Beyond One-Size-Fits-All: A Conceptual Framework for Personalizing XR Navigation Based on Individual Capacity and Context

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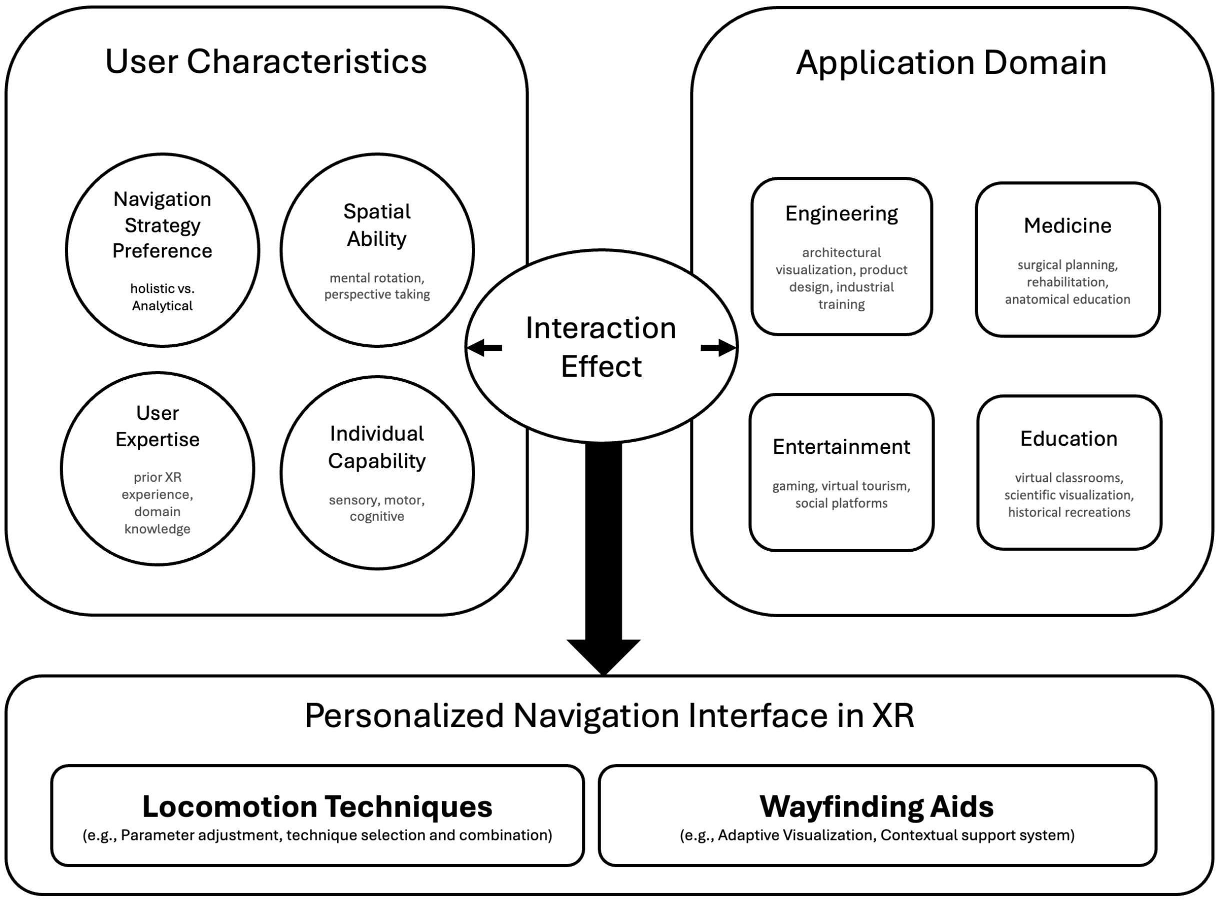

Figure 1: Conceptual Framework for Personalized XR Navigation Interface. The framework illustrates how effective navigation interfaces emerge from the dynamic interaction between individual user characteristics (navigation strategy preference, spatial ability, user expertise, and individual capability) and application domains (Engineering, Medicine, Entertainment, Education). This interaction effect drives the design of personalized navigation interfaces comprising locomotion techniques and wayfinding support.

Abstract

Our research introduces a conceptual framework for personalizing navigation interfaces in Extended Reality (XR) environments. We challenge the one-size-fits-all paradigm that dominates current XR navigation design, addressing the significant individual differences in spatial cognition that impact navigation performance. Our framework synthesizes evidence from multiple studies showing that users form distinct groups with different preferences and performance patterns when using navigation techniques. We demonstrate how the interaction between individual characteristics and application domains creates unique requirements that drive interface adaptation. Our framework identifies key components for effective personalization: (1) Incorporation of user Characteristics to incorporate individual capacity; (2) consideration of varied application domains; and (3) implementation of personalized and adaptive navigation interfaces in XR. This framework aims to transform XR navigation design from a one-size-fits-all approach to personalized solutions that are context-dependent to accommodate the full spectrum of individual human needs and capacities, ultimately creating more inclusive and optimal XR experiences.

Index Terms: Extended Reality, navigation, individual differences, personalization, spatial cognition.

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1 INTRODUCTION

Navigation is a fundamental requirement for interaction in most Extended Reality (XR) applications, encompassing both locomotion and wayfinding. Researchers have developed numerous techniques [18, 8, 3, 36, 12, 23] that aim to be superior across metrics like task completion time [6, 9], accuracy [10, 5], and user comfort [2, 13]. However, this pursuit of universally optimal solutions overlooks individual differences in spatial cognition. Research has established that people vary significantly in their spatial abilities [11, 27], wayfinding strategies [33, 26], and navigation preferences [24]. Some users prefer holistic mental rotation strategies [30, 25], while others rely on analytical approaches [16, 22]. These differences extend beyond basic spatial abilities to include variations in working memory capacity and responses to different types of visual feedback [10, 28].

Traditional XR navigation research has focused primarily on methodological innovations, neglecting the interaction between user capacities and usage contexts. Multiple studies have revealed distinct user groups that respond differently to the same navigation interfaces based on expertise and prior experience [31, 24]. For instance, when examining parameter control for target-based locomotion, most users preferred flying with automatic speed control, yet others performed better with teleportation in dense environments [19]. Similarly, for exo-centric navigation, some users favored precise scrolling while others preferred direct bimanual manipulation [20].

This one-size-fits-all paradigm fails to account for how individual capabilities and preferences [4, 14] might alter the effectiveness of navigation techniques across different application domains. We propose that the field would benefit from a shift toward frameworks that accommodate individual differences, advancing inclusive design in XR applications [21]. Our conceptual framework provides an initial structure for understanding the interplay between cognitive, contextual, and interface factors shaping navigation experiences. By modeling how individual characteristics interact with application demands, this framework offers a starting point for developing more flexible, responsive XR navigation interfaces that better serve the full spectrum of human spatial cognition across varied application contexts.

2 METHODOLOGY

Our methodological approach explores the relationship between individual navigation capabilities and application contexts within XR environments. We developed an initial conceptual framework through an extensive literature review spanning cognitive psychology, Human-Computer Interaction (HCI), design, and XR research. This review was complemented by evidence highlighting consistent patterns of individual differences in navigation performance. Together, these efforts established a foundation for examining how user characteristics—such as spatial abilities, strategy preferences, and working memory capacity—interact with application domains (e.g., professional, entertainment, educational) to generate specific navigation needs that call for personalized design solutions.

To structure this inquiry, we adopt a conceptual framework approach grounded in conceptual analysis, a method used to generate, identify, and trace a phenomenon's key constructs by synthesizing insights across multidisciplinary domains [15]. This approach is particularly appropriate for a complex, evolving domain like XR navigation, where diverse user needs and interaction demands converge.

3 CONCEPTUAL FRAMEWORK

The Conceptual Framework for Personalized XR Navigation (Fig. 1) illustrates how effective navigation interfaces emerge from the dynamic interaction between individual user characteristics and application domains. At its core, the framework challenges traditional approaches that seek universal solutions by explicitly modeling the relationship between who uses a system and for what purpose. The component on the top left side, User Characteristics, captures four critical dimensions of individual differences in spatial cognition: navigation strategy preference (holistic versus analytical approaches), spatial ability (mental rotation, perspective taking), user expertise (prior experience in XR), and individual capability (sensory, motor and cognitive). These individual characteristics have been consistently documented in spatial cognition research [11, 34, 29], creating a foundation for understanding why users respond differently to the same interface designs.

The top right side, Application Domain, represents diverse application domains that shape and differentiate navigation requirements in XR. Each domain imposes unique constraints and priorities on spatial interaction: Engineering (architecture visualization, product design, industrial training) where precision and accuracy in spatial interactions are paramount [7]; Medicine (surgical planning, rehabilitation, anatomical education) requiring detailed spatial understanding and careful movement control; Entertainment (gaming, virtual tourism, social platforms) prioritizing immersion and intuitive interactions over technical precision [8, 6]; Education (virtual classrooms, scientific visualization, historical recreations) balancing learning objectives with engaging spatial experiences [35]. These varying contexts inherently shape the design and deployment of navigation strategies within XR systems. Thus, rather than treating these domains as isolated categories, this framework emphasizes their relationship with user characteristics, recognizing that the same navigation technique might produce dramatically different outcomes depending on both who is using it and for what purpose.

The Interaction Effect emphasizes that effective design of personalized navigation interfaces requires consideration of the interplay between user characteristics and application domains to optimize user experience. This interaction creates unique requirements that cannot be addressed through a one-size-fits-all approach. For instance, a user with strong holistic spatial abilities might excel with one navigation technique in an entertainment context but struggle with the same technique in a professional environment that demands precise control. Similarly, a user with limited working memory capacity might benefit from different wayfinding support depending on whether they're navigating an educational simulation or a social platform [32].

The resulting personalized navigation interface comprises two main components: locomotion techniques (methods for moving through virtual space) and wayfinding support (guidance and environmental cues). These elements are directly determined by the Interaction Effect, with specific configurations emerging from the combination of user characteristics and application requirements. For example, a user with strong analytical spatial abilities working in a professional context might receive a navigation interface with finely-tuned parameter settings that prioritize accuracy over speed and detailed wayfinding guidance [19, 3].

4 DISCUSSION AND FUTURE CONSIDERATIONS

This section explores several key areas that warrant further investigation as we move toward more personalized XR navigation interfaces.

4.1 Empirical Validation of the Framework

Future work should focus on empirically validating this framework through controlled studies examining how specific user characteristics interact with various application contexts to influence navigation performance and preference. Developing and testing prototype systems that implement adaptive navigation mechanisms will be essential for translating these theoretical insights into practical applications.

4.2 Continuous Evaluation and Adaptation

Continuous evaluation should be added as a new component of the framework to underscore the need to treat personalization as a dynamic, iterative process. As users acquire new skills or engage with diverse tasks within an application, their navigation needs are likely to evolve, necessitating corresponding adaptations in interface design. This perspective acknowledges that both user characteristics and application contexts are fluid, highlighting the importance of responsive systems capable of evolving alongside users.

4.3 Personalization in Collaborative XR Environments

An important consideration involves collaborative XR environments where multiple users with personalized navigation interfaces must interact together. The framework's emphasis on individual optimization raises critical questions about multi-user scenarios where participants may employ fundamentally different locomotion techniques based on their unique characteristics and needs.

When users navigate with different techniques—for instance, one using teleportation while another employs continuous locomotion, or one utilizing automatic speed control while another prefers manual control [19]—several challenges emerge:

Spatial Coordination and Communication: Users with different locomotion techniques may experience disparate levels of presence and spatial awareness [17], potentially affecting their ability to coordinate movements, reference locations, or maintain shared understanding of the virtual space. For example, a user teleporting may lose the sense of traveled distance that a continuously moving collaborator maintains.

Task Performance Asymmetries: The interaction effect between user characteristics and application domains [1] becomes more complex when multiple users with different personalized interfaces must complete joint tasks. A user optimized for precision through one technique may struggle to synchronize with a partner optimized for speed through another.

Social Presence and Equity: Different navigation capabilities might create perceived or actual hierarchies in collaborative settings, where some users appear more competent or capable simply due to their interface configuration rather than their actual abilities.

Design Implications: Future research should investigate strategies for balancing individual personalization with collaborative requirements. This might include:

- Identifying which navigation elements should remain standardized to facilitate effective multi-user interactions
- Developing awareness mechanisms that help collaborators understand each other's navigation constraints
- Creating adaptive systems that can temporarily adjust individual interfaces during collaborative tasks
- Examining whether certain application domains (e.g., professional engineering contexts versus entertainment settings) require different approaches to balancing personalization and collaboration

This represents a crucial extension of the personalization framework, acknowledging that optimal individual experiences must sometimes be negotiated against collaborative effectiveness.

5 CONCLUSION

This paper presents a conceptual framework addressing the limitations of one-size-fits-all approaches to navigation interface design in XR environments. By highlighting the interaction between individual user characteristics and application domains, we advocate for a fundamental shift in how navigation interfaces are conceptualized and implemented. The growing body of evidence demonstrating distinct user groups with varying preferences and performance patterns across navigation techniques underscores the need for personalized approaches that can accommodate this diversity. By shifting the focus from universally optimal solutions to context-aware, personalized approaches, we can advance toward XR experiences that are more inclusive, effective, and attuned to the full spectrum of human spatial cognition.

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