Haptics as a sustainable proxy for exploring design variables for data physicalization

Christian Frisson* University of Calgary

Marcelo M. Wanderley† McGill University

Wesley Willett‡ University of Calgary

Sheelagh Carpendale§ University of Calgary

ABSTRACT

This workshop paper aims at bringing a new perspective to data physicalization by investigating how haptics can help designers explore design variables. We first introduce data physicalization and physical variables. We then delineate challenges in data physicalization: enabling granular data manipulation, reducing ideation waste. We cover emerging trends in haptics: accessible and modular devices; computable soft haptics materials; usable software frameworks. We propose opportunities in haptics for data physicalization: exploring physical data mappings with haptics; reducing ideation waste by haptic preprint.

Index Terms: Human-centered computing—Visualization—Visualization design and evaluation methods—Data Physicalization

1 INTRODUCTION

Data physicalization is a field that studies how data can be expressed in physical artifacts through encodings of material and geometrical properties. Jansen et al. recently compiled a list of opportunities and challenges for this practice [17]. They propose a research agenda that includes designing physical data representations, starting by charting the design space of physical variables. To come up with a unified design language for data physicalization, we believe that we first need to enable data physicalization designers to replicate artifacts. By replicating artifacts, designers empirically train themselves to map 1) descriptions of perceived variables (for instance verbal constructs) that they use for communicating among peers, to 2) perceptions that they obtain through their senses of touch and vision by manipulating such artifacts as individuals.

Physical variables are composed of haptic and visual variables, supporting the *look and feel* of data. Jansen et al. argue that it is important to study how visual and haptic variables can be combined in physicalizations [17]. Hogan et al. followed up by extending this combination with auditory feedback into a multisensory representation [14, 15]. Vision is certainly the human sense that received the most and earliest attention in the history of computerized systems (with communities such as computer graphics and visualization), followed by audition (with communities such as computer music, auditory displays) and later by the sense of touch decomposed into the *tactile-proprio-kinesthetic* senses (with communities such as haptics and more recently shape-changing interaction).

Visual variables have been studied by Bertin [5]. Mackinlay [20] and Carpendale [6] employed visual variables as a basis to describe graphical representations and to generate information visualizations.

*e-mail: christian@frisson.re
†e-mail: marcelo.wanderley@mcgill.ca
‡e-mail: wesley.willett@ucalgary.ca
§e-mail: sheelagh@ucalgary.ca

Haptic variables are employed in two research subcommunities that study haptic feedback: vibrotactile and force feedback. The first studies tactile properties perceived through the skin (*tactile*), the second complements it with the study of the perception through body mechanics (*proprioceptive*) and movement (*kinesthetic*). Though haptics is an active research field, the main outcomes of almost three decades of research are limited to cost-effective vibrotactile feedback (as in mobile phones) or expensive force-feedback devices (mainly for surgical operation simulation). Strohmeier and Hornbæk recently introduced tactile granularity variables (roughness, bumpiness, sharpness or adhesiveness) that they generate with audio signal variables (amplitude and timbre) to produce haptic textures [26].

The research community on shape-changing user interfaces proposes useful works that are instrumental for studying physical variables: Kim et al. propose an up-to-date taxonomy for reconfigurable user interfaces: Morphees+ [18]. Quamar et al. review shape-changing materials (such as auxetic materials) and discuss how these can support the engineering of applications in HCI [22].

2 CHALLENGES IN DATA PHYSICALIZATION DESIGN

We delineate two challenges in data physicalization: (1) enabling granular data manipulation; (2) reducing waste during ideation.

2.1 Enabling granular data manipulation

Willett, Jansen, and Dragicevic envisioned the concept of embedded or situated data representations [30]. In this concept, the display of data is situated near or directly embedded inside the source that generates data. We propose to extend this concept as follows: the manipulation of data with active (tactile-proprio-kinesthetic) feedback should be as granular as the visual display of data. An ideal example of granularity would be one haptic and visual representation per data point. Currently most systems enabling the direct manipulation of data are either granular but with passive feedback (multitouch user interfaces); or non-granular but with active feedback (haptic user interfaces with a single pointer or effector).

We need to find technologies that enable a manipulation of data physicalizations with granular haptic and visual feedback.

2.2 Reducing waste during ideation

The ideation and fabrication of data physicalization artifacts can be digital, manual, or mixed. This is comparable with choosing to sketch digitally or on paper. Several fabrication techniques can be employed and the choice of materials directly impacts sustainability in terms of the amount of waste produced. Traditional stiff 3d printed parts are usually made of Poly-Lactic Acid (PLA) plastic, *a biodegradable and bioactive thermoplastic aliphatic polyester derived from renewable resources, such as corn starch* (`https://en.wikipedia.org/wiki/Polylactic_acid`) and laser-cut parts are usually made of acrylic. Silicon is usually favored to 3d print softer materials.

We need to ensure that materials used for ideating data physicalizations are sustainable, recyclable. We need to find a proxy for simulating the feeling of the design space of such materials while ideating data physicalizations.

3 Emerging trends in haptics

We cover three emerging trends in haptics: (1) accessible and modular devices; (2) computable soft haptics materials; (3) usable software frameworks.

3.1 Accessible and modular devices

A decade ago, O'Malley and Gupta listed the following future trends: Haptic devices would gain greater accessibility in commercial applications. Data visualization would be improved by use of haptic displays that enable increased channels of information conveyance to the user [21].

Currently, mostly all smartphones or game pads provide basic vibrotactile feedback. There are lots of force-feedback haptic devices, but few are cheap, accessible, modular and opensource. An overview of existing force-feedback devices is offered by Haptipedia [24].

However, the new opensource Haply platform [9] enables designers to modularly create devices with up to 4 Degree(s) Of Freedom (DOFs), and is to our knowledge the only toolkit still available today and affording such a modularity. Other opensource projects not yet featured in Haptipedia are: the FireFader [3] offering a 1-DOF linear slider and WoodenHaptics [31] offering a 3-DOF serial device with a pen-like manipulator.

Usual "stiff" force-feedback devices usually feature up to 6 DOFs. Florens et al. pushed this boundary with their Ergos panoply customizing the amount of slices [11]. Recent advances in soft robotics offer opportunities to develop soft haptics applications with greater degrees of freedom.

3.2 Computable soft haptics materials

Bret Victor's research agenda poster [29] features visions among which one foresees how shape-changing user interfaces can support humans in thinking by manipulating dynamic objects. Alexander et al. recently defined the challenges of shape-changing interfaces [1]. They call for inspiration from soft robotics, with initiatives such as the IROS 2018 Workshop on Shape Changing Robotic Structures and Interfaces (`http://iros2018.softhaptics.website/`). The soft robotics community studies and produces complex deformable structures inspired by organic materials, with lower manufacturing costs and material weight.

Soft haptics interaction applications are emerging (for instance by Largillière et al. [19]). Authoring tools such as the Soft Robotics plugin by Coevoet et al. [7] for the open-source platform for physics-based simulation SOFA by Faure et al. [10] are however still currently targeted to expert users. Existing toolkits for pneumatic [12] or hydraulic [13] applications that could enable soft haptics are either unavailable for sale or still hard to replicate. The Fluidic Control Board Kit by Holland et al. [16] is opensource but available for sale only in the US (`https://softroboticstoolkit.com/paradox-robotics`).

3.3 Usable authoring tools

According to a survey [23], confirmed hapticians tend to favor C/C++ frameworks such as Chai3d [8].These software frameworks offer comprehensive haptics and physics simulation capabilities, however require expert engineering and software development skills.

To design the new generation of authoring tools for data physicalization, we propose to seek inspiration from tools for authoring haptic feedback coupled it together with sound synthesis. DIMPLE by Sinclair and Wanderley [25] integrated the Chai3d haptics framework with the PureData visual programming environment for audio dataflows so that haptic scenes can be procedurally generated and coupled with sound synthesis. The Synth-A-Modeler Compiler and Designer by Berdahl and Smith III [4] had its visual programming canvas resemble electronics schematics and mechanical diagrams.

4 Opportunities in haptics for data physicalization

We propose two opportunities in haptics for data physicalization: (1) exploring physical data mappings with haptics; (2) reducing ideation waste by haptic preprint.

4.1 Explore physical data mappings with haptics

One opportunity for data physicalization is to investigate how the design space of physical data mappings could be explored. We argue that haptics would enable designers to feel physical data mappings, by designing the right authoring tools.

Bret Victor envisioned the concept of explorable explanations in his talks [28] and research agenda poster [29]. A related community develops authoring tools for creating explorable explanations (`http://explorabl.es/tools/`). One of its principles is to explain facts supported by data rather than by words, and to improve understanding by having readers directly manipulate data when browsing the explanations. We propose to extend this concept to the manual exploration of data physicalizations.

4.2 Reduce ideation waste by haptic preprint

As second opportunity, we foresee haptic devices as tools to support proofreading data physicalizations before fabrication. This shares similar goals with preprint software for paper printing, for example tools that overlay all pages of a document with transparency to visually check if margins are the same, instead of noticing such errors after printing.

HapticPrint [27] adds tactility, flexibility, and weight to objects through two tools. Its first tool maps textures and UI elements onto arbitrary shapes. Its second tool modifies the internal geometry of models to affect compliance and weight characteristics. Inserting a supplementary step in the HapticPrint [27] workflow would allow designers to feel textures using haptic devices, before 3d printing.

To assess the sustainability of such a solution, we still need to address which device between a haptics device or a 3d printer would consume less energy [2].

5 Conclusion

In this workshop paper, we brought a new perspective to data physicalization by investigating how haptics can help designers explore design variables. We delineated challenges in data physicalization: enabling granular data manipulation, reducing ideation waste. We covered emerging trends in haptics: accessible and modular devices; computable soft haptics materials; usable software frameworks. We proposec opportunities in haptics for data physicalization: exploring physical data mappings with haptics; reducing ideation waste by haptic preprint.

Acknowledgments

Christian Frisson's current postdoctoral fellowship is funded through a project with the National Energy Board (NEB) of Canada (`http://ilab.cpsc.ucalgary.ca/energyvis/`).

Christian Frisson thanks Colin Gallacher from Haply Robotics Inc. for their insightful discussions about modular haptics hardware toolkits and future opportunities.

References

[1] J. Alexander, A. Roudaut, J. Steimle, K. Hornbæk, M. Bruns Alonso, S. Follmer, and T. Merritt. Grand Challenges in Shape-Changing Interface Research. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, CHI '18. ACM, 2018. doi: 10.1145/3173574.3173873

[2] O. Bates, M. Hazas, A. Friday, J. Morley, and A. K. Clear. Towards an Holistic View of the Energy and Environmental Impacts of Domestic Media and IT. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '14. ACM, 2014. doi: 10.1145/2556288.2556968

[3] E. Berdahl and A. Kontogeorgakopoulos. The FireFader: Simple, Open-Source, and Reconfigurable Haptic Force Feedback for Musicians. *Computer Music Journal*, 37(1), Mar. 2013. doi: 10.1162/COMJ_a_00166

[4] E. Berdahl and J. O. Smith III. An Introduction to the Synth-A-Modeler Compiler: Modular and Open-Source Sound Synthesis using Physical Models. In *Proceedings of the Linux Audio Conference*, 2012.

[5] J. Bertin. *Smiologie Graphique. Les diagrammes, les rseaux, les cartes.* Gauthier-Villars, 1967.

[6] M. S. T. Carpendale. Considering Visual Variables as a Basis for Information Visualisation. Jan. 2003. doi: 10.5072/PRISM/30495

[7] E. Coevoet, T. Morales-Bieze, F. Largilliere, Z. Zhang, M. Thieffry, M. Sanz-Lopez, B. Carrez, D. Marchal, O. Goury, J. Dequidt, and C. Duriez. Software toolkit for modeling, simulation and control of soft robots. *Advanced Robotics*, Nov. 2017.

[8] F. Conti, F. Barbagli, R. Balaniuk, M. Halg, C. Lu, D. Morris, L. Sentis, J. Warren, O. Khatib, and K. Salisbury. The CHAI libraries. In *Proceedings of Eurohaptics 2003*, 2003.

[9] S. Ding and C. Gallacher. The Haply Development Platform: A Modular and Open-Sourced Entry Level Haptic Toolset. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*, CHI EA '18. ACM, 2018. doi: 10.1145/3170427.3186512

[10] F. Faure, C. Duriez, H. Delingette, J. Allard, B. Gilles, S. Marchesseau, H. Talbot, H. Courtecuisse, G. Bousquet, I. Peterlik, and S. Cotin. *SOFA: A Multi-Model Framework for Interactive Physical Simulation*, vol. 11. Springer, June 2012. doi: 10.1007/8415_2012_125

[11] J.-L. Florens, A. Luciani, C. Cadoz, and N. Castagn. ERGOS: Multi-degrees of Freedom and Versatile Force-Feedback Panoply. In *Euro-Haptics 2004*, Proceedings of EuroHaptics 2004, June 2004.

[12] K. Gohlke. Exploring Bio-Inspired Soft Fluidic Actuators and Sensors for the Design of Shape Changing Tangible User Interfaces. In *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction*, TEI '17. ACM, 2017. doi: 10.1145/3024969.3025039

[13] K. Gohlke, E. Hornecker, and W. Sattler. Pneumatibles: Exploring Soft Robotic Actuators for the Design of User Interfaces with Pneumotactile Feedback. In *Proceedings of the TEI '16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction*, TEI '16. ACM, 2016. doi: 10.1145/2839462.2839489

[14] T. Hogan, U. Hinrichs, and E. Hornecker. The Visual and Beyond: Characterizing Experiences with Auditory, Haptic and Visual Data Representations. In *Proceedings of the 2017 Conference on Designing Interactive Systems*, DIS '17. ACM, 2017. doi: 10.1145/3064663.3064702

[15] T. Hogan and E. Hornecker. Towards a Design Space for Multisensory Data Representation. *Interacting with Computers*, 29(2), Mar. 2017. doi: 10.1093/iwc/iww015

[16] D. P. Holland, C. Abah, M. Velasco-Enriquez, M. Herman, G. J. Bennett, E. A. Vela, and C. J. Walsh. The Soft Robotics Toolkit: Strategies for Overcoming Obstacles to the Wide Dissemination of Soft-Robotic Hardware. *IEEE Robotics Automation Magazine*, 24(1), Mar. 2017. doi: 10.1109/MRA.2016.2639067

[17] Y. Jansen, P. Dragicevic, P. Isenberg, J. Alexander, A. Karnik, J. Kildal, S. Subramanian, and K. Hornbæk. Opportunities and Challenges for Data Physicalization. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, CHI '15. ACM, 2015. doi: 10.1145/2702123.2702180

[18] H. Kim, C. Coutrix, and A. Roudaut. Morphees+: Studying Everyday Reconfigurable Objects for the Design and Taxonomy of Reconfigurable UIs. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, CHI '18. ACM, 2018. doi: 10.1145/3173574.3174193

[19] F. Largillière, E. Coevoet, M. Sanz-Lopez, L. Grisoni, and C. Duriez. Stiffness rendering on soft tangible devices controlled through inverse FEM simulation. In *2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Oct. 2016. doi: 10.1109/IROS.2016.7759768

[20] J. Mackinlay. Automating the Design of Graphical Presentations of Relational Information. *ACM Trans. Graph.*, 5(2), Apr. 1986. doi: 10.1145/22949.22950

[21] M. K. OMalley and A. Gupta. Haptic Interfaces. In P. Kortum, ed., *HCI beyond the GUI: design for haptic, speech, olfactory and other nontraditional interfaces*, The Morgan Kaufmann series in interactive technologies. Elsevier/Morgan Kaufmann, 2008.

[22] I. P. S. Qamar, R. Groh, D. Holman, and A. Roudaut. HCI Meets Material Science: A Literature Review of Morphing Materials for the Design of Shape-Changing Interfaces. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, CHI '18. ACM, 2018. doi: 10.1145/3173574.3173948

[23] O. Schneider, K. MacLean, C. Swindells, and K. Booth. Haptic experience design: What hapticians do and where they need help. *International Journal of Human-Computer Studies*, 107, Nov. 2017. doi: 10.1016/j.ijhcs.2017.04.004

[24] H. Seifi, K. E. MacLean, K. J. Kuchenbecker, and G. Park. Haptipedia: An Expert-Sourced Interactive Device Visualization for Haptic Designers. In *Haptics Symposium, Works in Progress*, HAPTICS. IEEE, 2018.

[25] S. Sinclair and M. M. Wanderley. A run-time programmable simulator to enable multi-modal interaction with rigid-body systems. *Interacting with Computers*, 21(1-2), Jan. 2009. doi: 10.1016/j.intcom.2008.10.012

[26] P. Strohmeier and K. Hornbæk. Generating Haptic Textures with a Vibrotactile Actuator. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, CHI '17. ACM, 2017. doi: 10.1145/3025453.3025812

[27] C. Torres, T. Campbell, N. Kumar, and E. Paulos. HapticPrint: Designing Feel Aesthetics for Digital Fabrication. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology*, UIST '15. ACM, 2015. doi: 10.1145/2807442.2807492

[28] B. Victor. Humane Representation of Thought: A Trail Map for the 21st Century. In *Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology*, UIST '14. ACM, 2014. doi: 10.1145/2642918.2642920

[29] B. Victor. Research Agenda and Former Floor Plan. Technical Report v0.19, Communications Design Group, 2014.

[30] W. Willett, Y. Jansen, and P. Dragicevic. Embedded Data Representations. *IEEE Transactions on Visualization and Computer Graphics*, 23(1), Jan. 2017. doi: 10.1109/TVCG.2016.2598608

[31] M. C. Yip and J. Forsslund. Spurring Innovation in Spatial Haptics: How Open-Source Hardware Can Turn Creativity Loose. *IEEE Robotics Automation Magazine*, 24(1), Mar. 2017. doi: 10.1109/MRA.2016.2646748