SandExplorer: Exploring Geospatial Data, Grain by Grain

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ABSTRACT

In this paper, we introduce SandExplorer: a device to physically explore geospatial data by creating a 2.5-dimensional, topographic sand sculpture. This sculpture is created semi-manually, by moving a handle over a sandbox, which serves as a plotting canvas. The sandbox' shape represents the geospatial region the data is about. The amount of sand flowing from the system's sand reservoir through the handle is regulated by a mapping algorithm, depending on the underlying data. With SandExplorer, users can playfully create a sand-based data 'physicalization'.

CCS CONCEPTS

• **Human-centered computing → Interaction devices**.

KEYWORDS

Data Exploration, Tangible User Interfaces, 2.5D Displays

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Figure 1: SandExplorer creates a 2.5-dimensional topographic data map out of sand.

1 INTRODUCTION

Advances in computational techology have led to greater amounts of data being available. This could allow users to easily develop a better understanding of their world.

Unfortunately, much of the available data is only accessible to experts who are familiar with database interfaces. This makes much of the available data inaccessible to laypeople.

Fortunately, research in HCI steadily thrives to change that. For example, data visualization techniques are being continuously improved. These techniques provide an intuitive approach to understanding large amounts of data. They reduce the complexity of a dataset, enabling laypeople to interpret the data.

Recently, also data *physicalizations* have come to the attention of researchers and designers [8]. They offer intuitive and often surprising forms of displaying and exploring data. Often, physical representations of data are perceived as approachable and playfully explorable. The increasing availability of 3D printers has also contributed to the spread of

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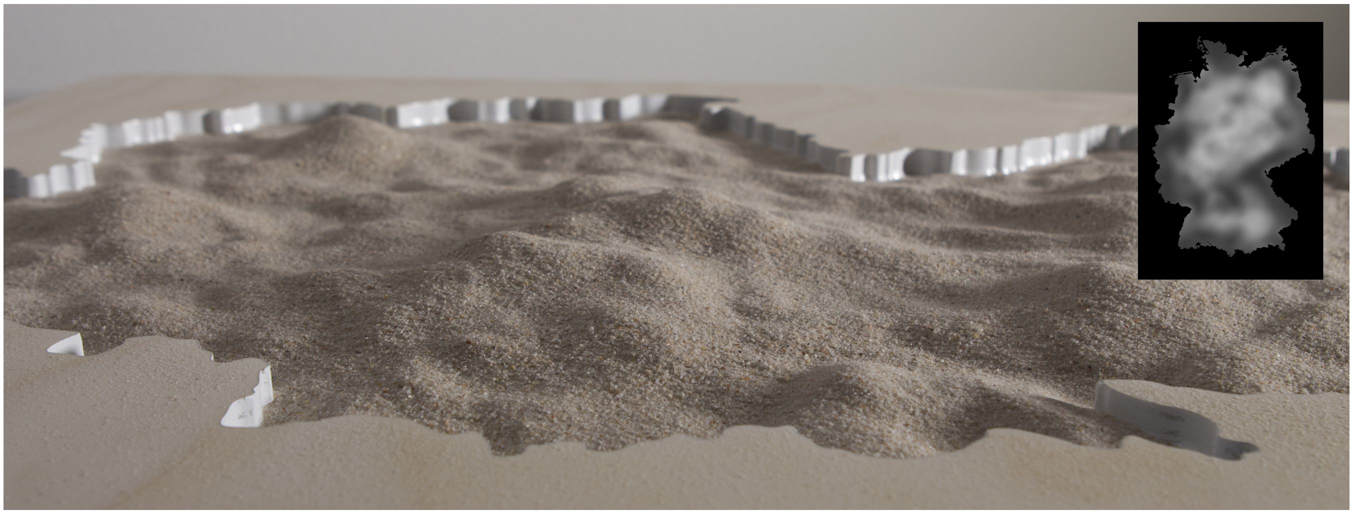

Figure 2: The height of the sand (a) corresponds to the underlying data points (b).

data physicalizations. 3D printing enables the ad-hoc creation of physical sculptures that correspond to an underlying dataset. Today, even though a variety of data physicalizations is available, the challenge of intuitively understandable, playfully engaging data exploration remains an active field of research. One potentially interesting approach may involve *manual operation*. Most current 3D printers require, after the initial setup, no manual operation from the user’s side. However, manual operation could have learning benefits. Another potentially worthwhile approach may involve *malleabilty*: currently, 3D-printed data sculptures rarely can be re-sculpted after printing.

2 RELATED WORK

This section provides an overview of existing research into granules-based interfaces, geospatial data exploration, computer-supported manual fabrication and data physicalizations.

Granules-Based Interfaces

Granules-based interfaces are an active field of research. They can be conceptualized as *ephemeral user interfaces*, as defined by Doering et al. [4]. Often, they also encourage imprecise interactions, which may also be a promising foundation for new styles of interacting with data [19].

For example, the AR Sandbox [13] explores sand as an input medium. It enables users to physically mold a landscape. An integrated projector visually augments the sand with height information and simulated water flows. Roo et al. [15] propose a sandbox-based interface for self-reflection, combining digitally augmented sand with EEG and breath sensors. Biefang et al. [3] propose a sand-based system for exploring archeological data in museum contexts. While these approaches offer novel ways of bridging the digital and the physical, none of them appears to be designed for exploring statistical data.

Geospatial Data Exploration

Exploring geospatial data is a complex activity. Research in this area often seeks to improve the ‘graspability’ of the underlying data. In the Venice Unfolding project [12], for instance, tangibles are used on an interactive tabletop to explore architectural projects in the city of Venice.

Such systems are often particularly viable to be used as interactive exhibits in museum contexts, as explored by Shapiro et al. in a recent project [16].

Such endeavours demonstrate the great potential of tangibility in exploring geospatial information, yet none of them appears to involve real-time, computer-supported manual fabrication as a means of displaying data.

Computer-Supported Manual Fabrication

Computer-supported manual fabrication devices offer the freedom of manual handling, combined with the guidance and, if needed, precision of digital fabrication.

Examples for this approach include Protopiper [1], which allows users to craft lightweight life-size models of large objects (e. g. to see what a piece of furniture would look like in their room). Other examples include the Shaper Origin [14] and FreeD [21] devices, which offer the precision of a CNC mill at a hand-held device’s size through a gimbal-like mechanism. Other projects, as, for instance, Quimo [10], explore deformable materials that connect physical malleability with digital content.

These examples underline the potential of data-driven, manually operated devices, enabling users to craft physically present models that can be looked at from different sides, and discussed with others.

Data Physicalizations

Data *physicalizations* can be beneficial in helping users understand complex datasets [8]. Stusak et al.'s research indicates that 3D physical data representation may be beneficial in terms of memorizability [17].

Most data physicalizations are static objects, such as in Stefaner et al.'s Emoto project [11], ANF's Fundament project [6] and Realitat's Microsonic Landscapes project [5]. All of these propose interesting mappings of data input and shape output, yet they are reduced in terms of interactivity.

Other data physicalizations are dynamic, such as Taher et al.'s dynamic bar charts [18] and Leithinger et al.'s Shape Displays [9]. These are highly interactive, yet they do not leverage on the potential of combining shape-changing and granules-based interfaces.

Research in the area of making data more graspable is actively shaping how we make sense of increasingly complex datasets. Despite new challenges for researchers in this area [2], great progress has been made in the past years.

While many research projects investigate the promising areas of granules-based interfaces, geospatial data exploration, computer-supported manual fabrication and data physicalizations, the overlap of these four areas appears to be rather unexplored.

This is surprising, as such an effort may investigate how real-world data could be playfully explored in new ways. To remedy this issue, we created SandExplorer – a device that allows users to create a granules-based data physicalization of geospatial information in a computer-supported manual fabrication process.

3 DESIGN RATIONALE

We set out to create a system that allows users to manually create a data physicalization in a simple, yet engaging way. The underlying metaphor should be easy to understand for experts, laypeople, and – especially in the context of exhibitions – children.

We sought for a system design that would leverage on the potential for rich interaction, offered by granules-based interfaces, and apply them to geospatial, semi-manual data exploration.

Another major goal was to not guide the user during the process, in order to maximize the free explorability of the system. The promising topic of geospatial data inspired us to investigate the utility of sand as an output medium, which led to the current system design.

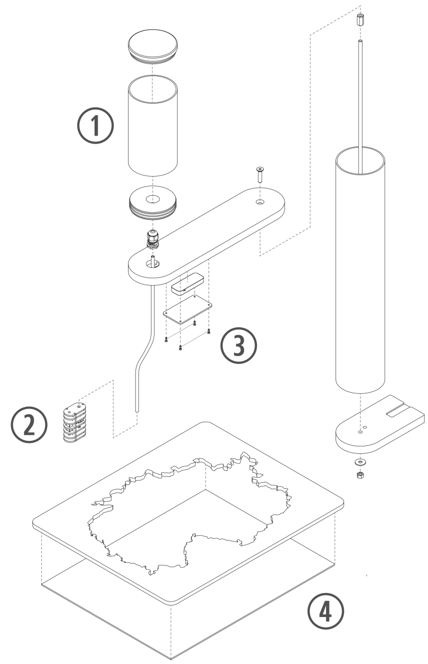

Figure 3: Explosion view: sand reservoir (1), nozzle handle (2), Leap Motion controller (3), sandbox (4).

4 PROTOTYPE

In the following, we describe the proposed system and the process of drawing a sand-based datascape.

System Design

A sand reservoir is located at SandExplorer's top (Fig. 3.1). Through a hole in the reservoir, sand can flow into a silicone tube, down to the device's nozzle handle (Fig. 3.2). A Leap Motion controller is embedded in the device's upper beam (Fig. 3.3). A sandbox is placed underneath the nozzle (Fig. 3.4). In the nozzle handle, the flow of sand is regulated by a 'pinch valve' mechanism, based on an Arduino-driven servo motor that squeezes the silicon tube. Tests during the system's development indicated that such a mechanism may be more suitable than a regular valve, especially in terms of avoiding sand clogging.

Data Import

The system is controlled through a nearby computer. It accepts grayscale bitmap images for data import: each pixel corresponds to one data point from the dataset. Higher values in the dataset are represented through brighter pixels in the map (Fig. 2b) and will be plotted as higher piles of sand. Geospatial data can easily be converted into such images through heatmap creation tools (e. g. QGIS).

Drawing a Datascape

The system is operated semi-manually: to plot the entire map, the system's handle needs to be hovered over the entire plotting canvas. After loading the dataset, the user's hand is tracked by the Leap Motion controller. It returns the hand's X/Y coordinates. These coordinates are then read from the input map. Depending on the input value and the computed niveau of sand under the valve, the valve is opened so that sand flows out of the handle. Once the computed niveau of sand under the valve reaches the value from the input map, the valve closes. Once all datapoints from the input map have been plotted to the datascape, the valve will open no longer and the datascape is finished.

5 DISCUSSION

In this section, we discuss some of the insights gained during the process of creating SandExplorer, hoping that they will be helpful for future research.

Metaphor

Initially, we chose sand as the system's output material for its connotation of 'earth', and its closeness to the topic of geospatial data. However, the use of sand as the system main material is turned out to be also advantageous in terms of sustainability: it can be – differently than ink, wood, resins or plastic filament – reused directly, with no loss in material quality.

Additionally, it conceptually underlines the often slow dynamics of geospatial data and allows for *malleability*: after the creation of a datascape, users often expressed the intent to change it, e. g. when discussing a datascape about the geospatial distribution of unemployment rates in a country.

In Zhao and van de Moere's [20] terms, the proposed system is a data sculpture that is close to the data (large values in the data are indexically represented through grain quantity), and close to reality (through a single, intuitive mental image: 'much is high' [7]).

While earlier prototypes included a simple rectangular sandbox as the plotting canvas, the final prototype uses a cut-out silhouette of the corresponding geospatial region as a canvas, making it easier for users to get a feeling for the context of the data. Different regions can be compared by exchanging these map underlays.

Trickle Effects

By nature, the applied plotting method blurs the data. Depending on the sand's material properties, after piling up to a steepness of ca. 34°, sand will trickle down to neighbouring, less steep regions of the sandscape. This phenomenon means that lower datapoints around a 'peak' are being 'overwritten' by the overflowing sand. Higher maximum heights for the sand piles thereby decrease the X/Y resolution of the sandscape (while increasing the Z resolution). Our final prototype uses bird sand, for which a maximum sand pile height of 30 mm has shown to be a good compromise between allowing for height contrast and avoiding trickle effects.

6 FUTURE WORK

SandExplorer offers a novel approach to data display, which may be used to display geospatial data of different scales. On the scale of cities, it could display emission rates, rent niveaus and population densities. On the scale of states, it could display unemployment rates and election data. On a global scale, it could display birth rate differences, wealth distributions and sea level rise effects.

Technically, the system could be extended with a projection mapping-based overlay that highlights cities, landmarks and other points of interest. Also, computationally controlled draining of the sand from the plotting canvas (e. g. via lowering a second floor underneath a sieve-based canvas) would enrich the interaction. Such a mechanism would also allow the system to continuously drain sand from the canvas, enabling the system to show dynamic data that changes over time.

Using different colours of sand for plotting would increase the output fidelity of the system, but, at the same time, prevent the sand from being reused instantaneously. Another interesting modification to the system could be a mechanism to wetten the sand, as to increase the stability of the datascape. Future versions of the system should be able to measure the height of the sand. If provided with such a functionality, the system could react to changes to the datascape (e. g. when users move sand in a discussion).

7 CONCLUSION

In this paper, we presented SandExplorer. SandExplorer is a novel system that allows playful explorations of geospatial datasets by helping users to semi-manually create a data sculpture of the dataset.

Its simple material approach makes it accessible to a wide range of users. The physical, yet malleable output of the system allows for an intuitive understanding of the underlying data and may also encourage discussions about it: what may cause the geospatial differences in the data points and what should be done about it?

Such discussions appear to be a great chance for our society, and they should involve experts, laypeople and children alike. That is why we hope that SandExplorer contributes to a development towards accessible and intuitively understandable interfaces for real-world data.

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