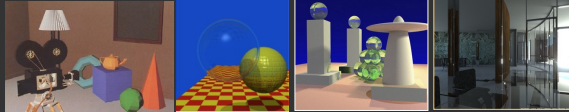


Computer Graphics II: Rendering

CSE 168 [Spr 24], Lecture 17: Image-Based Rendering
Ravi Ramamoorthi

<http://viscomp.ucsd.edu/classes/cse168/sp24>



1

To Do

- Project proposals due tomorrow (May 29)
- Final Projects due Jun 11
- PLEASE FILL OUT SET EVALUATIONS!!
- KEEP WORKING HARD

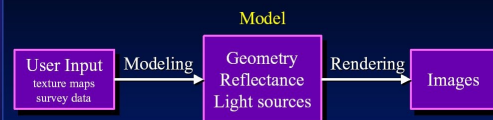
2

Motivation for Lecture

- Image-Based Rendering major new idea in graphics in past 25 years
- Many of the rendering methods, especially precomputed techniques borrow from it
- And many methods use measured data
- Also, images are an important source for rendering
- Sampled data rapidly becoming popular
- Core IBR problem of view synthesis/light fields renewed popularity (VR other applications)

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Traditional Modeling and Rendering



For Photorealism:

Modeling is Hard

Rendering is Slow

Next few slides courtesy Paul Debevec: SIGGRAPH 99 course notes

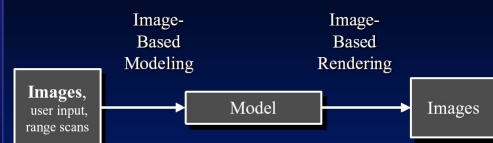
4



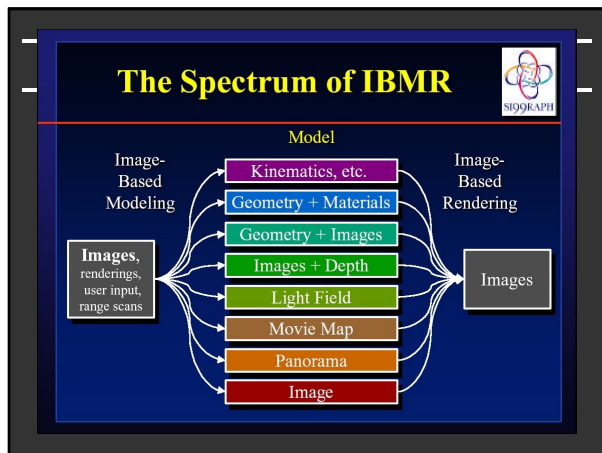
Can we model and render this?
What do we want to do with the model?

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Image-Based Modeling and Rendering



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IBR: Pros and Cons

- **Advantages**
 - Easy to capture images: photorealistic by definition
 - Simple, universal representation
 - Often bypass geometry estimation?
 - Independent of scene complexity?
- **Disadvantages**
 - WYSIWYG but also WYSIAYG
 - Explosion of data as flexibility increased
 - Often discards intrinsic structure of model?
- Today, IBR-type methods also often used in synthetic rendering (e.g. real-time rendering PRT)
 - General concept of data-driven graphics, appearance
 - Also, data-driven geometry, animation, simulation
 - Spawned light field cameras for image capture

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Image-Based Models: What do they allow?

Model	Movement	Geometry	Lighting
Geometry + Materials	Continuous	Global	Dynamic
Geometry + Images	Continuous	Global	Fixed
Images + Depth	Continuous	Local	Fixed
Light Field	Continuous	None	Fixed
Movie Map	Discrete	None	Fixed
Panorama	Rotation	None	Fixed
Image	None	None	Fixed

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IBR: A brief history

- Texture maps, bump maps, environment maps [70s]
- Poggio MIT 90s: Faces, image-based analysis/synthesis
- Mid-Late 90s
 - Chen and Williams 93, View Interpolation [Images+depth]
 - Chen 95 Quicktime VR [Images from many viewpoints]
 - McMillan and Bishop 95 Plenoptic Modeling [Images w disparity]
 - Gortler et al, Levoy and Hanrahan 96 Light Fields [4D]
 - Shade et al. 98 Layered Depth Images [2.5D]
 - Debevec et al. 00 Reflectance Field [4D]
 - Inverse rendering (Marschner, Sato, Yu, Boivin, ...)
- Today: IBR hasn't replaced conventional rendering, but has brought sampled and data-driven representations to graphics

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Game #1: increase the dimensionality

2D rgb	texture
2D rgbz	range image
2.5D rgb α z	layered depth images
4D rgb	light field / Lumigraph
4D rgbz	array of range images
4.5D rgb α z	layered light fields

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Game #2: replace the quantity represented

4D rgb	light field / Lumigraph
$\{u, v, s, t\}$	
5D rgb	plenoptic function
$\{x, y, z\} \times \{\theta, \phi\}$	
6D ρ	free-space BRDF field
$\{u, v, s, t\} \times \{\theta_s, \phi_s\}$	
7D ρ	BRDF volume
$\{x, y, z\} \times \{\theta_s, \phi_s, \theta_r, \phi_r\}$	

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Outline

- Overview of IBR
- Basic approaches
 - Image Warping
 - [2D + depth. Requires correspondence/disparity]
 - Light Fields [4D]
 - Survey of some early work

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Images as a Collection of Rays



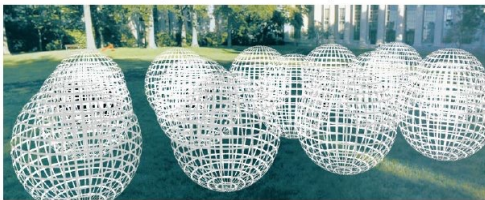
An image is a subset of the rays seen from a given point
- this "space" of rays occupies two dimensions

Warping slides courtesy Leonard McMillan, SIGGRAPH 99 course notes

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The Plenoptic Function

- ✓ The set of rays seen from all points ...

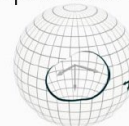


$$p = P(\theta, \phi, x, y, z, \lambda, t)$$

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Image-based rendering is about

- ...reconstructing a plenoptic function from a set of samples taken from it.



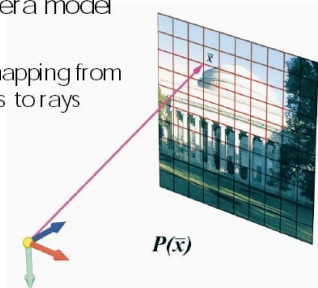
- ✓ Ignoring time, and selecting a discrete set of wavelengths gives a 5-D plenoptic function

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Where to Begin?

- ✓ Pinhole camera model

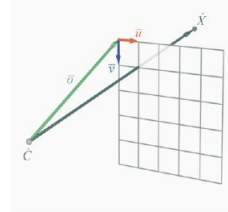
- Defines a mapping from image points to rays in space



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Mapping from Rays to Points

- ✓ Simple Derivation

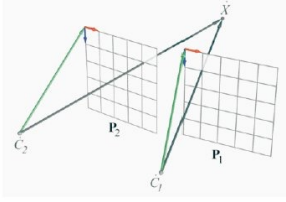


$$P = \begin{bmatrix} u_x & v_x & o_x \\ u_y & v_y & o_y \\ u_z & v_z & o_z \end{bmatrix}$$

$$\vec{X} = \vec{C} + t P \vec{x}$$

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Correspondence

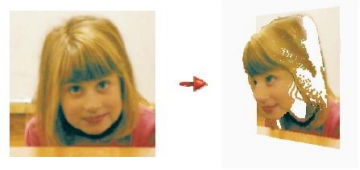


$$\begin{aligned}\dot{C}_2 + t_2 P_2 \vec{x}_2 &= \dot{C}_1 + t_1 P_1 \vec{x}_1 \\ t_2 P_2 \vec{x}_2 &= \dot{C}_1 - \dot{C}_2 + t_1 P_1 \vec{x}_1 \\ t_2 \vec{x}_2 &= P_2^{-1} (\dot{C}_1 - \dot{C}_2) + t_1 P_2^{-1} P_1 \vec{x}_1 \\ \frac{t_2}{t_1} \vec{x}_2 &= \frac{1}{t_1} P_2^{-1} (\dot{C}_1 - \dot{C}_2) + P_2^{-1} P_1 \vec{x}_1 \\ \vec{x}_2 &= \frac{1}{\delta} \underbrace{P_2^{-1} (\dot{C}_1 - \dot{C}_2)}_{\vec{e}_{21}} + \underbrace{P_2^{-1} P_1}_{H_{21}} \vec{x}_1\end{aligned}$$

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Warping in Action

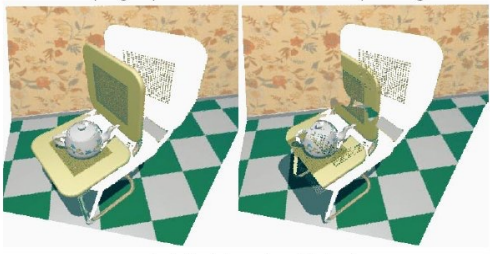
✓ A 3D Warp



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Visibility

✓ The warping equation determines where points go...

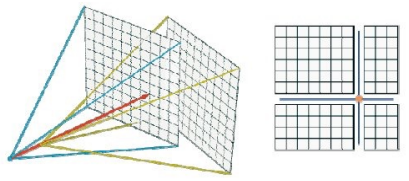


... but that is not sufficient

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Partition Reference Image

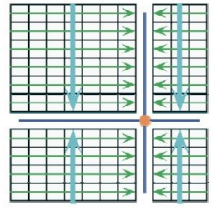
✓ Project the desired center-of-projection onto the reference image



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Enumeration

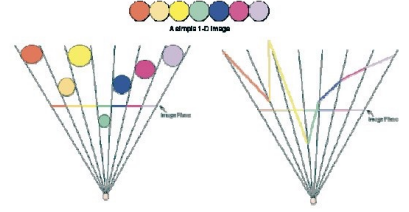
- ✓ Drawing toward the projected point guarantees an *occlusion compatible* ordering
- ✓ Ordering is consistent with a painter's algorithm
- ✓ Independent of the scene's contents
- ✓ Easily generalized to other viewing surfaces
- ✓ No auxiliary information required



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Reconstruction

- ✓ Typical images are discrete, not continuous
- ✓ An image can be formed by different geometries



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Outline

- Overview of IBR
- Basic approaches
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 - *Light Fields [4D]*
 - Survey of some early work

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Light Field Rendering

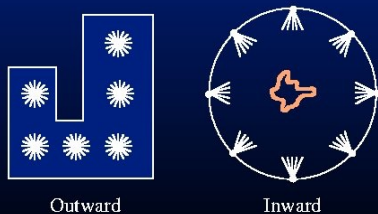
Marc Levoy Pat Hanrahan



Computer Science Department
Stanford University

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Apple's QuickTime VR



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Generating New Views

Problem: fixed vantage point/center

One Solution: view interpolation

- Interpolating between range images (Chen and Willams, 1993)
- Correspondences and epipolar analysis (McMillan and Bishop, 1995)

-> Requires depths or correspondences:
must be extracted from acquired imagery
relatively expensive and error-prone morph

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Light Fields

Gershun's and Moon's idea of a light field:  
Radiance as a function of a ray or line: $L(x, y, z, \theta, \phi)$

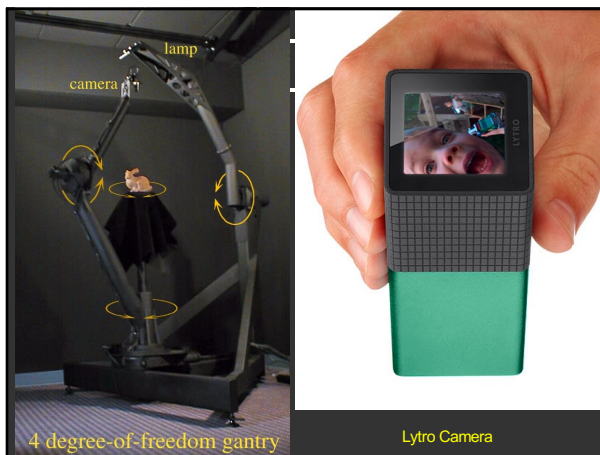
- In "free space" (no occluders) 5D reduces to 4D
 - Exterior of the convex hull of an object
 - Interior of an environment
- Images are 2D slices
 - Insert acquired imagery
 - Extract image from a given viewpoint 

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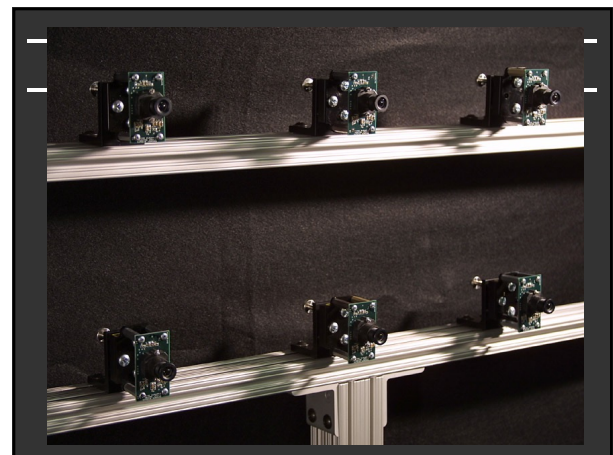
4D Light Field



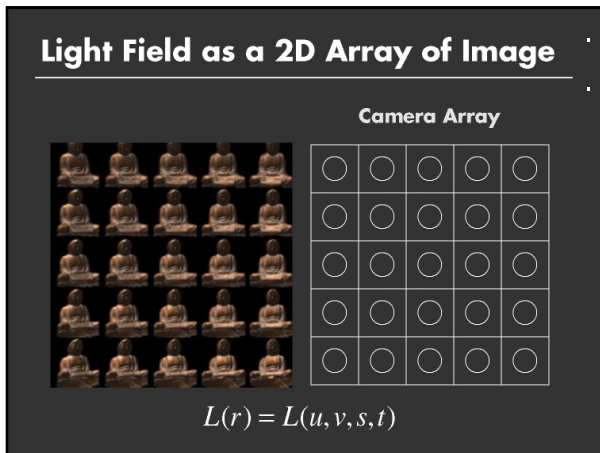
30



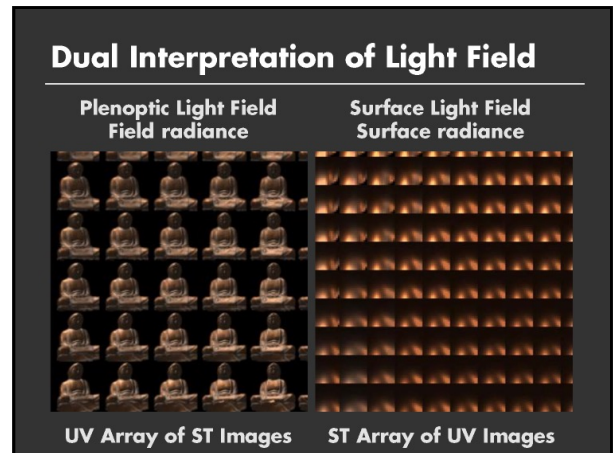
31



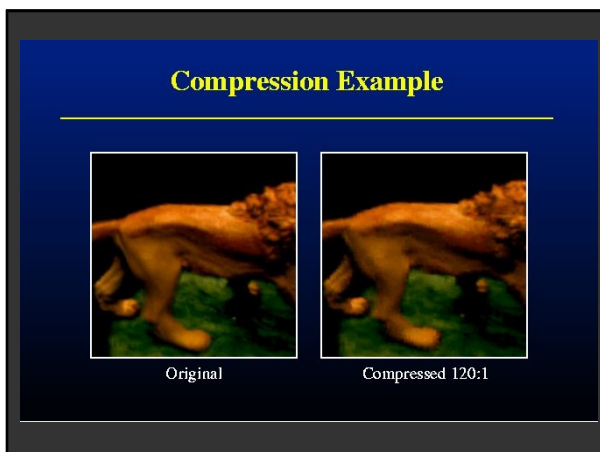
32



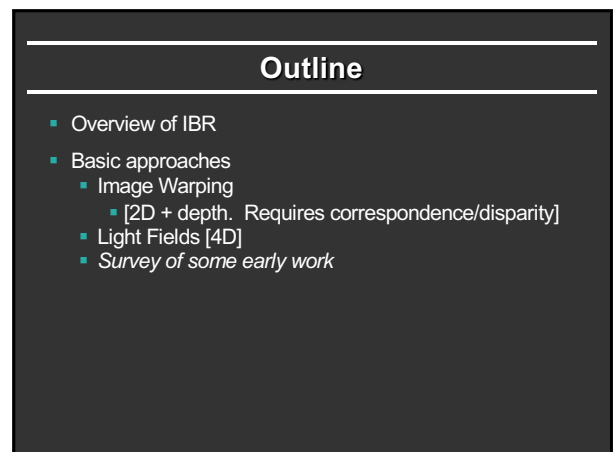
33



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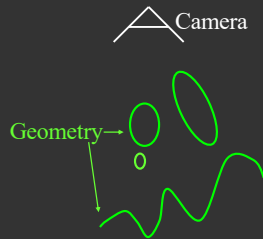


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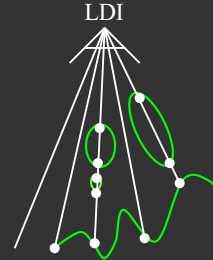
Layered Depth Images [Shade 98]



Slide from Agrawala, Ramamoorthi, Heinrich, Möller, SIGGRAPH 2000

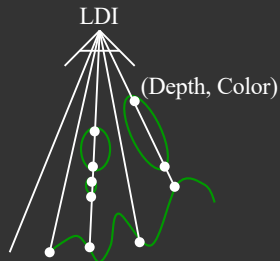
37

Layered Depth Images [Shade 98]



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Layered Depth Images [Shade 98]



39



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Surface Light Fields

- Miller 98, Nishino 99, Wood 00
- Reflected light field (lumisphere) on surface
- Explicit geometry as against light fields. Easier compress



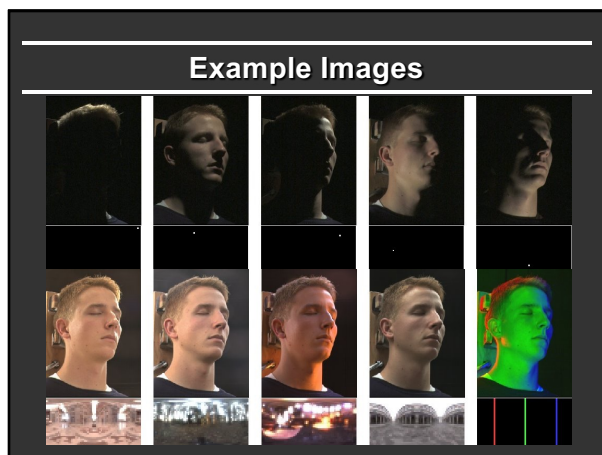
41

Acquiring Reflectance Field of Human Face [Debevec et al. SIGGRAPH 00]

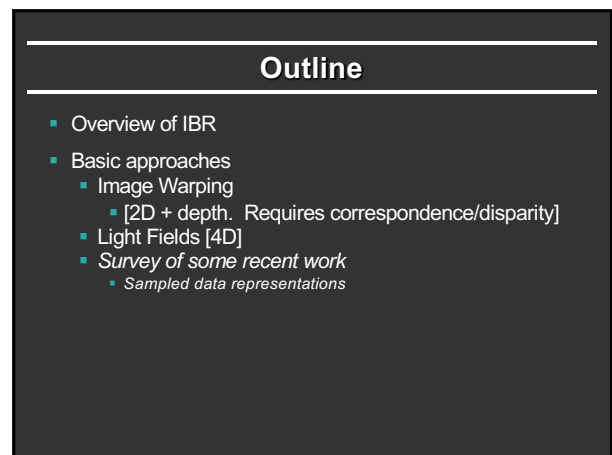
Illuminate subject from many incident directions



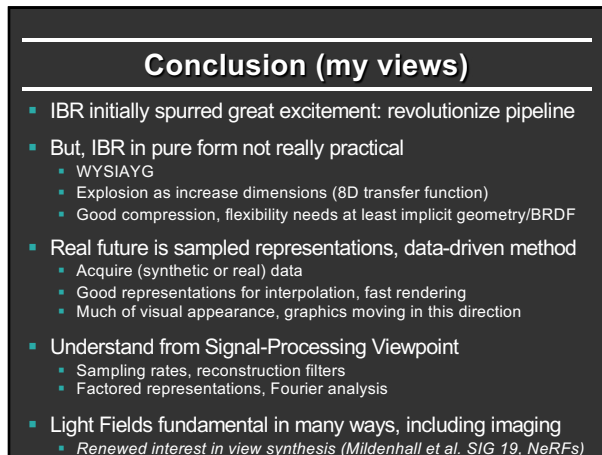
42



43



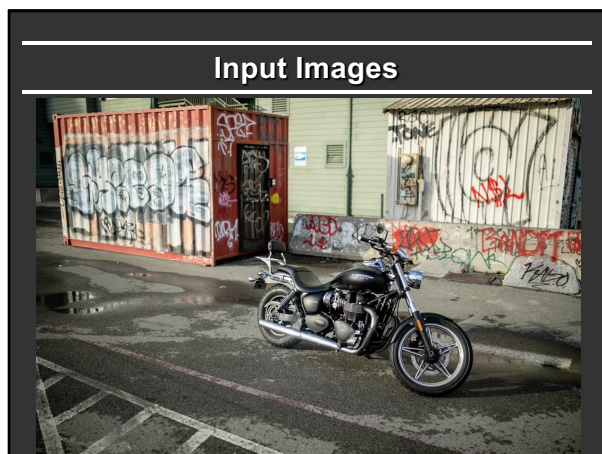
44



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46

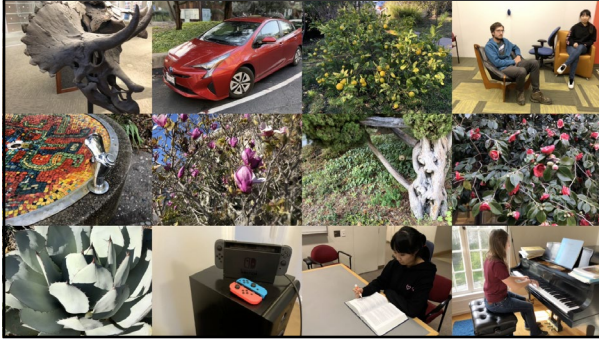


47



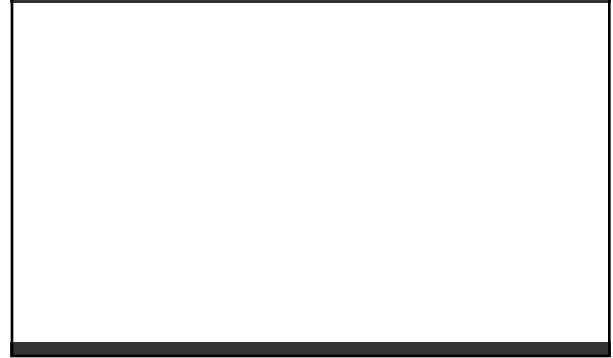
48

Local Light Field Fusion



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Neural Radiance Fields



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