AnchoR: Toward Asynchronous Collaboration and Guided Exploration for Mobile AR Visualizations

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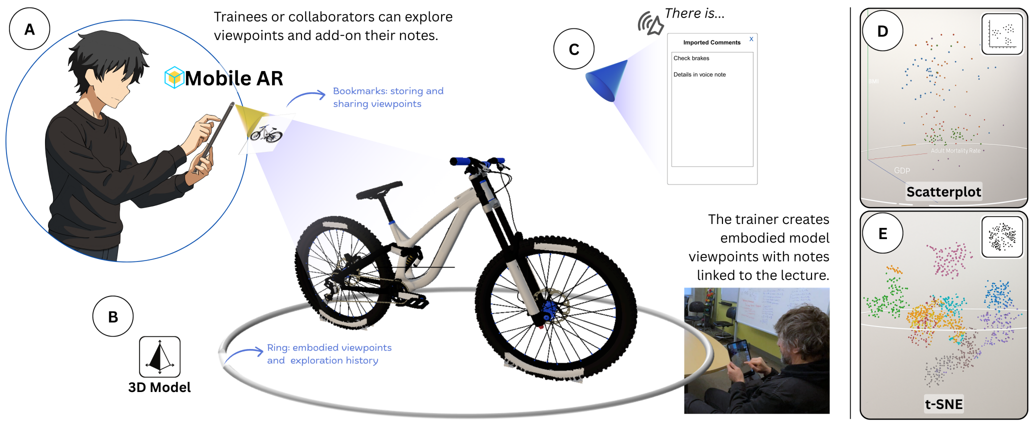

Figure 1: (A) A trainee captures a bookmark, spawning a yellow view cone and translucent snapshot for recall or sharing. (B) In 3D Model mode, a grey ring logs visited azimuths while rotating or walking around the off-road bike [3]. (C) Blue bookmarks link to asynchronous text/audio trainer notes via an "Imported Comments" panel. (D) Scatterplot mode visualizes WHO Adult Mortality [1]; orange segments highlight scagnostic hotspots, translucent ones mark explored views. (E) t-SNE mode shows a 3D MNIST embedding [4], supporting spherical inspection via combined rotation.

Abstract

We present AnchoR, a mobile augmented reality (AR) system for asynchronous, guided interaction with 3D visualizations on everyday tablets. AnchoR integrates spatial bookmarking, embedded annotations, occlusion management, and embodied view-history tracking across three modes: scatterplots, t-SNE embeddings and 3D models. Users can export bookmarks and histories as shareable JSON or annotated reports, enabling collaborative analysis without co-location or real-time coordination. Early expert feedback highlights AnchoR's potential to improve recall, communication, and navigation in mobile immersive analytics, while revealing design opportunities for refining handheld AR spatial interactions.

CCS Concepts

• **Human-centered computing → Visualization**; **Collaborative interaction**; **Mixed / augmented reality**.

ACM SUI '25, Montreal, QC

ACM ISBN 978-1-4503-XXXX-X/2025/11
https://doi.org/XXXXXXX.XXXXXXX

Keywords

Asynchronous Collaboration, Viewpoint Guidance, Visualization, Mobile AR Interfaces, Spatial Interaction

ACM Reference Format:
Neel Shah, Matthew Chan, Mariana Shimabukuro, Christopher Collins. 2025. AnchoR: Toward Asynchronous Collaboration and Guided Exploration for Mobile AR Visualizations. In *Proceedings of ACM Spatial User Interfaces (ACM SUI '25)*. ACM, New York, NY, USA, 3 pages. https://doi.org/XXXXXXX.XXXXXXX

1 Introduction

Mobile augmented reality (AR) on everyday tablets and smartphones enables intuitive spatial interaction with 3D visualizations via embodied movement and direct viewpoint manipulation. While this accessibility makes mobile AR ideal for situated data exploration, existing tools often lack support for **asynchronous collaboration**, **provenance tracking**, and **guided navigation** [13, 18].

Prior immersive analytics systems in CAVE environments [20], VR [11], and head-mounted AR [24] offer rich collaboration features but require specialized hardware, co-location, or complex infrastructure. Surveys highlight persistent challenges including high technical overhead, cognitive load from asymmetric setups, and poor support for asynchronous workflows [6, 23, 26]. Mobile AR systems such as GraSp [17] and VisTiles [19] demonstrate spatial interaction benefits, yet remain largely single-user. Vision papers overlook critical features like provenance and remote access [22].

Techniques common in 2D analytics—viewpoint bookmarking, analytic guidance, and exploration history [10, 12]—remain underdeveloped in spatial interfaces. While cross-platform systems like ReLive [15] bridge immersive and desktop views, and web-based approaches like SIMProv.js [9] enable client-side provenance, few mobile AR systems support lightweight, shareable provenance for asynchronous collaboration.

We present AnchoR, illustrated in Figure 1, a handheld AR system addressing these gaps through multiple visualization modes and interaction techniques: (1) **Viewpoint bookmarks** with embedded annotations for precise 3D pose recall and sharing; (2) **Viewing ring** visualizing exploration coverage and suggesting informative views via scagnostics; and (3) **Lightweight occlusion management** for dense 3D scenes.

These self-contained features, running entirely on commodity tablets, support asynchronous collaboration scenarios such as trainer, trainee hand-offs without requiring co-location or specialized hardware. We demonstrate AnchoR across scatterplots, high-dimensional t-SNE embeddings, and 3D models, with early expert feedback confirming feasibility and surfacing design refinements.

2 AnchoR: System Overview

AnchoR is a mobile AR system for tablets that enables asynchronous, guided exploration of 3D visualizations through **spatial bookmarking**, **viewpoint history tracking**, and **occlusion management**. Built with ARKit and SceneKit for iOS [2, 5], AnchoR runs entirely on commodity devices without specialized hardware or server infrastructure. It supports three modes: scatterplots, t-SNE embeddings, and 3D models. As illustrated in Figure 1, AnchoR's key features are shown across multiple modes: (A) bookmarks visualized as yellow view cones with semi-transparent snapshots for recall or sharing; (B) the viewing ring logging explored horizontal viewing angles during exploration; (C) imported blue bookmarks linked to asynchronous trainer notes; (D) scatterplot mode with scagnostic-based guidance highlighting hotspots; and (E) t-SNE mode enabling spherical inspection via combined rotation.

2.1 Core Interaction Techniques

Spatial Bookmarking and Provenance. Bookmarks capture the user's 6-DoF pose, a semi-transparent screenshot, and text/audio annotations, enabling precise viewpoint recall and sharing. Export/import uses lightweight JSON, with imported bookmarks shown in blue. A cone+snapshot design [8, 21] provides multi-scale guidance, fading screenshots as alignment improves. Bookmarks can be compiled into PDF reports for non-AR stakeholders.

Viewpoint History via Ring Visualization. A coverage-oriented viewing ring [26] encodes 3,600 one-degree spheres around the visualization. Viewed segments fade in transparency, while scagnostic-suggested viewpoints [25] appear in orange. Ring state is shared with bookmarks to reveal unexplored regions.

Navigation and Occlusion Management. Device-centric gestures [7] include drag-to-translate, pinch-to-zoom, and optional continuous rotation buttons. For dense scenes, interaction-driven transparency enables rapid decluttering: tapping toggles point opacity, and "scrub" mode fades intersected points without heavy geometry processing [14].

2.2 Visualization Modes

Scatterplots: Multivariate data with scagnostic-based guidance; orange ring segments indicate high-scoring attribute pairs, with on-view overlays (e.g., "Strong-Skewed, 0.76"). **t-SNE Embeddings:** Full 6-DoF exploration of high-dimensional projections, with customizable colours and scrub-to-hide for dense clusters. **3D Models:** CAD models for design review or training; bookmarks enable expert–trainee hand-offs with embedded annotations [16].

2.3 Early Feedback

Two experts (Mathematics, network analysis; Computer Science, immersive media) evaluated AnchoR, revealing: **Interactions:** Gesture-based rotation needed; scrub-to-hide worked well but requires region selection; **Guidance:** Scagnostics effectively highlighted non-linear patterns; **Collaboration:** Bookmarks enabled viewpoint sharing though snapshots proved essential for alignment; **Annotations:** Object-anchored annotations and desktop-consistent gestures desired for 3D models. These findings confirm feasibility while identifying key refinements.

3 Discussion & Next Steps

AnchoR demonstrates that asynchronous collaboration with 3D visualizations is feasible on commodity tablets, combining spatial bookmarking, coverage-oriented view history, and lightweight occlusion management. Early expert feedback confirmed the potential of this approach and suggested refinements such as gesture-based rotation, visual alignment cues for imported bookmarks, and region-based selection tools. These findings contribute to ongoing discussions in immersive analytics on balancing minimal mobile UI with expressive spatial control, and on designing asynchronous workflows that remain lightweight yet context-rich.

Future directions include *Interaction techniques:* Hybrid gesture–touch paradigms and adaptive UI elements responsive to scene complexity; *Collaborative workflows:* Role-based permissions, semantic clustering of annotations, and provenance visualizations to build trust in distributed teams; and *Technical advances:* Optimizing coverage algorithms for non-uniform data, personalized view suggestions beyond scagnostics, and support for volumetric/time-series data.

Use Cases and Broader Impact AnchoR can enable practical asynchronous workflows across diverse domains. In medical education, instructors could annotate 3D anatomical models with audio explanations, creating guided tours for student self-study. For automotive design, engineers on different continents could bookmark CAD model stress points during their work hours, with the viewing ring confirming complete inspection before approval. In architectural review, distributed teams could explore shared 3D spaces asynchronously, leaving spatially anchored feedback without scheduling conflicts. Unlike video tutorials or PDFs, AnchoR preserves the spatial discovery process; users inherit not just insights, but the exact viewpoints where they emerged, ensuring critical angles are not missed.

Our next step is a mixed-methods evaluation comparing mobile AR to desktop baselines, measuring task performance, cognitive load, and collaboration quality.

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