A Reflection on Haptics in Light of Interactive Systems Transcending the Digital-Physical Modality

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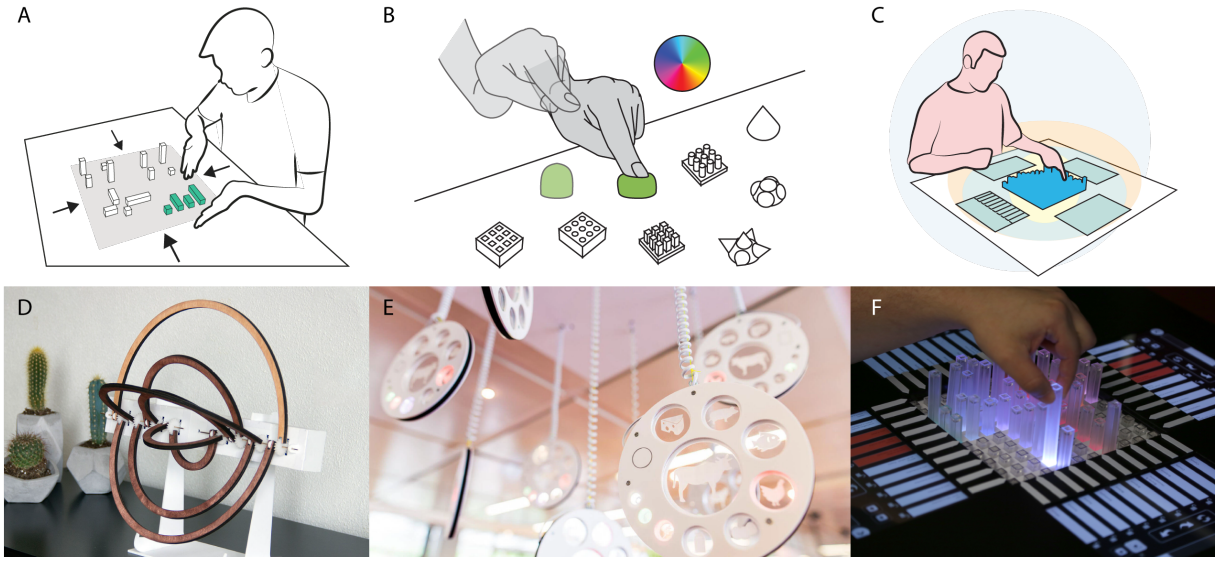

Figure 1: Overview of our prior research: Foundational perceptual studies such as (A) the perception of physical information across orientations [13] and (B) cross-modal interactions between tactile and visual stimuli [19]; conceptual discussions on physical computing such as (C) the physecology framework [15]; and the design, fabrication, and evaluation of interactive systems such as (D) LOOP [12], (E) Econundrum [11], and (F) EMERGE [20].

KEYWORDS

Haptics, Data Physicalization, Shape-Changing Interfaces

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1 INTRODUCTION

Haptics within Human-Computer Interaction (HCI) refers to technology that aims to make digital interactions more intuitive, engaging, and immersive by incorporating the sense of touch. It acts as a bridge, providing another layer of communication between people and technology, ultimately enhancing the way we interact with digital devices. Haptics come in a variety of form factors and applications, such as a flat electrotactile device that can be pinched between fingers for grasping interactions in VR [7], TactJam [22], a software and hardware suite for prototyping on-body vibrotactile feedback, FlexHaptics [9], a computational design method to create haptic input interfaces by 3D printing or laser cutting, and FluxTangible [6], introducing dynamic haptic feedback utilizing magnetic interference on commercially available touch devices. Collectively, these examples illustrate the versatility and potential impact of haptic technologies across various domains of HCI. From enhancing VR experiences to enabling on-body interactions and facilitating rapid prototyping, haptics play a crucial role in shaping the future of interactive systems by providing users with richer, more immersive digital experiences.

In our research, we have explored the design and evaluation of interactive systems that transcend the digital-physical modality, mostly focused on physicalization and shape-changing interfaces. These explorations echo the overarching goal of haptics: to seamlessly merge digital and physical realms into a cohesive interactive experience.

This position paper aims to explore the intersectionality between our expertise in data physicalization, shape-changing interfaces, and the workshop theme of inclusive haptic design. By reflecting

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on our prior research portfolio, we uncover the challenges and opportunities of inclusively designing haptics for digital-physical devices. We believe that the challenges we have encountered in our work hold transferable insights for the workshop's aims. Through our participation, we aspire to gain a deeper understanding of how haptics can be seamlessly woven into interactive experiences, fostering inclusivity and innovation in haptic design.

2 BIO

Kim Sauvé is a Research Associate in Human-Computer Interaction at the University of Bath, United Kingdom. Her research focuses on exploring the underlying principles of physicalization design, aiming to transform complex data into tangible forms for effective communication of critical subjects, such as climate change. She has conducted empirical studies investigating the perception of and interaction with physicalizations [13, 16], as well as exploratory work in designing physical representations of personal activity data [12] and the climate impact of dietary choices [11]. Currently, her work revolves around incorporating multiple physical modalities in a single device to explore the potential utility and usability of force-based interactions in interactive displays.

Jason Alexander is a Professor of Human-Computer Interaction at the University of Bath, United Kingdom. His research develops novel interactive systems that straddle the physical-digital interface. 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 – and their application to data physicalization.

3 PRIOR RESEARCH

Our explorations of interactive systems transcending the digital-physical modality encompass the design, fabrication, evaluation, and conceptual understanding of these systems. Within the realm of physical computing and communication through physical artifacts, our projects span a wide range of themes:

(1) **Fundamental perceptual studies:** We have conducted foundational studies on how individuals perceive and interact with physical representations of information. Our research has investigated topics such as how people perceive [13], construct [14], and interact [5, 16] with physicalizations and cross-modal interactions between tactile and visual stimuli [18, 19] (see Figure 1A&B).
(2) **Conceptual discussions on physical computing:** Our research extends beyond empirical studies to include conceptual discussions on physical computing paradigms such as shape-changing interfaces and data physicalization. We have engaged in workshops, published articles, and contributed to ongoing debates surrounding the ecological implications of physical interfaces, the integration of physical and digital design elements, and the grand challenges facing research on shape-changing interfaces [1] and physicalization [15] (see Figure 1C).
(3) **Design and fabrication of interactive dynamic systems:** Our work also encompasses the practical aspects of designing and fabricating interactive systems with dynamic haptic outputs. For instance, characterizing various actuation techniques for generating movement in shape-changing interfaces [21] and designing and fabricating interactive systems such as LOOP [12], Econundrum [11], and EMERGE [20] (see Figure 1D, E, and F respectively). Our current work is looking into dynamic physical displays and how to design and sense across multiple physical dimensions.
(4) **Evaluating interactive systems for specific application areas:** Furthermore, we have conducted evaluations of interactive systems in real-world contexts, exploring their efficacy and user experience in specific application areas. For instance, design studies [20] and qualitative in-the-wild investigations [11, 12] (see Figure 1D–F).

4 CHALLENGES

Drawing from our prior experience and insights from related literature, we have identified several challenges in incorporating haptics into our current research practices:

- **Facilitating replication and accessibility:** One of the primary challenges we have encountered revolves around the replication of haptic interfaces. In our current project, we aim to develop a prototype that facilitates replication and the use of off-the-shelf actuators, which poses a significant challenge given the custom-made nature of many existing haptic systems. Despite recent efforts [e.g. 9, 17, 22], the lack of standardized tools or software for incorporating haptics into interactive prototypes not only complicates the implementation process but also hinders accessibility for laypeople seeking to engage with haptic technology.
- **Conceptual understanding of haptics:** Navigating the conceptual landscape of haptics presents another challenge. While recent efforts have been made to define and measure the Haptic Experience (HX) [2, 8, 10], establishing a comprehensive understanding of haptics and its application in interactive systems remains a complex task.
- **Translating haptics into meaning-making:** Building on the previous challenge, we are particularly interested in exploring how haptic parameters can contribute to meaning-making in information communication and data physicalization. By leveraging insights from studies on tactile perception and interaction [3, 4], we seek to understand how different haptic parameters can be utilized to convey nuanced encodings and facilitate user engagement.
- **Rethinking evaluation methods:** Traditional evaluation methods for interactive systems often focus on discrete states rather than the dynamic transitions between them [5, 20]. However, to fully utilize the abilities of haptic feedback, we acknowledge the importance of adopting stage-based evaluation approaches that capture the granularity of haptic parameters and their impact on user experiences. This shift in perspective allows for a more nuanced understanding of haptic interactions and opens avenues for designing more effective future interfaces.

We hope that discussing these challenges at the workshop will help to progress the field meaningfully forward, fostering collaboration and innovation to make haptics more accesible and inclusive across several discplines within HCI and beyond.

5 CONCLUSION

In this paper, we have provided a brief overview of our work and outlined the challenges and opportunities associated with integrating haptics into interactive systems. Participating in the workshop would offer a valuable opportunity to contribute transferable knowledge gained from our experiences in data physicalization and shape-changing interfaces. Furthermore, it provides a platform for gaining insights into the effective incorporation of haptics into future practices, fostering more accessible and inclusive haptic design across various fields.

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