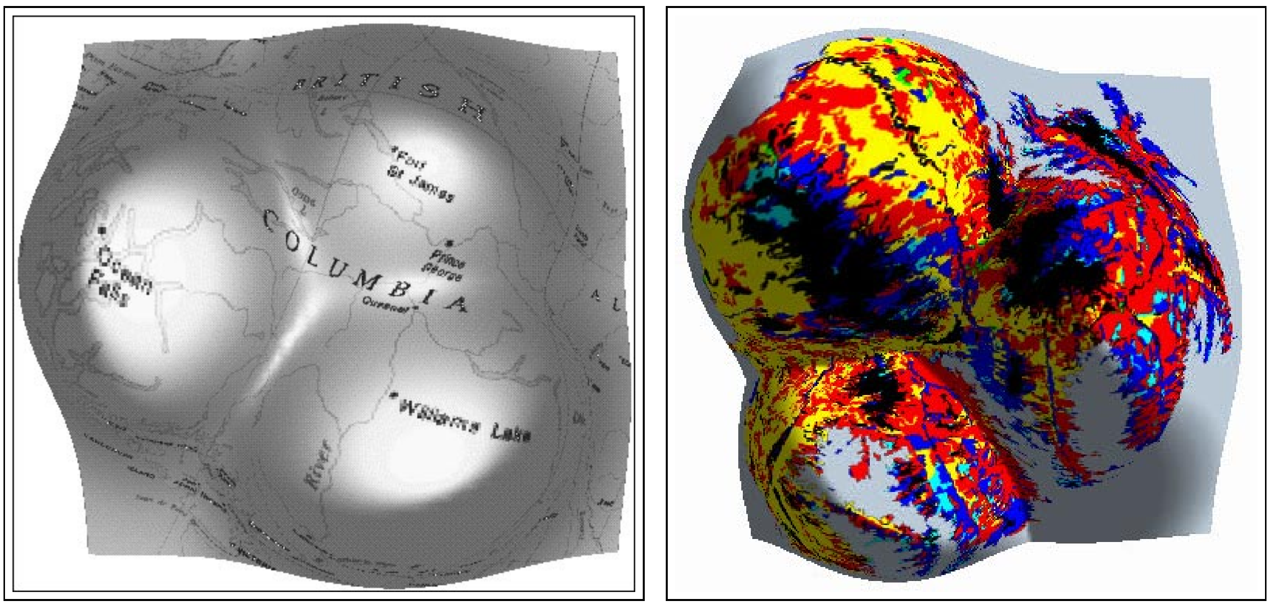
Visual representations of information ideally make certain relationships inherent in the information apparent: type of vegetation in a location, amount of rainfall that supports this vegetation, or how air moves over an obstacle. In many of these instances positional information plays a significant role. 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 misinformed.

Our intention is to provide sufficient support to make 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* [13]. However, these variables (size, colour, shape, value, orientation, and texture) were identified for printed graphics and 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 entirely applicable [169]. 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 note the advantages and disadvantages of each. Four types of visual cues are discussed and applied to distortion viewing: constructions, visual formalisms, acquired skills, and pre-attentive abilities.

6.7.1 Constructions

A construction is a visual cue that has been created especially for 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.



(a) (for map credit see Appendix C.2)

(b) (for map credit see Appendix C.5)

Figure 6.17: Two presentations showing manipulated surfaces

Application: The Surface

For users to build an interpretation of a representation they must associate it 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 user's perception, what does the distortion represent? The distortion can be created by relatively complex mathematical function. A user may not know this function and may not actually want to, and yet they need to understand how the information has been manipulated. One approach which can make distortions visually explicit is to place the information on a surface [20]. This yields a method of revealing the distortions even if some sections of the information representation are sparse. This provides advantages:

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

The 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 (Figure 6.17). Instead in provides a metaphor by which the distortions can be understood.

6.7.2 Visual Formalisms

A *visual formalism* is a previously used visual cue that will be understood by some segment of society. The term visual formalism was introduced by Harel [63] in connection with various types of graph layout. We use the term more broadly 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 common enough within given communities that it is reasonable to expect them to be understood within that community. 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. For example, the meanings of red and green above may not agree with all readers. Some of these formalisms have become so familiar for certain groups of people that they may even prefer them to the more intuitive pre-attentive abilities. However, these preferences will be culturally tied and therefore need to be used with care.

Application: The Grid

The grid is a visual formalism common in cartography and is familiar to those whose experience includes reading maps. In cartography the grid 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.

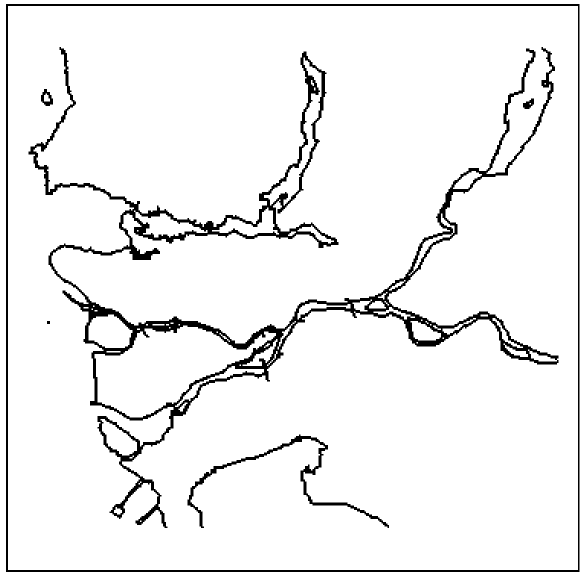
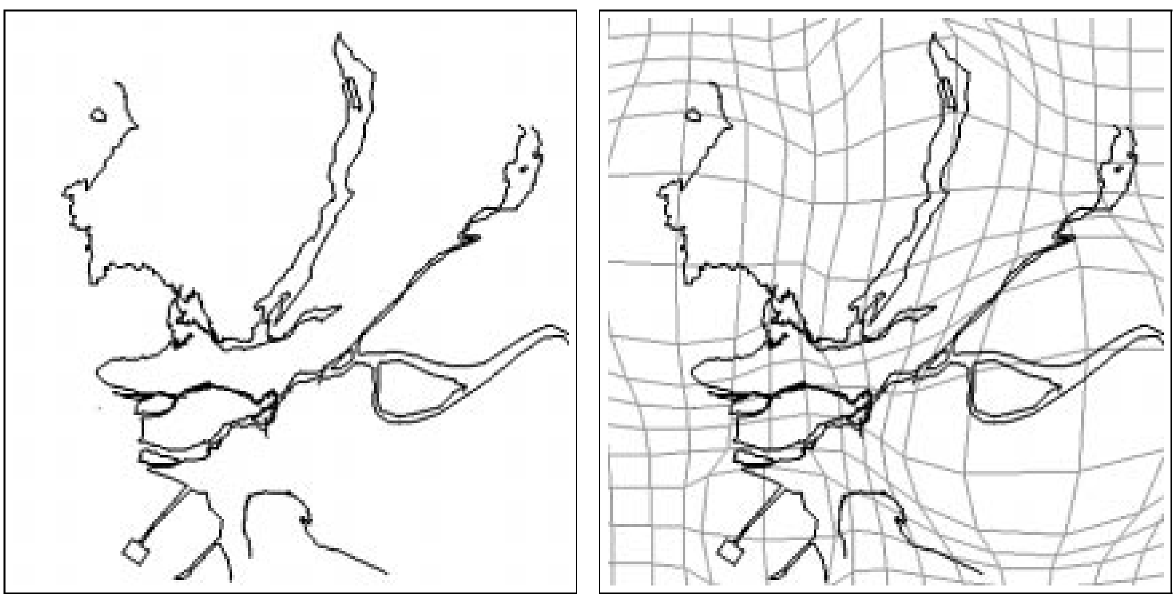


Figure 6.18: Coastline of Vancouver in normal presentation



(a) A distorted presentation of the Vancouver coastline

(b) The same distorted presentation of the Vancouver coastline with the four focal regions revealed with an overlayed grid

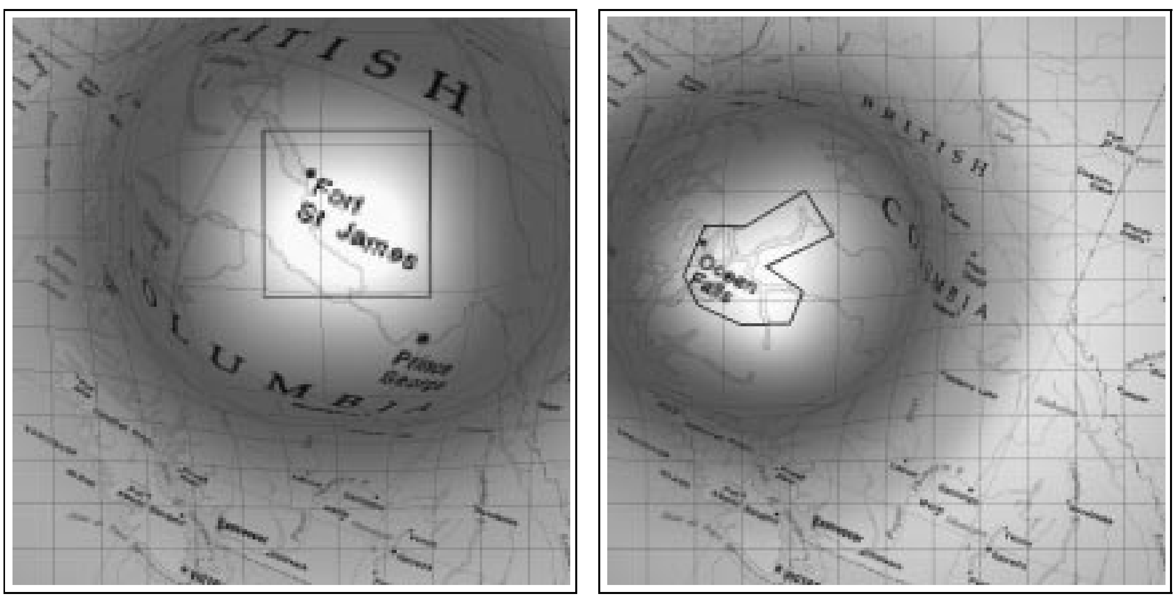
Figure 6.19: Use of the cartographic grid (for map credit see Appendix C.6)

Throughout this thesis the distortions in the illustrations have been shown through use of a regular grid. Figure 6.19 shows a four focus distortion of Vancouver on the left with no visual cues and on the right with the same distortion revealed by a grid. Overlayed across the entire information representation, a grid provides relative compression and magnification information.

The grid lines reveal the shape of the distortions by accessing two human depth cues: perspective information (see next section) and texture gradient.

Application: Outlines

Once the image is a complex combination of distorted and undistorted areas, it is useful to be able to see where one region starts and the other stops. Optional outlining of different regions can delineate the magnified focal regions, clearly separating regions of uniform scale from the distorted sections which link them to the surrounding context (Figure 6.20).



(a) (b)

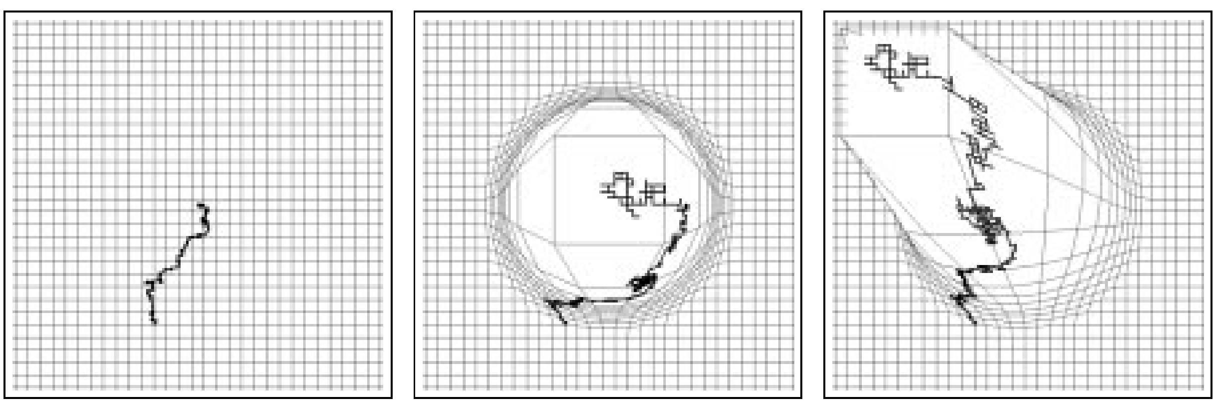
Figure 6.20: In these two presentations the outlines of the scaled-only regions of the focus are displayed (for map credit see Appendix C.2)

6.7.3 Acquired Skills

In this group we include perceptual skills that current research indicates, though not decisively, may be pre-attentive. For example, there is an interesting discussion as to the nature of our ability to read perspective. While some argue that this is pre-attentive (see Section 6.7.4), there is some indication that it is culturally tied. For example, stories exist of people from other cultures following a perspective diagram on planting and ending up with convergent rows [57]. In utilizing skills from this grouping it is possible that the advantages listed under pre-attentive abilities may accrue; however, one must be aware that this cannot be assumed. As these cues may be culturally tied like visual formalisms, they also may need to be learnt.

Application: Perspective

One of the more successful metaphors employed to date to make distortion viewing comprehensible is the use of three-dimensional space [20, 53, 99, 132]. These distortions are created using perspective to provide magnification and the resulting three-dimensional image provides visual information about how context has been distorted. Not only do humans 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.



(a) The normal presentation of a DNA H-curve walk

(b) A single focus magnifies the start of the DNA walk

(c) The single focus is tipped to better present the rest of the walk

Figure 6.21: The grid lines in this case support a 3D perspective reading

Perspective information is read from the three-dimensional shape. For instance, the edges in

Perspective Wall [99] provide useful information about the relative magnification and compression. Combining the grid with three-dimensional form also provides perspective (Figure 6.21).

6.7.4 Pre-Attentive Ability

A perceptual skill is called pre-attentive if it is thought that it does not require conscious processing. It is believed that such abilities have been with us for a long time evolutionarily. The possibility of using such skills as visual cues is very appealing [169] because:

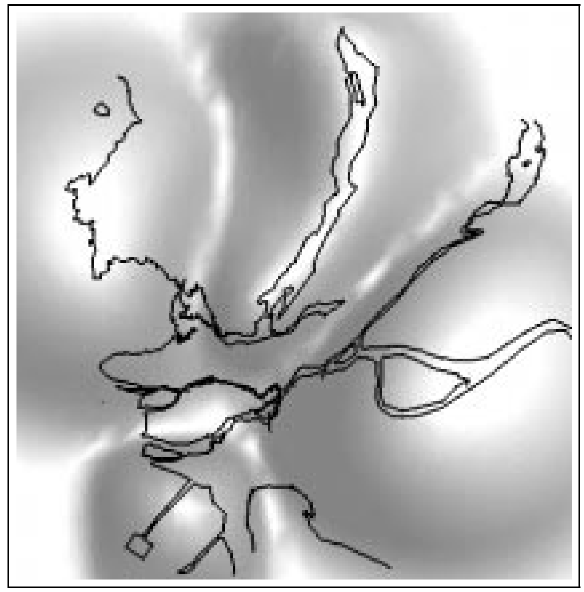
- processing should be virtually instantaneous;
- they should interfere very little with other conscious cognitive work;
- they should be readable to all humans since low-level ability will not be culturally tied; and
- they should require little or no learning to be understood.

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 abilities are, and there are several for which arguments can be made both for and against declaring them as pre-attentive. Second, even given that we could agree on a list of such abilities, these are very unusual aspects on which to base a design. For the purposes of this research we consider only those visual pre-attentive abilities about which there seems to be fairly unified agreement in the literature.

Application: Shape from Shading

As the desire is to utilize pre-attentive abilities where possible, an obvious choice is to use shading. “The human visual system is capable of quickly and accurately establishing three dimensions from variations in luminance [shading] only” [130]. Although the retinal image is two-dimensional, humans are capable of deriving an awareness of form and depth from shading [86]. 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 [86]. The prevalence of this is thought to indicate the significance of shade in detecting form. Ware [169] 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 [86, 130] also indicated that the extraction of shape from shading seems to assume a single light source. If

(a) The same distorted presentation of the Vancouver coastline as in Figure 6.19(a)

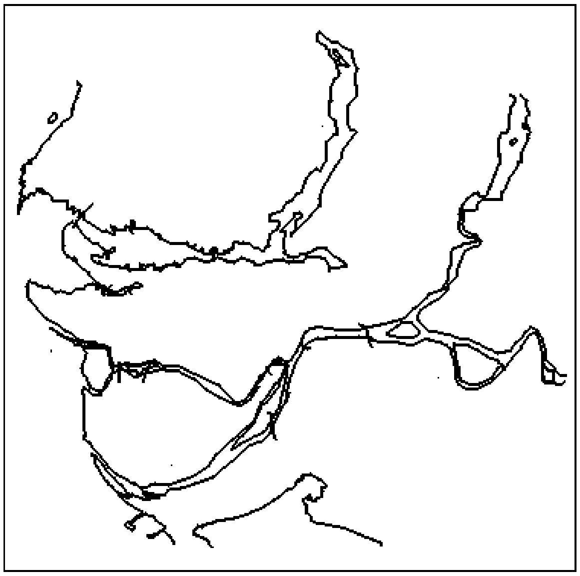


(b) This image reveals the four focal regions with shading

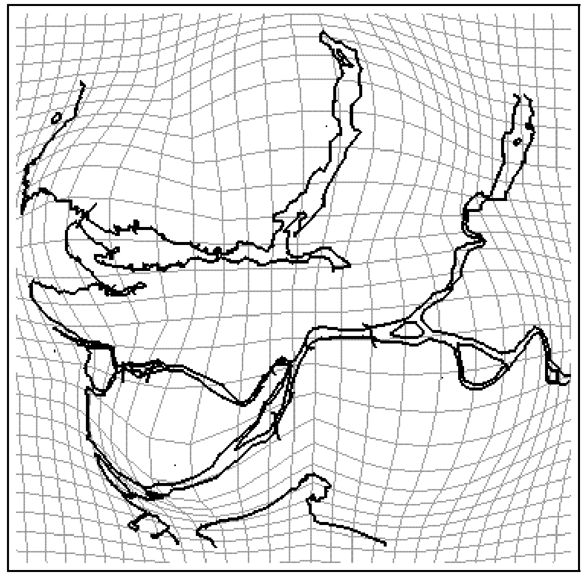
Figure 6.22: Shading gives an intuitive impression of the location shape of the focal regions (for map credit see Appendix C.6)

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 pre-attentive 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. Figure 6.22 shows a four focal distortion of the map of Vancouver coastline on the left with no visual cues and on the right with the distortion revealed through shading.

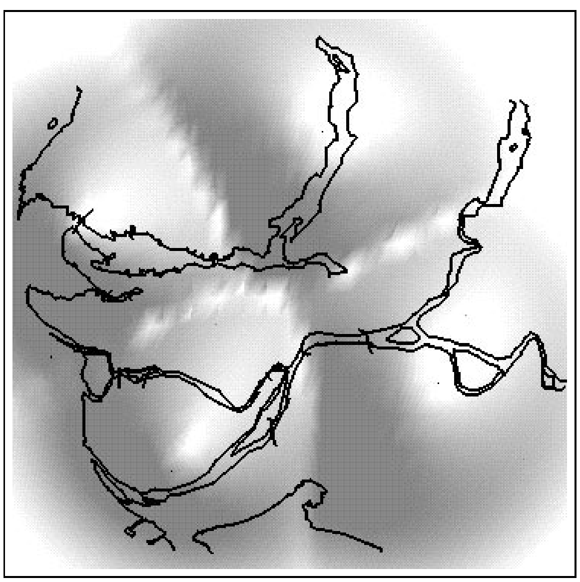
The two series of Figures 6.23 and 6.24 are included to reveal one of the distortions in each of the Figures 6.4(c) and 6.5(a) from Section 6.3. They show the use of the grid and shading alone and in combination.



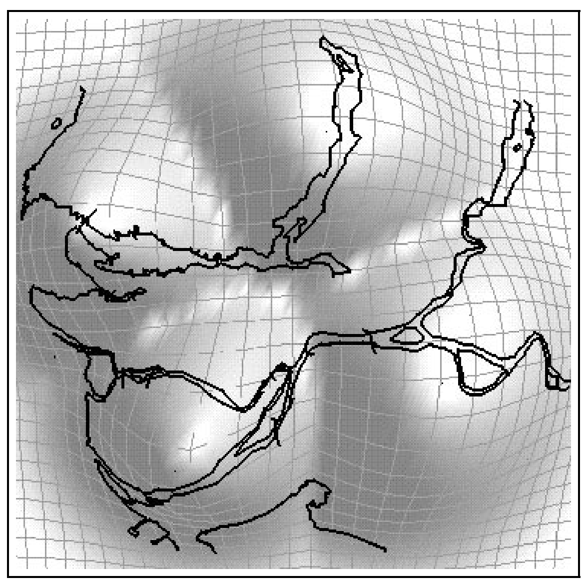
(a) A distorted presentation of the Vancouver coastline (same as Figure 6.4(c))



(b) Using the grid to reveal the four foci

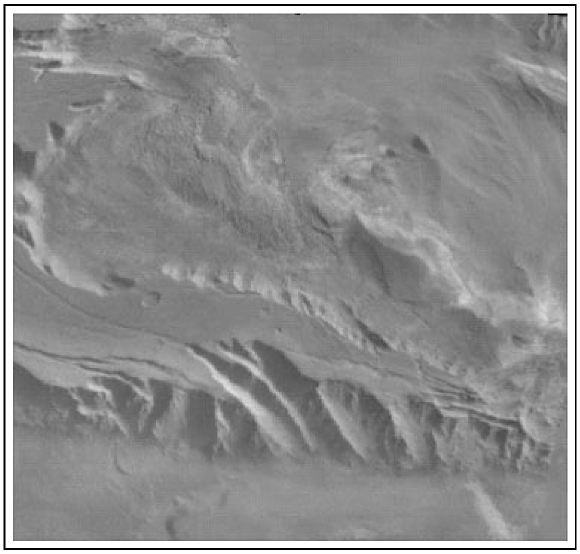


(c) Using shading to reveal the four foci

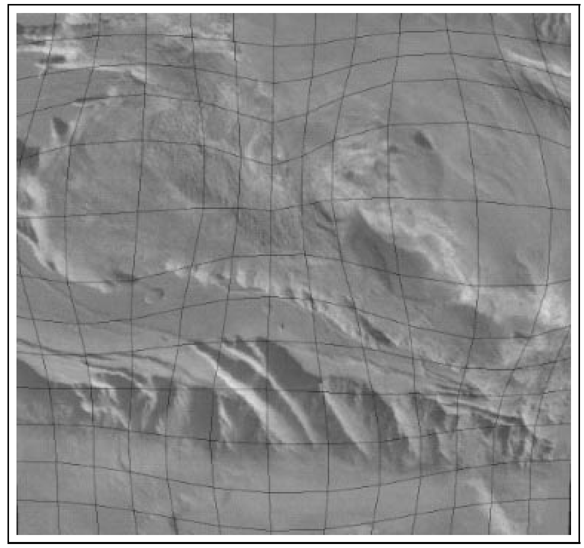


(d) Using the grid and shading to reveal the four foci

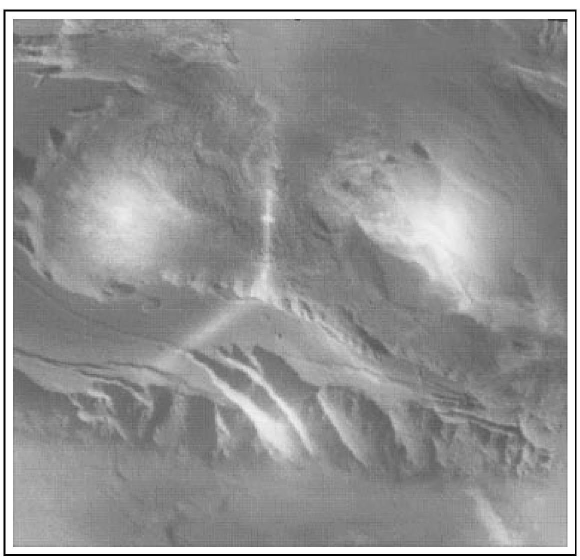
Figure 6.23: The grid and shading can be used alone or together (for map credit see Appendix C.6)



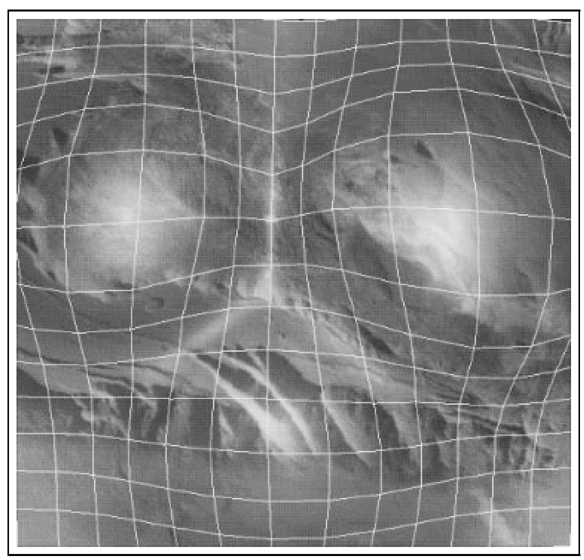
(a) A distorted presentation of the the surface of Mars (same as Figure 6.5(a))



(b) Using the grid to reveal the three foci



(c) Using shading to reveal the three foci



(d) Using the grid and shading to reveal the three foci

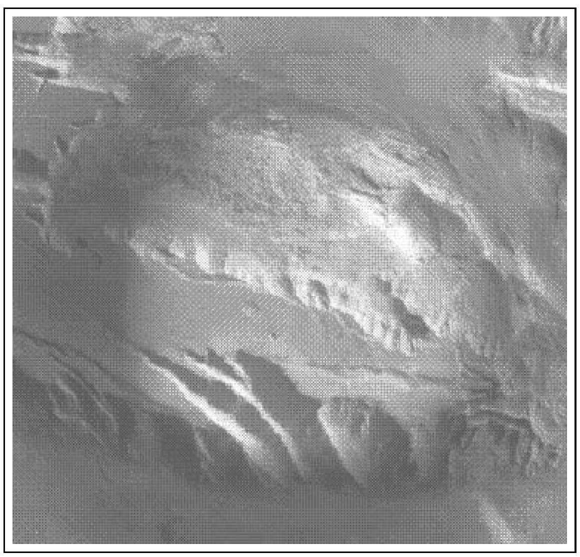
Figure 6.24: The grid and shading can be used alone or together (for image credit see Appendix C.4)

6.8 The On-going Comprehension Problem

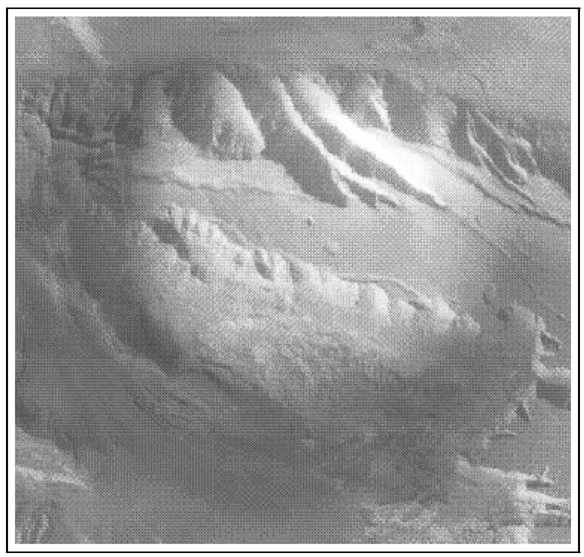
Though the visual cues discussed make it significantly easier to interpret the distortions, they are not a complete solution. This section discusses some noted on-going problems.

6.8.1 Issue: 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 6.24 one can still see the ravines but the overlaying of the grid has diminished their impact. Here the use of shading to reveal the focal areas is more effective and creates less interference.



(a) A single focus presentation of the surface of Mars. Here the light position used in the added shading agrees with the light position in the image

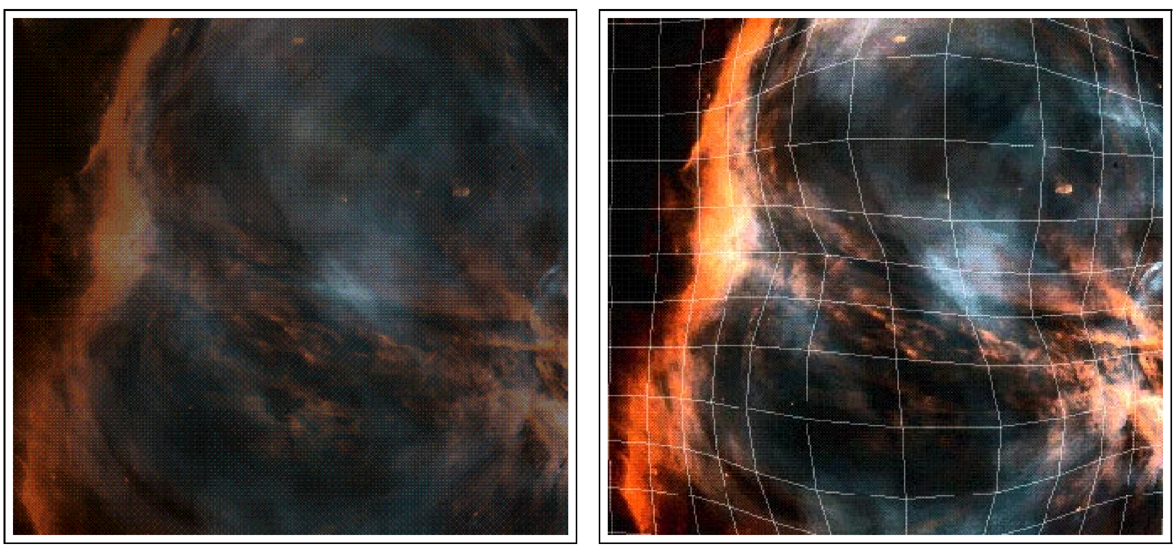


(b) The same single focus presentation of the surface of Mars has been rotated. Now the light position used in the added shading disagrees with the light position in the image

Figure 6.25: The shading effect in the photograph is combined with the shading effect of the viusal cue and changes how the information is interpreted (for image credit see Appendix C.4)

6.8.2 Issue: 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 from 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 vice-versa. Figure 6.25(a) shows a topographic photograph of the surface of Mars with a single focal point. In Figure 6.25(a) the photograph of the surface of Mars has been rotated 180 degrees. This places the lights in opposition and reverses the concavity reading.



(a) When shading is added to a complex coloured image it is merely read as changes in tone.

(b) The grid still reveals the distortions in the image

Figure 6.26: Both of these images show the same presentation of the Orion nebula with different visual cues (for image credit see Appendix C.3)

6.8.3 Issue: 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 6.26(a) shows an image of the Orion Nebula with two focal points. This image has been shaded but the shading is doing little to disambiguate the distortions. However, the image in Figure 6.26(b) is using the grid, which is effective.

Notice how in the map of BC 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 (Figure 6.11) 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 the map of BC.

6.9 Summary

This chapter has discussed the distortion viewing paradigm from the perspective of 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.

We identify three ways of addressing these comprehension issues. The structure of the distortion can be controlled in a effort to minimize both recognition and interpretation problems. The nature of the transitions is crucial in terms of the recognition problem. Furthermore, while structural and transitional changes are significant, a fundamental problem persists. It must be possible for the user to interpret the distorted images. To address this we suggest the addition of visual cues.

Visual cues are categorized according to the effort required to learn them, and to gain a better understanding of how to draw on aspects of the world that are already understood. The categories are: constructions, visual formalisms, acquired skills, and pre-attentive skills. This categorization provides pointers for places to look for relatively well-understood visual cues and helps identify which aspects may be cross-cultural. Choosing cues in this manner lets us be aware of what types of explanations the resulting presentations will need.

In following 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 users can understand the distortions they will be able to accurately interpret the information.