ICA
International Cartographic Association
Association Cartographique Internationale
ACI

Rethinking Cartographic Generalization in Mixed Reality for Dynamic Mobility Scenarios

Nianhua Liu [a,*] , Ziyu Hu [a]

[a] *Chair of Cartography and Visual Analytics, Technical University of Munich, Germany, nianhua.liu@tum.de, ziyu.hu@tum.de*

* Corresponding author

Keywords: Adaptive Abstraction, Natural User Interfaces, Cycling Navigation

Abstract:

Historically, cartographic generalization first emerged to optimize map design primarily for desktop computers and conventional screen-based displays (Shea and McMaster, 1989). Subsequently, the proliferation of smartphones shifted the research focus toward mobile-first generalization (Ricker and Roth, 2018), with mobile devices widely discussed as a holistic display category (Mullins, 2015). Although contemporary cartographic agendas have begun to acknowledge the rise of augmented and mixed reality (MR) environments (Roth et al., 2024), existing literature broadly categorizes these immersive mediums without specifying the exact generalization mechanisms required across diverse, real-world operational scenarios. Consequently, the transition from screens to MR environments challenges many foundational assumptions of traditional cartography, necessitating a multi-dimensional framework that addresses dynamic mobility.

MR devices enable users to view and interact with maps directly within the physical world, often in dynamic mobility scenarios such as walking or cycling. Navigation cues or maps can be presented in a heads-up, hands-free manner, allowing pedestrians or cyclists to receive guidance without looking away from their path (He et al., 2024; Qiu, 2024). Prior research has begun to explore MR interfaces for cycling contexts, such as using a head-up display (HUD) or helmet-mounted display for navigation (Sörös et al., 2013). In the context of dynamic mobility within MR environments, cartographic generalization must adaptively account for the following dimensions:

- Hardware constraints: Physical display constraints directly dictate the effectiveness of spatial communication. The choice between full-color and monochrome outputs requires adaptive reselection of visual variables to ensure that critical information remains legible. Furthermore, the distinction between monocular and binocular hardware alters the generalization strategy while significantly impacting the user's cognitive load and depth perception (Roth et al., 2024). Crucially, the Field of View (FOV) defines the information load that MR devices can present.
- Visual approach: Navigation cues require a strategic selection between directional arrows, networks, or a hybrid combination (Figure 1). Cartographic generalization must also determine which specific landmarks and how many should be displayed on the MR device to ensure spatial legibility. This process is essential for balancing orientation needs with the limitations of the display interface to prevent information overload (Keil et al., 2020).

Figure 1. Arrow (left); Network (right).

- Interaction modalities: Map interaction in MR represents an emerging frontier. Traditional input paradigms, such as mouse-wheel scrolling or finger-touch zooming, are not appropriate in immersive environments. This shift necessitates a fundamental exploration of how new interactions, including voice commands, eye tracking, and mid-air gestures, can be synchronized with map abstraction levels. Furthermore, the integration of wearable

https://doi.org/10.5194/ica-abs-12-77-2026

peripherals, such as utilizing a smart ring to control map scale through tactile sliding, offers a novel way to manage cartographic detail during high-mobility tasks where hands-free or discrete interaction is required.

- Situational context: The map scale in MR devices must be responsive to the user's status, specifically whether they are moving or stationary. All displayed information should be dynamically linked to movement speed and the surrounding environment to optimize spatial perception and ensure the level of detail remains appropriate.
- User-centric customization: Map generalization must be dynamically tailored to individual user characteristics and the prevailing cognitive load to ensure operational safety and efficiency. In demanding mobility scenarios, such as switching routes during cycling, the system should implement extreme data filtering to present only the most critical navigational cues based on the user's immediate needs (Meng and Reichenbacher, 2005). This scenario-driven customization minimizes the mental effort required to process spatial information, effectively preventing cognitive over-saturation.

We plan to conduct a two-stage exploratory study. First, expert interviews with cycling research specialists will examine how existing generalisation methods can adapt to MR environments mobility scenarios. Second, insights from these interviews will inform prototype generalization strategies that will be evaluated through pilot user studies in mobility scenarios. This pilot study aims to open new conversations about how cartographic generalization must evolve in the MR devices within mobility scenarios.

Acknowledgements

The authors gratefully acknowledge the financial support provided by EIT Urban Mobility Student Entrepreneur Grant Scheme under project 5200-SEGS 23-25 MapReal.

References

He, L., Wang, H., Goodwin, S., Tag, B., and Elvitigala, D. S.: Pedalling into the Future: Towards Enhancing Cycling Experience Using Augmented Reality, in: Companion Publication of the 2024 ACM Designing Interactive Systems Conference, New York, NY, USA, 190–194, https://doi.org/10.1145/3656156.3663699, 2024.

Keil J., Edler D., Kuchinke L., and Dickmann F.: Effects of visual map complexity on the attentional processing of landmarks, PLOS ONE, 15, e0229575, https://doi.org/10.1371/journal.pone.0229575, 2020.

Meng, L. and Reichenbacher, T.: Map-based mobile services, in: Map-based Mobile Services: Theories, Methods and Implementations, edited by: Meng, L., Reichenbacher, T., and Zipf, A., Springer, Berlin, Heidelberg, 1–10, https://doi.org/10.1007/3-540-26982-7_1, 2005.

Mullins, C.: Responsive, mobile app, mobile first: untangling the UX design web in practical experience, in: Proceedings of the 33rd Annual International Conference on the Design of Communication, New York, NY, USA, 1–6, https://doi.org/10.1145/2775441.2775478, 2015.

Qiu, C.: Ego- and Exocentric Navigation for Cyclists Using Augmented Reality, 2024.

Ricker, B. A. and Roth, R. E.: Mobile Maps and Responsive Design, Geographic Information Science & Technology Body of Knowledge, https://doi.org/10.22224/gistbok/2018.2.5, 2018.

Roth, R. E., Çöltekin, A., Delazari, L., Denney, B., Mendonça, A., Ricker, B. A., Shen, J., Stachoň, Z., and Wu, M.: Making maps & visualizations for mobile devices: A research agenda for mobile-first and responsive cartographic design, Journal of Location Based Services, 18, 408–478, https://doi.org/10.1080/17489725.2023.2251423, 2024.

Shea, K. S. and McMaster, R. B.: Cartographic generalization in a digital environment: when and how to generalize, autocarto-9, 1989.

Sörös, G., Daiber, F., and Weller, T.: Cyclo: a personal bike coach through the glass, in: SIGGRAPH Asia 2013 Symposium on Mobile Graphics and Interactive Applications, New York, NY, USA, 1–4, https://doi.org/10.1145/2543651.2543660, 2013.

https://doi.org/10.5194/ica-abs-12-77-2026