Towards Visual Exploration in Glyph-based Visualizations by Using Landscape Metaphors

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In this position paper, we create an outlook over the landscape metaphor as a tool help in data analyst tasks. As we are intuitively able to gauge the natural landscape, a metaphor can help to understand the data landscape. In this work, we present the meaning of metaphor-driven design, the essence of the concept "landscape" and discuss ways to interact with such a data environment. Finally, we suggest tools for orientation and operation tasks in a virtual landscape.

CCS Concepts: • **Human-centered computing → Virtual reality**; *Interface design prototyping*; *Information visualization*;

Additional Key Words and Phrases: Information Visualization, Human Computer Interaction, Virtual Reality

1 INTRODUCTION

The use of metaphors as a means of designing interactive systems is based on the idea that abstract structures in information technology do not have a "natural" shape. Data structures consist of relations, dependencies or proportions. With regard to the underlying arrangement and organization of elements, an "image" is not yet required. But only through an image, data structures become visible, navigable, memorable and manipulable. To solve this problem, we developed the method of metaphor production [12]. The basic idea is to prepare an appropriate image (a 2- or 3-dimensional metaphor, e.g. 'the book', 'a card game', 'the globe' or 'the nesting doll') for the data structure, so they will match and merge. The user can then use his experience from working with the image. To interact with the data becomes intuitive.

Basically, the method serves to design interaction metaphors for closed systems (e.g., the control system of a production unit). Such a system becomes understandable and usable. Suitable 3D widgets, forms of touch interaction or even Tangibles can now be designed.

In today's world of Big Data and the challenges it poses, visual analysis and visual data mining in complex 3D visualizations of multidimensional data is one field where metaphors are helpful. Data is mostly visualized by a reduced dimensional representation, i.e. coded by glyphs, color, numbers, or reduced to positions in two dimensions (see Fig 1). The variety of visualization forms illustrates that this complexity is difficult to master, especially with the traditional two dimensional or planar projection. A main problem is that the user with his experience based on practical life and bodily movements remains 'outside'. The lack of immersion, the deep mental involvement, creates a threshold.

Head-Mounted-Displays (HMDs) provide tools to address this problem. The visualizations are immersive, stereoscopic and virtually linked to the movement of the user. Furthermore, dynamic images that always follow the viewing direction do not have perspective distortions. To make use of the metaphorical idea for the visually supported exploration, we recommend metaphors which are related to the "earthly" movements and experiences of the user, for instance a "house", a "theater", a "sports arena", a "settlement" or in case of this work, a "landscape".

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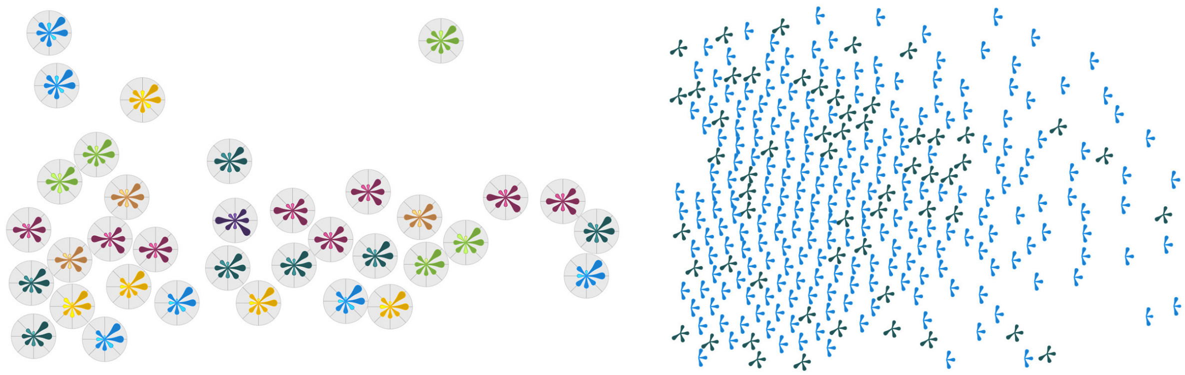

Fig. 1. Glyphboard Data Plot [11]

2 RELATED WORK

Data itself comes in vast amounts and in multivariate and multidimensional form. To demonstrate the complex facettes of data, Borgo proposes glyphs in [2]. He writes their "... major strength is that patterns of multivariate data involving more than two attribute dimensions can often be more readily perceived in the context of a spatial relationship."

Visual analytics proposes visual data exploration techniques to divide the labor of handling the data between human and computer. Keim [13] groups those techniques into six classes: geometric projection, icon-based, pixel-oriented, hierarchical, graph-based, and hybrid. Ferreira de Oliveira [6] takes those classes, proposes visualization techniques and adds interaction techniques, but without showing ways to generate them. Wenskovitch then exposes in [18] data analysts tasks in detail.

Lakoff and Johnson say in [15] "...metaphors structure the ordinary conceptual system of our culture...". As humans we are able to take those concepts known to us and apply them to new problems. One way to do so is described in [12]. Here the authors show a way to take affordances and images of known concepts and project them on data and interaction, which is in itself without Gestalt.

The landscape as metaphor has been used in related work. Gansner put recommender systems on a map in [7], the 2D-representation of an landscape. He visualized neighbourhood relations between movies and revealed to the users their positions on the map, as well as what they already visited. Kunkel [14] developed a visualization for recommender systems, which uses a 3D-landscape (see Fig. 2) as visualization. Furthermore he introduced interaction techniques like elevating and reducing the height of land to influence algorithmic parameters. These landscape visualizations use mostly text and icon-based techniques.

Jerald writes in [10] that creating "VR experiences is an incredibly complex challenge". In order to establish virtual environments for HMDs, he explains, it is essential to respect human limitations and different reference frames. They serve as coordinate systems and a "basis to locate and orient objects". Part of the virtual world reference frame are geographic directions and global distances agreements like the metric system. In principle, the reference frame should match the virtual environment regardless of the users position, orientation and scale. The real-world physical space defines the corresponding real-world reference frame, which is not influenced by modifications of the virtual world. For global application and the observation of a big landscape, exocentric virtual world frames are suggested. Thus, users will find it easier to form a cognitive map of the area and determine their

Fig. 2. 3D Landscape recommender system [14]

own location. Other reference frames include the torso, hands, head and eyes of the user. They are especially important for interaction tasks and spatial orientation in the virtual world [17].

3 LANDSCAPE METAPHOR

People feel uncomfortable in an open and empty environment. They need some kind of reinsurance to not feel lost [4]. An example for a landscape made of data items is the web application 'Google Arts': Thousands of small billboards complement each other to form hills, valleys and surfaces when the user views the environment from the distance (see Fig. 3). Here again, the creators use colors and icon-based techniques to present the data points. From close up, the shapes become noticeable individual pictures of artworks.

This works well with images as data points. When the user has to handle shapeless multivariate and multidimensional data sets, it gets complicated to apprehend data and understand its context. The task of browsing, comparing and exploring data gets harder if it is only reduced to two or three dimensions. Each data point should have its own unique form, which is generated from its own properties. Here we propose glyphs to present multiple dimensions of data in one form. The data gets distinguishable and comparable. Furthermore, it can also provide properties of a landmark, if there are multiple equally shaped or colored data points (see Fig 1). Together the glyphs create a landscape of forms and colors.

The usage of the landscape metaphor requires the consideration of some universal features. A landscape is

(1) infinite (not limited),
(2) disordered (not orthogonal aligned or screened),
(3) natural (not equipped with human paths or social networks),
(4) raw (not enriched by grids, contour lines or distance indices),
(5) non-directional (not north-oriented).

Looking at complex data visualizations, they have similar properties. Boundaries, geometric abstraction, paths, patterns of visual item, landmarks, line systems, and a compass help to make use of a landscape - in reality as

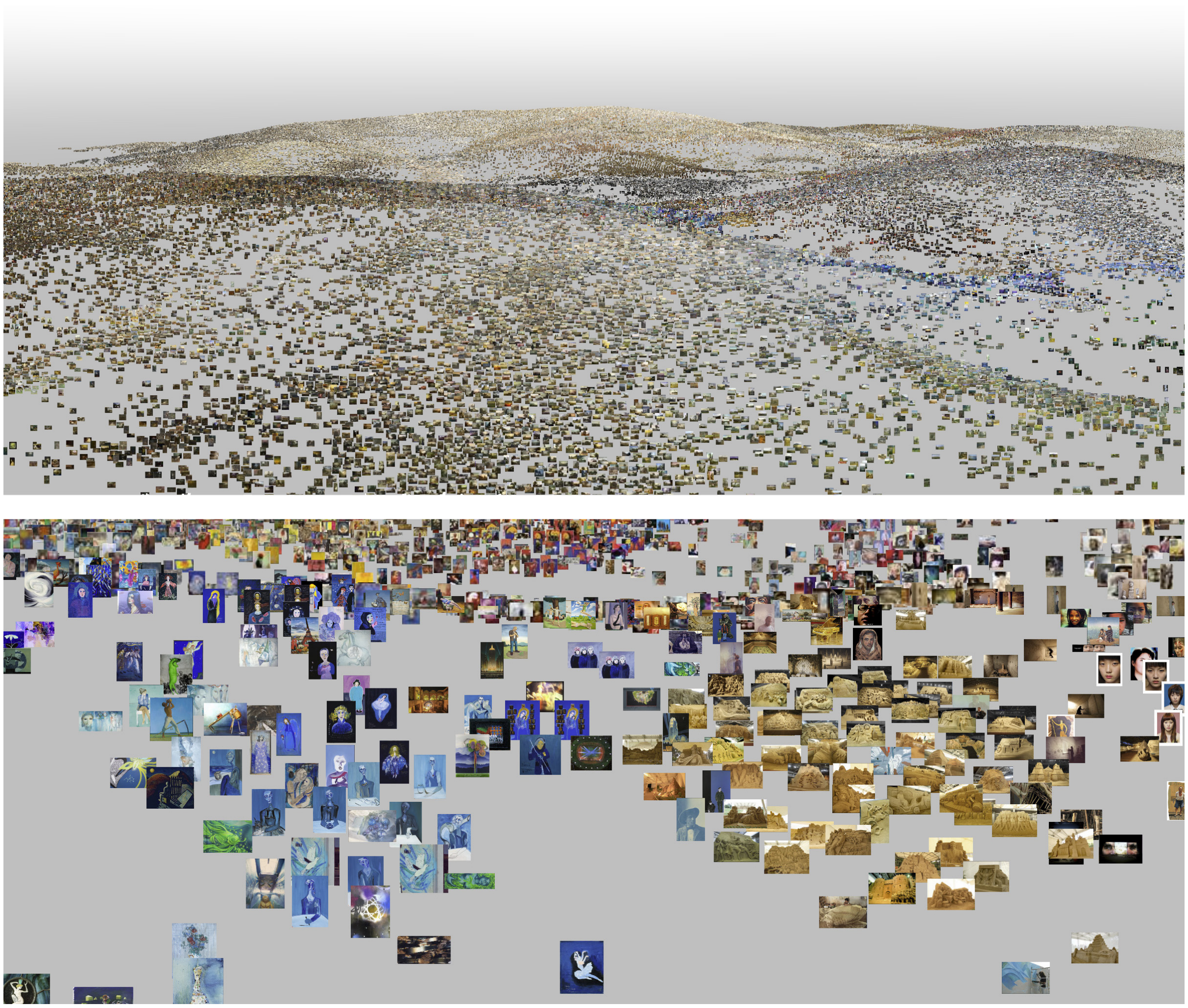

Fig. 3. Google Arts Billboard Landscape

well as on a map. In the same way, virtual landscapes made of data items should be enriched and humanized. Nature has to be transformed into culture.

In addition to the above-mentioned features, another very human characteristic must be added: A landscape is

(6) invisible (not adjusted to the human perspective)

This applies in particular for a virtual landscape that is visualized in an HMD. The landscape must be perceived from a human eye level, with a human opening angle and up to a plausible distance. Only then it fits human experience. The horizon is oriented orthogonal to gravity and separates the top from the bottom. The effects of near and far range perception should also be considered. The possibility to shift the field of view of the HMD slightly to notice visual displacements of landscape parts helps understanding the arrangement of data items. Utilizing the motion parallax of immersive systems is an option to recognize outliers or anomalies in data sets.

When we talk about a landscape for orientation, there is no way to ignore the interaction techniques and principles of navigation. Jerald defines the goal of navigation as "determining and maintaining a course of trajectory to an intended location" [10]. The main tasks are exploration, search and maneuvering [3] as they are for the data analyst [18]. With exploration techniques, the user is browsing through virtual space to attain an overview of the scene without a specific movement goal. The orientation leads to some initial knowledge of the virtual environment. Search tasks are used to find specific locations, goals, anomalies or patterns. Maneuvering tasks require small-scale movements of the user for positioning himself in front of an object or location. To execute these tasks, operators will use wayfinding and traveling methods. The first describes the mental component and the second the physical movement component [4].

Wayfinding requires certain skills like identifying the own position, creating a cognitive map of the environment or planning the next steps to the target. Landmarks or other unique cues in the world can help to perform this process. They are the first points of reference when the user enters a scene. The hints can be subtle or obvious, which is both necessary to find the correct way [5]. Examples are unique architectural or naturals structures, signposts, landmarks or paths. Other cues are dynamic objects, shadows and even sounds or smells, although we will only cover visual stimuli in this paper. As eye-tracking studies show, the guiding is influenced in a positive way by such cues, because the brain automatically distinguishes them from the rest of the scene [8]. The attentive perception and recognition of the environment is one central necessity of wayfinding. Furthermore, the user has to store and memorize the collected information to combine them to a cognitive map. Especially the orientation in virtual reality scenes will profit from wayfinding cues.

Travel describes the active or passive movement from one location to another. It can be done in various forms, e.g. walking, driving, flying. In some cases, the user will not have any choice at all (like in a movie or simulation), where in others he alone decides were he wants to travel. When people actively move, they rely on the optical flow and the egocentric direction. Optical Flow is "the pattern of visual motion on the retina [...] caused by the relative motion between a person and the scene" [10]. If the user travels forwards, near peripheral regions will move faster than regions that are further away. Direction changes can be noticed through the optical flow in the opposite direction. The estimation of the egocentric direction and distance relative to objects in the world helps to identify relevant cues and targets to move to the next location. Travel must be intuitive and natural, users should not be distracted from their main task by concurrent activities like walking [3].

It should also be considered that the user can use two fundamentally different forms of interaction. On the one hand, he has an influence over the perspective of the image through his limited bodily movements. On the other hand, the use of Controllers helps exploiting the possibilities of the virtual world. This transition should be noticeable. The user is able to utilize the parallax effect with a lateral movement of the head in one moment. Then he can suddenly shrink the patterned landscape to a small knot and view it from all sides. This example shows the existence of two main types of metaphors: Orientation Metaphors and Operation Metaphors [9][12]. The first type is used for interaction goals that focus on the orientation and memorization in immersive environments and is dominated by visual perception. The second type prompts the user to operate and interact with objects in the environment.

3.1 Orientation Tools

Orientation Metaphors describe ideas how users can deal with spatial orientation [15]. We have to keep in mind that individual experiences and culture play an important role in this context [1]. Therefore, a landscape metaphor should be universal and not dependent on special features of individual areas.

Due to the major importance of landmarks the use of some striking cues in a data item landscape should be considered. Those could be special peaks or towers that will be added to the data landscape manually. They do not necessarily have to have something in common with the data items at all. But it is also imaginable that data

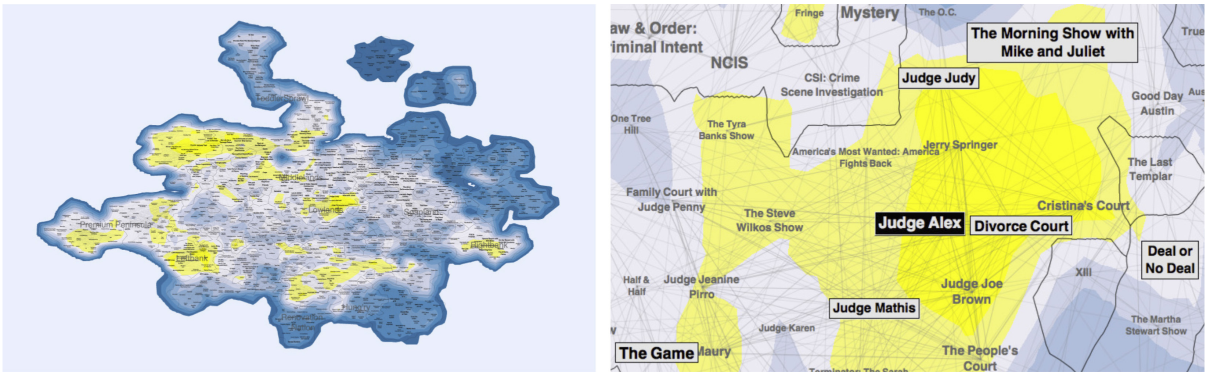

Fig. 4. Color coded map of a landscape with additional information by descriptions and annotations [7]

items are mapped in such a way that striking structures will provide visual cues that can serve as landmarks. Glyphs which have similar forms or positions may create a pattern which could serve as a landmark.

To distinguish separate areas, regions should be noticeable different. In real urban landscapes, building styles, colors and lights can do this task. In our case, assorted characteristics of data items like size or color help to highlight separate regions. For far distance perception, properties with high contrast should be used. As an additional help, edges are suitable to mark boundaries between regions. Possible counterparts in a real environment would be rivers, lakes or fences.

In order to simplify traveling in virtual data environments, the landscape can be enriched with paths. The segments between two locations will serve as prescribed direction when the user is walking. Furthermore, they will act as landmarks, if the user views the landscape with a bird's-eye view. How cues are perceived is context-driven. In conjunction with paths, knots and intersections are central orientation points. They can also be enriched with signs that point the way to a specific property or value.

A more artificial approach is the use of grids, patterns or contour lines. Like on a map, data landscapes can be enriched by descriptions, signs and especially reference systems that provide additional information. It is possible to add other semantic layers through color overlays or relation as in a graph visualization (see Fig.4).

The following list gives an overview of the mentioned orientation tools and some advantages and disadvantages.

Manually added landmarks

+ spatial orientation is significantly improved
+ great control of position and form of landmarks
○ only used for orientation purpose
− artificial landmarks may distract from data items
− adding requires additional manual work

Data mapped landmarks

+ spatial orientation is improved
+ no manual extra work
− data mapping must cover two tasks: information visualization and landmark establishment
− very limited control of position and form of landmarks

Separate regions

+ clear distinction of areas through style or color attributes
+ can be done automatically by data mapping algorithms
○ regions classification depends on data mapping or must be done manually
○ artificial cues like borders or fences are possible, ...
– ... but may detract from the data items

Paths

+ cues for walking directions help users to travel
+ network of paths forms intersections and knots
+ knots can be enriched with signs
+ from above, paths can serve as landmarks
– heavy manual workload during development
– path creation requires specialized experience

Grids, contour lines

+ reference systems that provide spatial information
+ can be enriched by descriptions, annotations, signs
+ further semantic layers can be added
○ more artificial approach
– additional workload and experience required

3.2 Operation Tools

Unlike in reality, the user has the freedom to scale and move any objects. Due to the level of freedom, adverse effects like lost-in-space or motion sickness can appear in virtual reality. However, the mentioned enrichment of the landscape creates the standards and reference systems that the user needs to evaluate his manipulations. In addition to usual methods for data handling, like filtering and sorting, we propose a more direct way. The user should modify, form and shape the presentation of the data world with his hands (or controllers) in a natural way. Thus, he becomes a craftsmen of his own vision.

To work with the landscape and thus with the data representation as glyphs the user needs interaction tools. The spectrum ranges from tools users would also use in a real landscape, e.g. a compass, to virtual tools for manipulation of the environment in a fanciful manner, e.g. shrinking mechanisms.

Before the user is able to manipulate the virtual data environment, a reasonable decision should be made, what objects and areas are part of the selection. Therefore, a selection tool is recommended. When the user walks through the landscape, he could just point with his hands or controllers towards a point of interest. Bigger areas could be encircled. This ray-cast-like option offers a fast but inaccurate selection performance. Even if the aiming field is adjustable in size and shape, the selection of data items which are far away will be quite difficult. Shifting perspectives to bird's-eye-view or similar options can help to specify the interaction. In some situations it is necessary to shrink the whole landscape to a manageable size to get an overall picture before further selection can be done. The same effect would be achieved with a zoom but considering the virtual possibilities it seems the more transparent option to let the user hold the landscape in his hands and form it to his own liking. The usage of multi-selection and grouping methods should also be considered.

Like mentioned before, shrinking the data world is an important manipulation opportunity. To achieve a solid handling of the virtual landscape, miniature tools for translation, rotation and scale tasks are suggested.

Examples are related 3D-gestures like turning and stretching. Despite landmarks and other cues, they prevent the loss of orientation, a virtual compass and a function for north-orientation of the landscape can also help. The comparison of different height levels in the data is another interesting task. Where are hills, where are valleys? A flooding-tool could be used to fill the landscape with a virtual fluid. An alternative is a section plane, which grants comparability.

For navigation, the possible methods range from walking to teleport. For exploration tasks of small group of data items, walking techniques are the best choice, where larger areas require flying- or floating techniques. The mentioned teleport-method should only be used for small distances because the risk of losing orientation is too high. Another way to facilitate the user movements are rotational and transitional gains as they will aid in exploring large virtual environments [19]. Therefore, movements of the user are be enforced and small actions lead to huge steps in the data world. Due to the perception interference disorientation and motion sickness may occur. One approach to skip negative effects is the subtle, hardly noticeable application of those techniques.

An overview of the mentioned operation tools including advantages and disadvantages can be found in the list below.

Compass
- + tool to prevent orientation loss
- + automatic north-orientation is possible
- ○ operation has to be learned

Flooding, Intersection plane
- + height overview and comparison of different levels
- + cutting intersection plane can reveal hidden data items
- – flooded area may covers relevant data underneath

Scale, rotate, translate landscape
- + user holds the world in his hands and adjust it as needed
- + exploration enables an overview
- + details can be shown on demand with scale/zoom
- – easy to loose orientation
- – operation is challenging and has to be learned

Perspective shift
- + user can use motion parallax to compare data items
- + patterns are easily recognized through shifting movement
- + rotational and transitional gains are applicable, which can help users to navigate through large environments and reduce exhaustion
- – disorientation and motion sickness may occur with gains

Travel
- + different navigation techniques possible, depending on the application
- + walking for deep exploration and detail browsing
- + flying/floating for fast overview
- ○ teleport to pass gaps or longer walking distances
- – walking: often too slow to explore whole data set
- – flying: continuous flow can be too fast for details

4 DISCUSSION

The idea of a landscape metaphor for glyph-based big data visualizations is a novel approach to make large volumes of data graspable for users. As we are intuitively able to appropriate and understand the circumstances of a natural landscape, we can also overview the data landscape. In this paper we present the means of metaphor-driven design, the landscape concept and discussed ways to interact with such a data environment. Finally, we suggest tools for orientation and operation tasks in connection with this topic.

Because this is a presentation of ideas and concepts, we can't offer evaluated conclusions. It should be examined whether the theoretical ideas work as expected. Therefore, user studies are considered. It is to be expected that the landscape metaphor will not fit every use case. Another task is hence the examination of different examples and data sets. For now, we did not cover the topic of mapping data items characteristics to features of the landscape. The variety of possibilities is enormous and will be included in future work.

Apart from this, the approach encourages the application of other metaphors like urban structures, cities or on a larger scale cosmic formations. For example, learning from architects and city planers [16] can help data scientists to explore, order and browse large quantities of data items.

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