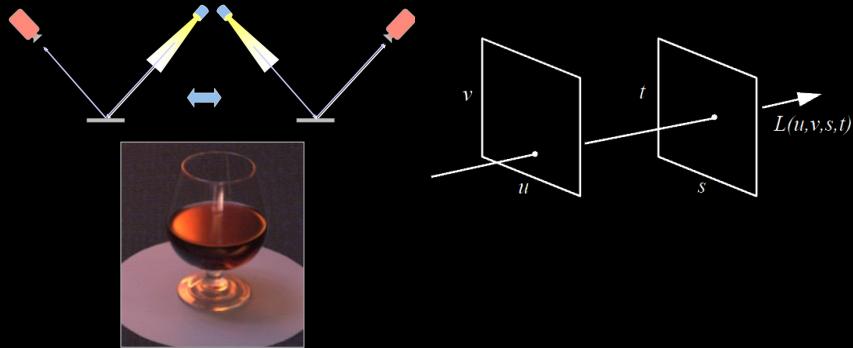


Reciprocity and Light Fields



70001 – Advanced Computer Graphics: Photographic Image Synthesis

Abhijeet Ghosh

Lecture 06, Jan. 26th 2024

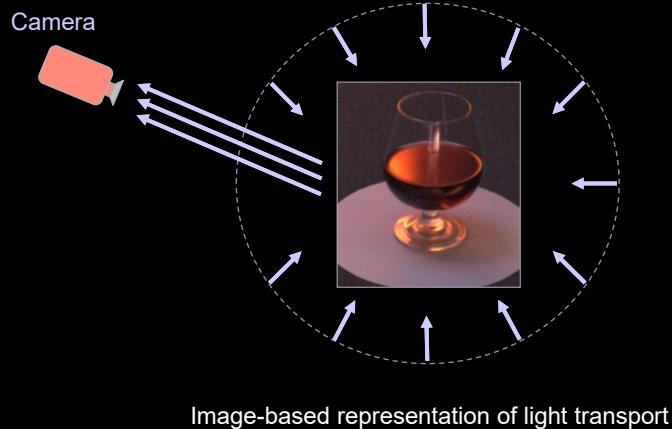
1

Dual Light Stage

Hawkins T., Einarsson P., Debevec P., “A Dual Light Stage”, Eurographics Symposium on Rendering, 2005

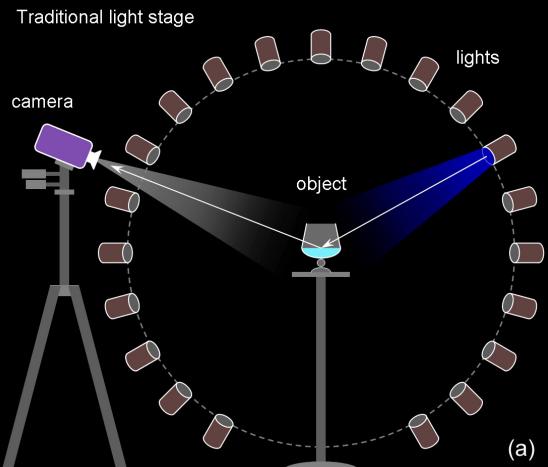
2

4D Reflectance Field



3

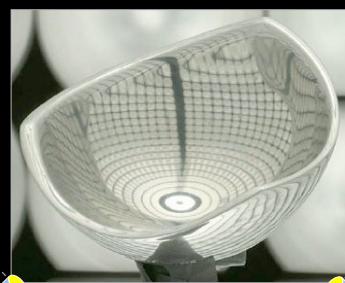
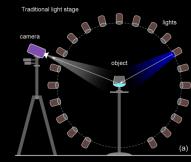
Conventional Light Stage



4

2

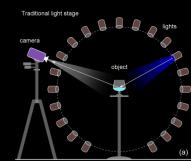
Problems



Sharp specular reflections have aliasing (Nyquist!)

5

Problems

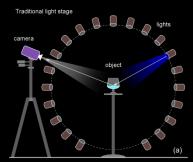


Smooth motion of shadows

6

3

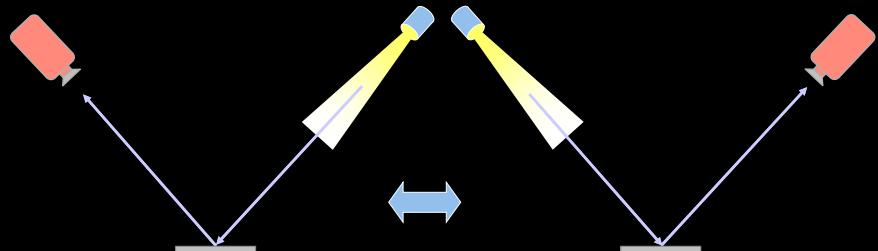
Problems



Smooth motion of shadows

7

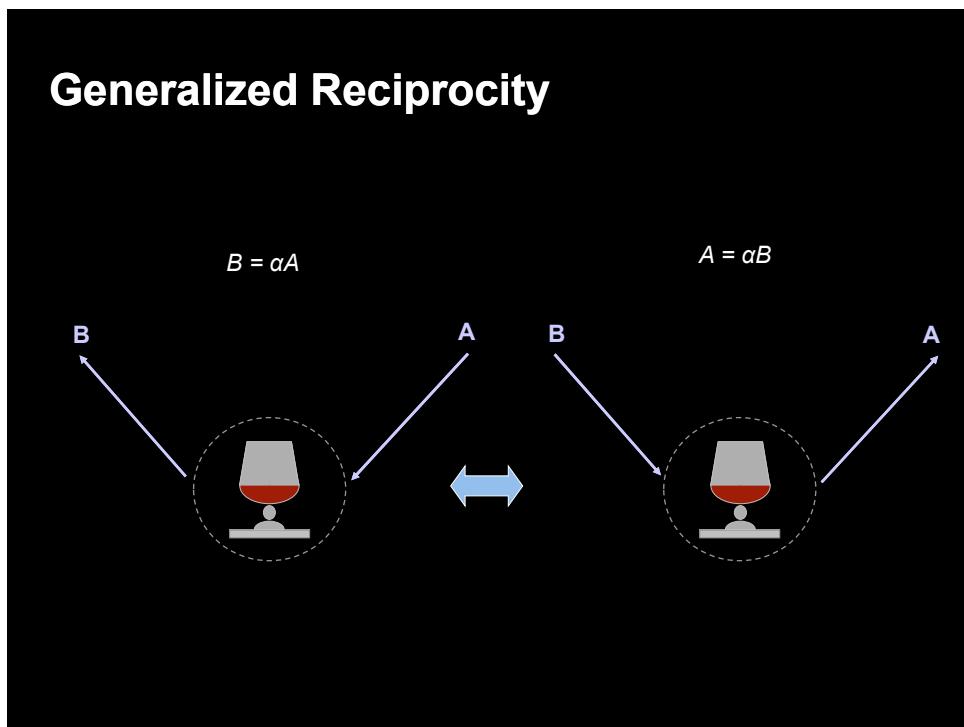
Helmholtz Reciprocity (BRDF)



8

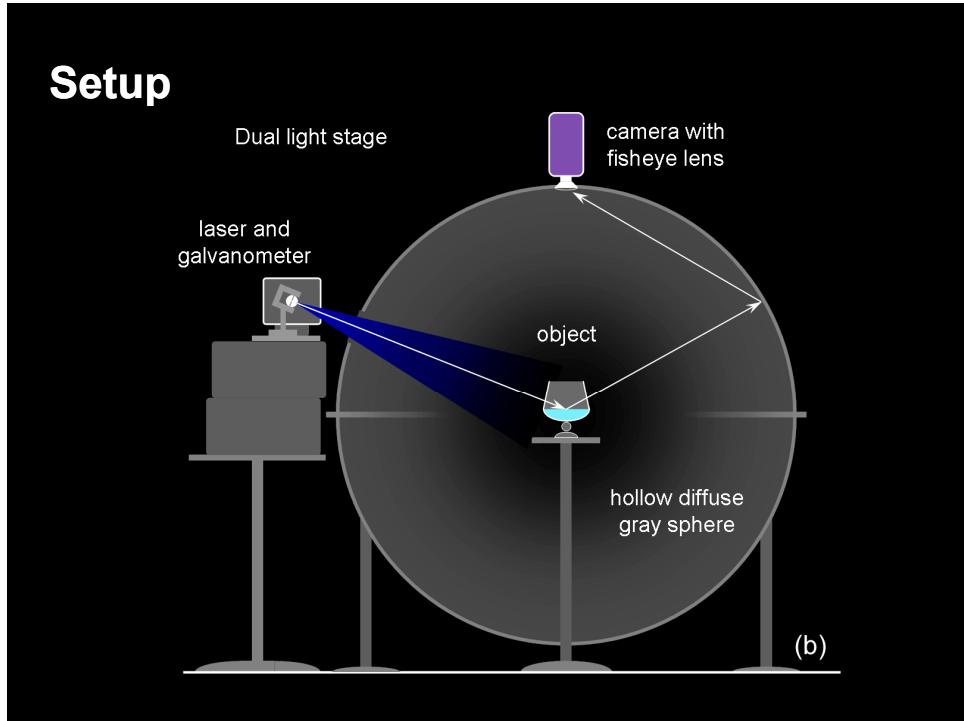
4

Generalized Reciprocity



9

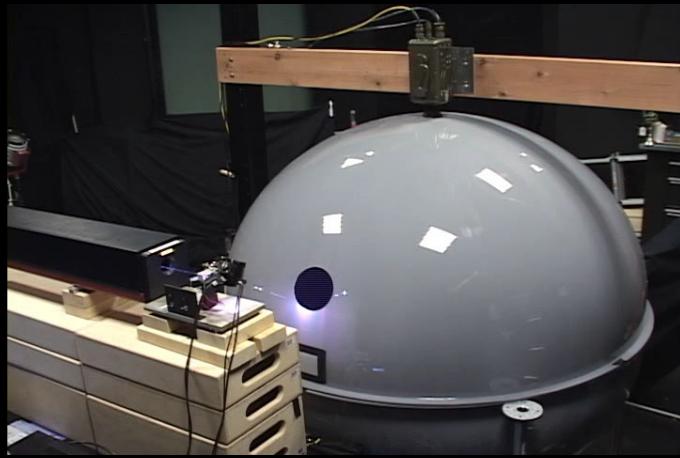
Setup



10

Setup

- 3 watt white laser with mirror galvanometer
- 30% reflective diffuse sphere
- High-speed camera with 180-degree fisheye lens



11

Captured Data

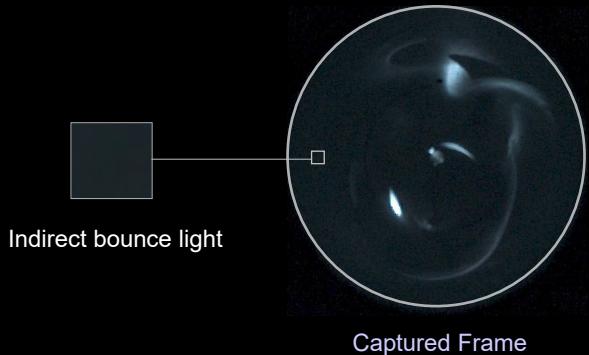
- 384x384 pixels
- 200x200 images ~ 10 GB
- 3 exposures for HDR



Captured Data

12

Data Processing

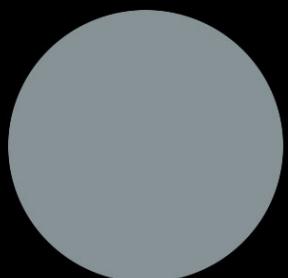


13

Remove Indirect Illumination



Captured Frame



Average Color * Sphere Color

14

Remove Indirect Illumination

Direct light response



Before



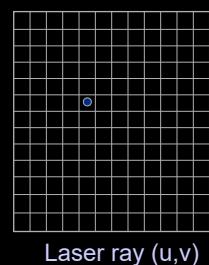
After

15

Relighting

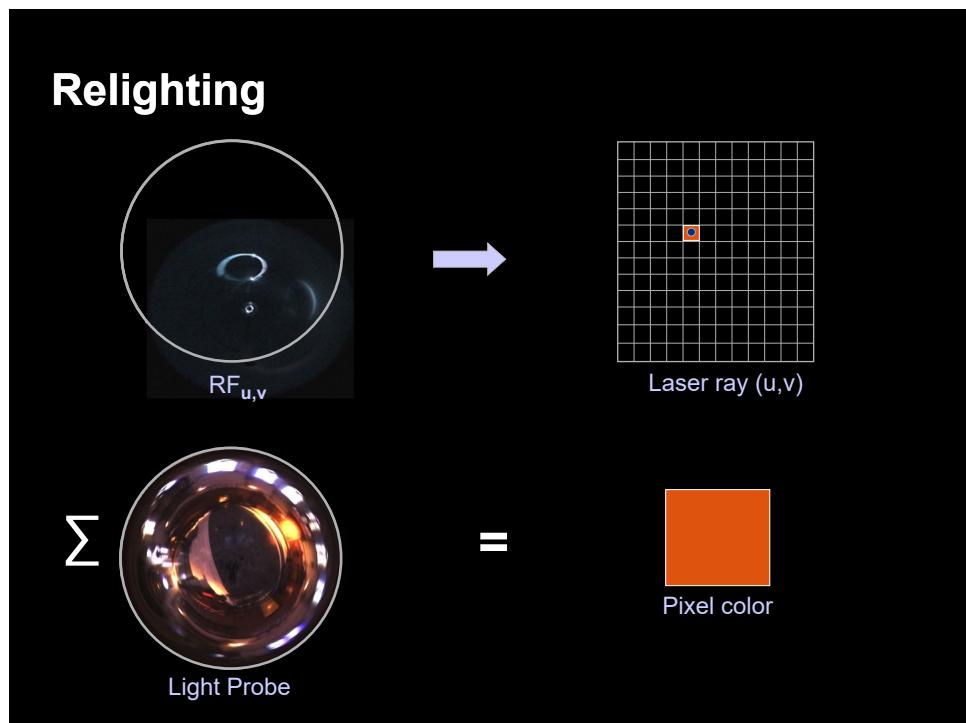


Light Probe

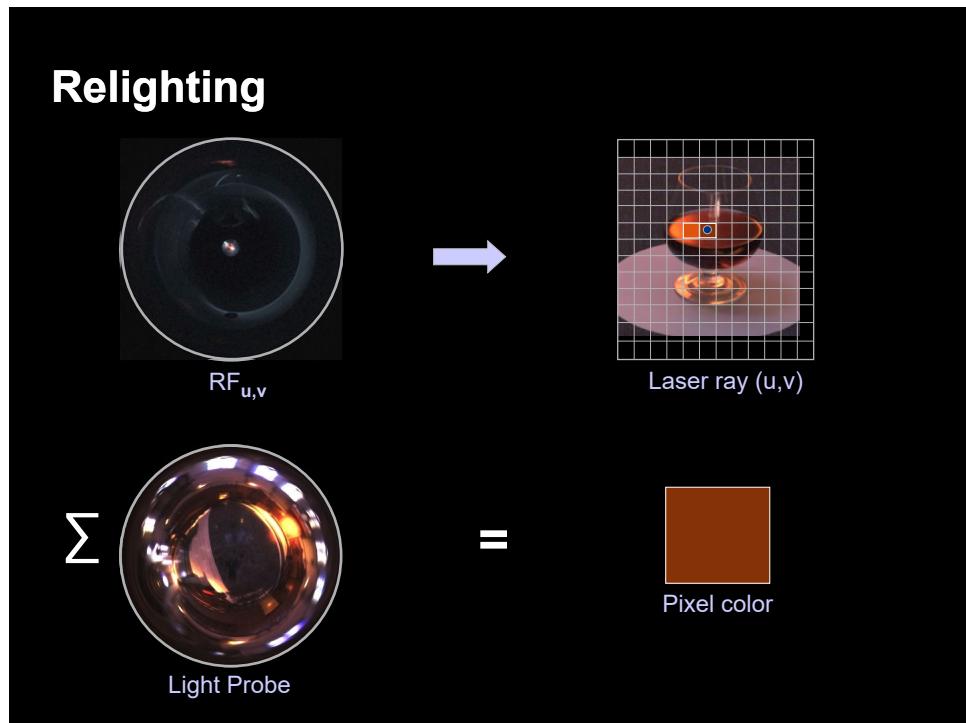


16

8



17



18

Relit Result



19

Results



20

10

Results



21

Results



22

Results



23

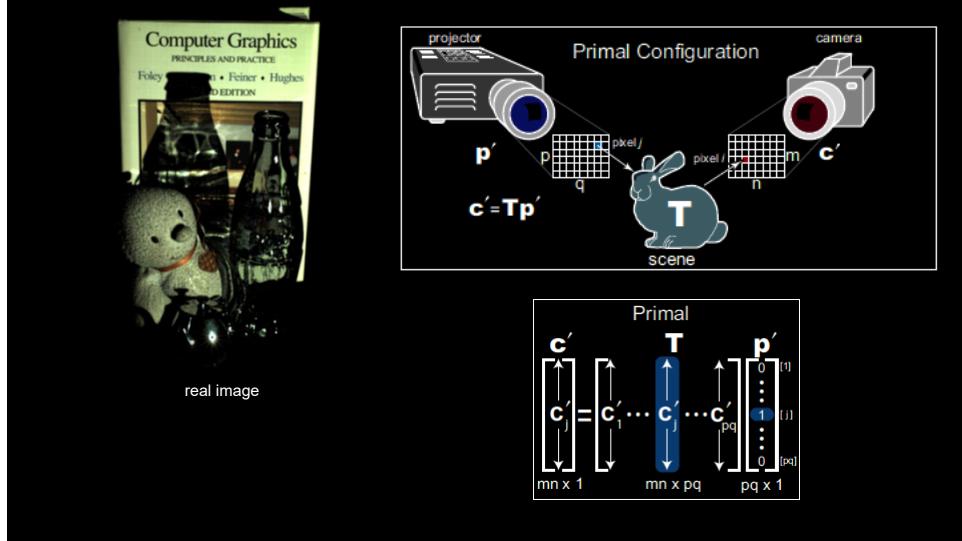
Dual Photography

Pradeep Sen, Billy Chen, Gaurav Garg, Stephen
R. Marschner, Mark Horowitz, Marc Levoy,
Hendrik P. A. Lensch, “[Dual Photography](#)”,

ACM SIGGRAPH, 2005

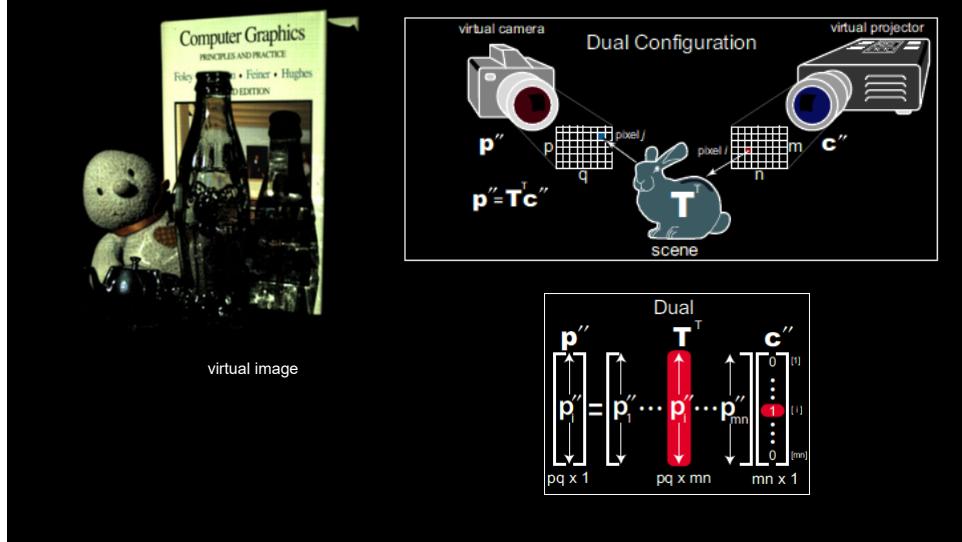
24

Primal configuration



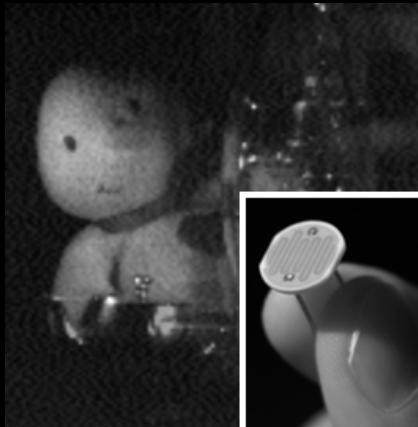
25

Dual configuration



26

Dual photography with a photodiode!

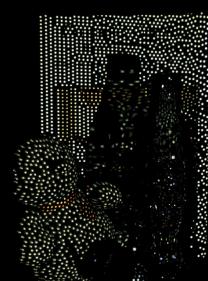
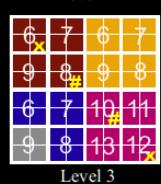
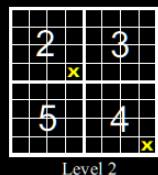
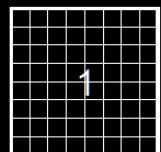


Real image captured by a photodiode
(one pixel camera!) with scene lit by a
projector's MxN pixels

Virtual (dual) image from projector's
viewpoint lit by point light source (1
pixel light source!)

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Adaptive measurements



28

14

Results

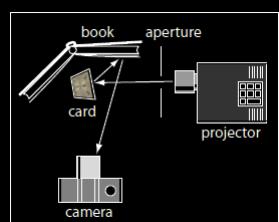


primal

dual

29

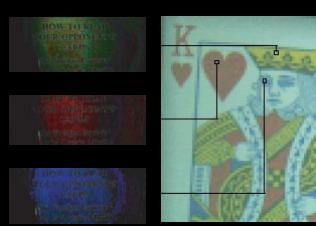
Results – revealing hidden image



setup



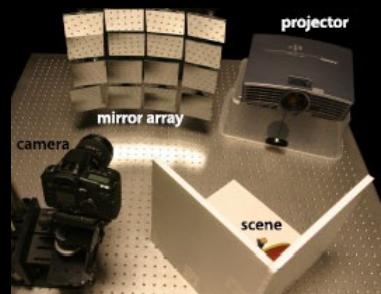
primal



dual

30

Results – 6D reflectance field



setup



dual

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Light Fields

Levoy & Hanrahan SIGGRAPH 1996

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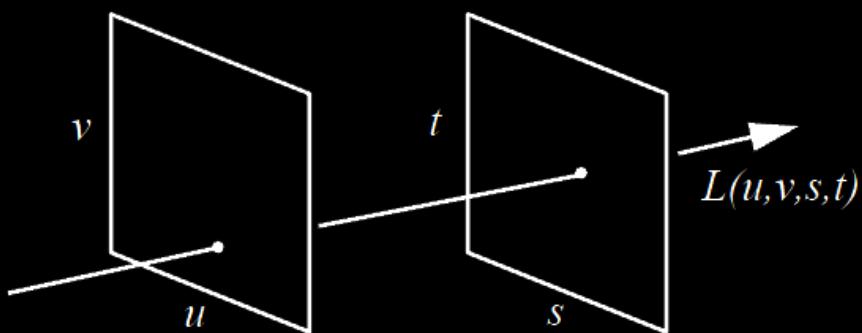
16

Light Field

- Radiance in 3D as a function of position (3D) and direction (2D)
- General case 5D plenoptic function on a surface
- 4D in free space
- An image is a 2D slice of a light field

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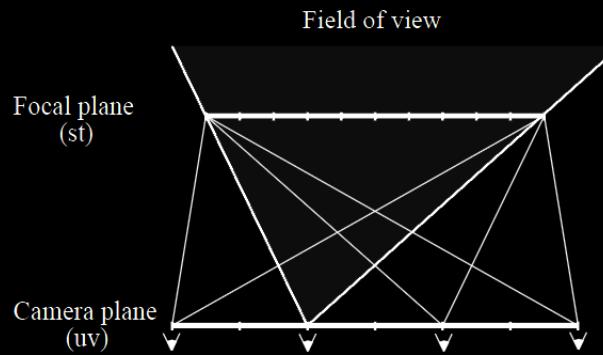
Light Field Parameterization



- Two-plane parametrization st - uv
- 4D in free space

34

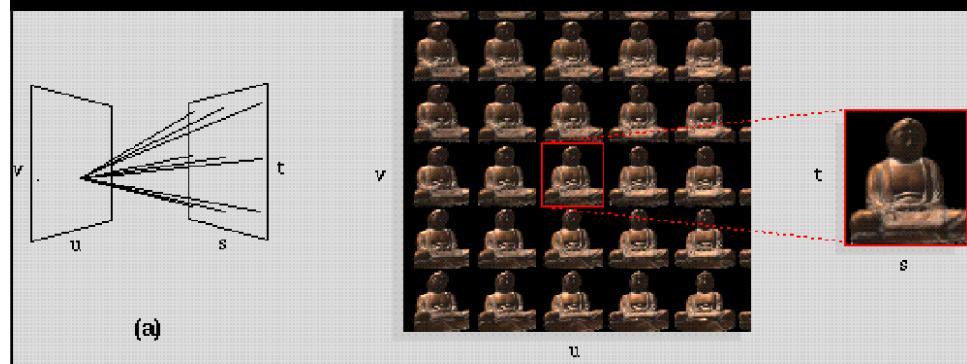
Light Field Parameterization



- Two-plane parametrization $st - uv$
- 4D in free space

35

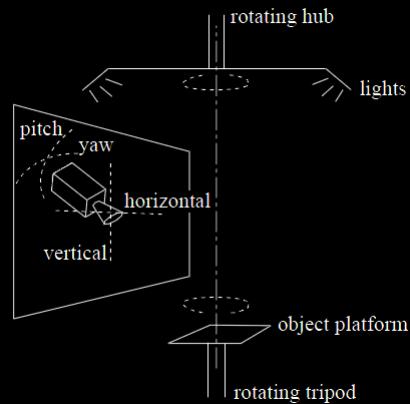
Light Field Representation



- E.g., Multi view capture with a camera array

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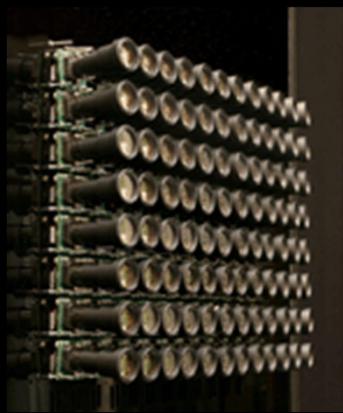
Light Field Capture



- Fixed illumination, multiview capture [Levoy & Hanrahan '96]

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Light Field Capture

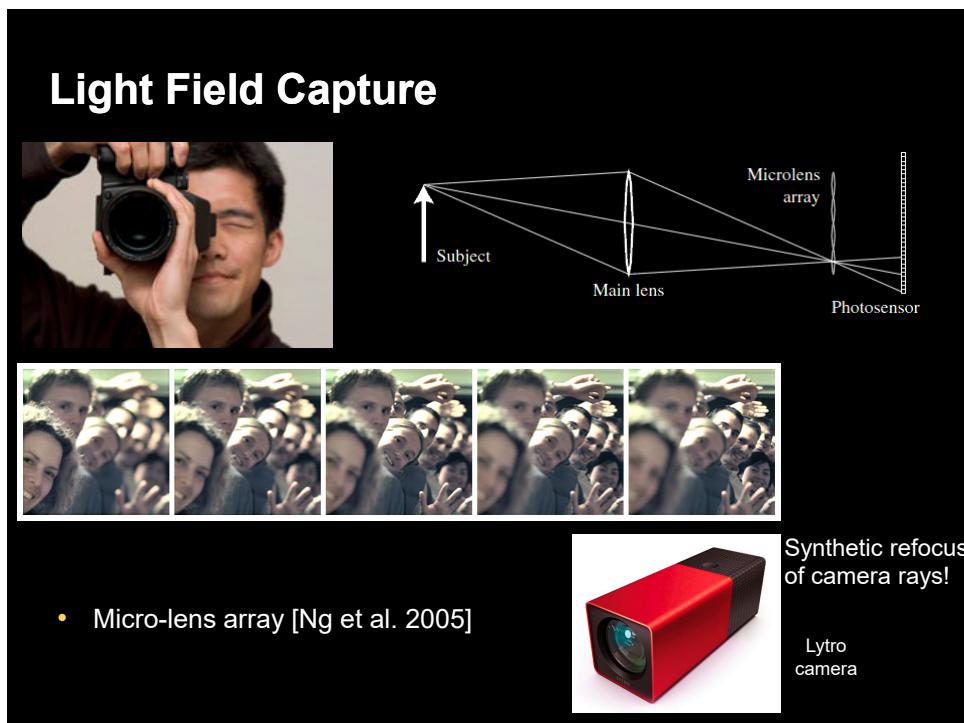


- Stanford camera array [Wilburn et al. 2005] Re-binning of rays to produce synthetic images with different focus planes.

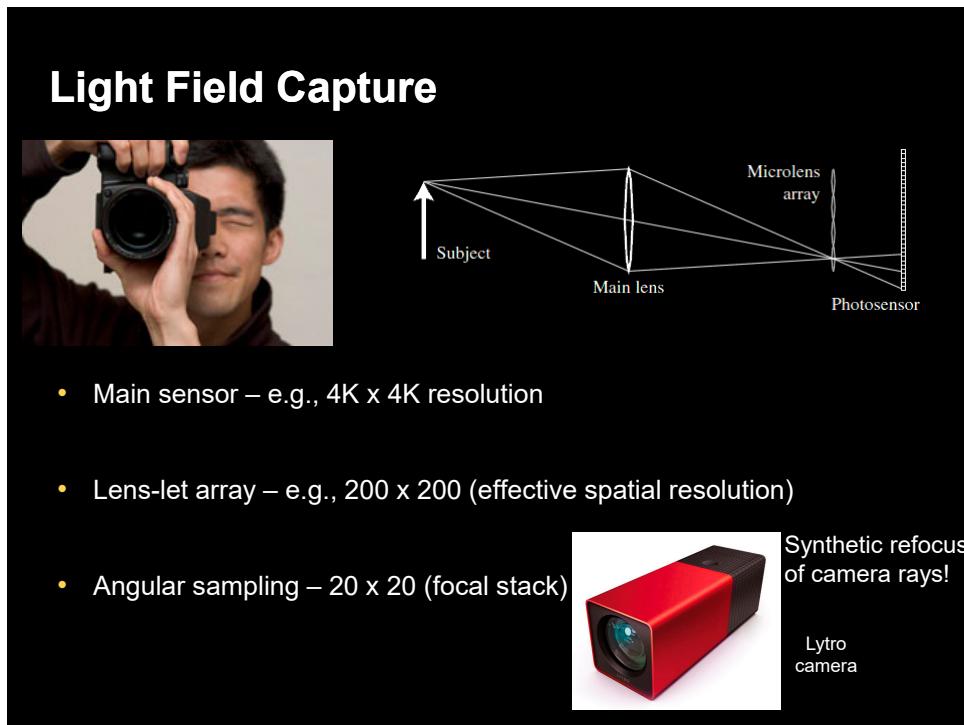
See objects behind the bush!

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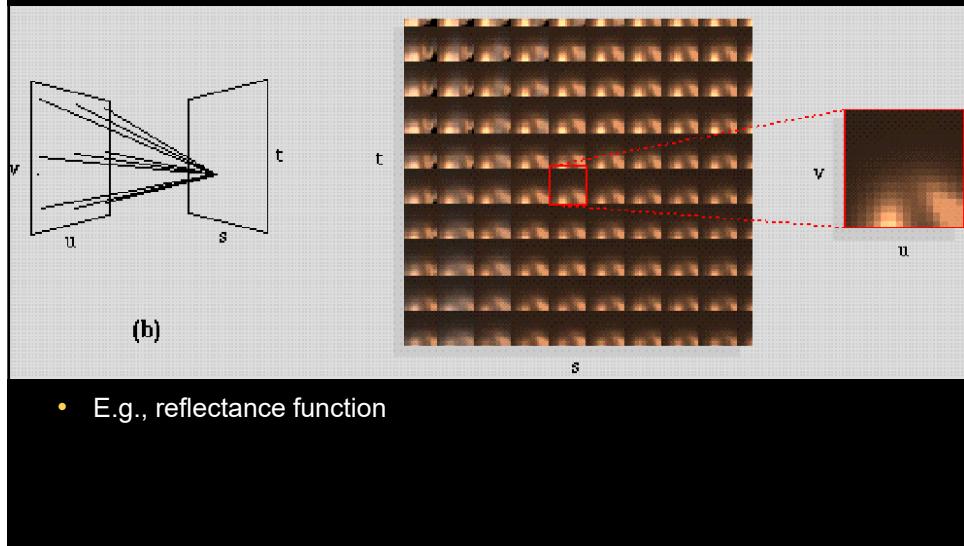


39



40

Light Field Representation



- E.g., reflectance function

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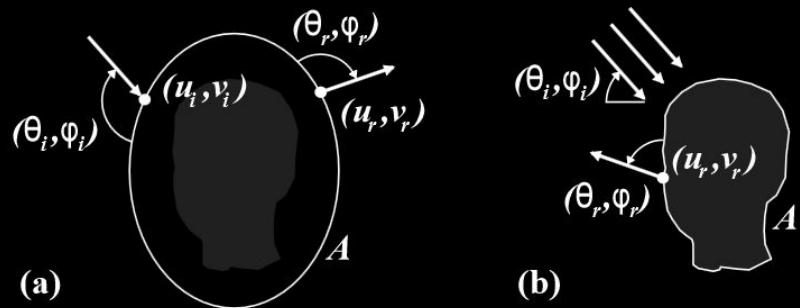
Reflectance Field Capture



- Light Stage 1 - fixed view, multiple illumination capture
[Debevec et al. '00]

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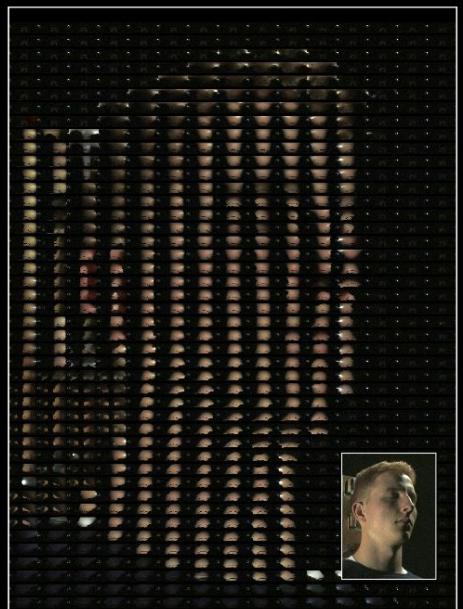
Reflectance Field – 8D vs 4D



- 4D - fixed view, multiple illumination capture $R_r(u_r, v_r, \theta_r, \phi_r)$
[Debevec et al. '00]

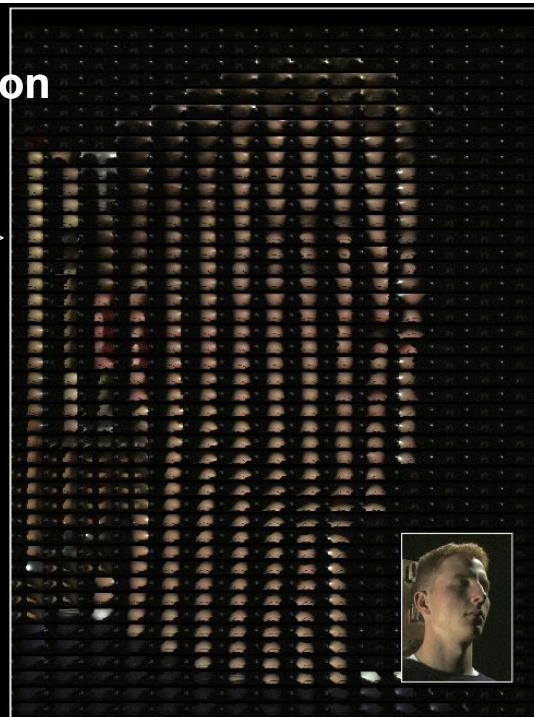
43

4D Reflectance Function



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Reflectance Function



- Resampling of reflectance field

45

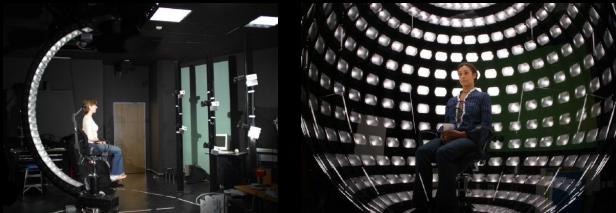
Reflectance Function

- Per-pixel light transport
 - Diffuse, specular
 - Subsurface scattering
 - Inter-reflection



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Light Stage designs for IBR



Light Stage 2
[Hawkins et al. 04]



Light Stage 5
[Wenger et al. 05]

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Light & Reflectance Field Capture



- Light Stage 6 - multiview, multiple illumination capture (6D reflectance field) [Einarsson et al. 06]
 - Large 6m diameter LED sphere for full body capture

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Light & Reflectance Field Capture



- Dynamic reflectance field capture with high-speed photography
- Rotation on turntable for multiple viewpoint capture

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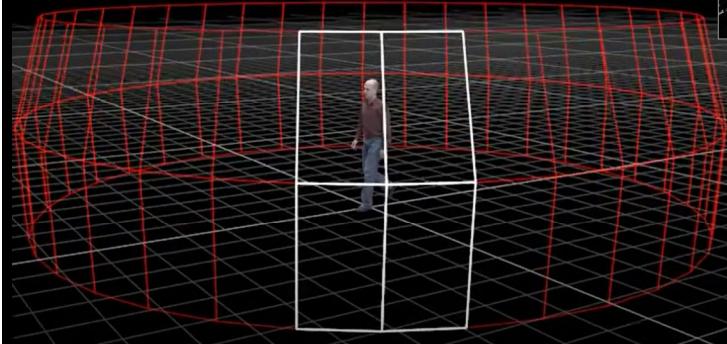
Light & Reflectance Field Capture



- Realistic relighting of dynamic performance under lighting environments
- Light field visualization from any viewpoint around the subject!

50

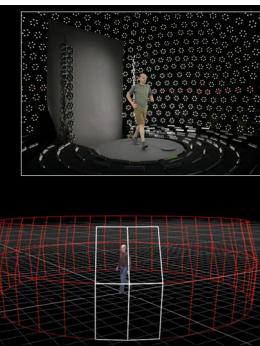
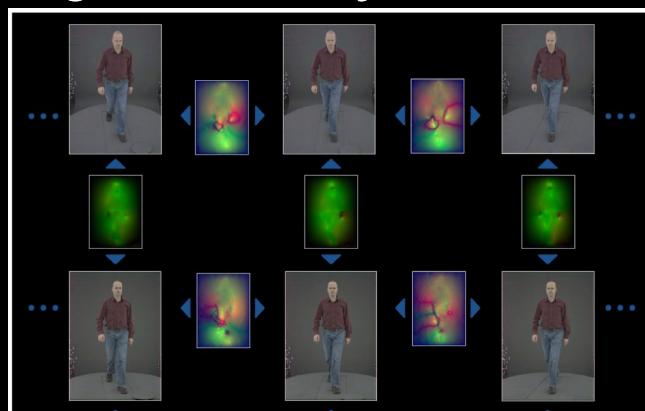
Lightfield view synthesis



- Vertices represent real camera viewpoints of light-field [Einersen et al. 06]
 - Dense correspondence between neighboring camera viewpoints using optical flow
 - View synthesis requires bilinear interpolation of neighboring camera images along optical flow vectors
 - Can result in artifacts due to occlusions/fine-scale structures

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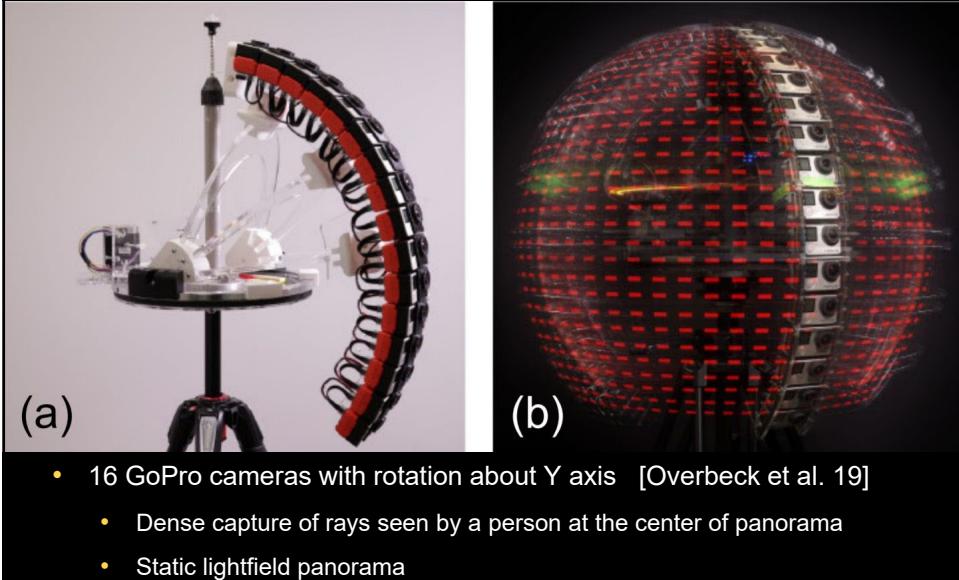
Lightfield view synthesis



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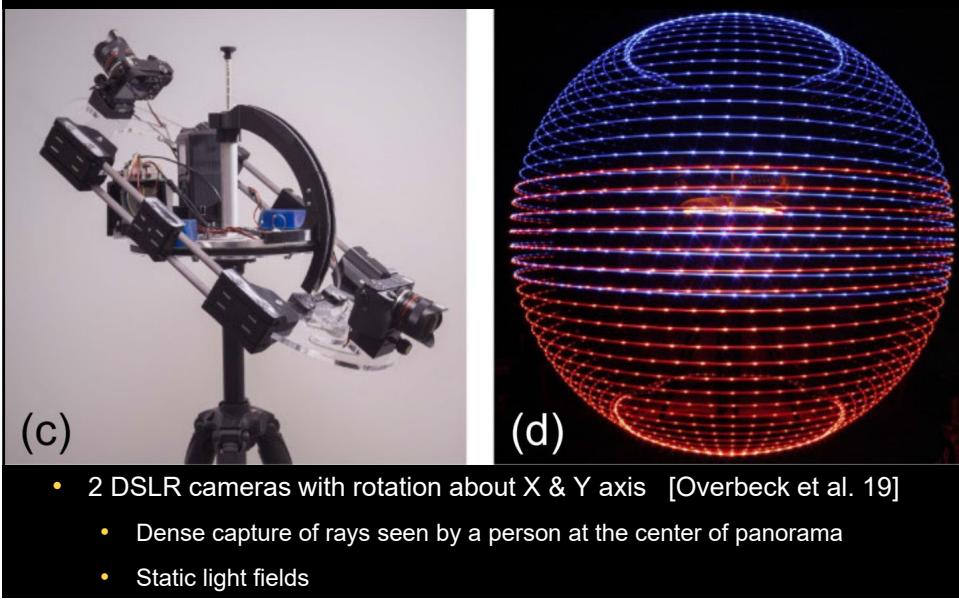
52

Lightfield capture for VR



53

Lightfield capture for VR



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Lightfield capture for VR [Overbeck et al. 19]



- <https://youtu.be/4uHo5liim8>
 - Dense capture of rays seen by a person at the center of panorama
 - Static light fields

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Lightfield capture for VR [Broxton et al. 19]



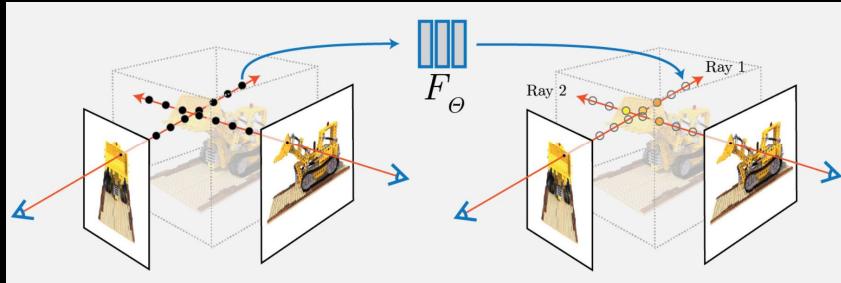
- Outward looking camera sphere
<https://youtu.be/ZHQqJkz8p3Y>
 - Dense capture of multiview video
 - Dynamic light fields!
 - Mobile phone camera optics

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NeRF – Neural Radiance Fields

[Mindelhall et al. 20]

$$(x,y,z,\theta,\phi) \rightarrow \boxed{\quad \quad \quad} \rightarrow (RGB\sigma)$$
$$F_{\theta}$$



- Train a fully connected network to learn a volumetric representation (position + direction) corresponding to lightfield camera images
- View synthesis requires querying volume densities along camera ray from network followed by standard volume rendering to create novel

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NeRF – Neural Radiance Fields

[Mindelhall et al. 20]

$$(x,y,z,\theta,\phi) \rightarrow \boxed{\quad \quad \quad} \rightarrow (RGB\sigma)$$
$$F_{\theta}$$



- View synthesis requires querying volume densities along camera ray from network followed by standard volume rendering to create novel view.
- Can handle complex occlusions that result in errors for standard view interpolation!

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3D Gaussian Splatting

[Kerbl et al. 23]

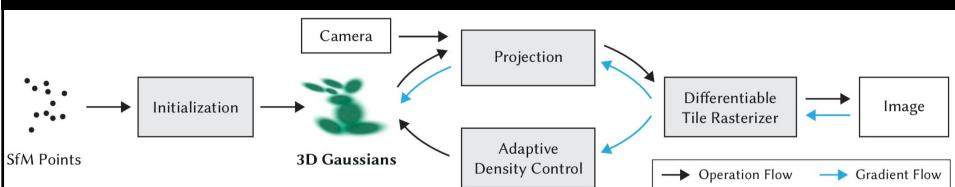


- Fit 3D Gaussians with mean and variance to points in 3D space reconstructed with structure-from-motion (SfM) (multiview capture).
- Fast training to fit anisotropic gaussians using differentiable optimization.
- Real-time rendering with rasterization (splatting) instead of 3D volume rendering employed by NeRF.
- Achieves higher quality than NeRFs on thin/high-frequency features.

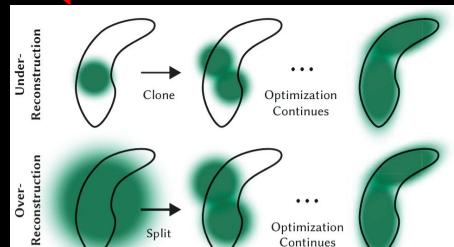
59

3D Gaussian Splatting

[Kerbl et al. 23]



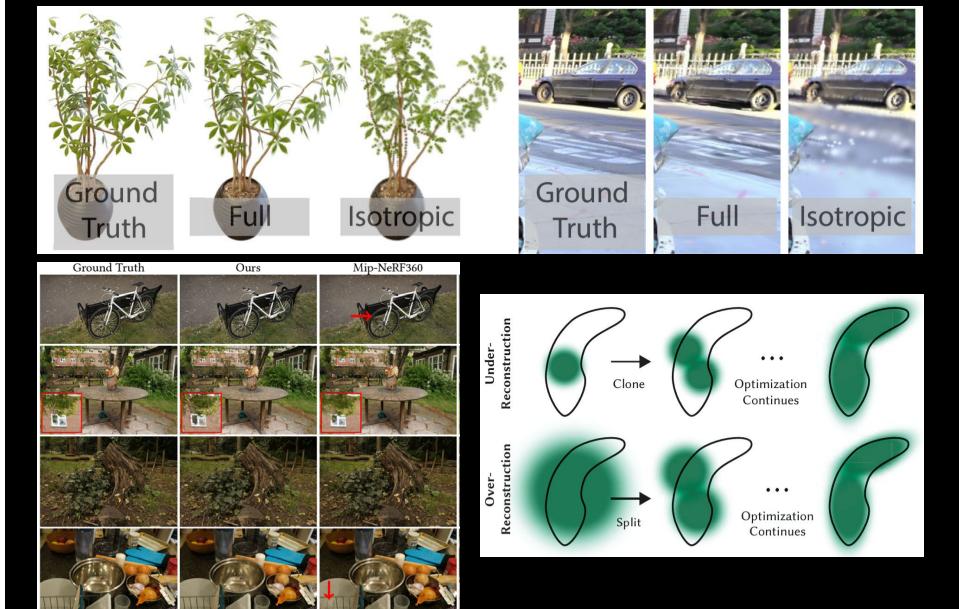
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- Real-time rendering with rasterization (splatting) instead of 3D volume rendering employed by NeRF.



60

3D Gaussian Splatting

[Kerbl et al. 23]



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