

# Image Based Relighting



70001 – Advanced Computer Graphics: Photographic Image Synthesis

Abhijeet Ghosh

Lecture 05, Jan. 23<sup>rd</sup> 2024

1

# Image Based Relighting

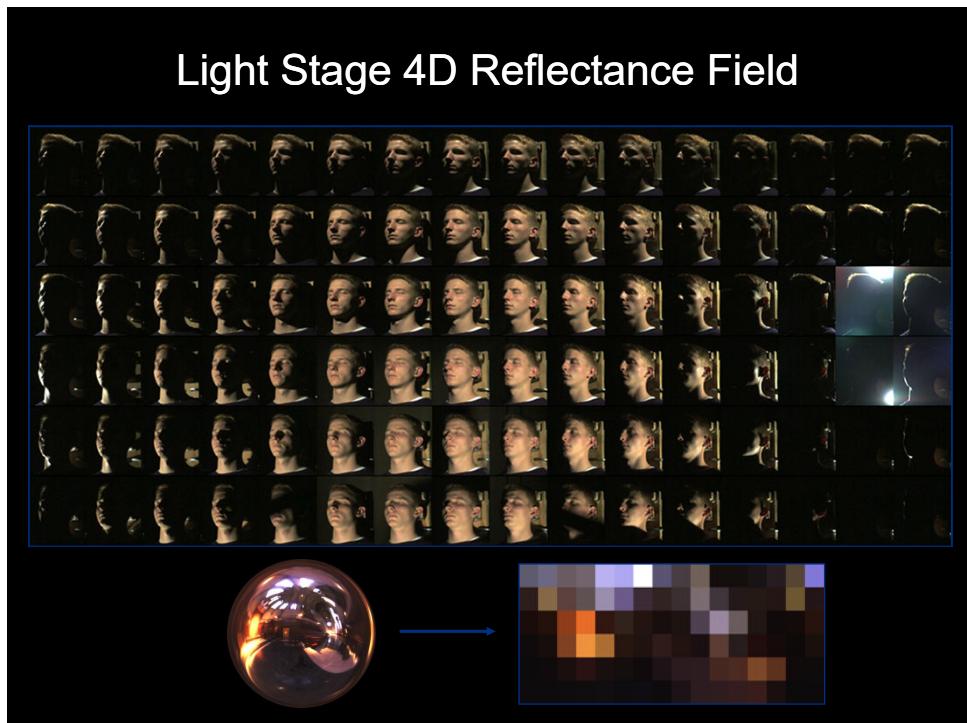
Debevec, Hawkins,  
Tchou, Duiker, Sarokin,  
and Sagar. *Acquiring  
the Reflectance Field  
of a Human Face.*  
SIGGRAPH 2000



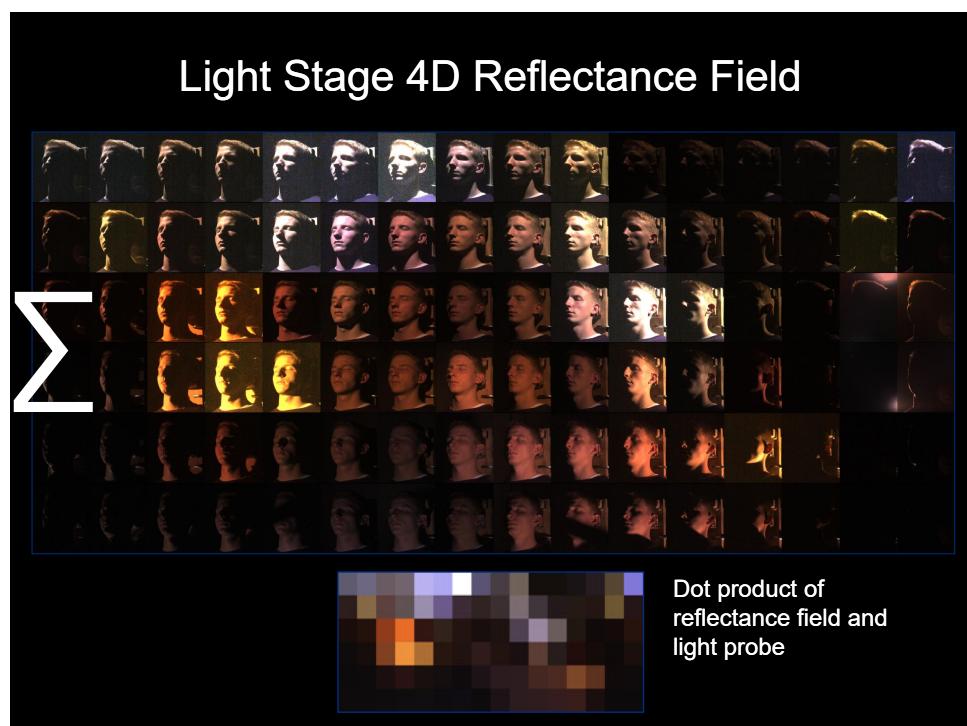
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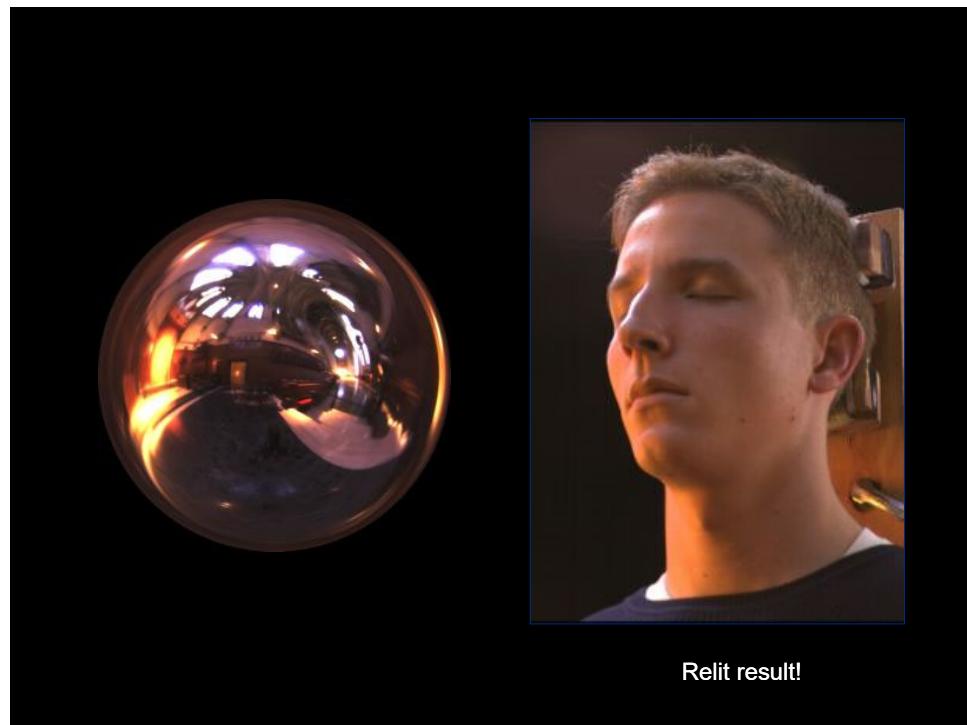
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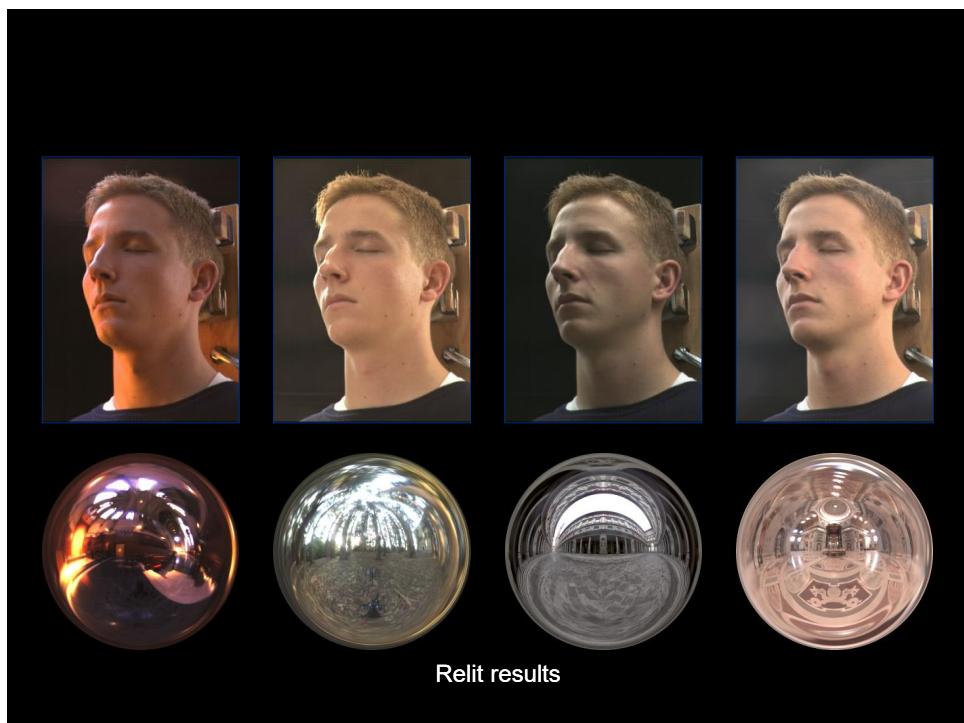
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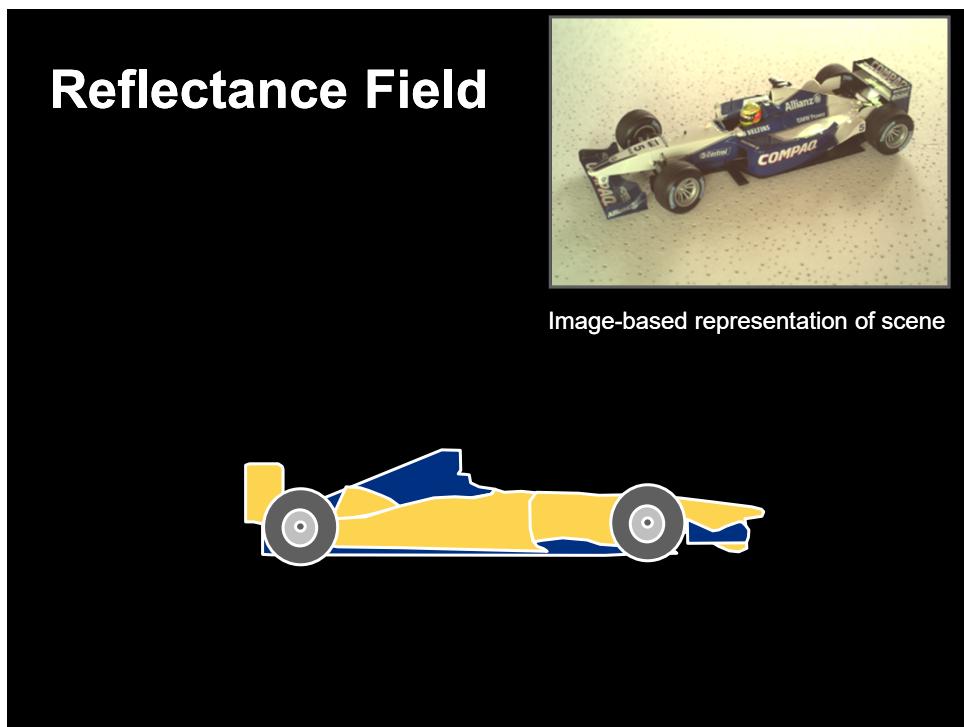
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6

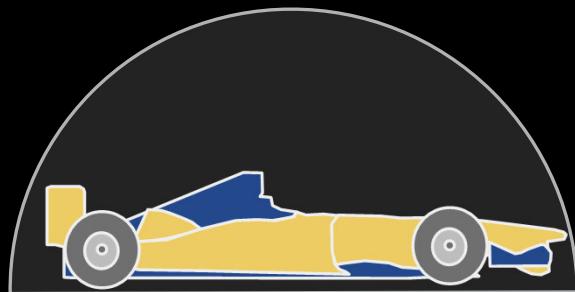


7



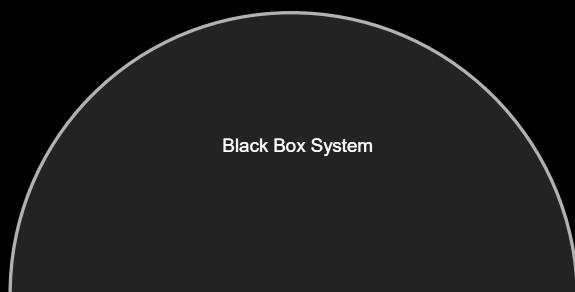
8

## Reflectance Field



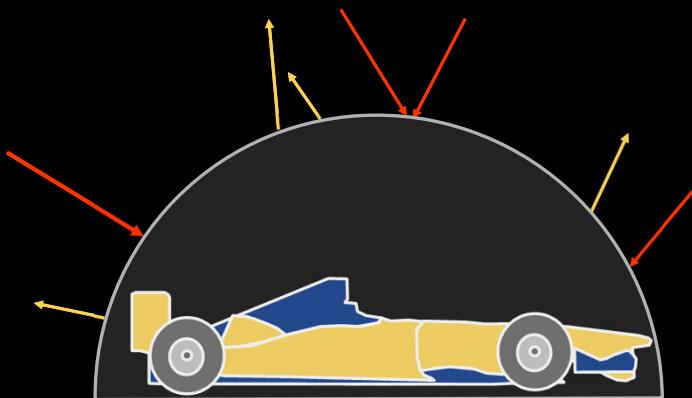
9

## Reflectance Field



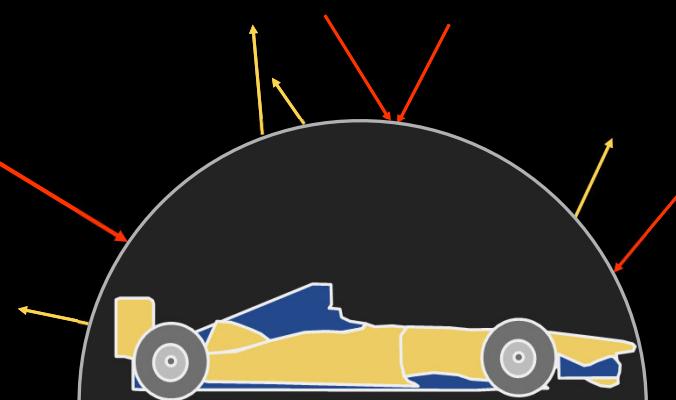
10

## Reflectance Field



11

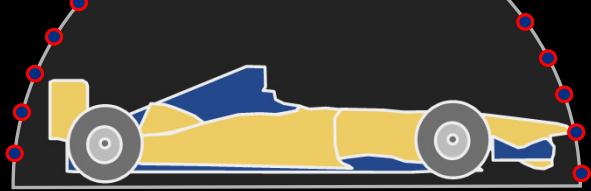
## Reflectance Field



8D Function

12

## Reflectance Field



8D Function

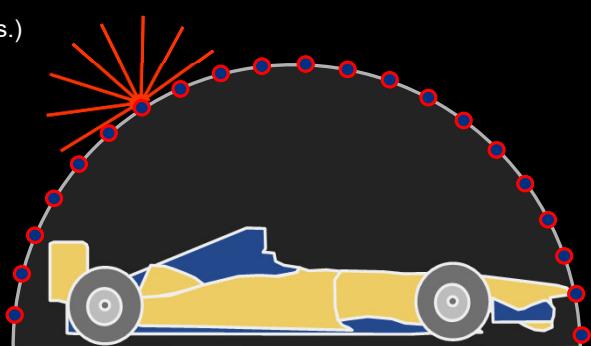
13

## Reflectance Field

4D Incident Light Field

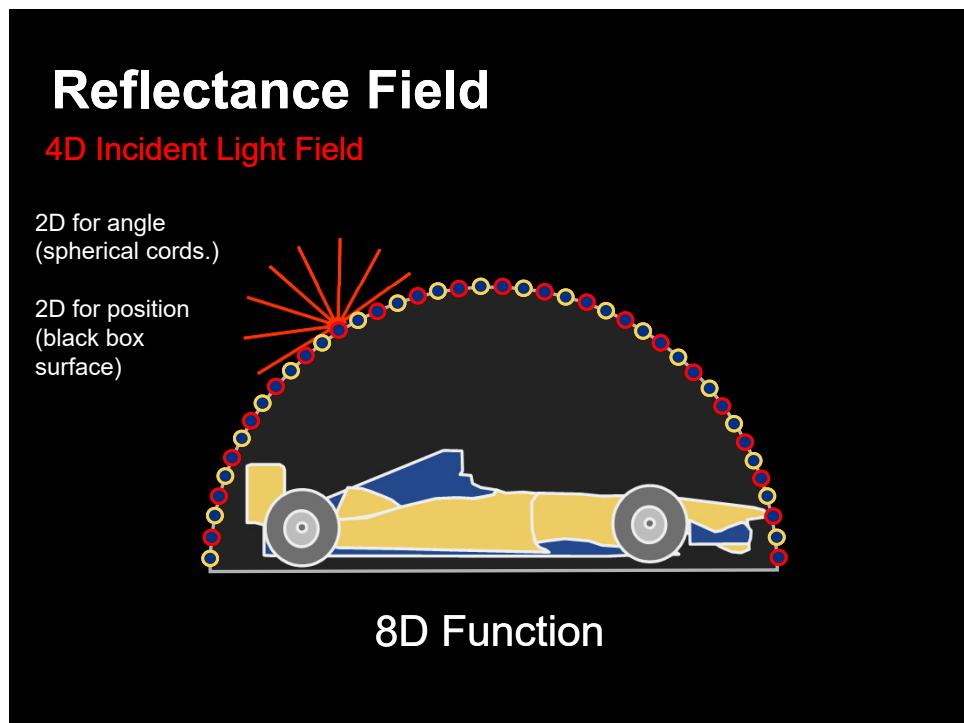
2D for angle  
(spherical cords.)

2D for position  
(black box  
surface)

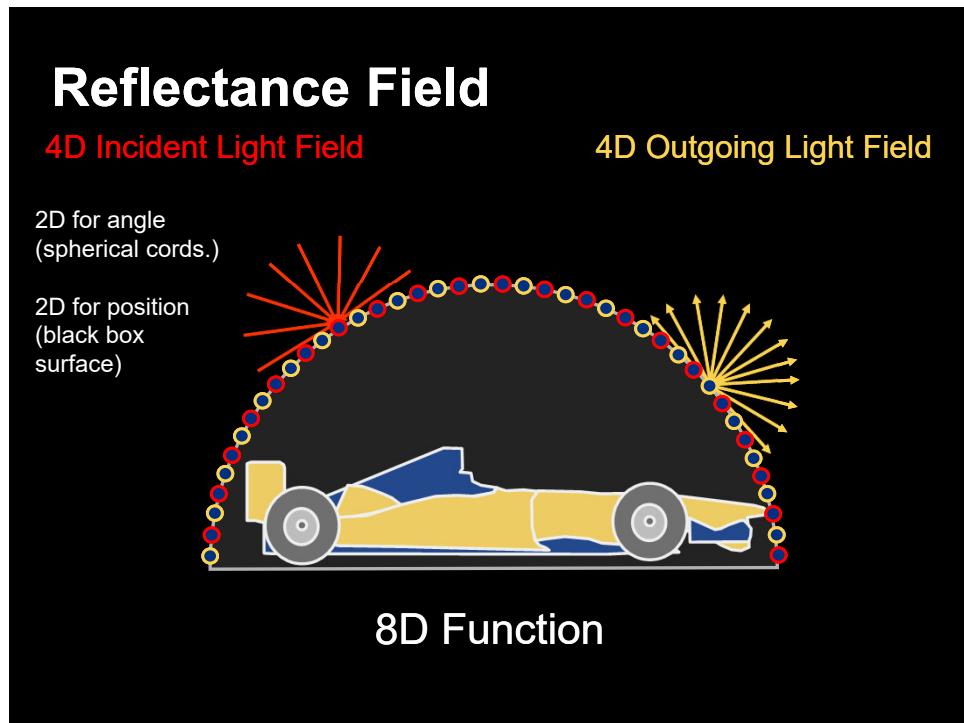


8D Function

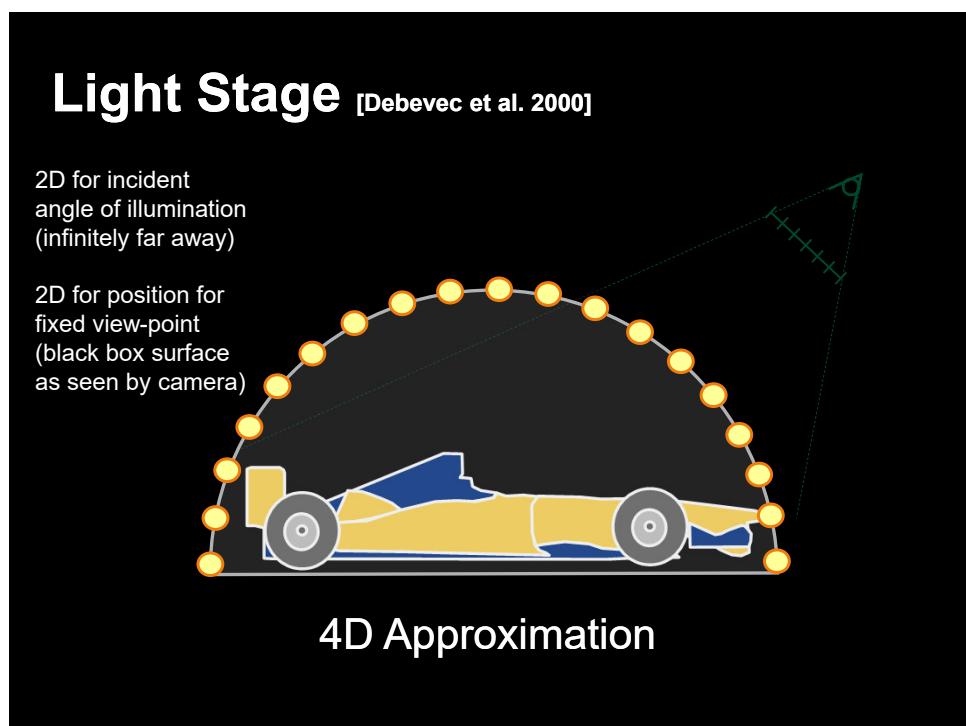
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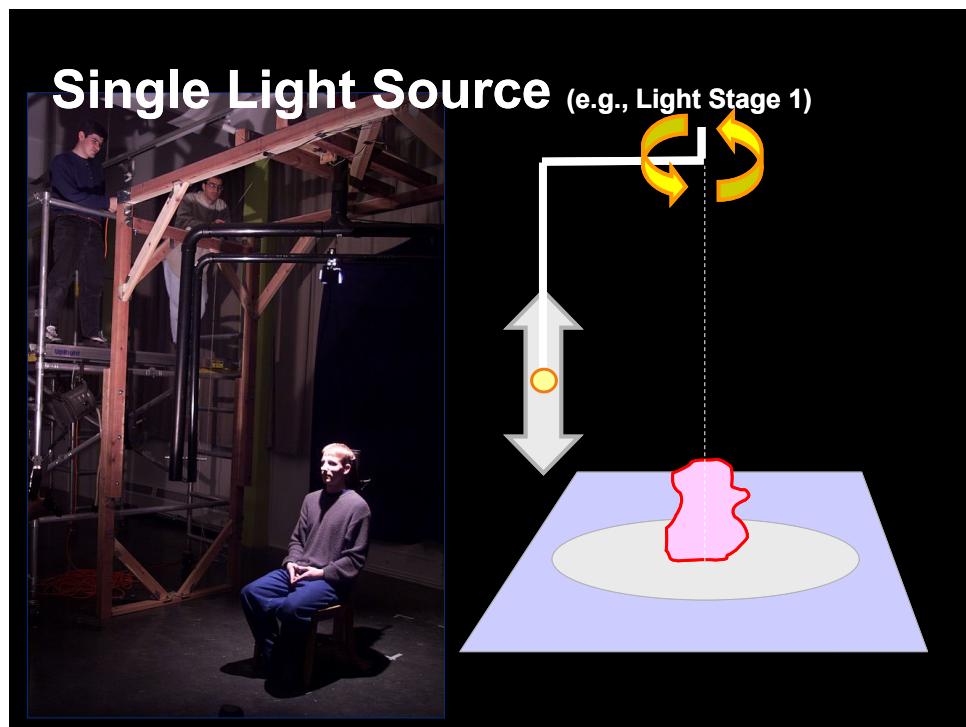
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16

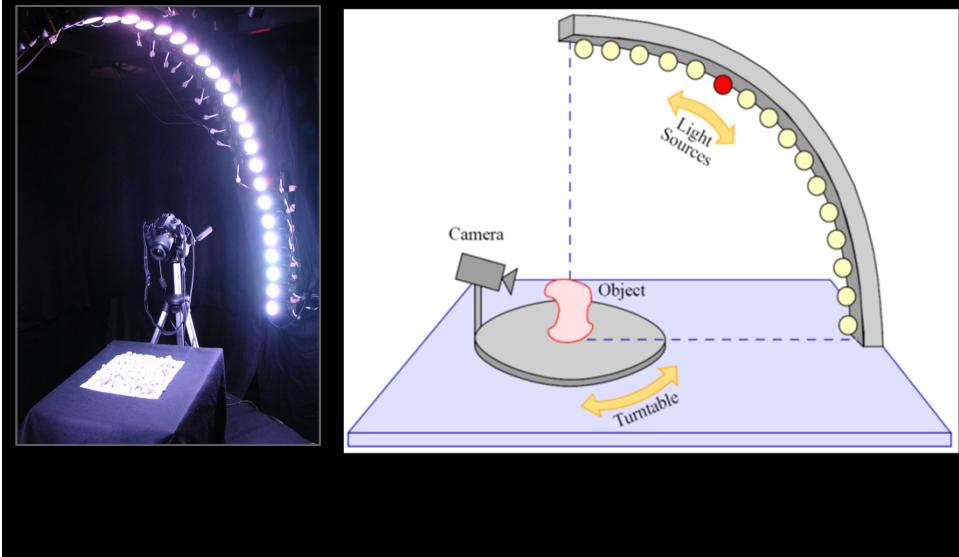


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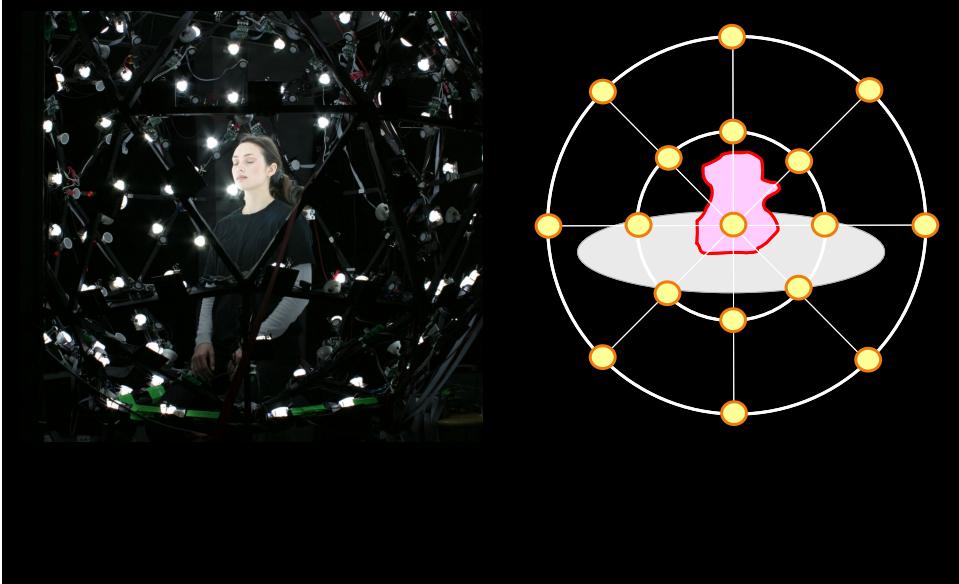
18

## Arc of Lights (e.g., Light Stage 2, Masselus et al. 2004)



19

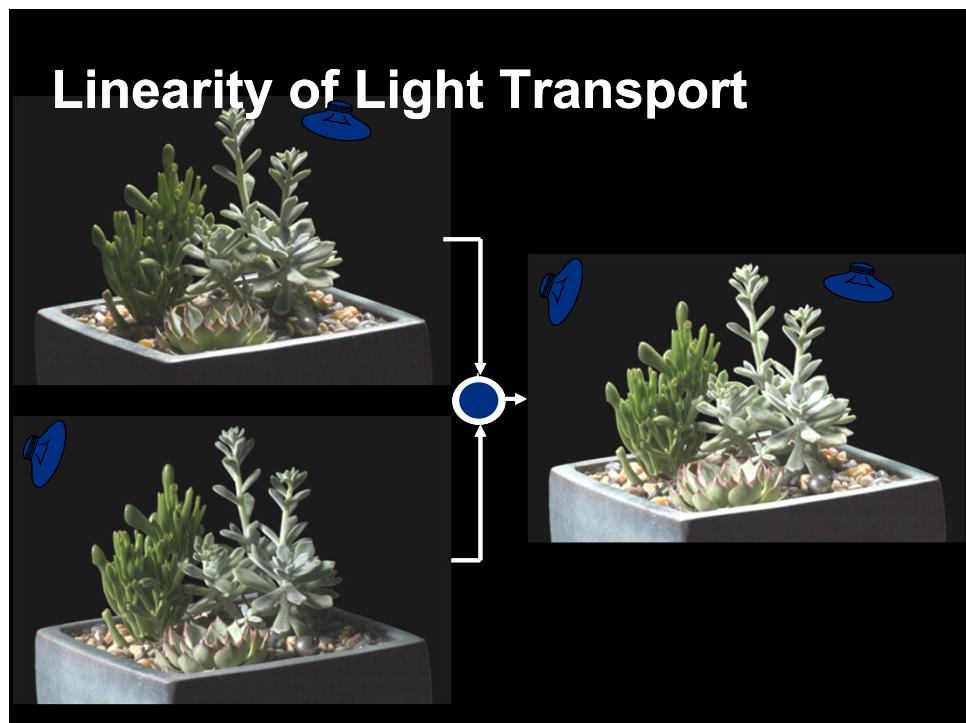
## Light Dome (e.g, LED sphere)



20

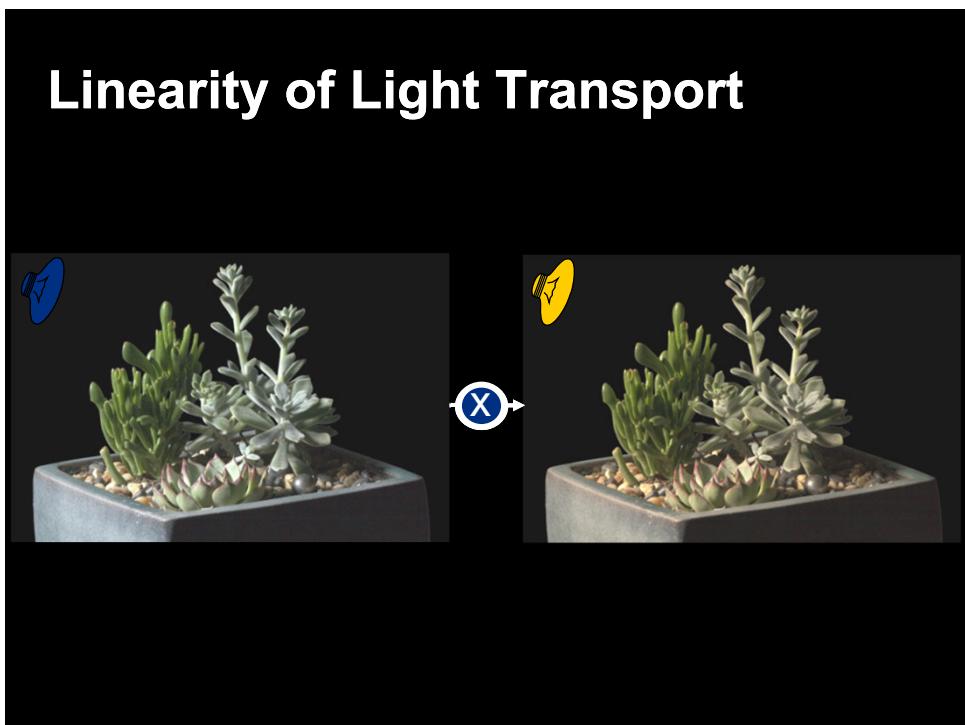
Type	Advantages	Disadvantages
Single Light Source	<ul style="list-style-type: none"> <li>Inexpensive</li> <li>Any Resolution</li> </ul>	<ul style="list-style-type: none"> <li>Slow Acquisition</li> <li>Difficult to automate</li> </ul>
Light Arc	<ul style="list-style-type: none"> <li>High Resolution</li> <li>Moderately Fast</li> </ul>	<ul style="list-style-type: none"> <li>Limited Acquisition Volume</li> </ul>
Light Dome	<ul style="list-style-type: none"> <li>Very Fast</li> <li>Fully Automated</li> </ul>	<ul style="list-style-type: none"> <li>Expensive</li> <li>Complex</li> <li>Low Resolution</li> </ul>

21



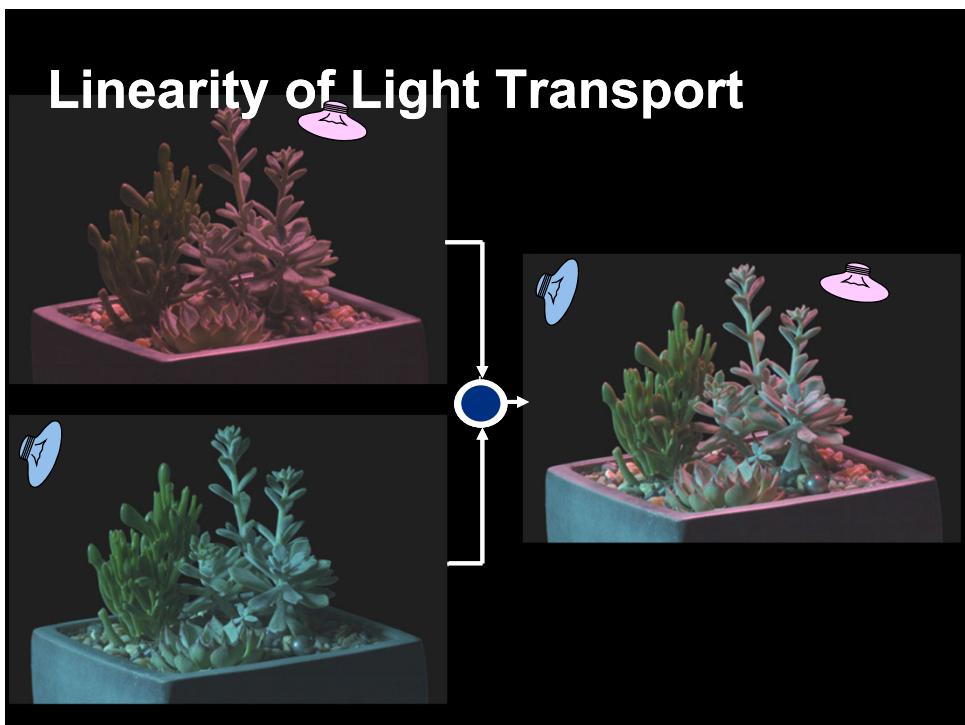
22

## Linearity of Light Transport



23

## Linearity of Light Transport



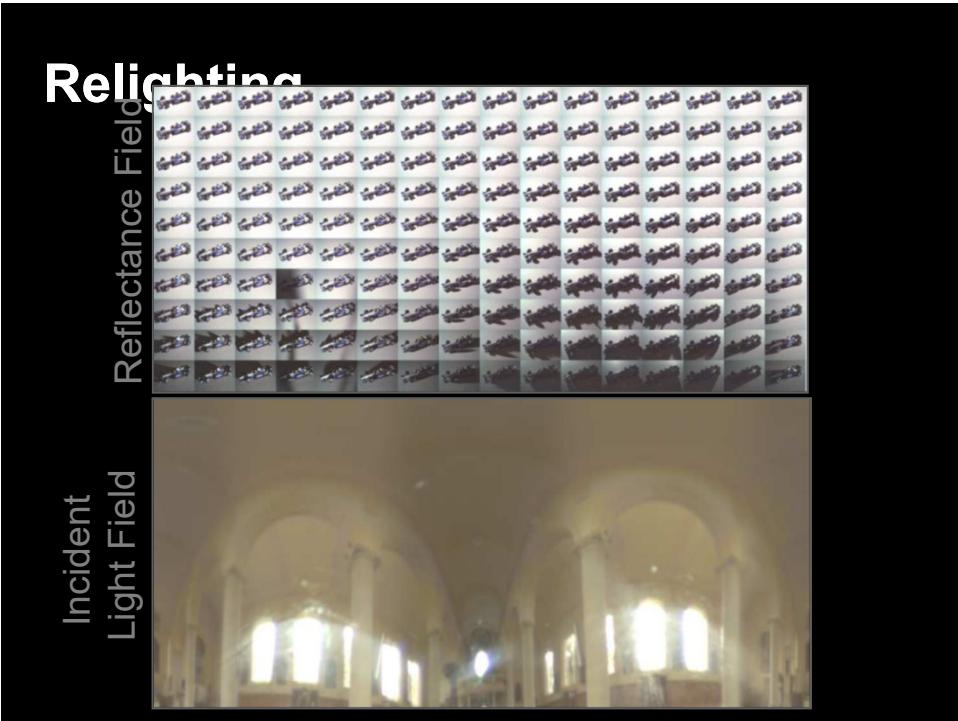
24

## Reflectance Field



25

## Relighting



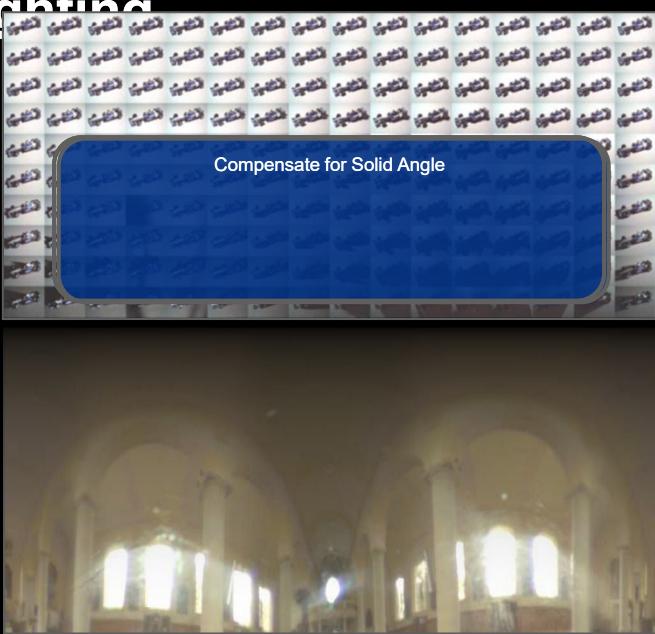
26

## Relighting

Incident  
Light Field

Reflectance Field

Compensate for Solid Angle



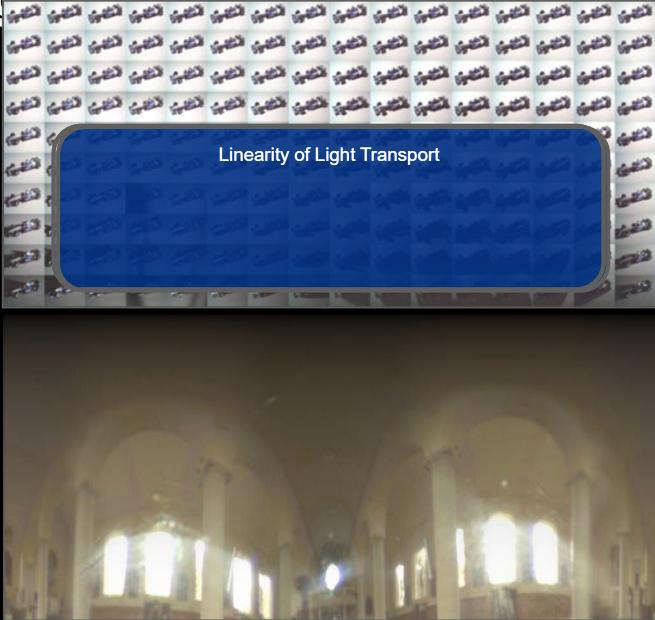
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## Relighting

Incident  
Light Field

Reflectance Field

Linearity of Light Transport

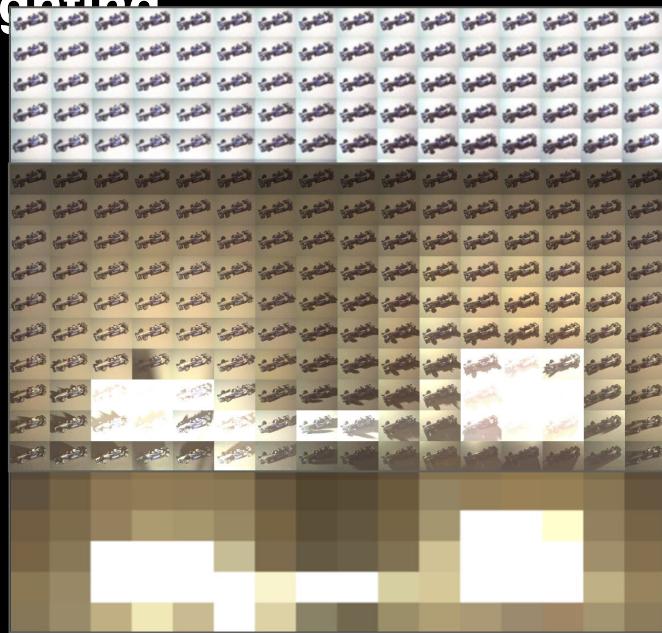


28

## Relighting

Incident  
Light Field

Reflectance Field



29

## Relighting

$\Sigma$



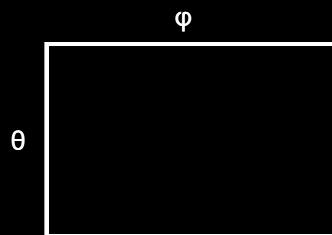
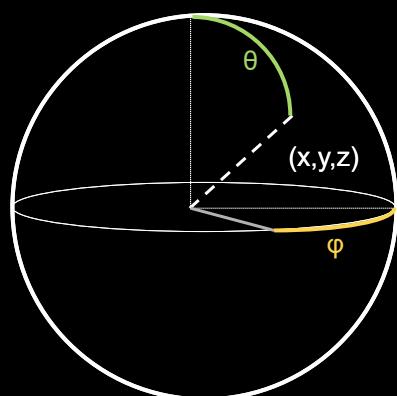
30

## Relighting: Result



31

## Compensate Solid Angle



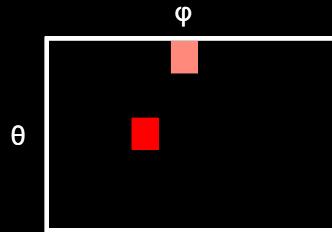
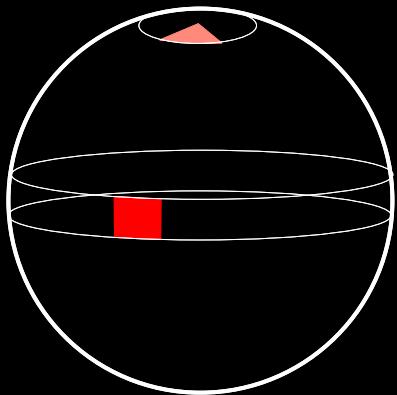
$$X = \cos \varphi \sin \theta$$

$$Y = \cos \theta$$

$$Z = -\sin \varphi \sin \theta$$

32

## Compensate Solid Angle



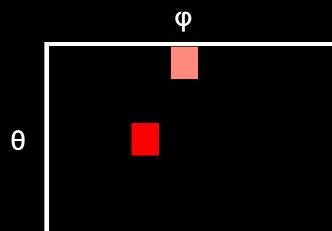
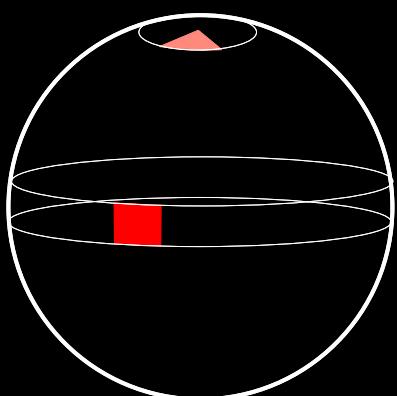
$$X = \cos \varphi \sin \theta$$

$$Y = \cos \theta$$

$$Z = -\sin \varphi \sin \theta$$

33

## Compensate Solid Angle



$$J = |\sin \theta|$$

(Jacobian)

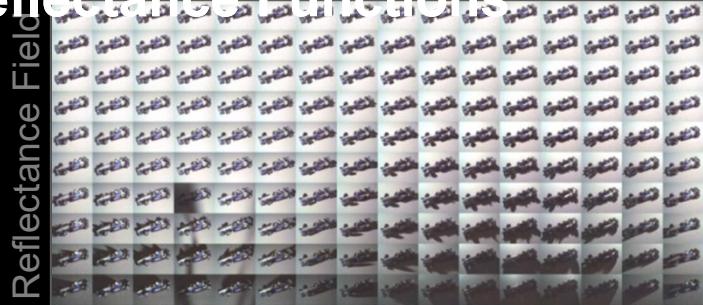
$$X = \cos \varphi \sin \theta$$

$$Y = \cos \theta$$

$$Z = -\sin \varphi \sin \theta$$

34

## Reflectance Functions



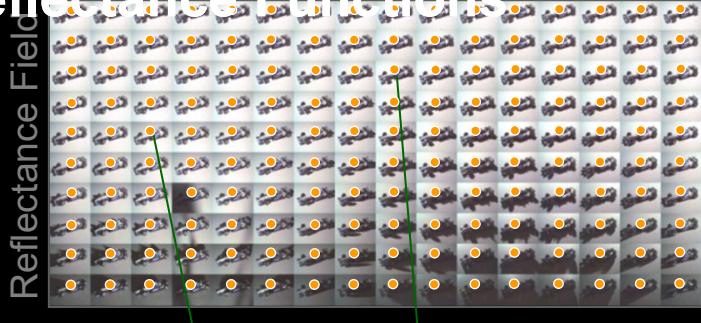
35

## Reflectance Functions



36

## Reflectance Functions



37

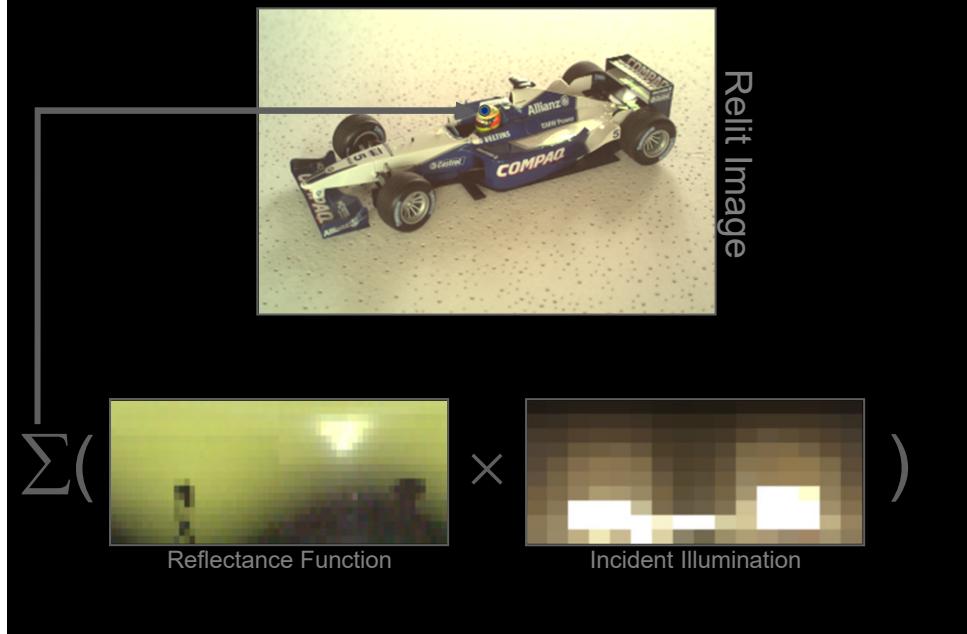
## Reflectance Functions: Relighting



38

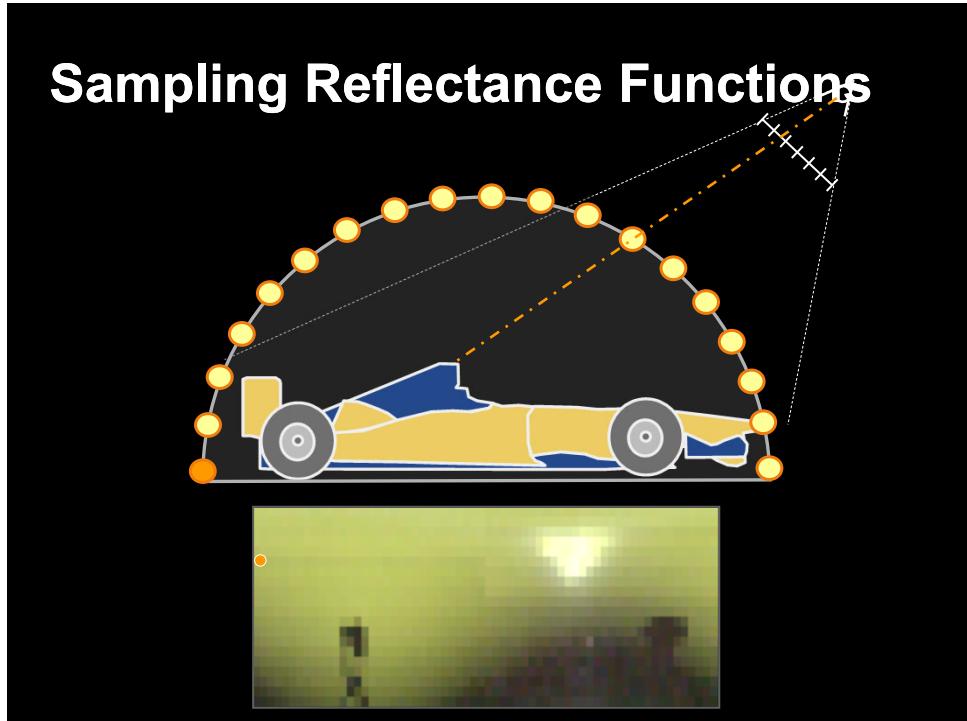
19

## Reflectance Functions: Relighting



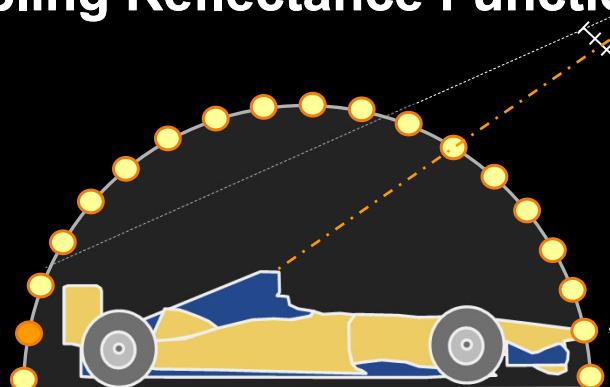
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## Sampling Reflectance Functions



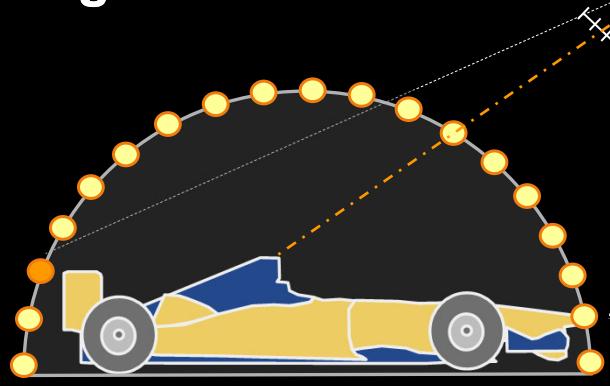
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## Sampling Reflectance Functions



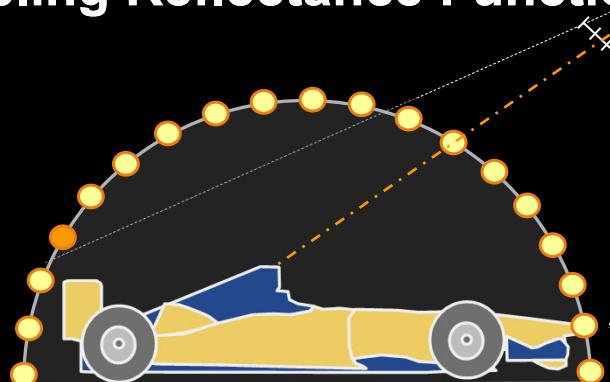
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## Sampling Reflectance Functions



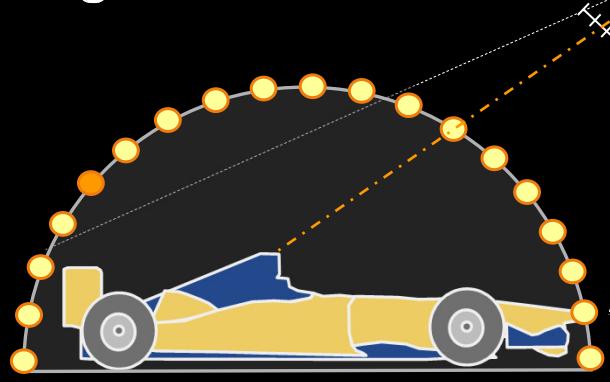
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## Sampling Reflectance Functions



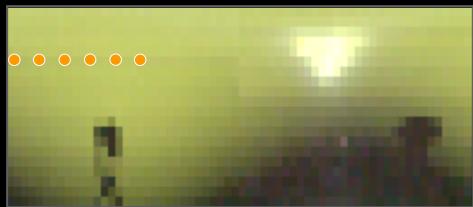
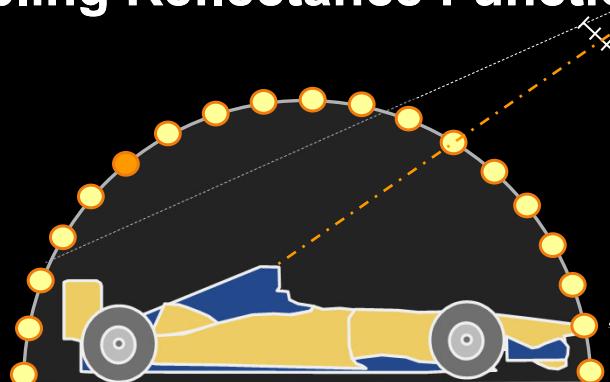
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## Sampling Reflectance Functions



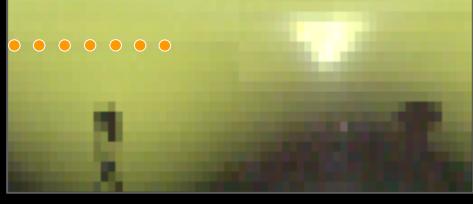
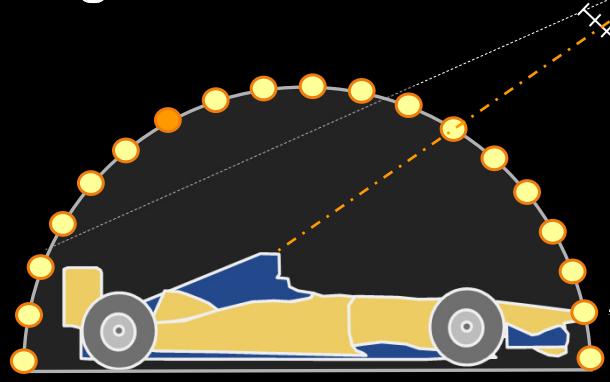
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## Sampling Reflectance Functions



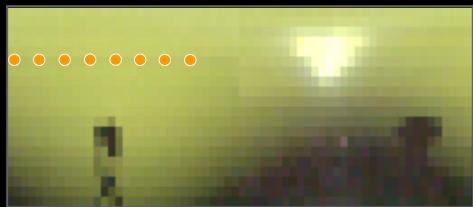
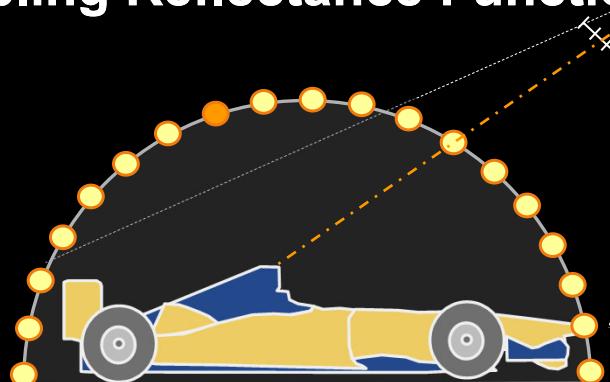
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## Sampling Reflectance Functions



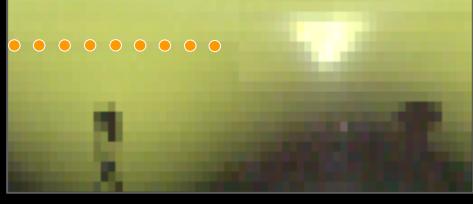
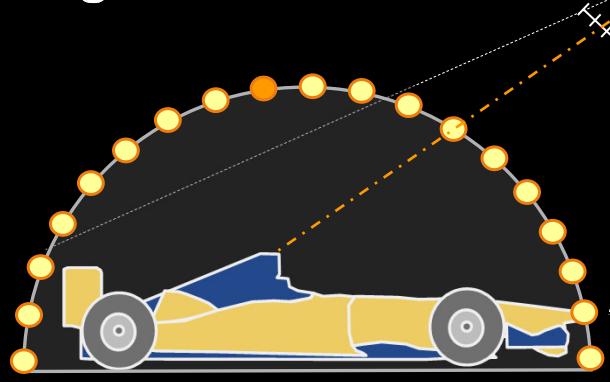
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## Sampling Reflectance Functions



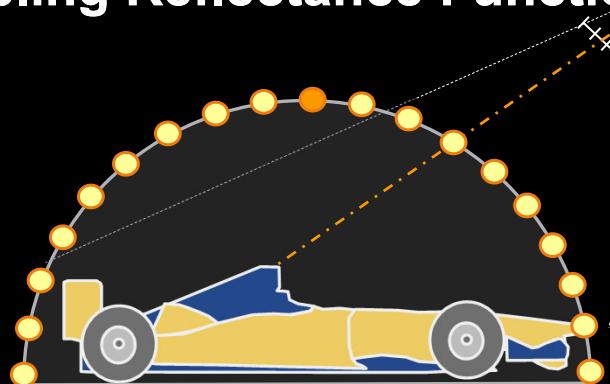
47

## Sampling Reflectance Functions



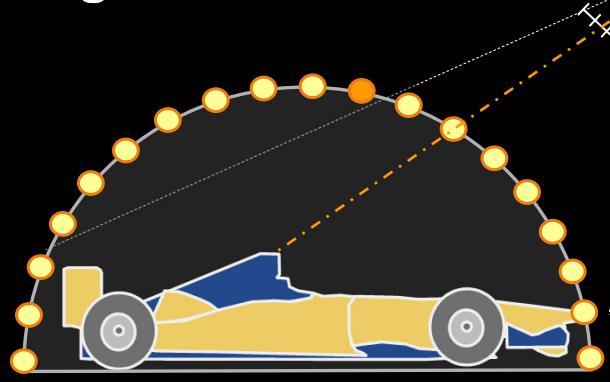
48

## Sampling Reflectance Functions



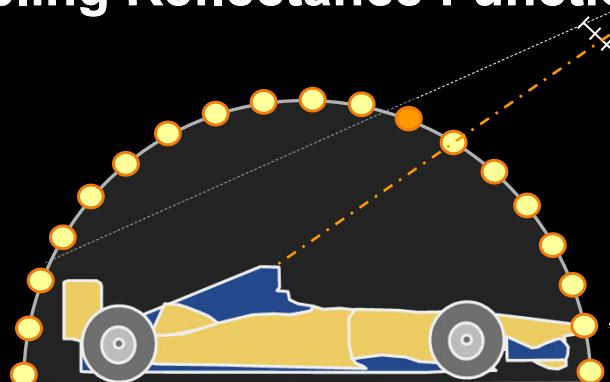
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## Sampling Reflectance Functions



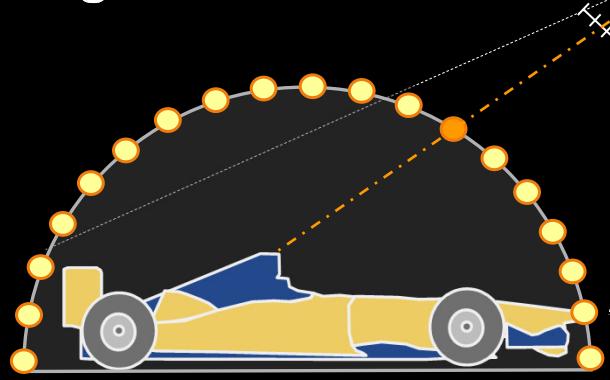
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## Sampling Reflectance Functions



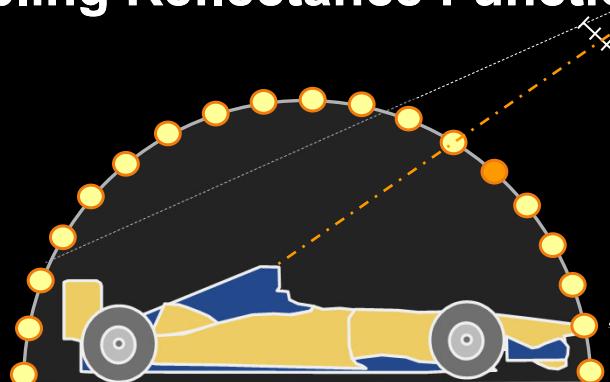
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## Sampling Reflectance Functions



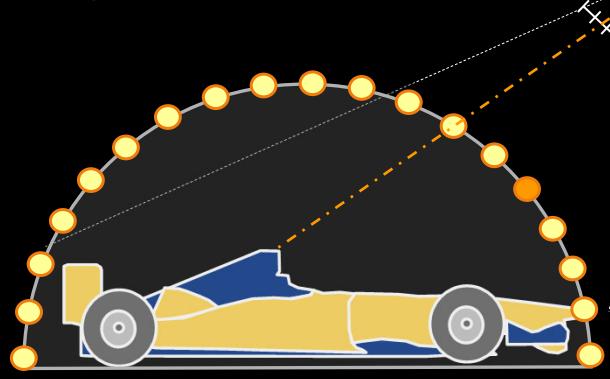
52

## Sampling Reflectance Functions



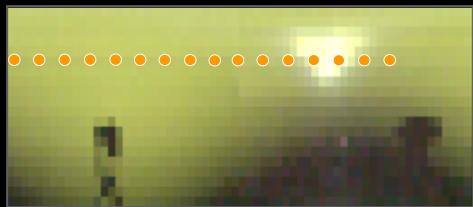
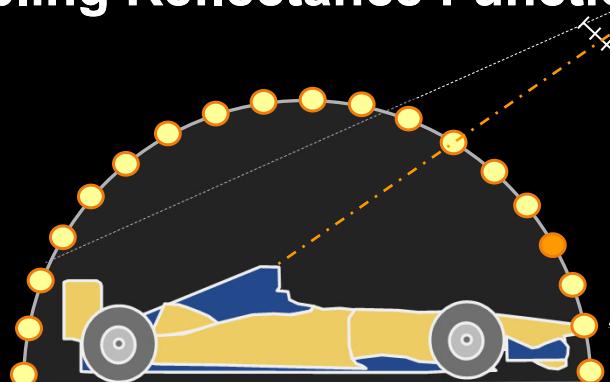
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## Sampling Reflectance Functions



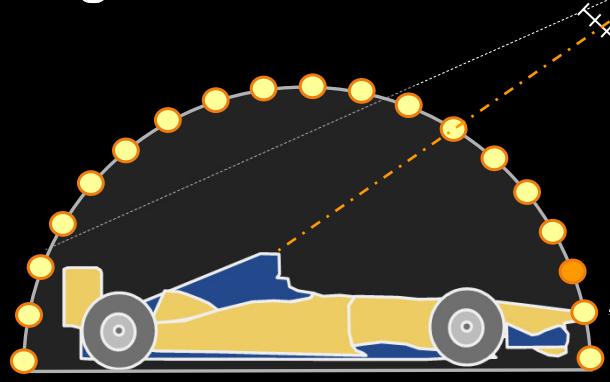
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## Sampling Reflectance Functions



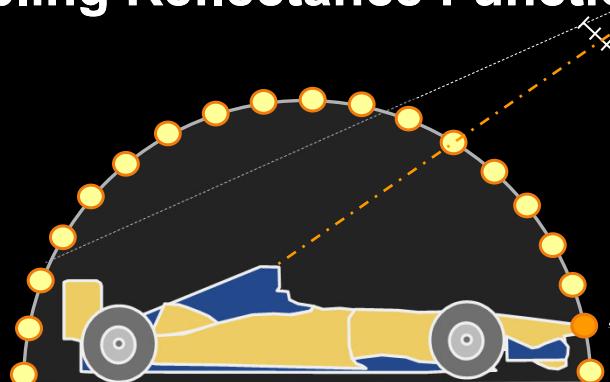
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## Sampling Reflectance Functions



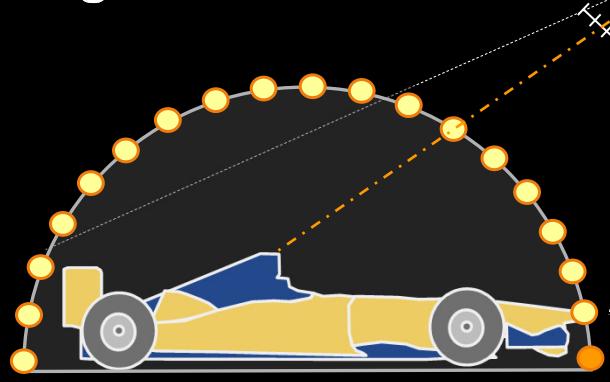
56

## Sampling Reflectance Functions



57

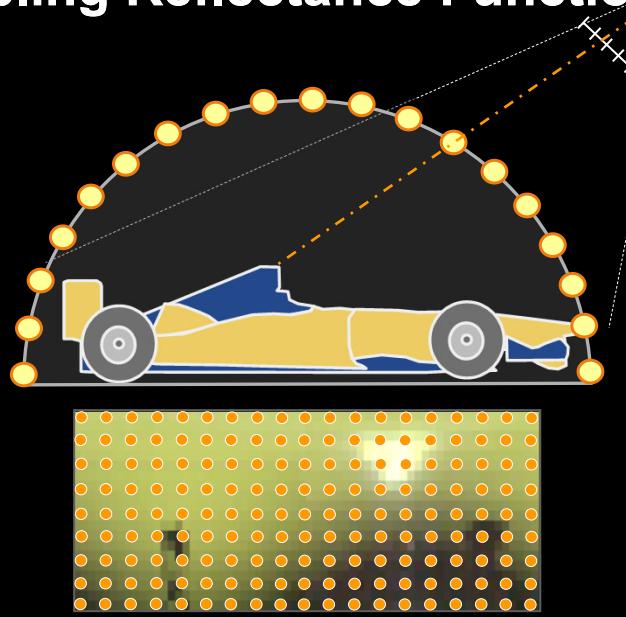
## Sampling Reflectance Functions



58

29

## Sampling Reflectance Functions



59

## Nyquist-Shannon Theorem

If a function  $f(t)$  contains no frequencies higher than  $B$ , then it is completely determined by giving its ordinates at a series of points spaced  $1/(2B)$  apart.

60

30

## Nyquist-Shannon Theorem

If a function  $f(t)$  contains no frequencies higher than  $B$ , then it is completely determined by giving its ordinates at a series of points spaced  $1/(2B)$  apart.

Question: what does this mean for  
Image-based Relighting

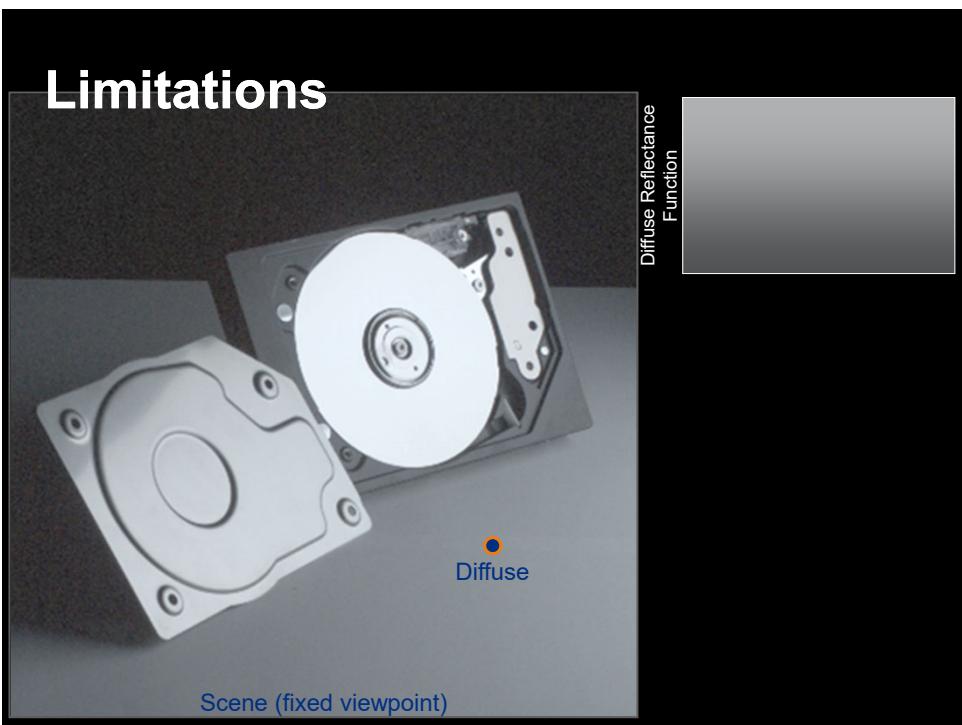
61

## Limitations

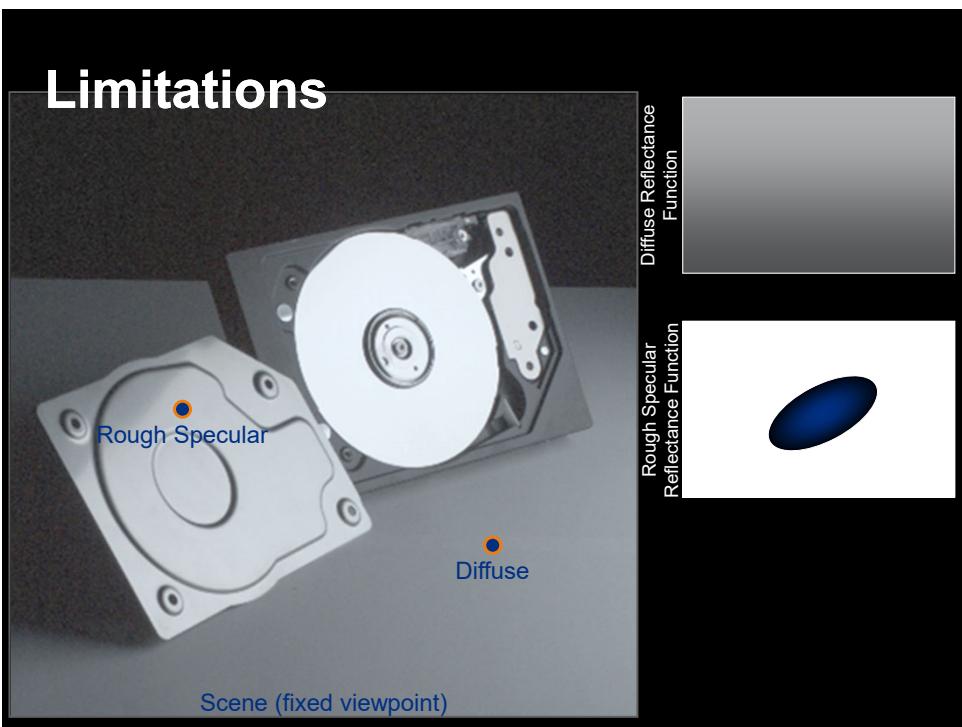


Scene (fixed viewpoint)

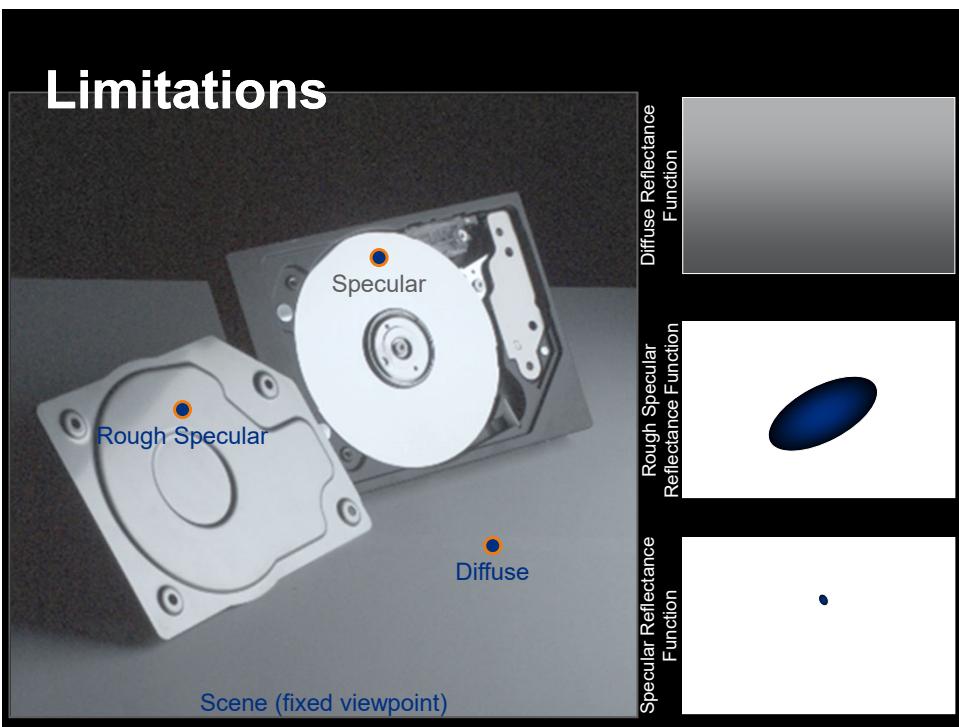
62



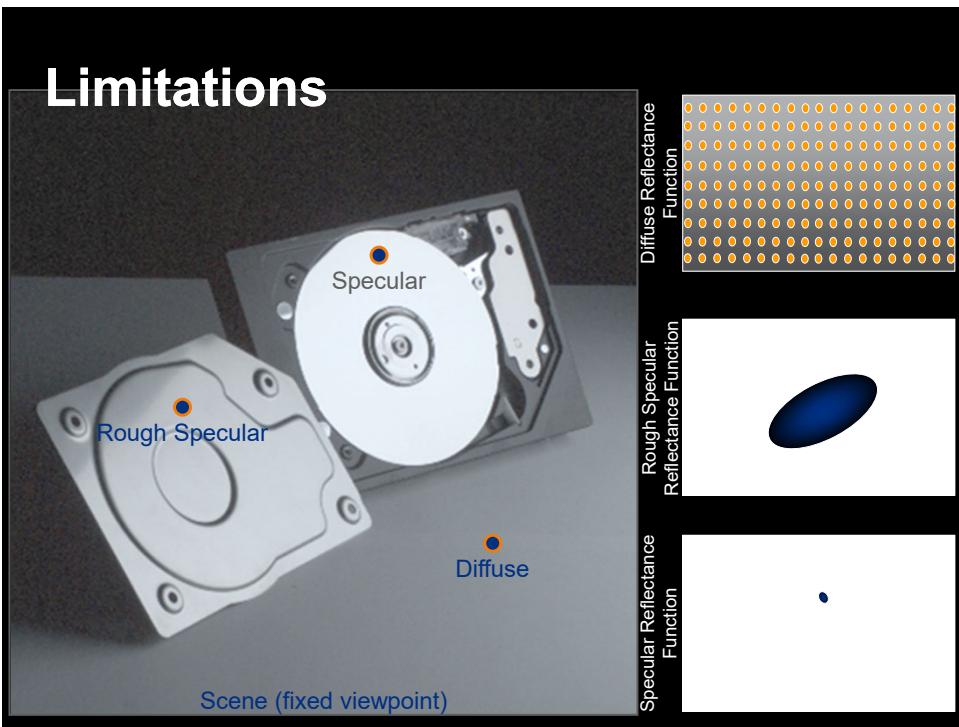
63



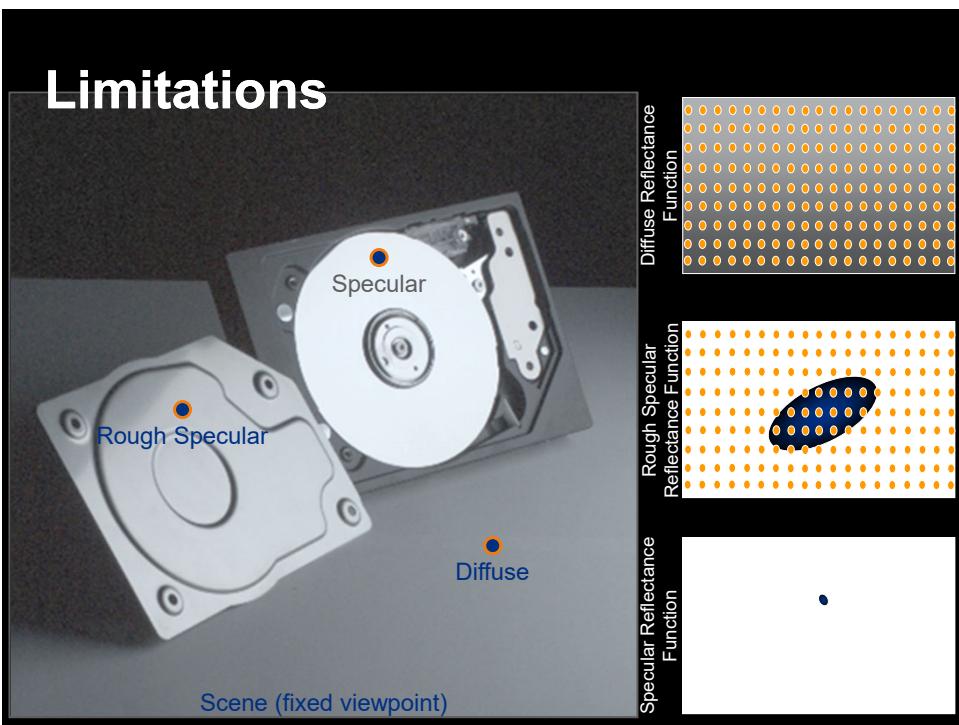
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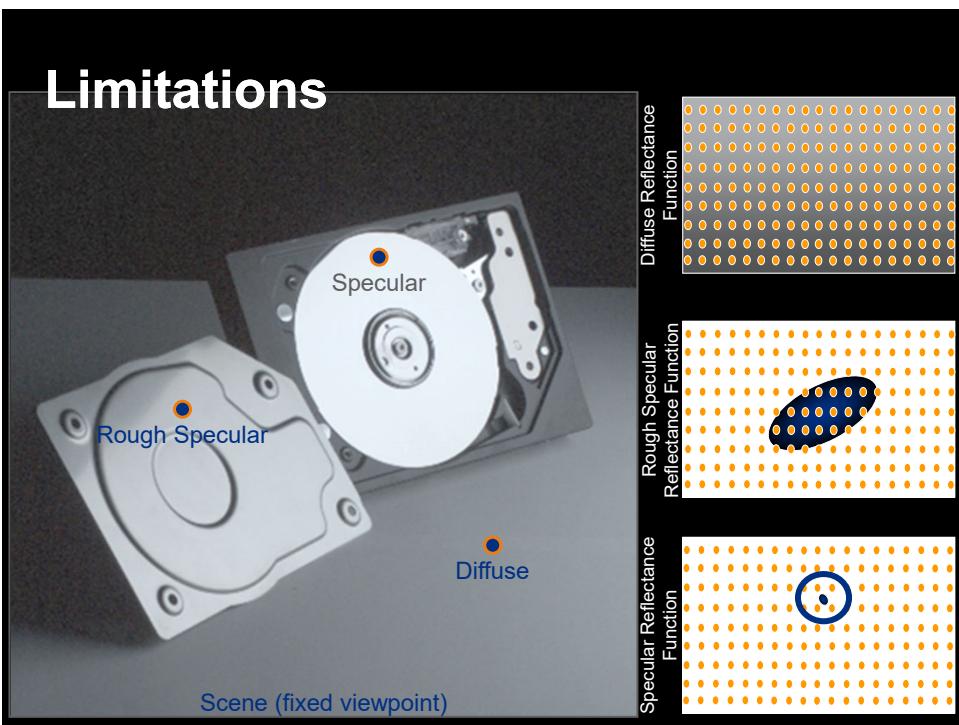
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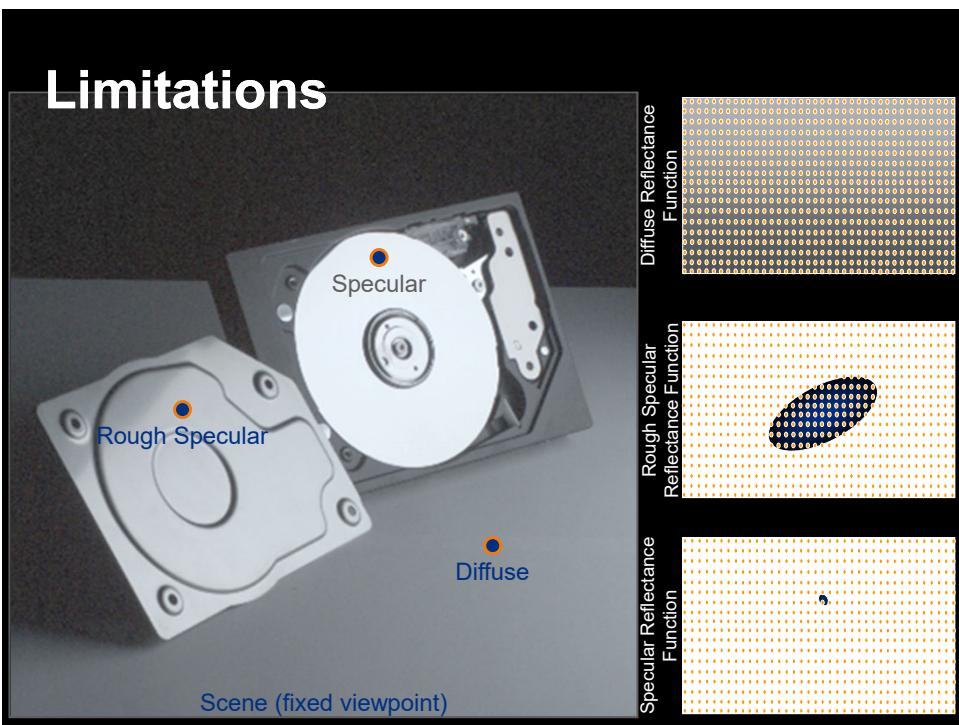
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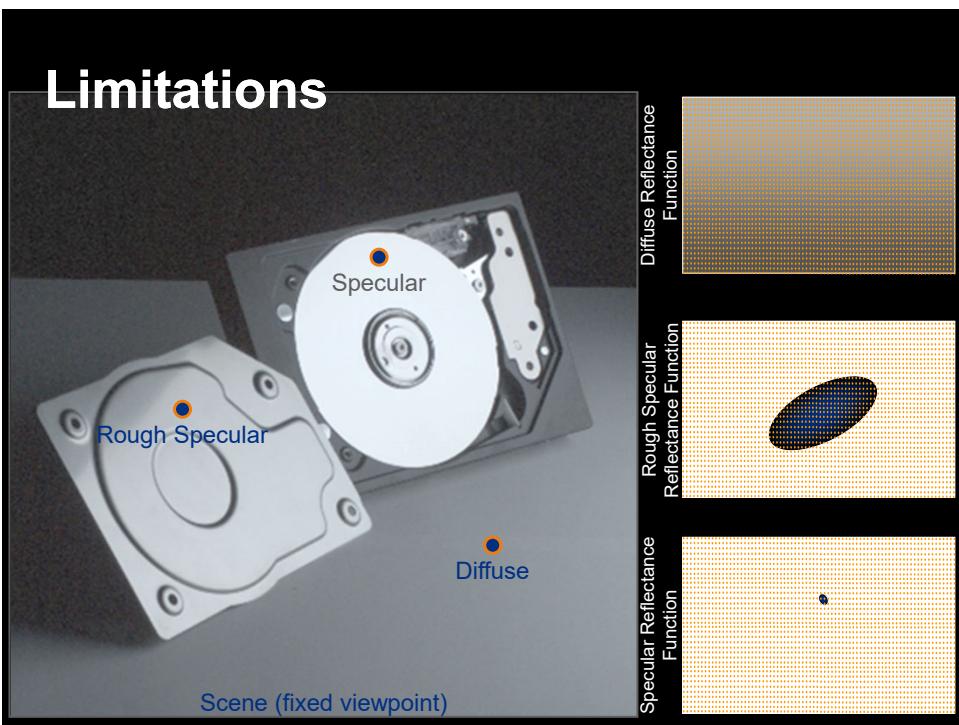
67



68



69



70

## Free-form Light Stage



71

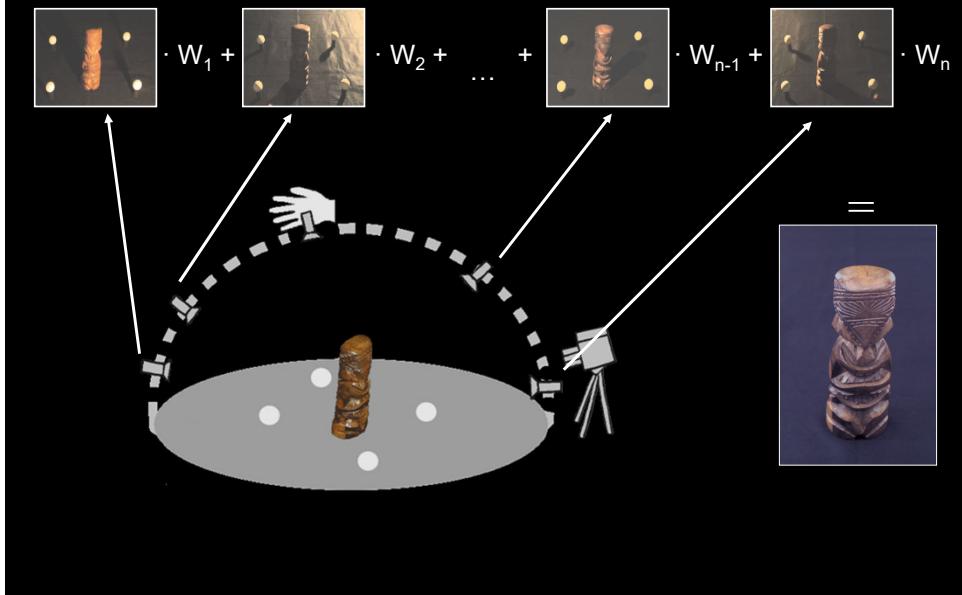
## Free-form Light Stage



Vincent Masselus, Philip Dutré and Frederik Anrys, [The Free-form Light Stage](#), Eurographics Workshop on Rendering 2002

72

## Relighting



73

## Illuminant direction estimation



74

## Illuminant direction estimation



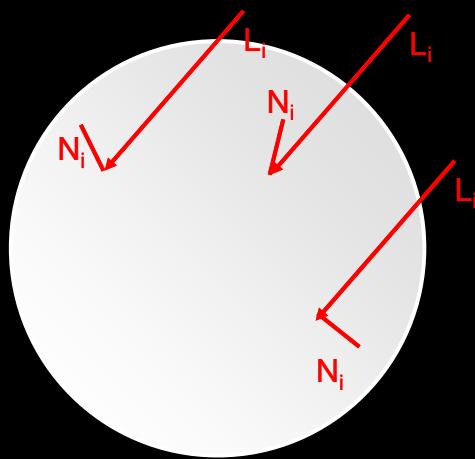
Diffuse white spheres

75

## Illuminant direction estimation

Lamberts Law

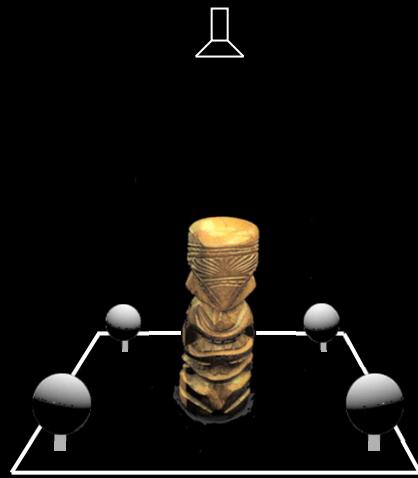
$$I_i = \rho I_L (\vec{N}_i \cdot \vec{L})$$



76

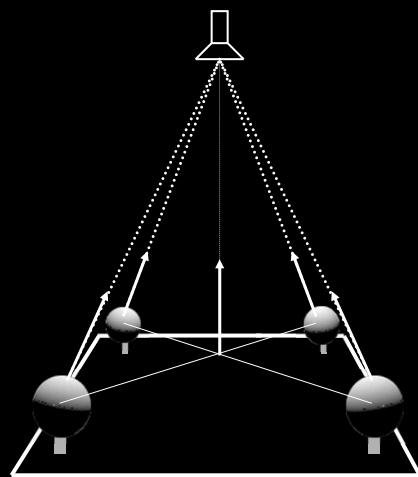
38

## Illuminant direction estimation



77

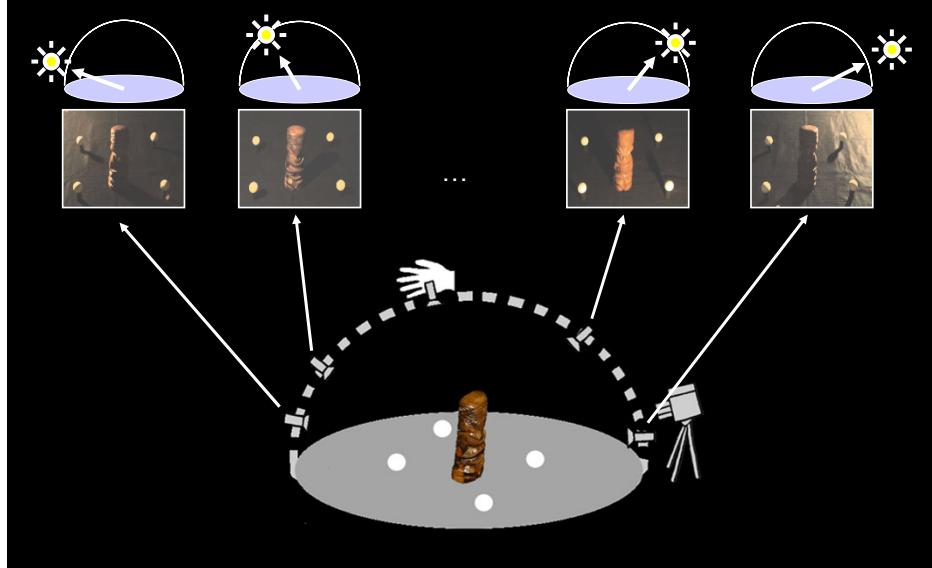
## Illuminant direction estimation



78

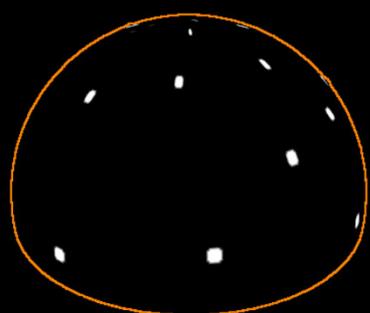
39

## Direction per Photograph



79

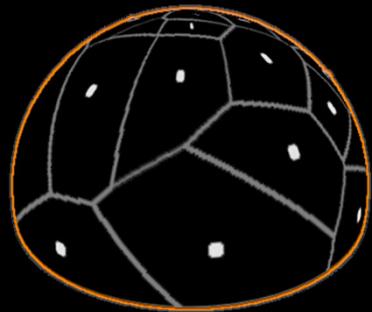
## Plot Directions on (hemi-)Sphere



30 light directions

80

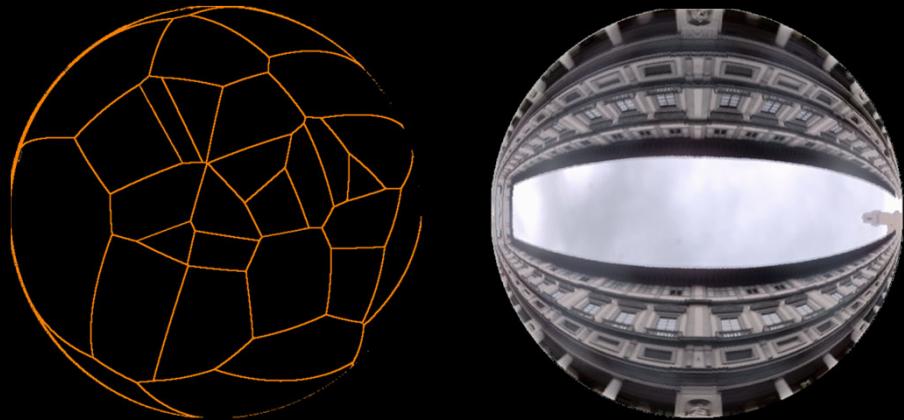
## Angular Voronoi Diagram



Distance = Angle between vectors  
 $= \text{acos}(v_i \cdot v_k)$

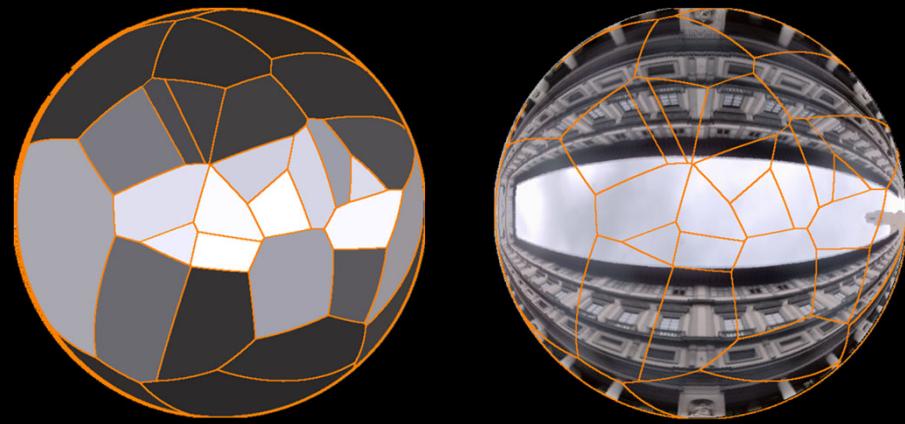
81

## Angular Voronoi Diagram



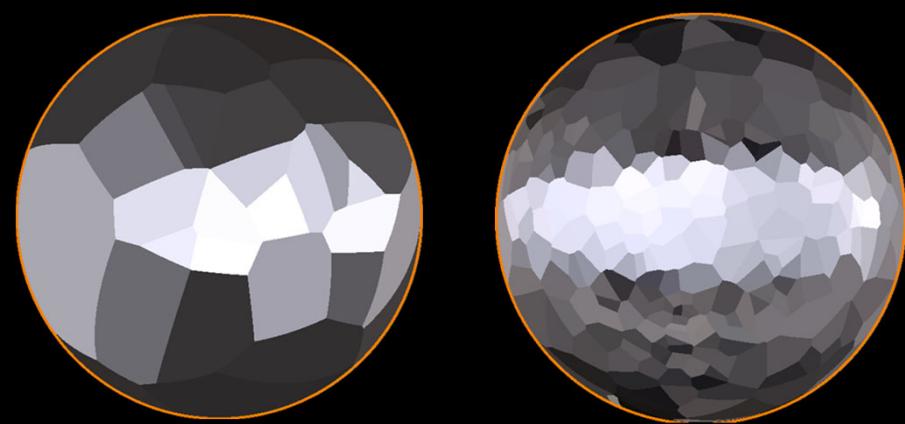
82

## Angular Voronoi Diagram



83

## Effect of Sampling Rate

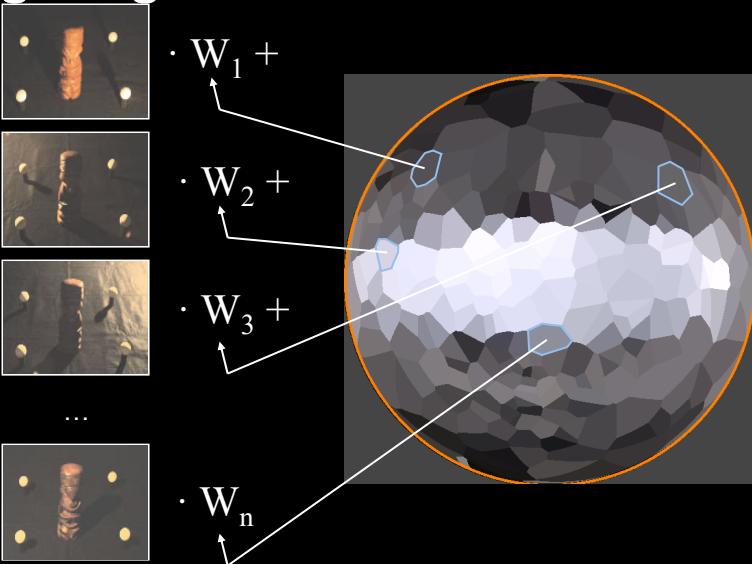


30 light directions

400 light directions

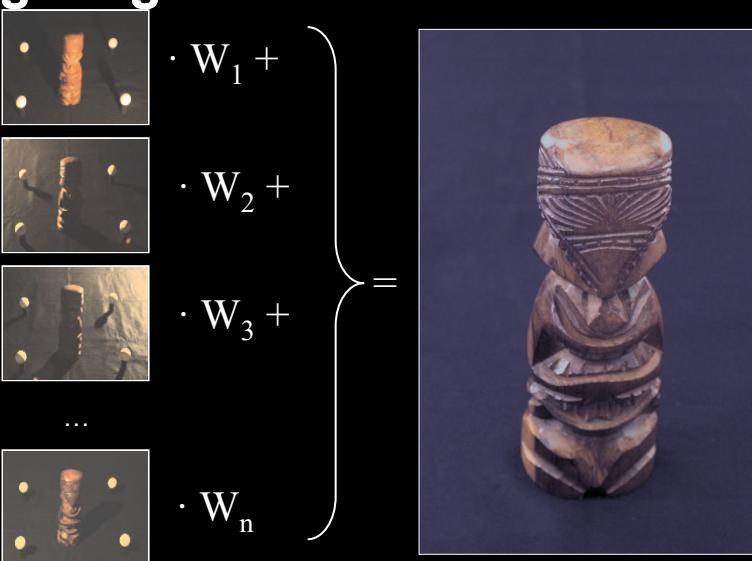
84

## Relighting



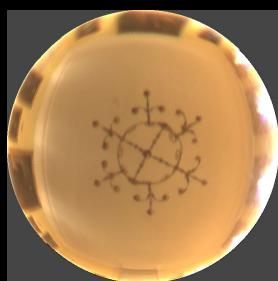
85

## Relighting



86

## Results



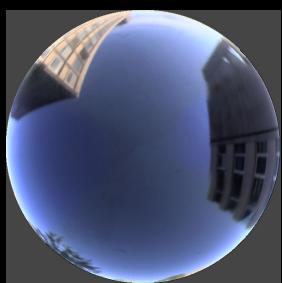
87

## Results



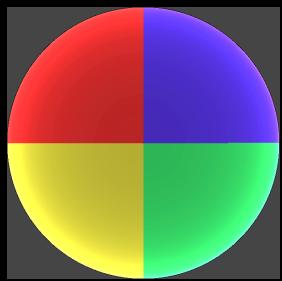
88

## Results



89

## Results



90

## Neural Networks for Relighting

[Ren et al. 2015]



- NN based interpolation of highly specular reflectance functions from a small number of images ( $\sim 200$ )
- Overcoming the sampling limit imposed by Nyquist theory!

91

## Neural Networks for Relighting

[Ren et al. 2015]

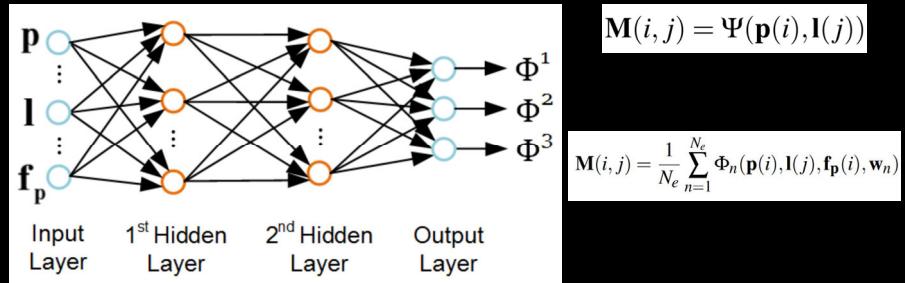


- NN based interpolation of highly specular reflectance functions from a small number of images (freeform handheld illumination)
- Exploit non-linear local coherence in transport matrix to learn function

92

## Neural Networks for Relighting

[Ren et al. 2015]



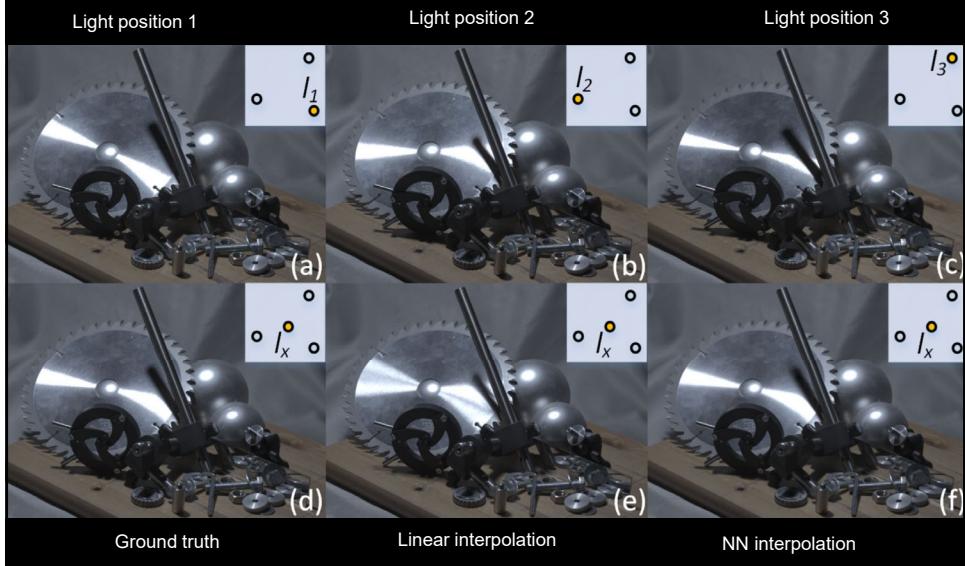
- $p$  is the set of image pixels,  $l$  is the set of 2D light position,  $f_p$  is the average color of pixel  $p$  across all input images.
- Outputs  $\phi$  are RGB color of the transport matrix entry  $M(i,j)$
- Local minima avoided by training an ensemble of NNs, each trained on a subset of the input, and averaging the result of the predictions.

93



94

## Interpolation accuracy



95

## Image-based Lighting Reproduction

- Direct lighting of an actor's performance with illumination of a virtual background
- For photorealistic compositing of dynamic performance into a virtual set
- Requires RGB LED-sphere



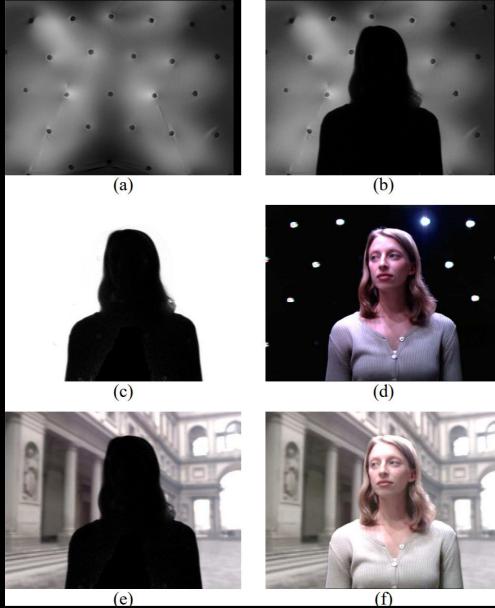
Light Stage 3: Debevec et al. 2002



Gravity's Light Box for space lighting

96

## Image-based Lighting Reproduction

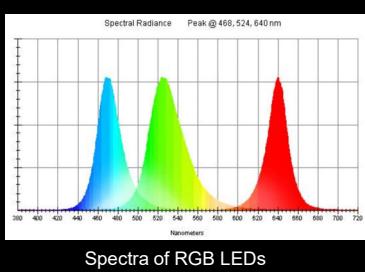


Light Stage 3: Debevec et al. 2002

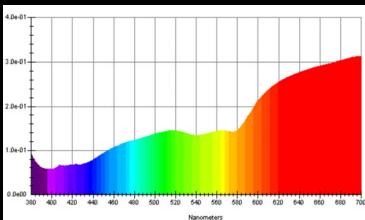
- Background plate illuminated to extract silhouette mask
- For a performance sequence, requires simultaneous capture of mask using infrared illumination and camera

97

## Spectral vs RGB Lighting Reproduction



Light Stage 3: Debevec et al. 2002

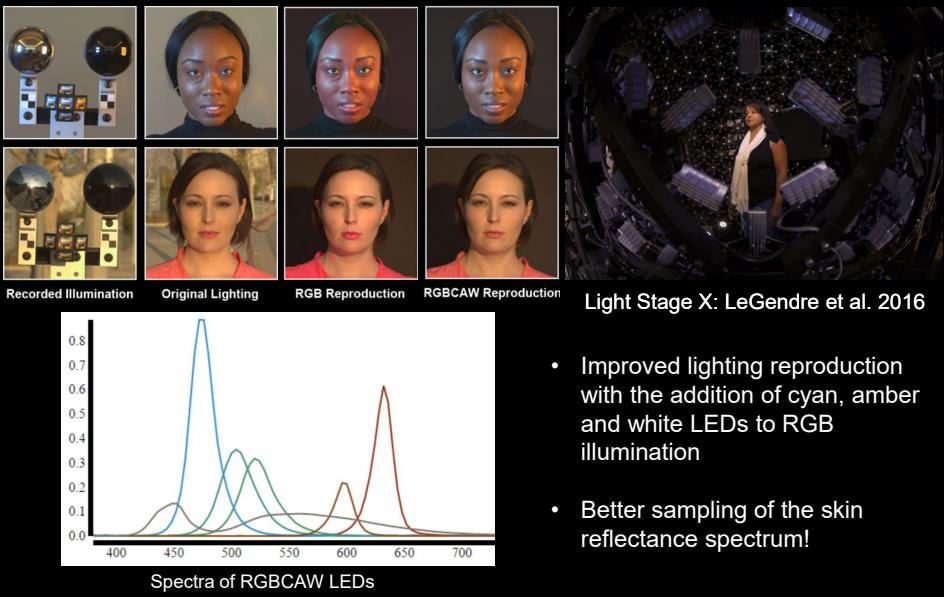


- RGB illumination has gaps in the spectrum
- This creates visible differences in color in lighting reproduction compared to a photograph!

98

49

## Spectral Lighting Reproduction



- Improved lighting reproduction with the addition of cyan, amber and white LEDs to RGB illumination
- Better sampling of the skin reflectance spectrum!

99