Mapping the Design Space of XR Interruption Delivery: Initial Framework

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ABSTRACT

As XR integrates into everyday workflows, users face interruptions causing spatial cognitive disorientation. Mitigating this requires a structured understanding of interruption management. We introduce a framework to map this design space, categorizing interruptions by their source location (collocated vs. remote) and delivery timing (immediate vs. deferred). We illustrate this matrix using select examples to demonstrate its structure, discuss initial design strategies for mediating these disruptions, and provide a starting point for future exploration.

Index Terms: Extended reality (XR), interruption management, taxonomy.

1 INTRODUCTION

As Extended Reality (XR) devices transition into ubiquitous environments for everyday productivity and knowledge work, the frequency of environmental and digital interruptions increases. Because XR is now utilized across diverse settings, the sources of these interruptions vary widely, encompassing everything from physical bystanders and objects to digital emails and system notifications. Currently, there is a lack of a structured model to understand this complex design space in terms of space and time. To address this, we adapt the classic Computer-Supported Cooperative Work (CSCW) Space-Time matrix [3]. While not collaborative, XR interruptions act as two-party interactions with often conflicting goals. We adopt the CSCW axes to explore these dynamics. As initial considerations, the spatial axis can define presentation flexibility (e.g., flexible virtual alerts vs. rigid physical cues), and the temporal axis can capture urgency (e.g., weighing flow disruption against immediate awareness). This mapping could eventually allow systems to manage interruptions by urgency, cognitive impact, and spatial flexibility.

2 STRUCTURING XR INTERRUPTIONS

Based on these dynamics, our model categorizes XR interruptions across two intersecting dimensions: **Source Location** (Physical collocated spaces vs. Remote digital networks) and **Delivery Timing** (Immediate vs. Deferred). Crucially, our temporal axis does not denote whether a message is inherently synchronous or asynchronous, e.g., a phone call vs. an email, but rather whether the disruption's visual or spatial delivery into the XR environment is immediate or deferred through system mediation.

By intersecting these dimensions, we identify four distinct design spaces, each utilizing specific interaction strategies to manage XR disruptions:

- **Immediate-Collocated:** Addresses interruptions originating from the user's local physical environment, e.g., a bystander or an unexpected physical object. Because the source occupies a fixed real-world coordinate, the primary objective is to safely integrate these real-world distractions into the XR space while preserving spatial consistency and proxemic awareness [5, 13].
- **Immediate-Remote:** Manages networked signals, e.g., incoming calls, that lack a fixed physical origin [4]. Unconstrained by physical coordinates, systems can leverage full spatial freedom to optimize interface placement—such as gaze-aware "Goldilocks" zoning [8]—delivering glanceable information while minimizing visual occlusion of the primary task [12].
- **Deferred-Collocated:** Explores system-mediated interactions with local spatial sources to prevent abrupt disruptions of presence. Here, systems can deploy proactive proxies [14] or manage an approaching bystander's expectations through subtle signaling [6], securing a natural stopping point before the user engages in cross-reality communication.
- **Deferred-Remote:** Focuses on buffering non-urgent, spatially flexible notifications, e.g., background updates. Systems actively model the user's cognitive state to hold cached alerts, delivering them during opportune moments to preserve uninterrupted cognitive flow [1].

3 KEY DESIGN GOALS AND CONSIDERATIONS

While the matrix defines the structure of XR interruptions, effective mediation relies on concrete interaction mechanisms to achieve high-level design goals. We highlight key strategies from the literature:

- **Preserving Spatial Presence:** For spatially anchored sources, systems manipulate how reality is rendered to preserve presence. This ranges from altering visual fidelity (e.g., blending bystanders as diegetic avatars [5]) to enhancing human perception—such as routing rear-facing passthrough views to the front [7]—allowing users to safely address physical intrusions without significant physical reorientation.
- **Reducing Visual Load:** While remote digital alerts possess full spatial flexibility, intentionally anchoring them to physical surfaces—such as mapping a notification onto a real-world desk [15]—makes them less intrusive. Combined with multimodal feedback, such as spatial audio or haptics, this reduces visual load while spatially grounding the interruption [10, 2].
- **Minimizing Visual Occlusion:** To minimize visual occlusion, interruptions initially manifest as minimal, low-saliency cues—such as a small thumbnail—expanding into detailed interfaces only when the user explicitly shifts their gaze or attention toward them [11, 16].
- **Socially Mediating Collocated Disruptions:** Deferred delivery involves more than internal system caching. For collocated environments, systems actively externalize the XR user's virtual workspaces or state of presence to the outside world—such as via physical shadows or external displays [9]. This informs bystanders, encouraging them to naturally defer their physical interruption until an opportune moment [6, 14].

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Table 1: A mapping of XR interruption delivery strategies and key design considerations

Timing \Location	Collocated (Spatially Anchored)	Remote (Spatially Flexible)
Immediate	**Manipulating spatial perception** • Routing rear views to front [7] • Providing proxemic awareness cues [13] **Modulating visual fidelity** • Rendering diegetic bystander avatars [5]	**Spatial placement & anchoring** • Gaze-aware interface positioning [4, 8] • Mapping alerts to physical surfaces [15] **Progressive disclosure & modality** • Details-on-demand (thumbnail to UI) [12, 11, 16] • Utilizing audio/haptic cues [10, 2]
Deferred	**Externalizing user state** • Displaying interface locations to bystanders [9] **Proactive social mediation** • Encouraging bystanders to defer [6] • Deploying proactive proxies [14]	**Cognitive-aware delivery** • Modeling state & predicting breakpoints [1]

4 Outlook

This work represents an initial exploration. To refine this conceptual foundation and resolve current broad and overlapping categories, future work includes a systematic literature review and coding process to clarify our novelty against existing taxonomies and validate utility via expert feedback. We will also layer micro-level dimensions—e.g., task urgency, cognitive workload, and social relationships—into the matrix to create a prescriptive design tool. Finally, beyond delivery, future research should connect this matrix with task resumption mechanisms, bridging how an interruption is presented and how the user recovers.

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References

[1] K.-W. Chen, Y.-J. Chang, and L. Chan. Predicting Opportune Moments to Deliver Notifications in Virtual Reality. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*, CHI '22, pp. 1–18. Association for Computing Machinery, New York, NY, USA, Apr. 2022. doi: 10.1145/3491102.3517529 1, 2

[2] H. Cho, D. Edgar, D. Lindlbauer, and J. O'Hagan. Evaluating Dynamic Delivery of Audio+Visual Message Notifications in XR. In *2025 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 277–287, Mar. 2025. ISSN: 2642-5254. doi: 10.1109/VR59515.2025.00052 1, 2

[3] C. A. Ellis, S. J. Gibbs, and G. Rein. Groupware: Some Issues and Experiences. *Commun. ACM*, 34(1):39–58, Jan. 1991. doi: 10.1145/99977.99987 1

[4] S. Ghosh, L. Winston, N. Panchal, P. Kimura-Thollander, J. Hotnog, D. Cheong, G. Reyes, and G. D. Abowd. NotifiVR: Exploring Interruptions and Notifications in Virtual Reality. *IEEE Transactions on Visualization and Computer Graphics*, 24(4):1447–1456, Apr. 2018. doi: 10.1109/TVCG.2018.2793698 1, 2

[5] M. Gottsacker, N. Norouzi, K. Kim, G. Bruder, and G. Welch. Diegetic Representations for Seamless Cross-Reality Interruptions. In *2021 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 310–319, Oct. 2021. doi: 10.1109/ISMAR52148.2021.00047 1, 2

[6] M. Gottsacker, R. Syamil, P. Wisniewski, G. Bruder, C. Cruz-Neira, and G. Welch. Exploring Cues and Signaling to Improve Cross-Reality Interruptions. In *2022 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*, pp. 827–832, Oct. 2022. ISSN: 2771-1110. doi: 10.1109/ISMAR-Adjunct57072.2022.00179 1, 2

[7] Z. Guo, Y. Shi, T. Ye, T. Wan, and H.-N. Liang. No More Head-Turning: Exploring Passthrough Techniques for Addressing Rear Interruptions from the Front in VR. In *2025 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 238–248, Mar. 2025. doi: 10.1109/VR59515.2025.00048 1, 2

[8] C. Ilo, S. DiVerdi, and D. Bowman. Goldilocks Zoning: Evaluating a Gaze-Aware Approach to Task-Agnostic VR Notification Placement. In *Proceedings of the 2024 ACM Symposium on Spatial User Interaction*, SUI '24, pp. 1–12. Association for Computing Machinery, New York, NY, USA, Oct. 2024. doi: 10.1145/3677386.3682087 1, 2

[9] T. Khan, A. Zimmerman, E. Andrews, D. Lindlbauer, and J. Biehl. Shadows of Reality: Enhancing Bystander Awareness of Mixed Reality Interfaces. In *Proceedings of the 2025 ACM Symposium on Spatial User Interaction*, SUI '25, pp. 1–12. Association for Computing Machinery, New York, NY, USA, Nov. 2025. doi: 10.1145/3694907.3765920 1, 2

[10] M. J. Lazaro, S. Kim, J. Lee, J. Chun, and M.-H. Yun. Interaction Modalities for Notification Signals in Augmented Reality. In *Proceedings of the 2021 International Conference on Multimodal Interaction*, ICMI '21, pp. 470–477. Association for Computing Machinery, New York, NY, USA, Oct. 2021. doi: 10.1145/3462244.3479898 1, 2

[11] F. Lu, S. Davari, and D. Bowman. Exploration of Techniques for Rapid Activation of Glanceable Information in Head-Worn Augmented Reality. In *Proceedings of the 2021 ACM Symposium on Spatial User Interaction*, SUI '21, pp. 1–11. Association for Computing Machinery, New York, NY, USA, Nov. 2021. doi: 10.1145/3485279.3485286 1, 2

[12] F. Lu, S. Davari, L. Lisle, Y. Li, and D. A. Bowman. Glanceable AR: Evaluating Information Access Methods for Head-Worn Augmented Reality. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 930–939, Mar. 2020. ISSN: 2642-5254. doi: 10.1109/VR46266.2020.00113 1, 2

[13] D. Medeiros, R. d. Anjos, N. Pantidi, K. Huang, M. Sousa, C. Anslow, and J. Jorge. Promoting Reality Awareness in Virtual Reality through Proxemics. In *2021 IEEE Virtual Reality and 3D User Interfaces (VR)*, pp. 21–30, Mar. 2021. ISSN: 2642-5254. doi: 10.1109/VR50410.2021.00022 1, 2

[14] A. Rahman, W. Ying, M. A. R. Azim, M. Annett, and S. Heo. "It Feels Like I am Invited to Communicate": Mediating Ad-Hoc Bystander-VR User Interruptions Through Proactive Proxies. In *Proceedings of the 2026 CHI Conference on Human Factors in Computing Systems*, CHI '26. Association for Computing Machinery, New York, NY, USA, 2026. doi: 10.1145/3772318.3791936 1, 2

[15] A. Raikwar, L. Plabst, A. U. Batmaz, F. Niebling, and F. R. Ortega. Ping! Your Food is Ready: Comparing Different Notification Techniques in 3D AR Cooking Environment. In *2024 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 1157–1166, Oct. 2024. ISSN: 2473-0726. doi: 10.1109/ISMAR62088.2024.00132 1, 2

[16] J. Zheng, X. Wang, S. Mayer, and L.-H. Lee. Non-Urgent Messages Do Not Jump into My Headset Suddenly! Adaptive Notification Design in Mixed Reality. *IEEE Transactions on Visualization and Computer Graphics*, 32(5):4217–4227, May 2026. doi: 10.1109/TVCG.2026.3679090 1, 2