

## Sampling and Reconstruction of Visual Appearance

CSE 274 [Fall 2018], Lecture 5

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## Applications: Sampling/Reconstruction

- Monte Carlo Rendering (*biggest application*)
  - Light Transport Acquisition
  - Light Fields and Computational Photography
  - Animation/Simulation (not covered in course)
- 
- Brief overview of these applications today, and opportunities/history for sampling/reconstruction

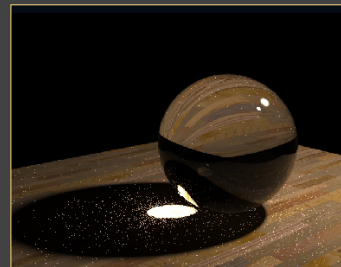
## Motivation

- Distribution effects (depth of field, motion blur, global illumination, soft shadows) are slow. Many dimensions sample



- Ray Tracing physically accurate but slow, not real-time
- Can we adaptively sample and filter for fast, real-time?

## Monte Carlo Path Tracing



1000 paths/pixel

Jensen

## Sampling and Reconstruction

- Monte Carlo is noisy at low sample counts
- Can we reduce time/samples by smart adaptive sampling and smart filtering/reconstruction?
- General area of Monte Carlo denoising
- Long history [Mitchell 91, Guo 98]

## History

- Adaptive sampling old technique Mitchell et al. 87, 91,...



- But not very widely used... artifacts, can miss features
- After seminal papers in 87-91, not much follow on

## Directional Coherence Maps

- Allocate samples to edges (Guo 98) Most of variance at those edges in the image

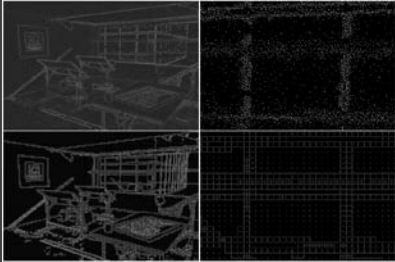


Figure 5: Comparison of the sampling pattern of adaptive anisotropic sampling (top view) and the DCM (bottom view). The patterns in the left column are taken from RADIANCE work images described in Section 5. Some of the fine features are shown in zoomed views of the sampling patterns in the right column. These zoomed views correspond to the same region in the zoomed views in Fig. 4.

## Directional Coherence Maps (Guo 98)

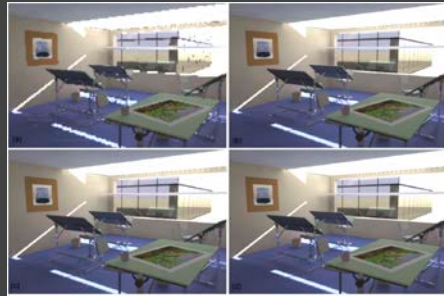
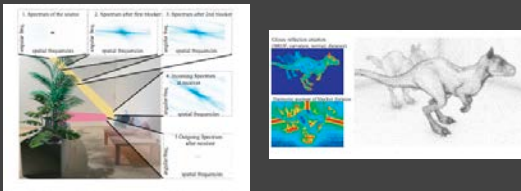


Figure 2: Progressive renderings of an office scene lit by sunlight transformed through a light shelf. (a) The approximate image at the end of the image adaptation, with 10% evaluated pixels located at the corners of the 8 x 8 blocks in the work image. (b) The approximate image after boundary evaluation for all 8 x 8 edge blocks in the work image, with 5% of pixels evaluated. (c) The approximate image after evaluating about 15% of the pixels, whose locations are shown in Fig. 3 (bottom left). (d) The final image as rendered by the baseline RADIANCE system. The scene model was supplied courtesy of Greg W. Lamon.

Guo 98

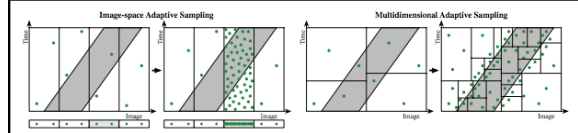
## Resurgence (2008 - )

- Eurographics 2015 STAR report by Zwicker et al. [former UCSD faculty]
- [Durand et al. 2005] Frequency analysis light transport. Proposed use for adaptive sampling. Not very practical

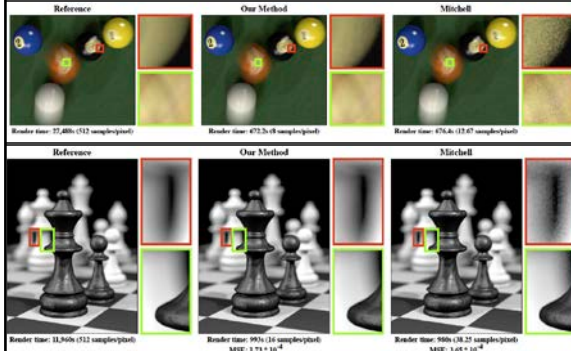


## Multi-Dimensional Adaptive Sampling

- Hachisuka, Jarosz, ... Zwicker, Jensen [MDAS 2008]
- Scenes with motion blur, depth of field, soft shadows
- Involves high-dimensional integral, converges slowly
- Exploit high-dimensional info to sample adaptively
- Sampling in 2D image plane or other dims inadequate
  - Need to consider full joint high-dimensional space



## Multidimensional Adaptive Sampling



## Multidimensional Adaptive Sampling

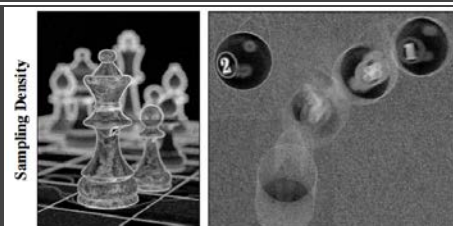


Figure 10: Visualizations of projected sample distributions using our method for the chess scene from Figure 8 and the pool scene from Figure 7. Our adaptive sampler places samples both around high frequency image discontinuities (in focus chess piece and stationary pool ball) as well as in regions which exhibit significant motion blur or depth of field effects.

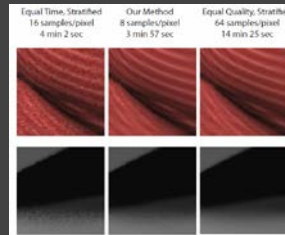
## Multi-Dimensional Adaptive Sampling



Motion Blur and Depth of Field 32 samples per pixel

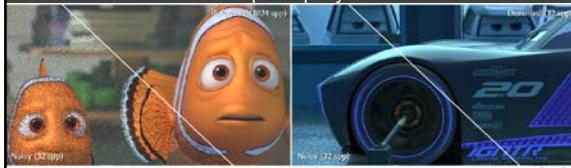
## A-Priori Methods

- Egan et al. 2009: Frequency Analysis and Sheared Filtering for Motion Blur; first deep use frequency anal.



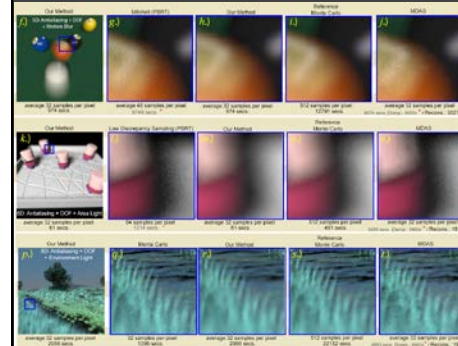
## A-Posteriori Methods

- Adaptive Wavelet Rendering (Overbeck et al. 2009)
- Handle general effects. Sample and denoise
- Many more sophisticated methods available now; used in almost every major production rendering software
- And at least one startup company



Bako et al. 17

## Adaptive Wavelet Rendering



FF VIDEO

Overbeck et al 09  
General high-D  
effects. Simple  
and fast (renders  
into wavelet dom)

## Real-Time

- Axis-Aligned Filtering (Mehta et al. 12,13,14)
- Optix plus image-space filtering
- Newer extensions to sheared filtering
- Most recent work (NVIDIA) is fully general, 1 sample per pixel, using modern machine learning methods (similar ideas relevant in offline rendering as well)

## Real-Time MAAF Video

### Multiple Axis-Aligned Filters for Rendering of Combined Distribution Effects

Lifan Wu<sup>1</sup> Ling-Qi Yan<sup>2</sup> Alexandr Kuznetsov<sup>1</sup> Ravi Ramamoorthi<sup>1</sup>

<sup>1</sup>University of California, San Diego <sup>2</sup>University of California, Berkeley

NO AUDIO

[Recurrent Autoencoder Video \(Chaitanya et al. 17\)](#)

## Applications: Sampling/Reconstruction

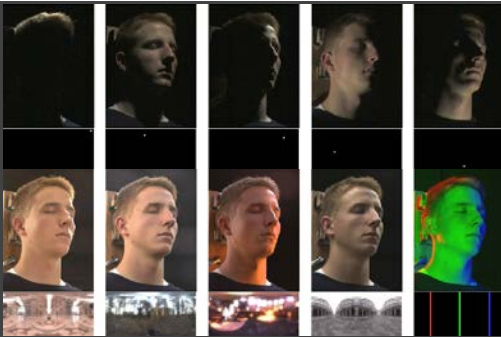
- Monte Carlo Rendering (biggest application)
- *Light Transport Acquisition*
- Light Fields and Computational Photography
- Animation/Simulation (not covered in course)
- Brief overview of these applications today, and opportunities/history for sampling/reconstruction

## Acquiring Reflectance Field of Human Face [Debevec et al., SIGGRAPH\_00]

Illuminate subject from many incident directions



## Example Images



## Motivation: Image-based Relighting



Sample Lighting Directions

## Motivation: Image-based Relighting



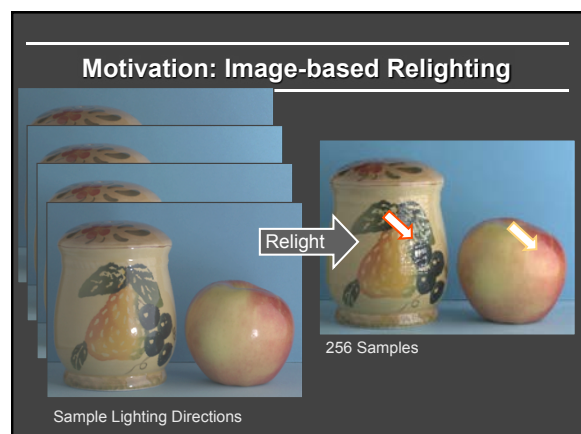
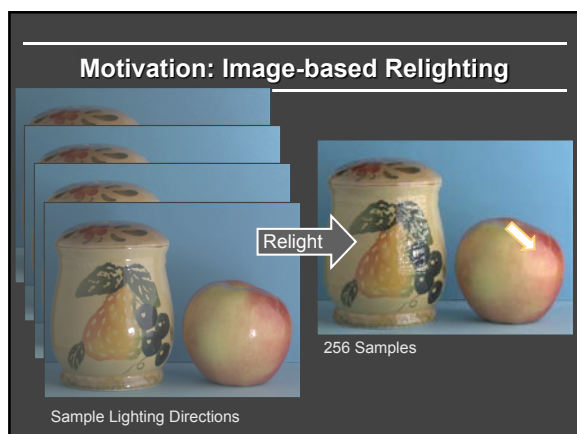
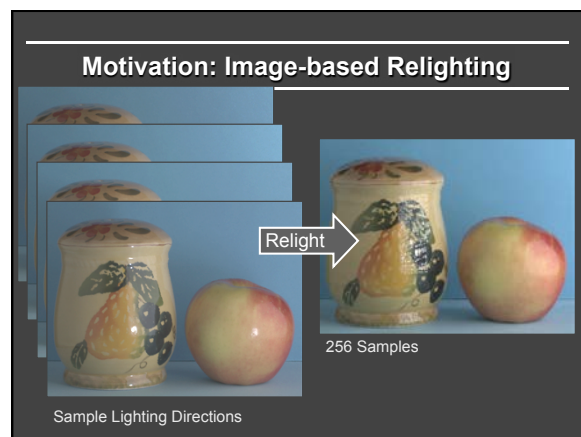
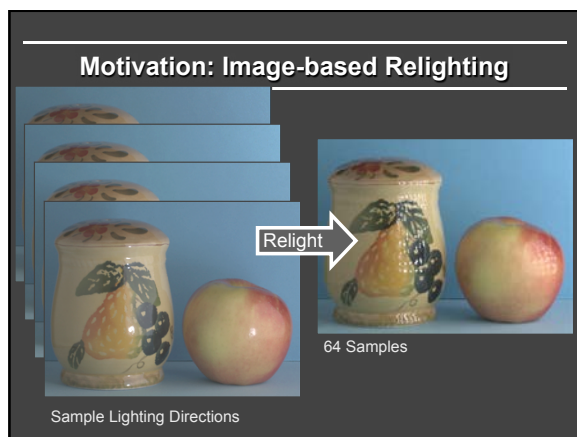
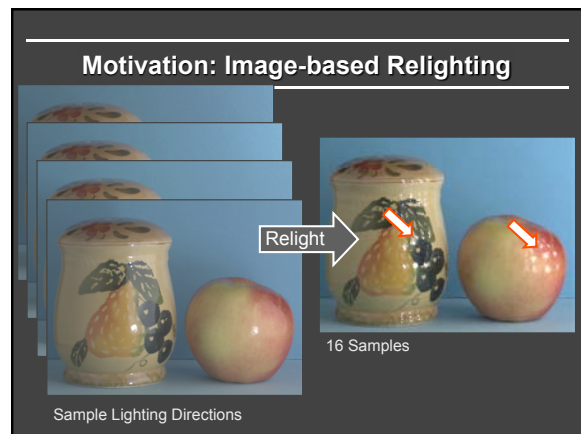
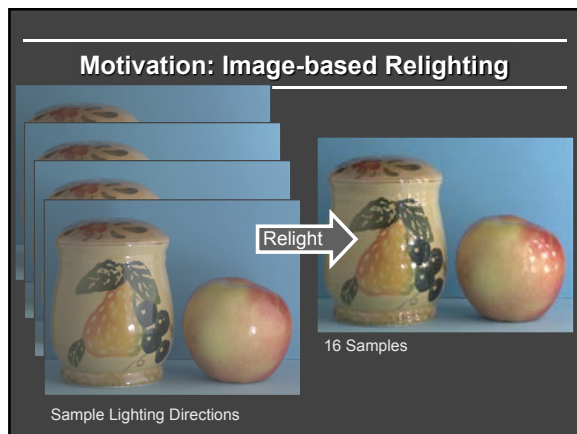
Sample Lighting Directions

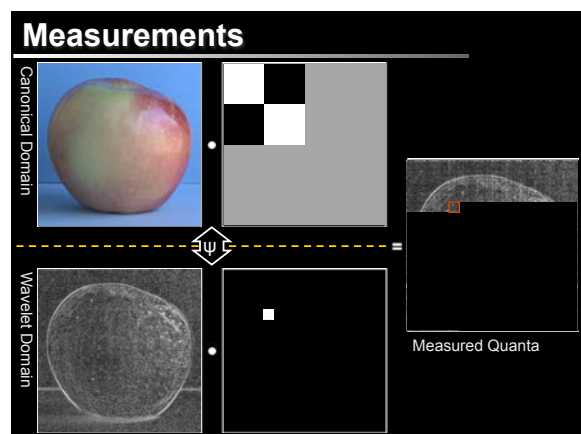
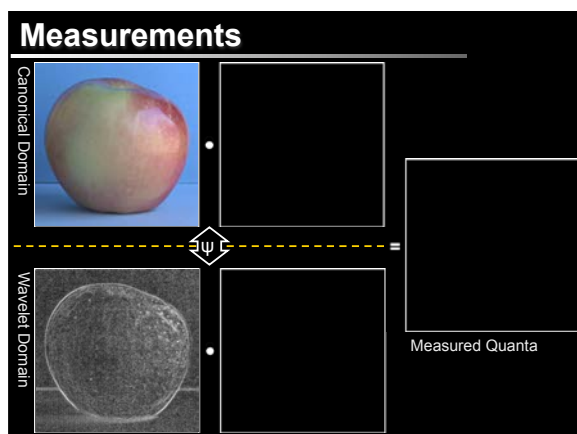
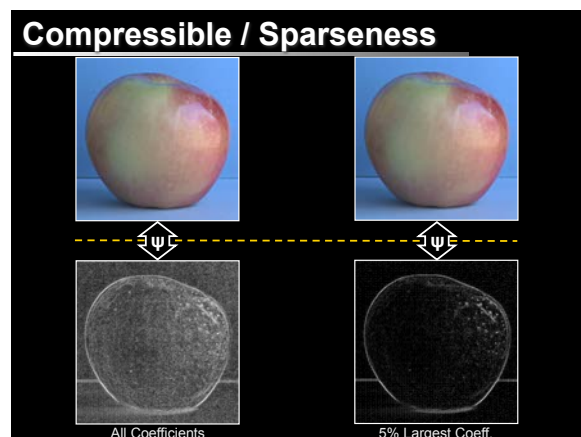
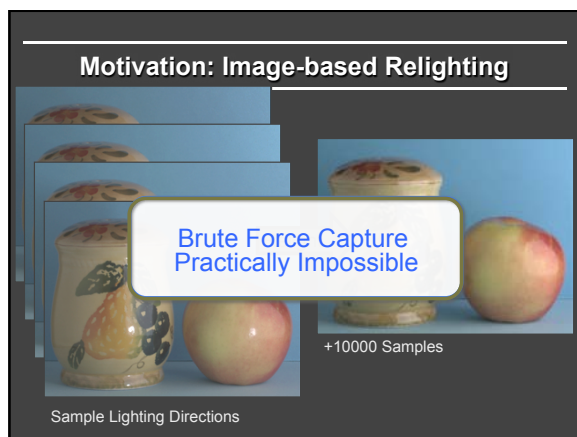
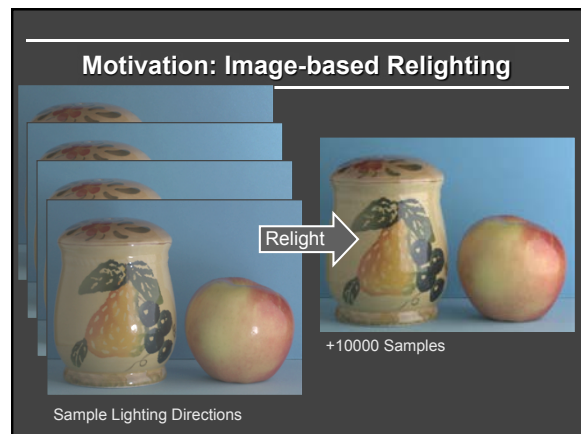
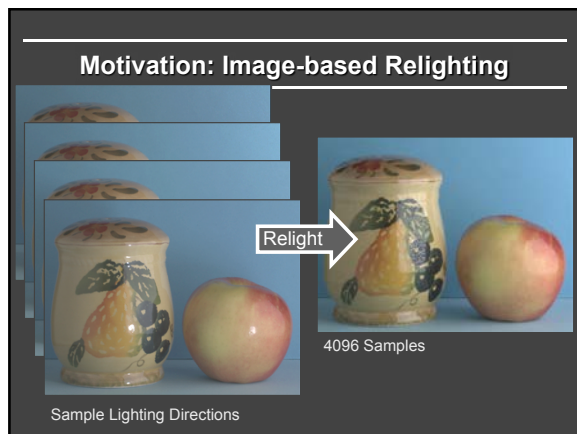
## Motivation: Image-based Relighting

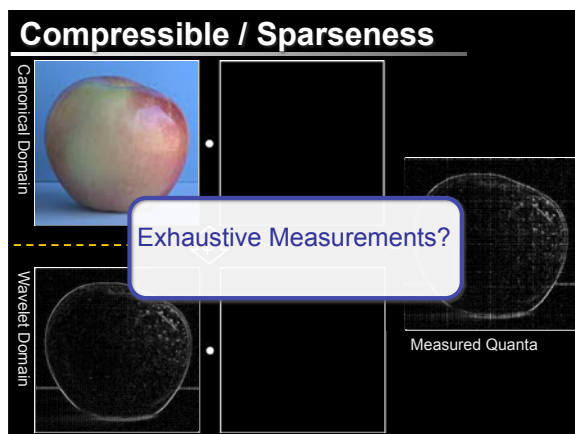
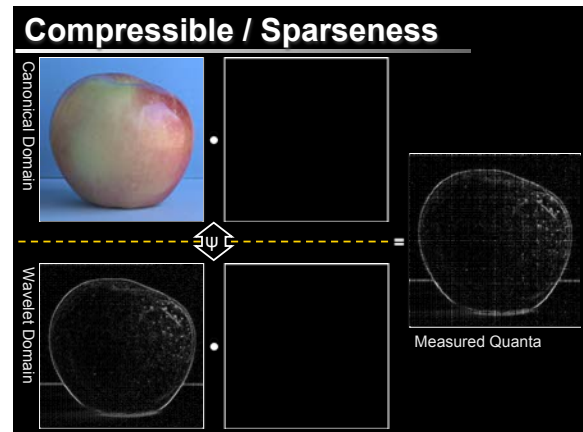
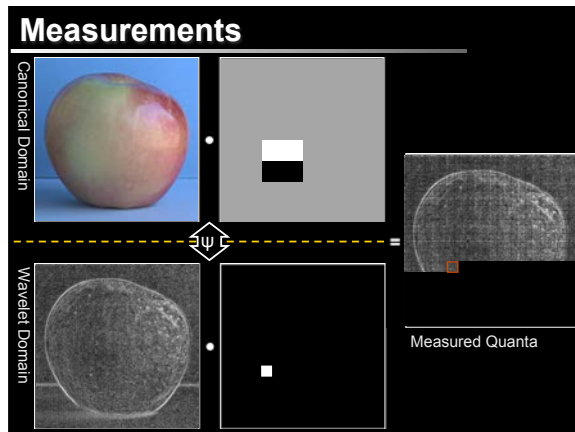


Sample Lighting Directions





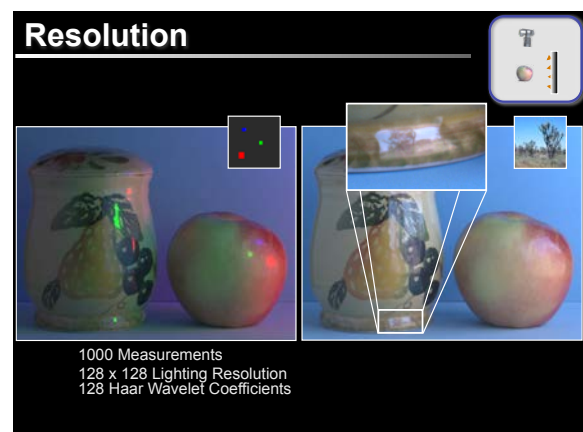
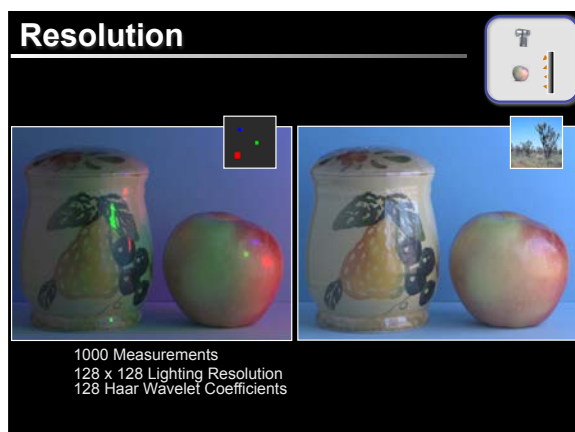


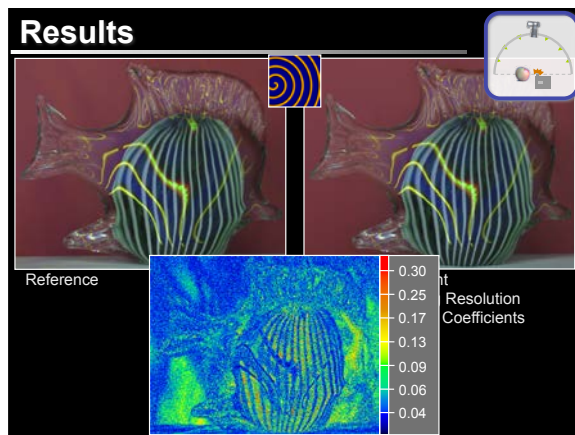
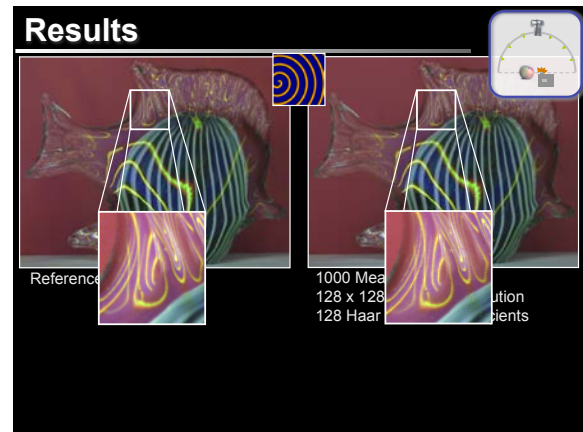
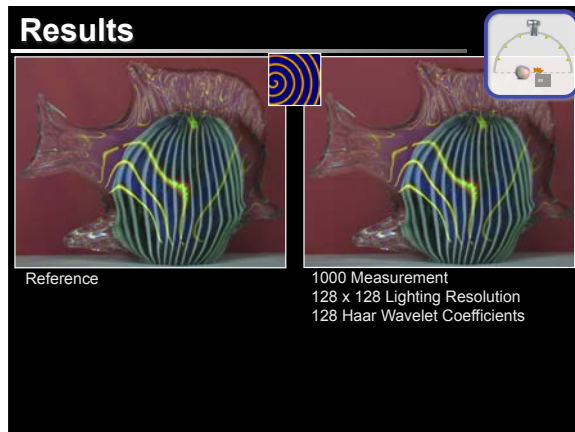


### Compressive Sensing: A Brief Introduction

[Candes et al., 06][Donoho, 06]...

- Sparsity / Compressibility:
  - Signals can be represented as a few non-zero coefficients in an appropriately-chosen basis, e.g., wavelet, gradient, PCA.
- For sparse signals, acquire **measurements** (condensed representations of the signals) with **random projections**.

$$A \begin{bmatrix} \text{Measurement Ensemble} \\ m \times n, \text{ where } m < n \end{bmatrix} \begin{bmatrix} \text{Signal} \\ n \times 1 \end{bmatrix} = \begin{bmatrix} \text{Measurements} \\ m \times 1 \end{bmatrix} b$$


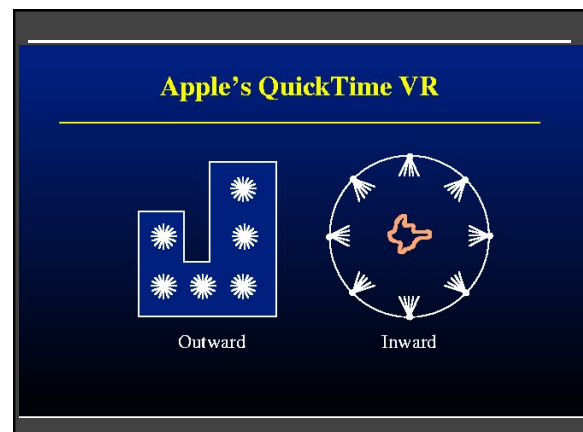


- ### Applications: Sampling/Reconstruction
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  - Light Transport Acquisition
  - Light Fields and Computational Photography*
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## Light Field Rendering

Marc Levoy Pat Hanrahan

Computer Science Department  
Stanford University





## Generating New Views

Problem: fixed vantage point/center



One Solution: view interpolation

- Interpolating between range images (Chen and Williams, 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

## Light Fields

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

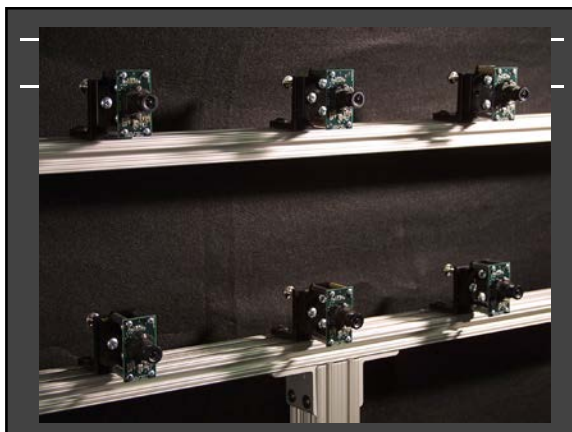
- In "free space" (no occluders) 5D reduces to 4D
  - Exterior of the convex hull of an object
  - Interior of an environment
- Images are 2D slices
  - Insert acquired imagery
  - Extract image from a given viewpoint



## 4D Light Field

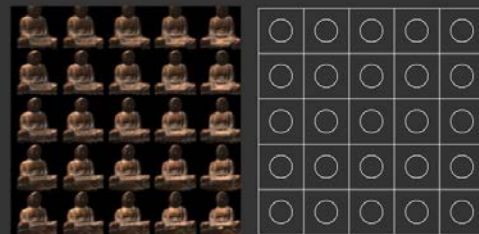


Lytro Camera

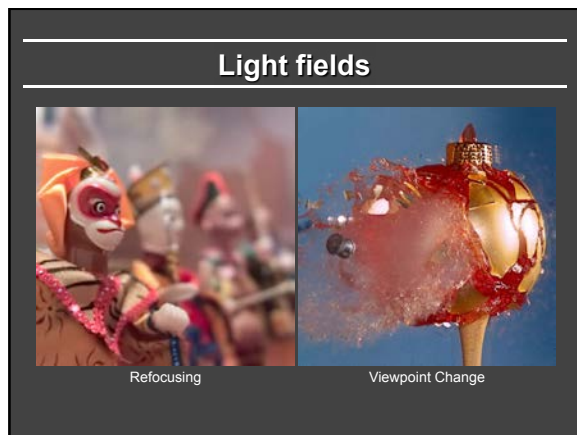
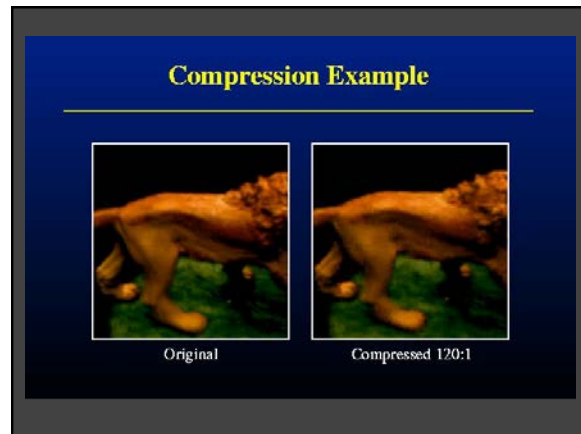
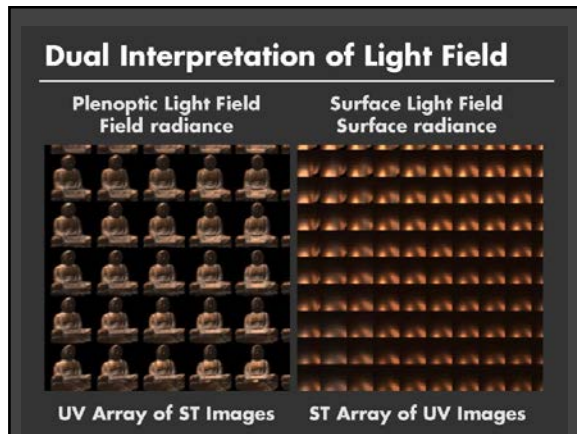


## Light Field as a 2D Array of Image

Camera Array

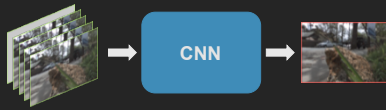


$$L(r) = L(u, v, s, t)$$



## Straightforward solution

- Model the process with a single CNN



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## Single CNN's result



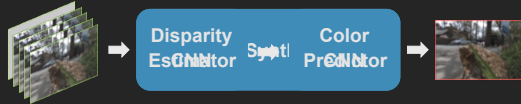
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## High-level idea

- 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



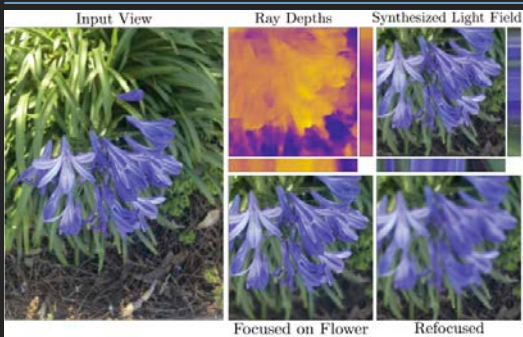
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## Our result



UC San Diego Kalantari et al.

## 4D RGBD Light Fields from 2D Image



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Srinivasan et al. ICCV 17

## Light field video

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



Lytro Illum (3 fps video)

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Wang et al. SIGGRAPH 17

## Lytro video



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## Hybrid Light Field Video System



## Our result



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## Summary

- Brief overview of applications, some algorithms
- Will cover in greater detail in rest of course
- Biggest practical progress in Monte Carlo rendering: order of magnitude speedups
- Widely used in production, also in real-time
- Very relevant in light transport acquisition
- Sampling/Reconstruction key for light fields
- Many other applications: PRT, Animation, etc.