Towards a systematic review of embodied interaction in empirical studies

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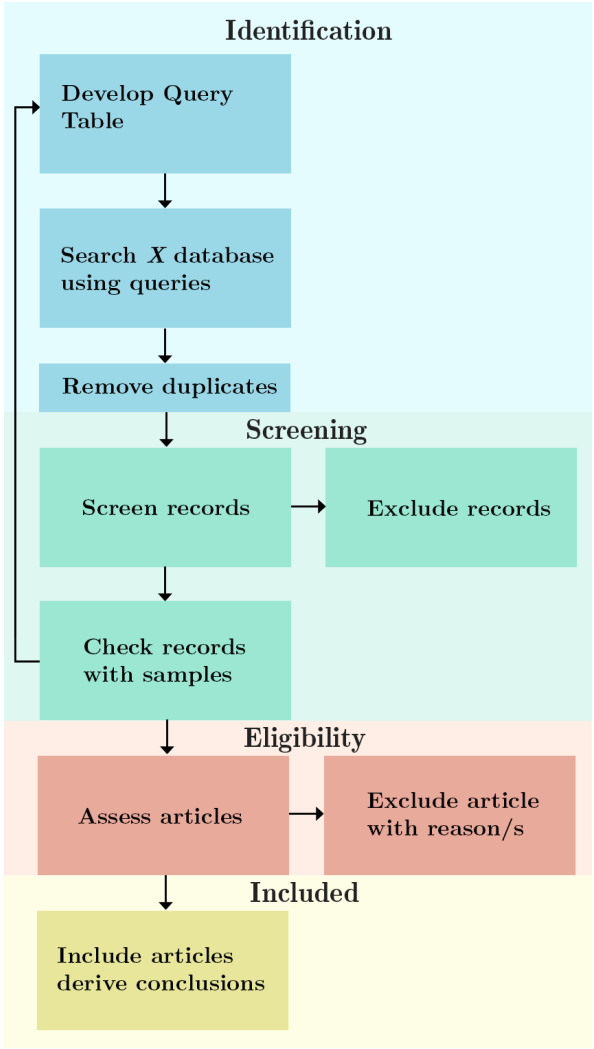

Figure 1: Flowchart of our methodology.

ABSTRACT

Researchers in the field of data visualisation have for some time been interested in spatial interactions with visualisations, afforded by large-screen touch interaction, advances in motion capture technologies, and commodity immersive headset displays. Many studies from the visualisation literature have investigated various designs for such "embodied" interaction with data, and there seems to be a tacit acknowledgement that there may be advantages over more traditional indirect interaction, for example, using a mouse. There is also much known in the Psychology research communities about spatial perception and cognition through direct testing of human ability. Loosely speaking, these can be considered, respectively, top-down research, from data visualisation systems to infer effectiveness of spatial interaction to support analysis tasks, versus, bottom-up research to infer a model of human spatial performance. We propose to begin to bridge this gap through a thorough survey of literature across both topics, with a view to inspiring future studies of embodied data interaction that is properly informed by the current state of the research landscape. This paper describes this work in progress, with a focus on the scope of our literature survey in terms of sources and topics.

CCS CONCEPTS

• **Human-centered computing**; • **Interaction design** → *Interaction design theory, concepts and paradigms*;

KEYWORDS

embodiment, immersive analytics, spatial memory, visualization, kinaesthesia

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INTRODUCTION

Paul Dourish [6] defines *embodiment* as "the property of being manifest in and as part of the world". Subsequently, Dourish associates *embodiment* with *phenomenology* which concerns "our experiences as embodied actors interacting in the world, participating in it and acting through it". In the context of human computer interaction (HCI), our interest in *embodied interaction* concerns our experiences as "embodied actors" interacting with computers. Subsequently, using our physical environment and motor functions to interact directly, or passively with computers. Our interest is how *embodied interaction* can support our interactions with computers as we head into the "beyond the desktop" era.

main terms	study term
spatial interaction	experiment
embodied interaction	subjects
spatial memory	participants
visio-spatial memory	study
kinaesthesi?	
kin?sth*	
embod*	
spatial interface	
immersive analytics	
situated analytics	
embedded visualisation	
situated visualisation	

Figure 2: Initial keyword selection, by the main terms × study term as separate queries.

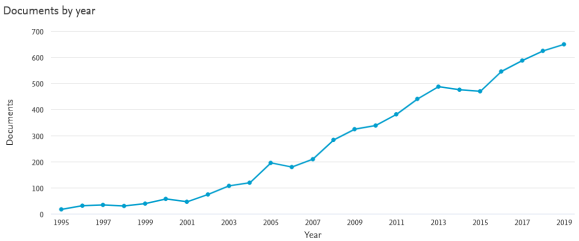

Figure 3: Use of keywords *embodied* and *interaction* in combination over time.

For example, the benefits of users interacting with virtual content in physical spaces using their arms and muscles in contrast to using a mouse and a keyboard. In addition, we need to understand and come to a consensus on how the term embodied interaction should be used in HCI, since the term is becoming fairly widely applied as seen in Figure 3. Furthermore, aspects of embodied interaction are prevalent in many other research areas such as spatial interaction and immersive analytics. Spatial interaction [9], however, concerns "any movement of people, goods, or information over space that results from a decision-making process" and does not encompass the entirety of embodied interaction. Similarly, immersive analytics [16] concerns "the use of engaging, embodied analysis tools to support data understanding and decision making" which is overarchingly more concerned with the application of immersive technologies, but less with the phenomenology of embodiment. Many studies and applications have elements of embodied interaction in a broad range of areas.

For example, in works such as IATK, Cordeil et al. [5] utilise handheld controllers for interactive authoring and exploration of multiple views of visualizations. Liu et al. [15] design several interaction techniques to explore and analyze 3D small multiples data visualizations in a virtual environment. Other interaction techniques such as eye-tracking and hand gestures are also likely to be within the umbrella of embodied interaction. Tonkin et al. [19] compare consumers' visual behaviour and argue a difference in visual search performance between a physical store and a virtual shopping environment. Uddin et al. [20] and Fruchard et al. [10] present works by introducing hand gestures and on-body interaction for command selection in a spatial context.

Research has also investigated the effect of physical navigation within virtual environments. Lages and Bowman [13] compared walking with manipulation for an examination of 3D scientific data. The result suggests that VR application designers should consider both controller experience and the spatial ability of the target users. Ball et al. [2] state that increasing physical navigation on larger displays can improve user performance. Embodied Interactions are also prevalent in the geo-visualization field. Gardony et al. [11] presented an empirical investigation in an AR system for virtual navigation. They suggest that task-relevant static views are beneficial to 3D geo-visualization performance and spatial memory. They also offer implications for interactive 3D geo-visualization and navigation-assistive AR application design. In the Psychology field, embodiment is examined together with spatial perception and cognition, such as spatial awareness [3, 8, 14], spatial memory [4, 12, 18] and kinesthesia [1, 7].

Whilst fields such as immersive analytics and situated analytics has been defined very clearly in literature, and its often noted where its been applied, applications of embodied interaction are sparse and undefined. Our goal is systematically survey past literature to find past examples of applications of embodied interaction in HCI, subsequently *conscious* and *unconscious* applications. In addition, empirical examples of how embodied interaction helped sense-making and problem solving in preexisting "beyond the desktop" applications and studies. By producing a comprehensive overview of embodied interaction, we wish to provide researchers and designers directions for implementing

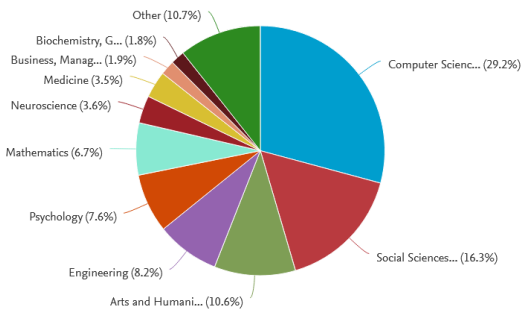

Figure 4: Use of keywords *embodied* and *interaction* in combination by subject area.

[1]https://www.scopus.com

the principles of embodied interaction based on what has been shown to be effective in the literature. Specifically, to guide domains such as Immersive Analytics that rely heavily on embodied interaction principles. Subsequently, precedents to what has already been done, and what gaps exist in future work. From this article, we present our initial methodology towards surveying the literature, our preliminary results, and future directions.

SYSTEMATIC REVIEW METHODOLOGY

Our methodology for conducting the systematic review is influenced by the PRISMA [17] approach which has widely been adopted in medicine, psychology, and social sciences. We have not seen PRISMA adopted widely in computer science, but acknowledge other surveys in the field likely follow a similar outline. Our outline follows the PRISMA approach by splitting our workflow into four steps: *identifcation*, *screening*, *eligibility*, and *included* (see Figure 1).

The purpose of the *identification* step is to produce a set of potentially relevant articles to the topic of interest. Using the SCOPUS[1] academic search engine, we ran a set of queries based on keywords that we believed would return results relevant to embodied interaction. Recognising that relevant articles may not necessarily use the term "embodied interaction", we constructed queries made up of a "main" term (to capture our topic of interest) and a "study" term (to capture records with evaluations, see Figure 2). Our main terms consisted of keywords that often coincided with examples of embodied interaction such as *immersive analytics* and *spatial interaction*. The study terms consisted of keywords used often in empirical studies including *experiment*, *subjects*, *participants* and *study*. After building a query table with the main terms and study terms, we produced a set of queries by crossing the main terms with study terms. This created 48 individual queries (12×4) that we used in SCOPUS, which produced 48 comma-separated files from and combined into one document with every record that matched our keywords. Following this, duplicates were removed based on the title of the paper.

Our next step *screening*, involved excluding records based on our own exclusion criteria. In contrast to subsequent steps, screening only takes the record into consideration, i.e (title, abstract, source title), and not the full text itself. Records were excluded based on the following criteria: (1) if the record *is not* a conference paper or article, and (2) *is not* related or connected to embodied interaction in a meaningful way. Firstly, we filtered out records that were not marked as conference papers and articles. Subsequently, we excluded records that appeared to have to have no connection to embodied interaction based on the title, abstract, and source title. Initial exclusion marking was divided evenly by six authors, with two reviewers marking the same paper. Reviewers would mark a record as *OT* if the record was off-topic, *R* if the record appeared to be relevant, and a dash "-" if the reviewer was undecided. Following this, articles were excluded from our records if both reviewers marked the *OT*. Before moving to the next step, we ensured that the records contained papers from a sample we

considered to fit the criteria we were looking for. In the case that not enough of the sample existed in our obtained records, we would have to rethink our search terms.

In succession is *eligibility*, which involves assigning reviewers evenly to articles to read the full text of each record. From here, reviewers needed to determine if the paper provided insight or evidence for embodied interaction to contribute to our survey. Finally in the *included* step, we would report our findings to derive conclusions. In addition, potential meta-analysis on our selection of articles.

PRELIMINARY RESULTS

From the initial main terms and study terms, after excluding duplicates and undesired document types, we obtained 1,415 records. After completing the screening phase, we obtained 452 records. The majority of records that we excluded were from domains outside of computer science due to being off-topic (see Figure 4). However, we did find records within subject areas such as neuroscience, multimedia, and anthropology that we marked as relevant or undecided. However, our initial results lacked papers from our sample set, with 0 out of 48 papers not appearing in our records. Identifying this problem, we decided to re-evaluate our search terms, since exploring outside of HCI appeared to be too extensive. We added an additional column to our query table emphasizing source title, and formulated a term based on the source title from our sample records. Our source term function became "SRCTITLE(embod* OR reality OR (human AND comput*) OR (us*) OR (visual*))" such that we obtained sources involving HCI, usability, visualisation, embodiment, or virtual/augmented reality. After going back to our identification step, and repeating screening we obtained 2,517 results. Subsequently, the sources obtained appeared to be more relevant to embodied interaction, with 19 out of 48 (39.58%) of papers from our sample set within the obtained records. In contrast to our original query, most of the records we obtained were from within computer science, with some records appearing from psychology.

FUTURE WORK AND DISCUSSION

Looking forward, our next step is to try to maximise the amount of samples that appear in our obtained records by potentially modifying our keywords further. In addition, we wish to formulate more source terms to broaden our search to include more sample papers from psychology. Furthermore, to head into *eligibility* and *included* stages to summarise the papers we found and report our findings. Subsequently, we need to clearly empirically define *embodied interaction* in context to current "beyond-the-desktop" literature. For example, what are the properties in a "beyond-the-desktop" application or study that make it applicable to *embodied interaction* based on how literature currently uses terms such as *embodied* and *embodiment*. In addition, are there properties outside of spatial perception and kinaesthesia that also exist within the umbrella of embodied interaction present in HCI.

REFERENCES

[1] Ravin Balakrishnan and Ken Hinckley. 1999. The Role of Kinesthetic Reference Frames in Two-Handed Input Performance. In *Proceedings of the 12th Annual ACM Symposium on User Interface Software and Technology* (Asheville, North Carolina, USA) *(UIST '99)*. Association for Computing Machinery, New York, NY, USA, 171–178. https://doi.org/10.1145/320719.322599

[2] Robert Ball, Chris North, Chris North, and Doug A. Bowman. 2007. Move to Improve: Promoting Physical Navigation to Increase User Performance with Large Displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '07)*. ACM, New York, NY, USA, 191–200. https://doi.org/10.1145/1240624.1240656

[3] Jessica Cauchard, Markus Löchtefeld, Mike Fraser, Antonio Krüger, and Sriram Subramanian. 2012. M+pSpaces: Virtual Workspaces in the Spatially-Aware Mobile Environment. In *Proceedings of the 14th International Conference on Human-Computer Interaction with Mobile Devices and Services* (San Francisco, California, USA) *(MobileHCI '12)*. Association for Computing Machinery, New York, NY, USA, 171–180. https://doi.org/10.1145/2371574.2371601

[4] Andy Cockburn and Bruce McKenzie. 2002. Evaluating the Effectiveness of Spatial Memory in 2D and 3D Physical and Virtual Environments. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Minneapolis, Minnesota, USA) *(CHI '02)*. Association for Computing Machinery, New York, NY, USA, 203–210. https://doi.org/10.1145/503376.503413

[5] M. Cordeil, A. Cunningham, B. Bach, C. Hurter, B. H. Thomas, K. Marriott, and T. Dwyer. 2019. IATK: An Immersive Analytics Toolkit. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, Osaka, Japan, Japan, 200–209. https://doi.org/10.1109/VR.2019.8797978

[6] Paul Dourish. 2001. *Where the Action Is: The Foundations of Embodied Interaction*. –256.

[7] Achim Ebert, Matthias Deller, Daniel Steffen, and Matthias Heintz. 2009. "Where Did I Put That?" — Effectiveness of Kinesthetic Memory in Immersive Virtual Environments. In *Proceedings of the 5th International Conference on Universal Access in Human-Computer Interaction. Part III: Applications and Services* (San Diego, CA) *(UAHCI '09)*. Springer-Verlag, Berlin, Heidelberg, 179–188. https://doi.org/10.1007/978-3-642-02713-0_19

[8] George W. Fitzmaurice. 1993. Situated Information Spaces and Spatially Aware Palmtop Computers. *Commun. ACM* 36, 7 (July 1993), 39–49. https://doi.org/10.1145/159544.159566

[9] A.S. Fotheringham. 2001. Spatial Interaction Models. In *International Encyclopedia of the Social and Behavioral Sciences*, Neil J. Smelser and Paul B. Baltes (Eds.). Pergamon, Oxford, 14794 – 14800. https://doi.org/10.1016/B0-08-043076-7/02519-5

[10] Bruno Fruchard, Eric Lecolinet, and Olivier Chapuis. 2018. Impact of Semantic Aids on Command Memorization for On-Body Interaction and Directional Gestures. In *Proceedings of the 2018 International Conference on Advanced Visual Interfaces* (Castiglione della Pescaia, Grosseto, Italy) *(AVI '18)*. Association for Computing Machinery, New York, NY, USA, Article 14, 9 pages. https://doi.org/10.1145/3206505.3206524

[11] Aaron L. Gardony, Shaina B. Martis, Holly A. Taylor, and Tad T. Brunyé. 2018. Interaction Strategies for Effective Augmented Reality Geo-Visualization: Insights from Spatial Cognition. *Human–Computer Interaction* 0, 0 (2018), 1–43. https://doi.org/10.1080/07370024.2018.1531001 arXiv:https://doi.org/10.1080/07370024.2018.1531001

[12] Yvonne Jansen, Jonas Schjerlund, and Kasper Hornbundefinedk. 2019. Effects of Locomotion and Visual Overview on Spatial Memory When Interacting with Wall Displays. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, Article 291, 12 pages. https://doi.org/10.1145/3290605.3300521

[13] Wallace S Lages and Doug A Bowman. 2018. Move the object or move myself? walking vs. manipulation for the examination of 3D scientific data. *Frontiers in ICT* 5 (2018), 15. https://doi.org/10.3389/fict.2018.00015

[14] Frank Chun Yat Li, David Dearman, and Khai N. Truong. 2009. Virtual Shelves: Interactions with Orientation Aware Devices. In *Proceedings of the 22Nd Annual ACM Symposium on User Interface Software and Technology* (Victoria, BC, Canada) *(UIST '09)*. ACM, New York, NY, USA, 125–128. https://doi.org/10.1145/1622176.1622200

[15] J. Liu, A. Arnaud, B. Ens, and T. Dwyer. 2020. Design and Evaluation of Interactive Small Multiples Data Visualisation in Immersive Spaces. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, Atlanta, Georgia, USA.

[16] K. Marriott, F. Schreiber, T. Dwyer, K. Klein, N.H. Riche, T. Itoh, W. Stuerzlinger, and B.H. Thomas. 2018. *Immersive Analytics*. Springer International Publishing. https://books.google.com.au/books?id=vaVyDwAAQBAJ

[17] David Moher, Alessandro Liberati, Jennifer Tetzlaff, Douglas G. Altman, and The PRISMA Group. 2009. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLOS Medicine* 6, 7 (07 2009), 1–6. https://doi.org/10.1371/journal.pmed.1000097

[18] Desney S. Tan, Jeanine K. Stefanucci, Dennis R. Proffitt, and Randy Pausch. 2001. The Infocockpit: Providing Location and Place to Aid Human Memory. In *Proceedings of the 2001 Workshop on Perceptive User Interfaces* (Orlando, Florida, USA) *(PUI '01)*. Association for Computing Machinery, New York, NY, USA, 1–4. https://doi.org/10.1145/971478.971526

[19] Chip Tonkin, Andrew Ouzts, and Andrew Duchowski. 2011. Eye tracking within the packaging design workflow: Interaction with physical and virtual shelves. *ACM International Conference Proceeding Series*, 3. https://doi.org/10.1145/1983302.1983305

[20] Md. Sami Uddin, Carl Gutwin, and Benjamin Lafreniere. 2016. HandMark Menus: Rapid Command Selection and Large Command Sets on Multi-Touch Displays. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 5836–5848. https://doi.org/10.1145/2858036.2858211