

# Computational Imaging: The Race Against Time




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


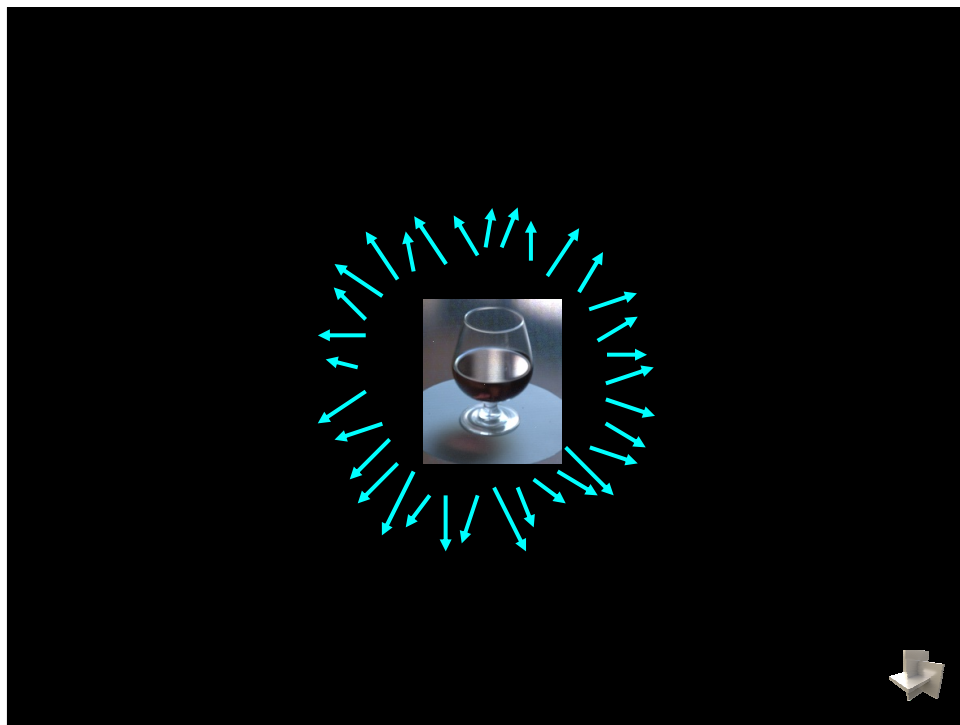
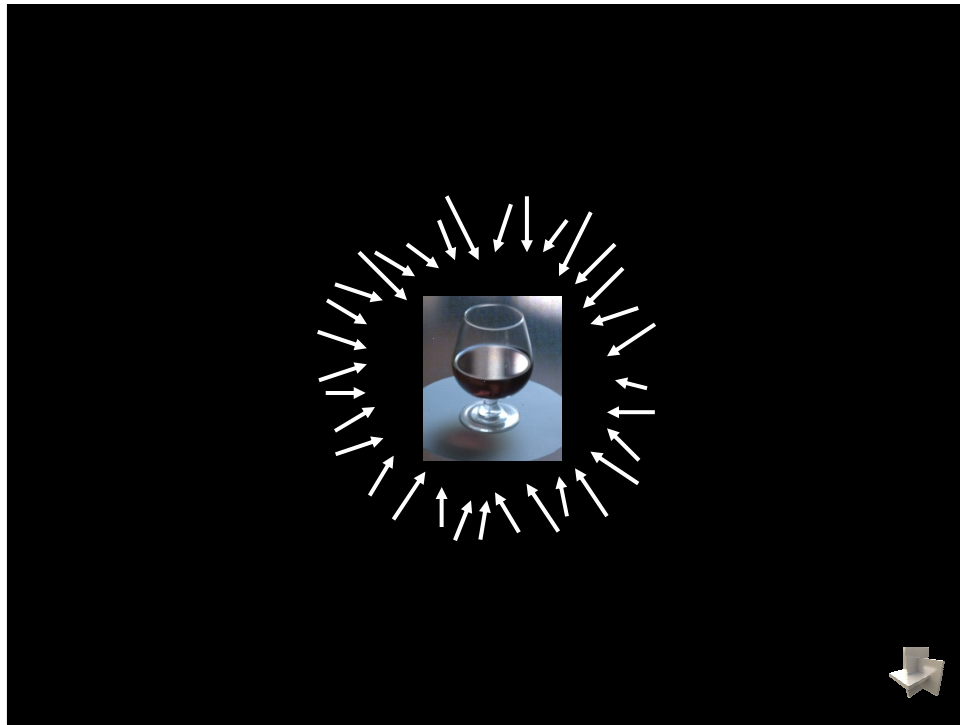
**2005 Symposium on Computational  
Photography and Video**  
MIT Stata Center • 24 May 2005

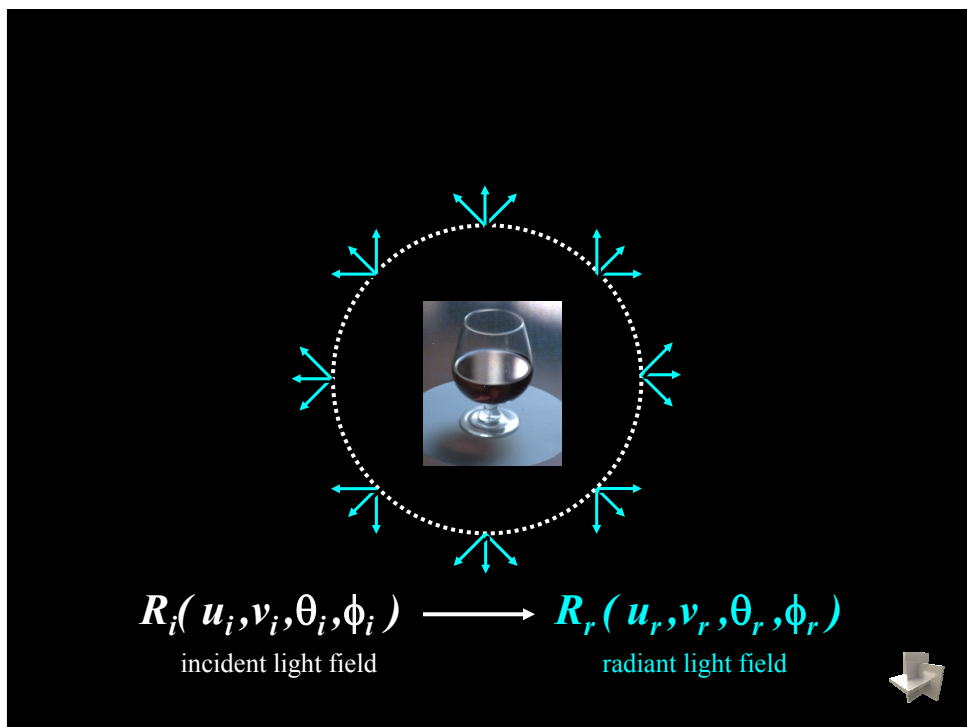
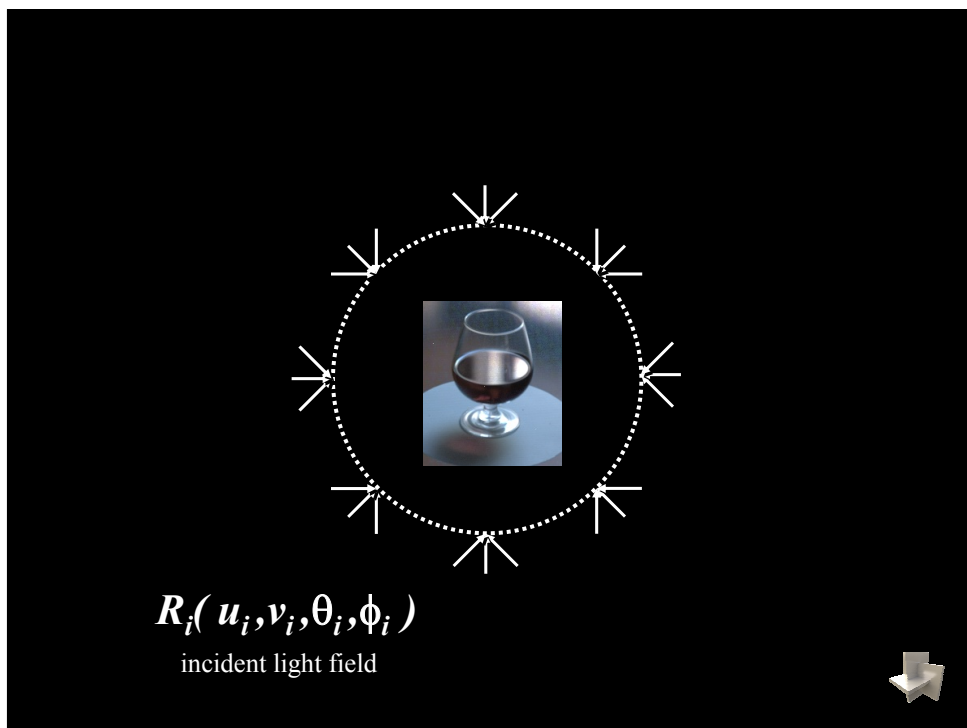





object








# The Reflectance Field


$$R(u_i, v_i, \theta_i, \phi_i; u_r, v_r, \theta_r, \phi_r)$$

8D reflectance field



Since it is linear, we can represent as a matrix



# Reflectance Field Storage Requirements

$$R(u_i, v_i, \theta_i, \phi_i; u_r, v_r, \theta_r, \phi_r)$$


**360 x 180 x 180 x 180 x 360 x 180 x 180 x 180**  
= 4.4e18 measurements  
x 6 bytes/pixel (in RGB 16-bit)  
= 26 exabytes (billion GB)  
= 82 million 300GB hard drives  
(41 million if we exploit Helmholtz Reciprocity)



# The Reflectance Field


$$R(u_i, v_i, \theta_i, \phi_i; u_r, v_r, \theta_r, \phi_r)$$


8D reflectance field



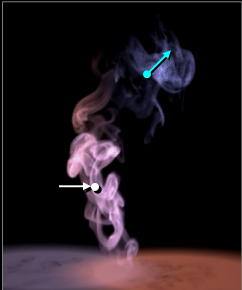
# The Reflectance Field


$$R(u_i, v_i, \theta_i, \phi_i; u_r, v_r, \theta_r, \phi_r)$$


8D reflectance field




# The Reflectance Field


$$R(x_i, y_i, z_i, \theta_i, \phi_i; x_r, y_r, z_r, \theta_r, \phi_r)$$


10D reflectance / scattering field  
(plenoptic functions in and out)




# The Reflectance Field


$$R(x_i, y_i, z_i, \theta_i, \phi_i; x_r, y_r, z_r, \theta_r, \phi_r)$$


10D reflectance field



# The Reflectance Field


$$R(x_i, y_i, z_i, \theta_i, \phi_i, t; x_r, y_r, z_r, \theta_r, \phi_r)$$

11D reflectance field



# Smoke Scanning Video



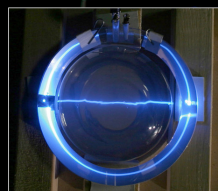
Hawkins, Einarsson, and Debevec. "Capturing Time-Varying Participating Media", SIGGRAPH 2005 (to appear)



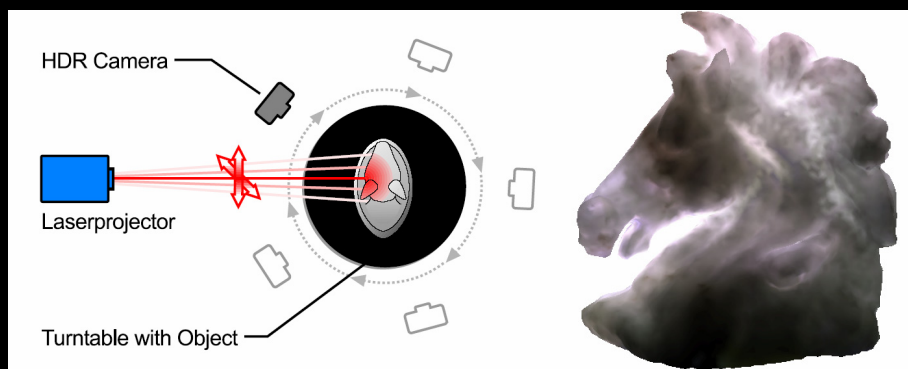
# Smoke Scanning Analysis

$$R(x_i, y_i, z_i, \theta_i, \phi_i, t; x_r, y_r, z_r, \theta_r, \phi_r)$$

Weakly scattering medium allows one laser plane sweep to cover 3D  
 Angular dependence measured independently  
 Camera sees nearly unoccluded view along the z axis



# DISCO



$$R(u_i, v_i, \theta_i, \phi_i; u_r, v_r, \theta_r, \phi_r)$$

Michael Goesele, Hendrik Lensch, Jochen Lang, Christian Fuchs and Hans-Peter Seidel. *DISCO - Acquisition of Translucent Objects*. SIGGRAPH 2004.



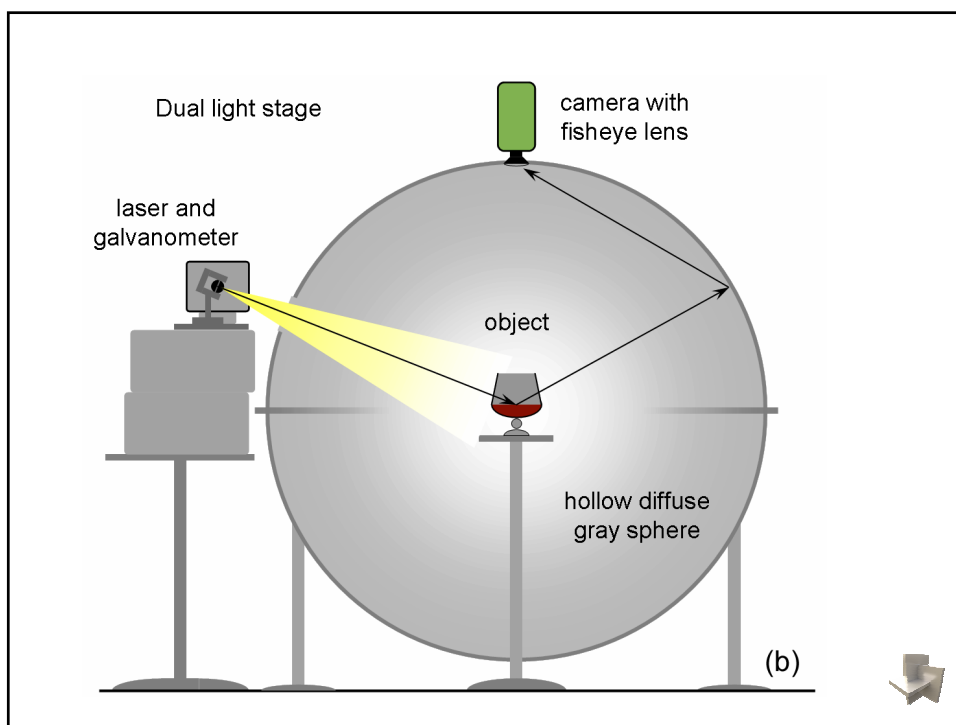
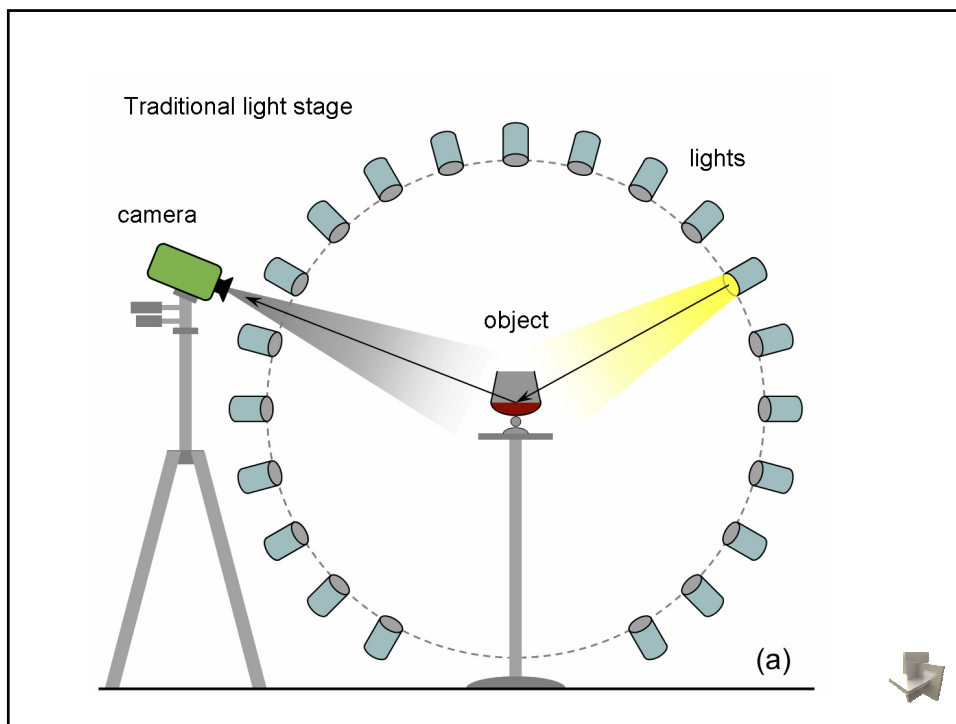


# The Reflectance Field

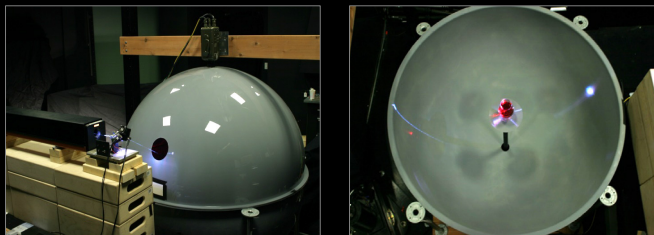
$R(u_i, v_i, \theta_i, \phi_i; u_r, v_r, \theta_r, \phi_r)$   
8D reflectance field

## 4D Slices of the 8D Reflectance Field

$R(\cancel{u_i}, \cancel{v_i}, \theta_i, \phi_i; u_r, v_r, \cancel{\theta_r}, \cancel{\phi_r})$   
4D reflectance field



# Dual Light Stage Video



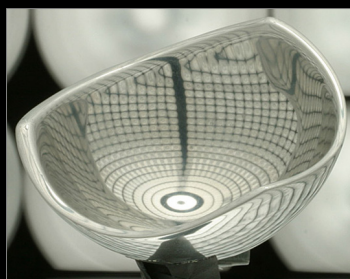
Hawkins, Einarsson, and Debevec. "A Dual Light Stage", EGSR 2005 (to appear)



# What was gained?

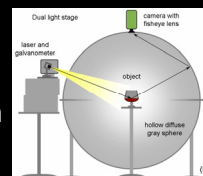


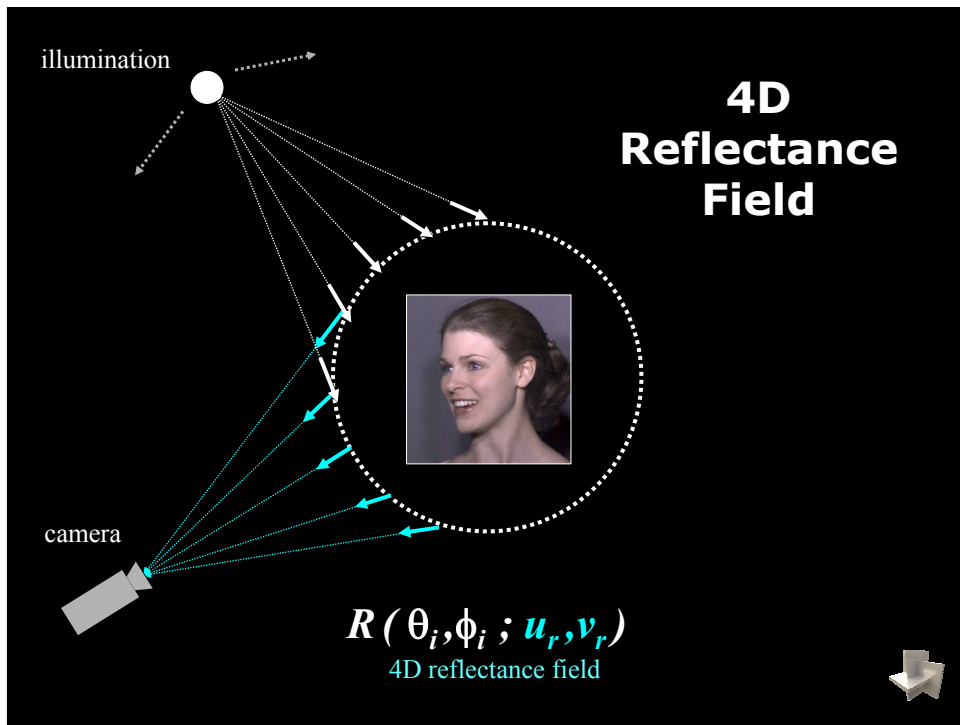
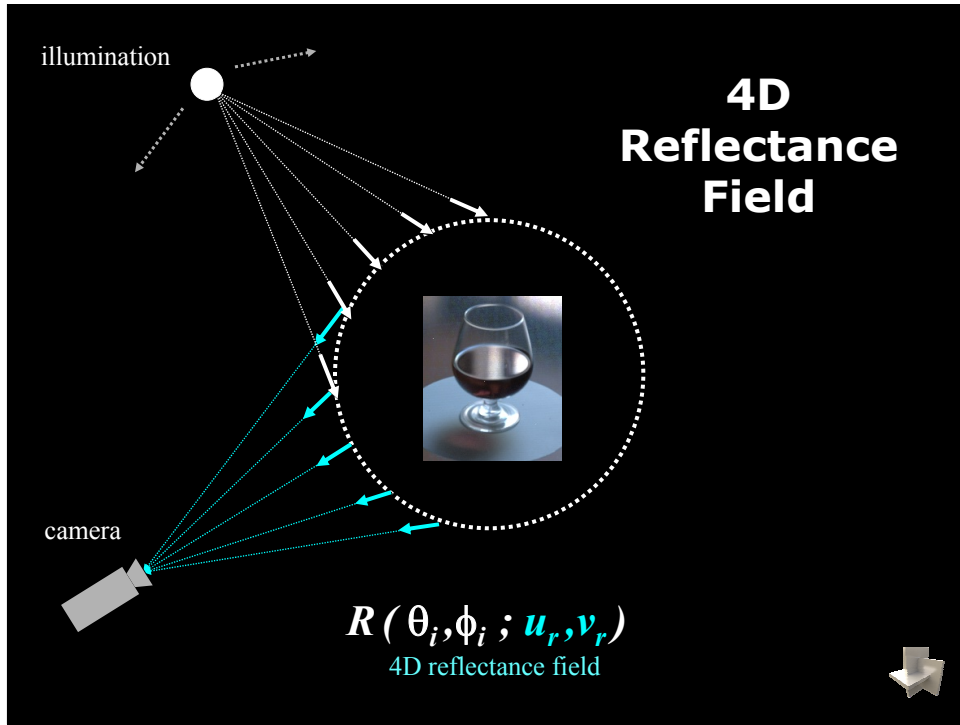
Dual Light Stage

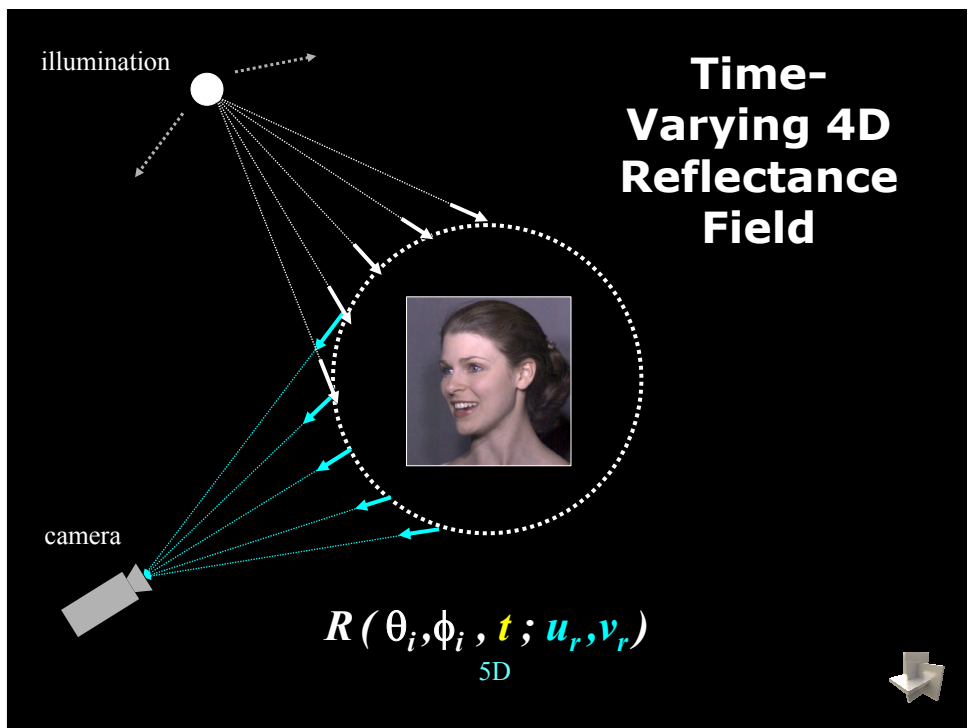


Light Stage 2

Better reflectance resolution  
 Does reciprocity help win the race against time?  
 Maybe...  
 Same amount of information being captured with  
 the same number of measurements  
 Laser produces bright, concentrated light

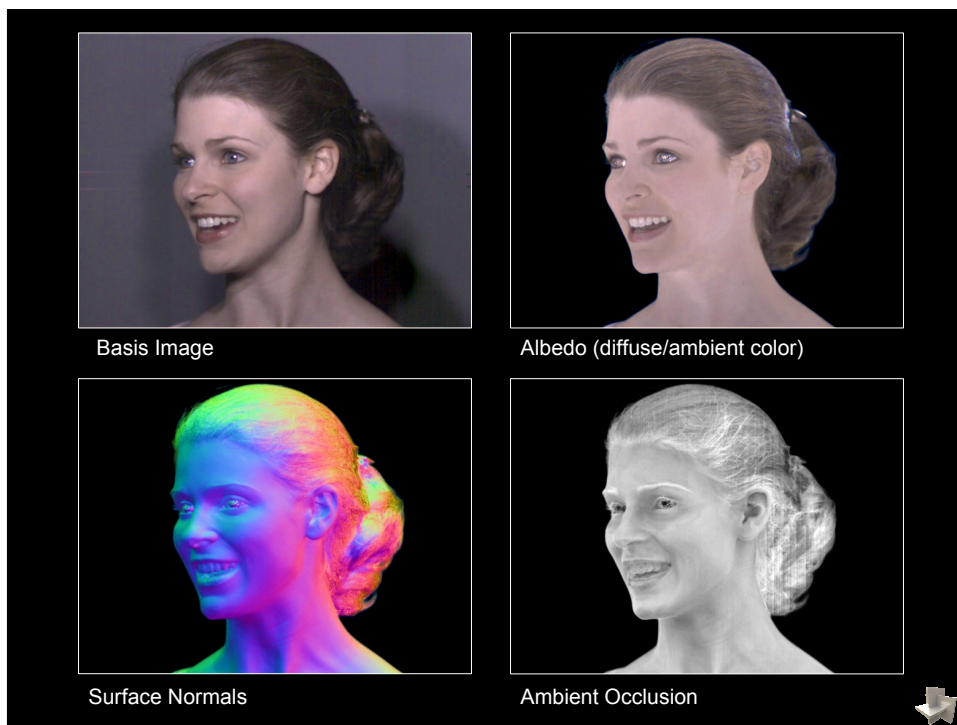
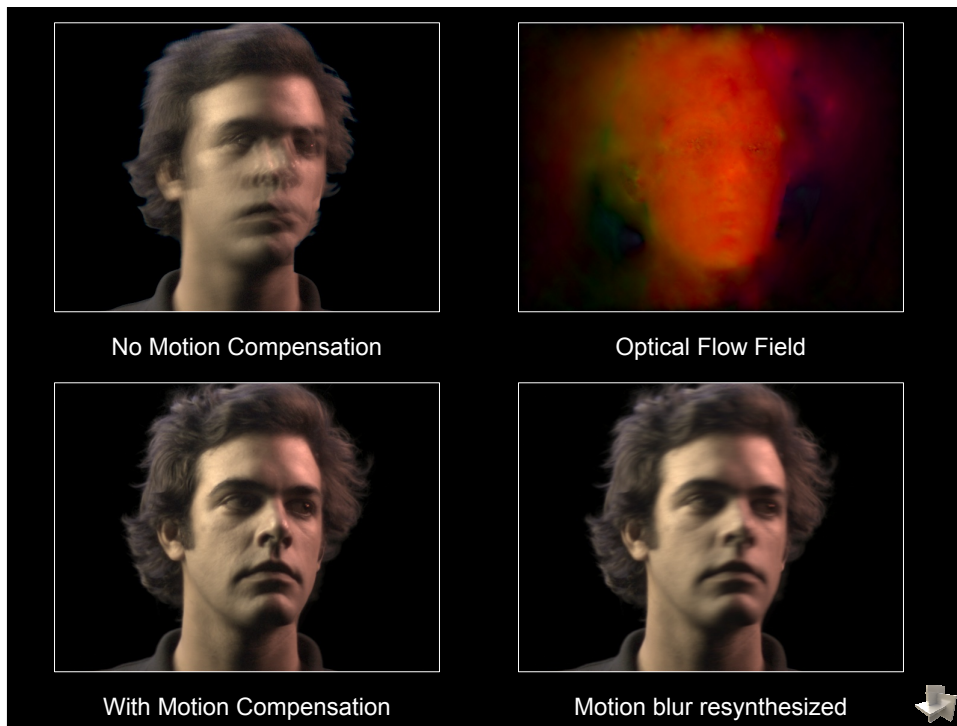


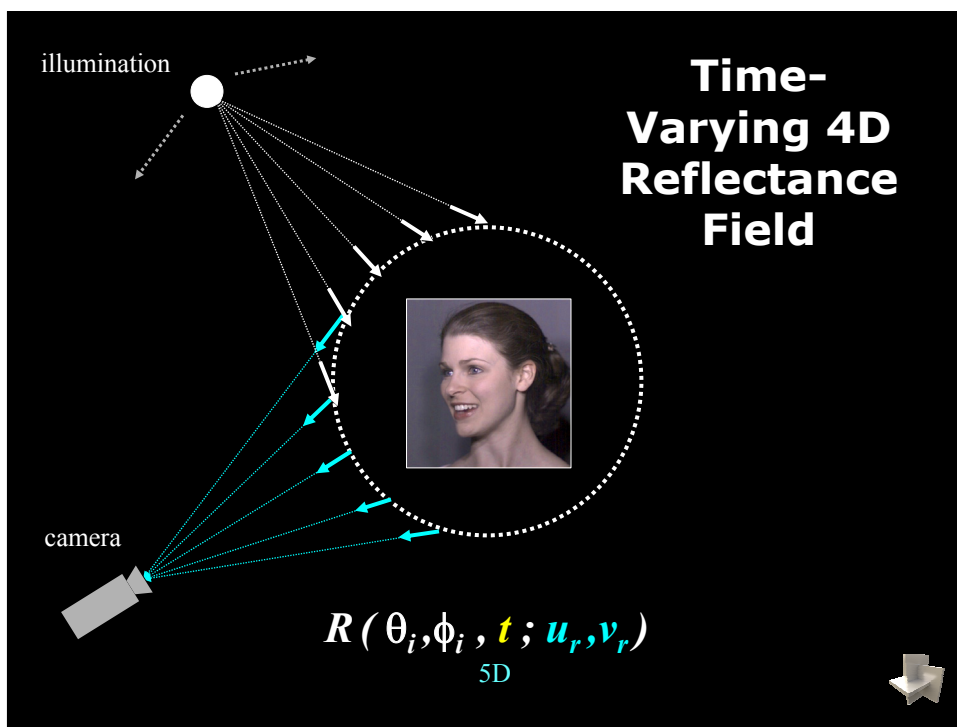














# Time-Varying 8D Reflectance Field



$$R(u_i, v_i, \theta_i, \phi_i, t; u_r, v_r, \theta_r, \phi_r)$$

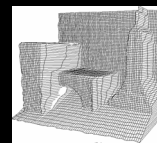
9D

Idea: Use an underlying model to extrapolate other dimensions

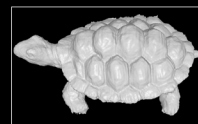


## Real-Time 3D Scanning

S. K. Nayar, M. Watanabe, and M. Noguchi, "Real-Time Focus Range Sensor," ICCV 95.



S. Rusinkiewicz, O. Hall-Holt, M. Levoy. Real-Time 3D Model Acquisition. SIGGRAPH 2002.

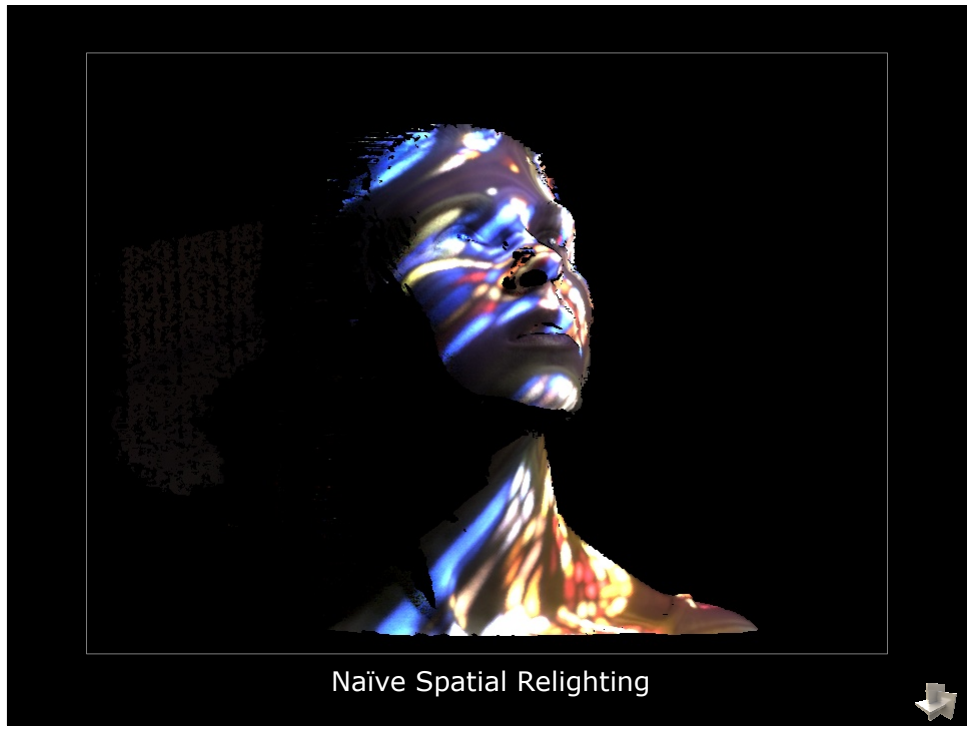


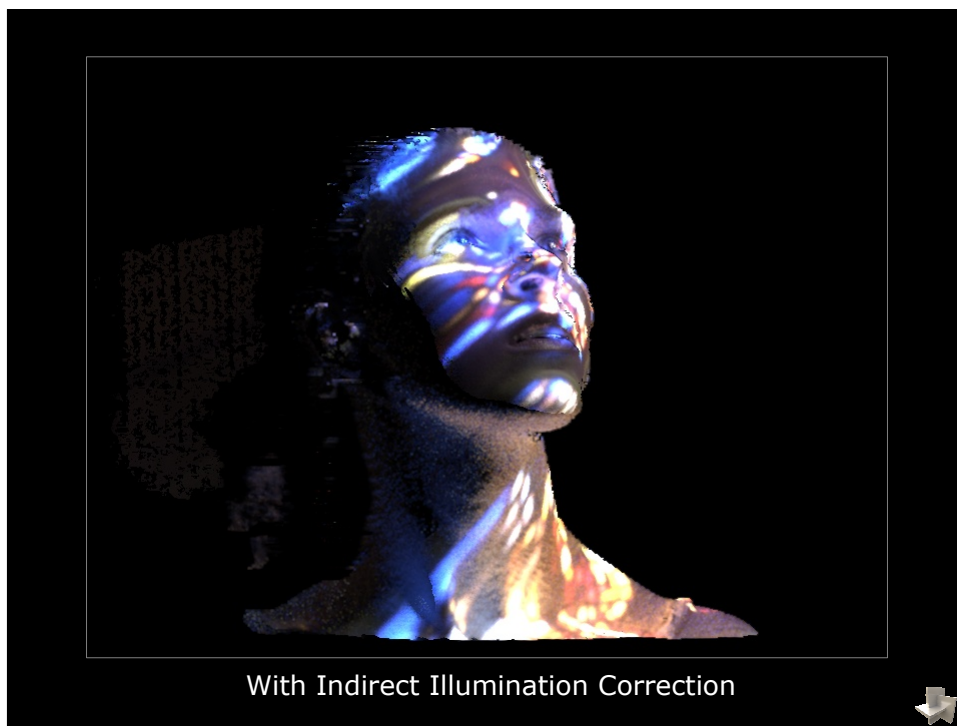
Li Zhang, Noah Snavely, Brian Curless, and Steven M. Seitz. Spacetime Faces: High-resolution capture for modeling and animation. SIGGRAPH 2004.



M. B. Vieira, L. Velho, A. Sa, P. C. Carvalho. A Camera-Projector System for Real-Time 3D Video. Procams 2005.







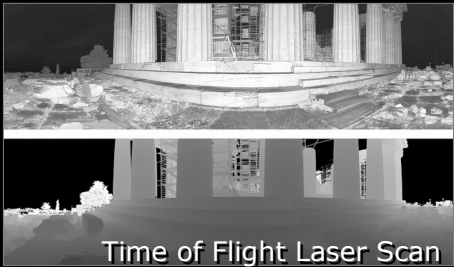

**One More Dimension**

$$R(x_i, y_i, z_i, \theta_i, \phi_i, t_i; x_r, y_r, z_r, \theta_r, \phi_r)$$

Time-Varying Reflectance Field

$$R(x_i, y_i, z_i, \theta_i, \phi_i, t_i; x_r, y_r, z_r, \theta_r, \phi_r, t_r)$$

Time-Resolved Reflectance Field



Time of Flight Laser Scan

Can measure depth, separate direct/indirect reflection, surface/subsurface



How could a time-resolved light stage dataset be useful?



## Time-Resolved IR Brain Imaging

See:

Gabriele Gratton and Monica Fabiani. *Shedding light on brain function: the event-related optical signal*. *TRENDS in Cognitive Sciences* Vol.5 No.8 August 2001.



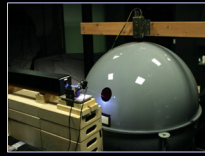
# Thank you

Coauthors: Tim Hawkins, Per Einarsson, Andreas Wenger, Chris Tchou, Andrew Gardner, Jonas Unger

“Performance Relighting and Reflectance Transformation with Time-Multiplexed Illumination”, SIGGRAPH 2005 (to appear)

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