A Hand-on Tutorial on NeRF for XR Applications

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T2: A PRACTICAL GUIDE TO RADIANCE FIELDS FOR XR RESEARCH AND APPLICATIONS

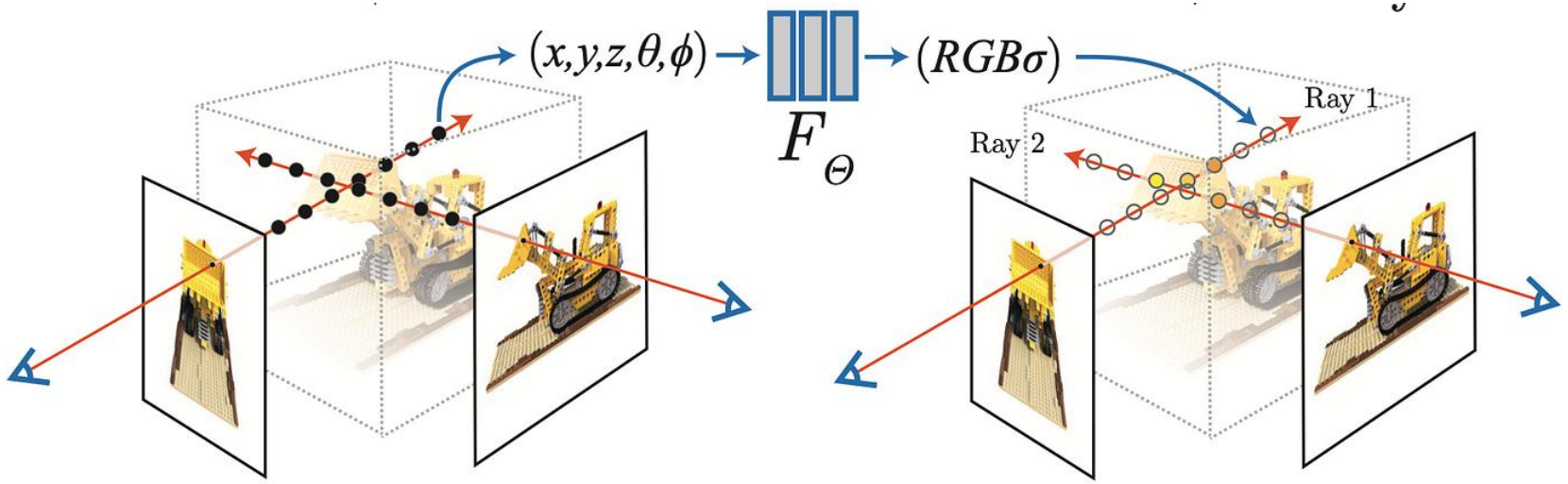
IEEE IEEE COMPUTER SOCIETY IEEE COMPUTER SOCIETY VGTC Inria

Agenda

- Brief introduction to **NeRF**
- Brief introduction to **instant-ngp**
- Introduction to **immersive-ngp**
- Live tutorial on immersive-ngp toolkit
  - Scene rendering in VR
  - Interaction & editing
  - Performance consideration

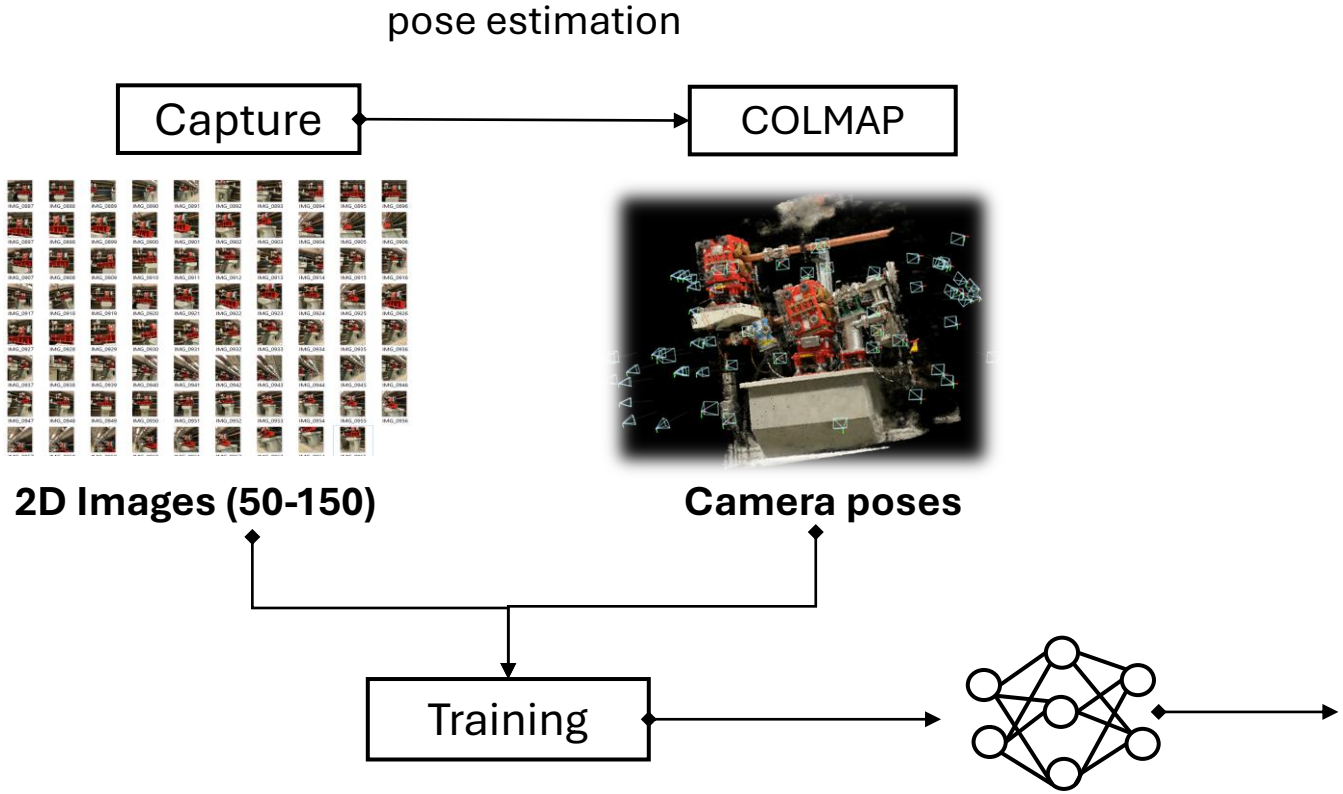
Neural Radiance Fields (NeRF)

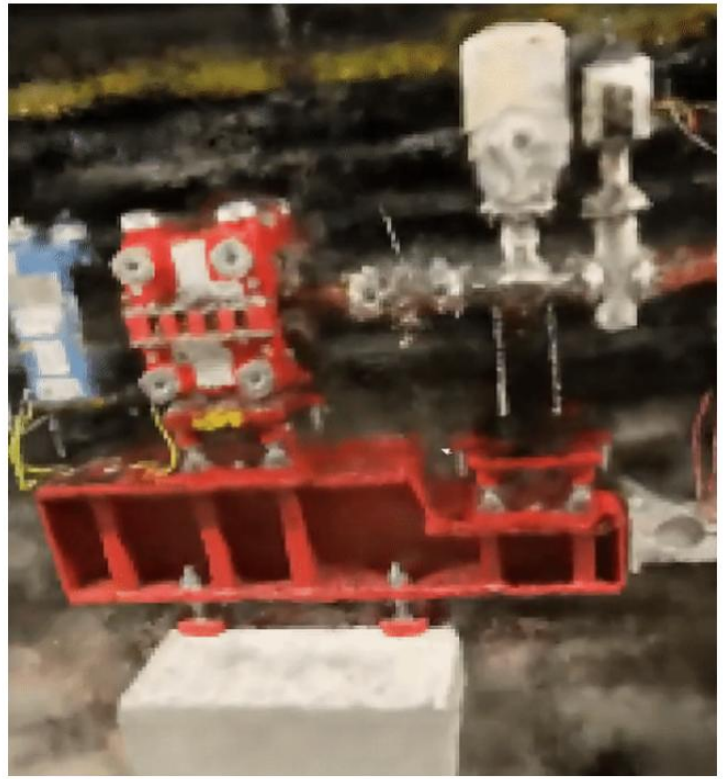
Neural network can learn from 2D images through gradient descent, therefore, **compressing** the 3D scene representation to a small scene function.



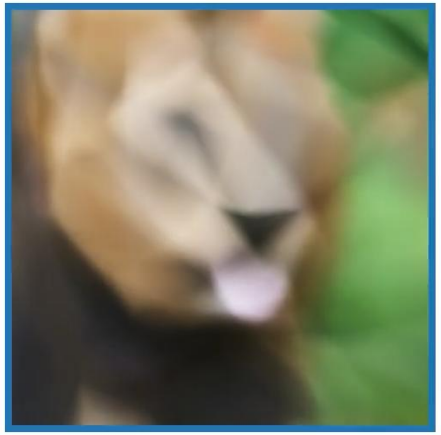
Mildenhall, B., Srinivasan, P.P., Tancik, M., Barron, J.T., Ramamoorthi, R., & Ng, R. (2020). NeRF. *Communications of the ACM, 65*, 99 - 106.

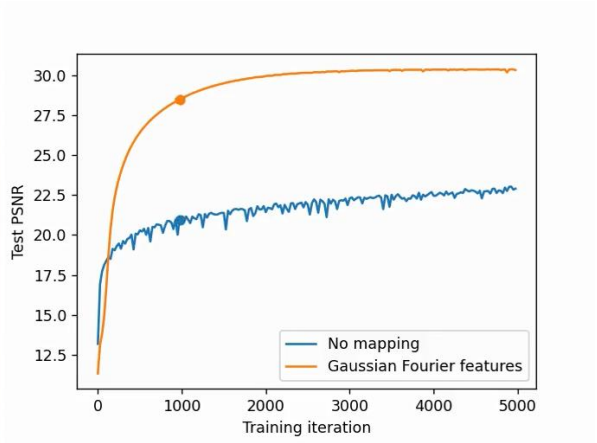
Neural Radiance Fields (NeRF) Generation





Positional Encoding: the Key to NeRF‘s Success

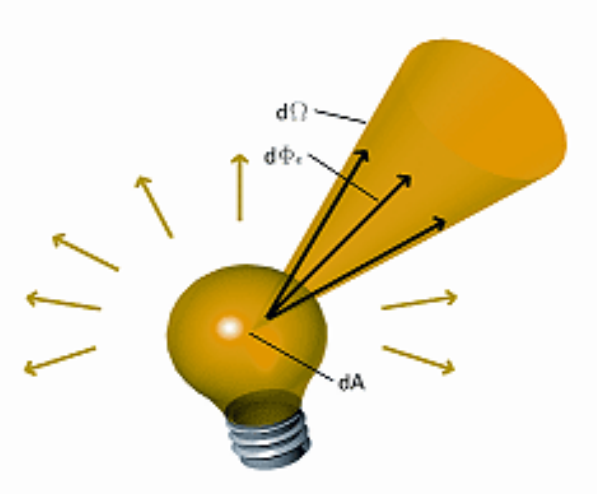


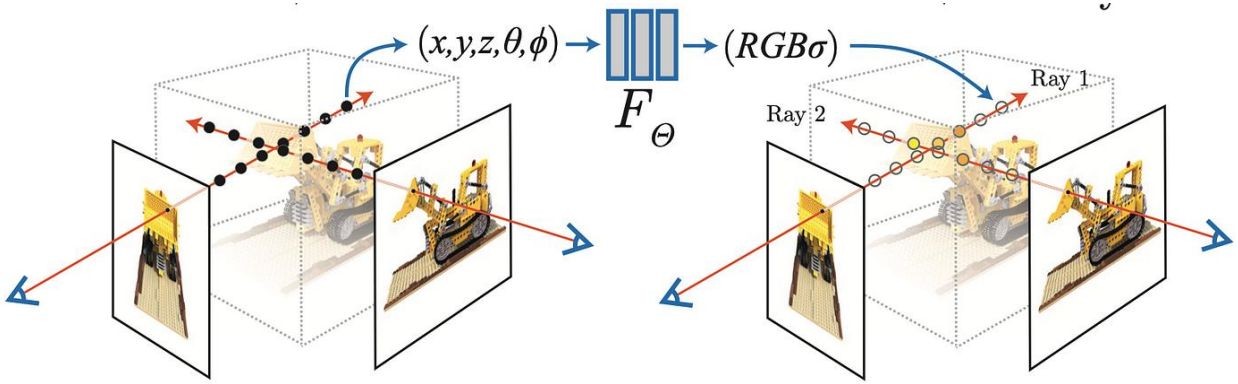


- Neural networks tend to have a bias against low frequency functions
  - But most image details are high frequency features (like fine surfaces, sharp edges, or order small-scale variations, reflections, etc)
  - Apply a fourier feature network to the input position p to transform it to high dimensional space

$$\gamma(p) = \left(\sin\left(2^0\pi p\right), \cos\left(2^0\pi p\right), \cdots, \sin\left(2^{L-1}\pi p\right), \cos\left(2^{L-1}\pi p\right)\right)$$

What does Radiance Fields Actually Mean?

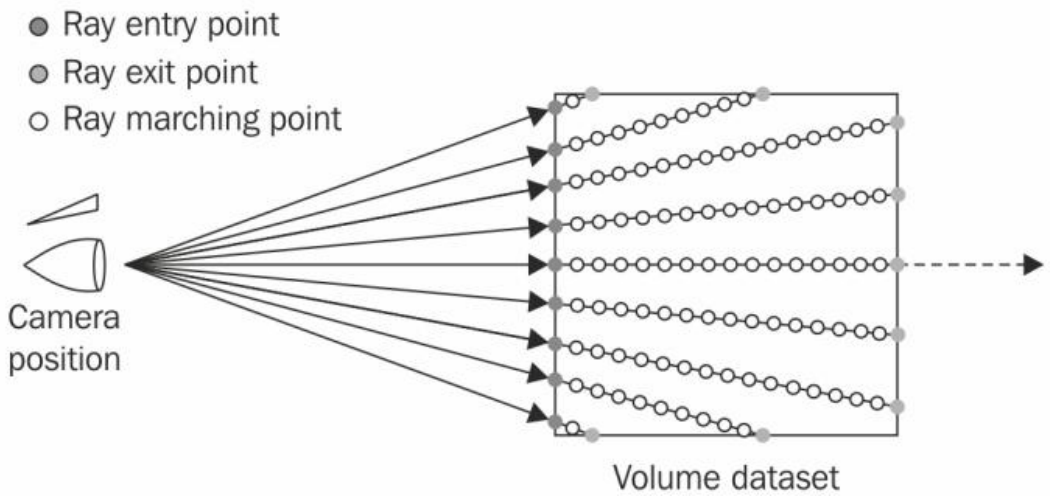




Radiance characterizes how a surface emit, reflect, transmit, or absorb light.

In NeRF, it characterizes how each point in the scene emits light (e.g, which color is the light, at what intensity/opacity) at different viewing angles

How is NeRF rendered?



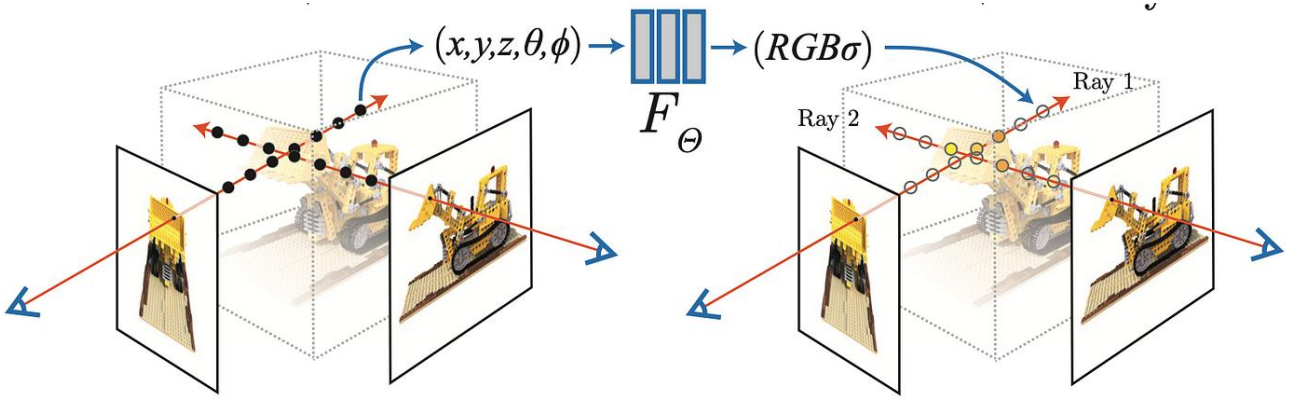
- NeRF can be rendered through the classic volume rendering equation

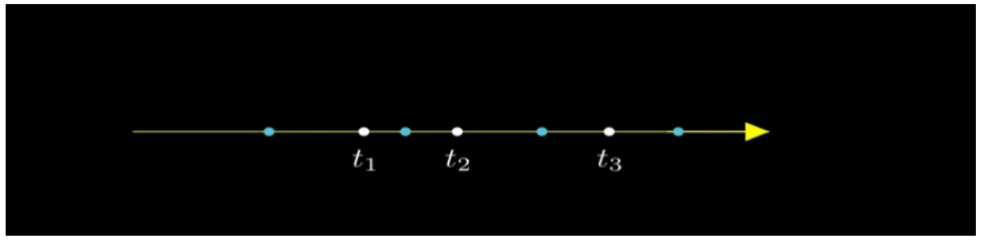
$$C(\mathbf{r}) = \int_{t_n}^{t_f} T(t)\sigma(\mathbf{r}(t))\mathbf{c}(\mathbf{r}(t), \mathbf{d})dt\,, \text{ where } T(t) = \exp\left(-\int_{t_n}^{t} \sigma(\mathbf{r}(s))ds\right)$$

with r(t) = ray point at distance t, d = view-direction,

σ(x) = density, c(x) = color

Volume Rendering through NeRF can be Super Expensive!





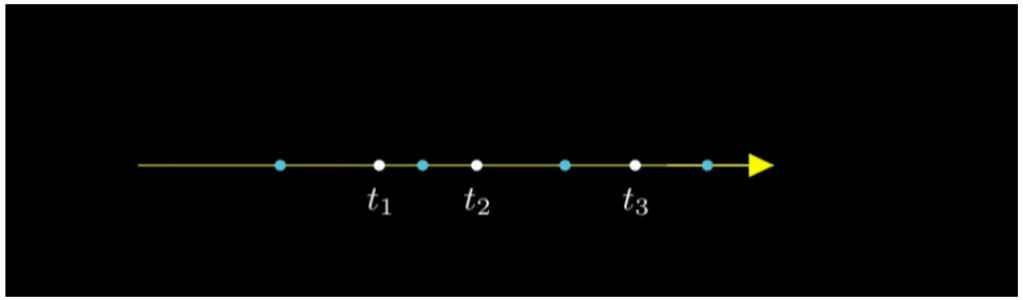
$$P_{(h,w)} = R_h \times R_w \times N_{\boldsymbol{r}(t)} \times \overline{F}$$

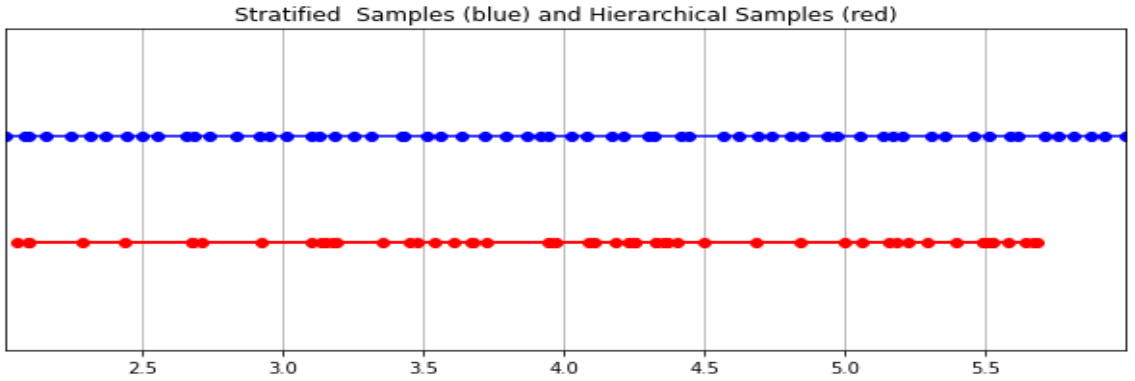
spacial-temporal trade off

A high resolution image can take > 30s to render!

Hierarchical Sampling

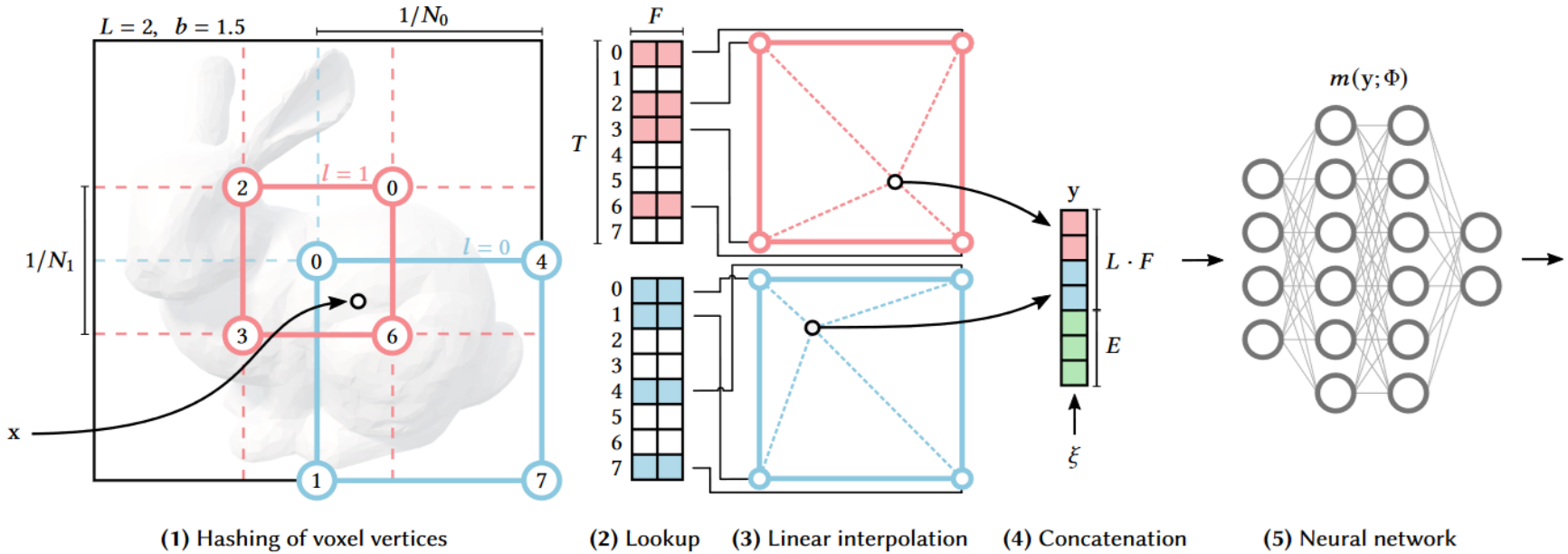
- We don‘t want to evenly sample every ray
  - Adjust the density of the sample points based on the required level of detailed





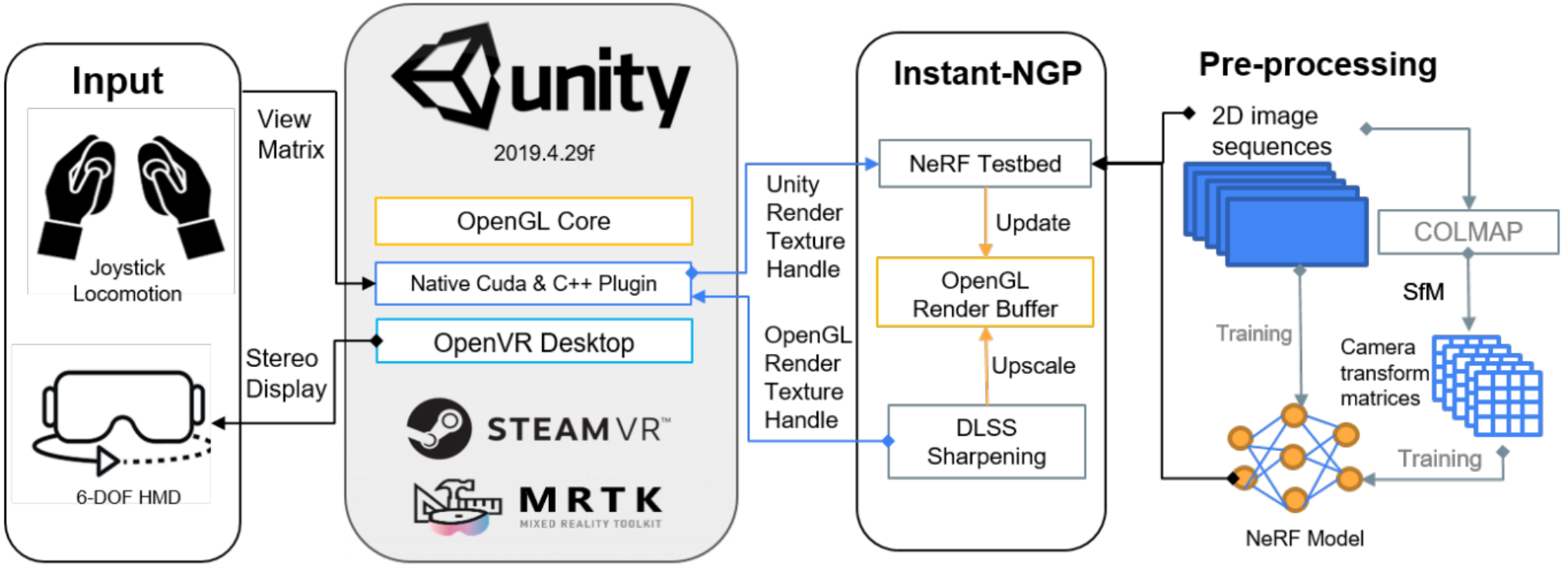
Instant Neural Graphics Primitives (Instant ngp)

- Learn a multi-resolution positional encoding instead of precomputing it



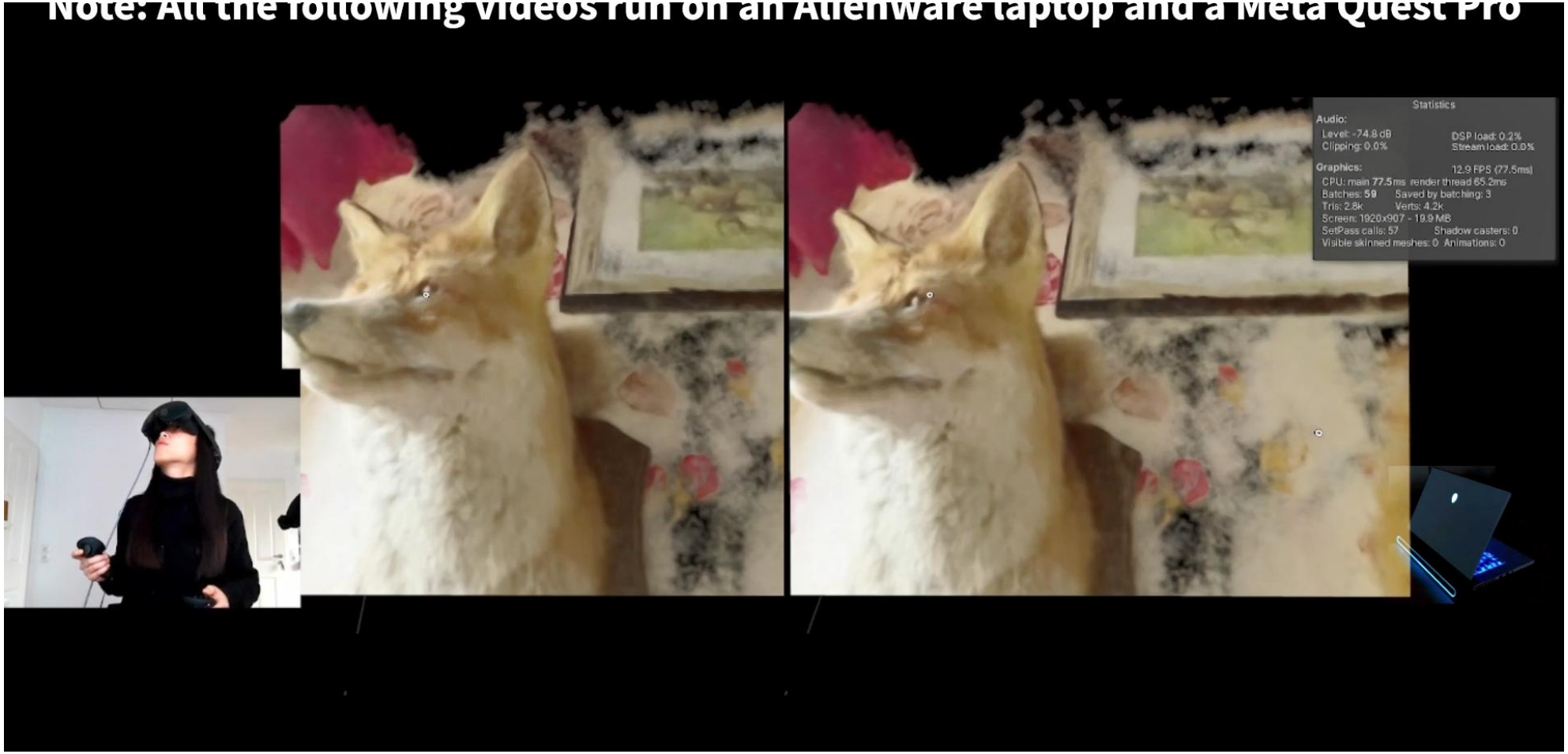
Müller, T., Evans, A., Schied, C., & Keller, A. (2022). Instant neural graphics primitives with a multiresolution hash encoding. *ACM Transactions on Graphics (TOG), 41*, 1 - 15.

Immersive-ngp

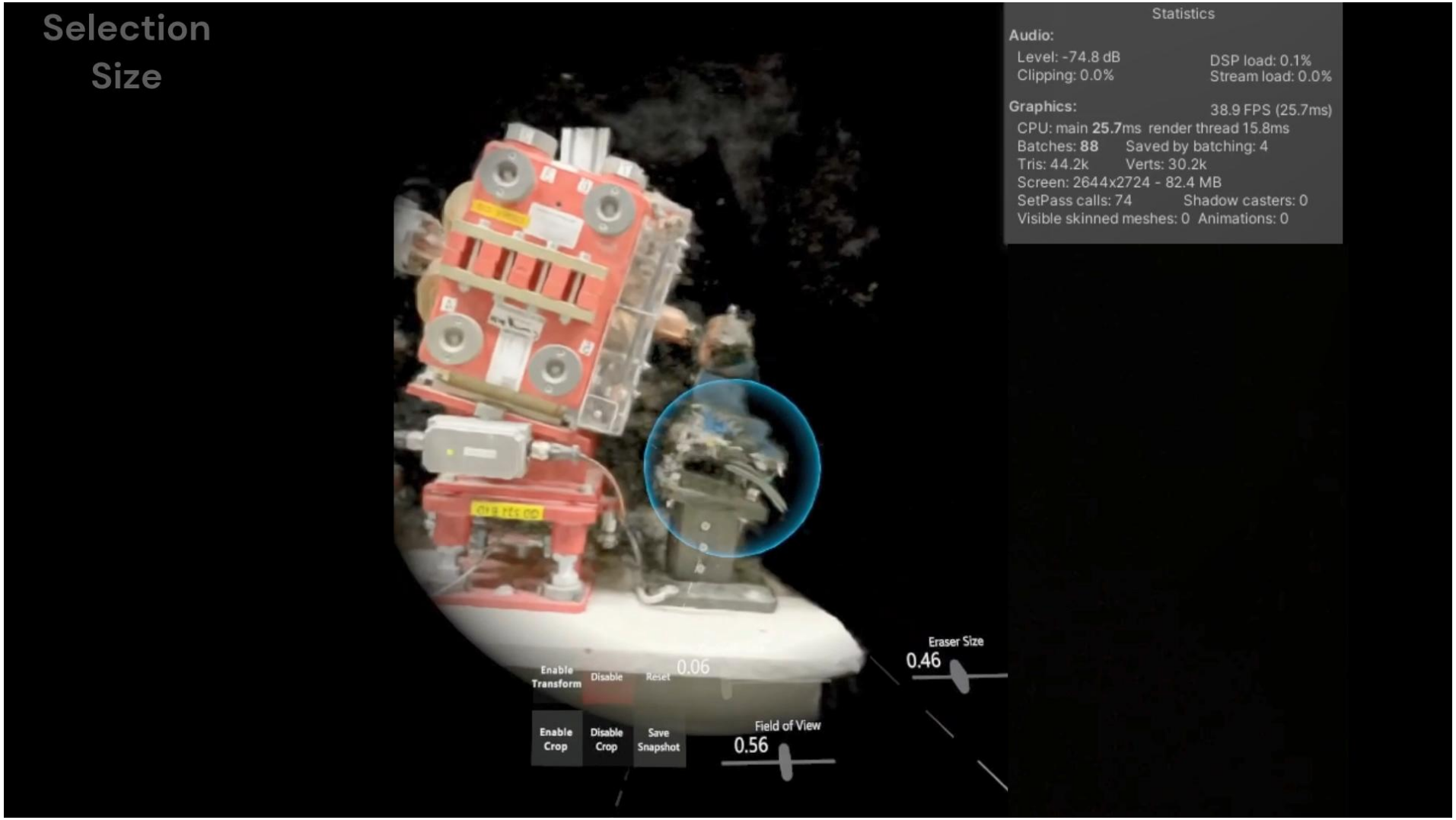


[1] **K.Li*, T.Rolff***, S. Schmidt, R.Bacher, W.Leemans , S.Frintrop, F.Steinicke:Bringing Instant Neural Graphics Primitives to Immersive Virtual Reality, IEEE Conference on Virtual Reality and 3D User Interfaces (IEEE VR) 2023, (2 pages)

Rendering NeRF in immersive VR

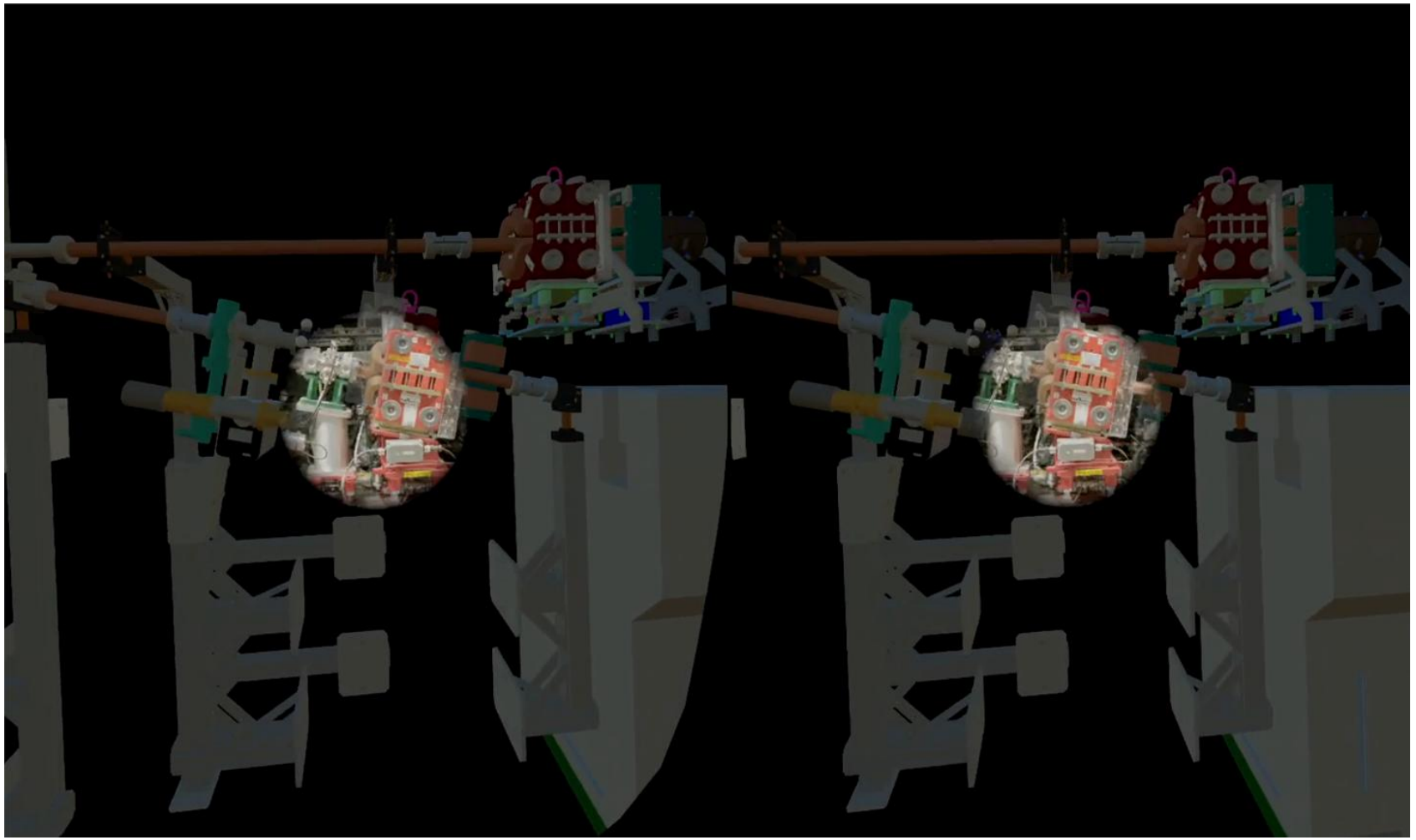


Voxel-wise 3D Edition on NeRF [1]



Interactive Contextual Visualization

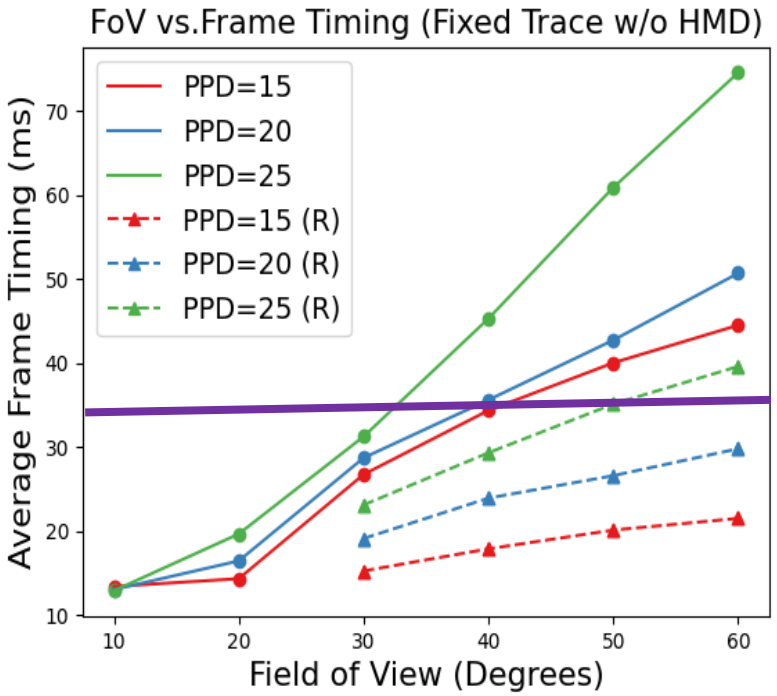
Magic NeRF Lens Effects

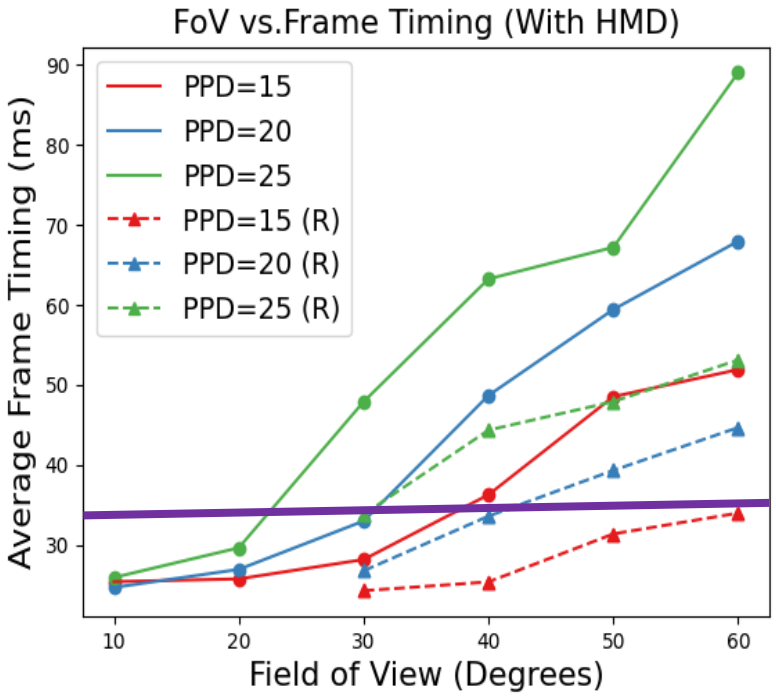


Li, Ke et al. “Magic NeRF Lens: Interactive Fusion of Neural Radiance Fields for Virtual Facility Inspection.” *ArXiv* abs/2307.09860 (2023)

Live Demo

Performance benchmark

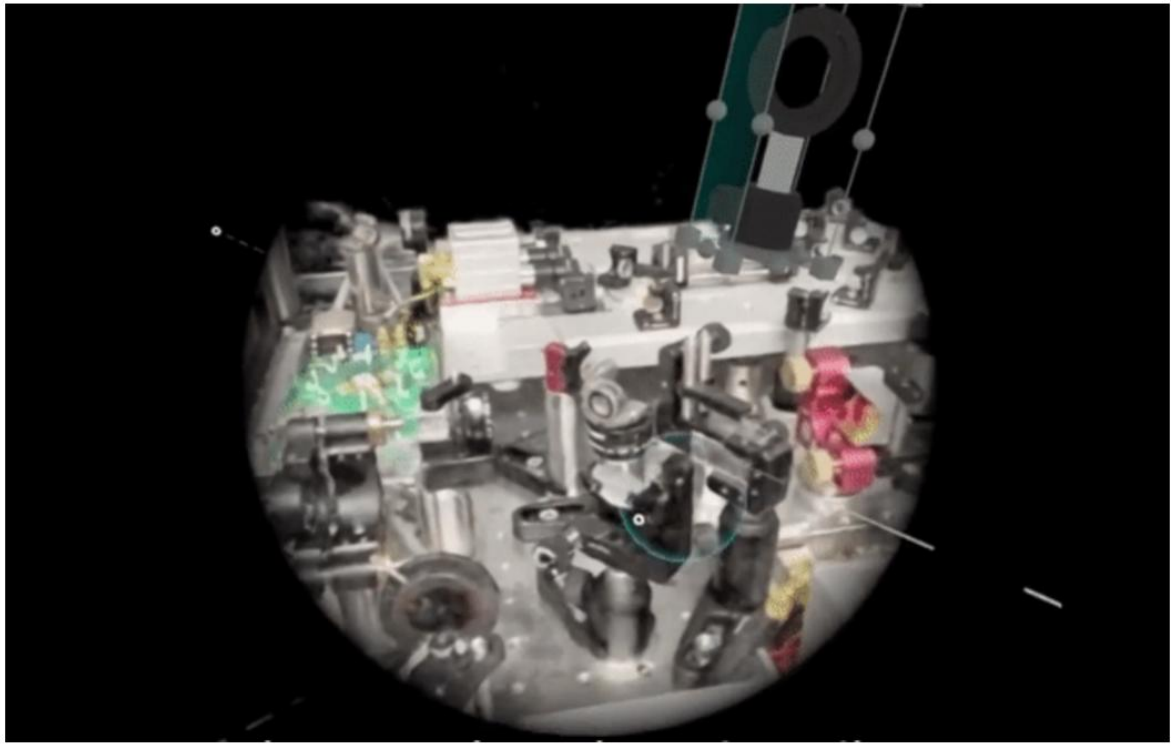


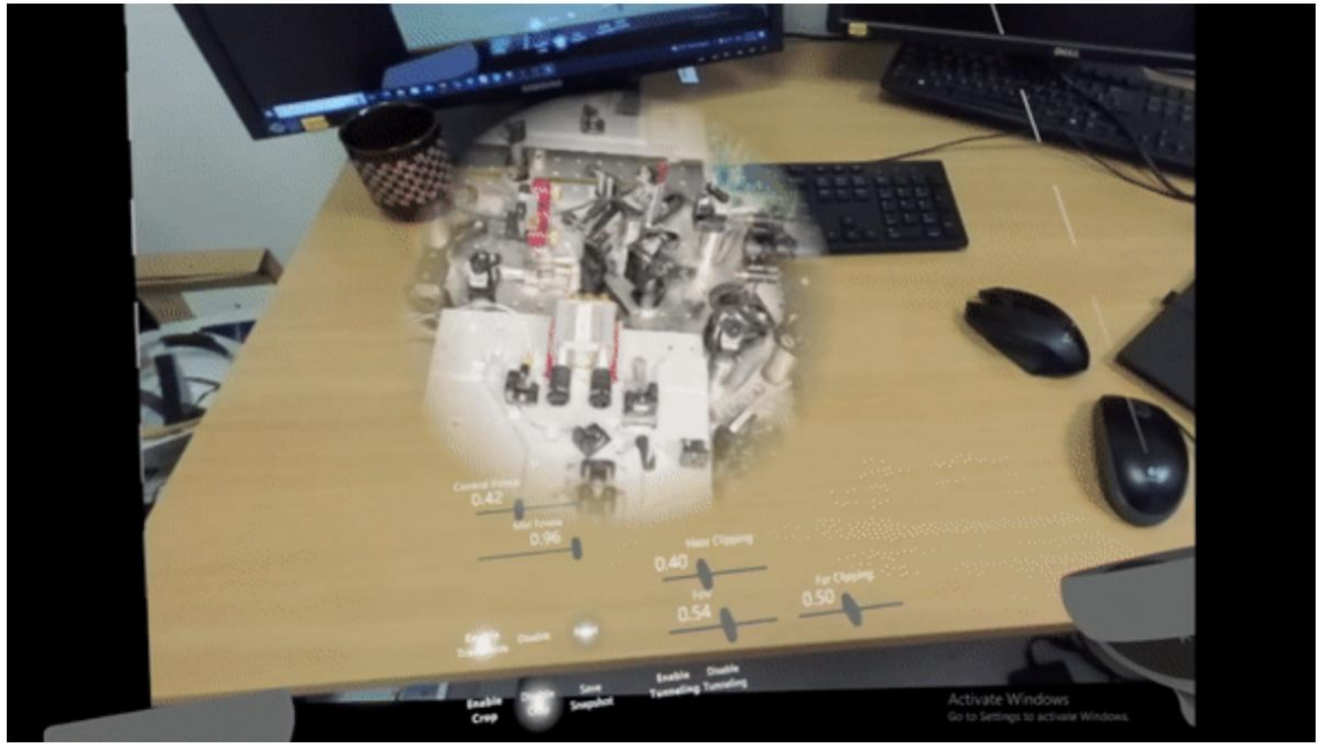


Optimal configuration at one-to-one real-world size is **20 PPD at 30° FoV, 15 PPD at 40° FoV** (RTX 3090 GPU)

Li, Ke et al. “Magic NeRF Lens: Interactive Fusion of Neural Radiance Fields for Virtual Facility Inspection.” *ArXiv* abs/2307.09860 (2023)

NeRF in Immersive MR [1]





1. **K Li**, T.Rolff, R.Bacher, F.Steinicke: RealityGit: Cross Reality Version Control of R&D Optical Workbench, at IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct) 2023 (2 pages)

NeRF limitation

- **Interoperability**: Limited compatibility with standard 3D tools/pipelines.
- **High Compute Cost**: Resource-heavy volumetric rendering.
- **Limited interactbility**: Implicit representation complicates geometry-based editing & interaction.
- **Sparse View Artifacts**: Hallucinates details with insufficient input views.
- **Pose Sensitivity**: Requires precise camera calibration; errors degrade quality.