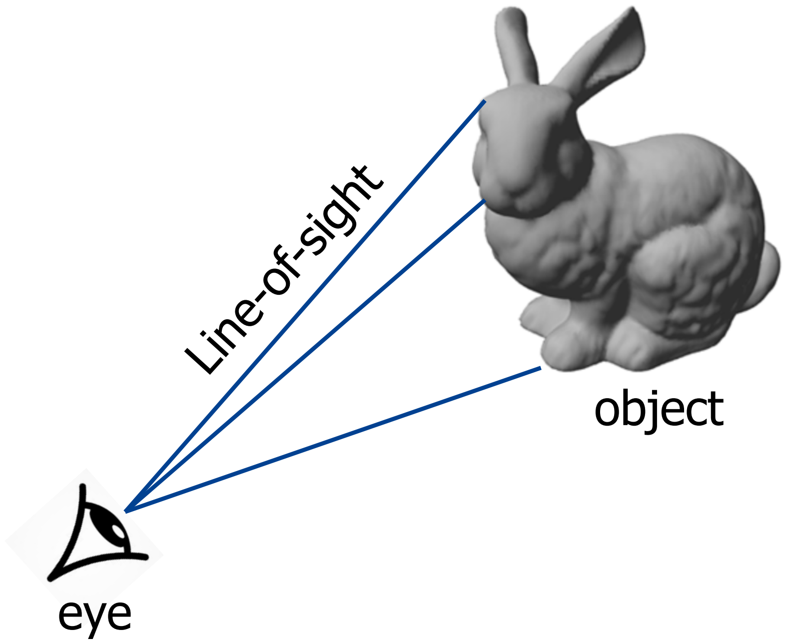
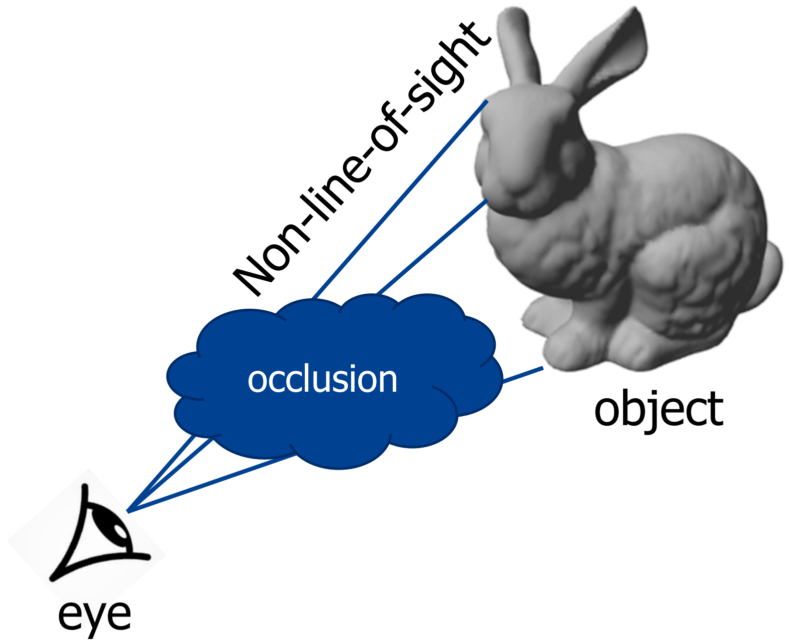
NeRF-like
Non-line-of-sight Imaging

Team 2

Kiseok Choi   Donggun Kim

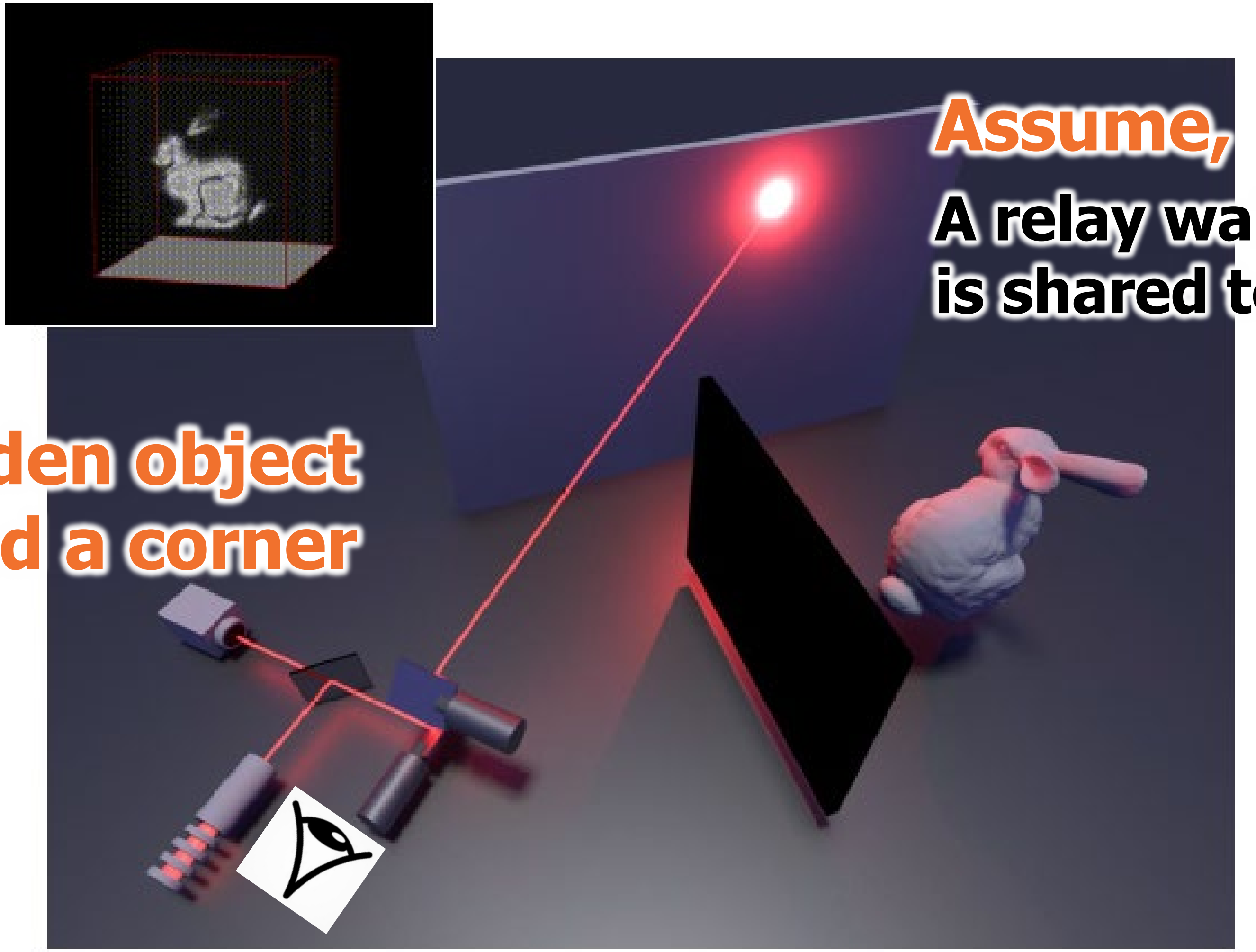
Line-of-sight vs. Non-line-of-sight





Non-line-of-sight (NLOS) Imaging

Seeing a hidden object around a corner



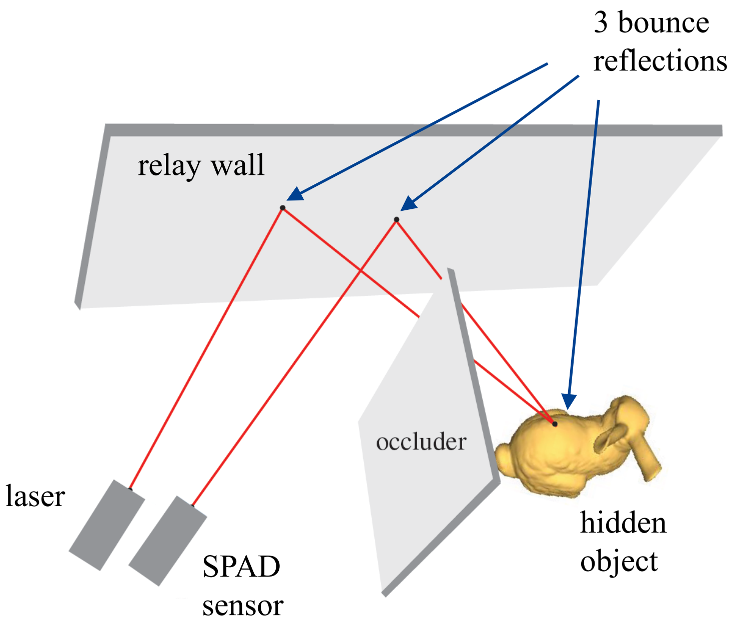
Assume,

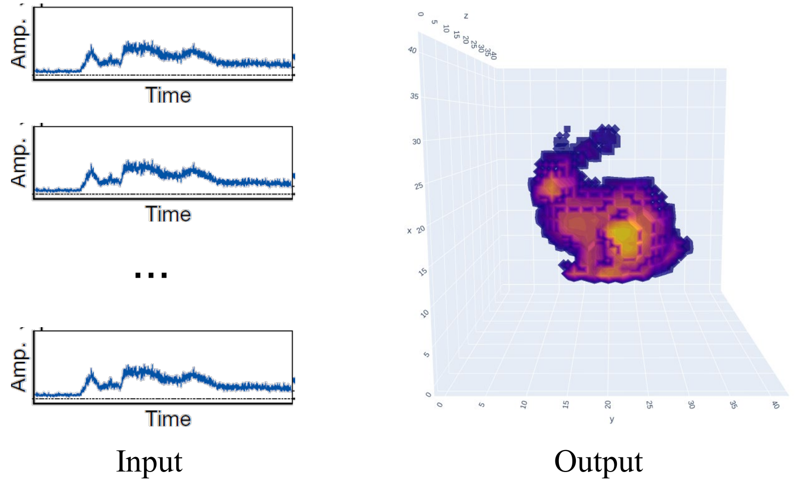
A relay wall (not a mirror) is shared to both sides

* SPAD: Single Photon Avalanche Diode

Problem

- Hardware Set-up
  - Laser + SPAD sensor
  - Diffuse reflection in a relay wall
  - 3 bounce reflections during a light transport
- Requirement
  - Input: transient intensity
  - Output: 3D point cloud
    (with albedo or radiance)
- Method?

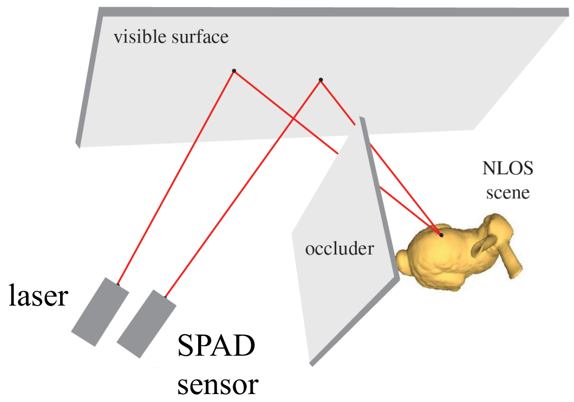


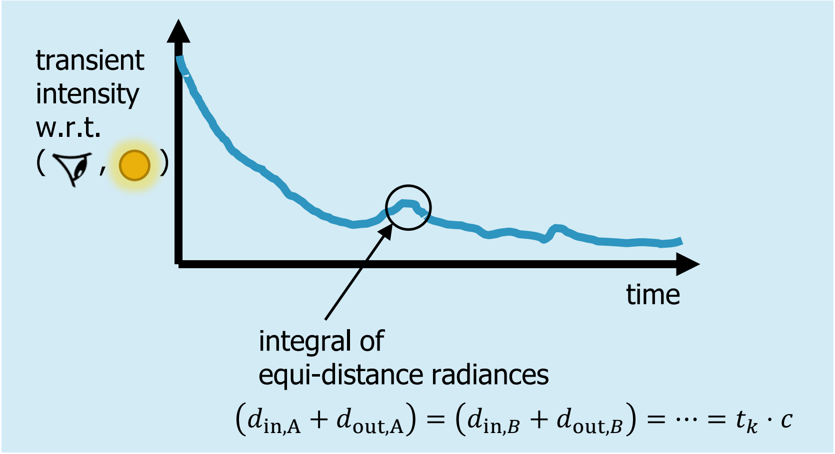


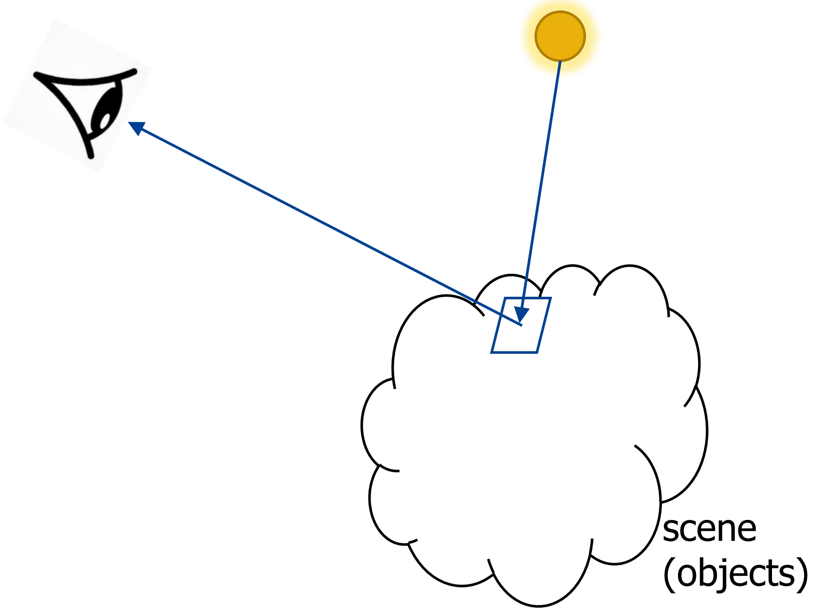
Chia-Yin Tsai et al., Beyond Volumetric Albedo — A Surface Optimization Framework for Non-Line-of-Sight Imaging, CVPR 2019.

Problem

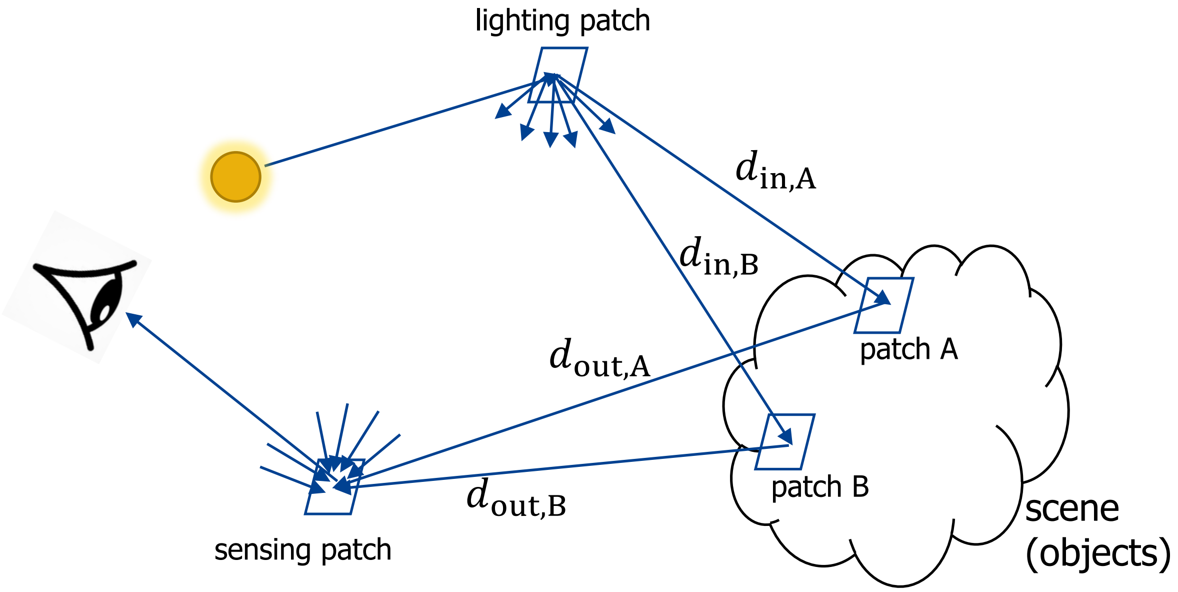
- Transient intensity
  (assumption:
  inter-reflection within scene is negligible)





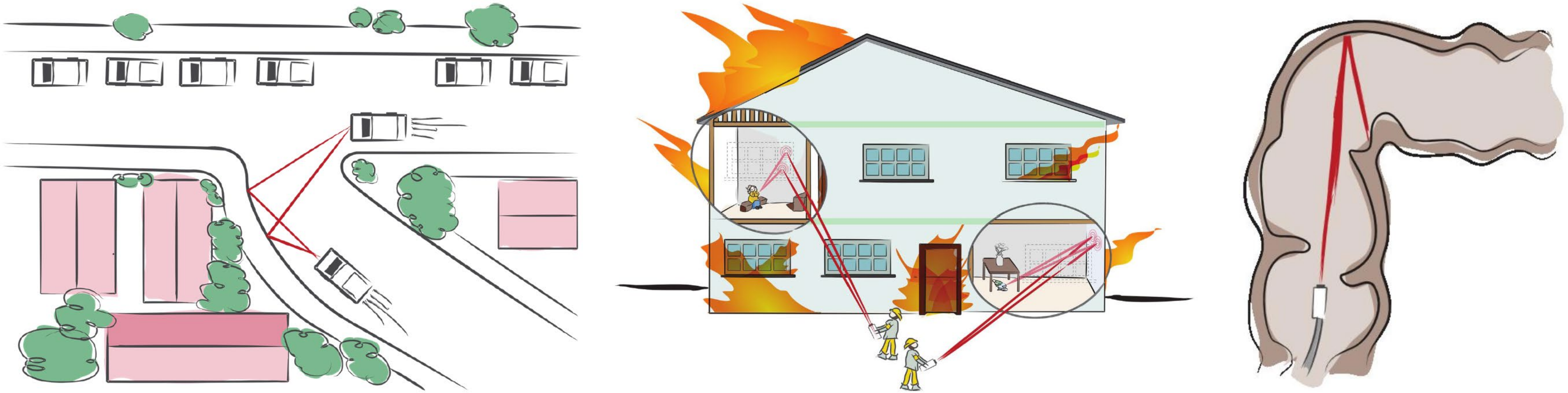


radiance of
line-of-sight ray



radiance of
non-line-of-sight ray
(transient intensity)

Where?



(a) Detection objects around corner for autonomous navigation

(b) Localization of survivors in rescue operations

(c) Seeing inaccessible region in endoscopy

Reference: Tomohiro Maeda et al., Recent Advances in Imaging Around Corners, Arxiv. 2019.

Related Papers

- Confocal non-line-of-sight imaging based on the light-cone transform (Nature Comm. 2018)

  → Light Cone Transform

- Non-line-of-sight imaging using phasor-field virtual wave optics (Nature 2019)

  → Phasor-field

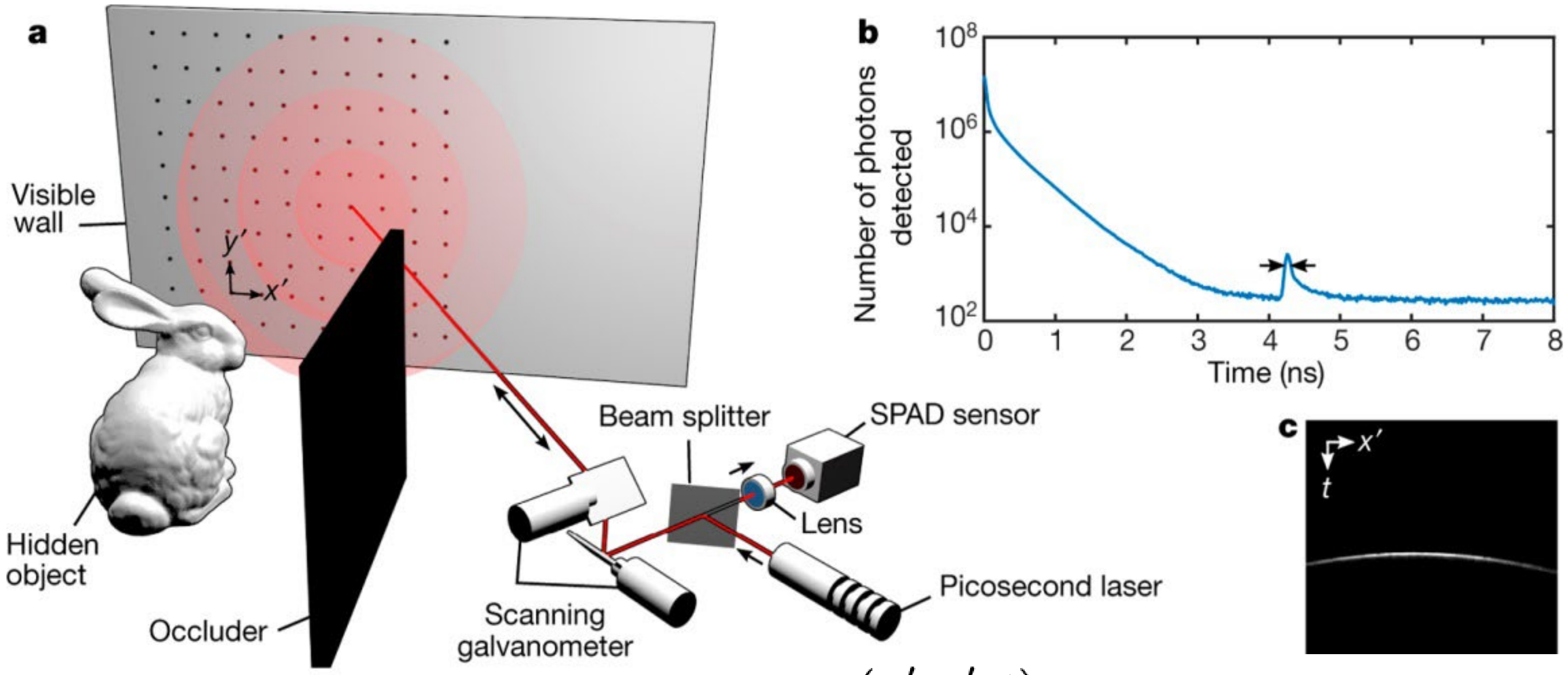
- Non-line-of-Sight Imaging via Neural Transient Fields (TPAMI 2021)

  → NeTF

Light Cone Transform (LCT)

Matthew O'Toole et al., Nature Comm. 2018

Confocal non-line-of-sight imaging based on the light-cone transform



$$\tau(x',y',t) = \iiint_{\Omega} \frac{1}{r^4} \rho(x,y,z)\,\delta\left(2\sqrt{(x'-x)^2+(y'-y)^2+z^2} - tc\right) \mathrm{d}x\mathrm{d}y\mathrm{d}z$$

transient rendering equation

Light Cone Transform (LCT)

Matthew O'Toole et al., Nature Comm. 2018

Confocal non-line-of-sight imaging based on the light-cone transform

$$\underbrace{v^{3/2}\,\tau(x',y',\,2\sqrt{v}/c)}_{\mathcal{R}_t\{\tau\}\,(x',y',v)} =$$

re-parameterization + re-sampling

$$\iiint_{\Omega} \underbrace{\frac{1}{2\sqrt{u}}\,\rho(x,y,\sqrt{u})}_{\mathcal{R}_z\{\rho\}\,(x,y,u)}\,\underbrace{\delta((x'-x)^2+(y'-y)^2+u-v)}_{h(x'-x,y'-y,v-u)}\,\mathrm{d}x\mathrm{d}y\mathrm{d}u$$

convolution form

$$\mathcal{R}_t\{\tau\} = h * \mathcal{R}_z\{\rho\}$$

$$\boldsymbol{\tau} = \mathbf{R}_t^{-1}\mathbf{H}\mathbf{R}_z\boldsymbol{\rho}$$

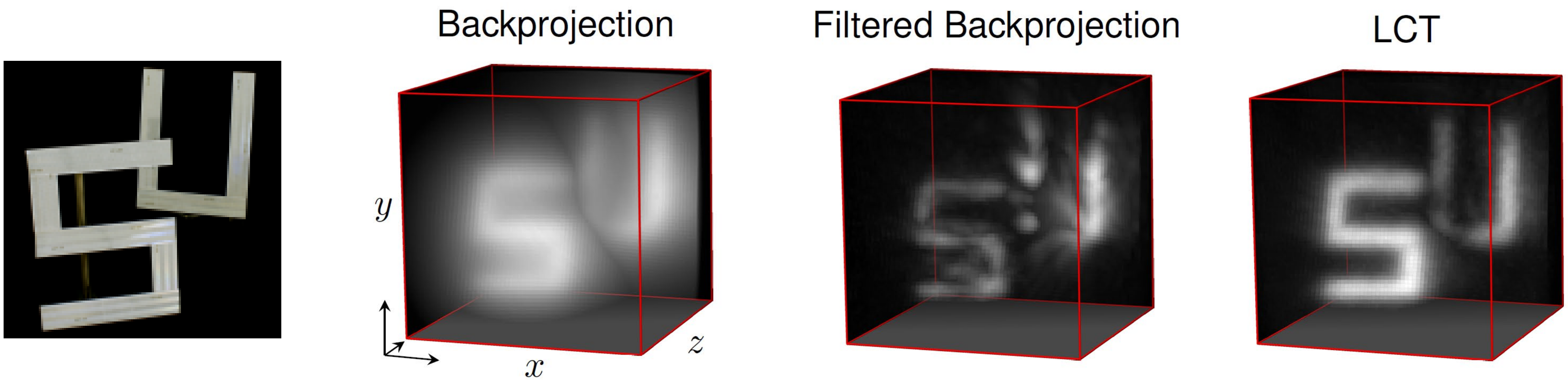
$$\boldsymbol{\rho}_* = \mathbf{R}_z^{-1}\mathbf{F}^{-1}\left[\frac{1}{\widehat{\mathbf{H}}}\cdot\frac{|\widehat{\mathbf{H}}|^2}{|\widehat{\mathbf{H}}|^2+\frac{1}{\alpha}}\right]\mathbf{F}\mathbf{R}_t\boldsymbol{\tau}$$

Wiener filter

Light Cone Transform (LCT)

Matthew O'Toole et al., Nature Comm. 2018

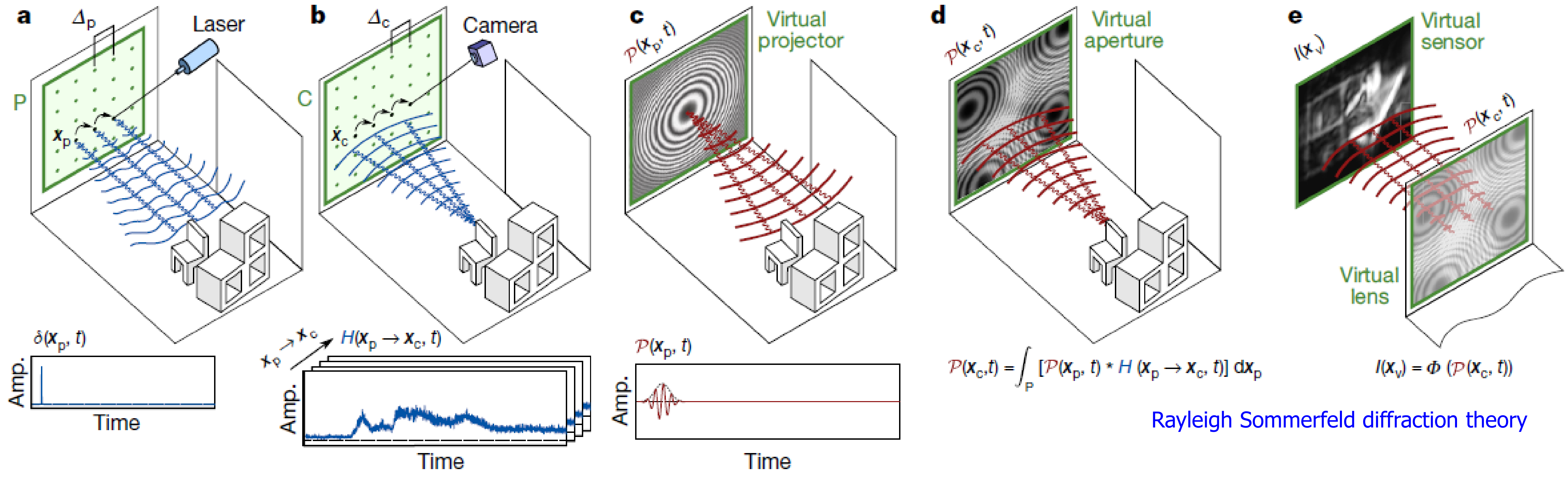
Confocal non-line-of-sight imaging based on the light-cone transform



Phasor-field

Xiaochun Liu et al., Nature 2019

Non-line-of-sight imaging using phasor-field virtual wave optics

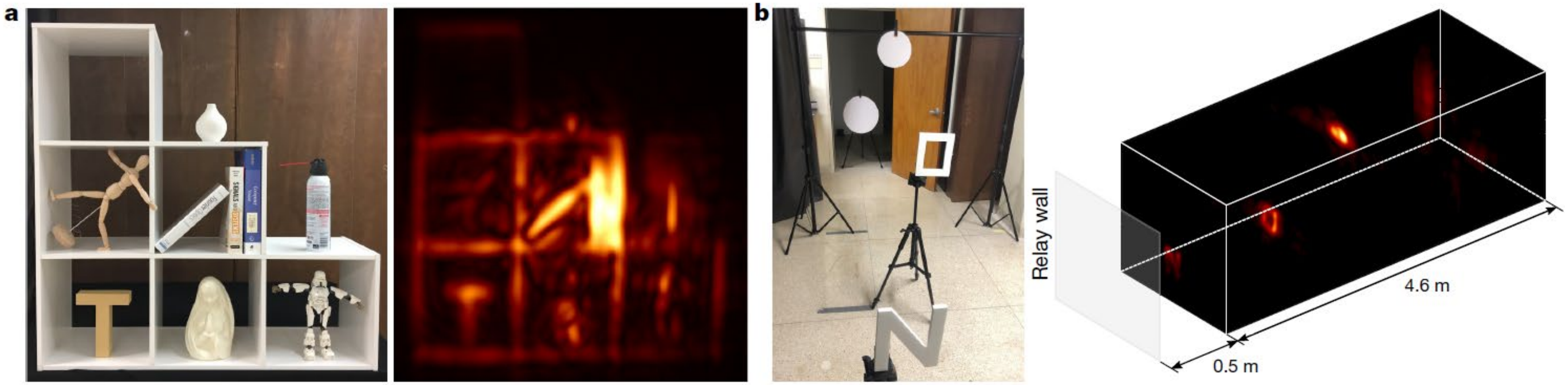


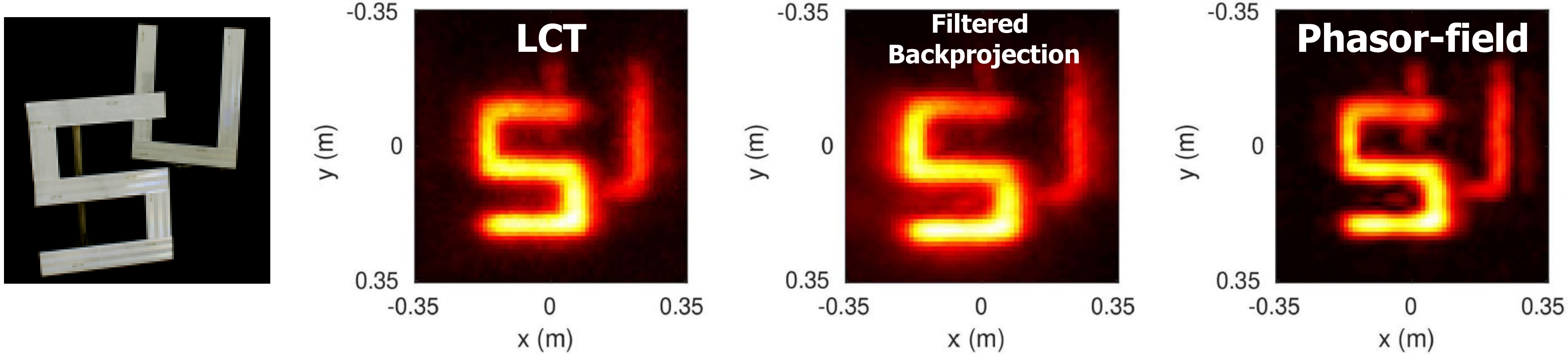
Rayleigh Sommerfeld diffraction theory

Phasor-field

Xiaochun Liu et al., Nature 2019

Non-line-of-sight imaging using phasor-field virtual wave optics

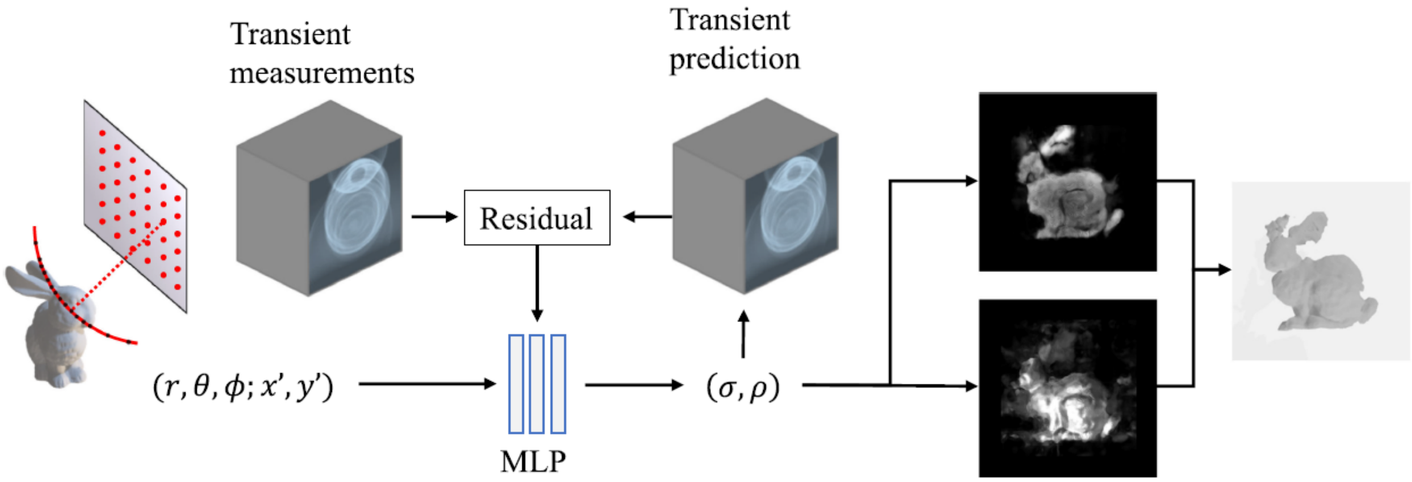


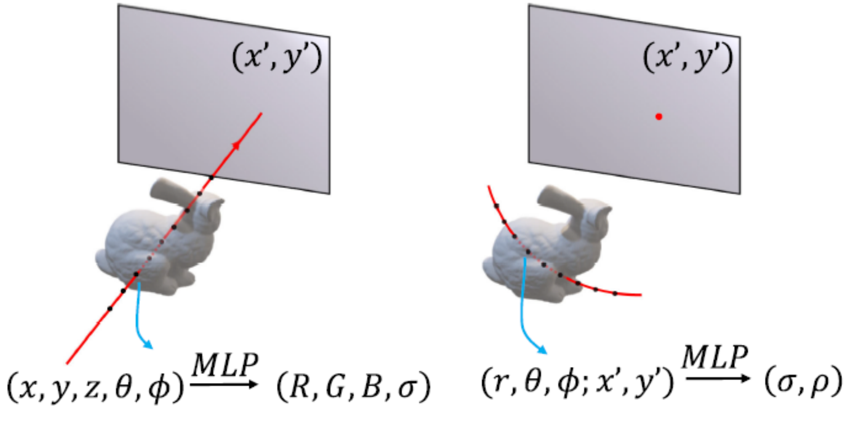


NeTF

Siyuan Shen et al., TPAMI 2021

Non-line-of-Sight Imaging via Neural Transient Fields





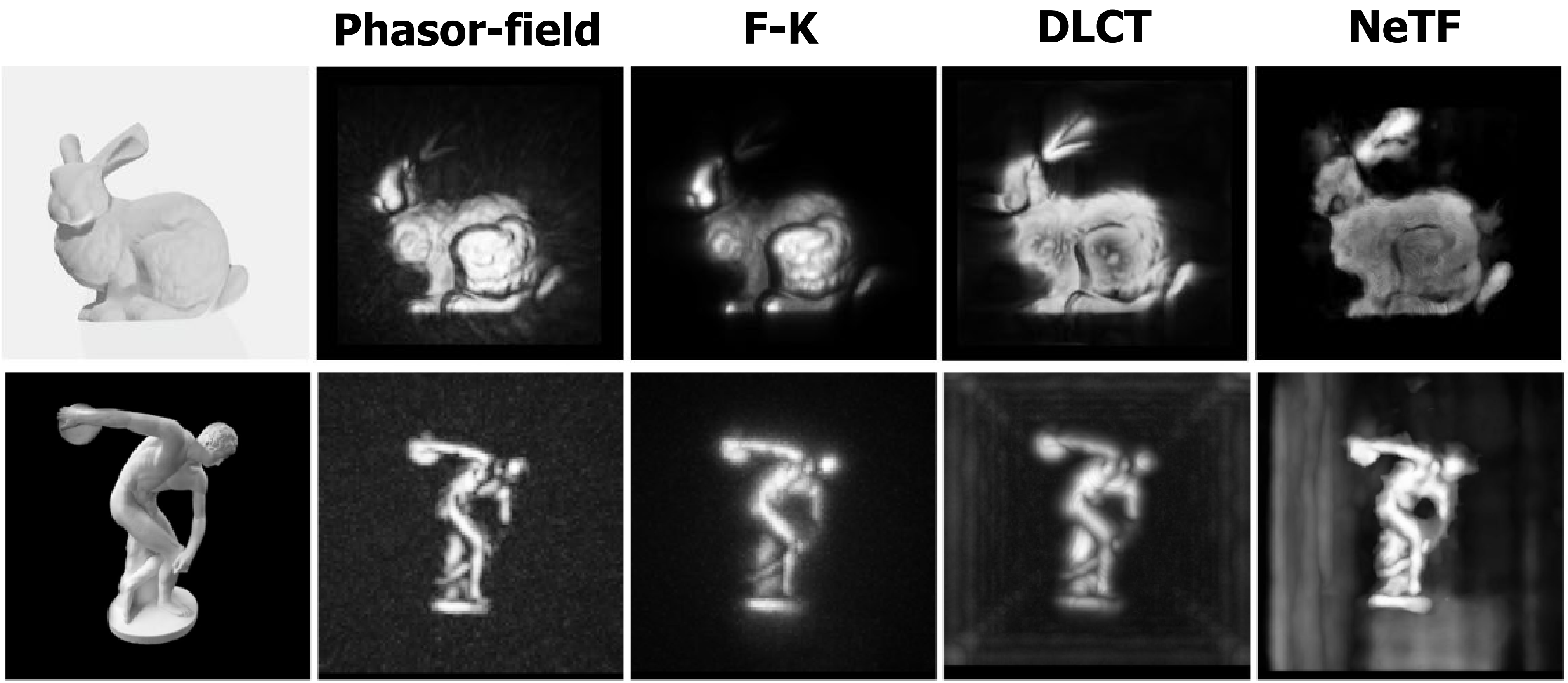
(a) Neural Radiance Field (b) Neural Transient Field

$$\tau(x',y',t) = \Gamma_0 \iint_{H(x',y';\frac{ct}{2})} \frac{\sin\theta}{r^2}\sigma(r,\theta,\phi)\rho(r,\theta,\phi)\cdot exp\left(2\int_0^r -A\sigma \mathrm{d}r'\right)\mathrm{d}\theta\mathrm{d}\phi,$$

NeTF

Siyuan Shen et al., TPAMI 2021

Non-line-of-Sight Imaging via Neural Transient Fields



Limitations

LCT

- Confocal sensing required
- Huge memory required
- Output voxel resolution constrained to sensing point resolution

Phasor-field

- High computation
- Output artifact by diffraction theory

NeTF

- Confocal sensing required
- Training time necessary
- Low quality output

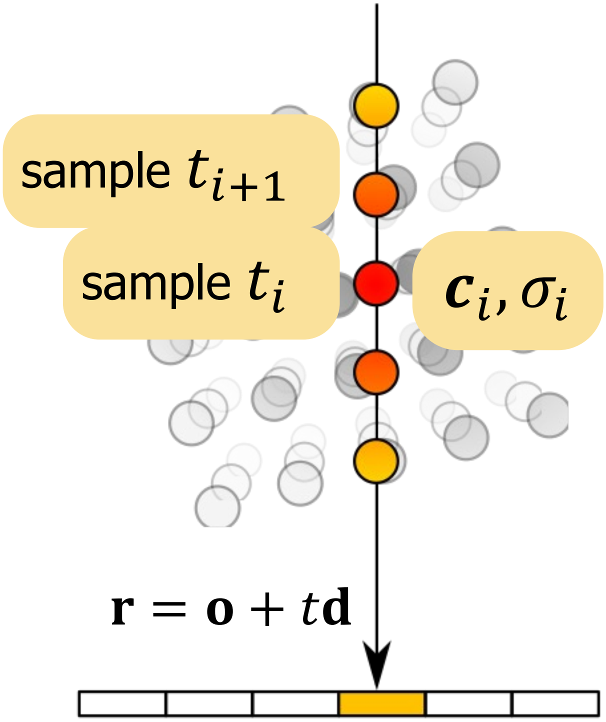
Approach (Plan A)

NeRF-like NLOS imaging

- NeRF volume rendering → transient intensity

$$(x, y, z, x', y') \xrightarrow{MLP} (\rho, \sigma)$$

object space point | relay wall point | albedo | density

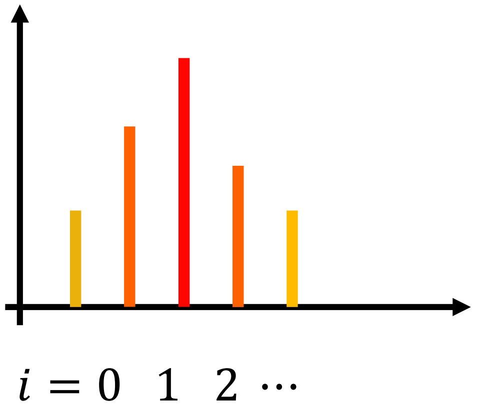


NeRF: $$\hat{C}(\mathbf{r}) = \sum_{i=1}^{N} T_i \alpha_i \boldsymbol{c}_i$$

$\alpha_i = 1 - \exp(-\sigma_i \delta_i)$: compositing value

$T_i = \exp\left(-\sum_{j}^{i-1} \sigma_j \delta_j\right)$: accumulated transmittance

Ours: $$\hat{C}(\mathbf{r}, i) = T_i \alpha_i \boldsymbol{\rho}_i$$

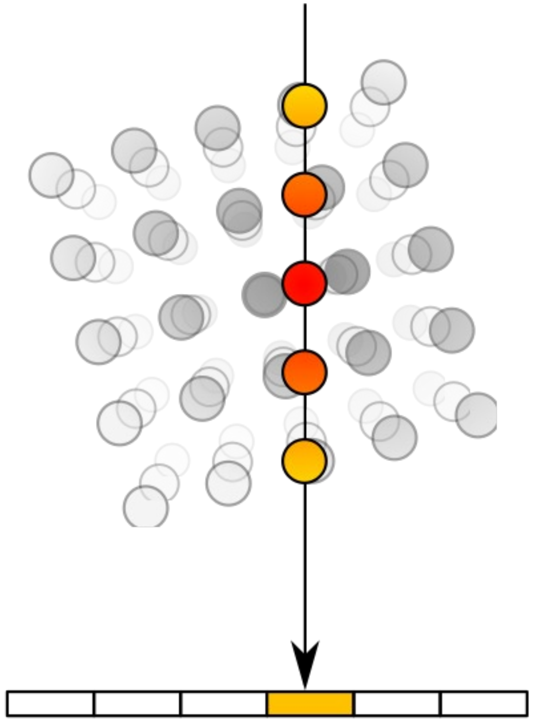


Approach (Plan A)

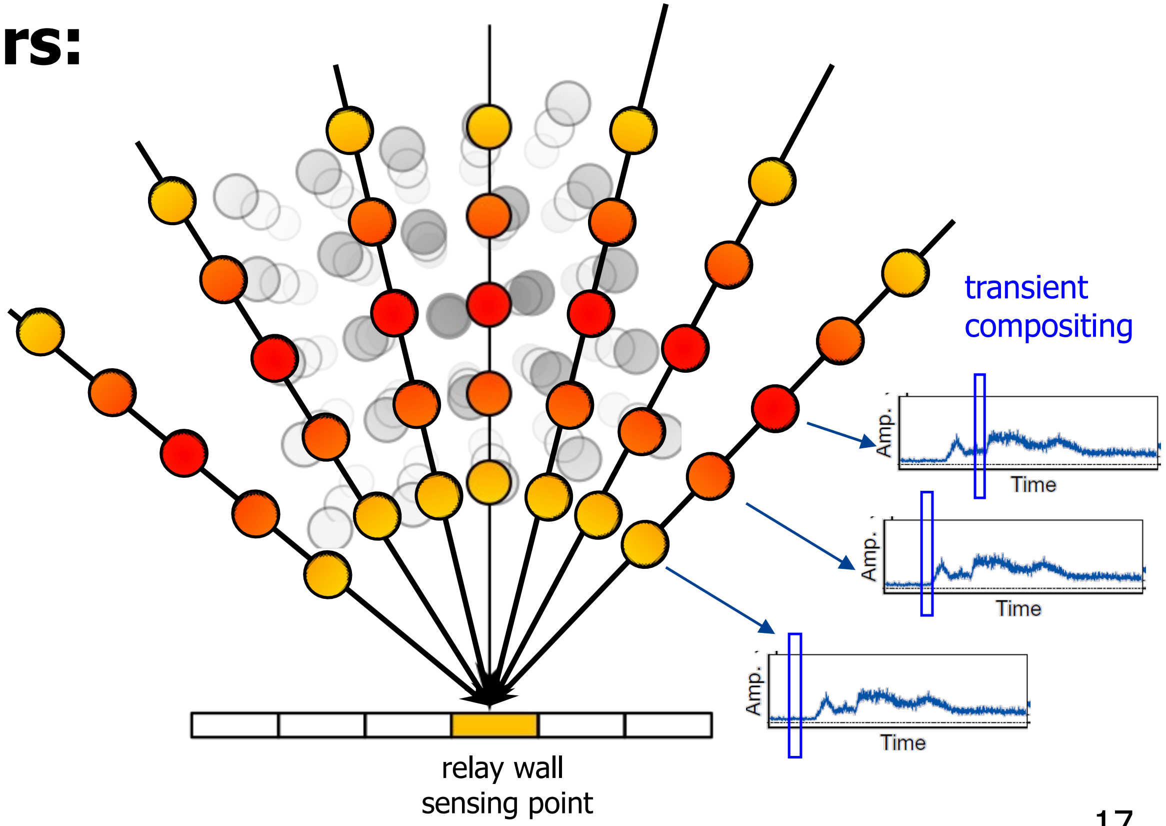
NeRF-like NLOS imaging

- NeRF volume rendering → transient intensity

NeRF:



Ours:



Approach (Plan B)

NeRF-like NLOS imaging

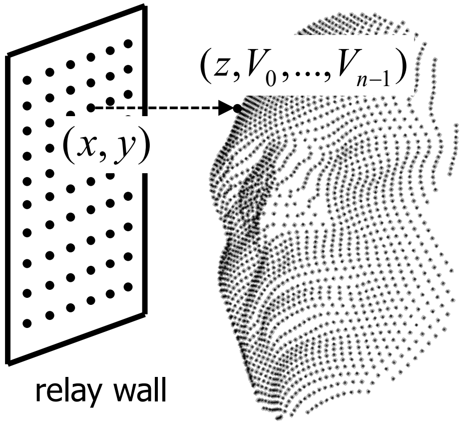
- Confocal/non-confocal sensing compatible
- Higher quality output achievable by an accurate transient renderer

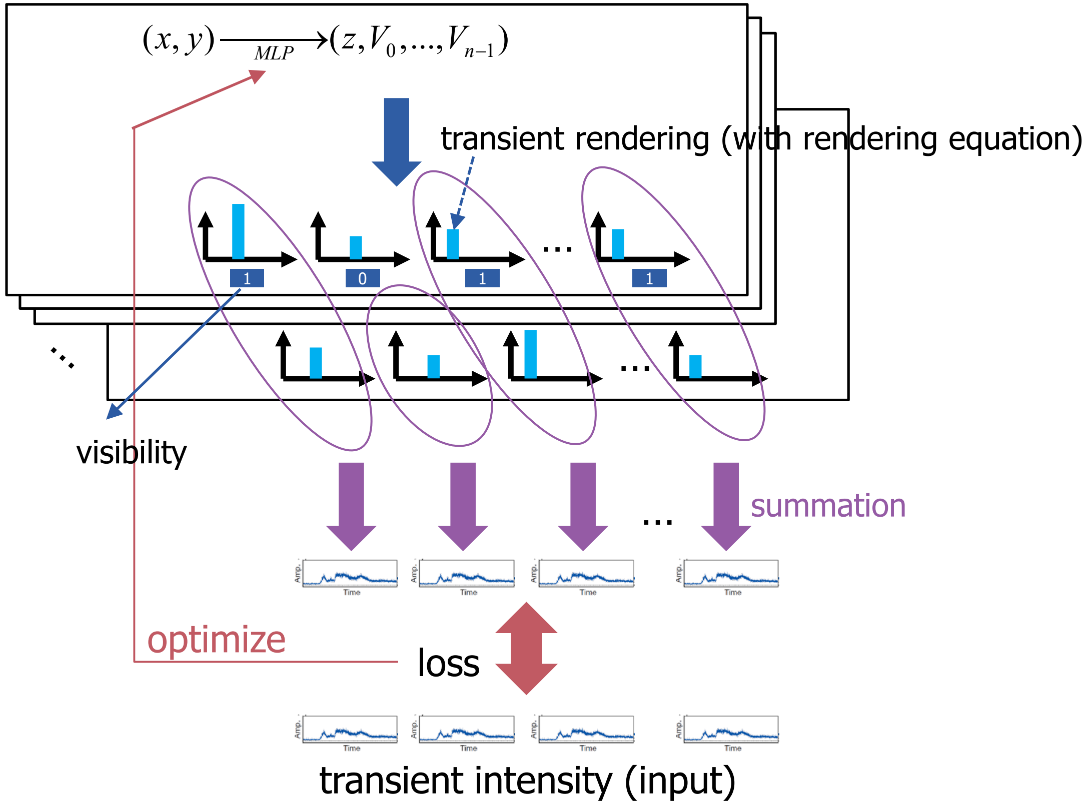
$$(x, y) \xrightarrow{MLP} (z, V_0, \ldots, V_{n-1})$$

relay wall point

depth of hidden object

visibility to sensing points



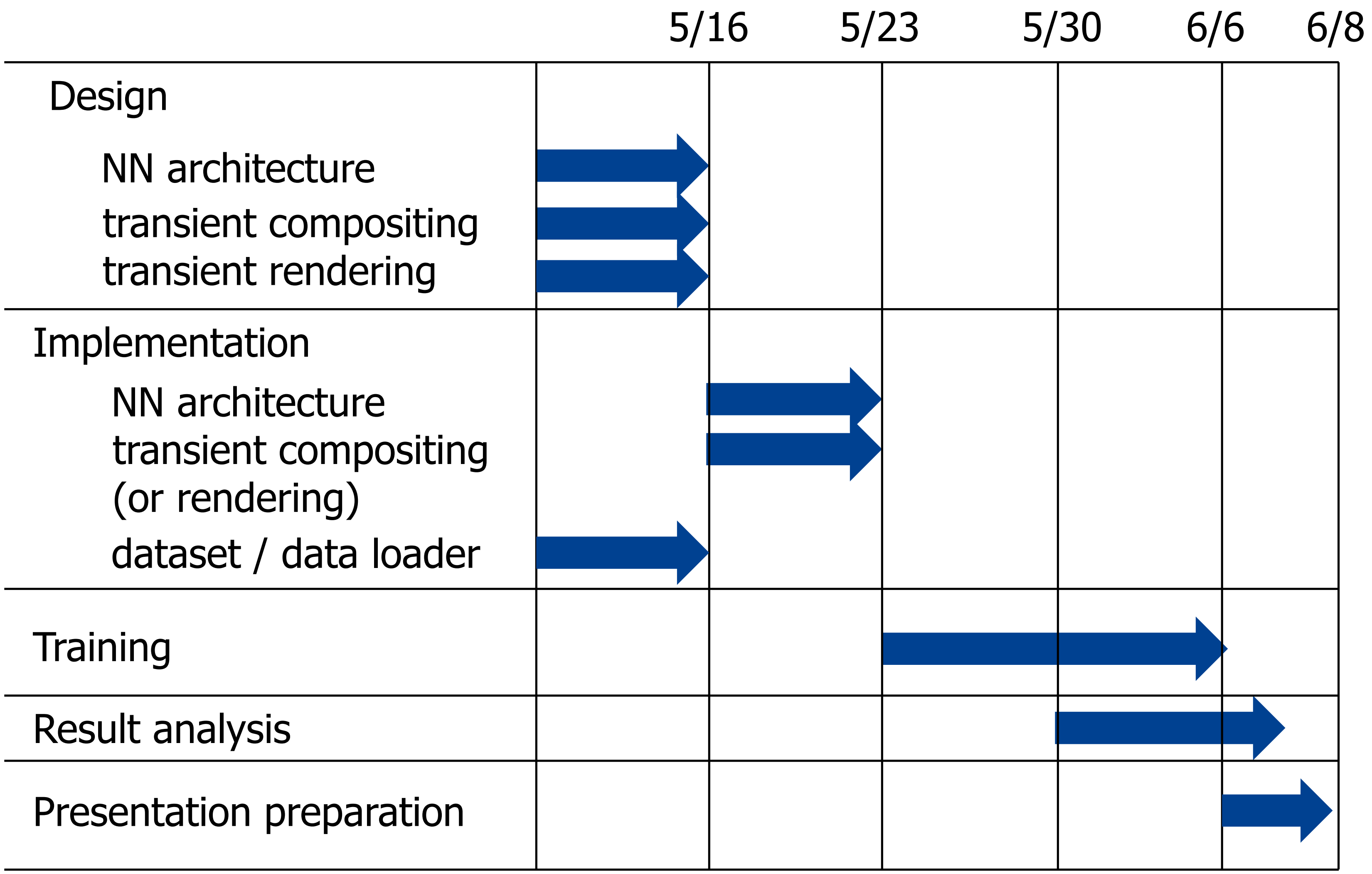


Role

- Kiseok Choi
  - Survey of NLOS imaging papers
  - transient rendering design & implementation
  - Simulation/Real data generation
  - Result analysis, Presentation preparation

- Donggun Kim
  - Survey of NeRF papers
  - transient compositing design & implementation
  - Neural network architecture design & implementation
  - Dataset, Data loader implementation
  - Training a neural network
  - Result analysis, Presentation preparation

Plan


5/16
5/23
5/30
6/6
6/8
Design
NN architecture
transient compositing
transient rendering
Implementation
NN architecture
transient compositing
(or rendering)
dataset / data loader
Training
Result analysis
Presentation preparation

Q&A