Holes, Pits, and Valleys: Guiding Large-Display Touchless Interactions with Data-Morphed Topographies

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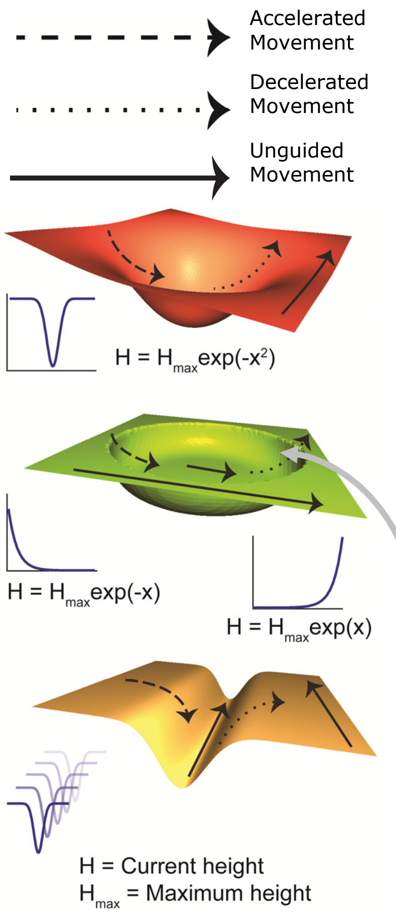

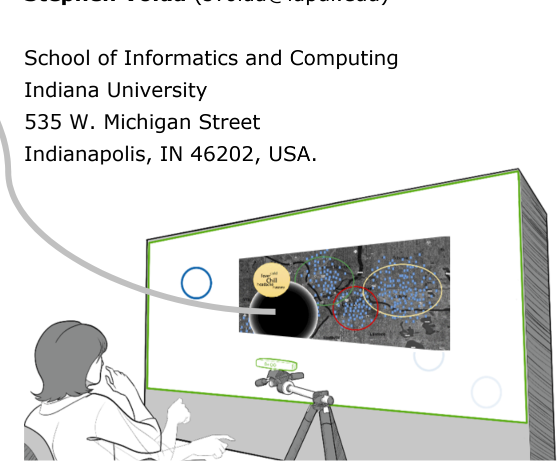

Figure 1. To guide touchless interactions, topographies such as holes (top), pits (middle), and valleys (bottom) overlay the visualized data. User's cursor movement is modified as a function of the *height maps,* thus accelerating or decelerating cursor behavior appropriately.

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Abstract
Large, high-resolution displays enable efficient visualization of large datasets. To interact with these large datasets, touchless interfaces can support fluid interaction at different distances from the display. Touchless gestures, however, lack haptic feedback. Hence, users' gestures may unintentionally move off the interface elements and require additional physical effort to perform intended actions. To address this problem, we propose *data-morphed topographies for touchless interactions*: constraints on users' cursor movements that guide touchless interaction along the structure of the visualized data. To exemplify the potential of our concept, we envision applying three data-morphed topographies—holes, pits, and valleys—to common problem-solving tasks in visual analytics.

Author Keywords
Touchless interactions; Large-display interfaces; Topography; Information Visualization.

ACM Classification Keywords
H.5.2 [User Interfaces]: Interaction styles.

Introduction
Visualization is increasingly moving off the desk to a large display environment and *beyond the desktop* to novel interaction modalities. Control rooms, meeting

<table>
<tr><th>Interaction Taxonomy [11]</th><th>Information Visualization</th><th>Proposed Topography</th></tr>
<tr><td>Filter & Explore</td><td>Matrix</td><td>Valley</td></tr>
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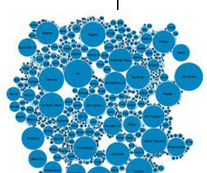
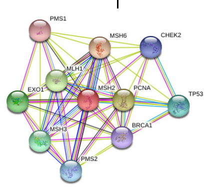
<tr><td></td><td colspan="2"></td></tr>
<tr><td>Filter & Explore</td><td>Graphical Network</td><td>Valley & Hole</td></tr>
<tr><td></td><td colspan="2"></td></tr>
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Table 1. The proposed data-morphed topographies map to common interaction tasks with different information visualizations in visual analytics.

rooms, research labs, and libraries are setting up large, interactive displays. Scientists, big data analysts, artists and physicians are using them for visualizing data in a variety of contexts (e.g., during visual analytics [3] or in sterile operating rooms). Compared with traditional desktops, these high-resolution displays support efficient visualization of large datasets, effective sense-making, difficult data manipulations, and seamless co-located collaborations [3] [9]. But because of their size and their affordances for physical navigation, large-display interaction calls for input modalities beyond the traditional mouse and keyboard.

Touchless interfaces enable users to interact with large displays from a distance, thereby providing a panoramic view and the possibility of being *laid back* and comfortably seated during the interactions [2]. However, device-less touchless interactions lack any form of haptic feedback, requiring users to depend solely on their proprioception (one's sense of position and orientation of the body parts) to be efficient and effective. Empirical studies have shown that device-less touchless gestures are fatiguing and lack fine-grained motor control [10]. Furthermore, the variation in arm configuration required for interacting with different parts of a large display has been shown to increase physical effort in touchless interactions [7].

To reduce the fatigue associated with large-display touchless interactions, we propose *data-morphed topographies*: geometrical structures that dynamically guide users' cursor movements while analyzing different parts of any dataset, such as nodes and edges of a graphical network. Specifically, we designed and applied three topographical structures—holes, pits, and valleys—to infovis tasks on large displays (Table 1).

Related Work

The increased research focus on big data and data-driven decision making has made efficient visualization of large data sets paramount. The decreasing cost of high-resolution large displays makes them attractive for this purpose [3] [9]. Beyond visualization, effective *interaction* with data plays an important role. Infovis interactions can be categorized as *selection, exploration, reconfiguration, encoding, elaboration, filtering, and connecting* [11]. Among these categories, certain interactions such as exploration, elaboration or filtering may benefit from physical navigation and the panoramic view provided by a large display. For difficult data-manipulation tasks, empirical studies show that physical navigation around large displays is significantly more efficient than traditional desktop visualization techniques, such as focus+context or overview+detail [9]. Touchless techniques have the potential to support such infovis interactions. However, touchless interactions suffer from a lack of haptic feedback. Few studies have proposed air pressure to provide tactile feedback in touchless interactions (e.g., [6]).

Research has found that while using a mouse, users are able to perceive pseudo-haptic textures, such as bumps and holes, with or without visual feedback [8]. These textures accelerate (or decelerate) the mouse cursor according to a negative (or positive) slope of the texture. For browsing data with a mouse, data-sensitive cursor guides have been proposed, such as to scroll a document contextually or to guide movement along a decision tree. In pen-based interactions, content-relative cursor guides have been proposed to aid digital drawing [4]. However, the potential of data-morphed topographies in *touchless interactions* with large displays remains unexplored.

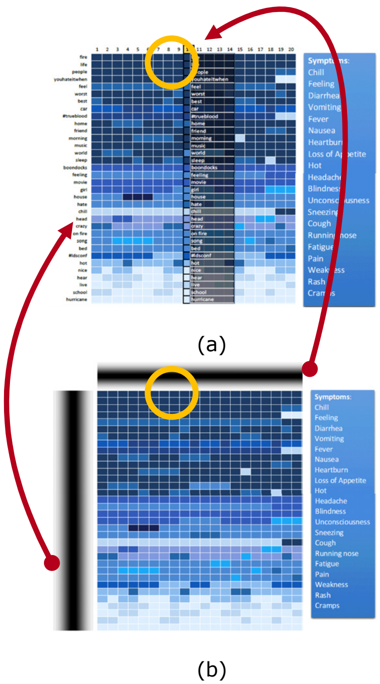


Figure 2. Task 1 is an example use of valleys to guide touchless interaction in a matrix-like visualization. (a) Unguided interaction: The user's cursor hovers over a column label; the label and the column is highlighted, and the row names are displayed next to the cells. (b) Data-morphed interaction: a *vertical valley* along the vertical axis and a *horizontal valley* along the horizontal axis constrain the user's cursor movement along the axes.

Data-Morphed Topographies for Large-Display Touchless Interactions

A data-morphed topography builds on the core idea of modifying a touchless cursor's motion on the large display. Specifically, the control-display (CD) ratio for the input device (user's hand) is adjusted as a function of the simulated *height* of the topographical structure, over which the cursor is travelling [8]. For example, on a flat surface, the cost of displacement between any two consecutive pixels is 1; while for an upward slope, the difference in height between two consecutive pixels determines this *cost of displacement* and is greater than 1 (e.g., 2 or 20). Hence, a deceleration of the touchless cursor simulates a positive slope, while an acceleration a negative slope. We propose using *height maps* to simulate holes, pits, and valleys:

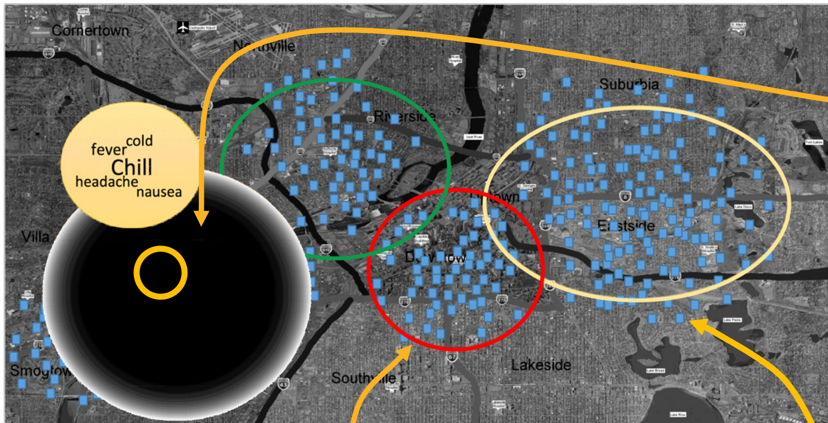
> *Holes*: A narrow, circular depression from a baseline plane that is simulated using a Gaussian function with a height less than 0 (Figure 1, top).
>
> *Pits*: A wide, circular depression from a baseline plane whose left and right slopes are simulated using an exponential decay and an exponential growth function respectively (Figure 1, middle).
>
> *Valleys*: A linear depression (of varying width) from a baseline plane that is simulated using a series of Gaussian functions (Figure 1, bottom).

Since the cost of displacement for going out of these topographies is more than traversing a plane (e.g., twice), they would guide users to constrain their cursor movement. Data-morphed topographies can be implemented using toolkits for designing custom cursor behaviors (e.g., NUICursorTools [1]). To illustrate the use of these topographies, we demonstrate three problem-solving tasks in visual analytics (Figures 2–4). These tasks are based on the VAST 2011 challenge [5] that includes a city map, and microblog messages.

Task 1: *"An epidemic may have started in the city during last month. From the given list of symptoms, identify at least five symptoms that were shared at the same time and the corresponding date range."* For this task, users need to traverse the horizontal (or vertical) axis to locate a date range of commonly appearing symptoms. When users move their cursor along the axes, a vertical valley along the vertical axis and a horizontal valley along the horizontal axis will constrain users' cursor movement (Figure 2).

Task 2*: "Four regions from where the epidemic may have started, are marked on the city map. Identify the most commonly appearing word in each region."* For this task, users will navigate within one region at a time to find the most common word. While interacting, pits underlying the circles will allow free cursor movements within the region of interest, but prevent users from accidentally moving out of those regions (Figure 3).

Task 3: *"Find out if a majority of people who went to the convention later got ill. Assume that the convention attendees used words such as convention, technology, and airport."* For this task, users will interact with a graphical network in which nodes represent words and edges represent number of people mentioning any two words. Users will hover over nodes and traverse edges to find word association(s). While interacting, holes underlying the nodes will accelerate users' cursor to move into them, and valleys along the edges will prevent users from moving off the paths (Figure 4).



Pits underlying the circles allow free cursor movements within the region of interest, but prevent users from accidentally moving out of those regions.

Figure 3. Task 2: Colored circles represent regions of interest. Blue squares represent origin points of individual microblog messages. A tag cloud is dynamically generated from microblog messages originating around the user's current cursor position.

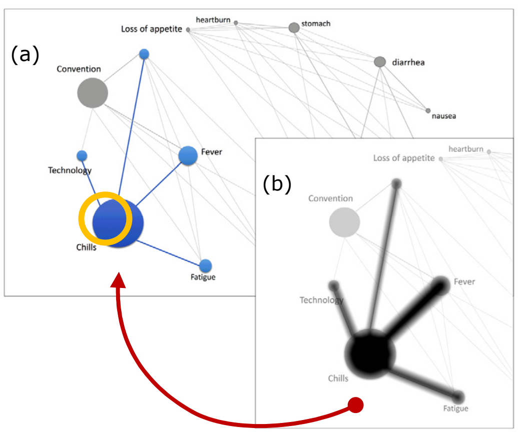


Figure 4. Task 3: (a) When the user's cursor hovers over the "Chills" node, its edges and its nearest-neighbor nodes are highlighted; all other nodes and edges remain greyed out. (b) Holes underlying the nodes draw the user's cursor toward these regions of interest, and valleys along the edges prevent users from accidentally moving off the paths.

Conclusion and Future Work

We introduced a novel concept—data-morphed topographies—that provides motor guidance in touchless interactions with large displays to reduce physical effort and augment fluid manipulation. Using examples of problem-solving tasks in visual analytics, we described how data-morphed topographies (e.g., holes, pits, and valleys) support three types of infovis interactions: exploration, elaboration, and filtering. We plan to implement these topographies and invoke them for data visualizations. To evaluate our approach, we will compare task performance and fatigue among topography-enhanced touchless, multitouch and unguided touchless interactions.

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