Neural Radiance Field

A novel, data-driven solution to the long-standing problem in computer graphics of the realistic rendering of virtual worlds.

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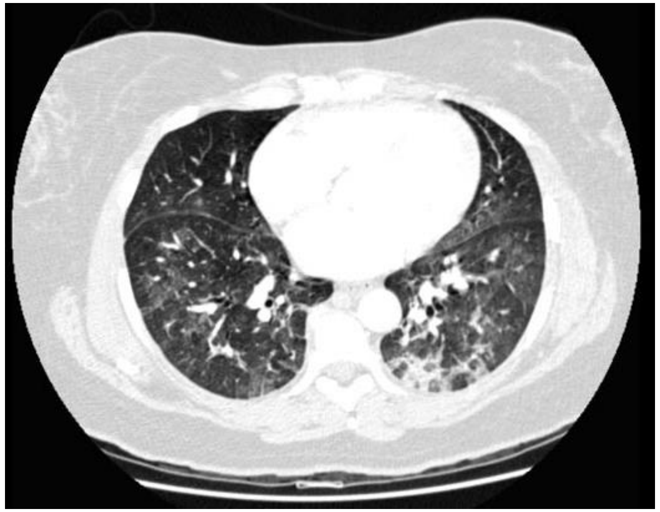
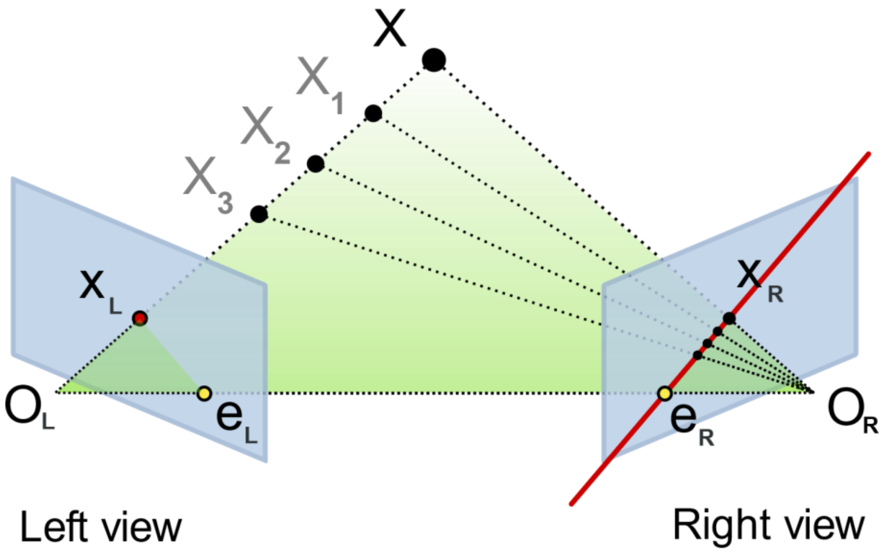
Overview

- Novel View Synthesis & Reconstructions
- Scene Representations
  - Neural Scene Representations
  - Light Field / Radiance Field
- Differentiable Rendering (TODO)
  - Volume Rendering
- Positional Encoding (Mip-NeRF)
- Sampling Strategies

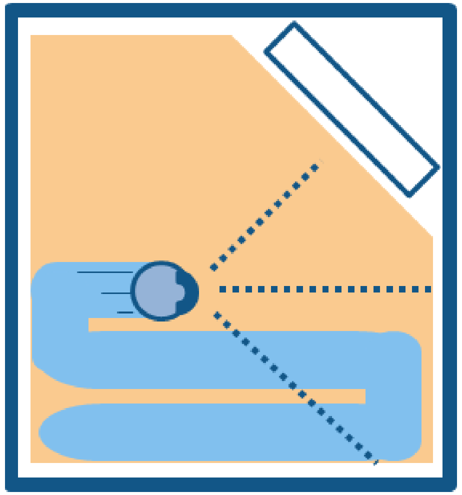
Novel View Synthesis & Reconstructions

- Photo-realistic rendering.
    - Rasterization / Ray tracing,
- Synthesizing views under camera viewpoint transformations from one or multiple input images.

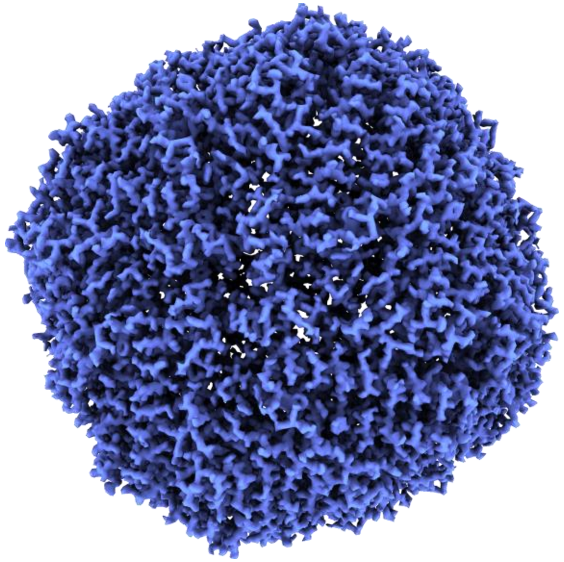




Epipolar Geometry



SLAM

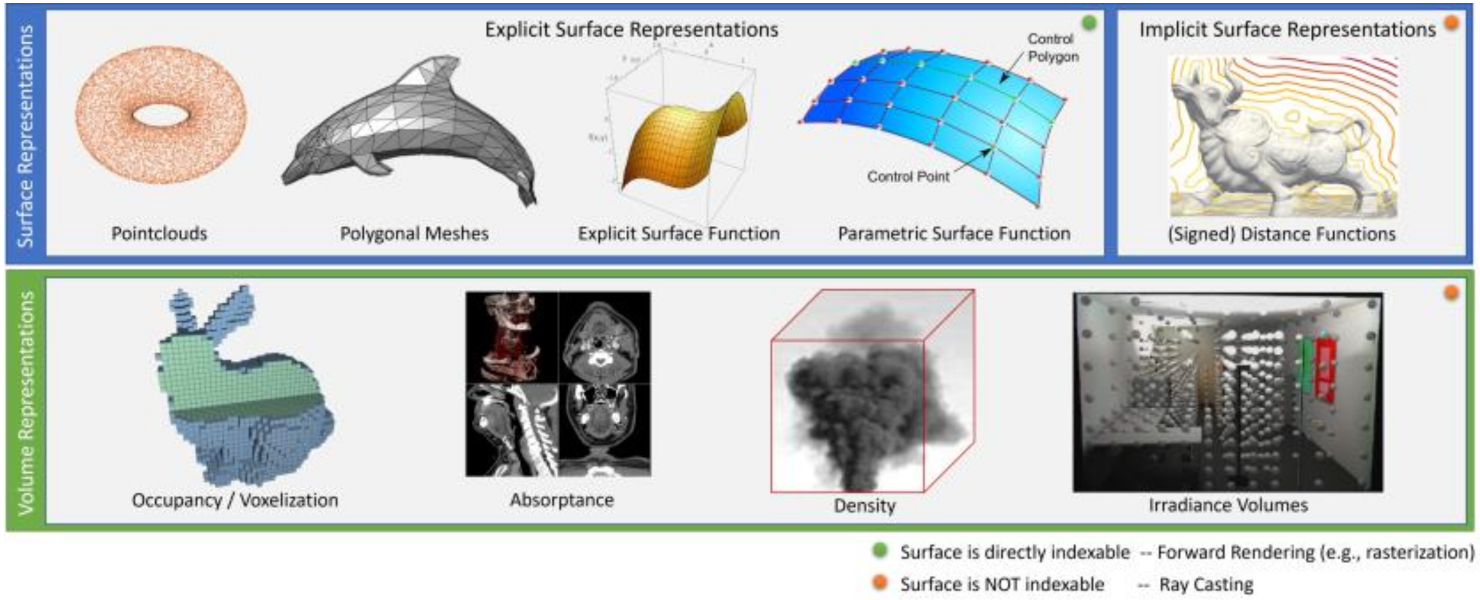


Scene Representations

- Specifically defined representations of geometry and material properties.
    - A scene consists of one or more objects.
- Surface and volumetric representations.
- Discretized and continuous representations.
- Explicit and implicit representations.

Surface and Volumetric Representations

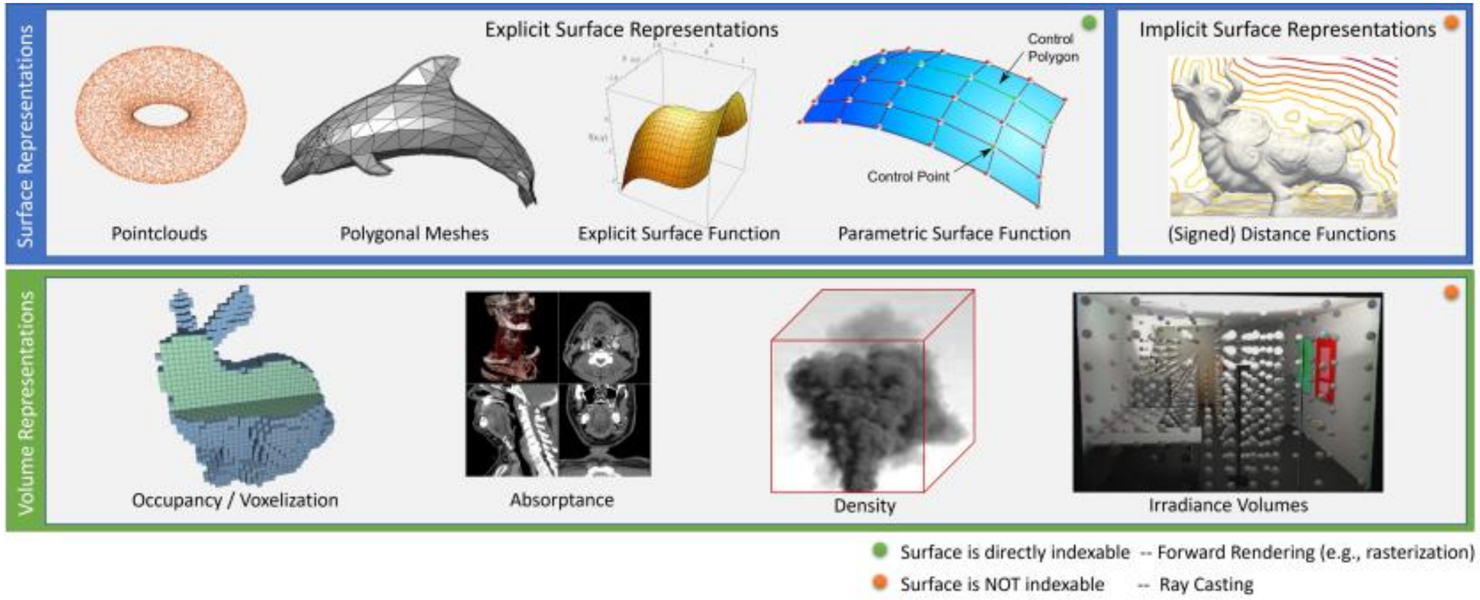
- Surface representations store property w.r.t. the surface such as colors, normal vectors or brdf.
- Volumetric representations volumetric properties such as densities, opacities or occupancies.



Discretized and Continuous Representations

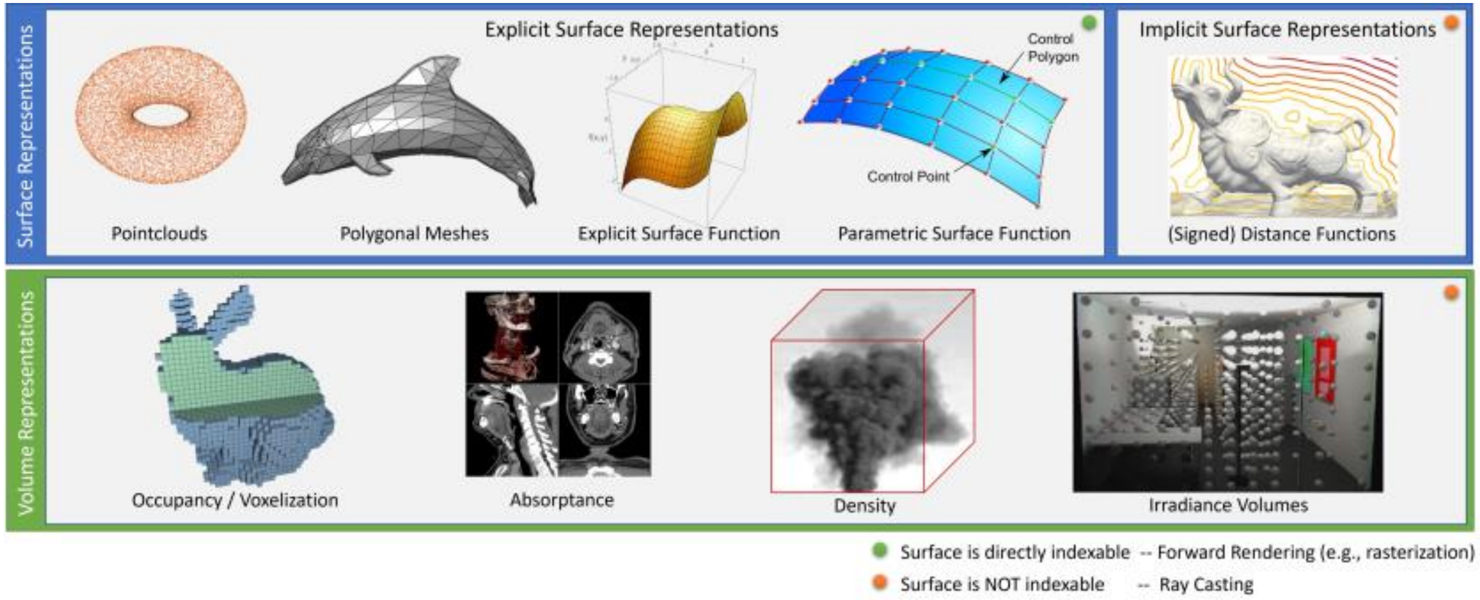
- For both surface and volumetric representations, there are continuous and discretized counterparts.

	Discretized	Continuous
Surface	Pointclouds, meshes	Parametric Surfaces, SDFs
Volumetric	Voxels, 3D textures	Neural Networks



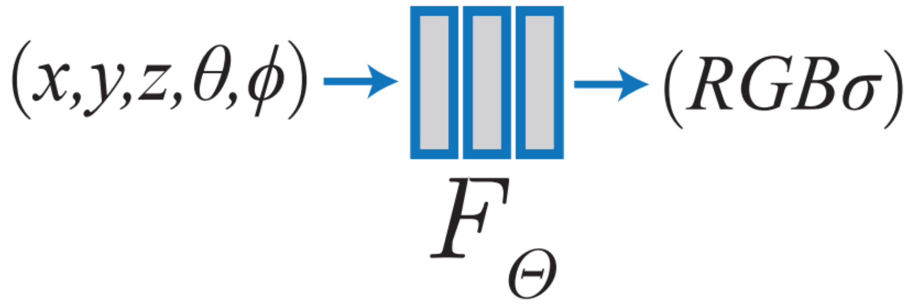
Explicit and Implicit Representations

- Explicit and implicit representation are meant to surface representations.
- Explicit: $y = f(x)$, i.e. $(u, v) \mapsto (\cos(u)\sin(v), \sin(u)\sin(v), \cos(v))$
  - Images/Textures, Pointclouds, Meshes, Parametric Surface, (Volumetric Representations).
- Implicit: $F(x, y) = 0 \Longrightarrow y = y(x)$, i.e. $x^2 + y^2 - 1 = 0$
  - Neural Network, Signed Distance Function/Level Set, Gaussian Mixtures.



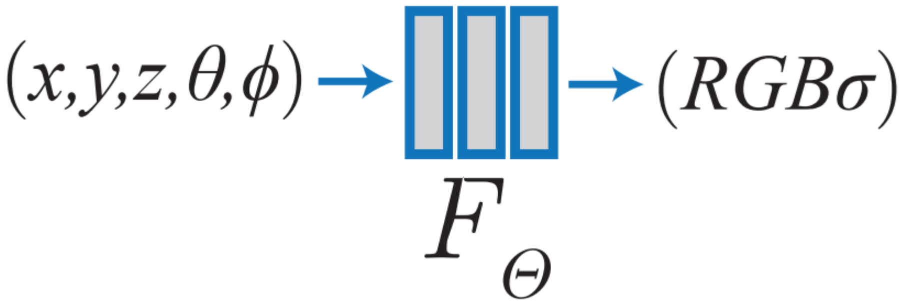
Explicit Continuous Volumetric Representations

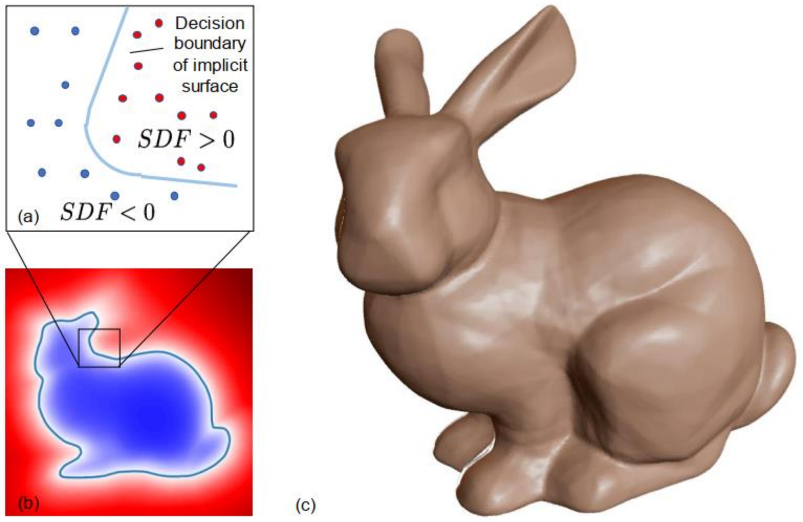
- NeRF can be categorized as explicit continuous volumetric representations.
  - Why not other representations?
- Explicit v.s. Implicit.
- Continuous v.s. Discretized.
- Surface v.s. Volume.
- Why some one says NeRF is implicit representation?
  - Embedding.



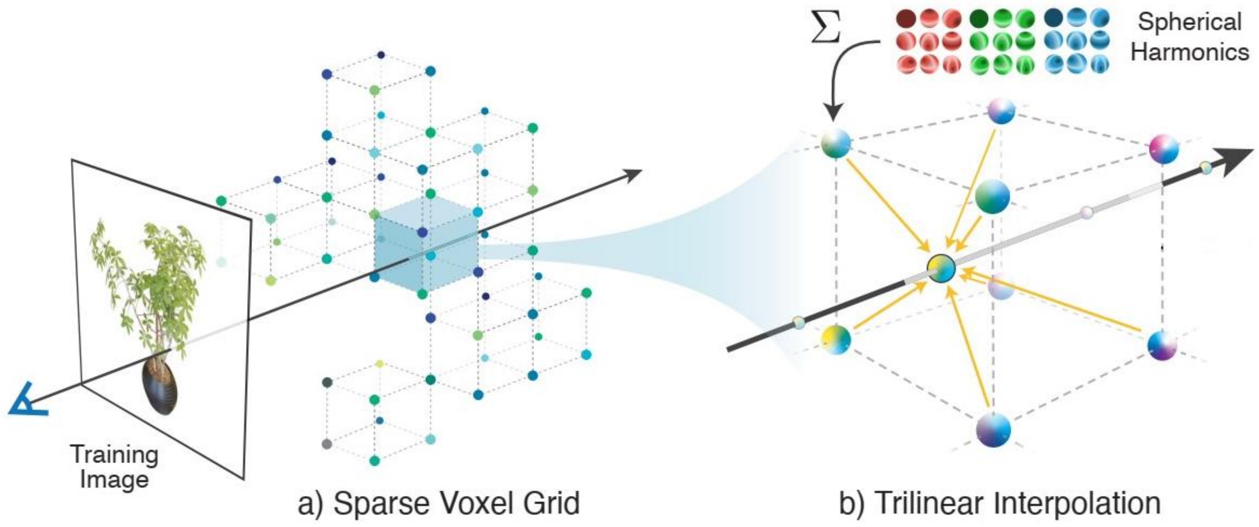
Neural Scene Representations

- NeRF can be categorized as neural scene representation.
- DeepSDF (Park et al. CVPR 2019)
- Plenoxels (Yu et al. CVPR 2022)





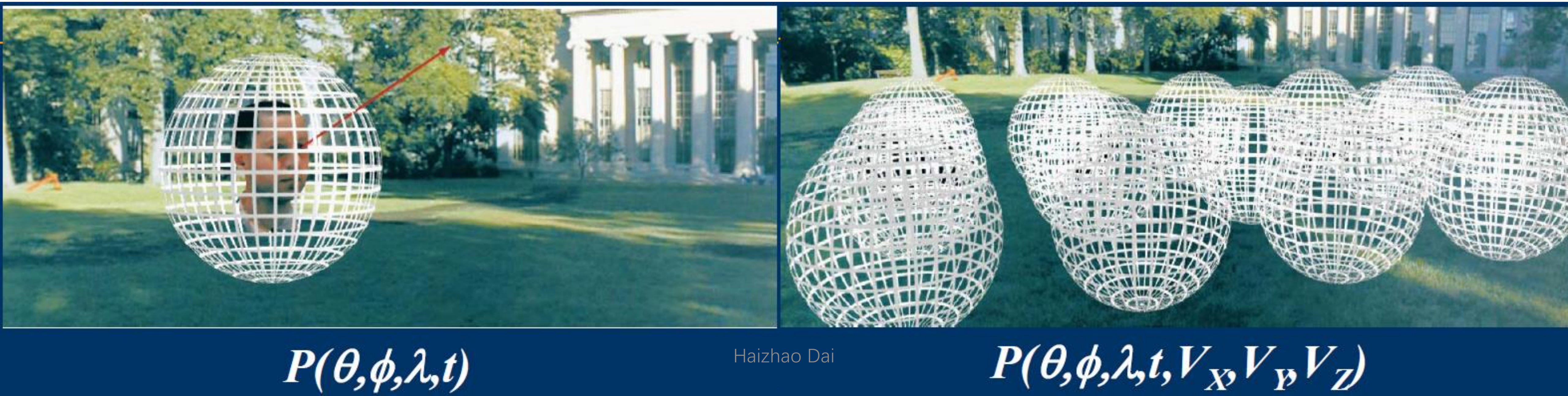
DeepSDF



Plenoxels

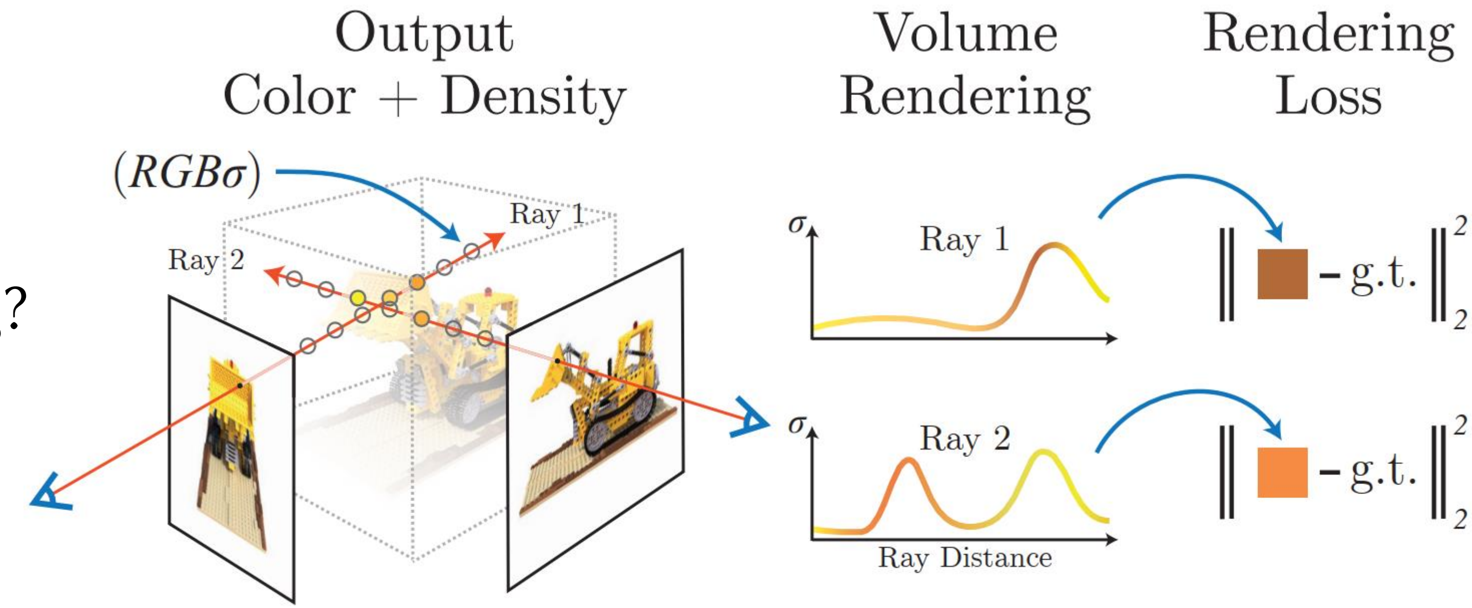
Light Field / Radiance Field

- The light field describes the amount of light flowing in every direction through every point in space at every time point.
- Plenoptic function: $L(x, y, z, \theta, \phi, \lambda, t)$.
- Substitute λ with RGB, t with different frame.



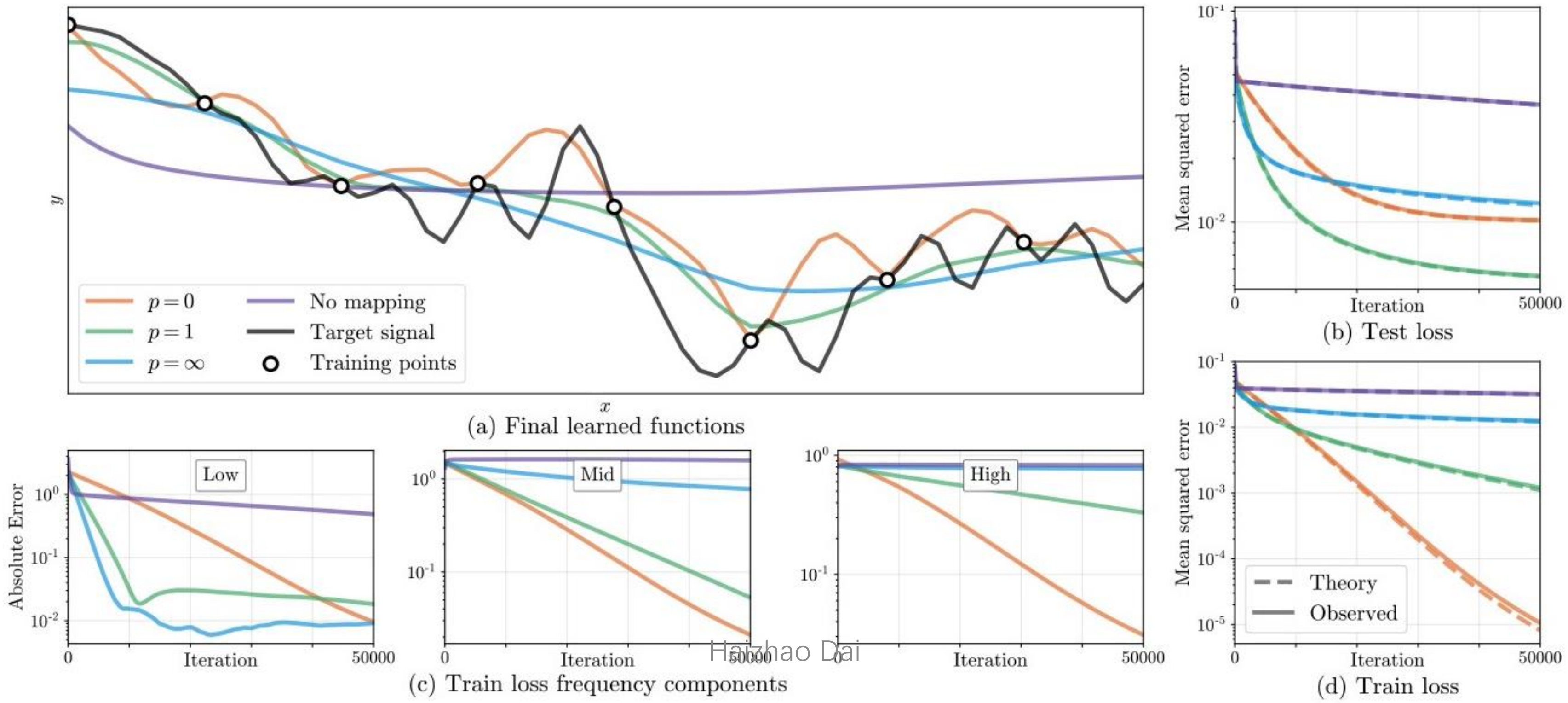
Differentiable Rendering

- Last week, we have introduced the volume rendering.
- Continuous:
  - $C(\boldsymbol{r}) = \int_{t_n}^{t_f} T(t)\sigma\big(\boldsymbol{r}(t)\big)\boldsymbol{c}(\boldsymbol{r}(t), \boldsymbol{d})\mathrm{d}t$
  - $T(t) = \exp(-\int_{t_n}^{t} \sigma\big(\boldsymbol{r}(s)\big)\mathrm{d}s)$
- Discretized:
  - $\hat{C}(\boldsymbol{r}) = \sum_{i=1}^{N} T_i \alpha_i c_i$
  - $T_i = \prod_{i=1}^{N}(1-\alpha_i)$
- What is differentiable rendering?
  - Inverse rendering



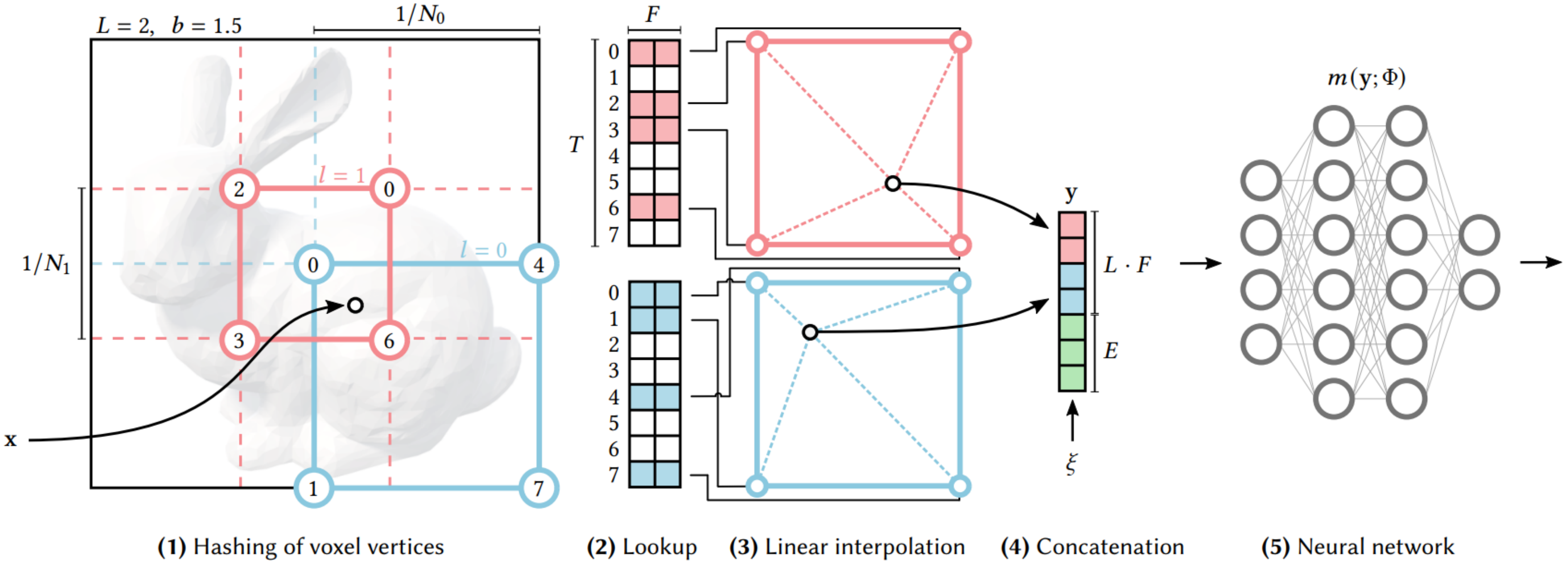
Positional Encoding

- Attention Is All You Need. (Vaswani et al. NeurIPS 2017)
- A mapping that maps input coordinates from low dimensional space to high dimensional encoding space.
  - Fourier Features Let Networks Learn High Frequency Functions in Low Dimensional Domains. (Tancik et al. NeurIPS 2020



Hash Encoding

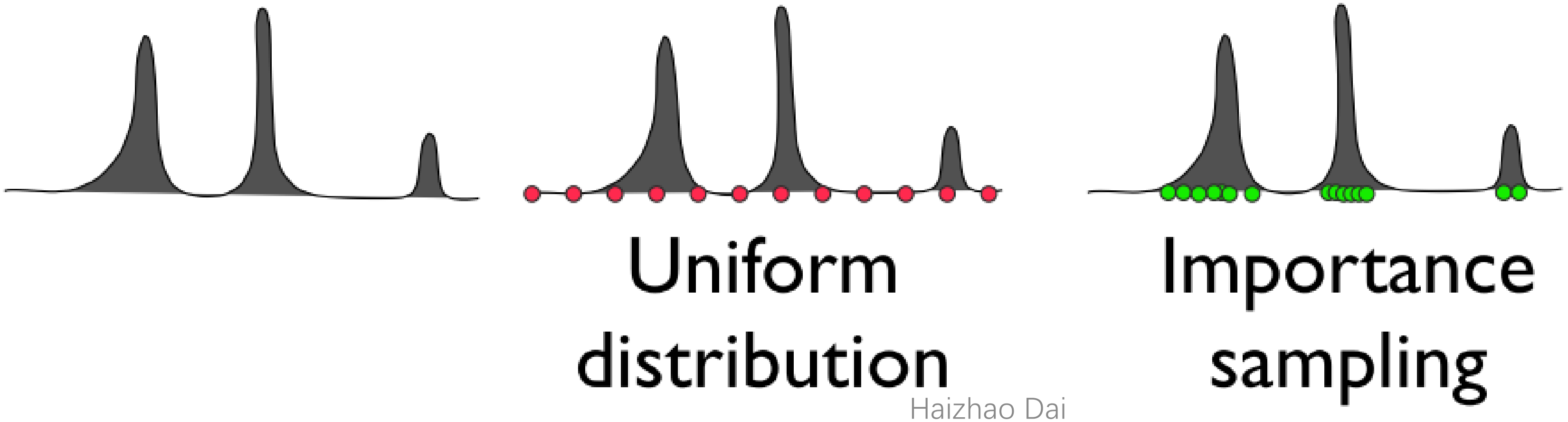
- Instant Neural Graphics Primitives with a Multiresolution Hash Encoding. Muller et al. Siggraph 2022 Best Paper Award



Sampling Strategies

- Monte Carlo Integral.
- Stratified sampling.

- Importance sampling.



Discussions

- Why NeRF works?
  - Positional Encoding (Neural Tangent Kernel Analysis)
  - 5D Neural Radiance Fields based on MLP (Neural Representations)
  - Volume Rendering (Differentiable Rendering)
  - Sampling (Performance Improvement)
- What are the limitations of NeRF?
  - Extremely slow for rendering and training
  - Bad Surface reconstruction
  - Cannot model reflection and refraction well
  - Hard to edit the local area
  - ...

References

- DeepSDF: Learning Continuous Signed Distance Functions for Shape Representation. Park et al. CVPR 2019.
- Plenoxels Radiance Fields without Neural Networks. Yu et al. CVPR 2022.
- Advances in Neural Rendering. Tewari et al. EuroGraphics 2022.
- Instant Neural Graphics Primitives with a Multiresolution Hash Encoding. Muller et al. Siggraph 2022 Best Paper.