Output to input: concepts for physical data representations and tactile user interfaces

Steve Szigeti, Anne Stevens, Robert Tu, Ana Jofre, Alex Gebhardt, Fanny Chevalier, Jonathan Lee, Sara Diamond

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Steve Szigeti
OCAD University
100 McCaul Street
Toronto, Canada, M5T 1W1
sszigeti@ocadu.ca

Anne Stevens
OCAD University
astevens@faculty.ocadu.ca

Robert Tu
OCAD University
rt07kk@student.ocadu.ca

Ana Jofre
OCAD University
aj13mj@student.ocadu.ca

Alex Gebhardt
OCAD University
ag11kd@student.ocadu.ca

Fanny Chevalier
OCAD University
fchevalier@ocadu.ca

Jonathan Lee
BBM Analytics
1500 Don Mills Road
Toronto, Canada, M3B 3L7
JLee@bbmanalytics.ca

Sara Diamond
OCAD University
sdiamond@ocadu.ca

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Abstract

Tangible user interfaces and physical representations of data are both promising approaches to improving insights derived from large data sets. Interactive tangible representations of data, which seamlessly combine those two approaches, potentially take advantage of cognitive processes, data representations, and interactions not supported by current approaches and may enhance collaboration. This paper describes user evaluations of two sets of prototypes comprised of physical blocks to represent data. One set uses six blocks of identical dimensions and another set uses six blocks with different dimensions. The objectives of this pilot study include (i) making general observations on how users interact with the two prototypes, (ii) making observations on the role these tangible interfaces play in collaboration, and (iii) comparing the two sets of tangible interfaces. We report on the results of the study and discuss future work.

Author Keywords

Human Factors; Design; Physical visualization; Tangible Computing; NUI

ACM Classification Keywords

H5.2 User Interfaces: Evaluation/Methodology

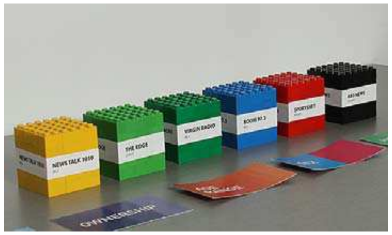

Figure 1: The uniformly-sized set of blocks (simple TUI). Prototype of tangible interface representing six radio stations.

Figure 2: The data-sculpture set of blocks (data sculpture + TUI). Prototype of tangible interface and data sculpture representing six radio stations. The height of the block represents the *number of listeners* and the depth of the block represents *the total time listened*.

Introduction

Physical representations of data combine cognition, representation and interaction in novel ways, offering the potential for discovering insights into a data set that traditional WIMP based approaches may not.

As interest in the physical representation of data continues to grow, research has focused on one of two different but related facets: the tangible interface as input and physical representations as output.

Background and motivation

Tangible user interfaces (TUI) afford interactions that push the boundaries of traditional WIMP interfaces, including the direct manipulation of 2D graphical forms [4], the use of gesture [11] and 3D space [11][1].

Research in TUI explore possible improvements to how we can interact with data sets and computer models, particularly with regard to learning [3][12] and collaborative work [8]. Kim and Maher, for example, compared Graphical User Interfaces (GUI) with TUI in a collaborative design task, finding that the groups using TUI performed multiple cognitive actions in a shorter time, made more unexpected discoveries of spatial design features, and exhibited more problem-finding behaviours [8].

Physical data representation is the materialization of data into physical artefacts, which may offer more intuitive approaches to data analysis and lead to insights into data sets [13]. Although we are only beginning to understand the efficiency of physical visualization, evaluations have found that in some circumstances they outperform on-screen equivalents when retrieving information and that the component of touch appears to be a key cognitive aid [6][7].

We present the results of a pilot study in which we compare two sets of TUIs that are used to interrogate and represent data on radio station listening demographics. Both TUIs consist of a set of blocks, where each block represents a single radio station. The uniformly-sized set (see Figure 1) comprised six blocks of identical dimensions and the data-sculpture set (see Figure 2) comprised six blocks with dimensions representing the number of radio listeners (height) and the total time they listened (depth) in a 24 hour period

The user evaluation also considered the role of collaboration, which may be a key differentiator between tangible and WIMP style interfaces. Lee et al argue that analysis should include not only the user, but the potential social dimensions of the interaction which takes places when users engage with each other while navigating physical devices [11].

Methodology

We undertook two user evaluation sessions, each of which involved four participants. Participants were first asked to complete ten tasks in response to questions[1] using one set of blocks. The procedure was then repeated using the other set of blocks. The order of the sets was counterbalanced to prevent order bias. Both sessions were video and audio recorded and lasted less than one hour.

[1] Questions were based on queries that may be asked using existing data visualization software. For example, participants were asked to determine which radio station had the greatest number of male listeners between the ages of 44 to 55.

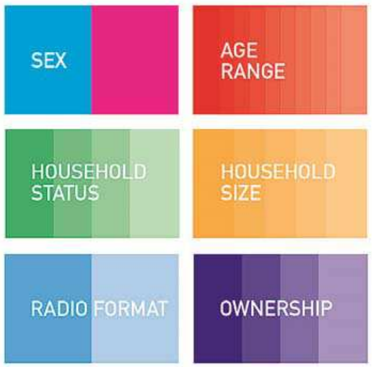

Figure 3: Prototype of interactive data category cards

The user interaction of the low fidelity prototypes was simulated using a *Wizard of Oz* technique.[2] Participants were also asked to complete a post-study survey.

Data Sets
Compiled by BBM Canada, the data consisted of detailed demographic information on radio listeners and the media consumption habits of market research participants collected on April 1, 2013 for the Toronto area in Canada.

Apparatus
In addition to the two sets of blocks described above, six cards were used to represent additional data variables: radio format, ownership, age range, sex (gender), household status, and household size (see Figure 3). Sheets of paper were placed on the table between the participants to represent a surface on which the blocks and cards could be placed to produce a visualization of the data. A wall mounted screen was positioned in front of the participant group, on which the resulting visualizations appeared[3].

Participants
The eight participants were BBM Analytics employees, who were over 25 years old, had at least one year of experience, and were familiar with data visualization software, although their familiarity with the specific data set used in the study varied. The two groups were composed of 2 men and 2 women, and 3 women and 1 man respectively.

Procedure
The first group completed the ten questions using the uniformly sized set and then the data-sculpture set, whereas the second group began with the data-sculpture set and then used the uniformly-sized set. While the pilot study did not compare 2D with TUI, we wanted to allow for a discussion of the relevance of TUI in the context of the participant's work. Hence we asked questions that were similar to queries study participants would perform in the course of their work using existing 2D analytic software. The questions started simply and increased in complexity (see Figure 4, 5 and 6 for illustration of how a query could be answered by manipulating the blocks and cards on a sensor pad and viewing the resulting visualization on a screen).

Measures
The primary variable in the study was the different set of blocks. The uniformly-sized set used colour and a written label to represent specific radio stations. No other data variable was physically represented. The data-sculpture set included a physical visualization of the total listening time for each radio station and the total audience embodied in the dimensions of the block. We captured audio and video recordings to allow us to measure the time to complete tasks, error rate and to capture inter-participant interaction during completion of the tasks.

We asked the participants to complete an online survey immediately following their session, in which they answered questions regarding perceived collaboration, usability of the prototype (using the System Usability

[2] This technique allows for rapid prototyping and evaluation since the interactions between the user and the tool are simulated by researchers (see the work of Greenberg, Carpendale, Marquardt & Buxton [5] for a more details regarding a technique first proposed by Jeff Kelley.)

[3] Note that not all the potential combinations of blocks and cards could be anticipated and displayed. Researchers described the visualization where an actual visualization did not exist.

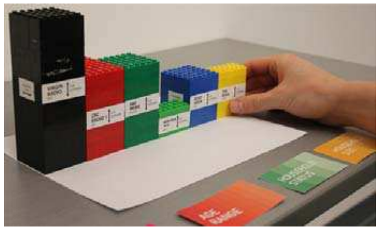

Figure 4: placing blocks on sensor pad to answer query (which radio station had the greatest number of male listeners between the ages of 44 to 55.)

Figure 5: manipulating blocks and cards on sensor.

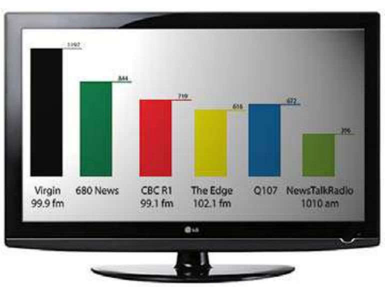

Figure 6: visual output from user interaction with blocks on the sensor pad

Scale), preferences between the sets, and potential uses of TUIs.

Results

Collaboration and engagement

Overall, both user sessions provided examples of collaboration and active participation. However, there were some notable differences between the use of the uniformly sized set and the data-sculpture set of blocks. We defined collaboration as social interaction (handling the blocks, discussing how they should be used and helping formulate answers). This was greater with the data-sculpture set of blocks, which participants recognized in the survey.

Usability

We did not observe any differences in the handling of the blocks, all of which were light enough to be handled by one-hand. Participants were asked to rate the use of blocks to analyze the data. Using the System Usability Scale (SUS) for measurement, the average score of the seven respondents was 76.4. A SUS score above 68 is considered above average [2]. Only one participant gave the system a score below this benchmark (their score was 60). An average score of 76.4, supported by positive commentary from participants, suggests that they found the block TUI valuable for the analysis of data. Six of seven survey respondents agreed with that statement that *the blocks are a useful way to explore the data*, and five of seven agreed that *this method of analyzing data would lead to new insights*.

Preferences

When asked regarding their preference for either set, four out of seven of the respondents preferred the uniformly sized set, citing a belief that they led to more insight regarding the data. In addition, six of the seven participants who responded to the survey question "which set helped you complete your task more quickly?" felt that the uniformly sized set was more efficient (the seventh participant did not indicate a difference between the two sets). The sessions revealed some confusion regarding the data-sculpture set and that the inclusion of data in the TUI may have been a confounding (instead of an enlightening) factor. It is possible that the data-sculpture set required more training for effective use than the uniformly sized set. One participant felt that physically representing two important facets of a radio station's data gave her an immediate impression of the station relative to other stations, an impression she did not get from the uniformly sized blocks. However, none of the questions were answered by the participants using only the physical aspects of the block (ie. without recourse to the flat surface and screen display.)

Potential Uses

Participants were asked if specific types of data would lend themselves to the use of blocks for analysis; specific data sets used in the course of work were proposed. This finding will be used to select data sets in future development work and evaluation. Participants also compared existing 2D visualizations (which are generated by existing software tools to analyze the data sets comparable to those used in this study) with the use of blocks, generally finding that the block concept held potential in revealing insight that existing tools did not. As one participant commented,

> *I think the blocks will work for any data that has a common base as the 3D shape has an advantage over common 2D visualizations to display different facets of the data in a more manageable fashion. I also find that manipulating the blocks is easier than checking*

off a list of boxes to find the results you want. I felt like the visual aspect of the block forces the brain to see data differently and prompts questions that a bar graph or histogram wouldn't necessarily provoke.

Although efficiency was not a key measurement in the study, the time to complete tasks (the time taken to answer each question) was also recorded. The time to complete tasks with the uniformly sized set was half that of the data-sculpture set for both groups.

Discussion

Participants in both user sessions expressed a keen interest in TUI, finding the use of blocks to be fun, although this may have been a product of novelty. The pilot study helped us to test various ideas and beliefs we held regarding the use of TUIs. For example, we believed that the data-sculpture set would lead to more efficient responses to our questions since potential answers were embedded within the physical representation of the data, but this was not the case. Even though participants could line up the blocks and see differences in terms of height, for example, the presence of other aspects of the data (as represented by the depth) may have caused some uncertainty, reducing efficiency. At times the participants were unsure of the correct orientation in which to place the blocks; perhaps more training time prior to making use of the blocks could have increased efficiency.

The efficiency of using blocks to analyze data remains unclear and requires further study. In this pilot study, we focused on gathering qualitative data on how users interacted with the TUIs, on how the TUIs spurred social interaction, and on how each of our two TUIs compared with one another. We were therefore more interested in recording the spontaneous group discussions that arose among participants, rather than measuring efficiency, and thus we are hesitant to make any claims regarding efficiency. We believe that the information gleaned from these tangential group discussions is more useful to us at this time than time-to-complete tasks measurements because we are still in the process of determining which specific affordances are most relevant to the user. The group discussions informed possible ways that a query may be answered, such as placing blocks on different parts of the input surface, stacking, and rotating the angle of the blocks in relation to each other and to the participants. This interaction between participants suggests a need to further study the use of a TUI and whether it may instigate social interactions. Social instigation may need to be balanced against efficiency as social interaction may improve the effectiveness or quality of data analysis [8] [12].

Future Work

The pilot study involved only eight participants, but it allowed us to share the concept with a potential user group. We would like to better understand the differences of data sculpture approach versus non-data sculpture and the possible affordances of physical blocks. We would also like to better understand the role of colour on the perceptions of data. However, we believe there are properties beyond efficiency that hold promise for TUI, such as improved collaboration and accessibility. We would like to better understand the role of collaboration in the use of TUIs, particularly if collaboration reveals novel insights from data. In other words, to what degree can TUIs facilitate human to human to computer interaction so that we may uncover currently hidden facets of a data set. Contemporary artists have led in the creation of evocative data sculptures, a burgeoning art practice which may bear future value in providing clues to effective formal expression in the use of TUIs [14].

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References

[1] Baudisch, P., Becker T., and Rudeck, F. Lumino: Tangible Blocks For Tabletop Computers Based On Glass Fiber Bundles. In *Proc. CHI 2010*, ACM Press (2010), 1165-1174.

[2] Brook, J. SUS – A Quick And Dirty Usability Scale. In *Usability Evaluation In Industry*. Taylor & Francis Ltd, London, 1996, 189-194.

[3] Do-Lenh, S., Jermann, P., Cuendet, S., Zufferey, G., and Dillenbourg, P. Task Performance Vs. Learning Outcomes: A Study Of A Tangible User Interface In The Classroom. In *Sustaining TEL: From Innovation to Learning and Practice*. Springer, Berlin, Heidelberg, 2010. 78-92.

[4] Gorbet, M.G., Orth, M. and Ishii, H. Triangles: Tangible Interface For Manipulation And Exploration Of Digital Information Topography. In *Proc. CHI 1998,* ACM Press (1998), 49-56.

[5] Greenberg, S., Carpendale, S., Marquardt, N., and Buxton, B. Sketching User Experiences: The Workbook. Morgan Kaufmann Publishers, Waltham, MA, USA, 2012.

[6] Jansen, Y., Dragicevic, P. and Fekete, J.-D. Evaluating The Efficiency Of Physical Visualizations. In *Proc.* CHI 2013, ACM Press (2013), 2593-2602

[7] Kenderdine, S., Au, O.K.-C. and Shaw, J. Cultural Data Sculpting: Omnispatial Visualization for Cultural Datasets. *Proc. of Information Visualisation (IV) 2011*, IEEE (2011), 570- 579

[8] Kim, M.-J., and Maher, M.-L. The impact of tangible user interfaces on spatial cognition during collaborative design. *Design Studies* 29, 3 (2008), 222-253.

[9] Klum, S., Isenberg, P., Langner, R., Fekete, J.-D., and Dachselt, R. Stackables: combining tangibles for faceted browsing. In *Proc. of Advanced Visual Interfaces (AVI) 2012*, ACM Press (2012), 241-248

[10] Lakatos, D., and Ishii, H. Towards Radical Atoms—Form-giving to transformable materials. *Cognitive Infocommunications (CogInfoCom),* IEEE (2012), 37-40.

[11] Lee, B., Isenberg, P., Riche, N.H., and Carpendale, S. Beyond Mouse and Keyboard: Expanding Design. Considerations for Information Visualization Interactions. *IEEE Transactions on Visualization and Computer Graphics* 18, 12 (2012), 2689-2698.

[12] Schneider, B., Jermann, P., Zufferey, G., and Dillenbourg, P. Benefits Of A Tangible Interface For Collaborative Learning And Interaction. In *Transactions on Learning Technologies,* IEEE (2011), 222-232.

[13] Vande Moere, A. Beyond the tyranny of the pixel: Exploring the physicality of information visualization. Proc. of Information Visualization (IV) 2008. IEEE (2008), 469- 474.

[14] Viégas, F. B., and Wattenberg, M. Artistic data visualization: Beyond visual analytics. In *Online Communities and Social Computing*. Springer, Berlin (2007), 183-191.