

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
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- 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

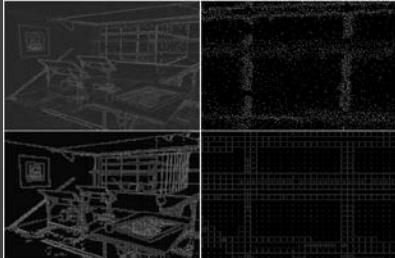


Figure 5: Comparison of the sampling patterns of adaptive stochastic sampling (top row) and the DCM (bottom row). The patterns in the left column are taken from RADIANCE: work images described in Section 5. Some of the fine features are shown in zoomed views of the sampling patterns in the right column.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

Directional Coherence Maps (Guo 98)

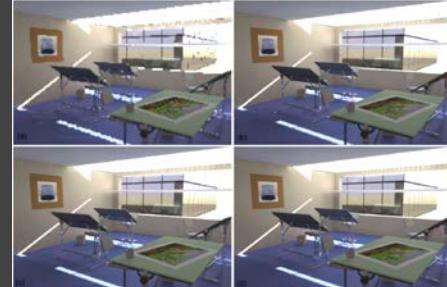
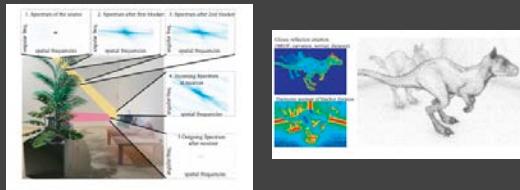


Figure 2: Progressive renderings of an office scene. (a) The approximate image at the end of the raytrace, with 1.0% evaluated pixels located at the corners of the 5x5 blocks in the work image. (b) The approximate image after boundary evaluations for all 5x5 edge blocks in the work image, with 5% of pixels evaluated. (c) The approximate image after about 10% 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. Larson.

Guo 98

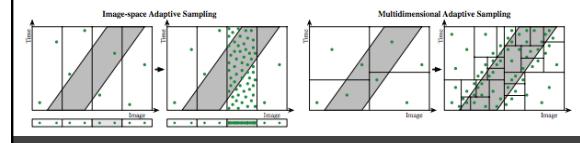
Resurgence (2008 -)

- 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

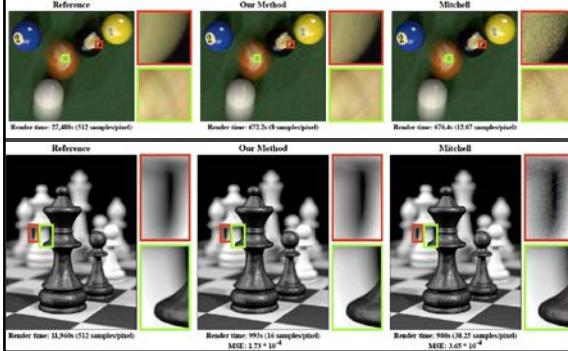


Multi-Dimensional Adaptive Sampling

- 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

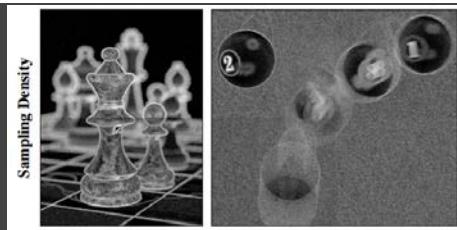


Figure 10: Visualizations of projected sample distributions using our method for the chess scene from Figure 8 and the pool scene from Figure 7. Our adaptive sampler places samples both around high-frequency image discontinuities (in focus chess piece and stationary pool ball) as well as in regions which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

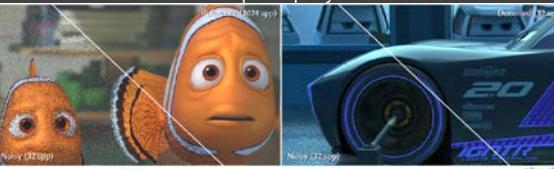
- Egan et al. 2009: Frequency Analysis and Sheared Filtering for Motion Blur; first deep use frequency anal.

Equal Time, Strained 16 samples/pixel 4 min 2 sec	Our Method 8 samples/pixel 3 min 57 sec	Equal Quality, Strained 64 samples/pixel 14 min 25 sec
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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



Training: Nelly (32 samples) Test: Nelly (32 samples) TFR: 10.0 R: 0.000000
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

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¹University of California, San Diego ²University of California, Berkeley

NO AUDIO

Recurrent Autoencoder Video (Chaitanya et al. 17)

Applications: Sampling/Reconstruction

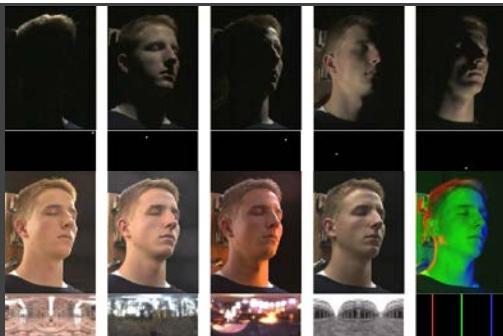
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Acquiring Reflectance Field of Human Face [Debevec et.al. SIGGRAPH 00]

Illuminate subject from many incident directions



Example Images



Motivation: Image-based Relighting



Sample Lighting Directions

Motivation: Image-based Relighting

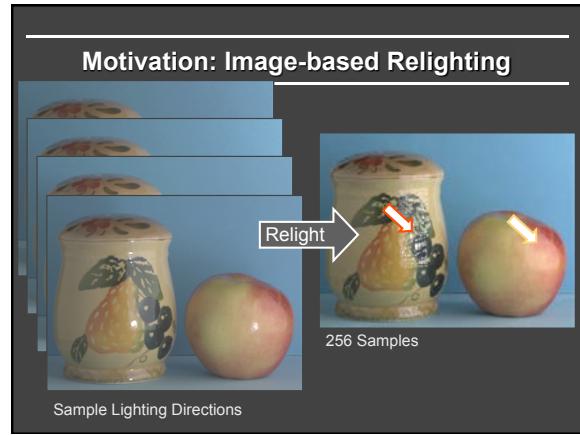
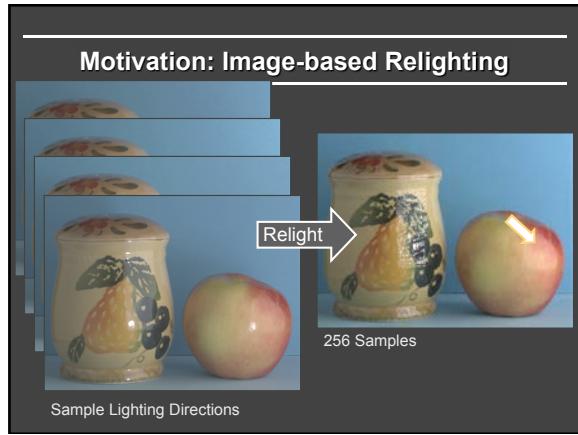
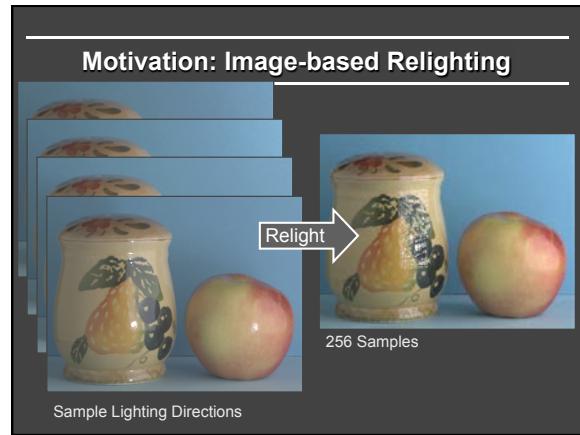
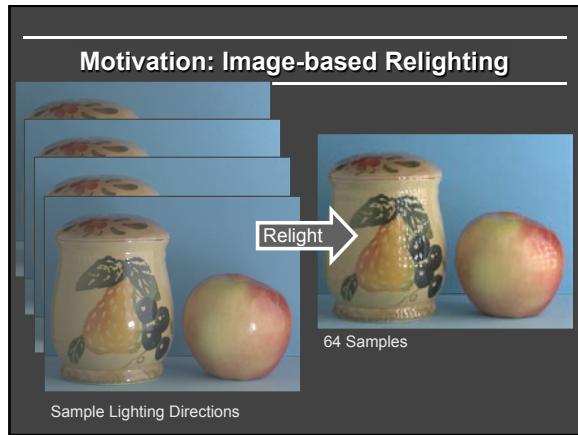
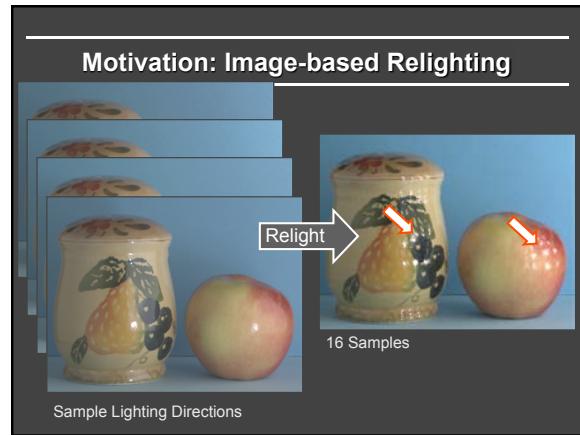
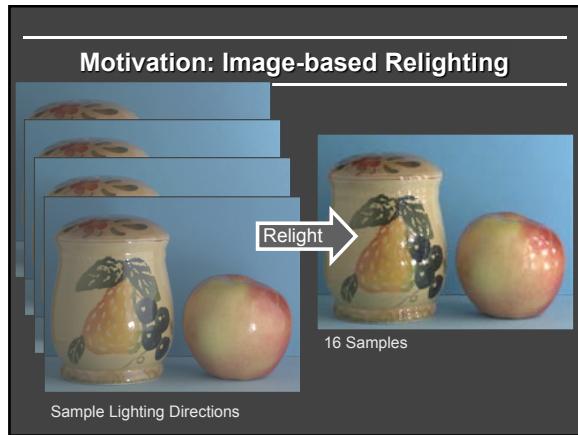


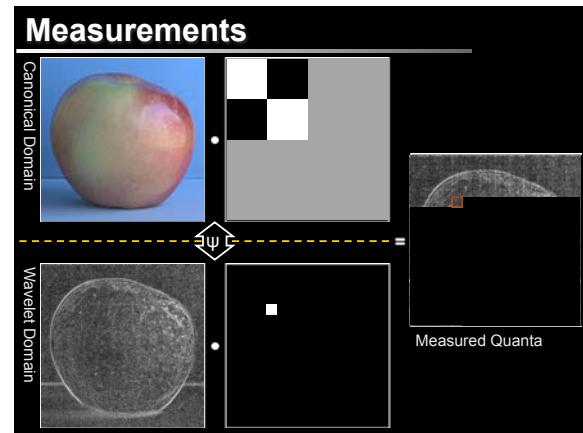
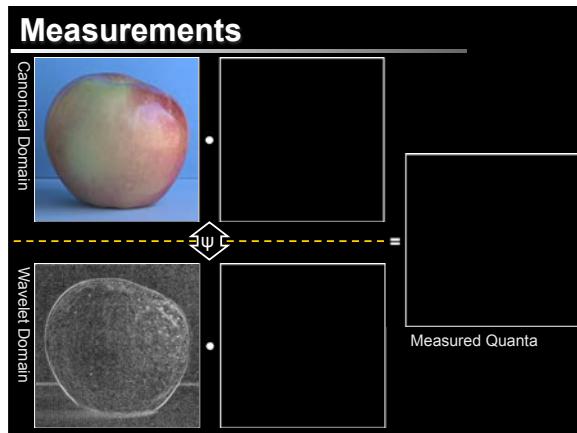
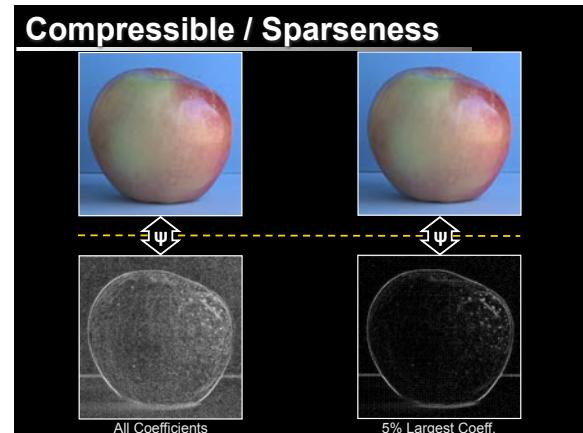
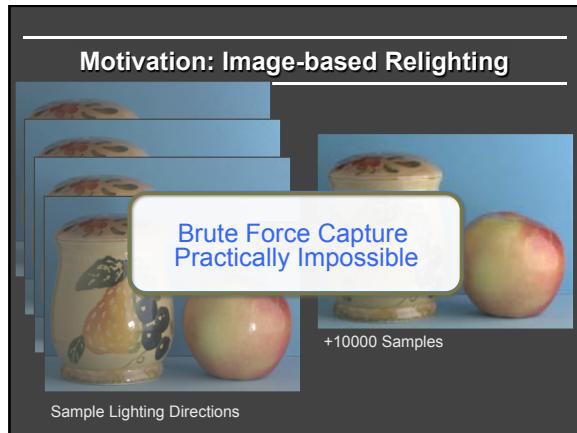
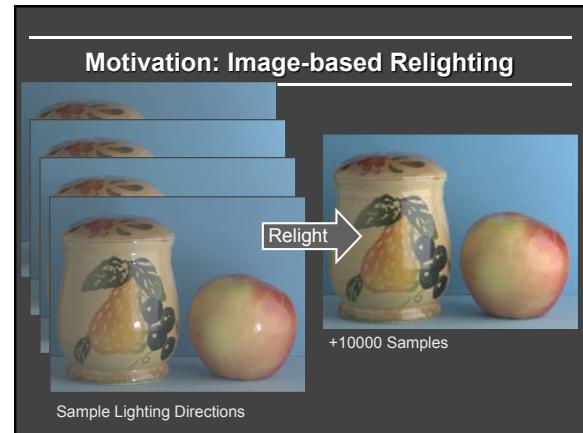
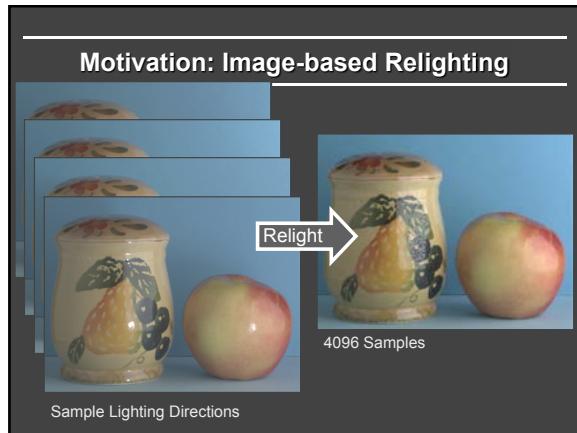
Sample Lighting Directions

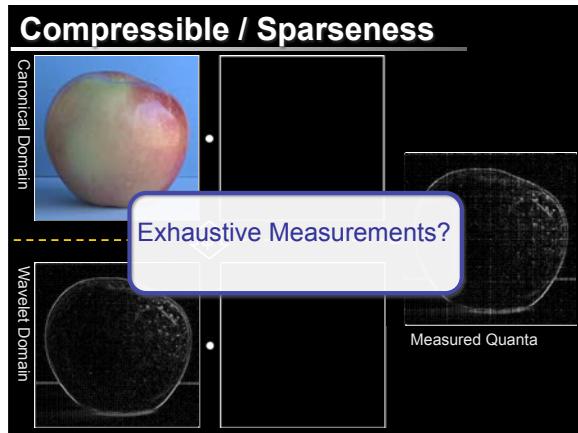
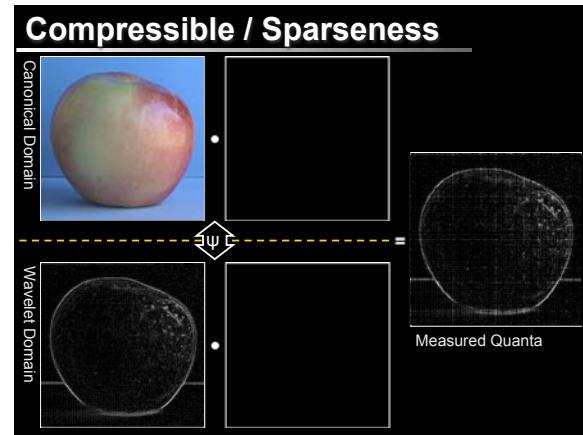
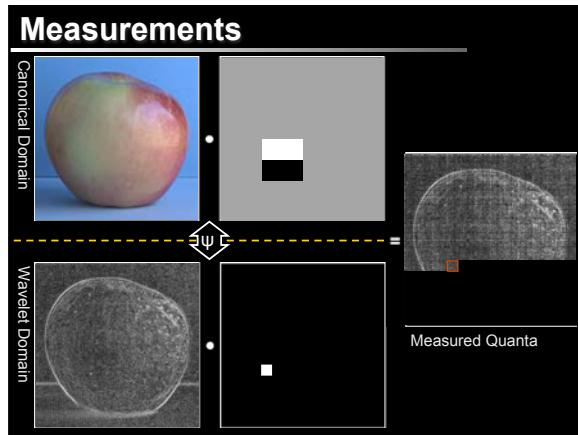
Motivation: Image-based Relighting



Sample Lighting Directions



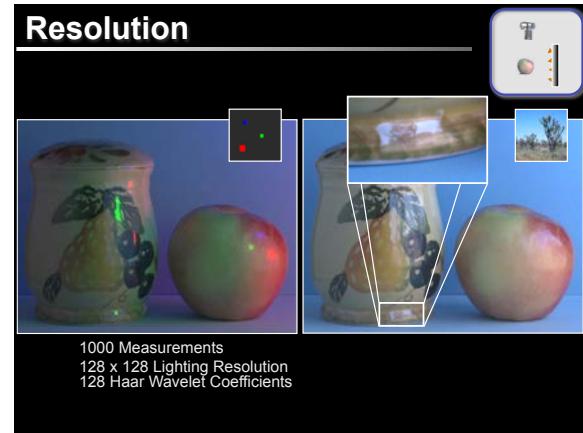
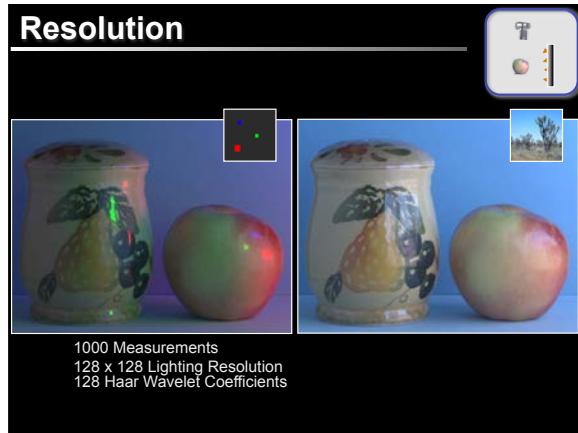


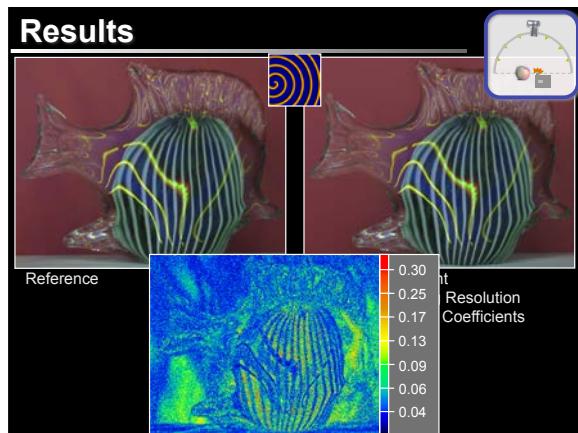
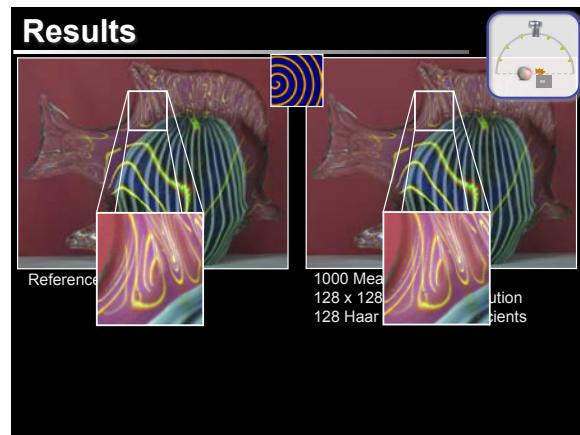
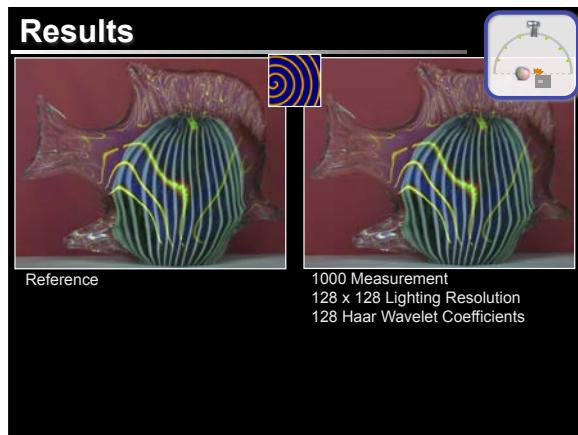


Compressive Sensing: A Brief Introduction

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

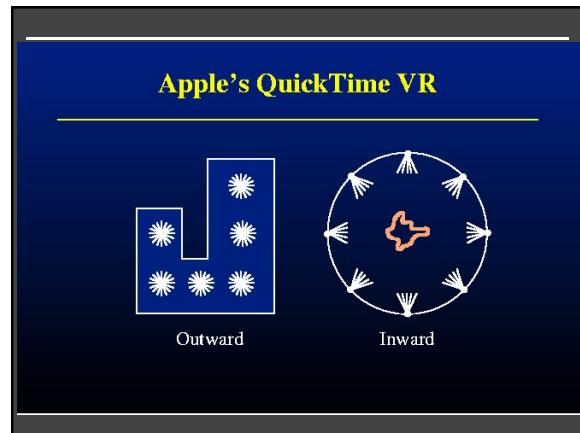
- Sparsity / Compressibility:
 - Signals can be represented as a few non-zero coefficients in an appropriately-chosen basis, e.g., wavelet, gradient, PCA.
- For sparse signals, acquire **measurements** (condensed representations of the signals) with **random projections**.

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




Applications: Sampling/Reconstruction

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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

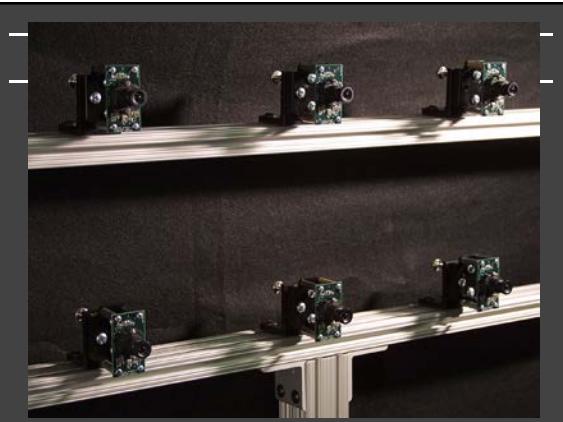
4D Light Field



4 degree-of-freedom gantry



Lytro Camera

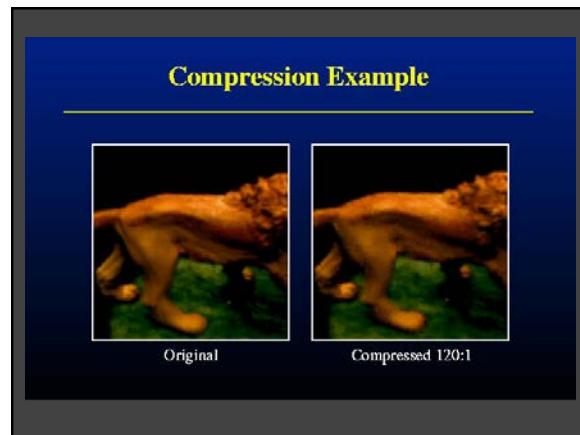
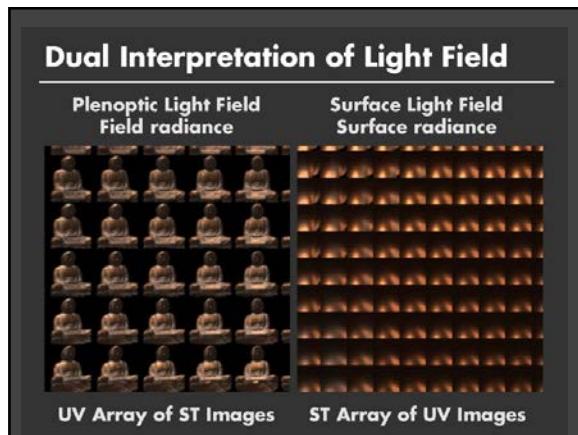


Light Field as a 2D Array of Image

Camera Array



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



Straightforward solution

- Model the process with a single CNN



UCSanDiego

Single CNN's result



UCSanDiego

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



UCSanDiego

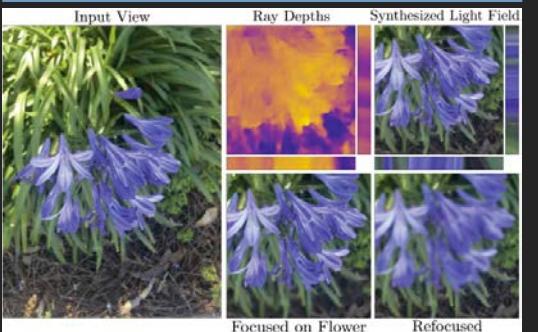
Our result



UCSanDiego Kalantari et al.

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4D RGBD Light Fields from 2D Image



UCSanDiego

Srinivasan et al. ICCV 17

Light field video

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

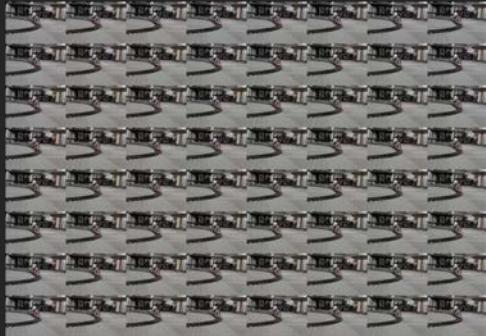


Lytro Illum (3 fps video)

UCSanDiego

Wang et al. SIGGRAPH 17

Lytro video

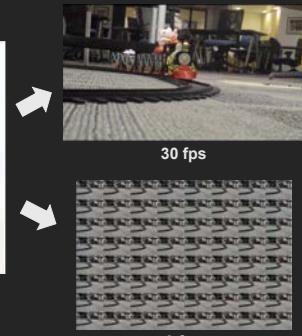


UC San Diego

Hybrid Light Field Video System



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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.