The Natural Landscape Metaphor in Information Visualization: The Role of Commonsense Geomorphology

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The landscape metaphor was one of the first methods used by the information visualization community to reorganize and depict document archives that are not inherently spatial. The motivation for the use of the landscape metaphor is that everyone intuitively understands landscapes. We critically examine the information visualization designer's ontologies for implementing spatialized landscapes with ontologies of the geographic domain held by lay people. In the second half of the article, we report on a qualitative study where we empirically assessed whether the landscape metaphor has explanatory power for users trying to make sense of spatialized views, and if so, in what ways. Specifically, we are interested in uncovering how lay people interpret hills and valleys in an information landscape, and whether their interpretation is congruent with the current scientific understanding of geomorphologic processes. Our empirical results suggest that neither developers' nor lay users' understanding of terrain visualizations is based on universal understanding of the true process that has shaped a natural landscape into hills and valleys, mountains, and canyons. Our findings also suggest that the information landscape metaphor for sense making of a document collection is not self-evident to lay users, as claimed by information landscape designers. While a deep understanding of geomorphology will probably not be required to successfully use an information landscape, we do suggest that a coherent theory on how people use space will be necessary to produce cognitively useful information visualizations.

Introduction

With the advance of the World Wide Web and its diverse applications for the exchange of information, many have tried to conceptualize and depict digital information collections such as online libraries, Web-based multimedia collections or digital discussion forums (Dodge & Kitchin, 2000). Information providers and users have considered properties of digital information collections represented as "spaces," including their size, shape, and form. What is the nature of an information space, and what do they look like when depicted? How is information located in these spaces, and how do their spatial properties represent nonspatial properties of the information? Do depictions of information spaces (i.e., external visualizations) correspond with the mental maps (i.e., internal visualizations) of the information spaces held by their users?

Depicting information collections as concrete spatial layouts, even when the collections are not themselves explicitly spatial, is an information visualization technique known as *spatialization* (Kuhn & Blumenthal, 1996). Spatialization is based on utilizing spatial metaphors such as location, distance, size, and connectivity to devise graphic displays that depict the structure or content of nonspatial information stored in very large databases. Instead of presenting users with large tables or long lists of queried items in text format, information spatializations allow users to explore graphic displays of information, often allowing users to see the "layout" of the information in a single view (Skupin & Fabrikant, 2003). Spatialization attempts to exploit the power of graphic displays as cognitive aids, allowing people to sift more efficiently through and gain knowledge from vast amounts of accumulated data such as medical records, banking transactions, or information-bearing items stored in online archives (Fabrikant & Buttenfield, 2001). However, empirical findings have suggested that information landscapes should be based on sound geographical principles (Fabrikant, 2000, 2001a, 2001b) and adhere to cartographic design guidelines to be cognitively inspired and usable (Fabrikant & Skupin,

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FIG. 1. An information landscape by Kartoo (www.kartoo.com).

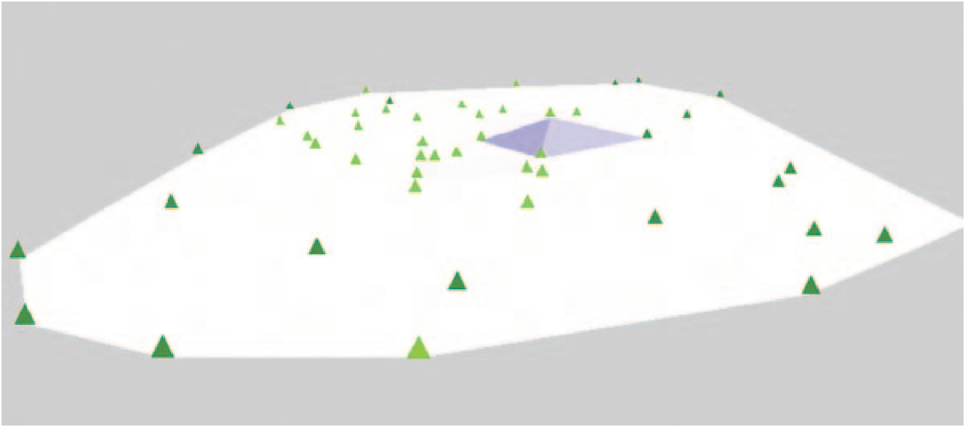

FIG. 2. An information landscape by Chalmer's (1983) bead system, depicting articles from an HCI conference (CHI '91).

2005). Very often, however, spatializations are presented to users without "metadata," such as a legend explaining the symbolization, labels, source information, or mathematical construction details so that lay users can evaluate the basis of the spatial layout.

Several Web search engines have embraced the idea of a landscape metaphor to depict data holdings. The landscape metaphor was one of the first methods used by the information visualization community to depict document archives and is still an extremely popular method (Card, Robertson, & Mackinlay, 1991; Chalmers, 1993; Wise et al., 1995). The information landscape also has been applied to scientometric analyses (Scharnhorst, 2000). Of the myriad of existing spatialization examples,[1] we were interested in evaluating classic representatives of information landscape visualizations in our study. One such prototypical example of an information landscape accessible on the Web is depicted in Figure 1. Another very early example is shown in Figure 2, a sample screen from Chalmer's (1993) Bead information landscape system.

As Kuhn (1993) suggested, powerful interface metaphors are those that create explanatory theories for users interacting with a system. That is, users can map the processes and relations of the source domain (e.g., the natural landscape) onto the processes and relations of the target domain (i.e., the information space), allowing them to use their knowledge of source domain operation to predict the target domain operation. The power of the landscape metaphor as an interface lies partially in the rich ontology provided by the landscape concept in the real world. Landscapes are ubiquitous in the evolution of the human species, the development of human cultures, and the personal experience of individuals. Landscapes thus provide not only a deep source domain for

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[1] See, for example, Martin Dodge's online collection in the "Atlas of Cyberspace on the Web at: http://personalpages.manchester.ac.uk/staff/m.dodge/cybergeography/atlas/atlas.html

the creation of various spatial metaphors (Couclelis, 1998) but also provide a theoretical basis for spatialization previously missing in the field of information visualization (Wise, 1999). Of course, if the landscape metaphor suggests certain properties of an information system target domain that do not actually apply to that target domain, users run the risk of being confused or misled by the landscape metaphor. This is both a blessing and a curse when using a metaphor. A metaphor is only *like* a source domain, not the domain itself (Lakoff, 1987). This means that a metaphor may include only some, but not all, characteristics, and may in fact have additional (i.e., "magical") properties.

In the present article, we critically examine the explanatory theories that the landscape metaphor suggests to lay users. A common claim in information visualization is that the landscape metaphor is intuitively understood by the public because it is based on the familiarity of the organization of the natural environment (Dourish & Chalmers, 1994), and the interpretation of natural forms is part of humans' biological heritage (Wise, 1999). Specifically, we are interested in uncovering how lay people interpret hills and valleys in an information landscape, and if their interpretation is congruent with the current scientific understanding of geomorphologic processes. In the first section, we consider possible ontologies embodied by the landscape metaphor. We contrast the information visualization designer's ontologies for implementing spatialized landscapes with ontologies of the geographic domain held by lay people (i.e., commonsense or naïve geomorphology). In the second half of the article, we report a qualitative study in which we empirically assessed if the landscape metaphor has explanatory power for users trying to make sense of spatialized views, and if so, in what ways.

The Landscape Metaphor in Information Visualization

Although the landscape metaphor has become almost ubiquitous in the literature of human–computer interaction (HCI), information science, and information visualization, this literature almost completely avoids any reference to geographic theory and research. The few references made to geography, cartography, or GIS/GIScience are generally somewhat misleading. For example, the following quote comes from a state-of-the-art information visualization article by Börner, Chen, and Boyack (2003): "Geographic Information Systems (GIS) represent a gray area between information visualization and traditional cartography.... Thematic maps provide a rich metaphor for a class of information visualization known as information landscape" (p. 185). There is a fundamental difference to use geographical space as a reference system to depict additional attribute information of geographic phenomena (i.e., inherently spatial), compared to an abstract three-dimensional space for multivariate, nongeographical data (i.e., metaphorically spatial). GISs are not "just" visualizations or maps but are quite complex hardware and software tools employed to store, manage, analyze, and display geographically referenced data to help everyone from scientist to citizen to solve geographic problems (Longley, Goodchild, Maguire, & Rhind, 2005). The core of a GIS is the georeferenced database. Geographic data stored in a GIS are represented in various visual (and nonvisual) forms. Visual GIS outputs can include tables, graphs, images, and various types of "traditional" cartographical products (i.e., maps). In other words, maps are just one of many forms that the GIS offers as spatial database representations. Thematic maps show the spatial distribution of a particular geographic phenomenon or process (Dent, 1999). Specifically, thematic maps, known since the 19th century (thus well before computers), are one class of visuospatial forms that can be produced with GIS, but they also can be produced with a simple graphic-design package or even by hand. They illustrate physical and cultural phenomena (and processes) or abstract ideas about them (e.g., statistical relationships) within a geographical reference frame (e.g., shown on a cartographic base map). While featuring abstract statistical data and respective statistical graphics (e.g., statistical surfaces, pie and bar charts, etc.), thematic maps are based on inherently spatially referenced data (e.g., by latitude and longitude), and thus show data that are not spatialized.

While cartographic maps or GIS maps refer to the geographic environment, we now turn to the mapping of abstract spaces. The basis for using a landscape metaphor is to "exploit our familiarity with the naturally spatial organization of the real world" (Dourish & Chalmers, 1994, p. 1) and to "potentially gain a great benefit by employing many of our innate perceptual skills" (Chalmers, 1995, p. 106). But details of exactly how or why a landscape metaphor might "work" are seldom presented, nor is a connection made to any evidence of how people understand landscapes or their meaning. The landscape metaphor expresses the idea of depicting typically high-dimensional and abstract data spaces with lower dimensional intuitive spaces, but details of the alleged metaphorical mapping between the target domain and the source domain are sketchy or absent. One example of such an information landscape is the landscape provided in VxInsight (Boyak et al., 2002a, 2002b) depicting

> . . . a 3-D virtual landscape that looks like a mountain range. This three-dimensional environment is readily understood because there is only a small cognitive step between seeing the virtual terrain and then exercising our innate human expertise in navigating through real terrains. (Boyack et al., 2002a, p. 766)

A second landscape example, according to Wise et al. (1995), is said to "reveal thematic patterns and relationships between documents in a manner similar if not identical to the way the natural world is perceived" (p. 52). Although neither Wise nor other information visualizers provided detail as to how the natural world is in fact perceived, they suggested that the landscape metaphor carries a natural interpretation that does not require instruction or prolonged training to be appreciated and used (Wise, 1999).

Geographers have traditionally used the term "landscape" to refer to a perspective view of a portion of the material earth surface that can be perceived by humans via the senses, especially vision; this term also has been used to

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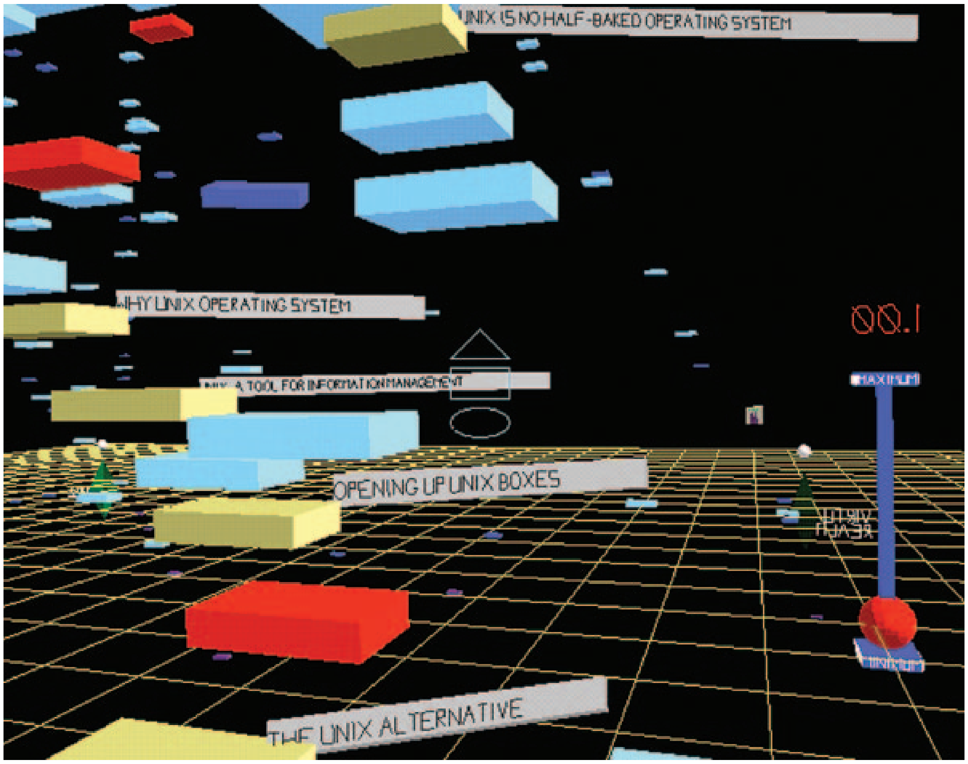

FIG. 3. Example of a Populated Information Terrain (PIT; available at: http://www.crg.cs.nott.ac.uk/research/applications/pits/#examples).

refer to a homogenous area of earth surface, similar to "region" (Granö, 1929/1997; Johnston, Gregory, & Smith, 1993; Martin & James, 1993). Landscape is thus closer to two-dimensional than to three-dimensional—the landscape is part of the curved (i.e., undulating) two-dimensional surface grounding a three-dimensional volume in which life exists on Planet Earth. Geographers distinguish additionally between natural (i.e., biophysical) and cultural (i.e., artificial, anthropogenic, etc.) landscapes to recognize the importance of human agency on Earth's features and processes. Terrain implies the curved two-dimensional surface of the Earth, and its use suggests why Gibson's (1979) ecological perception theory has become popular in the few theoretical discussions to be found in the information visualization literature. In contrast, the term "terrain" is often used interchangeably with information landscape in the information visualization community. Following the Gibsonian tradition, Wise (1999) attributed to the information landscape "the advantage of the visual appearances of natural forms that humans have learned to interpret visually as part of the biological heritage from their species history on Earth" (p. 1225). This quote also suggests that the term *landscape* for some information visualization researchers is synonymous with the *natural* landscape, emphasizing physical Earth features and processes.

Unfortunately, there seems to be confusion about the ontology (i.e., geographic primitives and their relationships) of landscapes in the real world (i.e., the source domain) that information visualization designers draw upon when developing information landscapes to represent the content of databases (i.e., the target domain). As mentioned earlier, when there is a mismatch between source domain and target domain, developers run the risk of confusing or misleading the audience with a metaphor. For example, consider the *Populated Information Terrain* (PIT) (Benford, Snowdon, & Mariani, 1995; Mariani et al., 1994), a screenshot from which is shown in Figure 3. As terrain, according to the evolutionary argument mentioned earlier, a user would expect data objects in PITs to be subjected to gravity and thus grounded on a horizontal surface; however, as the screenshot reveals, data items are depicted as abstract-looking geometric shapes floating in three-dimensional space, and information seekers fly through the space to browse the data archive. The issue of dimensionality is another problem area in information visualization. Wise et al. (1995), creators of probably the most well-known information landscape, *ThemeScapes*, stated that "ThemeScapes are abstract, three-dimensional landscapes of information that are constructed from document corpora" (p. 55); however, ThemeScapes and similar spatializations such as VxInsight (Figure 4) are not three-dimensional, nor 2.5-dimensional as noted by Boyack et al. (2002b), but rather curved two-dimensional surfaces. They are undulating, surfacelike entities which a viewer does not penetrate or travel beneath to explore. Typically, the distance measures assigned to the *x*–*y* surface (the ordination output distance based on input similarities) are not in the same units as in the *z* dimension (e.g., frequencies, or densities). The exploration volume surrounding the landscape or terrain is three-dimensional

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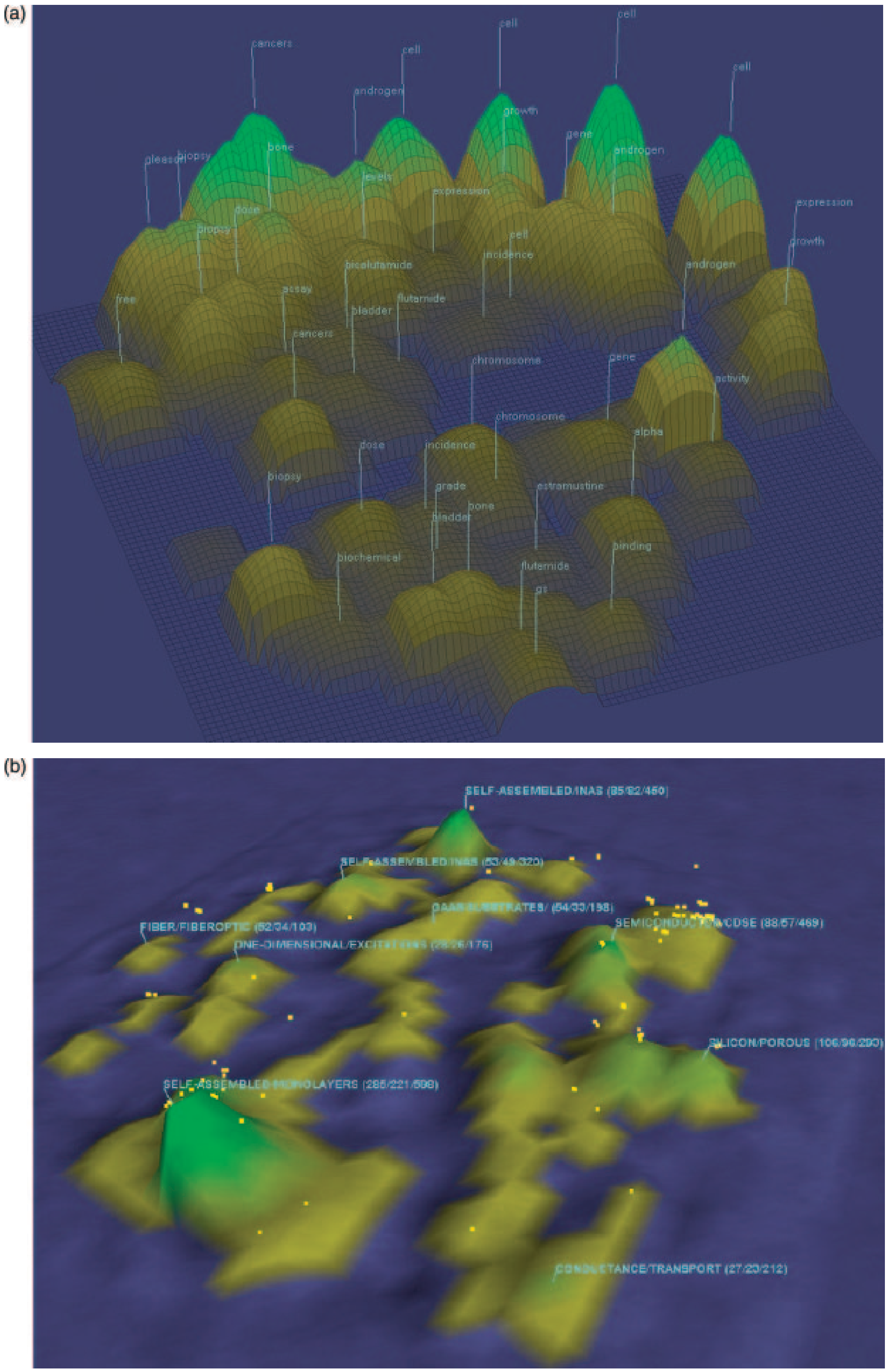

FIG. 4. Screenshots of (a) ThemeScapes and (b) VxInsight Information landscapes. Themescape image created with a demo version of ThemeScape (available at http://inspire.pnl.gov/). VxInsight image from Boyack, Wylie, & Davidson (2002a).

because a viewer can fly over and around them and is typically able to rotate them as if they were toy blocks in one's hand. When depicted on a two-dimensional computer monitor, the image projected to a viewer makes them look like 2.5-dimensional perspective views.

Some of the confusion about dimensionality may stem from restricting the term *landscape* to *natural* landscapes, as found in some of the information visualization literature (e.g., Wise, 1999), but unlike traditional use in geography. As mentioned earlier, natural landscapes are typically experienced *on* the curved two-dimensional surface, by hiking *on* trails, climbing mountains, using boats to navigate on lakes, and so on (crawling through caves or diving in water provide atypical experiences.) However, *anthropogenic* landscapes, such as urban environments, contain buildings with multiple stories, bridges, tunnels, and subway systems. Human movement *in* buildings, for example, would not be restricted to the curved two-dimensional surface (as on the physical terrain) but would be possible in three dimensions (e.g., going up the stairs and down the hall inside a three-dimensional building). Humans also have created flying devices such as airplanes and balloons that provide opportunities to directly experience the third dimension above the curved two-dimensional surface of the Earth. What seems important to emphasize with these examples are the human *activities* that various spaces afford (Gibson, 1979). In addition to natural landscapes, researchers have proposed using urban landscapes as spatialization metaphors (Dieberger & Frank, 1998). We recently conducted a study of how users interpret such "cityscapes," and intend to present the results in a future article.

A mixing of source–domain ontology, semantics, and dimensionality can be found in the *City of News and the Galaxy of News* information landscapes (Sparacino, Pentland, Davenport, Hlavac, & Obelnicki, 1997). Even though these systems reflect a distinction between two-dimensional and three-dimensional spaces, Rennison (1994) contended that they overlook a distinction between spaces such as rooms and buildings that are encountered on a daily basis and abstract spaces such as galaxies and solar systems that we understand only on a conceptual level since we do not directly experience these types of spaces. These confusions may only represent semantic carelessness (i.e., misuse of terms), but the ambiguity in the intended use and power of the landscape metaphor for information access is more troubling. The power of visual data mining is not so much how it facilitates learning or memorization of spatial information but how it facilitates perceiving unexpected data relationships and knowledge construction from highly complex, multivariate databases (Card, Mackinlay, & Shneiderman, 1999).

Ontology of the Landscape Metaphor

What is the ontological basis for using a landscape metaphor in information visualization? More specifically, what are an information landscape's basic building blocks, and how are they related? Boyack et al. (2002b) suggested that data are presented as a landscape because this is a layout with which we are familiar, a layout we are adept at interpreting. This echoes Minsky's (1988, p. 122) idea that "much of how we think in later life is based on what we learn in early life about the world of space." In this sense, one could motivate the use of spatial metaphors because space plays an important role in human cognition and perception (Lakoff, 1987; Lakoff & Johnson, 1980). Wise (1999) claimed that information landscapes are "built as 'emergent forms' in the manner that natural visual patterns originate" (p. 1225), and this familiarity allows a person to intuitively interpret the information landscapes. ThemeScapes landscapes, for example, are understood as natural landscapes, stimulating "fundamental visual experiences of our world that people have incorporated and responded to for eons" (Wise, 1999, p. 1225). Furthermore, the landscape "synthesizes a mimic of the natural physical form-giving process of sedimentation" (Wise, 1999, pp. 1229–1230) in which themes represent sedimentary layers. It "may be treated in most all respects like a sedimentary form, including taking a probe or 'core samples' at any point in the landscape" (Wise, 1999, p. 1229). Similarly, with the VxInsight tool,

> three kinds of mountain landscapes can be requested, a transparent wire frame rendering which lets the analyst see the density of data elements below the mountain, or solid mountains, which can either rise from a synthetic sea, like an island or can rise up from an interior grassland region. (Davidson, Hendrickson, Johnson, Meyers, & Wylie, 1998, p. 270)

All of these quotes both suggest a "pile-up" ontology for information landscapes, akin to sugar cones, book stacks, or geologic deposition processes such as sand-dune formation or erupting volcanoes. As suggested earlier, it may not be necessary to have a deep, scientifically correct understanding or theory of sedimentary forms to comprehend landscape spatializations—simply the long-experienced human *activity* of piling "stuff" (e.g., clothes, coins, books, CDs) on a surface within a manipulable (tabletop) space will do the trick.

The pile-up ontology also matches a "more-is-up" metaphor, proposed by Lakoff and Johnson (1980; Johnson, 1987) based on their verticality image-schema. The verticality schema is the basis of the "more-is-up/less-is-down" or "more-is-larger/less-is-smaller" metaphor used in everyday language to map metaphorically the notion of magnitude of an abstract concept to the notion of vertical location or size in the familiar and intuitively understood geographical domain. Two examples are the phrases "inflation is steadily going up" and "her reputation is higher than ever." The fact that understanding the mapping of vertical location or size onto magnitude increase/decrease seems so natural or intuitive explains why this image schemata also has been so popular in statistical graphing (e.g., bar graphs and line charts) and in thematic mapping (e.g., graduated symbols, cartograms). In fact, statistical graphing has been equating "higher" with "more" for several hundred years, and the idea of plotting nonspatial data into three-dimensional-looking statistical surfaces goes at least as far back as Perozzo (1880).[2]

According to Robinson (1961), one of the most important concepts in cartography is representing volumetric geographic data by means of a statistical surface. Volumetric geographic feature data are characterized by at least three

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[2] An example is available on the Web at: http://www.math.yorku.ca/SCS/Gallery/images/stereo2.jpg

dimensions, such as two-dimensional location (x- and y-coordinates on the plane), and a feature's characteristic mapped into the third dimension (i.e., attribute). For topographic surfaces (i.e., relief or landform maps), the third dimension is typically elevation above sea level; for abstract statistical surfaces, it can by any attribute that smoothly varies over space (e.g., population density, access distance to grocery stores, noise levels, etc.). Over many years, cartographers have developed an array of graphical symbols, including points (dot-density maps), lines (isolines or fishnet surfaces), and areas (isopleth and shaded relief maps), to depict volumetric data in the form of statistical terrains.

Geomorphology 101

Given the claim by information visualization researchers that people rely on their understanding of terrain-formation processes to interpret terrain metaphors, it is instructive to review those processes from a geographical and geological perspective. Geomorphology is the science that studies landforms and the processes that shape them (Summerfield, 1991). Over the last several centuries, a creationist view of the landscape as immutable was replaced first by theories that the landscape was shaped by the Biblical flood, and later by scientific models that the landscape was formed by the processes we can observe today, acting over very long time periods. Geomorphologists now believe that the Earth's terrestrial surface has been shaped primarily by tectonic forces that cause uplift, folding, and faulting, and the erosion and deposition ("denudation") of sediments by wind, water, glaciers, and the action of chemical and gravitational processes. These processes often gouge out valleys or canyons ("local minima"), or fill in basins to form plains and other flat features. A large proportion of the Earth's protruding landforms—"local maxima" that lay people often identify as hills or mountains—are created by the differential erosion of materials varying in hardness. For example, much of the "mountainous" areas of the Western Appalachians of the Eastern United States and the intermontane plateaus of the Western United States were formed in this way. Although these erosional features often operate on plateaus that have been uplifted by tectonic forces, they do not result directly from true orogenic (mountain-building) processes. Such orogenic processes primarily include the folding and faulting, not just uplift, due to plate tectonics. Volcanism is important, too, but accounts for a relatively small proportion of the Earth's protruding landforms.

Where sediments were deposited by water, they either fill basins in the bottoms of water bodies or produce flat-topped fills in the forms of deltas, flood plains, and alluvial fans. In other words, fluvial deposition tends to make land surfaces more level. In a fluvially eroded landscape, geomorphic activity generally produces concave topographic features such as valleys and canyons, and not convex forms such as hills or mountains. Fluvial erosion may increase local variation in height by carving the low parts even lower or may itself produce a leveling by eroding the high areas. When tectonic forces cause land to rise, areas often rise as masses, retaining (more or less) the forms they had at lower elevation. The increased elevation exposes surfaces to higher potential energy and potential erosion, with hill and valley forms being created through erosion of the valleys. In typical geomorphic systems, maximum geomorphic process activity leads to larger and lower valleys whereas true hills and mountains are the places in the landscape where the least activity has happened. Thus, the topography of natural landscapes, including what most lay people would call hilly or mountainous terrain, is mostly not formed via piling-up processes.

Commonsense Understanding of Landscape Forms

Given that the interpretation of terrain spatializations supposedly requires understanding of geomorphological processes primarily by lay people, not geomorphologists, it is important to take the next step and ask how lay people understand the basic facts of geomorphology we have just reviewed. Very little is known about commonsense knowledge of topography by the general public, nor about how this might vary across cultures (but see Mark & Turk, 2003; Mark, Turk, & Stea, 2007). In various places across the Earth, prominent convex forms such as mountains and hills often provide good landmarks for navigation in natural landscapes. Individual mountains are given proper names in many cultures, and sacred significance is often attributed to them (Tuan, 1974). People generally know that water runs downhill, and are likely aware that valleys collect and concentrate the water that may form a river on the valley floor. They probably know that floods can carry sediment and deposit it as flow slackens, and that erosion can create gullies and landslides. If they live in affected areas, they may know that volcanic eruptions can produce lava flows or cinder cones, and that wind can pile up dunes that can move across the landscape. Processes such as these may be available to users of information displays as a grounding for metaphors that allow display interpretation.

Commonsense geomorphology (or naïve, intuitive, etc.) is the understanding that lay people—nonspecialists—have of geomorphological structures and processes. This notion is inspired by early work on commonsense physics (Hayes, 1978; McCloskey & Kohl, 1983) and by more recent work on commonsense understanding of the Earth and geography (Egenhofer & Mark, 1995; Vosniadou & Brewer, 1992). In fact, the systematic analysis of how lay people perceive and conceive earth-surface topography can be traced at least as far back as Granö's (1929/1997) early writing on "pure geography," with its focus on perceived landforms as the basis for a human-centric physical geography. This also is reflected in work on landform "ontologies"—how do lay people perceptually and conceptually organize the solid earth surface into features, subsequently labeling them verbally (Hoffman & Pike, 1995; Montello, Sullivan, & Pick, 1994; Smith & Mark, 2003). In related work, educational researchers have been concerned with the conceptions of geology that students bring

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to their earth-science classes (Ishikawa & Kastens, 2005). One of the main goals of the research we report here is to investigate further the commonsense understanding (ontology) people have of processes that create landforms. This is of interest in itself, but it also will help us understand how landscape metaphors may work well or poorly when used to spatialize data for lay people.

Research in environmental perception might provide insights on how information landscapes are "read" and understood. Behavioral geographers, environmental psychologists, and others have long studied human–environment relationships, including the way people perceive, cognize, experience, and behave in natural environments (Amedeo & Golledge, 2003; Golledge & Stimson, 1997; Hoffman & Pike, 1995). Montello, Sullivan, and Pick (1994), for example, compared experienced topographic map users to novice users on a recall memory task involving photographed scenes of natural landscapes; in addition, half the experienced participants had to match from memory the landscape scenes with viewing directions marked on a topographic map. The relative proportion of terrain features recalled on drawings and verbal descriptions of the scenes, as opposed to nonterrain features such as vegetation or atmosphere, did not differ as a function of prior map experience, nor did the types of terrain features recalled. Generally, participants tended to parse the continuous landscape shown on the photographs into discrete features. All participant groups recalled hills, as opposed to valleys, flat areas, and slopes, most commonly. But performing the map-matching task did influence recall for the natural landscape scenes. Experienced map-reading participants who had to match the scenes with viewing directions on a map of the area recalled relatively more terrain than nonterrain features (e.g., vegetation or atmosphere), and among the terrain features they recalled, relatively more were hills, valleys, or slopes, and fewer were flat features.

How Do Landscape Metaphors "Work?"

To our knowledge, displays based on people's actual commonsense knowledge of landscape processes have not yet been created. Among information visualization specialists, Wise (1999) should be commended for attempting to provide an explicit connection between information displays and the source domains for display "metaphors" such as stars or terrains. Most others who present information landscapes do not even bother to outline why they think that the displays they create might be effective. However, Wise's (and other information visualizers') understanding of the geomorphological source domain was not always accurate. For example, Wise began with a general thesis inspired by evolutionary psychology: Humans are adapted as a species to interpret certain aspects of natural environments. By designing information visualizations in forms that imitate these natural environments, users will find it easier and more intuitive to interpret the visualizations. Wise referred to this as the "ecological approach" to visualization, evocative of Gibson's (1979) ecological theory of perception (Note that Gibson himself was not particularly specific about this being innate rather than learned.)

Wise (1999) got more specific about the metaphorical mappings between displays and source domains in landscape spatializations:

> It was not accidental that the "Galaxies" visualization invoked the metaphor of documents as stars in the night sky, or that ThemeScapes™ represented themes as sedimentary layers that together create the appearance of a natural landscape. These are fundamental visual experiences of our world that people have incorporated and responded to for eons. They both carry a natural interpretation that does not require instruction or prolonged training to appreciate and use. (p. 1225)

But how do people really interpret the night sky? Wise (1999) did not cite any research on this question, nor does he state specifically how human interpretation of astronomical forms and processes in the night sky might transfer to users' interpretations of the "Galaxies" visualization. In the case of terrain, Wise was more specific, suggesting that users interpret the meaning of sedimentary deposits quickly and "naturally" because the human species has viewed such deposits for millennia. Do people really see and correctly interpret sedimentary layers in hills and canyon walls as a regular and repeated component of their experience?

Wise (1999) described the process of creating ThemeScape representations to imitate sedimentary deposition:

> The terms are used like layers of sedimentary strata, wherein each term's layer will vary in thickness as the real probability of finding that term within a document at each point in the 2-D plane.... In a ThemeScape™, a term layer is thickest at the highest density of documents that carry that term because the probability of finding that term there is correspondingly greater.... As term layers accumulate, the highest elevations occur where the thickest layers overlay each other. Lower regions reflect places where there are fewer documents or where the documents are less thematically focused.... Such a thematic terrain synthesizes a mimic of the natural physical form-giving process of sedimentation. (pp. 1229–1230)

However, the physical forms of landscapes are generally not produced in the way Wise described. The sedimentary strata evident on the sides of many landforms, particularly in arid landscapes, are revealed by erosion of surrounding material, not build-up of material (Summerfield, 1991). If "local maxima" such as hills and mountains are not formed in the way Wise described, how do terrainlike information visualizations "work" to communicate information? Either they work for reasons different than those Wise hypothesized or they work because the users of spatialized displays apply the same commonsense geomorphology as did Wise, which is actually inaccurate. Another possibility is that they do not, in fact, work well. Our primary goal in the research we present here is to investigate which of these options is true.

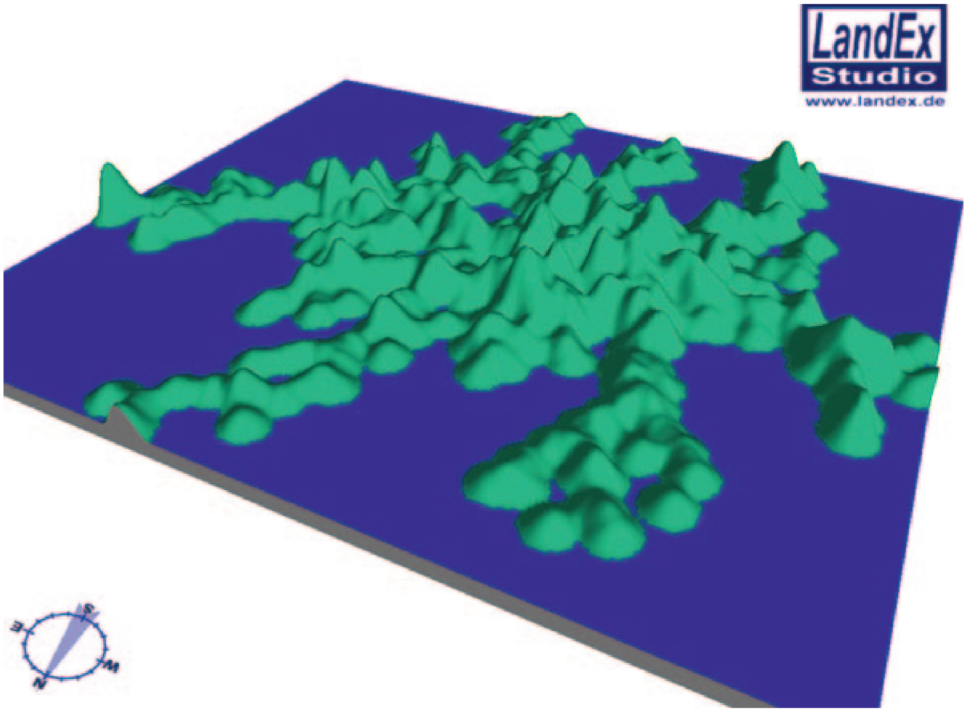

FIG. 5. A sample display used in the experiment. The display was created with LandEx software (see http://www.3dgeo.de/landx.aspx).

If we believe that users of information visualizations are familiar with the true nature of geomorphic processes, and the true origins of hills and valleys, we might predict that users would naturally interpret valleys and canyons as places of *maximum* information activity, and mountains as places of *minimal* information activity, unless the rendering looks like dunes or volcanoes. If, on the other hand, users interpret larger hills and mountains as representing *more* information, this would be evidence that users' commonsense or naïve ideas about topography *do not* reflect a valid comprehension of geomorphological processes, at least as expressed in current scientific understanding.

Experiment

We conducted an experiment with nonspecialists on their understanding of geomorphology and their interpretation of natural landscapes in information spatializations. Our concern was to characterize the nature of lay understanding of geomorphological processes—what we are calling commonsense geomorphology. We also were interested in how lay people understand spatialized displays based on natural landscapes, and in what ways commonsense geomorphology explains how people interpret spatialized displays based on natural landscapes. Are spatialized displays based on landscapes interpreted on the basis of one's understanding of actual landscapes? If so, how does that understanding resemble an expert's understanding of geomorphology? If not, how do people interpret spatialized displays? Do they interpret them easily and consistently, particularly when they are given only very minimal instructions?

To address these questions, we showed participants curved two-dimensional surface displays that they could explore in a three-dimensional space depicted on a two-dimensional computer monitor. As can be seen in Figure 5, the test stimuli were inspired by the kinds of information landscapes produced and commonly used in the information visualization community (e.g., Boyack et al., 2002a). About half the participants were told that they were looking at an actual earth-landscape surface; the rest were told they were looking at an "information space." Using a mouse as an interaction device, participants were able to zoom in and out of the display, rotate the landscape, and fly over it if they wished before answering a test question. Participants were asked to explore the depicted surface and answer a series of open-ended questions about the convexities and concavities visible in the display.

Method

Participants

Twenty-three students (13 females, 10 males) from an introductory undergraduate human geography course took part in the experiment. Their mean age was 20.0 years. The participants had many different majors, mostly not geography; most of them had not taken other geography courses. Students received a small amount of course credit for participating in the experiment.

Materials

Participants viewed an interactive computer display composed of a curved two-dimensional surface depicted in

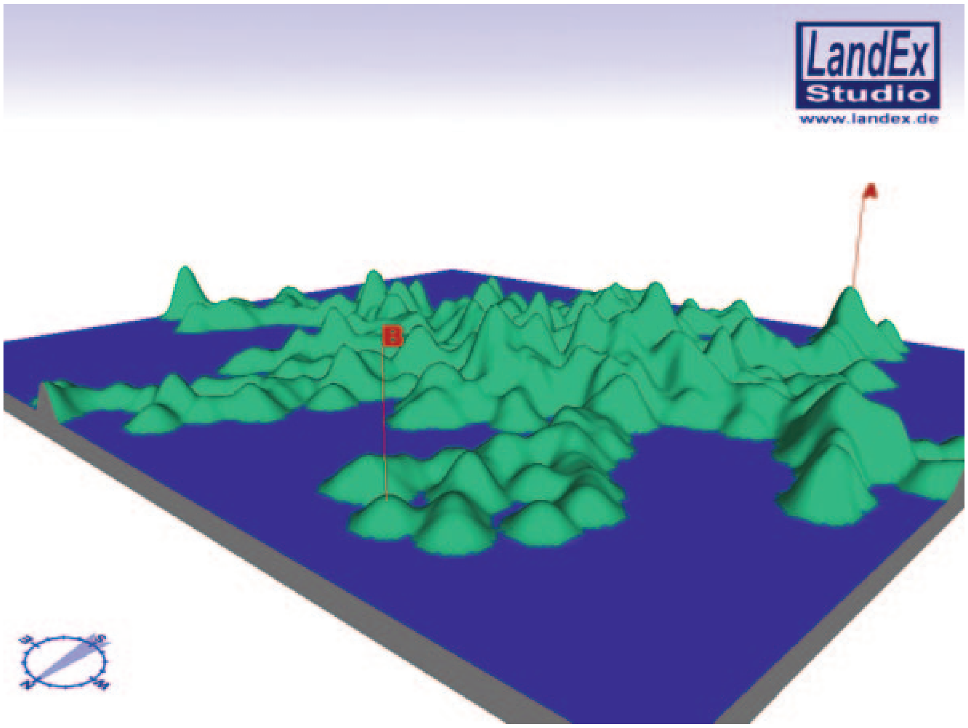

FIG. 6. Sample screenshot from an experiment trial showing two convexities of different heights, labeled "A" and "B."

three-dimensional space; the surface was colored green, and the surrounding flat area was blue (see Figure 6). The surface displays were depicted on a 20-in. computer monitor, using a Windows 2000 Pentium III personal computer. The surfaces were derived from a Reuters news stories database, applying spatialization procedures described in further detail in Fabrikant (2001b) and Skupin and Fabrikant (2003). The surfaces were displayed using the LandEx software (Döllner, 2005), a state-of-the-art, three-dimensional visualization software developed for display of natural and urban landscape models. On various trials, either two or three point locations on the surface were labeled *A*, *B*, or *C*. To avoid a "preferred" or default viewing perspective, the point labels rotated along with the viewer position, but remained fixed (i.e., "billboarding"), when participants chose to change the viewing perspective of the surface.

Participants were randomly assigned to one of two experimental conditions. In the *landscape* condition, 12 participants were told that the displays represented "a portion of the Earth's surface. Your task is to explore the depicted landscape and answer a series of questions about the convexities and concavities visible in the landscape." In the *information space* condition, 11 participants were told that the displays represented "a portion of a document collection of news stories.... The display shows a portion of an information space. Your task is to explore the depicted information space and answer a series of questions about the convexities and concavities visible in the information space." That is, landscape participants were told to interpret the displays as actual topographic ground surfaces while information space participants were told to interpret them as abstract spatializations of nonspatial semantic content. We attempted to keep the length of the display descriptions in the two conditions as nearly equal as possible, although the information space did require a little additional description. These descriptions aside, participants in both conditions saw exactly the same displays.

Participants in both conditions answered a series of 10 questions about the display, often specifically about the labeled points (see Appendix A). The questions were the same for the two conditions, with the exception that "natural" or "landscape" for the landscape group was substituted with "information" or "information space" for the information space group. The questions asked participants about the general appearance of the landscape or information space; how they interpreted the depth, height, shape, width, and volume of the convexities, concavities, and the space between the convexities (i.e., saddles); and how they interpreted the two-dimensional locations of the comparison points. The final question asked participants to compare three points, imagining that the points were the locations of three soil or information samples. Participants had to decide which of two samples would be more similar to the third. This question was particularly interesting insofar as it dealt with how viewers relate distance in information spatializations to similarity—the "distance-similarity metaphor" (Montello, Fabrikant, Ruocco, & Middleton, 2003).

Procedure

Participants were tested individually in a small laboratory room. They first answered questions about their age and gender, and the number of geography/cartography classes they had taken. They then read a description of their task printed on paper, tailored to whether they were in the landscape or information space condition, as described earlier. This description explained that they would see three-dimensional computer displays containing "convexities and concavities;" a sample image of each was shown to them. Participants were told they would have to answer 10 questions about the displays, and were assured that there were no right or wrong answers. They were told to use the mouse to navigate the landscape or information space, using the left button to rotate the display and the wheel to zoom in or out. Thus, participants were able to manipulate their viewing perspective at will during the test, with 2 *df* of motion. Finally, participants were told that they could take as much time to answer the questions as they needed. The test administrator manually switched the displays, and participants wrote their answers directly into a paper questionnaire booklet.

Coding of responses. A coding system was developed to categorize open-ended responses into classes of similar responses, to interpret the responses in ways relevant to our research goals. In particular, we wanted to characterize generally our participants' commonsense notions of geomorphology (in the landscape condition), and we wanted to see how these notions would or would not be applied to interpret the displays when they were described as information spaces depicting the content of nonspatial documents (in the information space condition). However, because we wanted to compare the two conditions directly, as much as was feasible, we attempted to code responses in the two conditions within the framework of a common coding system. Having said that, we coded more features for the landscape condition (see Appendix B) because our respondents produced more features in that case (see Table 2) compared to the respondents in the information space condition (see Table 4).

First, each response was segmented into one or more statements that expressed a single idea; these segments were the fundamental coding unit; they consisted of as few as one word and as much as an entire phrase. For all 10 questions in both conditions, we then coded segments in terms of three categories: Feature, Process, and Appearance (Appendix B). For responses in the landscape condition, *Feature* codes classified mentions of geographic entities, generally nouns, such as mountains (hills, peaks, etc.) or water bodies. *Process* codes classified mentions of geomorphological processes, generally actions that describe how places get formed, such as erosion, uplift, or deposition. *Appearance* codes classified mentions of what the display image itself looked like, generally adjectives such as high, large, or smooth. With respect to segment categories, coding was mutually exclusive; a segment coded as a Feature could not be coded as a Process or an Appearance; however, code types within categories were not exclusive; an erosion Process could be coded as a deposition Process as well, although this would be rare.

Responses in the information space condition were coded in a very similar way, with just a few of modifications. Process and Feature categories were not coded into the articulated set of natural processes and features described earlier for the landscape condition; they were coded only as natural or human processes and features. In addition, Process and Feature categories in the information space condition were coded in terms of information processes and features, such as writing or stories, instead of natural processes, such as erosion.

Coding responses into specific types within the three categories of Process, Feature, and Appearance constituted the bulk of the coding we did to interpret participants' records. In addition, for Question 1, we coded whether the display reminded participants of a particular place, and if so, whether it was a general type of place (e.g., "a mountainous area") or a specific place token (e.g., "Boulder, Colorado"). For Question 10, we coded whether participants thought Location *B* or *C* was more similar to Location *A*, and whether they used the First Law of Geography ("Closer locations will be more similar.") (Tobler, 1970) to reason about the similarity of the samples (If they did, they would presumably have answered "C.")

We developed our coding system through a standard iterative process in which we started with some ideas for categories and types based on our own expectations about what participants would write in response to each question and what we would find relevant in these responses. We modified these ideas repeatedly to accommodate the content of particular responses, and to increase the clarity and ease of coding. We established the reliability of our coding system by having a subset of 12 randomly selected records coded independently by two research assistants. We achieved an interrater reliability of 71% on this subset of records before we completed coding of all of the records.

Results and Discussion

Landscape Condition

Looking first at the landscape condition, participants wrote a mean of 3.6 codable statements per question. This was rather consistent across questions, except for Question 1, in which participants were asked if the landscape reminded them of a particular place. This specific and concrete question led to only 1.5 statements, on average. In fact, 8 of the 12 participants said the landscape image did remind them of a particular place. Half of these were specific places, including Hawaii, Switzerland, or the Santa Barbara Mountains; the other half were general types of places, including islands, volcanoes, or mountains.

Response statements were classified exclusively into categories (i.e., each statement was classified into one and only one category). Participants made a mean of 1.3 Feature statements (36% of statements), 0.6 Process statements (18% of statements), and 1.6 Appearance statements (46% of statements) per question. As Table 1 indicates, this pattern of categories generally holds across questions, with three considerable exceptions. Question 1 is again unique; given that it asks for a place or an object, 82% of replies were Features.

TABLE 1. Proportion of Statement Categories for each Question in Landscape Condition.

	Question[a]										
	1	2	3	4	5	6	7	8	9	10	Overall
Feature	0.82	0.44	0.31	0.36	0.45	0.35	0.35	0.30	0.37	0.14	0.36
Process	0.03	0.18	0.36	0.11	0.15	0.19	0.19	0.14	0.08	0.24	0.18
Appearance	0.15	0.38	0.33	0.53	0.40	0.47	0.46	0.56	0.55	0.63	0.46
Total Statements	1.5	3.1	3.0	4.4	4.8	3.7	4.8	4.2	3.7	2.8	

Note. Because statement categories were coded exclusively, proportions within each question sum to 1.00, within the limits of rounding error.
[a]Questions are listed in Appendix A.

TABLE 2. Mean Proportions of Feature, Process, and Appearance Types for each Question in Landscape Condition.

Feature		Process		Appearance	
a. human, urban	0.00	a. age related	0.08	a. color	0.01
b. island, peninsula	0.07	b. altitude related	0.11	b. image height	0.27
c. land, landscape (generic)	0.22	c. deposition	0.03	c. image location, distance	0.26
d. lava	0.02	d. erosion, all types	0.35	d. shape	0.15
e. local max (mountain, hill)	0.40	e. human	0.03	e. size, volume	0.15
f. flat (plain, mesa)	0.00	f. other; generic natural process	0.18	f. texture	0.04
g. saddle	0.02	g. plant, animal	0.03	g. width	0.11
h. local min (valley, canyon)	0.11	h. tectonic, up-lift	0.11		
i. water body	0.16	i. volcanism, lava	0.08		

Note. Proportions of statement type within each category, so proportions within each category sum to 1.00, within the limits of rounding error.

Question 3 asked about the meaning of the volume of the concavities. Participants replied the highest proportion of Process statements, 36%, to this question. Finally, Question 10 asked participants to compare the similarity of soil samples taken at three point locations and explain their answer. Participants replied the lowest proportion of Feature statements, 14%, and the highest proportion of Appearance statements, 63%, to this question. We address these variations further in our examination of types of statements within each category.

We next considered the coded types within each category of statement in the landscape condition (Table 2). The majority of Feature statements referred to local maxima (e.g., hills). Generic statements about land or landscape were next, followed by statements about water. Statements about local minima were a distinct fourth. The preponderance of statements about local maxima over other types of features replicates the findings of Montello et al. (1994), in a task that required participants to recall the content of topographic maps or landscape photographs. The largest proportion of Process statements referred to erosional processes (overall and on 7 of 10 questions). Generic natural processes were next, followed by tectonic statements and altitude-related statements. The majority of Appearance statements referred either to height on the image or to other aspects of location on the image (e.g., distance or connectivity). Shape and size were the next most frequent statements.

We gain some further insights by separately examining the types of statements for each question. In general, participants mentioned types that were asked about in the question. For example, 42% of participants mentioned an island feature on Question 1. This question asks about the identity of the overall image; an island is a straightforward interpretation of what the entire landmass is. Question 5 is the only image to contain what looks like a lake, and 83% of participants referred to water on this question. Questions 4 and 7 elicited large numbers of height responses, a property of the images specifically asked about in those questions. Similarly, Questions 5 and 8 elicited many width statements, which is what those questions asked about. Notably, even when participants were asked about concavities (i.e., local minima), as in Questions 3 to 5, most still mentioned the surrounding convexities (i.e., local maxima) even more so than they referred to the concavities (i.e., local minima). We noted earlier that in response to Question 3 about the meaning of the volume of the concavities, participants gave the highest proportion of Process statements. Apparently, this is because the volume of the concavities asked about in this question, more than any other question, suggested processes of erosion to respondents; 45% of them made an erosion statement in reply to this question.

Question 10 is of special interest because it speaks directly to the distance-similarity metaphor in landscape spatializations. It asked participants to compare the similarity of soil samples taken at three point locations and explain their answer. Specifically, participants were asked which soil sample, “B” or “C,” is more similar to Sample “A” (see Figure 7). Participants gave the lowest proportion of Feature statements, 14%, and the highest proportion of Appearance statements, 63%, in response to this question. Looking at the types of Appearance statements offered by participants, we find 67% of participants gave statements about height, and 58% gave statements about location or distance. Height and/or

TABLE 3. Proportion of Statement Categories for each Question in Information Space Condition.

	Question[a]										
	1	2	3	4	5	6	7	8	9	10	Overall
Feature	0.83	0.27	0.22	0.21	0.32	0.25	0.17	0.15	0.15	0.08	0.26
Process	0.00	0.30	0.38	0.23	0.15	0.16	0.25	0.18	0.15	0.16	0.20
Appearance	0.17	0.43	0.40	0.56	0.53	0.59	0.58	0.67	0.70	0.76	0.54
Total Statements	1.6	2.7	2.7	3.6	3.7	4.2	3.0	3.9	2.4	3.0	

Note. Because statement categories were coded exclusively, proportions within each question sum to 1.00, within the limits of rounding error.
[a]Questions are listed in Appendix A.

TABLE 4. Mean Proportions of Feature, Process, and Appearance Types for each Question in Information Space Condition.

Feature		Process		Appearance	
a. human	0.15	a. human	0.24	a. color	0.01
b. info about geographic places	0.06	b. information	0.68	b. image height	0.29
		c. all natural	0.08	c. image location, distance	0.34
c. info not about geographic places	0.12				
				d. shape	0.19
d. natural features	0.35			e. size, volume	0.17
				f. texture	0.01
				g. width	0.14
				h. centrality/periphery	0.17

Note. Proportions of statement type within each category, so proportions within each category sum to 1.00, within the limits of rounding error.

distance provided the major rationales for a particular answer to Question 10. Although caution must be taken in drawing a conclusion from 11 participants (One did not answer.), it is interesting that 6 of the 11 said “C” was more similar to “A,” and 5 said “B” was more similar to “A.” This is not particularly consistent with the distance-similarity metaphor, for which other research has found strong evidence (e.g., Montello et al., 2003). For one, “C” is much closer to “A” than “B” is; yet, only about half the participants said it was more similar. Furthermore, while we expect distance statements as rationales for choosing the more similar pair, at least as many participants actually provided height statements as rationales. Based on height, “B” and “C” should be considered about equally similar to “A,” which is what we found.

Information Space Condition

Turning next to the information space condition, participants uttered a mean of 3.9 codable statements per question, about the same as that in the landscape condition. Again, this was fairly consistent across questions, except for Question 1, which led to only 1.6 statements on average. Also like the landscape condition, 8 of the 11 participants said the information space image did remind them of a particular place. Again, about half said a specific place, including the Foothills of Northern/Central California, the Rockies, or the Los Angeles area, and the other half said a general type of place, including mountain ranges, islands, and city/urban zones.

Response statements were again classified exclusively into categories. Participants made a mean of 0.8 Feature statements (25% of statements), 0.6 Process statements (20% of statements), and 1.7 Appearance statements (55% of statements) per question. This is quite similar to the breakdown in the landscape condition. As Table 3 indicates, this pattern of categories again generally holds across questions, with three considerable exceptions. Question 1 again elicits a very high proportion of Feature statements, 83%. Question 3 about the volume of the concavities again elicited the highest proportion of Process statements, 38%. Finally, also like the landscape condition, Question 10 about the similarity of information samples taken at three point locations elicited the fewest Feature statements, 8%, and the most Appearance statements, 76%.

We next considered the coded types within each category of statement in the information space condition (Table 4). these types were substantially different than those in the landscape condition and are not completely comparable. However, we can see that 15% of participants referred to human features, which none did in the landscape condition. Fully 35% of participants referred to natural information features in the information space condition, which suggests a likely confusion between abstract information spaces and the concrete physical landscapes being used to depict them. The great majority of Process statements referred to “informational” processes (e.g., “more news stories in the center than in the periphery” or “more people are informed about news stories” in one area compared to another, or one area “gathered more news” than another). Human processes were fairly

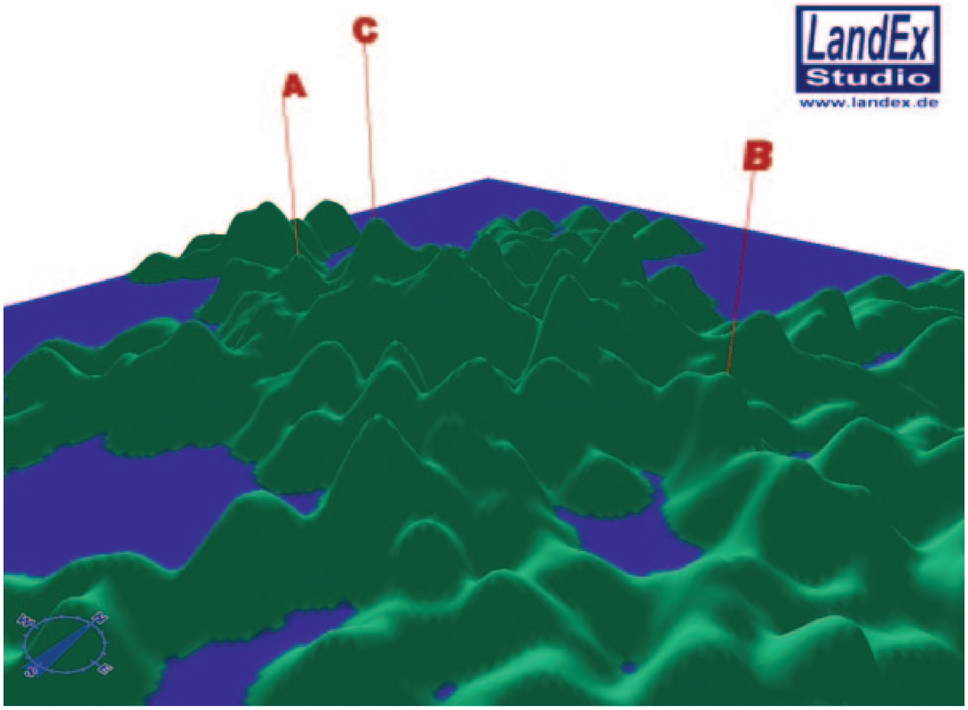

FIG. 7. Screenshot from Question 10, showing hypothetical soil (information) Samples "B" and "C" to be compared to Sample "A" for similarity.

common as well, being offered by 24% of participants. Natural processes of any kind were rarely mentioned. Height and location statements were again the most common Appearance statements, and shape and size were again quite frequent. Interestingly, a spatial concept that had not been mentioned in the landscape condition—centrality/periphery—surfaced in participants' answers in the information space condition.

We next separately examined the types of statements for each question in the information space condition. As in the landscape condition, participants clearly tended to mention types asked about in the question. Questions 4 and 7 again elicited large numbers of height responses, a property of the images specifically asked about in those questions. Similarly, Questions 5 and 8 again elicited many width statements, which is what those questions asked about. But in this condition, natural features were intended to be metaphorical rather than literal, suggesting that a focus on natural landscape features and processes constitutes confusion in interpreting the spatialization. For example, 55% of participants in the information space condition mentioned a natural feature (usually an island, as in the landscape condition) on Question 1, but only 36% mentioned an information feature (e.g., news stories), and these were all said to be information about geographic features or places. In fact, to all but two of the questions, participants mostly provided natural features as descriptions of their interpretations of the spatialized images. On no question did a majority of participants provide other types of features, including information features. This is true even though the questions asked participants to interpret "information spaces" and said nothing about landscape, terrain, and so on. Questions also asked participants to interpret "information processes," and this did elicit more statements about information processes, such as writing news stories, than statements about natural processes, such as erosion. On all but two questions, information processes were the most commonly listed. On no question did more than 10% of participants mention natural processes. In other words, participants are neither familiar with the true nature of geomorphic processes (e.g., more information is accumulated in the valley) nor do they share commonsense/naïve ideas about topography as suggested by designers (e.g., higher mountain means more information).

Question 10 again asked participants to compare the relative similarity of two pairs of points located in the information space. Participants were asked which information sample, "B" or "C," is more similar to Sample "A" (Figure 7). As compared to the landscape condition, participants gave an even lower proportion of Feature statements, 8%, and a higher proportion of Appearance statements, 76%, in response to this question. Looking at the types of Appearance statements offered, we found that all participants mentioned relative location, but a full 73% mentioned height. As in the landscape condition, height and distance provided the major rationales for answers to Question 10. In this condition, we find that 8 of 11 participants said "C" was more similar to "A," while only 3 participants said "B" was more similar to "A." Although this is a small sample, it appears to more consistently reflect the distance-similarity metaphor; the two information points closer in planimetric distance are seen as more similar. Still, we found that a clear majority of participants did mention height as a rationale for deciding on similarity, as in the landscape condition.

Conclusions and Outlook

In this article, we examined the explanatory theories that the landscape metaphor suggests to lay users for accessing information in a document archive. Information visualization designers seem to have commonsense or naïve ideas about topography that do not reflect a valid comprehension of geomorphological processes, at least as expressed in current scientific understanding. Our empirical results suggest that the landscape metaphor is not as self-evident as information designers seem to believe, and like visualization designers, lay users reveal a similar naïve understanding of geomorphological structures and processes. Moreover, this commonsense or experiential understanding of geomorphology and landscapes (Egenhofer & Mark, 1995) does not transfer well to spatialized views for lay people. Our results suggest that naïve users have difficulty interpreting and fully grasping the spatial metaphor for information visualization. In one sense, the metaphor is taken literally, as most participants mention islands, mountains, and so on, even after they have been specifically told that the display is an abstract information space of new stories. On the other hand, once the abstract news concept is applied, it is mixed with naïve conceptions about landscape forms.

Geographic space is not only characterized by physical or geometric principles but also carries experiential meaning, reflected in people's knowledge structures (Lakoff, 1987; Lakoff & Johnson, 1980) and manifested in perceptual (Gibson, 1979) and cognitive (Kuhn & Blumenthal, 1996; Norman, 1988) affordances. Perhaps the natural landscape, as one type of space, does not provide enough familiarity for human experience, as is suggested by the commonsense (naïve) geomorphology understanding of lay people, which is not congruent with the current scientific understanding. A lack of familiarity with the source domain seems to result in metaphorical mappings that do not structure the target domain well enough, and thus the resulting mapping hierarchy seems too shallow for generating the intended meaning. An emphasis on the physical landscape conceptualized as a continuous field might be one problem. If humans have great difficulty dealing with continuous phenomena, then representing continuous properties of space in a discrete manner would be cognitively more adequate because this is how humans make sense of the environment (Rosch, 1973). For this reason, and because we believe that an urban environment might be more familiar to naïve users, we have transformed the source data employed for this natural landscape study into a discrete-looking representation, simulating an urban landscape. We plan to report on the collected empirical data from the urban landscape experiment in a follow-up publication.

How then do terrain metaphors work, if indeed they do, given that neither the designers nor the users appear to know how terrain really is shaped? We contend that accurate and complete process knowledge is not required for a metaphor to work. Instead, we believe the explanation is much simpler than the mechanism suggested by Wise and other information visualizers (e.g., Boyack et al., 2002a, 2002b). Clearly, users' understanding of terrain visualizations is not based on universal understanding of the true processes that have shaped the landscape into hills and valleys, mountains, and canyons. It also appears that interpretations of displays are not consistently based on commonsense understandings of the present-day functions of topographic forms, where again we might predict that users would think that larger valleys would collect more water and feed larger rivers.

Instead, we believe that terrain metaphors work because of a very basic understanding of the world, in no sense specific to geomorphological landscapes. Everyday experience with manipulable tabletop spaces is extended metaphorically to a wide variety of domains of other spatial scales. From this variety of experiences, typically related to everyday activities and interactions with the world, people naturally assume, often correctly, that higher is more and that bigger is more (Lakoff, 1987). A higher mountain requires more effort to climb it. A higher book pile needs more effort to construct or will take longer to produce. Bigger things are not only made of more stuff but also require more effort, more strength, and more activity to deal with. If we removed two rocky hills by quarrying the rock, we would get more crushed rock from the larger hill than we could from the smaller one, and it also would take longer for the bigger one. This is so obvious that it is hardly a metaphor in itself, and it is metaphorically extended to a variety of abstract domains. For example, greater value is readily mapped onto higher position in graphs of nonspatial data, and size has long been recognized as a fundamental graphic variable to represent quantity by cartographers and graphic designers (Bertin, 1967; Dent, 1999; Flannery, 1956). The property of *more* is readily mapped onto *higher* in linguistic expressions (e.g., Gattis, 2001), and social dominance is sometimes associated with a location that is literally higher (Keating, 1995).

To follow the Gibsonian argument, it is perhaps not "innate" interpretations humans have *about* landscape forms and processes that make spatial metaphors useful for information visualization but the potential *affordances* that (physical or cultural) landscapes generate for human activities *in* and interactions *with* space. In fact, some may argue that it is the grounding of virtual activities in and interactions with virtual information spaces, or more generally computer interfaces (target domain), on real *activities* and *interactions* in the real world (source domain) that is the basis of a successful metaphorical mapping (Kuhn & Blumenthal, 1996; Norman, 1988). Such activities include moving along a path, climbing up a hill, recognizing landforms, manipulating objects, flying over a landscape, and so on.

In empirical experiments on spatialized views where participants were told at the beginning of the test sessions that the landscapes were not a representation of geographic terrain but of a library archive, Fabrikant (2001a) recorded user comments such as, "it is shorter to hike from the valley to this mountain than to that one over there," or "oh, the sun has just gone down" (reacting to the addition of relief shading in the view). These statements clearly suggest that participants were responding to test questions as if they were exploring a real-world environment.

One aspect of landscape perception that is potentially relevant, but that the information visualization community has not investigated much, concerns aesthetic responses to landscapes. One could argue that when people are attracted to a pleasing-looking display, they might perform better with it because they would attend to it more. Kaplan (1992) reviewed literature suggesting that humans prefer landscapes that are well-balanced between order and uncertainty, involving factors such as coherence, complexity, and mystery. Complexity of the environment is of particular relevance when humans engage directly with the environment (e.g., while exploring it). Aesthetic satisfaction is produced when the complex environment becomes legible for an observer, and when it generates mystery for the human explorer.

Finally, many information-display designers reason that since we live in a three-dimensional visual world, we should be able to convey more information in displays that take full advantage of all three spatial dimensions of vision rather than restricting ourselves to just two (Wise, 1999); however, to this day, there has been little empirical evidence whether a potential information increase afforded by adding an additional (i.e., third) display dimension outweighs the potential increased costs (cognitive, perceptual, and technological) caused by more resource-demanding three-dimensional displays (Ware, 2008; Westerman, Collins, & Cribbin, 2005). Based on our ongoing experiments, we believe that adding the third dimension will actually detract somewhat from people's ability to see similarity relationships in spatialized displays. This is because people map document similarity onto interposing distance, as we have shown in prior work (Montello et al., 2003), and because the third dimension of depth is perceived so differently than the "fronto-parallel" dimensions of width and height. Our ongoing results lead us to conclude that a potential information increase afforded by adding an additional (i.e., third) display dimension does not outweigh the increased perceptual costs caused by more resource-demanding three-dimensional displays (Fabrikant, Montello, & Neun, 2008).

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Appendix A

Questions Answered by Participants in Both Conditions

1. Does this landscape (information space) remind you of a particular place?
2. What does the volume of the convexities mean to you, if anything, considering the natural (information) processes shaping this landscape (information space)?
3. What does the volume of the concavities mean to you, if anything, considering the natural (information) processes shaping this landscape (information space)?
4. Compare the depths of concavity A to B. What can you say about their depths, if anything, with respect to the land (information) represented in the display at locations A and B? What type of natural (information) feature do the shapes of A and B remind you of, if any? What does this depth difference mean to you, if anything, considering the natural (information) processes shaping this landscape (information space)?
5. Compare the width of concavity A to B. What does this width difference mean to you, if anything, considering the natural (information) processes shaping this landscape (information space)? What do the shapes of A and B remind you of, if anything?
6. Consider the two convexities labeled A and B. How could you describe the surface between A and B? What type of natural (information) feature does the shape between A and B remind you of, if anything? What does this shape mean to you, if anything, considering the natural (information) processes shaping this landscape (information space)?
7. Compare the heights of convexity A to B. What can you say about their heights, if anything, with respect to the land (information) represented in the display at locations A and B? What type of natural (information) feature do the shapes of A and B remind you of, if any? What does this height difference mean to you, if anything, considering the natural (information) processes shaping this landscape (information space)?
8. Compare the width of convexity A to B. What does this width difference mean to you, if anything, considering the natural (information) processes shaping this landscape (information space)? What do the shapes of A and B remind you of, if anything?
9. Consider the places labeled A and B. What can you say, if anything, about their relative locations with respect to the landscape (information space)?
10. Imagine taking a soil (information) sample at locations A, B and C. Your task is to compare the soil (information) composition of B and C with respect to A. Which soil (information) sample, B or C, would be more similar to A? Why?

Note. Text inside parentheses presents the wording used in the information space condition, as an alternative to the wording in the landscape condition.

Appendix B: Types Coded Within Each Statement Category

Landscape Condition

Feature Types
1-human, urban
2-island, peninsula
3-land, landscape (generic)
4-lava
5-local max (mountain, hill, etc.)
6-flat (plain, mesa)
7-saddle, natural dam
8-local min (valley, canyon, etc.)
9-water body

Process Types
1-age related
2-altitude related
3-deposition, accumulation
4-erosion (all types)
5-human
6-natural processes not in other categories
7-plant, animal
8-tectonic movement, up-lift
9-volcanism (flowing lava)

Appearance Types
1-color
2-higher on image
3-relative location (distance, etc.)
4-shape
5-size
6-texture
7-width

Information Space Condition

Feature Types
1-human, urban
2-information (documents, stories, files) about geographic features/places
3-information (documents, stories, files) not about geographic features/places
4-natural features

Process Types
1-human process
2-information processes (writing, etc.)
3-natural process

Appearance Types
1-centrality/periphery
2-color
3-higher, lower elevation, depth
4-relative location (distance, etc.)
5-shape
6-size
7-texture
8-width