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Trevor Hogan, Uta Hinrichs, Samuel Huron, Jason Alexander, Yvonne Jansen

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Guest Editors' Introduction

DATA PHYSICALIZATION

Trevor Hogan, Munster Technical University, Cork T12 T66T, Ireland

Uta Hinrichs, University of St Andrews, St Andrews, KY16 9AJ, U.K.

Samuel Huron, Telecom Paris School, Polytechnique de Paris, 91120 Palaiseau, France

Jason Alexander, University of Bath, Bath BA2 7AY, U.K.

Yvonne Jansen Sorbonne Université, CNRS, ISIR, 75005 Paris, France

The practise of representing data in physical form has existed for thousands of years, yet it has only become an area of investigation and exploration for scientists, designers and artists much more recently [3]. Advances in areas such as digital fabrication, actuated tangible interfaces, and shape-changing displays have spurred an emerging area of research now called Data Physicalization [1]. This special issue of IEEE Computer Graphics and Applications presents five articles spanning a wide breadth of current Data Physicalization research, from theory to practise.

Today we are surrounded by data representations in our work, home and social lives, yet the way we experience these remains almost exclusively through our eyes. Imagine for a moment, instead of viewing or reading a graph (Data Visualization) we are presented with a representation of data that we can touch, feel, or hold (Data Physicalization). Now imagine how the experience and understanding of the data may change for you as you interrogate it through a different sensory modality. This is Data Physicalization. Or more specifically, *Data Physicalization is a physical artifact whose geometry or material properties encode data* [1]. Data Physicalization has gained in popularity over the last few years, and it has grown outwards to include a broad spectrum of fields, including Computer Scientists, Artists, Designers, Psychologists, and practitioners in Human-Computer Interaction and Information Visualisation. A demonstration

of the breadth of the Data Physicalization field can be seen in the series of workshops that have been held over the last six years at conferences such as IEEE VIS, ACM CHI, ACM TEI, DRS and at Dagstuhl (for more information on these see Dataphys Wiki [2]). Such diversity has had a positive impact on the field, through rich collaborations and cross-domain exposure of concepts, approaches, and methodologies.

A fundamental question that is often posed about the value of Data Physicalization is why we should go through the often complex process of making data physical. While we would argue that there are many perceived benefits, arguably the main one is that physical data representations allow to study research questions difficult to approach with purely digital/virtual representations. The physicality of such representations supports direct interaction with data in tangible ways, which in turn opens up opportunities for potential cognitive benefits that are not accessible with a digital counterpart. This is not a new notion. For many years scientists used physical props to help explain difficult to grasp concepts. Take for example the many props used to explain thermodynamics, and those used to introduce and explain the double helix of the gene and the structure of haemoglobin. All of these concepts and discoveries were made easier to understand through the use of physical models. Other fields also use similar strategies, including the use of scale models in architecture and teaching aids such as an

abacus in math education (see also dataphys gallery for more examples [3]).

The community has explored the perceived benefits of Data Physicalization in the recent past and through this the popularity of the field has grown. We therefore believe it is timely to draw together some of the most current research on Data Physicalization in this SI. In doing so we aim to bring further attention to this field as it matures and, hopefully, it will inspire new researchers to join the community and attempt to answer the many open questions and challenges.

IN THIS ISSUE

In this issue, you will find five research articles. First, "What we talk about when we talk about data physicality" critically reflects on the notion of "data" in the context of data physicalization. He introduces a conceptual framework (design space) that can help to characterize the different ways in which data physicalizations relate to data ("epistemological" vs. "ontological" and "representational" vs. "relational"). The dimensions of this design space are discussed illustrated with existing example physicalizations.

Second, in "Thinking with Things: Landscapes, Connections, Performances as modes of Building Shared Understanding", the authors describe the use of physicalizations to support the elicitation of how designers and academics imagine and understand interdisciplinary systems. The paper describes three workshop modes, "deploying elements of landscape, emphasizing connective tissue, and exploring dynamic performance", and focuses on the qualitative aspects of the experiences from the perspective of how people think through material manipulation.

Next, "Data Badges: Making an Academic Profile through a DIY wearable physicalization" describes the design process and results of the data physicalizations "data badges" – personal

wearable visualizations to facilitate networking and social interactions during professional events such as academic conferences. These Data Badges were used as part of the Dagstuhl seminar on Data Physicalization, which was held in October 2018 [4].

Then, "Move&Find: The value of kinesthetic experience in a casual data representation" presents a study where participants pedaled on a bicycle to exert the energy required to power a search on Google's servers. The authors explore how the bodily experience of that data, the power required, may affect how the "viewer" experiences and reflects on the data.

Finally, "Data Clothing and BigBarChart: designing physical data reports on indoor pollutants for individuals and communities" brought data physicalizations into the field by using physical data representations to communicate data about in-door pollutants to the participants in the Green Housing Study. Their article reports on how the physicalizations were received by diverse audiences.

FUTURE DIRECTIONS

The last decades have brought many advances in digital fabrication, actuated tangible interfaces, and shape-changing displays, yet many technical challenges remain to implement and support data physicalizations which can compete in meaningful ways with the automation capabilities offered by digital visualizations. However, instead of focusing on current limitations, we believe it is important to develop techniques that combine the best of both worlds (physicalization and visualization). The large space of combining bits and atoms to represent data remains largely unexplored, and designing and evaluating techniques for such mixed representations will be paramount to shape future interaction with data.

While there are powerful tools to create a diverse range of visualizations there are

currently no similar tools available for physicalizations. Some examples exist to create rather specific types of physicalization both for the creation of actuated physicalizations (Zoids [5], ShapeClips [6]) as well as free-form toolkits for manual assembly and manipulation (Constructive Vis [7]), but there are currently no comparable tools to what D3.js or Tableau offer the visualization world.

Beyond physicalization construction, it is often postulated that data physicalizations may increase the accessibility of data representations for people with visual impairments. What can we learn about designing data representations for this group? Or, should we go one step further and explore whether data physicalizations may be an approach to achieve universal, inclusive data representation regardless of viewer ability?

The vibrant activity in the physicalization community opens future directions, including concrete research questions to pursue, potential applications to explore, and technical challenges to solve.

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ABOUT THE AUTHORS

Trevor Hogan is a Lecturer in Design at the Munster Technical University (formally known as CIT), Ireland, where he also leads the Human-Data Interaction Group. He received his Ph.D degree from the Bauhaus-Universität Weimar in 2016. His current research is concerned describing and better understanding how embodiment influences and augments people's experience of data representations. His work is strongly interdisciplinary and may be situated in the field of Interactive Design, at the intersection of Tangible Computing, Human-Computer Interaction, Data Physicalization and

Psychology. He is the corresponding author of this special issue. Contact him at trevor.hogan@cit.ie

Uta Hinrichs is a lecturer at the University of St Andrews in Scotland. Uta's research is driven by the question of how to utilize and teach visualization and interface design to facilitate insightful, pleasurable and critical interactions with information. She has applied data physicalization especially in interdisciplinary contexts to teach data-driven thinking to audiences ranging from children to adult professionals. Uta's research draws heavily from fields outside of computer science and has been presented at a range of academic venues spanning the fields of visualization, HCI, literary studies, design and digital humanities, as well as museums, libraries, and art galleries. You can contact her at uh3@st-andrews.ac.uk

Samuel Huron is an associate professor in Design of Information Technologies inside the Social and Economical Science Department of Telecom Paris school at the Institut Polytechnique de Paris, and part of the CNRS Institut Interdisciplinaire of innovation. His research is focused on democratizing data visualization to every one. This focus led him to explore different themes such as data physicalization authoring processes, design processes and methods of visualization, and data physicalization workshop. You can contact him at samuel.huron@telecom-paris.fr

Jason Alexander is a Professor in Human-Computer Interaction in the Department of Computer Science at the University of Bath. His primary research area is Human-Computer Interaction, with a particular interest in developing novel interactive systems to bridge the physical-digital divide. His recent work focuses on the development of shape-changing interfaces—surfaces that can dynamically change their geometry based on digital content or user input. He has employed these in several examples of dynamic data physicalization. Alexander's other work has

investigated novel interaction techniques using eye-gaze, haptic feedback, and gestural interaction. You can contact him at jma73@bath.ac.uk.

Yvonne Jansen is a permanent Research Scientist at the Centre National de Recherche Scientifique (CNRS) since 2016. She received her doctoral degree from Université Paris Sud in 2014. Her research interests include data physicalization, situated and embedded data visualization, and methods and techniques to facilitate the transparent reporting of research outcomes. Contact her at yvonne.jansen@sorbonne-universite.fr