Critical Review: Exploring Interactions with Physically Dynamic Bar Charts

Introduction

Studies investigating how data can be effectively presented to, explored and interpreted by users forms the core part of Information Visualisation ('InfoVis') to support users in the decision-making process [Card and Mackinlay, 1997]. This review summarises and critically analyses Taher et al. [2015] whose paper explores the use of physically dynamic bar charts as devices for exploring user interactions with visualisations of data, to determine future work in this domain of Information Visualisation.

Summary of Contributions

Taher et al. seeks to extend existing work on use of physical visualisations (*physicalizations*) [Jansen et al., 2015] to investigate how users interact with *physically dynamic* bar charts as a way of exploring and manipulating shape-changing datasets in the physical world. Much of the existing work reliant on use of physicalizations involve problematic *static* models that do not respond to user interactions [Jansen et al., 2013] and are therefore "*disconnected*" from the source of the data when they are created. With the advent of shape-changing technology and tangible interfaces [Rasmussen et al., 2012], there is a window of opportunity for the manufacture of physically dynamic displays to help decision makers reason about and manipulate data sets in a non-virtual and non-static way. It is this motivation that leads Taher et al. to explore the ways users interact with data displayed in this mode to understand whether *physical* interactions with data (such as touching specific bars) or *gestures* (such as swiping a touch-screen) or a combination of the two is more intuitive to users interacting with data visualisations in order to solve common problems. Whilst the authors concede that the use of physical dynamic visualisations is not new [Leithinger and Ishii, 2010, Follmer et al., 2013], they claim there is little in the way of analysis into effective *interactions* with data of *dynamic* physical modality, unlike the abundance of work investigating their static counterparts [Stusak and Aslan, 2014].

The point system described by the article to support the author's research is *EMERGE* - a 10×10 physical bar chart which uses a set of dynamic self-actuating rods with an RGB display projected onto it (Figure 1). An immediate and obvious limitation of using a Bar Chart point system is that any conclusions drawn about its effectiveness in physically-dynamic form cannot be generalised to other types of InfoVis systems, such as Dynamic Histograms, Parallel Coordinates and Theme Rivers.

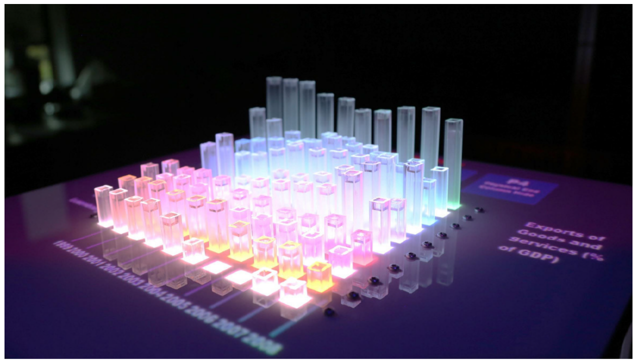

Figure 1: EMERGE: Exploring Interactions with Physically Dynamic Bar Charts using actuating physical rods and RGB LEDs to display international export data.

EMERGE allows users to interact with the dataset it represents using a set of 4 task-sets derived from subcategories of the taxonomy of interactive dynamics for visual analysis described by Heer and Shneiderman [2012] - *annotation*, *filtering*, *organisation* and *navigation* (Table 1). Heer and Shneiderman lay out 3 high-level categories in their model - *Data and View Specification*, *View Manipulation*, and *Process and Provenance*. (Figure 2). In this sense, whilst the selection of InfoVis model is careful and grounded in background theory, the choice of subcategories by Taher et al. for interacting with EMERGE is somewhat arbitrary and limited in scope, which immediately invites further research into different forms of interactions with physicalisations from the taxonomy.

*Table 1: Task-sets and interaction techniques explored during the user study with EMERGE: annotation, filtering, organisation and navigation with the category of Heer and Shneiderman [2012] in **bold**.*

Task	**Overview**	**Interaction Techniques**
Annotation ***(Process & provenance)***	Selecting and marking individual data points.	Point, pull, press.
Filtering ***(Data view & specification)***	Hiding and refining data for enhanced perception and comparison.	Swipe away, manual press, assisted press, press shortcut, and press to compare.
Organization ***(View manipulation)***	Data arrangement by moving rows and columns.	Drag and drop with immediate transition and hide-all with transition, press with instant transition and hide-all with transition.
Navigation ***(View manipulation)***	Controlling the view of large data sets.	Scroll, directional arrows, directional press, and paging.

Data and View Specification	**Visualize** data by choosing visual encodings.
	Filter out data to focus on relevant items.
	Sort items to expose patterns.
	Derive values or models from source data.
View Manipulation	**Select** items to highlight, filter, or manipulate them.
	Navigate to examine high-level patterns and low-level detail.
	Coordinate views for linked, multidimensional exploration.
	Organize multiple windows and workspaces.
Process and Provenance	**Record** analysis histories for revisitation, review, and sharing.
	Annotate patterns to document findings.
	Share views and annotations to enable collaboration.
	Guide users through analysis tasks or stories.

Figure 2: Taxonomy of interactive dynamics described by Heer and Shneiderman [2012].

The main contributions of Taher et al. [2015] is threefold. First, the authors present a set of 14 potential interactions (both physical and gesture based) for manipulating and exploring data presented in dynamic physical bar charts such as EMERGE. Second, the findings of their user study ($N = 17$) evaluates which of the 14 interactions are effective and intuitive in completing a set of data analysis tasks, and which interactions match users' initial preconceptions for how to achieve these tasks. Finally, a set of important design considerations are presented to advise future research on the challenges of presenting data in physically dynamic form. Overall, we learn that a combination of gestures and physical interaction is effective. Smaller interactions such as annotation of specific data points can be afforded by physical interaction whereas larger interactions such as organization can be afforded touch-screen gestures.

Justifications for Conclusions

Taher et al. set about their investigations by creating a list of proposed or *baseline* interactions by which users could interact with EMERGE. The authors by their own admission avoided early experimentation to generate different types of interaction before the main study as existing research forewarned against this due to the immaturity of the area [Hornbæk, 2013]. Whilst this was sensible to consider, the mechanics of the baseline interactions to be used in the user study are strongly-coupled with the hardware capabilities of EMERGE and no explanation is given by the authors into where the inspiration for each proposed interaction came from, which causes some early concern over generalisability of results to other implementations of physically dynamic bar charts.

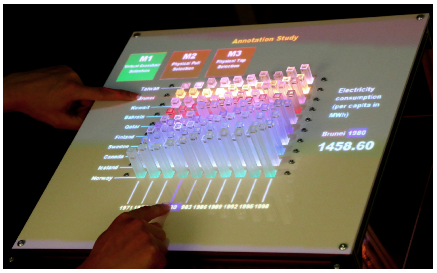

Figure 3: Annotation (Point technique).

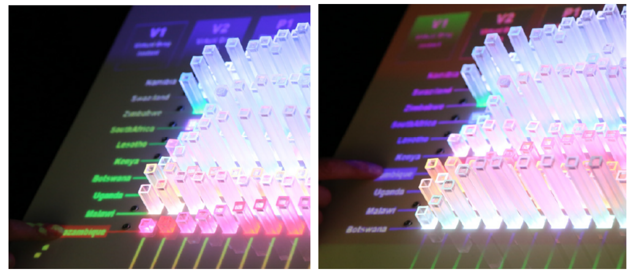

Figure 4: Organisation (Drag and Drop technique).

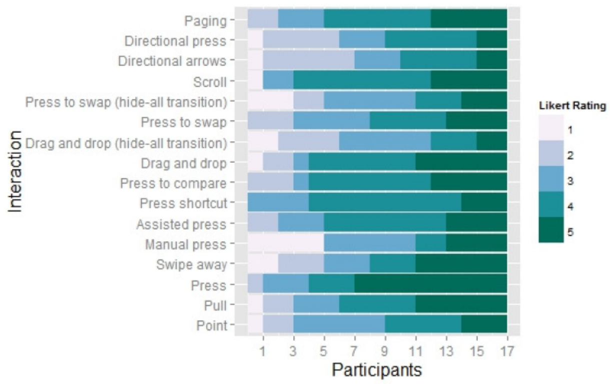

Figure 5: Likert scale ratings for helpfulness of interaction techniques. Range = 1: Strongly Disagree, 5: Strongly Agree.

Limitations and Suggested Further Work

Taher et al. [2015] present a respectable overview of potential techniques to interact with data presented in a physically dynamic form, but a set of limitations with their work leads to some questions being open to future research.

The authors concede themselves that the hardware implementation of EMERGE presents a large limitation in their findings. Representation of larger datasets would require a far more data points than the 10×10 grid currently allows for. Also, the technical challenges discussed previously (actuation speed and noise, rod spacing, size of setup) may have also mediated or impacted the results in ways that were not accounted for. Almost all participants reacted hesitantly due to these speed and noise of actuation. Further analysis (e.g. use of parallel mediated regression testing) should investigate this.

The InfoVis design space is very large [Card and Mackinlay, 1997], so it would be novel to explore how users perceive dynamic physicalisations which represent complex datasets which *change* in real time - e.g. social network data [Federico et al., 2011]. As well as responding to human interaction via shape-changing interfaces, these datasets could also change of their own accord which opens up more questions into how users would respond to this type of visualisation.

Authors:

- Data manipulation with external objects
- Multi-finger input
- Pressing over time
- Complex task explorations from taxonomy - undo/redo, different filtering (e.g. thresholding)
- Combining interactions
- Controlled studies with performance metrics (e.g. task completion times, accuracy)

Novel:

- Larger sample size - 17 not enough.
- Excluded vertical axis data - difficult to anticipate how this might change user interactions and behaviours.
- Not just bar charts!
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- Different taxonomy - zoom, select, derive, sort, history.
- Lack of parametric data - study could investigate performance and accuracy of tasks being completed.
- Apply it to a specific context to compare across modalities in an educational setting for those who learn best by adopting kinaesthetic techniques [Pourhosein Gilakjani, 2011] or even used in a VR-kin setting [Tennent et al., 2017].

Conclusion

Taher et al. [2015] set the foundations for future investigations into use of shape-changing displays for accomplishment of common InfoVis tasks. Their research is limited in several ways by the implementation of the EMERGE system, but raises important design considerations for future work investigating dynamic physicalisations in other domains. Findings have potentially wider consequences in the topic of Information Visualisation - with recommendations on how to design systems supporting the fundamental interactions such as those described by Heer and Shneiderman [2012], these visualisations can serve as effective data analysis tools in a variety of domains.

Word count: 0 words (not inc. Citations, Figures or References)

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