# Radiance Fields for XR

## A Survey on How Radiance Fields are Envisioned and Addressed for XR Research




[1] Ke Li , [2] Mana Masuda , [3] Susanne Schmidt , [4] Shohei Mori

[1] Human Computer Interaction Group, Hamburg University, Germany

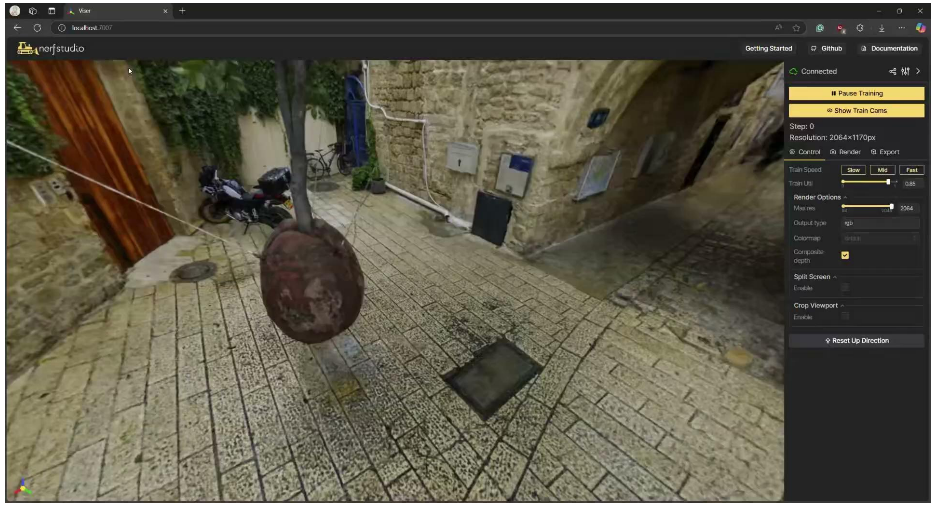
[2] Keio University, Japan

[3] HIT Lab, University of Cantebury, New Zealand

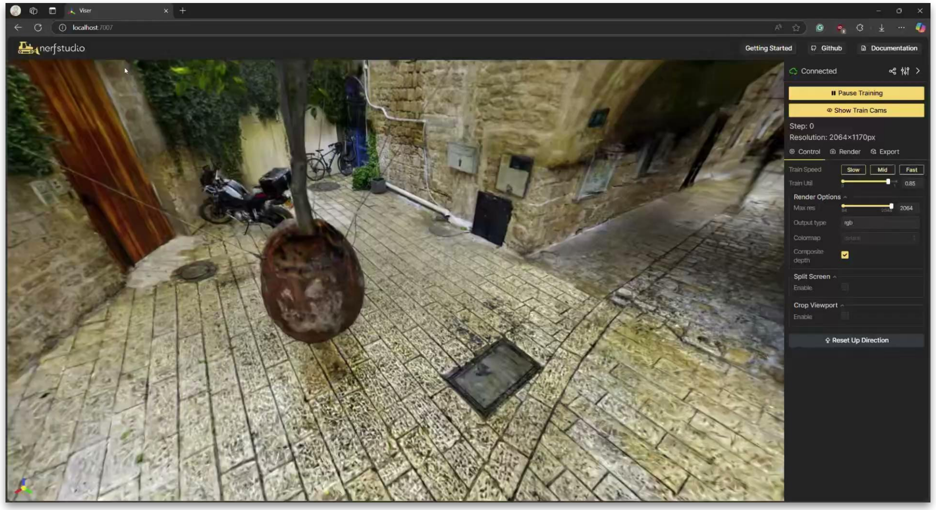
[4] Visualization Research Center (VISUS), University of Stuttgart, Germany

# Radiance Field for Photorealistic 3D Scene Reconstruction and Representation

## Neural Radiance Fields (NeRF) [1]



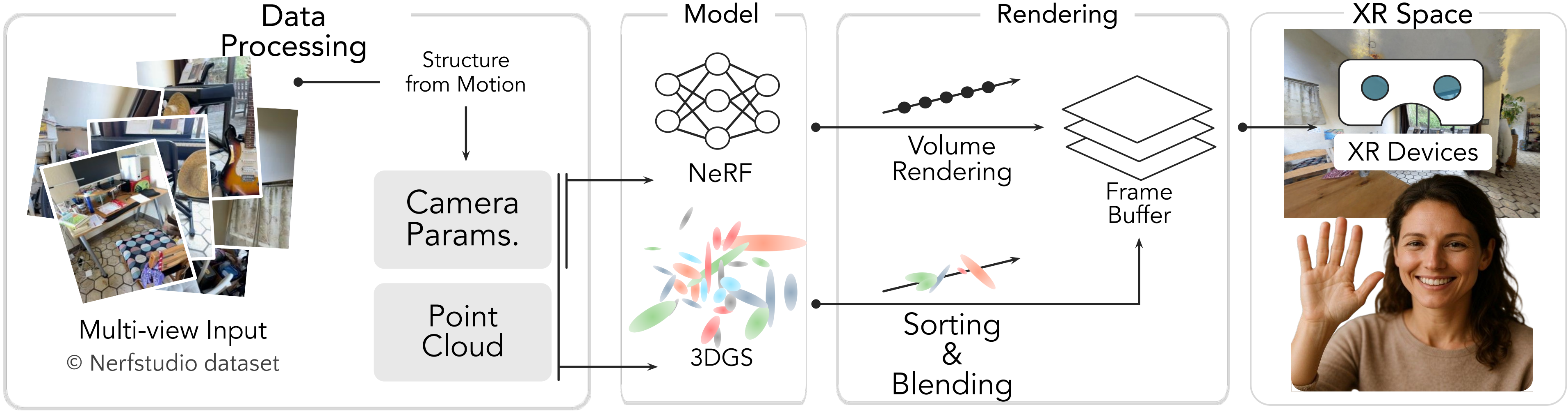

## 3D Gaussian Splatting (3DGS) [2]

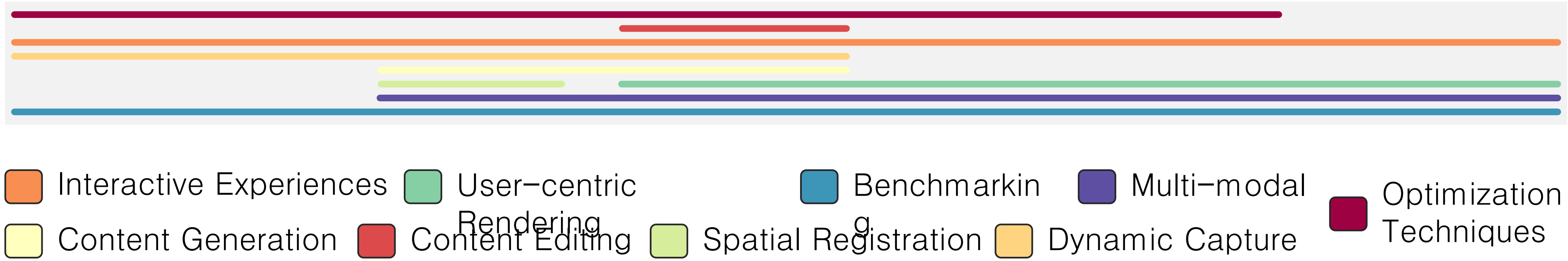



Mildenhall, B., Srinivasan, P.P., Tancik, M., Barron, J.T., Ramamoorthi, R., & Ng, R. (2020). NeRF. *Communications of the ACM, 65*, 99 - 106.

Kerbl, B., Kopanas, G., Leimkuehler, T., & Drettakis, G. (2023). 3D Gaussian Splatting for Real-Time Radiance Field Rendering. *ACM Transactions on Graphics (TOG), 42*, 1 - 14.

# Research themes increasingly relevance to user's XR experiences across the **capture → render** pipeline



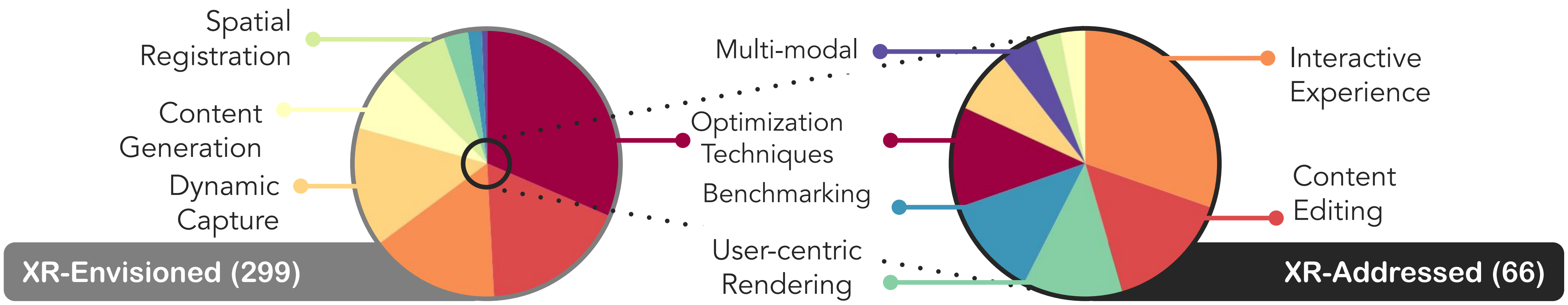
# Research Questions

RQ1: How are radiance fields **envisioned** for XR?

RQ2: What have been **implemented** in actual immersive XR settings?

RQ3: What are the **research gaps** for widespread adaptation in XR?

# Paper Screening via PRISMA 2020 [1] Guideline




- RF papers : 03.2020 – 02.2025
- 1676 papers: XR, HCI, CV, CG, Robotics, MM
- Thematic analysis : 365 XR–Mentioned
- Full text analysis : 66 XR–Addressed → involves XR devices or users
  - 🔬 XR–Study (24) → In depth user study or benchmark
  - ⭐ XR–Showcase (42) → proof–of–concept demo

[1] Page, Matthew J. et al. "The PRISMA 2020 statement: an updated guideline for reporting systematic reviews." *Systematic Reviews* 10 (2020)

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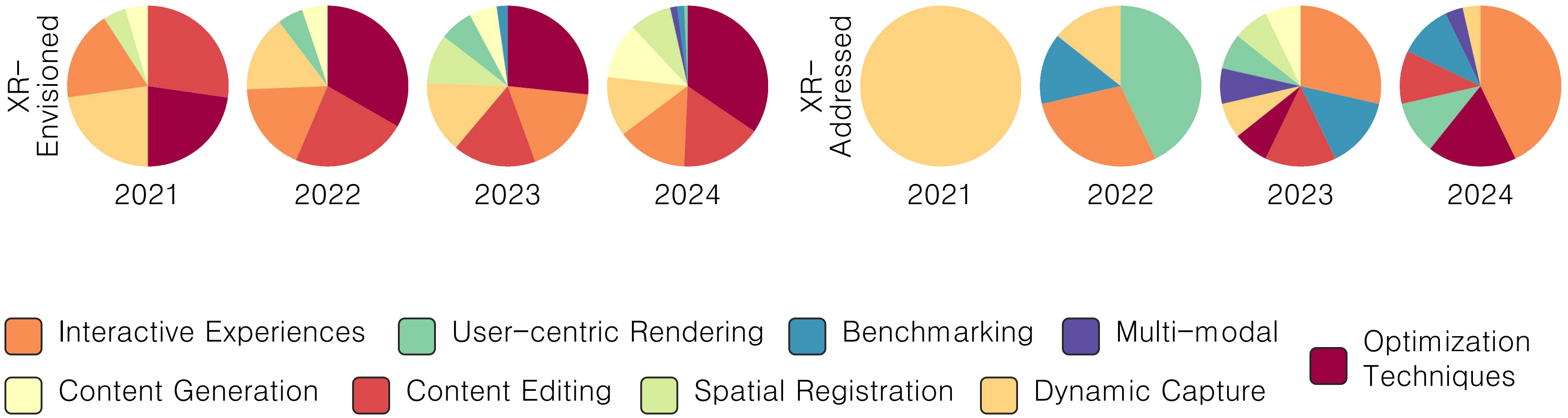
# Gaps in Trends

## Envisioned vs. Addressed Topics

•Addressed in all 9
•sparsely implemented/tested in XR systems

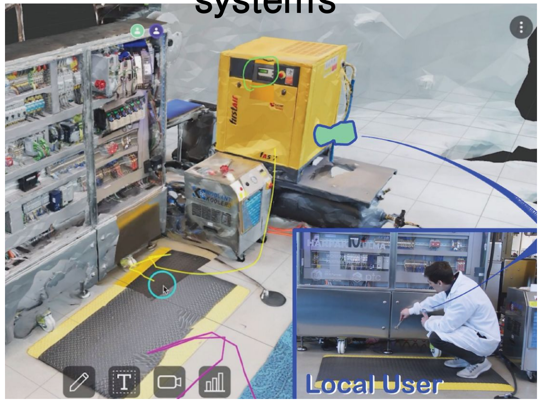
## Open Source

• Envisioned papers (62.5%) vs. Addressed (34.8%)



# 1. Interactive Experiences

### Collaborative systems




Pop-up Metaverse, Reynolds et.al

### Avatar&Agents

VOODOO XP, Tran et.al

### Medical & Industrial Applications

AnthroNeRF, Zou et.al

### Interaction Mechanism

VR-GS, Jiang et.al

**Challenges** :

- **Dynamic** object changes
- Complex manual setup
- **Speed vs. fidelity** trade-off

**Opportunities** :

- Richer physics-based interaction
- Move from **XR-showcase to XR-study**
- Multimodal and multisensory interaction
- Hybrid representations

XR-addressed(5)
XR-showcase(15)
Open source(9)

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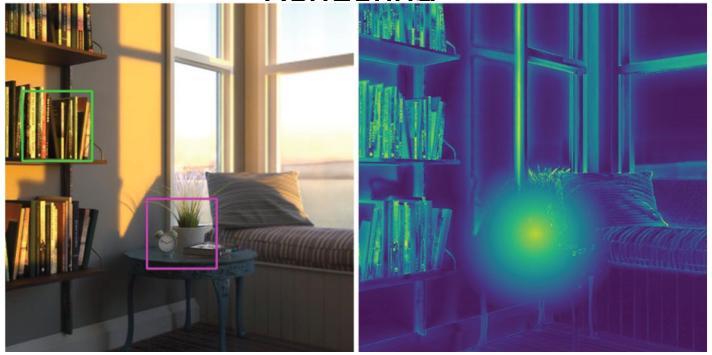
# 2. User-centric Rendering

**Foveated Rendering**



VPRF, Wang et. al

**Omnidireaction & light field**

OmniPlane, Kou et.al

## Challenges:

- Multi-resolution synthesis: retraining & storage intensive
- Real-time saliency for complex/dynamic scenes
- **Aliasing** degrade user experiences

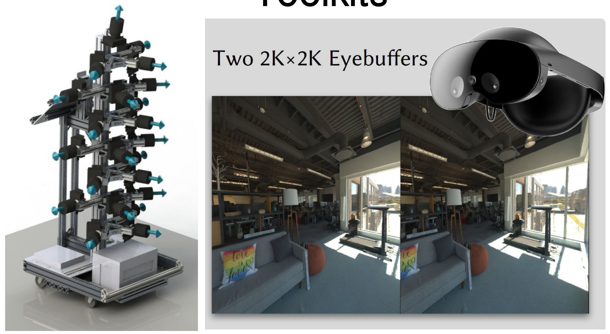
## Opportunities :

- Storage-efficient data structure & representations
- Dynamic scene handling via video **saliency prediction**
- **Real-world** integration beyond psychophysics experiments

XR-addressed(5)
XR-showcase(3)
Open source(1)

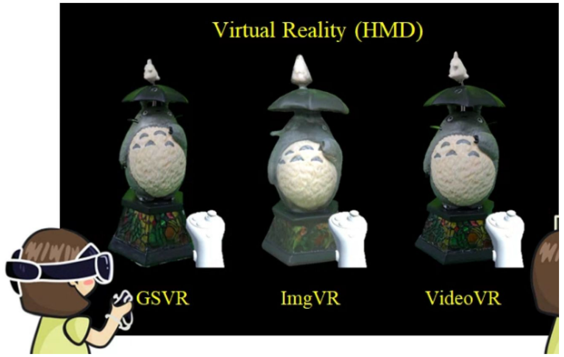
# 3. Benchmarking & Toolkit

### Frameworks & Toolkits




VR-NeRF, Xu et.al

### User Evaluation & Pilot Testing




Is 3DGS Useful? Kim et.al

XR-addressed (4)
XR-showcase (4)
Open source (2)

**Challenges:**

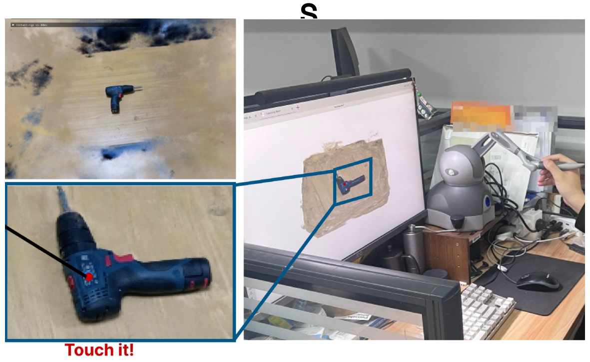
- Lack of **standardization** for RF in XR
- **Interoperability** issues between neural rendering with traditional graphics pipeline
- Limited user-centric benchmarking

**Opportunities** :

- **Standardized** benchmarking framework for XR
- Improve accessibility, e.g. enhance single-shot technique
- Gaze/motion prediction for reducing streaming/rendering latency
- Comprehensive user evaluation (e.g. IPQ, SSQ, QoE, etc)

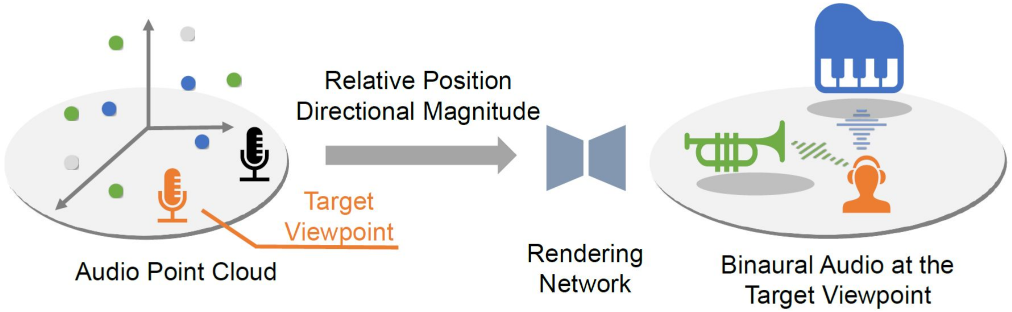
# 4. Multimodal & Multi-sensory RF

Haptic
s




Haptics Rendering of NeRF, Zhang et.al

Audio




Extending GS to Audio. Yoshida et.al

XR-addressed (1)
XR-showcase (2)
Open source (0)

**Challenges:**

- Lack of **precise geometric** information
- High refresh rate haptics require additional compute resource
- Multi-modal and multi-sensory **data synchronization**

**Opportunities**:

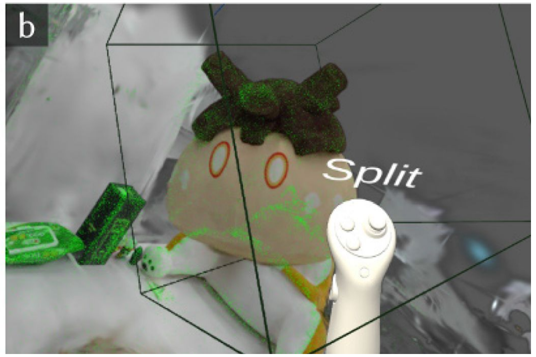
- Extend to other sensory or data modalities
- Infer material or textile-level feedback from visual info
- Unification and **synchronization**

# 5. Content Editing

### Object Insertion or Removal

DimSplat, Waldow et.al

### Segmentation and decomposition




GaussianShopVR, Shen et.al

### Interactive Color Editing


Palette Gaussian, Ren et.al

**Challenges** :

- **Relighting** and simulating intricate lighting effects (e.g. multi-bounce)
- Current methods limited to static scenes
- Heavy pre-processing still required

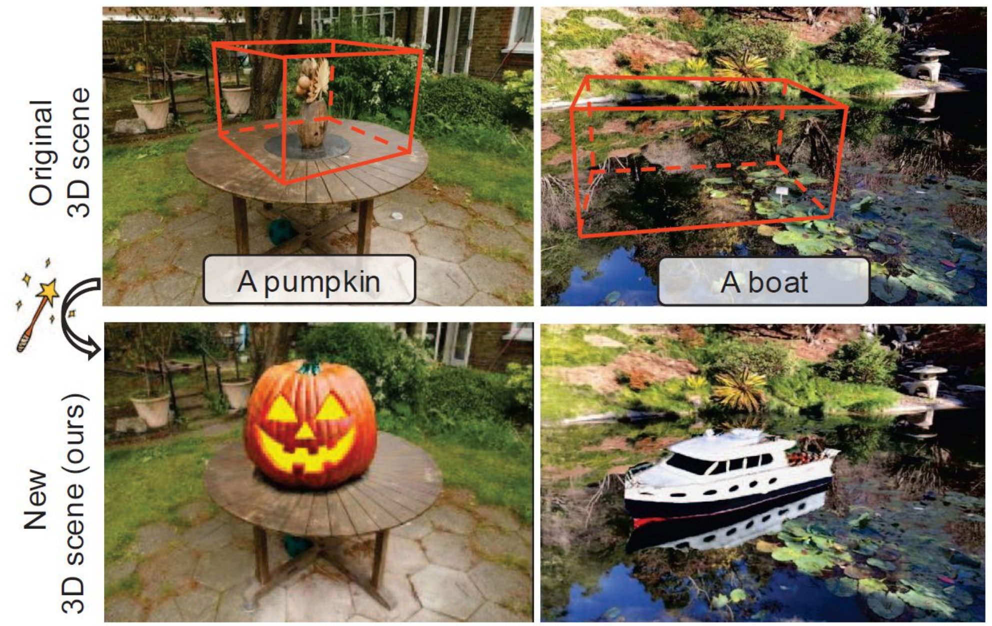
**Opportunities** :

- Limited in depth technical benchmark and user evaluation
- More diverse and innovative **interaction design paradigm**

XR-addressed (3)
XR-showcase (7)
Open source (3)

# 6. Content Generation

Text-to-3 D




Go-NeRF, Dai et.al

<u>Challenges:</u>

- **Consistency** between generated objects and existing scenes (e.g. realistic lighting)
- High text-to-3D latency
- Physical realism is limited, particularly for MR

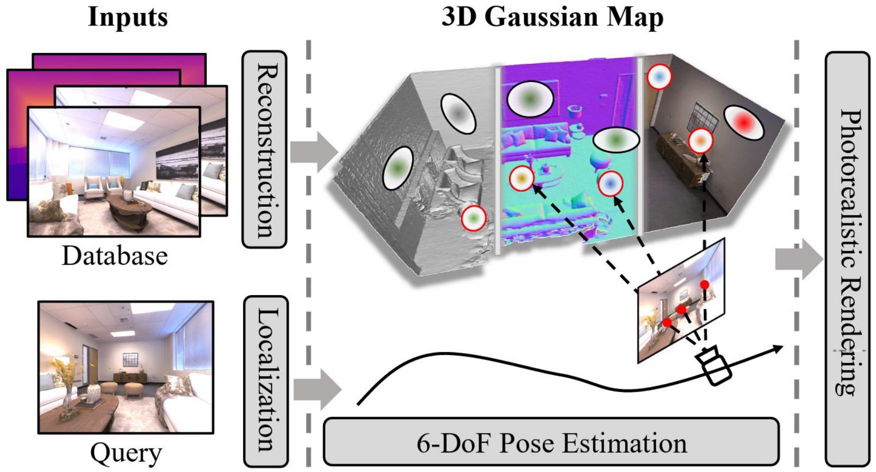
<u>Opportunities</u> :

- Investigate realistic inpainting and blending
- Intuitive authoring interface
- Usability study between different 3D content authoring methods
- Extend to **real-world immersive MR**

XR-addressed (1)
XR-showcase (1)
Open source (0)

# 7. Spatial Registration

Inverse pose estimation/ cam param optimizations




SplatLoc, Zhai et.al

**Challenges:**

- **Accurate, efficient** registration with XR
- Mobile device has limited compute, particularly for dynamic environment
- Better scene initialization and relocalization

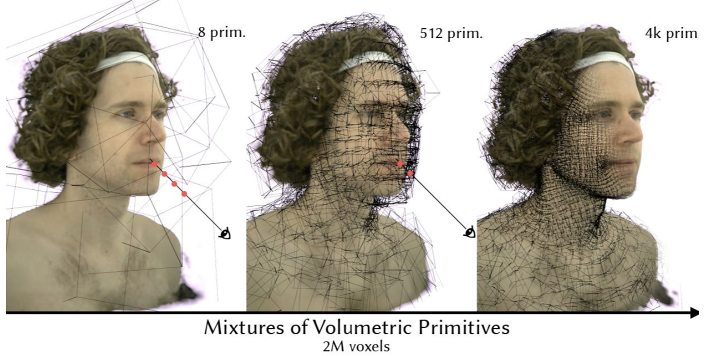
**Opportunities:**

- Integrate **registration** tightly with **real-time rendering**
- Lightweight, efficient XR registration pipelines for **mobile devices**

XR-addressed (1)
XR-showcase (1)
Open source (2)

# 8. Dynamic Capture

Dual 3DGS for Immersive Human Volumetric Video, Jaing et al




Mixture of Volumetric Primitive, Lombardi et.al

**Challenges:**

- **No XR-addressed** (n=0)
- High computational cost with avatar rendering
- Real-time, high-fidelity dynamic scene capture & rendering not yet achieved for XR

**Opportunities** :

- How photorealistic dynamic avatars are **perceived** (e.g. IPQ, embodiment, **uncanney valley** )
- Robust dynamic scene reconstruction for XR

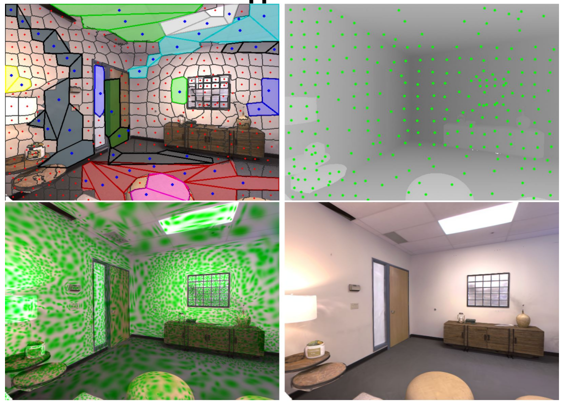
XR-addressed (0)
XR-showcase (5)
Open source (2)

# 9. Optimization Techniques

## Resource constrained Rendering

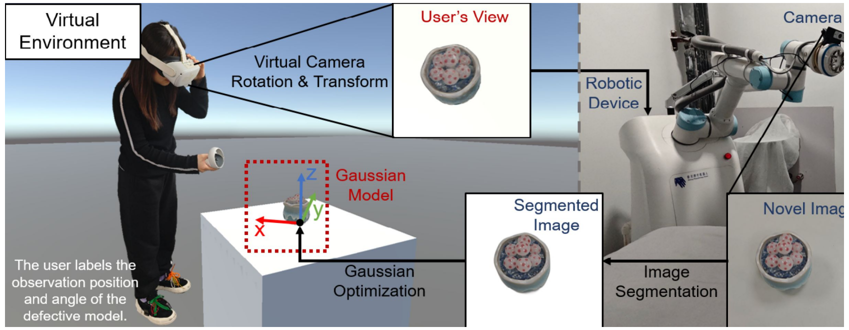
Re-ReND, Rojas et.al

## Compressio
n



Superpixel-guided sampling for
3DGS compression, Kim et.al

## Capturing Improvement




Human in the loop capturing, Dongye et.al

**Challenges** :

- On the fly capturing  for XR
- 3D/4DGS scalability
- Conversions (e.g. NeRF→ mesh)
- Speed vs. memory trade-off

**Opportunities** :

- Scene-aware 3D reconstruction
- Optimize for physics-based interactions and haptics
- Improve RF performance on mobile (speed + memory)

XR-addressed (4)
XR-showcase  (4)
Open source  (2)

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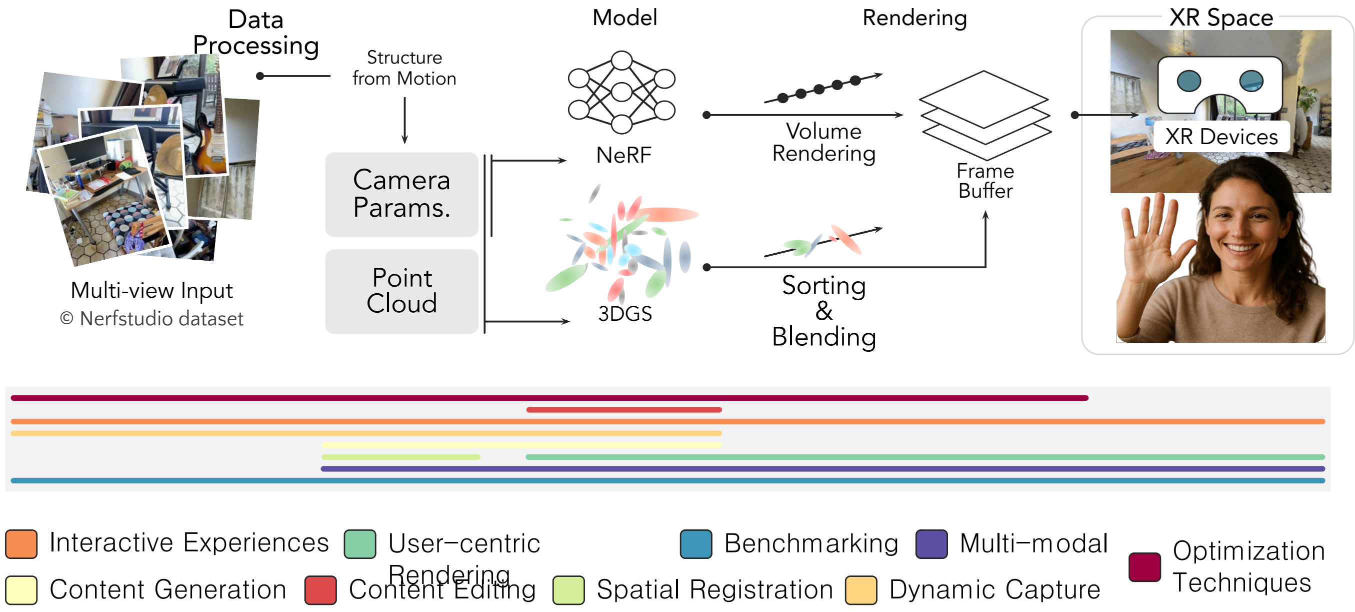
# Conclusion s

- Nine key themes of RF for XR
- Majority of XR implementation remains XR–showcase/XR–envision
- XR–Addressed OSS is limited
- Limited <u>**ethical considerations**</u>



## Awesome RF4XR Repo

https://github.com/mediated-reality/awesome-rf4x
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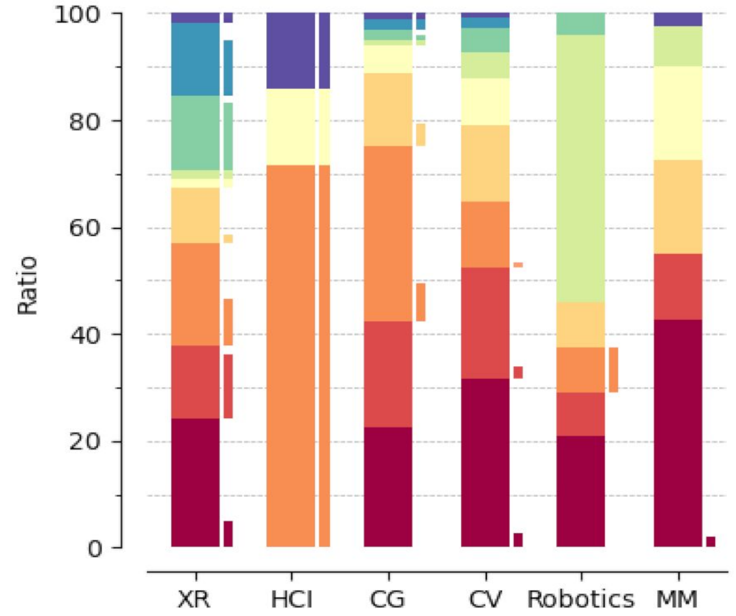
## Project Page

https://mediated-reality.github.io/rf4xr/papers/li_tvcg25/

# Trends & Observations




## <u>Communities & Interests</u>

- XR + HCI → more **practical implementations** (XR-Addressed)
- CV + CG + Robotics + MM → mostly **envision**
- Non-XR communities provide technical advances but limited system-level validation

Interactive Experiences | User-centric Rendering | Benchmarking | Multi-modal | Optimization Techniques
Content Generation | Content Editing | Spatial Registration | Dynamic Capture