Are Displays Maps or Views?

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Abstract

Metaphors are powerful means to design and learn user interfaces for computer systems. This paper discusses metaphors for display operations in Geographic Information Systems (GIS). Specifically, the metaphor DISPLAYS ARE VIEWS is proposed and analyzed. It is presented as an antithesis to the metaphor DISPLAYS ARE MAPS, which is consciously or unconsciously adopted by designers and users of most GIS interfaces. Displays are understood here as graphic screen presentations of geographic space, maps as static (paper) maps and views as visual fields, containing what humans see in a given situation. The major advantage of the visual field as a metaphor source is that it naturally accommodates scale changes. Thus, analyzing its structure also sheds new light on the generalization problem for displays.

1. Introduction

Metaphors have had a significant impact on general user interface design practice and are now established as a powerful means to control complexity in human-computer interaction [Carroll, Mack, and Kellogg 1988]. Their potential for improving user interfaces of Geographic Information Systems (GIS) is also rapidly gaining recognition, as indicated by a series of recent publications dealing with the subject [Gould and McGranaghan 1990, Jackson 1990a, Kuhn 1990, Mark 1989, Wilson 1990]. A common theme of these studies is the selection of appropriate metaphors for GIS user interfaces. Currently, map metaphors dominate, but it has been suggested that they fail to organize GIS operations adequately [Gould and McGranaghan 1990].

This paper discusses the metaphor question for GIS display functions, where the map idea is least controversial and most entrenched, as exemplified by the common expressions "virtual map", "screen map", or "CRT map". The paper contends that map metaphors are deficient even for display purposes and proposes the contrasting metaphor DISPLAYS ARE VIEWS. It shows that human vision provides a rich and powerful source of metaphors for retrieving and displaying information. In particular, it focuses on the capacity of the visual system to deal with resolution and scale changes.

Research in cognitive science has established that humans perceive, conceptualize and deal with the world at multiple levels of detail [Marr 1982, Minsky 1985]. A GIS should support this capacity, by representing data at multiple resolutions and offering operations appropriate to scale [Buttenfield and Delotto 1989]. Yet, while there has been considerable interest in database representations and manipulations at multiple levels of resolution [Guptill 1989, Oosterom 1991, Samet 1989], the same cannot be said for user interface representations.

Cartographers and GIS specialists are still struggling for a satisfactory understanding of the concepts of scale and resolution. There appear to be two dominating lines of thought: the "pragmatists" understand resolution in terms of map scale, acknowledging the limits of this concept, and the "objectivists" look for geographic scale or dimensions in the real world.

Since resolution is also a concept of human vision [Marr 1982], a third way could be to explain scale in terms of vision and its properties. Such an "experientialist" approach [Lakoff 1987] based on human perception of and interaction with the world [Arnheim 1969] is taken here. Specifically, the fundamental relation of scale and scale changes to viewing distance is explored. The goal is to apply this elementary human experience to GIS user interfaces through metaphors.

The remainder of the paper contains a discussion of interface metaphors for GIS in section two, preparing for an analysis of the DISPLAYS ARE VIEWS metaphor in section three, after which conclusions are drawn and further work is suggested in section four.

2. Metaphors and GIS interfaces

2.1. Metaphors and image-schemas in human-computer interaction

Johnson [1987, p. XIV] has characterized metaphor as

> *...a pervasive mode of understanding by which we project patterns from one domain of experience in order to structure another domain of a different kind.*

The two domains are commonly called the *source* and *target* domains of a metaphor and the metaphorical projection can be seen as a *mapping* (in the mathematical sense) from source to target. Johnson's characterization expresses a projective view of metaphor: the metaphor *imposes* a structure on the target domain, rather than assuming similarities between source and target.

Lakoff and Johnson have argued convincingly that ordinary (i.e., non-poetic) thought, action, and language are structured by metaphor [Lakoff and Johnson 1980]. It seems reasonable to presume that this is true for thought, action, and language in human-computer interaction as well. Interface metaphors are doing far more than just helping novices to learn a new application. They structure the application domain and organize the user's tasks. The designer's choice of metaphor(s) determines what concepts the users will have to deal with, how the labor is distributed between users and system, and in what terms users and system will communicate.

Since metaphorical projections can be described as mathematical mappings between domains, what remains invariant under them? Lakoff's invariance hypothesis [Lakoff 1990] claims that it is the image-based reasoning patterns of the source domain, the so-called image-schemas [Johnson 1987, Lakoff and Johnson 1980]. These are idealized cognitive structures, consisting of a small number of parts and relations, made meaningful by human sensori-motor experience. Examples are the CONTAINER, PATH, LINK, NEAR-FAR, PART-WHOLE, and CENTER-PERIPHERY schemas. Image-schemas are more abstract than mental images, being essentially reduced to topology, but less abstract than logical propositions, being related to sensori-motor experience.

It has been suggested that image-schemas play a fundamental role in user interfaces and that they are likely to be especially relevant for GIS interfaces, since many image-schemas are spatial, particularly topological, in nature [Mark 1989]. General GIS metaphors are further discussed by Gould and McGranaghan [1990]. An extended discussion of the role of metaphors and image-schemas in user interfaces, including a formalization, can be found in [Kuhn 1991].

2.2. Map metaphors and GIS

Most of today's GIS interfaces have been designed explicitly or implicitly with (hardcopy) maps and mapping operations in mind. Consequently, mapping concepts dominate the whole spectrum of GIS functions, from data acquisition through analysis to display.

Some generic problems with map metaphors have been discussed in the literature [Downs 1981, Gould and McGranaghan 1990]: Maps may not be understood well enough to serve as a useful source domain, they provide little guidance beyond display operations, they tend to hide uncertainty in the data, and they are two-dimensional representations of a three- or four-dimensional reality.

At any rate, maps are unlikely to be adequate sources of GIS metaphors for *all* the different kinds of functions which paper maps fulfill, serving at the same time as data storage and presentation devices, and as analysis and design tools. For example, maps and map sheets are now widely recognized as inappropriate analogues for the data storage function of a GIS. The main reason is that maps lead to undesirable partitionings of data, both horizontally (sheets) and vertically (layers) [Chrisman 1990, Frank 1988]. The evolution from layered mapping systems to seamless geographic databases with integrated topological data structures is practical evidence for this movement away from the map metaphor in data storage.

What about data presentation functions? GIS displays are generally understood as "screen maps", implying the metaphors DISPLAYS ARE MAPS and DISPLAYING IS

MAPPING. Thereby, they inherit not only useful conventions on symbolisms and the goal of graphic excellence, but also some limitations and problems. For instance, paper maps handle multiple resolutions in a rigid way through series of scales and pose the difficult problem of cartographic generalization, i.e. adapting information and its presentation to scale [Brassel and Weibel 1988]. While many aspects of this problem will also have to be dealt with for displays no matter what metaphors are chosen, it is worth looking for possible differences between requirements for maps and displays.

One way to do this is by asking how the visual system copes with generalization: For example, why does one never see a cluttered world (at least not in the sense of a cluttered map or display)? Controlling data density, one of the hardest problems in generalization, seems no problem at all in human vision. Understanding how the visual system achieves this could help solving the problem for displays. Also, objects which are too small to recognize are acceptable in visual fields: we ordinarily see things of which we cannot make sense because they are too small. On maps, such unrecognizable objects are not tolerable. Displays as well as views, however, can allow users to "zoom" in and see more detail (see 2.4. for more detail on this).

2.3. Visual interfaces and GIS

Clearly, electronic screens offer far more possibilities for GIS data presentation than paper maps [Moellering 1984, Robertson 1988], despite their yet inferior resolution. For example, they allow for reactive, dynamic, and three-dimensional displays [Goodchild 1990]. Thereby, an entirely new kind of communication about geographic phenomena becomes possible, where users can interact directly with suitable and adaptive representations of these phenomena [Mark 1989].

This direct communication between user and system is not limited to the visual channel; non-visual means are rapidly gaining importance [Negroponte 1989]. State-of-the-art user interface technology, however, favors visual over auditory and tactile interaction. GIS interfaces are generally not disadvantaged by this emphasis, given the highly spatial nature of vision.

It is well established by now that seeing is more than passive perception [Arnheim 1969] and typically involves categorizing what is seen [Lakoff 1987]. An entire chapter of "The Nature of Maps" [Robinson and Petchenik 1976] is devoted to the discussion of how theories of visual perception and cognition relate to geographic data presentation. It emphasizes that our visual system is not a neutral input device and that seeing is an active process: we make sense of what we see by attempting to construct meaningful shapes.

The notion of "visual interfaces" [Tauber 1987] implies such an active involvement of the user. Apart from pointing gestures and actions like "dragging" [Apple Computer 1987], visual interfaces often contain metaphors related to special visual experiences like seeing through frames, lenses, and other optical instruments. Examples of these metaphors are "windows" [Smith et al. 1982], "panning" and "zooming" [Jackson 1990a], or "fisheye views" [Furnas 1986].

The widespread occurrence of these viewing metaphors suggests a more literal interpretation of the notion of "visual interfaces", exploring metaphors based on the human visual system as such, independent of optical instruments. The visual field not only offers the logic and functionality expected from displays - being a bounded, connected region which can be moved to see something else - it also deals very effectively with changes of scale (see 3.1.).

Geometric aspects of visual perception have been discussed, for example, by [Marr 1982, Zeeman 1962] or, in relation to geography, by [Tobler 1976]. For metaphors based on vision, the effects of these geometric properties on visual cognition are of interest. An important case of such an effect is the phenomenon that, by moving closer to a scene, we not only get to see enlarged objects, but *different kinds* of objects. For example, we may see a house across the street as consisting of walls, windows, a door, and a roof and from its front yard, we can identify individual planks and bricks in the walls, but don't see the house as a whole anymore (Figure 1).

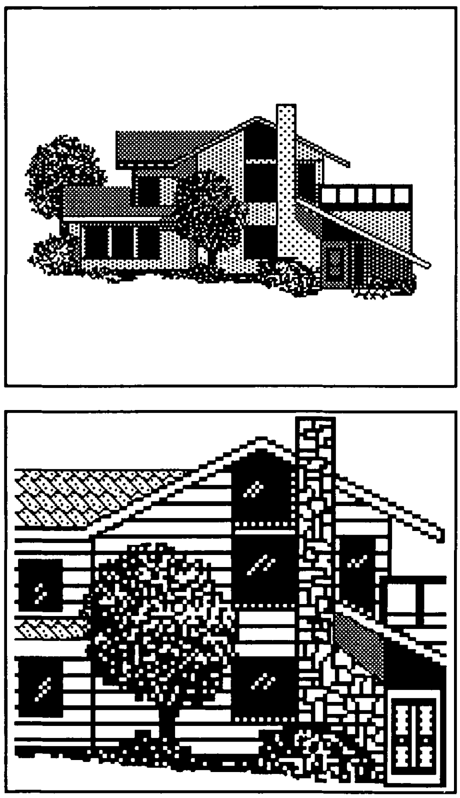

Figure 1: Getting to see different things by moving closer

This basic property of visual cognition, imposing lower and upper bounds on the level of detail perceived at a given viewing distance, is the source of many metaphors. In everyday language, it is often combined with the metaphor UNDERSTANDING IS SEEING to produce expressions like "let's take a closer look at this idea" or "he can't see the forest for the trees". In technical as well as colloquial language it is sometimes referred to as the "zoom" effect. The connection between levels of detail and the concepts of "close" and "distant" is also touched on in the final paragraphs of [Robinson and Petchenik 1976]:

> *"Scale" also refers to the level or depth with which one contemplates or analyzes something, as for example whether one "looks closely" at something or contemplates it "from a distance."*

2.4. Zooming in on "zooming"

The term "zooming" is used in cinematography, photography, computer graphics and everyday language to describe getting "close-up" views of something. In the context of GIS, Burrough [1986, p. 79] states, for example, that "most graphics systems allow the user to zoom in and display an enlarged part of the database". This description leaves it open whether "an enlarged part" means "the same, but enlarged" or "a part of the database that becomes only visible at a larger scale", or both.

The notion of a "cartographic zoom" proposed in [Bjørke and Aasgaard 1990] applies the concept of zooming to the generalization of map displays. It implies that zooming allows a user to see different things at different scales, but the idea of zooming is not further explored.

Zooming and panning operations on digital images and map displays have been studied and described, independently from the generalization problem, by Jackson [1990b]. The main conclusion from this work was that intuitive and effective interface tools require a deeper understanding of zooming and panning than one in terms of cameras or other optical instruments.

The Oxford English Dictionary (second edition, 1989) defines the original meaning of "zoom" as follows:

> *To make a continuous low-pitched humming or buzzing sound;*
> *to travel or move (as if) with a "zooming" sound; to move at speed, to hurry.*

The use of the term in photography and cinematography is, thus, already doubly metaphorical: It explains the variation of the focal length by a (fictive) motion of "rapidly closing in on a subject" which, in turn, is metaphorically related to the corresponding sound effect. (Note that one of the key metaphors in visual interfaces is, therefore, rooted in auditory perception).

Combined with our visual experience that the viewing distance influences *what* we see, zooming naturally acquires a stronger interpretation than "seeing the same, but enlarged". It becomes a mechanism to change the scale or level of detail at which one perceives and conceptualizes the world or a computer model.

This understanding of zooming suggests the more general metaphor DISPLAYS ARE VIEWS, which also accommodates additional transformations of the visual field. One of them is "panning", i.e. moving the view to another part of a "panorama" without changing the level of detail. Since transformations of the visual field correspond to

> ... *basic cognitive processes such as focusing, scanning, superimposition, figure-ground shifting, vantage-point shifting* [Lakoff 1988, p. 121]

they are ideal candidates for metaphor sources.

3. The metaphor DISPLAYS ARE VIEWS

3.1. Image-schematic structure

While a general notion of interface "views" has been around for some time [Goldberg and Robson 1981], the richness of visual fields as a source domain for interface metaphors has not yet been analyzed. The discussion of GIS "user views" in [Mark 1989] relates views to image-schemas, but concentrates on the notion of database views rather than displays.

In order to make the DISPLAYS ARE VIEWS metaphor applicable to user interface design, its image-schematic structure needs to be analyzed [Kuhn 1991]. Determining the image-schemas underlying views allows designers to define the functionality of display operations based on the metaphor.

The basic image-schema involved in the visual field is the CONTAINER schema [Lakoff 1987]. It structures the visual field as a bounded space, consisting of a boundary, an interior, and an exterior: In a first approximation, things are either in or out of sight and they come into or go out of sight.

The visual field has also a center of attention and a surrounding region. Thus, the CONTAINER schema is combined with the CENTER-PERIPHERY schema [Johnson 1987], which provides for distinguishing foveal and peripheral vision.

In addition, and less obviously, the visual field is structured by an interaction of the PART-WHOLE with the NEAR-FAR schema. We experience objects in the world as configurations of parts, forming wholes. Our perception has evolved so that it can distinguish these elements. Visual perception, in particular, requires motion of the body or of the objects to extend this distinction beyond the limited range of configurations present in one view: Getting certain parts into view involves moving nearer and vice versa. This connection is the essence of scale changes and of the zooming mechanism described above.

The combination of the PART-WHOLE and NEAR-FAR schemas enters the visual field in a second way: Moving nearer entails that only a part of the things one saw before remains within the visual field. Thus, the visual field shrinks with respect to the scene viewed. This property can be applied to simulate the relative motion of observer and objects in interactive zooming operations. By shrinking a frame of reference corresponding to the visual field, the user simulates a close-in motion (figure 2) after which the system displays a part of the scene at a larger scale.

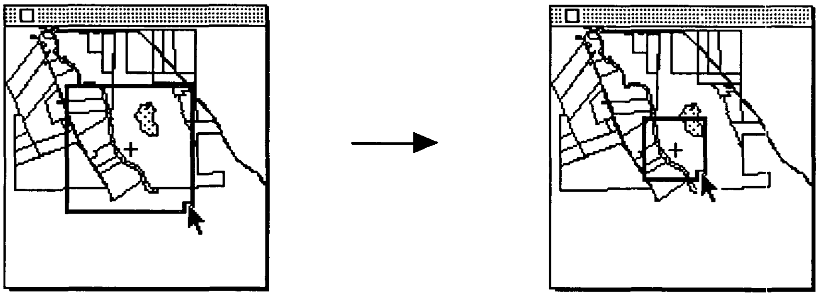

Figure 2: Combining the PART-WHOLE and NEAR-FAR schemas: Shrinking the visual field simulates motion in zooming operations. From [Jackson 1990b].

An interesting deviation from the "normal" behavior of containers defined by Lakoff and Johnson is that visual fields are not transitive: It is *not* necessarily true that, if A is in B and B is in sight, then A is in sight, too (even if one excludes the trivial cases where "in" means "enclosed by"). For example, if a wall is in sight and it is made from bricks, then it does not follow that individual bricks can be seen. Other examples are raster dots in an image or leaves in trees.

The superimposition of the PART-WHOLE and NEAR-FAR schemas on the CONTAINER schema explains this paradox: It allows a more specific interpretation of "A is in B" as "A is part of B" and lets the combination of PART-WHOLE and NEAR-FAR determine whether A is in sight or not.

DISPLAYS ARE VIEWS is a metaphor and not a literal equivalence. The matching between the two domains of a metaphor is by definition partial. Lakoff's invariance hypothesis suggests that some of the image-schematic structure in the two domains must correspond to support the metaphorical mapping. In the case of displays and views, this correspondence can be established for a combination of, at least, the CONTAINER, CENTER-PERIPHERY, PART-WHOLE, and NEAR-FAR schemas. Aspects which are non-topological and not image-schematic, such as the shape of the container boundary (elliptic vs. rectangular) or the type of optical projection involved (central vs. parallel), need not be equal or even comparable. Furthermore, some important features of displays, like symbolizations and their explanation, are obviously not accounted for by this partial correspondence with views.

3.2. Metaphor combinations and extensions

The DISPLAYS ARE VIEWS metaphor is both extensible and open to combinations with other metaphors in a GIS user interface. For example, GIS displays have to show properties and relations of phenomena which are invisible, such as borders, land values, or population densities. This situation requires the same additional metaphors as it does to explain why maps can represent them.

An extension of the visual field metaphor for displays is the previously mentioned idea of "fisheye views". Fisheye views of spatial phenomena are actually just an exaggeration of human views, which already have the property that the visual acuity lapses toward the periphery [Zeeman 1962]. This property provides a straightforward extension of the DISPLAYS ARE VIEWS metaphor. It has rarely been adopted for GIS displays, presumably because it violates the idea of a (roughly) constant scale inherent in the DISPLAYS ARE MAPS metaphor.

Fisheye views of non-spatial phenomena [Furnas 1986] and proposals for "conceptual" (logical, semantic) zooming [Mohan and Kashyap 1988, Tanaka and Ichikawa 1988] are all based on the same metaphor extension and combination: The idea that concepts are resolution dependent gets extended beyond spatial phenomena. The additional metaphor involved is that ABSTRACT SPACE IS PHYSICAL SPACE. Such an abstract space can, for example, be a hierarchy or a lattice. Thus it becomes possible to zoom in on an organization chart of a company from top-level divisions to individual workers.

Another direction of metaphor extension and combination leads beyond displays towards interface metaphors for *manipulating* GIS models. Such an approach is David Zubin's proposal to differentiate object classes based on object sizes relative to human experience [Mark et al. 1989]. Zubin discusses how shifting our viewpoint results in objects of different sizes becoming accessible to vision and manipulation. For example, a city which cannot be perceived as a unit when we are in it becomes a scene which we can scan when we drive away from it, and part of a single perspective when we are far away or flying over it. Zubin's classes of objects or spaces, thus, imply the notion of viewing distance and its influence on what object classes humans deal with. However, they are defined in terms of physical object sizes which become irrelevant for interaction with computer models. Further developing Zubin's ideas, Eric Bier has suggested editing paradigms for manipulating objects based on their relative sizes [Kuhn and Egenhofer 1991].

A promising extension of a perception-oriented understanding of displays are virtual realities [Conn et al. 1989]. GIS are probably the computing systems which come closest to dealing with actual three- or four-dimensional reality (although still too often only through two-dimensional projections). Thus, they should be ideal forerunners to systems which transcend the limitations of physical reality and allow users to experience motion through different scales by sight, sounds, and tactile cues, e.g. flying over territories or diving into atoms [Brooks 1988].

4. Conclusions

This paper has proposed human vision as a source domain for GIS interface metaphors. Specifically, it has argued for interfaces based on the metaphor DISPLAYS ARE VIEWS. The analysis of the image-schematic structure of visual fields, particularly of the fundamental connection between viewing distance and visible object classes, suggests that seeing is in some respects more powerful than mapping as a source domain for interface metaphors.

What does it mean to adopt the metaphor DISPLAYS ARE VIEWS? First, it involves the user in an active process of viewing rather than observing static maps. Second, it acknowledges the key role of the user's point of view in defining display contents. Here, "point of view" is still meant spatially. Social, political, and other viewpoints may, however, come to play an explicit role in future GIS applications. They are likely to fit this framework by direct metaphorical extension. Third, the metaphor allows the viewpoint to move conceptually closer to or further apart from a scene, supporting a notion of zooming which goes beyond magnification by relating different concepts to different scales.

WYSIWYG interfaces, where What You See Is What You Get, will clearly become more intuitive and more powerful when you have the kind of control over what you see that you have in ordinary visual experience. Spatial query and manipulation languages can become entirely different from today's awkward formalisms when they employ visual metaphors. A generalized zooming mechanism, for example, naturally integrates data retrieval and display operations. These are two aspects of querying which have been separated so far, in accordance with the idea that displays are maps, but to the disadvantage of the user [Egenhofer 1990].

For the sake of the argument, the notions of maps and views have been contrasted rather than integrated in this paper. An alternative approach to improved user interface metaphors would be to expand the notion of maps with visual concepts, taking today's display technology into account. It is equally valid and potentially leads to the same improvements. However, starting with visual concepts forces designers to evaluate more radically the role traditional mapping concepts should play in displays.

The contentions of the paper are not meant to imply that cartography has no role to play in visual displays. There are indeed many common concerns in the design of displays and maps and there is a lot to be learned from mapping and graphic excellence for data presentation on screens [Tufte 1983, 1990]. Arguing against the paper map as a dominating metaphor source is also not necessarily arguing against symbolization or against features like labels, legends, north arrows, and scale indications in displays.

The point made here is that there are important differences between requirements for good dynamic (display) and static (map) presentations. They are mainly due to the reactive character of electronic display media which supports a direct visual communication between user and system. These differences may allow for displays to relax some of the constraints on maps, like those on minimal dimensions and separations, which make automatic map generalization such a troublesome problem [Beard and Mackaness 1991].

It should be kept in mind that a metaphor such as DISPLAYS ARE VIEWS is never a literal equivalence. Thus, choosing human vision as a source domain does not restrict the scale range of displays to that of human views. The metaphor, establishing only a partial correspondence, takes some aspects of visual perception and uses them to structure displays. The possibility of zooming is one of these aspects, but restrictions of scale range, perspective, and thematic flexibility are certainly not.

The paper has touched on a few possible and actual extensions of the DISPLAYS ARE VIEWS metaphor as well as on combinations with other metaphors. While more should be said about these and other examples could be given, the point is that they all rely on perception-oriented rather than mapping-oriented metaphors. The fact that mapping itself is based on perception is not enough. GIS users need powerful dynamic control over what they perceive, rather than being presented with more or less static results of what a designer thought they want to perceive.

Finally, in order to become applicable to interface design, image-schematic analyses of interface metaphors like the one presented for the visual field need to be formalized. An approach based on algebraic specifications has been proposed in [Kuhn 1991]. At the same time, prototypes of interface tools which implement and visualize the metaphors have to be developed, like the ones proposed by Jackson [1990a] for zooming and panning in displays of images and maps. Current research addresses the question of how these tools can be extended to deal with zoom and pan operations in the conceptual domain.

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