Exploring Data Agency: Autonomous Agents as Embodied Data Visualizations

Sarah Schömbs* Jorge Goncalves† Wafa Johal‡

The University of Melbourne

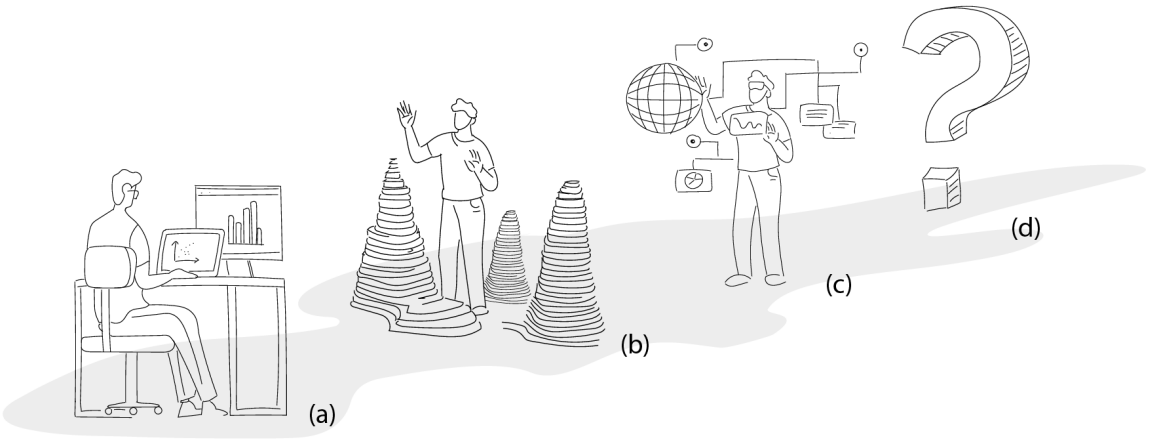

Figure 1: (a) 2D data visualization, (b) tangible physicalizations exemplified by data sculptures, (c) immersive data visualizations that can be experienced and manipulated. (d) We envision *Data Agency* as a result of increasingly tangible and immersive visualizations, however it is up to future research to inform guidelines and investigate a potential *Data-Agent Interplay*.

ABSTRACT

In the light of recent advances in embodied data visualizations, we aim to shed light on agency in the context of data visualization. To do so, we introduce *Data Agency* and *Data-Agent Interplay* as potential terms and research focus. Furthermore, we exemplify the former using Human-Robot Interaction, and identify future challenges and research questions.

Index Terms: Human-centered computing—Data visualization—Visualization techniques—Agency; Human-robot interaction—Visualization—Agency

1 INTRODUCTION

Autonomous agents are computational entities or systems that operates independently and exhibits a degree of autonomy in decision-making and behaviour. They can be a software or hardware system that can perceive its environment, make decisions, and take actions to achieve specific goals or objectives without constant human intervention. Examples of autonomous agents are now find in our everyday life in the form of robots such as autonomous vehicle, or online agents such as chatbots. These agents collect and generate a large amount of data, often aggregated and used for their decision making.

Over the past decade, the data visualization community has explored various means and ways to map and visualize data. Doing so, data visualizations have gone beyond the traditional 2D graphical user interface and entered the real-world to help people explore and understand data more easily, see Fig. 1. With the rise of tangible, immersive and embodied data visualizations, we encourage future research to look at the *Data-Agent Interplay* and *Data Agency* based on two reasons: (1) It is necessary to investigate and acknowledge potential interaction effects and perceptual changes due to the fact that data is embodied and visualized through an agent. This *Data-Agent interplay* might become particularly important when we look at research areas such as human-robot interaction (HRI). (2) If agency is defined by an increase in interactivity, autonomy, and adaptability [4] then data visualizations supporting those criteria might be perceived as an agent itself, which we define as *Data Agency*.

*e-mail: sschombs@student.unimelb.edu.au

†e-mail: jorge.goncalves@unimelb.edu.au

‡e-mail: wafa.johal@unimelb.edu.au

2 RELATED WORK

2.1 Data Physicalization

Data physicalization is a research area that investigates physical representations of data, bridging data visualization, tangible user interaction, and design. In brief, *physicalizations* are shapes or forms which convey data with the aim to facilitate data exploration and analysis. Jansen et al. [6] defined data physicalizations as "physical artifact[s] whose geometry or material properties encode data", earlier referred to as "beyond-desktop visualization systems" [5]. In contrary to immersive visualizations, physical artifacts are typically mapped physically into the real-world to enrich their perception and support their manipulation [5]. To illustrate, data physicalizations vary from data sculptures [15], physically dynamic bar charts [12], to physicalizations based on kirigami, a traditional Japanese art form, to explore paper-cutting to map variables [2].

2.2 Immersive Data Visualization

As a domain-overlapping application, immersive technologies including augmented reality (AR) and virtual reality (VR) have en-

abled users to experience data away from conventional flat screens, moving towards situ, embedded and on-the-fly experiences. To illustrate, Whitlock et al. [13] investigated situated AR visualizations to enhance the collection of field data and to improve user's situation awareness on site. The authors explored immersive and field embedded scatterplots to compare new data to archival data and to display gaps in data coverage. Others have recently investigated how to visualize immersive gesture data to support data exploration [7] or how to combine physical, tangible input with virtual visualisation in the context of geospatial data [11].

2.3 Embodiment

In the area of data physicalization, embodiment refers to the mapping of abstract data to physical representations. To do so, metaphors oftentimes serve as translators to make abstract data tangible, understandable and directly interactable [15]. Hence, users are usually able to touch or walk through the visualized data. In the context of immersive data, embodiment is described as "the mapping of data artifacts to 3D virtual constructs that users can directly manipulate, examine, and rearrange" [14]. Thus, embodiment in an immersive context interestingly emphasizes the user's interaction with the visualized data.

3 Problem Definition

3.1 Data Visualization in HRI

Data visualizations are becoming more and more experienceable through both touch and interaction. However, no prior research has investigated how data representations might affect the user's perception and interaction due to agency. The latter becomes particularly interesting when we look at other research domains including HRI. Research in HRI is beginning to increasingly examine data visualizations to enhance a robot's safety [8], to display sensor data [1] or to convey perception results to support a robot's explainability [3]. However, contrary to data sculptures or shape-changing bar charts, robots are perceived as agents as a consequence of their autonomy, interactivity and adaptability [4].

3.2 Data-Agent Interplay and Data Agency

We therefore introduce the term *Data-Agent Interplay*, which is inspired by Satriadi et al. [11], and describes potential interaction effects and perceptual changes of (a) the visualized data due to the robot and (b) the robot due to the visualized data.

Early research by Nass et al. [9] already showed that we perceive computers not only as tools or machines, but also as social actors. Today's research on anthropomorphism indicates that a robot's appearance, motion or behaviour affects the user likeability, acceptance, trust and whether or not users perceive a robot as intelligent [10]. This change in perception and attitude towards robots raises several questions when it comes to data being embodied and conveyed by a a robot, e.g.: If data is being embodied and conveyed by a robot, how does its agency affect the interaction, user's perception and attitude towards the conveyed data? For instance, how does a robot's agency influence the user's trust in data? In line with previous research in data visualization, the latter additionally raises the question of how to map data onto a robot's output parameters, e.g. light, vibration, or motion. On the other hand, we also asked ourselves how data visualizations might change the perception of and interaction with a robot (e.g. whether they enhance the robot's explainability, highlight its functionality or disguise its true purpose).

Moreover, the question of data agency goes beyond the human-robot interaction scope. It is arguable that agency does not have to involve actual agency, but can be ascribed, thus perceived [4]. Hence, if data is being visualized and embodied with an increasing autonomy, interactivity and adaptability - will that data be perceived as an agent itself? If this assumption confirms to be true, it is up to future research to inform design guidelines on how *Data Agency* might look like in the future.

4 Conclusion

The aim of this poster paper is to bring together the Information Visualization community and the Human-Robot Interaction community, to initiate a discussion in regard to *Data Agency* and the *Data-Agent Interplay* and to propose both as a potential focus of multidisciplinary research. Furthermore, we identified several research questions that could be addressed to explore agency in the context of data visualizations. To simplify, we exemplified agents as robots. However, it is important to highlight that *Data-Agent Interplay* is not solely reduced to robots and can be expand to all sorts of agents, e.g. automated systems.

Acknowledgments

We wish to acknowledge the contribution of the Melbourne Research Scholarship funded by the University of Melbourne. This research is partially supported by the Australian Research Council Discovery Early Career Research Award (Grant No. DE210100858). Further, we wish to thank Samangi Arachchi for her help with the visualizations.

References

[1] A. Cleaver, M. Faizan, H. Amel, E. Short, and J. Sinapov. SENSAR: A visual tool for intelligent robots for collaborative human-robot interaction. *CoRR*, abs/2011.04515, 2020.

[2] F. Daneshzand, C. Perin, and S. Carpendale. Kiriphys: Exploring new data physicalization opportunities. *IEEE Transactions on Visualization and Computer Graphics*, 29(1):225–235, 2023. doi: 10.1109/TVCG.2022.3209365

[3] Z. Han, A. Wilkinson, J. Parrillo, J. Allspaw, and H. A. Yanco. Projection mapping implementation: Enabling direct externalization of perception results and action intent to improve robot explainability. *CoRR*, abs/2010.02263, 2020.

[4] R. B. Jackson and T. Williams. A theory of social agency for human-robot interaction. *Frontiers in Robotics and AI*, 8, 2021. doi: 10.3389/frobt.2021.687726

[5] Y. Jansen and P. Dragicevic. An interaction model for visualizations beyond the desktop. *IEEE Transactions on Visualization and Computer Graphics*, 19(12):2396–2405, 2013. doi: 10.1109/TVCG.2013.134

[6] 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, p. 3227–3236. Association for Computing Machinery, New York, NY, USA, 2015. doi: 10.1145/2702123.2702180

[7] A. Li, J. Liu, M. Cordeil, J. Topliss, T. Piumsomboon, and B. Ens. Gestureexplorer: Immersive visualisation and exploration of gesture data. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, CHI '23. Association for Computing Machinery, New York, NY, USA, 2023. doi: 10.1145/3544548.3580678

[8] Z. Makhataeva, A. Zhakatayev, and H. A. Varol. Safety aura visualization for variable impedance actuated robots. In *2019 IEEE/SICE International Symposium on System Integration (SII)*, pp. 805–810, 2019. doi: 10.1109/SII.2019.8700332

[9] C. Nass, J. Steuer, and E. R. Tauber. Computers are social actors. In *Conference Companion on Human Factors in Computing Systems*, CHI '94, p. 204. Association for Computing Machinery, New York, NY, USA, 1994. doi: 10.1145/259963.260288

[10] E. Roesler, D. Manzey, and L. Onnasch. A meta-analysis on the effectiveness of anthropomorphism in human-robot interaction. *Science Robotics*, 6(58):eabj5425, 2021. doi: 10.1126/scirobotics.abj5425

[11] K. A. Satriadi, J. Smiley, B. Ens, M. Cordeil, T. Czauderna, B. Lee, Y. Yang, T. Dwyer, and B. Jenny. Tangible globes for data visualisation in augmented reality. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*, CHI '22. Association for

Computing Machinery, New York, NY, USA, 2022. doi: 10.1145/3491102.3517715

[12] F. Taher, Y. Jansen, J. Woodruff, J. Hardy, K. Hornbæk, and J. Alexander. Investigating the use of a dynamic physical bar chart for data exploration and presentation. *IEEE Transactions on Visualization and Computer Graphics*, 23(1):451–460, 2017. doi: 10.1109/TVCG.2016.2598498

[13] M. Whitlock, K. Wu, and D. A. Szafir. Designing for mobile and immersive visual analytics in the field. *IEEE Transactions on Visualization and Computer Graphics*, 26(1):503–513, 2020. doi: 10.1109/TVCG.2019.2934282

[14] Y. Zhang. [dc] supporting embodied sensemaking in immersive environment. In *2023 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*, pp. 981–982, 2023. doi: 10.1109/VRW58643.2023.00333

[15] J. Zhao and A. V. Moere. Embodiment in data sculpture: A model of the physical visualization of information. In *Proceedings of the 3rd International Conference on Digital Interactive Media in Entertainment and Arts*, DIMEA '08, p. 343–350. Association for Computing Machinery, New York, NY, USA, 2008. doi: 10.1145/1413634.1413696