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Design Strategies and Optimizations for Human-Data Interaction Systems in Museums

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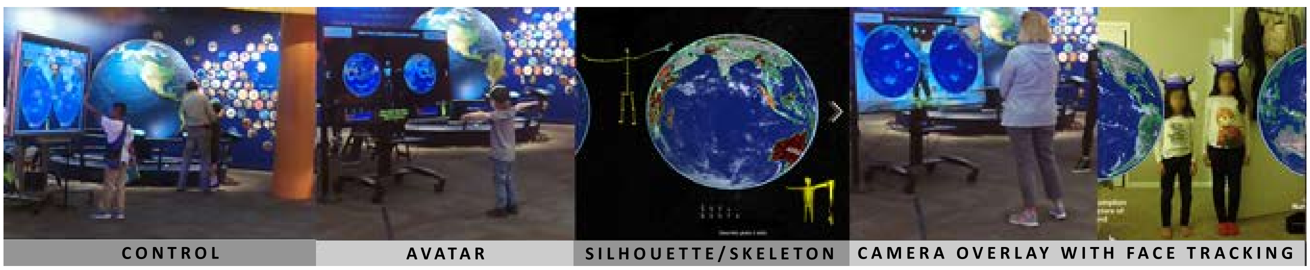

Fig. 1: Museum visitors can use our Human-Data Interaction system to interact using gestures and body movements with a data visualization (two 3D globes displaying geo-referenced data). The user is either represented as an avatar, skeleton, or using a full camera overlay.

***Abstract*—Embodied interaction is particularly useful in museums because it allows to leverage findings from embodied cognition to support the learning of STEM concepts and thinking skills. In this paper, we focus on Human-Data Interaction (HDI), a class of embodied interactions that investigates the design of interactive data visualizations that users control with gestures and body movements. We describe an HDI system that we iteratively designed, implemented, and observed at a science museum, and that allows visitors to explore large sets of data on two 3D globe maps. We present and discuss design strategies and optimization that we implemented to mitigate two sets of design challenges: (1) Dealing with display, interaction, and affordance blindness; and, (2) Supporting multiple functionalities and collaboration.**

***Index Terms*—Embodied Interaction, Human-Data Interaction, Public Displays, Informal Learning, Museums**

I. Introduction

Museums have embraced embodied interaction [3], [5] because of its educational value: the use of hand gestures and body movements does not only increase the engagement with their installations [8], but also facilitates the learning of the "thinking skills" that exhibits are designed to promote. Motion tracking devices allow to capitalize on the embodied cognition finding that our body plays a fundamental role in our cognitive processes: our discoveries happen thanks to the interaction between our body and the surrounding environment [15]. For example, children are able to remember physics concepts better when asked to "embody" a meteor in an interactive simulation than when they use a traditional desktop interface [7].

This paper particularly focuses on Human-Data Interaction (HDI) [2], [4], a class of embodied interactions that promotes the learning of thinking skills for data exploration. Because we live in a world in which we are more and more surrounded by data, being able to navigate and interpret such data are essential skills for being informed citizens and for entering the modern workforce. Human-Data Interaction investigates how to design interactive, embodied installations in which users interact with a data visualization using gestures and body movements. We report on the design challenges that we encountered when implementing a prototype HDI installation (see Figure 1) that we tested at Discovery Place, a science museum in Charlotte, NC, and discuss the design strategies and optimizations that we adopted to mitigate those challenges.

II. Background and Related Work

A. Human-Data Interaction (HDI)

The wording "Human-Data Interaction" (HDI) has been used to denote a broad range of research topics [16]. For example, Mortier et al.'s work [9] provides guidelines on how to place the human in the center of data flow, with a focus on privacy and "personal" data. The work in this paper is better positioned in a different line of HDI research, which focuses on the design of the users' interaction with data [2], [4].

B. Display Blindness, Interaction Blindness, and Affordance Blindness

Display Blindness is when the users never notice the display [11]. Similarly, Interaction Blindness refers to when users do not realize that the system is interactive [6]. Affordance Blindness is when the user notices the display, but does not understand how to use the system [14].

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C. Supporting Multiple Functionalities and Collaboration

Designing for Human-Data Interaction implies implementing complex interactive installations that do not serve a single-purpose application, but supports multiple functionalities. Additionally, collaboration is crucial for embodied learning, because of the many narratives that a diverse crowd of people may bring to the table [13].

III. System Design & Implementation

As illustrated in Figure 1, our HDI installation visualizes geo-referenced datasets on two 3D globes. In line with pervasive display literature, we created three variations of the system, in which the user is represented as an avatar, skeleton, or using a full camera overlay and face tracking - for a comparison on the effect on museum visitors of these different ways of representing the user on the screen, see [] [TODO Cite our CHI paper] . We implemented our installation using three subsystems that work simultaneously in real-time: a sensor controller, a gesture manager, and a dataset designer.

A. Sensor Controller

Raw video feeds streaming from the depth and color camera sensors are the motion inputs of our system. The 3D positions (x, y, z) of users joints is identified through Unity packages and additional developed scripts that support the specific functionality of our global system.

B. Gesture Manager

We developed multiple gestures to navigate and control the 3D globes. For the **Spine Movement** the globe object is used to overlay the tracked spine mid joint in order to transform and rotate the angle based on the user's spine location. The purpose on this functionality is to allow visitors to explore and see the data from different perspectives to foster spatial reasoning. For **Zoom In/Out** and in order to get a closer look on the data presented on the globe, we developed a hand movement to to zoom in on the globe. This gesture provides a mechanism to compare the two datasets at different scales. For **Jump/Swipe** both gestures are implemented using using a time window to record a joint movement (legs for jump, hands for swipe) for a period of time while a condition is valid. Performing either gesture changes the data sets presented on both globes. For **Hand Hold/Grab** the cursor and it functionalities can be controlled with hand grab, release, and click gestures, for which the hand and fingers joints tracking is crucial. This functionality allows to explore each data point presented on the globe. For **Face Tracking** we track the primary and secondary users and show a hat or mask on their faces. The purpose of this functionality is to allow visitors in the interaction space to recognize who is currently controlling the system.

C. Global Datasets Designer

The system displays two different datasets on two 3D globes, see Figure 1. The colors gradients are based on a value that has been normalized among all datasets to reflect a color range. There are up to 20 datasets depicted on these globe maps, along with thought-provoking, scaffolding questions, e.g., "Does Firearm Ownership Influence Number of Murders?" and "Does Female Employment Influence Male Unemployment?"

IV. Methodology, Results and Discussion

When we designed our prototype installation, we anticipated two major design challenges (highlighted in the literature that we reviewed in the background section): (1) dealing with Display/Interaction/Affordances Blindness; and, (2) Supporting Multiple Functionalities and Collaboration. Thus, we included a series of design strategies and optimizations in our system.

A. Methodology

In order to explore the effect of our design strategies and optimizations, we conducted three sessions of in-situ testing at Discovery Place, a science museum in Charlotte, NC, during which 830 museum visitors (children and adults) freely interacted with the prototype installation. These sessions were video recorded and analyzed by a team of five researchers, who used a thematic analysis approach [1] to qualitatively identify examples of use cases related with the design strategies and optimizations that we introduced.

B. Design Challenge 1): Display/Interaction/Affordances Blindness

Design Strategies and Optimizations. The system is equipped with the following design strategies and optimizations to mitigate these problems: (1) The user is represented on the display as skeleton, avatar, or using a full camera overlay -see Figure 1, because this aids with communicating interactivity [10], [14]. (2) Question on the display such as game menu prompt to begin playing/interacting with the system, e.g. "Choose a Continent" (3) Thought-provoking scaffolding questions on top of the data visualization targeted to different age groups (adults, children), as recommended by Perry [12]. (4) Face tracking to add a hat on the players who are currently controlling the system.

Results and Discussion. The scaffolding questions that we added to our data visualization were able to make museum visitors aware of the display, to intrigue them, and to promote further interaction. For example, a father P3 and daughter P4 approached the visualization; P3 exclaimed: *Looks like a lot of things are threatened* (referring to the number of threatened fish species on the globe map). Similarly, the instructions on how to use the system served a similar purpose -although only when they were mentioned by a moderator (future work should investigate how to make them more visible on the screen). For example, two women (P9 and P10) began to interact and discuss what they could do.

P9: "This is cool [and then begins reading the instructions on the screen]. Oh I can move around, jump, change the data. "As you turn, the world turns with you"

C. Design Challenge 2): Supporting Multiple Functionalities and Collaboration

Design Strategies/Optimizations. As described in the Gesture Manager Section, the system includes multiple functionalities for data exploration. To enable a collaborative learning experiences, the system activates and deactivates some features based on the total number of visitors in the interaction space (if a single user in-front the display, we give that user all the control; if there are two or more users, the second user can control part of the system). Additionally, some features that help with interaction blindness can also be used to foster and support collaboration, such as (1) Question on the display and (2) Face tracking.

Results and Discussion. As we expected, the scaffolding questions also facilitated collaboration and the discovery of the multiple functionalities. We observed families in which the parents encouraged their children to engage with the scaffolding question. In the case of P3 and P4 (father and daughter), after reading and commenting the question, the father and daughter took turns to play around, using their hands/arm to pan around the globe. The father then let the child play on her own, and she used her arm to swipe around different data sets and also jumped to change them. We want to highlight that this parent/child interaction with the system in a museum settings shows how the HDI installation can be a learning intermediary between a parent and their children. When children may not be able to understand the information on the screen on their own, parents can use the globe to call out certain information that is of relevance or interest.

Similarly, the instructions on how to use the system supported collaboration. In the case of P9 and P10 (two women), after P9's remark (when P9 started to explore multiple system functionalities), P10 started to interact and to comment on the system functionalities and on the data visualization:

P10. "Oh this is kinda like a wii [...] Are all the dots little cities?"

Interestingly, collaboration between users also produced unplanned, visitor-led learning experiences. Although we designed our system for data exploration, visitors used the globe-based visualizations in ways that go beyond the analysis of the specific dataset on display and that speak to an additional array of thinking skills. For example, after looking at the display with her son, P12 (parent) decided to use the system to teach P13 (child) geography, by asking P13 to name the countries on display and to point out where the United States are located on the globe. This resulted in a collaborative learning experience: P12 was not in direct control of the installation, but prompted her child to move in the interaction space to visualize the data.

P12: "See if you can find the United States. Keep going keep going [...] and that's our what?"

P13: "Our country"

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V. Conclusion and Future Work

In this paper, we described the design and implementation of a prototype installation for Human-Data Interaction, reviewed three groups of design and technical challenges for implementing HDI installations in museums, and discussed design strategies and optimizations to mitigate or overcome these challenges. Future work should include quantitative user-studies to assess each design strategy and optimization and a longitudinal study to more comprehensively evaluate HDI learning goals in informal learning settings.

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