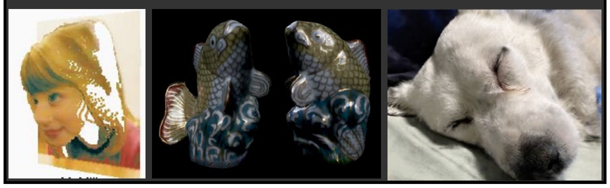
Image-Based Rendering

CSE 274, Lecture 5: Light Transport Acquisition

Ravi Ramamoorthi

http://www.cs.ucsd.edu/~ravir



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To Do

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Motivation

- IBR is not just view synthesis (4D)
- Vary light instead of view, reflectance field (4D)
- Light and view variation (light transport) (6D-8D)
- Inverse Rendering for Material Properties
- All of these remain active areas of research

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General Plenoptic Function

- All knowledge of light in scene [Adelson 91]
- Anywhere in space (x,y,z)
- In any direction (ω_i, ω_o)
- At any time instant (t)
- For any wavelength of light (λ)
- Function of 7 variables, therefore 7D function
- View synthesis typically looking at 4D slice (x_o, ω_o)
- *General Scattering Function is 14D (Two plenoptics)* $f(x_i, y_i, z_i, \theta_i, \varphi_i, \lambda_i, t_i\ ;\ x_o, y_o, z_o, \theta_o, \varphi_o, \lambda_o, t_o)$

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Common Assumptions

- Ignore time dependence (no phosphorescence or time-varying BRDF properties)
- Ignore wavelength (no fluorescence, assume RGB)
- Travel in free space, parameterize on surfaces (no z)
  - For light fields: 4D space of rays (intersections in 2 planes)
- Each of these removes 1D of plenoptic, 2D of scattering
- Left with 8D function of greatest importance for class
- 8D Bi-Directional Surface Scattering Distribution Function (BSSRDF) $f(x_i, y_i, \theta_i, \varphi_i;\ x_o, y_o, \theta_o, \varphi_o)$

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Taxonomy of 8D Scattering Function

- Function of two spatial positions, two spherical angles (4 total)
- Can consider any subsets of 1-4 of these
  - Slices of the full 8D BSSRDF
- Number of possible slices is 4+6+4+1 = 15.
  - Not all make sense, but most do and have been studied
  - IBR for view synthesis is only one of these slices
  - Broader framework for general light transport acquisition

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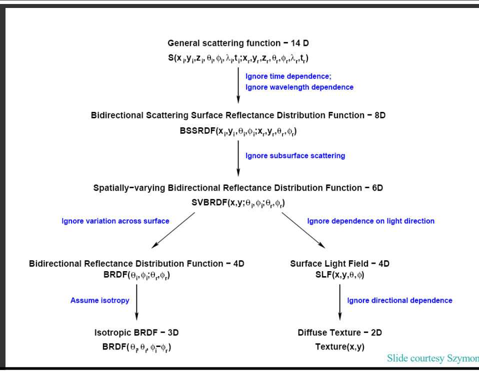
Taxonomy of Appearance



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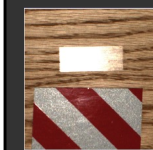
Key 6D Scattering Functions

$f(x_i, \omega_i\,;\, x_o, \omega_o)$

Ignore subsurface scattering $x_i = x_o = x$

$f(x, \omega_i, \omega_o)$



Spatially-Varying BRDF (6D SVBRDF)
BiDirectional Texture Function (6D BTF)
Also, for relighting image, changing view

SVBRDF Lawrence 06

CURET: Corduroy BTF

"Other" Functions (slices not open to easy interpretation).
See if you can find a good interpretation (briefly discuss later)

$f(\vec{x}_i; \vec{x}_o, \vec{w}_o)$ $f(\vec{w}_i\,; \vec{x}_o, \vec{w}_o)$ $f(\vec{x}_i, \vec{w}_i\,; \vec{x}_o)$ $f(\vec{x}_i, \vec{w}_i\,; \vec{w}_o)$

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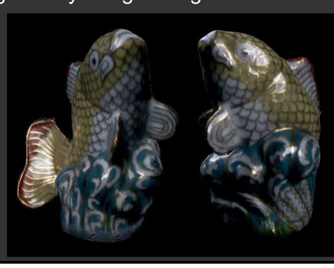
4D: Surface Light Fields

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



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4D: Reflectance Field of Human Face

Illuminate subject from incident directions $(x\ \ , \omega_i)$

Light stage 1 from Debevec et al. 00

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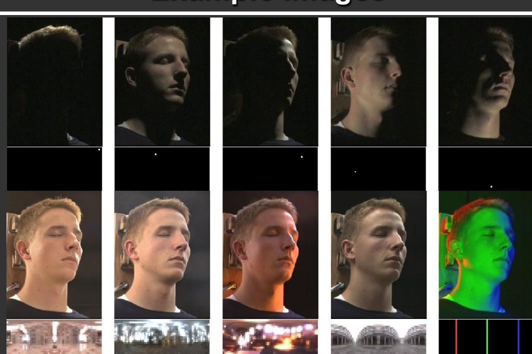
Example Images



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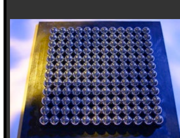
Some 4D "Scattering" Functions

$f(\vec{x}, \vec{w}_i, \vec{w}_o)$

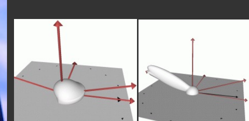
$f(\vec{x}, \vec{w}_i)$
Incident Light Field

$f(\vec{w}_i, \vec{w}_o)$
4D BRDF
BiDirectional Reflectance Distribution Function

$f(\vec{x}, \vec{w}_o)$
Surface Light Field

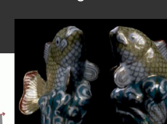


Unger et al. 03



Oren-Nayar He et al.

From Oregon BRDF Library



Wood et al. 00

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Historical Timeline

- Built up from 2D to 4D to 6D to 8D functions
  - 2D functions (texture, env maps) known since 1975-80
  - 4D functions (light fields) in 1996 catalyzed revolution
  - 6D functions (CURET 1999, Incident LF 2003)
  - 8D functions 2006, first acquisitions of full transport
- Generally, individual papers on each topic
- General framework and theory now mostly clear
- We focus on general light transport acquisition, inverse rendering as applications of IBR
- Discuss Peers et al. 09 for Compressive Relighting
  - Bonus: View Synthesis LF cameras Kalantari 16, 17

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Motivation: Image-based Relighting

Sample Lighting Directions

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Motivation: Image-based Relighting

Sample Lighting Directions

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Motivation: Image-based Relighting

Sample Lighting Directions

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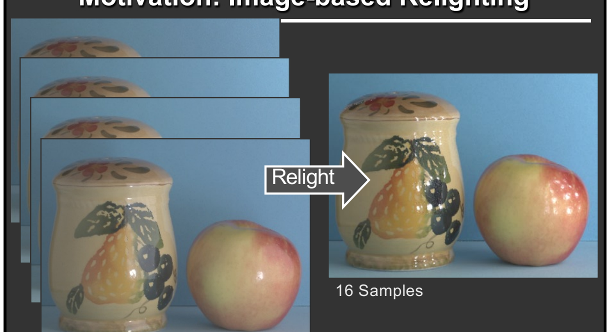
Motivation: Image-based Relighting



16 Samples

Sample Lighting Directions

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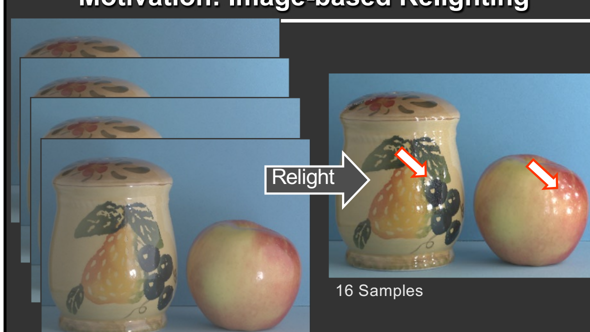
Motivation: Image-based Relighting



16 Samples

Sample Lighting Directions

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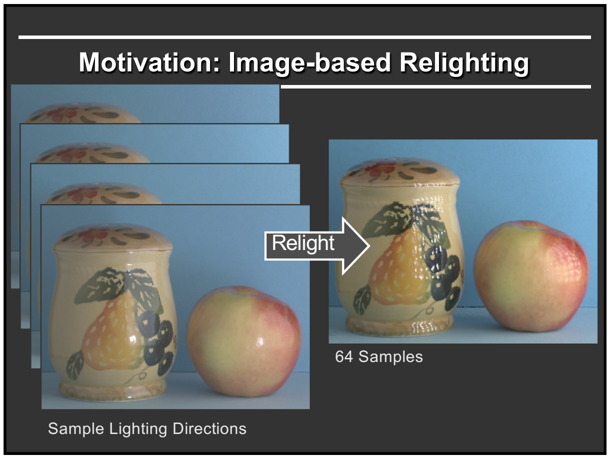

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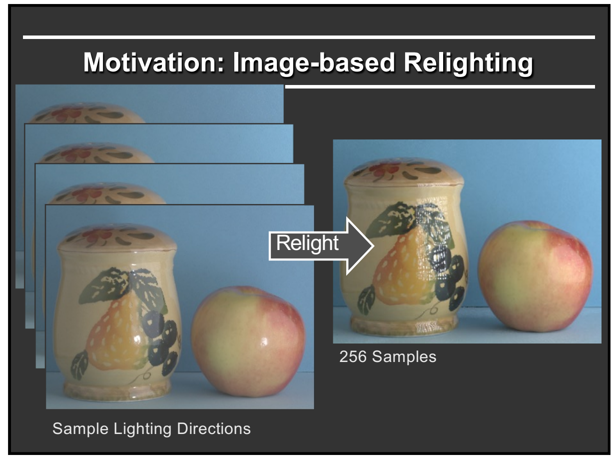

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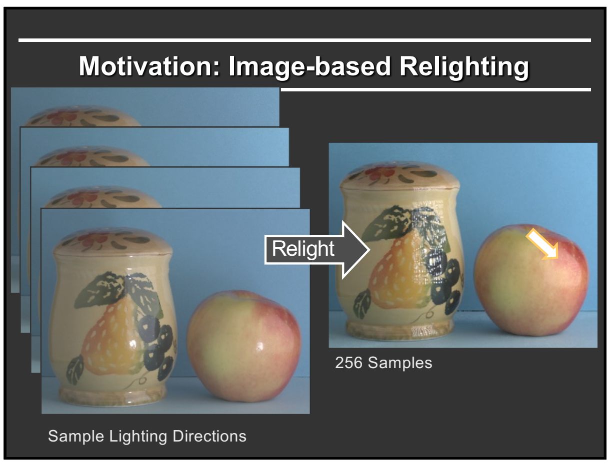

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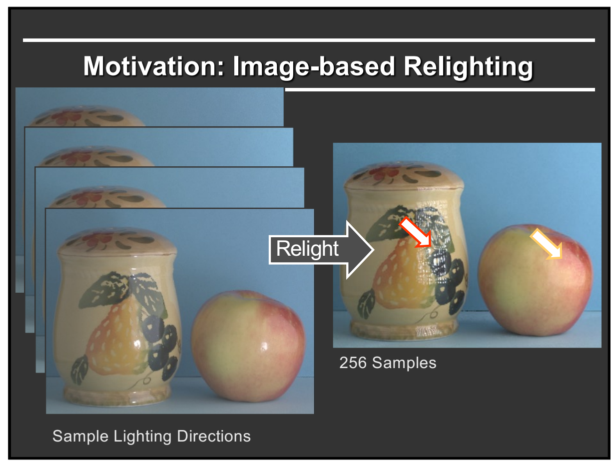

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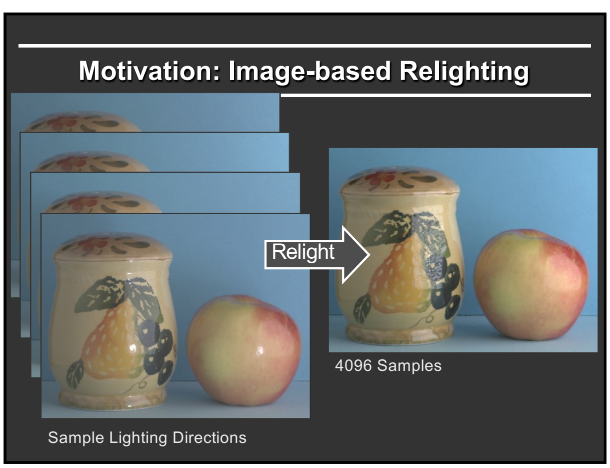

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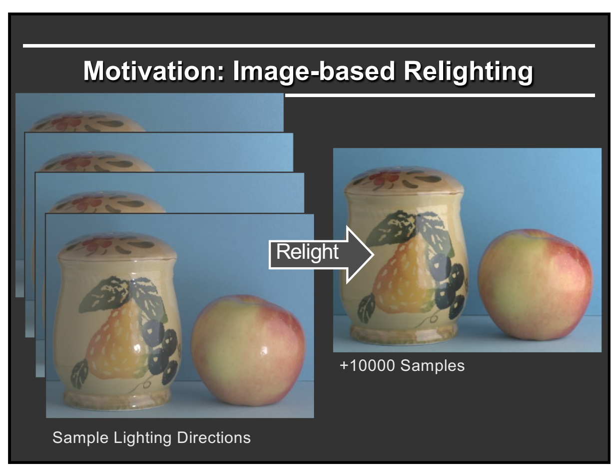

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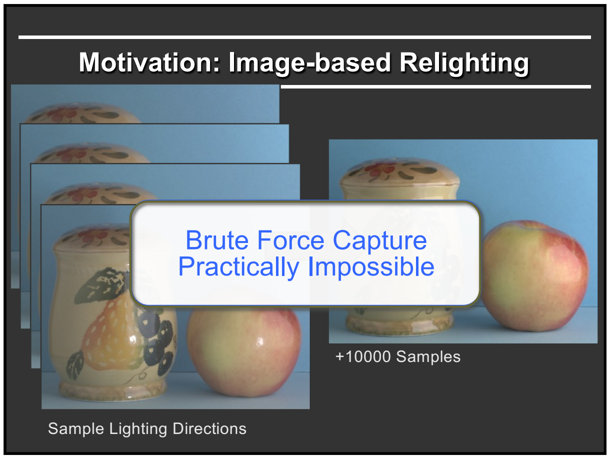

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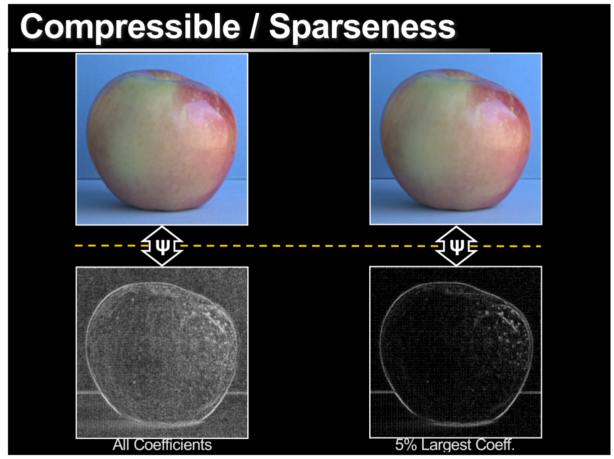

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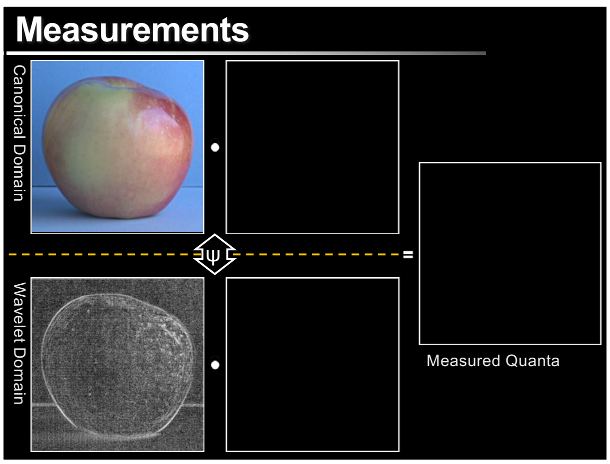

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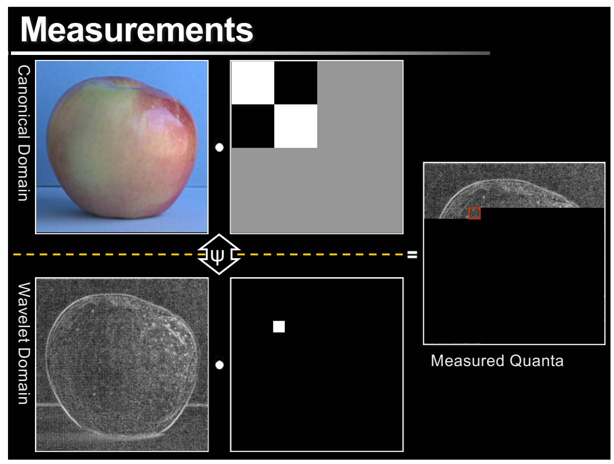

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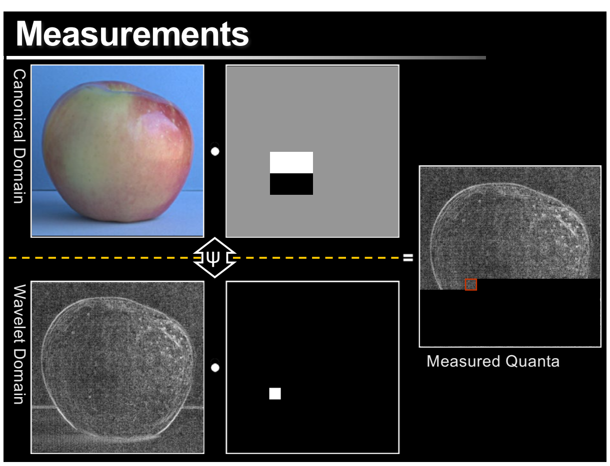

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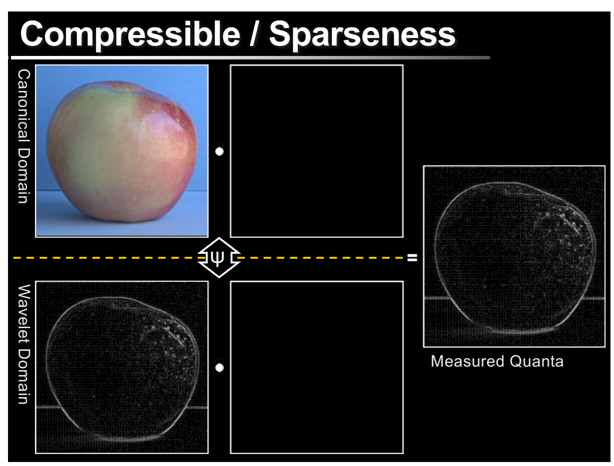

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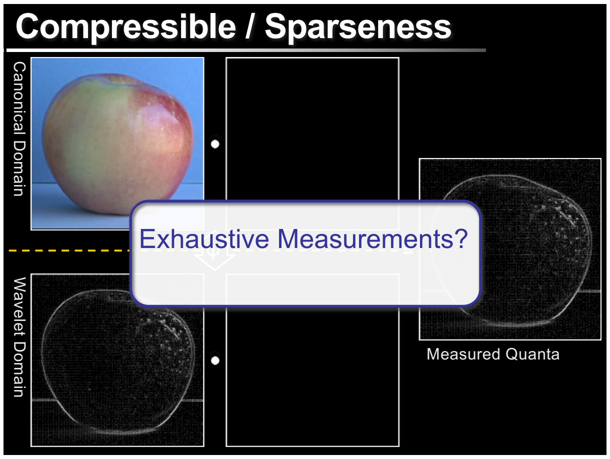

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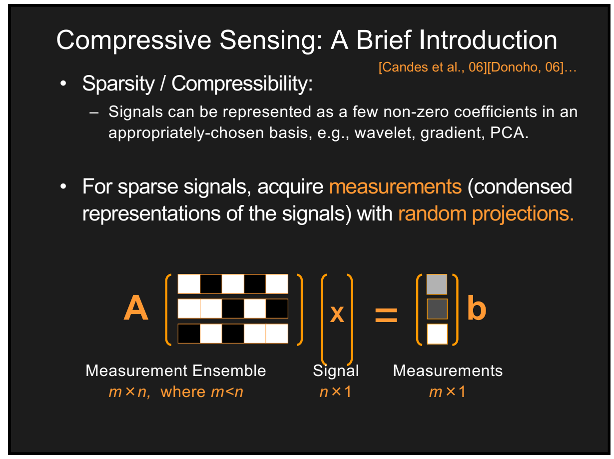

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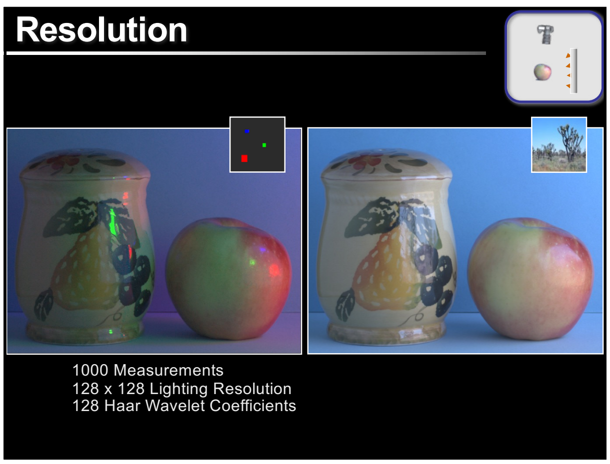

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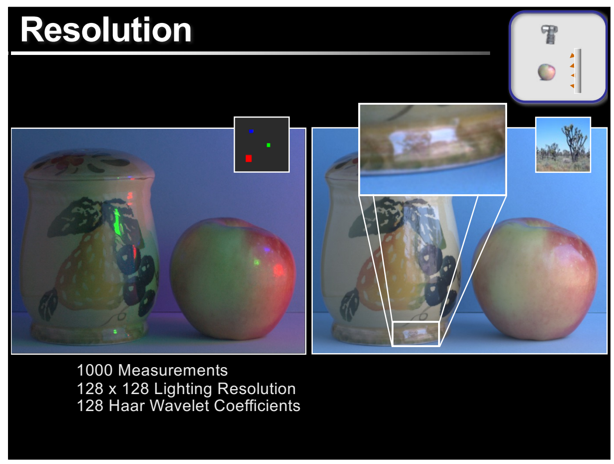

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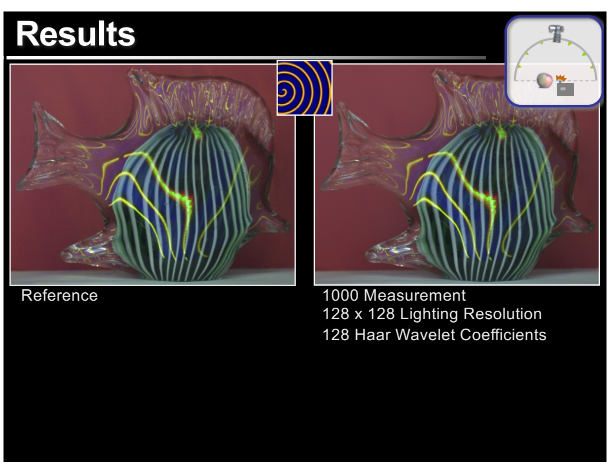

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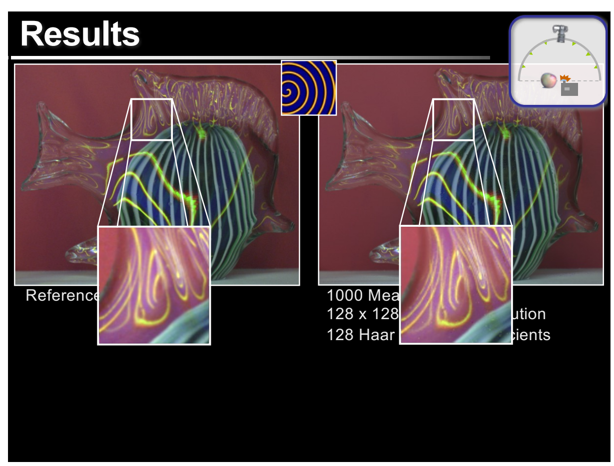

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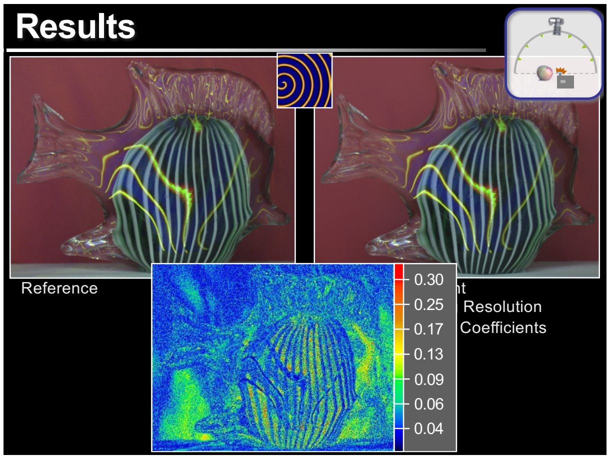

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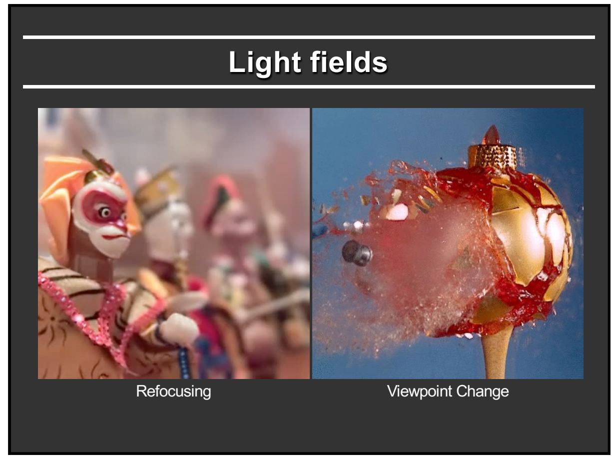

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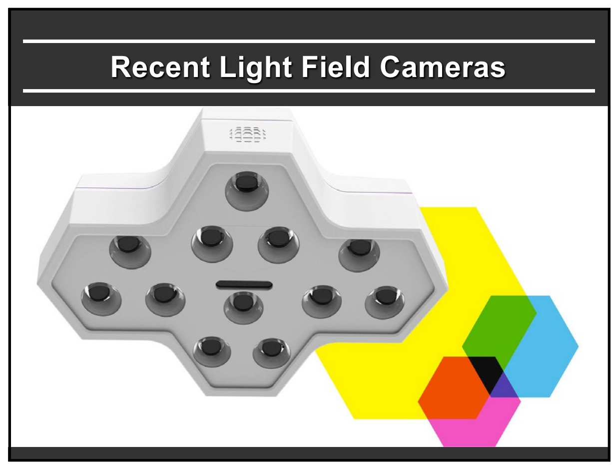

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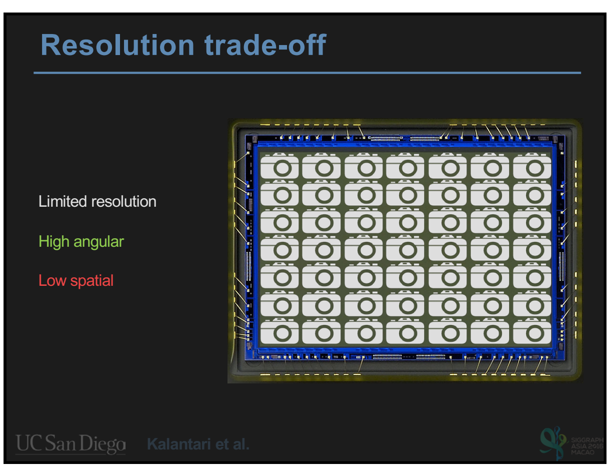

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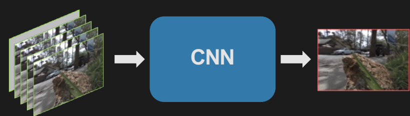
Straightforward solution

- Model the process with a single CNN



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Single CNN's result

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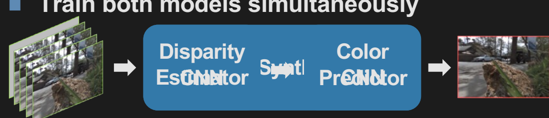
High-level idea

- Follow the pipeline of existing techniques and break the process into two components
  Goesele et al. [2010]; Chaurasia et al. [2013]
  - Disparity estimator
  - Color predictor
- Model the components using learning
- Train both models simultaneously



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Our result

UC San Diego Kalantari et al.

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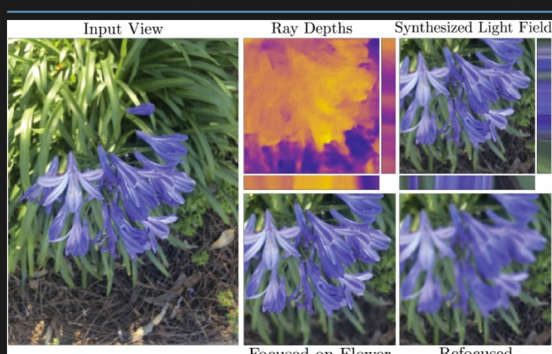
4D RGBD Light Fields from 2D Image



UC San Diego Srinivasan et al. ICCV 17

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Light field video

- Consumer light field cameras limited bandwidth
- Capture low frame rate videos

Lytro Illum (3 fps video)

UC San Diego Wang et al. SIGGRAPH 17

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Lytro video

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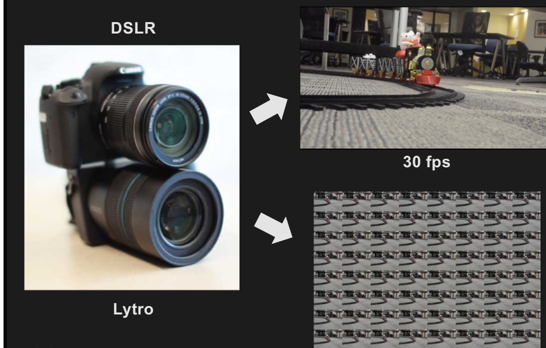
Hybrid Light Field Video System



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Our result

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NeRFs in the Metaverse

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Neural-PBIR: Shape, Material, Lighting

Neural-PBIR recovers high-fidelity material (b1,2), shape and lighting (b3), enabling realistic re-rendering (c1-3).

- Long term goal not just view synthesis but relighting
- Change lighting, materials, put objects in new scenes
- Requires *inverse rendering* (invert rendering equation to recover shape, lighting, materials), note ambiguities
  - *Inverse Rendering for Computer Graphics, Marschner PhD 98*
  - *A Signal Processing Framework for Inverse Rendering, R.&Hanrahan 01*

Sun, Cai et al. ICCV 23

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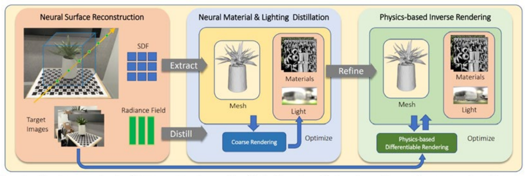
Neural-PBIR: Shape, Material, Lighting



Our pipeline is comprised of three main stages. The first stage is a fast and precise surface reconstruction step that brings direct SDF grid optimization into NeuS. Associated with this surface is an overfitted radiance field that does not fully model the surface reflectance of the object. Our second stage is an efficient neural distillation method that converts the radiance fields to physics-based reflectance and illumination models. Lastly, our third stage utilizes physics-based inverse rendering (PBIR) to further refine the object geometry and reflectance reconstructed by the first two stages. This stage leverages physics-based differentiable rendering that captures global illumination (GI) effects such as soft shadows and interreflection.

- Modern pipelines learn/predict, optimize properties
- Refine by directly optimizing differentiable renderer

Sun, Cai et al. ICCV 23

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