Data Physicalization

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THE PRACTICE 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 four articles spanning a wide breadth of current data physicalization research, from theory to practice.

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 visualization. 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 us to study research questions difficult to approach with purely

Digital Object Identifier 10.1109/MCG.2020.3027223
Date of current version 23 October 2020.

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 Special Issue. 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 four 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. The author introduces a conceptual framework (design space) that can help to characterize the different ways in which data physicalizations relate to data ("epistemological" versus "ontological" and "representational" versus "relational"). The dimensions of this design space are discussed and illustrated with existing example physicalizations.

Second, in "Thinking With Things: Landscapes, Connections and 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 article 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]

Finally, "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.

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 to for the creation of actuated physicalizations (Zooids,[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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