Information Design Journal 10(1), 58–68

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Examining comprehension issues in elastic presentation space

Keywords: presentation, visual comprehension, viewing cues, information visualization, user interface design, screen real estate

Making effective use of the available screen space is a fundamental issue in user interface design. Researching this presentation problem has led to the development of a framework that describes a presentation space in which the adjustments and reorganizations are elastic, in the sense that reverting to previous presentations is facilitated. The resulting presentations make effective use of screen space through the use of various types of distortion. Distortion in information presentation can be problematic, giving rise to comprehension issues. Use of the third dimension provides the possibility of making these presentation adjustments comprehensible.

1. Introduction

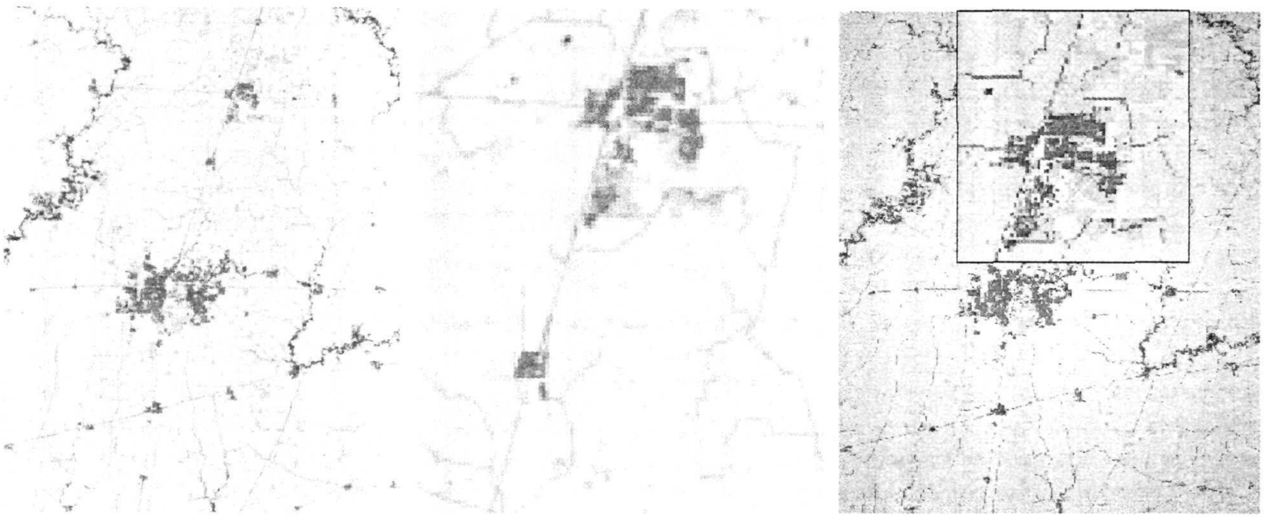
All too often it is the size of the screen on which the information is displayed that is the limiting factor when viewing information on a computer. This can be true whether one is viewing a single image or map, coping with multiple files when editing or coding, or trying to organize the windows and icons which are necessary for one's current task. In fact, computational advances have intensified this problem. Processing power and storage capacity have increased in leaps and bounds while in comparison the sizes of our display screens have inched outwards. This discrepancy between a computer's display space and its information space has been called the *screen real estate problem* and is associated with issues in navigation, interpretation and recognition of relationships between items in the representations.

There are several significant indications as to the importance of addressing the screen real estate problem and in doing so endeavouring to provide, in computer presentations, support for the use of human perceptual abilities. For instance, when searching for an object (i.e. a book), people often have a less than precise recollection of exactly what they are looking for (i.e. they may not know its precise name) but they may know the location where it was last seen (Spence and Apperley 1982: 43–54). Also, there are studies indicating that humans form a *mental map* or internal representation of objects of interest and that this mental map can then used for recognition and navigation (Coren and Ward 1989). Visually supporting the use of spatial memory should aid search tasks.

Studies (Furnas 1986: 13–17) in various subject areas (geography, workplaces, history, and newspapers) reveal that people naturally retain and present information in a manner that provides more detail about areas of interest and less detail about their context. Also, the human visual system is capable of perceiving much greater detail for objects that are being directly examined (foveated vision) than for objects in the surrounding areas (peripheral vision) (Coren and Ward 1989). Furthermore, studies indicate that humans integrate information that is perceived as belonging to a single entity much more readily than information that is deemed as originating from more than one source (Massaro 1985:221–243). Together these indicate the apparent usefulness of providing presentations that display detail within its context.

While there is research into alternate display technologies (Tidwell et al. 1995:325–334), video display terminals are still the primary interface to the computer. Making the best use of this display space has been an important issue in user interface design ever since the introduction of video display terminals. The necessity for effective solutions to this problem has intensified as technology has advanced, with the ability to produce visual data continuing to outstrip the rate at which display technology has developed.

With a computer, a space of presentation possibilities exists, including the ability to adjust a presentation dynamically. The term *elastic* implies both the ability to be stretched and deformed and the ability to return to its original shape, and appears to reflect one of the distinguishing characteristics of a computer's presentation space. Different aspects of the computer's elastic presentation facility have been utilized in the creation of several techniques, for instance, Stretch Tools (Sarkar and Reiss 1992), Rubber Sheet (Sarkar et al. 1993:81–91), Pliable Surfaces (Carpendale et al. 1995, 217–226), Elastic Labels (Iturriaga and Lubiw 1997:181–192) and Elastic Windows (Kandogan and Shneiderman 1997:250–257). This article introduces the use of Elastic Presentation Space (EPS) (Carpendale 1999) to address the screen real estate issue and variations in computational presentation of visual information are discussed particularly in respect to comprehension issues. EPS provides a way of relating seemingly distinct presentation methods, facilitating the inclusion of more than one presentation method in a single interface. Furthermore, it supports extrapolation between the



(a) A full compressed view (b) A zoomed view (c) A magnified inset

Figure 1. Contrasting presentation of a land usage map of Champaign, Illinois

presentation methods it describes, and its use of the third dimension allows for the inclusion of visual cues to address some of the comprehension issues.

2. The screen real estate issue

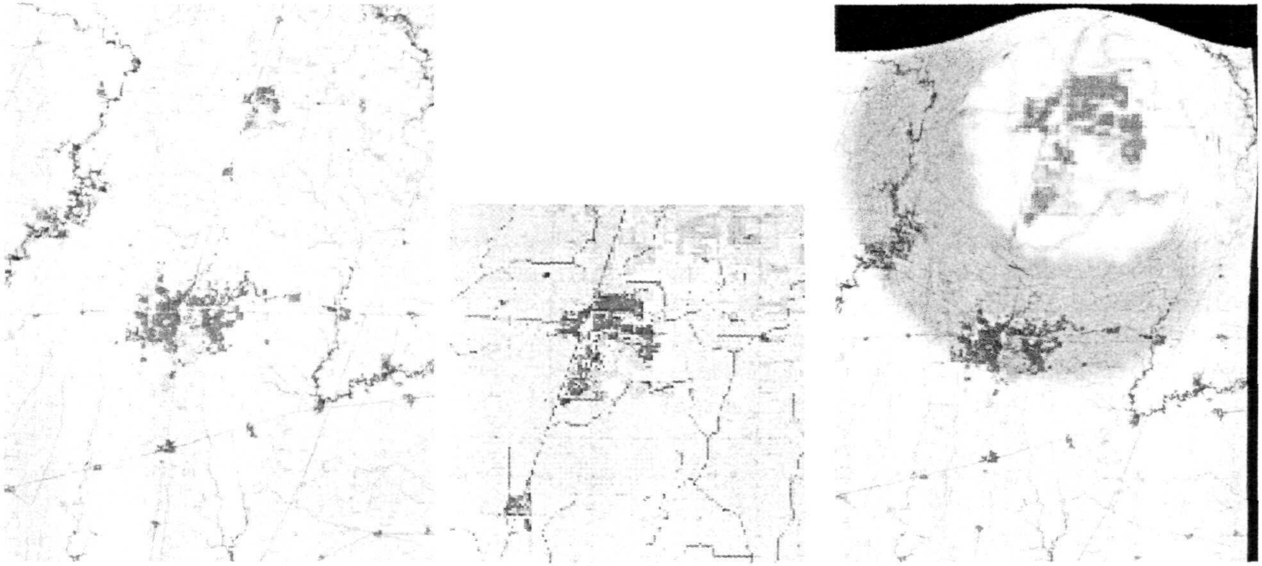
The fact that we can store and manipulate vast amounts of information in a computer and have only a comparatively small screen on which it can be viewed is an issue in almost all aspects of computing. As the primary metaphor for computer use shifts from an extension of one's personal desktop to a form of access into a vast information space, viewing this expanding information space through relatively small computer screens becomes increasingly problematic.

The introduction of windows was a notable presentation advance over the previous command line access (Johnson et al. 1989: 11–26). This overlapping partitioning of two-dimensional space has greatly increased the amount of usable display space. However, even when windows include scrolling, panning and zooming it has become apparent that the ability to examine details of the representation often conflicts with the ability to maintain global context. Zooming-out, or compressing the data to fit within the space of the screen, can result in an image that is too dense to discern detail. Figure 1a shows a land usage map of Champaign, Illinois compressed uniformly to fit a given frame, causing much of the detail to be difficult to see. Zooming-in, or magnifying the whole image (Figure 1b), provides a detailed view but results in the loss of context because only a sub-region will fit in the available display space.

Examining the representation with panning and scrolling has been compared to peering through a keyhole onto a vast display of information. Panning and scrolling allow movement of the information across the keyhole but require the user to keep track of their location. This is one of the factors that has led to discussions of being *lost in computer space* (Meister 1989: 5–21). Creating an inset, by zooming-in or magnifying a sub-region in place, obscures local context (Figure 1c). The inset provides detail for the selected region but the space required for magnification causes the adjacent regions to be covered, making it impossible to see how the details in the inset, for instance roads, connect to the roads in the rest of the map.

Multiple views in separate windows allow global structure to be displayed in one view and the required detail in another. Figure 2a displays a magnified sub-region separately in its own frame. This solution removes the occlusion in Figure 1c; however, the connections between the two images are not necessarily obvious and must be performed consciously by the user. The only situation where detail can be viewed within its context is when the entire image will fit without compression into the display space.

The phrase *detail-in-context* is defined as the ability to see a *focus*, or chosen region of the representation, in sufficient detail while it is still set in its global context. The difficulty with supporting detail-in-context readings in a windowing environment has led to several techniques that combine the advantages of zooming-in with those of zooming-out. Essentially these techniques allow a user to magnify chosen sections to reveal the desired detail and compensate for the extra space this magnification requires by various types of compression in the rest of the image. Figure 2b shows a detail-in-context view. The advantages attributed to these techniques include: increased amount of information that can usefully be presented on a computer screen; human preference for remembering and presenting information in this manner (Furnas 1986: 13–17); utilization of visual gestalt by retaining the perception of the information space as a single event; and increased user performance in path finding tasks (Hollands et al. 1989: 313–320; Schaffer et al. 1995: 87–96).



(a) Separate views (b) A detail-in-context view

Figure 2. Contrasting separate views with detail-in-context

3. Detail-in-context techniques

Over the last approximately twenty years there has been considerable research towards developing computational display methods that provide detail-in-context. This research has led to several methods that differ considerably both algorithmically and visually. It has also led to a surprising degree of consensus about the functionality that a 'good' detail-in-context method would provide. The desired functionality includes the ability to magnify a chosen focus within its context; the freedom to specify the shape and location of the focal region; the ability to request the degree of magnification; and the possibility of multiple foci. However, while there may be some agreement that context should be maintained, the manner in which this should be done still seems to be in question.

One group of approaches follows and extends the idea of maintaining *full context* as first suggested in Bifocal Display (Spence and Apperley 1982: 43–54). These approaches try to minimize spatial reorganization and tend to consider it important that all items in the context are visible in the presentation even though they may be very compressed (Sarkar and Reiss 1992). Furnas (Furnas 1986: 13–17) observed that a fisheye camera lens creates an image that provides detail in the centre of the image and decreasing detail in the periphery and introduced an idea he called Generalized Fisheyes in which he suggested creating detail-in-context views by maintaining a *sufficient context.* Generalized Fisheyes in turn instigated three directions for the handling of handling context. One is to filter the context (Furnas 1986: 13–17), another is to combine filtering and distorting (Bartram et al.

1995: 207–215), and the third uses distortion only (Mackinlay et al. 1991: 173–180; Robertson and Mackinlay 1993: 101–108; Sarkar and Brown 1994: 73–84; Lamping et al. 1995: 401–408).

While all of the methods provide a detail-in-context presentation, not all of the desired functionality was available within one approach and often some aspects had been only partially achieved. For example, the best approximation of freedom of focal shape was Sarkar et al.'s provision for user selection of convex polygons (Sarkar et al. 1993: 81–91). Several methods offered multiple foci but would often cause unrequested additional foci to appear (Sarkar and Reiss 1992) or had to limit the foci in size and proximity (Sarkar et al. 1993: 81–91). For surveys of research in this area see Noik (Noik 1994: 225–233) and Leung and Apperley (Leung and Apperley 1994: 126–160). More recently, fully functional detail-in-context methods have been developed (Carpendale et al. 1995: 217–226; Keahey and Robertson 1996: 19–25; Hamel et al. 1996: 123–132).

4. Elastic presentation space

4.1. *Focusing on presentation*

On a computer, the display problem can be considered to have two aspects: representation and presentation (Carpendale 1999). Representation is the act of creating a basic image that corresponds to information such as creating a drawing of a graph. Defined in this way, a given representation provides specific information about the data and differing representations more readily reveal differing aspects of the data. This definition parallels D. Marr's (Marr 1982), and his use of a numerical example provides a useful illustration; the number thirty-four can be given in Arabic: **34**, Roman: **XXXIV** and binary: **100010** representations. Arabic numerals more readily reveal information about powers of ten while a binary representation makes information about powers of two more apparent. Defined in this way a visual representation is a result of a mapping from the information or data to something that can be displayed.

Presentation is defined as 'the act of setting forth information for the attention of the mind' (Webster 1998). Therefore, the presentation part of the display problem is the act of setting forth or organizing information. This takes place within the capabilities and limitations of the presentation space of the selected medium. A given set of information can be presented very differently in a film, on a billboard, on the radio or on a computer. To continue with the numerical example 34, *34* and **34** are different text presentations of the Arabic numeral. For a different example, a map of a city may be presented with one's route to work magnified to reveal street names.

This distinction between representation and presentation is particularly useful when discussing the computational display problem. On a computer the creator of a visual display will need to make a visual representation and provide a method of presenting it that considers such things as the size and aspect ratio of the available display space. It has become common to provide more than one presentation method such as pan, scroll and zoom. This inclusion is in recognition of the fact that a given representation will often be viewed on a different machine and that the user who is viewing the representation will have a secondary authoring function in that they can and will adjust the presentation.

4.2. *Capabilities in elastic presentation space*

EPS is a framework for presentation methods that provides a fully functional detail-in-context technique and provides a method for relating this technique to previous detail-in-context techniques as well as other presentation possibilities such as full zooming, panning scrolling and insets. As this framework relates these methods algorithmically, it allows the inclusion of more than one presentation style in

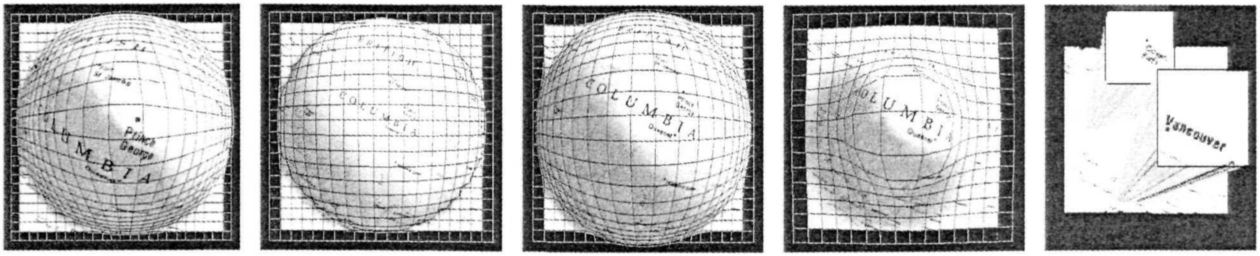


Figure 3. Variations in magnification styles: linear, hemisphere, hyperbola, Gaussian, Manhattan

a single interface. EPS makes use of 3D manipulation and perspective projection creating 3D presentations that allow for the inclusion of visual cues to support comprehension. For more complete explanation see (Carpendale 1999).

Creating a detail-in-context presentation involves finding a balance between the magnification required and some form of compensation to create the space necessary for the magnification. This compensation can take the form of loss of context, compression, distortion, or other visual discontinuities. Different mathematical functions create characteristic curvatures and result in different presentation patterns. Whether these characteristic patterns have advantages or disadvantages is probably dependent on the information, the task and the preferences of the user. Figure 3 shows a variety of individual lenses. Figure 4 shows different lenses used in combination.

As these lenses can all co-exist in a single presentation environment, this can be thought of as developing a lens library. As these lenses exist within one framework, the choice of which lens(es) to use can be left to the developer of an application. It is hoped that having a lens library to choose from will allow an application developer to make a better match for specific information and task needs.

Though there seems to be considerable support for the importance of detail-in-context presentation, these new methods were not receiving widespread acceptance. Perhaps this is because, as all of these methods use some degree of distortion, addressing the issue of comprehension is essential.

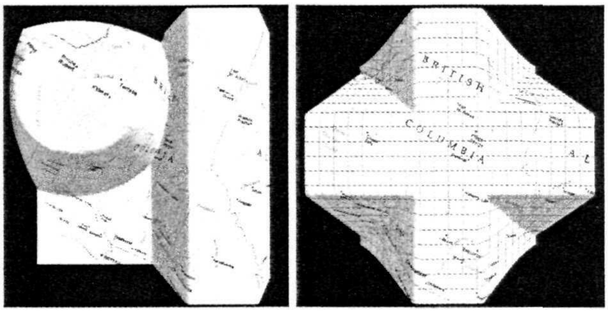


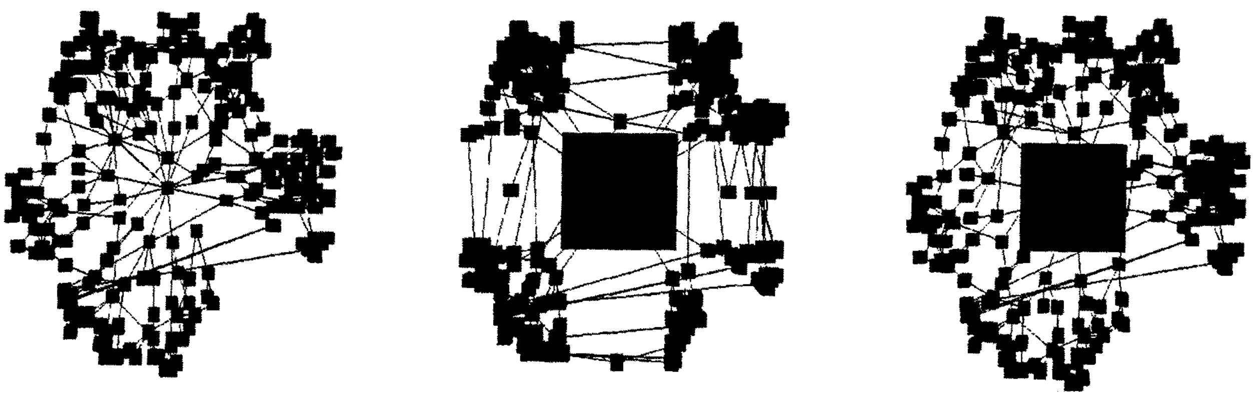
Figure 4. Lenses in combination

4.3. *Comprehension issues in elastic presentation*

Along with positive evidence of increased user performance, users' comments about disorientation were also reported (Bartram et al. 1995:207–215; Hollands et al. 1989:313–320; Sarkar and Brown 1994:73–84). Specific comments are vague, but, complained about such things as sudden moves, not seeing how the image changed, and expressing doubts as to whether the rescaled image is actually of the same information. In response to this, the importance of animating the transition between differing presentations was established (Hollands et al. 1989: 313–320; Schaffer et al. 1995: 87–96). Another possible explanation is that the user's disorientation occurs when the modified visual image conflicts with the users' prior *mental map* of the image (Misue et al. 1995: 183–210). While there is considerable discussion in regards to the nature of our mental models (Nardi and Zarmer 1994: 5–35), it does seem to be a useful concept to consider. The question of preserving the mental map has been used to identify those aspects of a layout that should be preserved. Misue et al. (Misue et al. 1995: 183–210) 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).

Preserving the mental map is further discussed in Storey and Muller (1995) where a distinction between orthogonal and radial distortion is noted. Figure 5 shows both orthogonal and radial distortion. Note how the orthogonal distortion preserves orthogonal relationships but creates new, perhaps artificial, clusterings. A radial distortion is perhaps better at preserving proximity relationships, which may be more important in some situations (Storey and Muller 1995: 487–499). 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 more difficult to interpret how the graph has been transformed.

Figure 6 shows three presentations of a coastline map of Vancouver. Even for those familiar with this map it is difficult to decide which presentation is not distorted. The issue of comprehensible detail-in-context presentation involves both recognition that the information is the same and the interpretation of a given distorted presentation (Carpendale et al. 1997: 36–45). A different tack taken towards providing comprehensible distortion is to make use of 3D presentations (Carpendale et al. 1995: 217–226; Mackinlay et al. 1991: 173–180; Robertson and Mackinlay 1993: 101–108). With these methods, perspective is used to create the detail-in-context presentations. Elastic Presentation Space (EPS) (Carpendale 1999) follows this lead.



(a) Original graph layout (b) Orthogonal distortion (c) Radial distortion

Figure 5. The basic configuration of the graph layout in (a) is better preserved in (c)

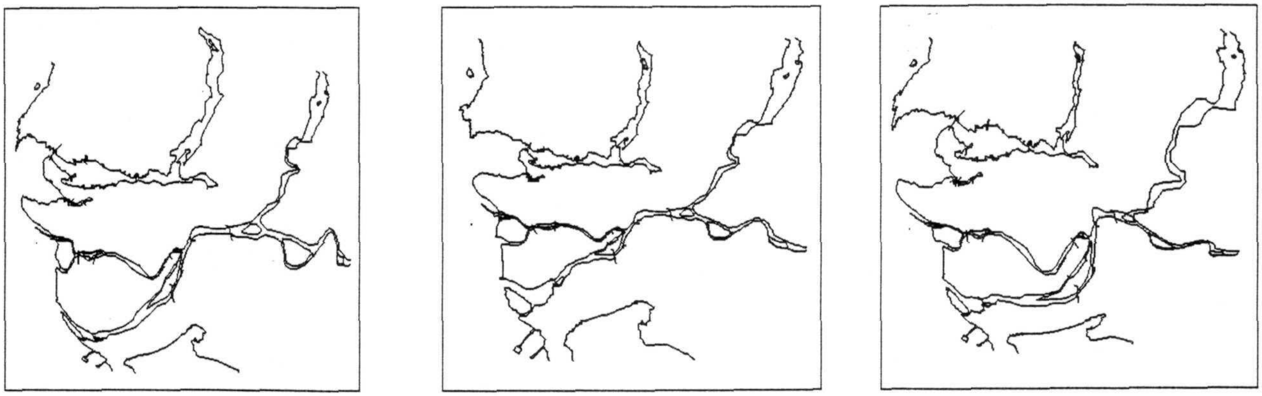
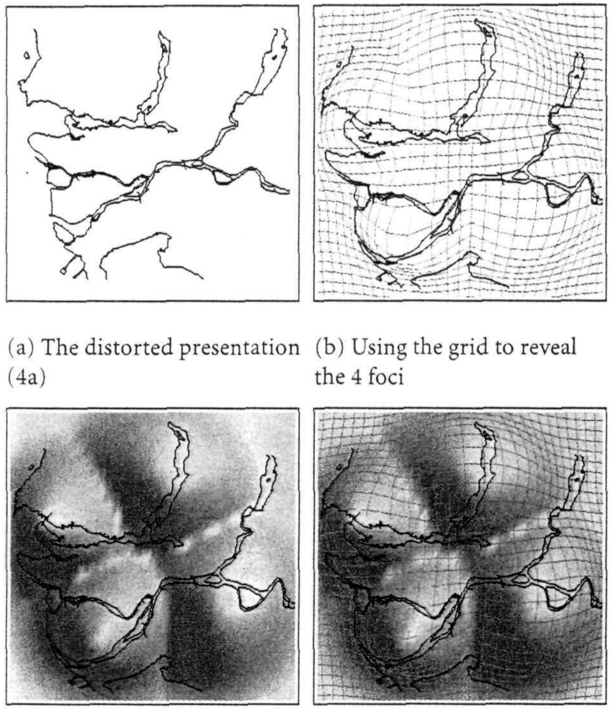


Figure 6. Three different presentations of a map of the Vancouver coastline

In our everyday life we deal effortlessly with multi-scale information. Not only do we understand how a three-dimensional world incorporates more than one 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 idea is used to create a 3D multi-scale viewing environment for two-dimensional visual information. In 3D the 2D information can be thought of as lying on a planar surface. This surface is manipulated with simple mathematical functions allowing for arbitrarily shaped multiple foci and control of the extent and pattern of magnification and compression. This in itself does not make a convincing 3D space. Visual information about the form must be provided that will reveal the nature of the distortion even through areas of sparse data.

Ideally these visual cues should not interfere with interpreting the actual information, or create a significant drain on cognitive processing. Presently the user has the option of applying either shading or a grid. Considering the extensive literature establishing that humans can discern three-dimensional shape from shading alone (Ramachandran 1988: 163–166), and the considerable evidence to support the fact that this is a pre-attentive



(a) The distorted presentation (4a)

(b) Using the grid to reveal the 4 foci

(c) Using shading to reveal the 4 foci

(d) Using the grid and shading in combination

Figure 7. The grid and shading can be used alone or together

skill, shading should give an intuitive impression of the 3D shape. Such a low level visual routine will interfere less with conscious processing and may even provide an aspect of the interface that requires no learning (Ware 1993: 91–100) (Figure 7c). A regular grid reveals the shape of the distortion by accessing two depth cues: it provides perspective information without requiring edges and serves as a texture gradient (Figure 7b). Furthermore, the shape and size of the grid squares give an approximate quantitative reading about relative magnification and distortion. As this use of a grid parallels use of a reference grid in cartography, its interpretation will be familiar to many. Figure 7d combines the use of the grid and shading.

5. Conclusions

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. Use of a spatial metaphor with visual cues (Carpendale and Strothotte 1999) helps make the distortions present in a multi-scale view understandable. This support will allow users to maintain an accurate mental representation, learning that the information is not impaired by the distortion.

The Elastic Presentation Space framework describes existing presentation methods, identifies new presentation variations, and provides methods for combining them. This removes some of the current difficulty around making a presentation choice, and allows a designer of new information visualizations to include a combination of presentation methods that best suit the needs of their application's information and tasks. Though the EPS framework has been successfully extended to 3D data (Carpendale et al. 1996: 42–51), the comprehension issues for 3D data are significantly different. While it seems that layout considerations in terms of supporting the user's mental representations may remain, similar issues around the use of visual cues such as shape from shaping are currently being investigated.

Acknowledgments

This work was supported in part by a postgraduate scholarship from the Natural Sciences and Engineering Research Council of Canada. We also acknowledge resources provided by the Graphics and Multimedia Research Lab at Simon Fraser University and Intel. I am grateful for helpful and insightful suggestions from David Cowperthwaite and F. David Fracchia.

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