# Critical Review: Exploring Interactions with Physically Dynamic Bar Charts

## Introduction

Studies investigating how data can be effectively presented to and explored by humans forms the core part of Information Visualisation ('InfoVis') to support them 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. extend existing work on 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 visualisations of datasets. Existing work into physicalizations involve problematic *static* models that do not respond to user interactions [Jansen et al., 2013] and are therefore "*disconnected*" from the data source when created. With the advent of shape-changing technology [Rasmussen et al., 2012], there is scope 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. This motivation leads Taher et al. to explore the ways users interact with data displayed in this mode to understand whether *physical* interactions (such as touching specific bars) or *gestures* (such as swiping a touch-screen) or a *combination* of the two is more intuitive to users when solving common problems. Whilst the authors concede that physical dynamic visualisations are not new [Leithinger and Ishii, 2010, Follmer et al., 2013], they claim there is little 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 to support the author's research is *EMERGE* - a $10 \times 10$ 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 without further research.

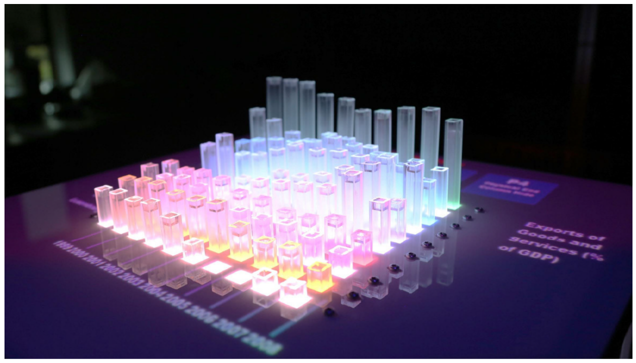

*Figure 1: EMERGE: Exploring Interactions with Physically Dynamic Bar Charts using actuating physical rods and RGB LEDs to display international export data.*

EMERGE allows users to interact with the dataset it represents using a set of 4 interaction-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 with little justification, which immediately invites further research into different interactions from the taxonomy with dynamic physicalisations.

*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].*

Main contributions of Taher et al. [2015] are threefold. First, 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 interactions are effective and intuitive in completing a set of analysis tasks, and which interactions match users' initial preconceptions for how to achieve these tasks. Finally, a set of design considerations to advise future research on the challenges of presenting data in physically dynamic form. Overall, we learn that a *combination* of gestures and physical interactions are 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 14 *baseline* interactions across the 4 main tasks (annotation, filtering, organisation, navigation - e.g. Figure 3 and 4) for users to interact with EMERGE. The authors avoided early experimentation to generate different types of interaction for each task 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 used in the 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.

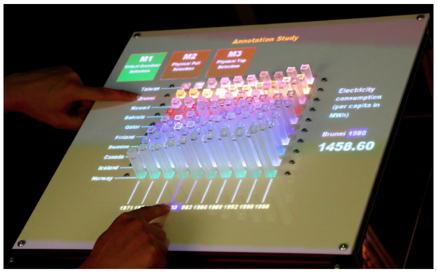


Figure 3: Annotation (Point technique).

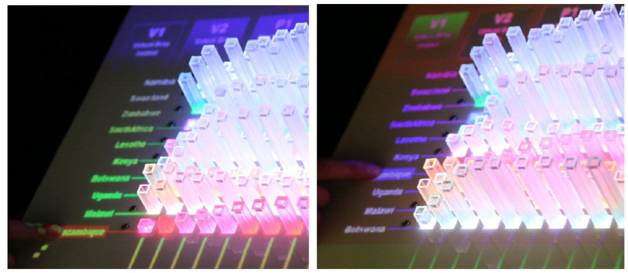

Figure 4: Organisation (Drag and Drop technique).

A within-subjects study ($N = 17$, 6 female, mean age $= 27$) investigated the authors' research questions. Participants had no experience with shape changing displays but no detail is given about their selection criteria or origin (i.e. the selection pool) which means it is difficult to comment on results being representative. The small sample size, lack of representative sampling with respect to gender and use of extrinsic (monetary) motivation are all limiting factors on the study's external validity. After participants were individually introduced to EMERGE, they were asked how they initially thought they could achieve each task. Then, each technique for a given task was demonstrated before a verbal data analysis task was set for each interaction (e.g. "*Select the year and country with the highest electricity consumption.*") to observe user behaviours and feedback.

Counter-balancing on the ordering of task-sets and techniques reduced order bias, but it could be argued that the within-subjects design caused a training effect as users became more comfortable with the EMERGE interface. After each task, a 5-point Likert questionnaire was carried out (Figure 5) along with elicitation of users' comments. In this sense, the study was well-designed, allowing for initial preconceptions of interactions to be captured before any demonstrations took place. That said, different datasets were used for each task, which could have varying effects on the participants' ability to interpret the visualisation and therefore influence their rating of the interaction under scrutiny. Also, besides the Likert ratings the data collected is purely qualitative and so more parametric data such as performance metrics (task completion times) would strengthen the authors' conclusions.

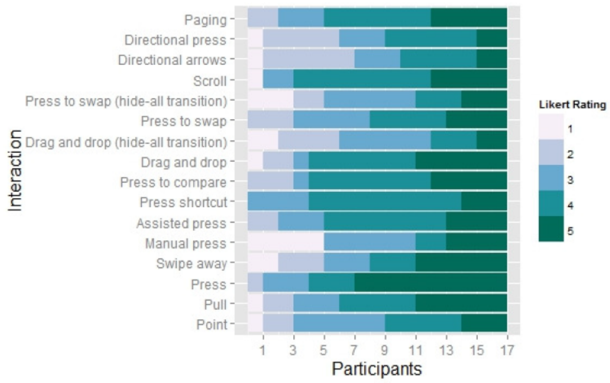


*Figure 5: Likert scale ratings for helpfulness of interaction techniques. Range = 1: Strongly Disagree, 5: Strongly Agree.*

Overall, the conclusion of Taher et al. that *both* physical interactions such as pressing and gesture interactions such as swiping are effective and intuitive for dynamic physicalisations is well-evidenced by the Likert scale data above and notable user comments presented in the article. However, EMERGE's implementation presents a large limitation in the authors' findings. Firstly, the chart itself is of a 3D modality with no vertical axis. The only meaningful vertical information is ascertained by visual comparison of bar heights rather than reading of direct data. Secondly, the representation of larger datasets would require a far more data points than the $10 \times 10$ grid currently allows for - it is likely that for higher resolution of data points, navigation interactions such as pagination would suffice whereas pressing data points to navigate between single rows would be cumbersome. It is also likely that new background theory may need to be considered with higher resolution of data points - perhaps use of the *overview first, zoom and filter, then details on demand* mantra described by Shneiderman [1997]. Thirdly, specific technical challenges discussed (actuation speed and noise, rod spacing, size of setup) may have also mediated or impacted the results in ways that were unaccounted for. For example, 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.

## Limitations and Suggested Further Work

Taher et al. [2015] present a respectable investigation of potential techniques to interact with data presented in a physically dynamic form and their conclusion on the effectiveness of adopting *both* physical and gesture-based interactions with these systems seems valid, but a set of limitations with their work leads to some questions being open to future research.

Crucially, the number of participants involved should be increased and to ensure conclusions are generalisable with external validity, the sample should be representative of the general population (approx. 50% gender split). Also, aside from the Likert scale data, the paper lacks a lot of parametric data which might provide further insight into efficacy of interactions - further controlled studies could attempt to measure performance metrics such as task completion times and accuracy for each interaction type. Seeing as the investigation focuses on a narrow subset of the interaction taxonomy of Heer and Shneiderman [2012] on a Bar Chart, the obvious extensions to the authors' work would be to explore different interaction types such as Record, Co-ordinate and Share using EMERGE, and extend experiments across different point systems such as Dynamic Histograms, Parallel Coordinates and Theme Rivers. As *both* physical and gesture based interactions are effective for small and large grained tasks respectively, it would also be wise to see how *combining* both interactions into one activity affects findings.

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. Another novel suggestion would be to apply these visualisations to a specific context or domain, to compare efficacy of interactions across modalities (i.e. *static physical* versus *dynamic physical* versus *virtual*). An example might be in an educational setting where kinaesthetic techniques are encouraged [Pourhosein Gilakjani, 2011]. Furthermore, investigations could also be extended to observe the effects of using dynamic physicalisations whilst a user is immersed in a VR environment, to combat a lack of 'presence' in these settings and afford data manipulation in virtual settings with physical assistance [Tennent et al., 2017]. Finally, existing work analysing use of static physicalisations for assisting the blind [Perkins, 2002] can be extended to understand how dynamic physicalisations can offer further support in data manipulation by the visually impaired.

## 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: 1618 words (not inc. headings, citations, figures or references)*

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