

## Sampling and Reconstruction of Visual Appearance

CSE 274 [Winter 2018], Lecture 10

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## Applications

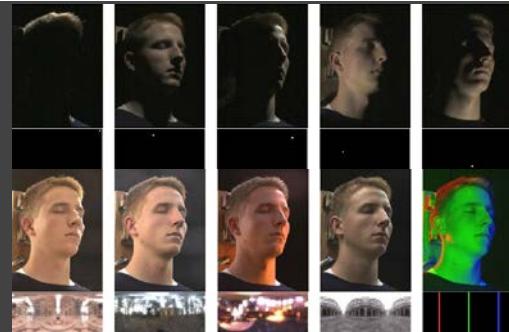
- Monte Carlo Rendering (biggest application)
- *Light Transport Acquisition / Many Light Rendering*
- Light Fields and Computational Photography
- Animation/Simulation (not covered in course)
- Introduce concepts of sparsity, coherence, compressive sensing for reconstruction

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

Illuminate subject from many incident directions



## Example Images



### Motivation: Image-based Relighting

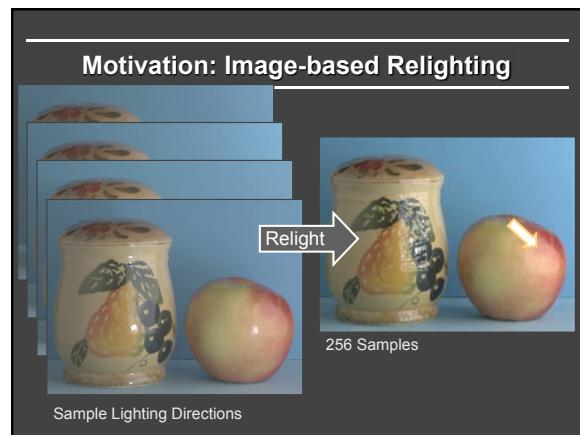
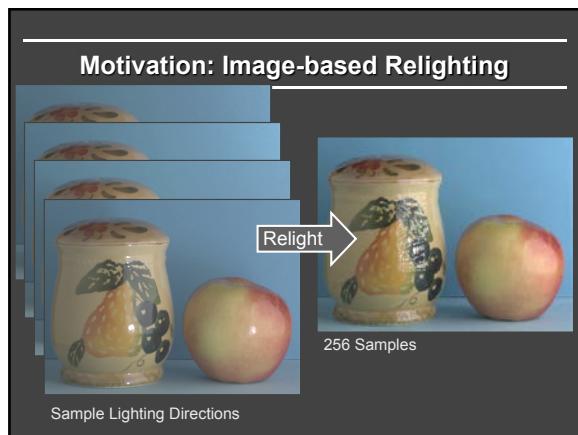
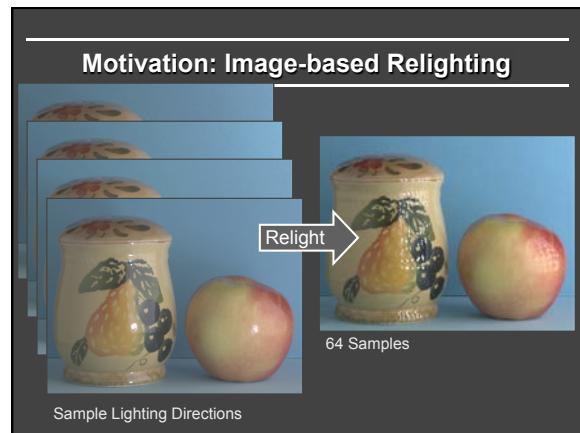
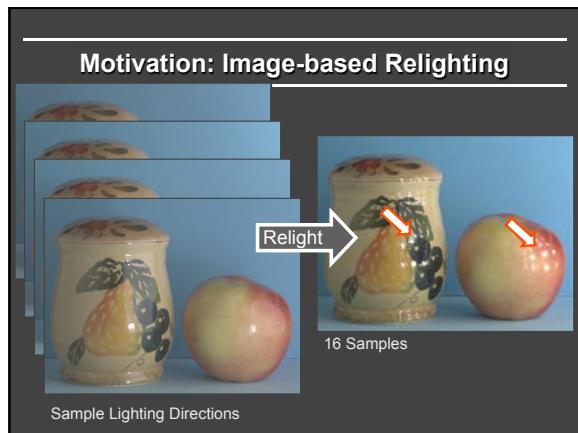
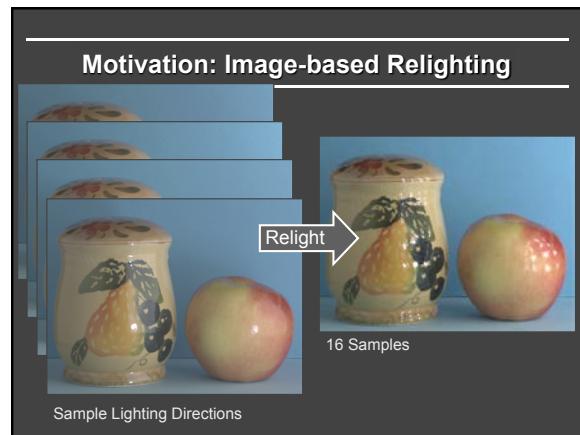
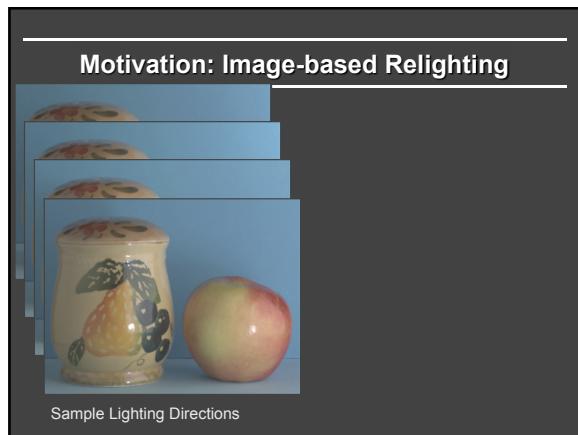


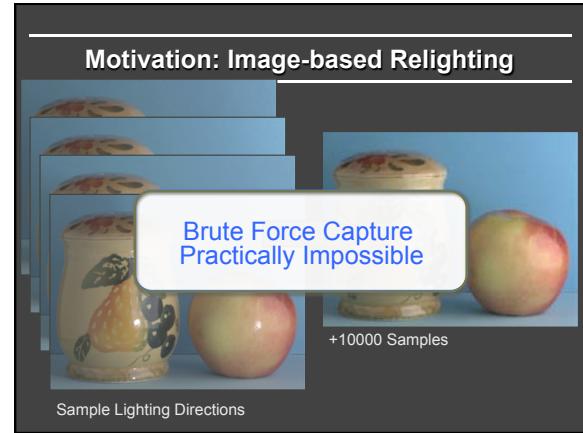
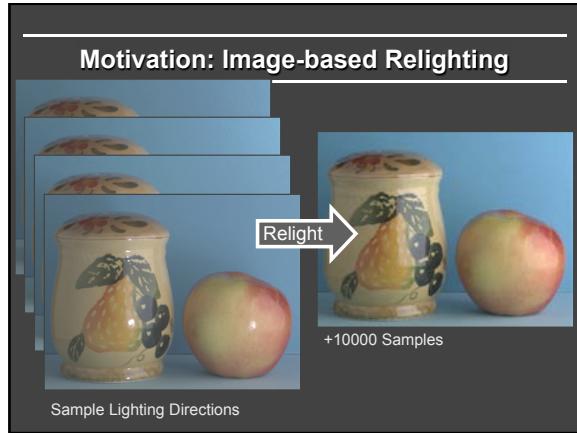
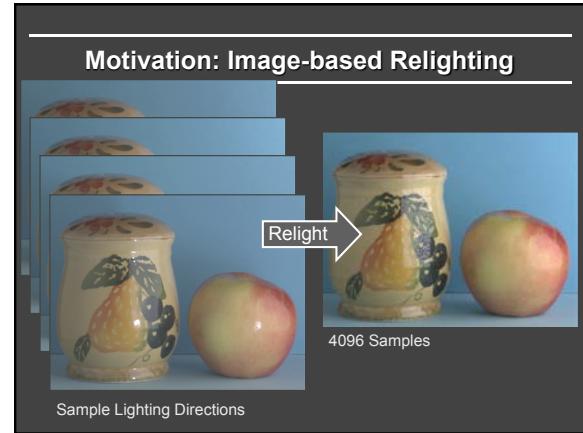
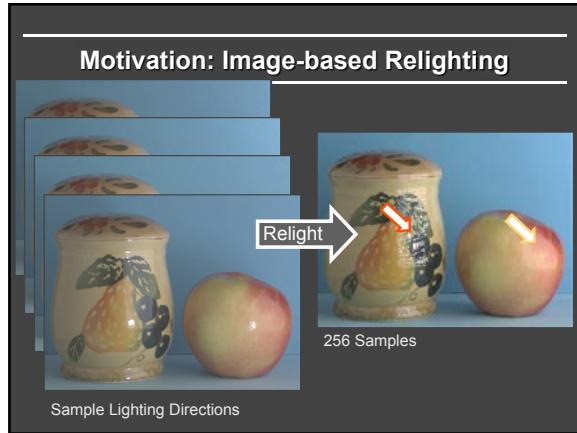
Sample Lighting Directions

### Motivation: Image-based Relighting



Sample Lighting Directions





**Relighting as a Matrix-Vector Multiply**

$$\begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ \vdots \\ P_N \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} & \cdots & T_{1M} \\ T_{21} & T_{22} & \cdots & T_{2M} \\ T_{31} & T_{32} & \cdots & T_{3M} \\ \vdots & \vdots & \ddots & \vdots \\ T_{N1} & T_{N2} & \cdots & T_{NM} \end{bmatrix} \begin{bmatrix} L_1 \\ L_2 \\ \vdots \\ L_M \end{bmatrix}$$

**Relighting as a Matrix-Vector Multiply**

$$\begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ \vdots \\ P_N \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} & \cdots & T_{1M} \\ T_{21} & T_{22} & \cdots & T_{2M} \\ T_{31} & T_{32} & \cdots & T_{3M} \\ \vdots & \vdots & \ddots & \vdots \\ T_{N1} & T_{N2} & \cdots & T_{NM} \end{bmatrix} \begin{bmatrix} L_1 \\ L_2 \\ \vdots \\ L_M \end{bmatrix}$$

Output Image (Pixel Vector)

Input Lighting (Cubemap Vector)

Precomputed Transport Matrix

### Matrix Columns (Images)

$$\begin{bmatrix} T_{11} & T_{12} & \cdots & T_{1M} \\ T_{21} & T_{22} & \cdots & T_{2M} \\ T_{31} & T_{32} & \cdots & T_{3M} \\ \vdots & \vdots & \ddots & \vdots \\ T_{N1} & T_{N2} & \cdots & T_{NM} \end{bmatrix} \quad \begin{array}{c} \text{A green plant} \\ \text{in a white pot} \end{array}$$

### (Pre)compute: Ray-Trace Image Cols

$$\begin{bmatrix} T_{11} & T_{12} & \cdots & T_{1M} \\ T_{21} & T_{22} & \cdots & T_{2M} \\ T_{31} & T_{32} & \cdots & T_{3M} \\ \vdots & \vdots & \ddots & \vdots \\ T_{N1} & T_{N2} & \cdots & T_{NM} \end{bmatrix} \quad \begin{array}{c} \text{A black owl} \\ \text{silhouette} \end{array}$$

### (Pre)compute 2: Rasterize Matrix Rows

$$\begin{bmatrix} T_{11} & T_{12} & \cdots & T_{1M} \\ T_{21} & T_{22} & \cdots & T_{2M} \\ T_{31} & T_{32} & \cdots & T_{3M} \\ \vdots & \vdots & \ddots & \vdots \\ T_{N1} & T_{N2} & \cdots & T_{NM} \end{bmatrix} \quad \begin{array}{c} \text{A small sunburst} \\ \text{in a dark space} \end{array}$$

### Outline

- Matrix Row-Column Sampling (Many Lights)  
(clustering for matrix completion of light transport)
- Compressive Sensing for Light Transport
- Matrix Completion

Hasan, Pellacini, Bala SIGGRAPH 07

### Complex Illumination: A Challenge



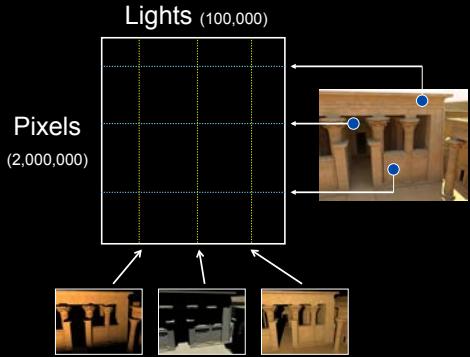
### Conversion to Many Lights

- Area, indirect, sun/sky



Courtesy Walter et al., Lightcuts, SIGGRAPH 05/06

## A Matrix Interpretation



## Problem Statement

- Compute sum of columns

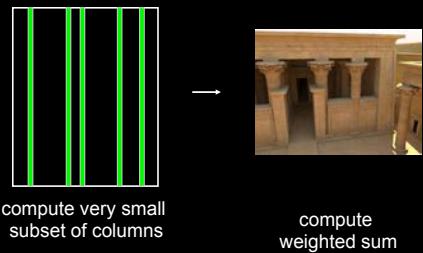
$$\text{Lights} = \sum (\text{Pixels})$$

Diagram showing the problem statement: Compute the sum of columns of the 'Lights' matrix. The 'Lights' matrix is shown as a large grid, and the 'Pixels' matrix is shown as a smaller grid. Arrows indicate the summation operation.

- Note:** We don't have the matrix data

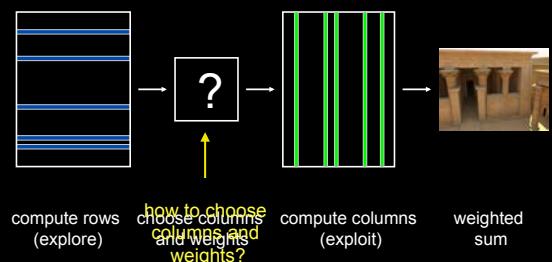
## Image as a Weighted Column Sum

- The following is possible:

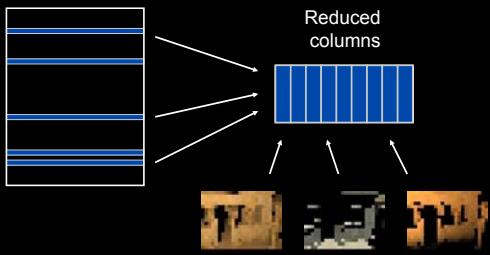


- Use rows to choose a good set of columns!

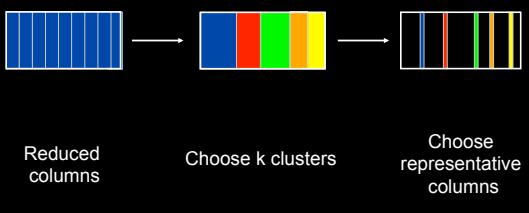
## Exploration and Exploitation

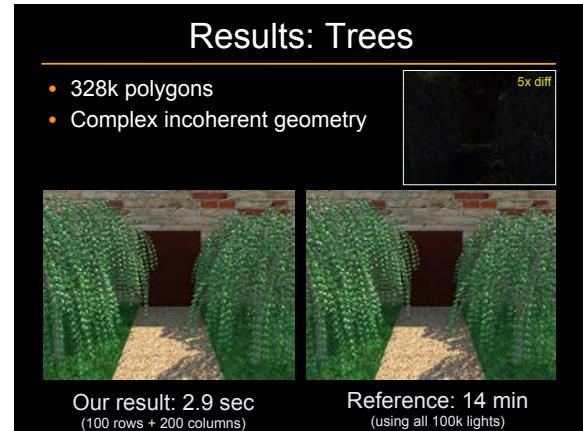
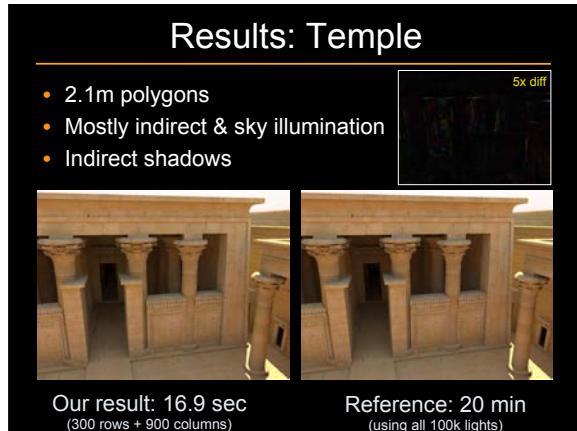
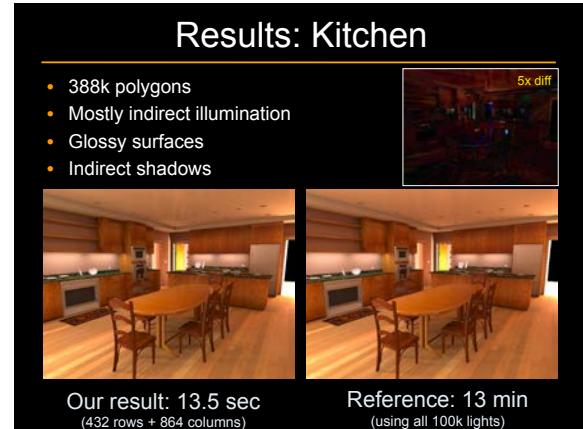
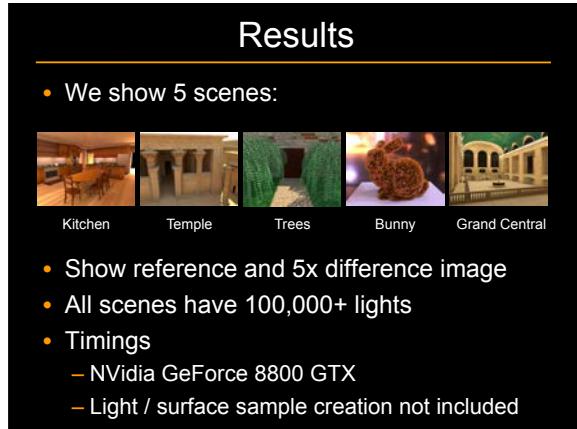
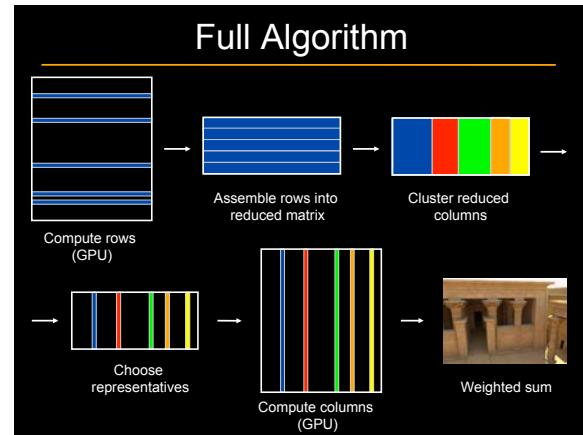
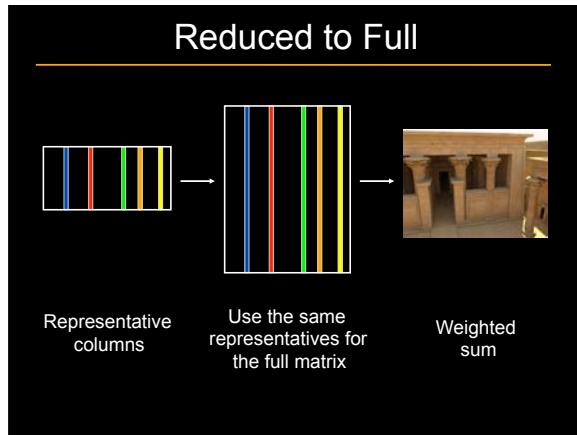


## Reduced Matrix



## Clustering Approach





## Results: Bunny

- 869k polygons
- Incoherent geometry
- High-frequency lighting
- Kajiya-Kay hair shader



Our result: 3.8 sec  
(100 rows + 200 columns)



Reference: 10 min  
(using all 100k lights)



5x diff

## Results: Grand Central

- 1.5m polygons
- Point lights between stone blocks



Our result: 24.2 sec  
(588 rows + 1176 columns)



Reference: 44 min  
(using all 100k lights)



5x diff

## Outline

- Matrix Row-Column Sampling (Many Lights)  
(clustering for matrix completion of light transport)
- Compressive Sensing for Light Transport*
- Matrix Completion

Gu et al. ECCV 08  
Peers et al. SIGGRAPH 09  
Sen and Darabi EG 09 (reading)

## Motivation: Image-based Relighting



Brute Force Capture Practically Impossible

+10000 Samples

Sample Lighting Directions

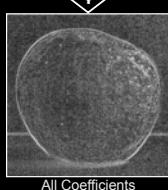
## Compressible / Sparseness



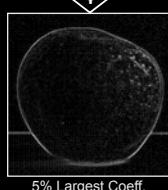
•  $\Psi$



•  $\Psi$



All Coefficients



5% Largest Coeff.

## Measurements

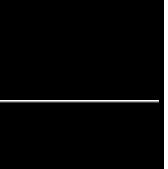
Canonical Domain



•

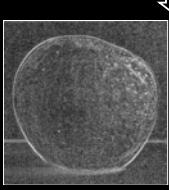


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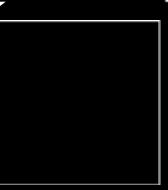


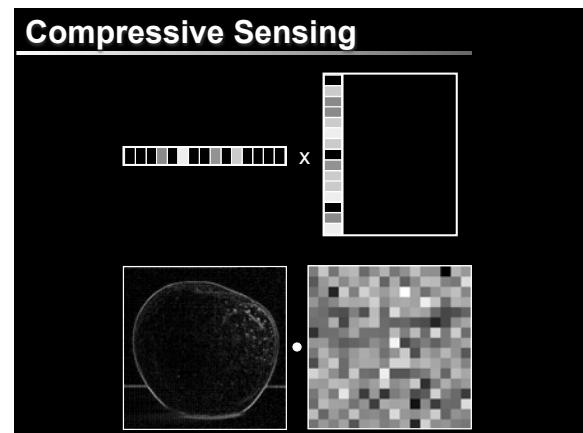
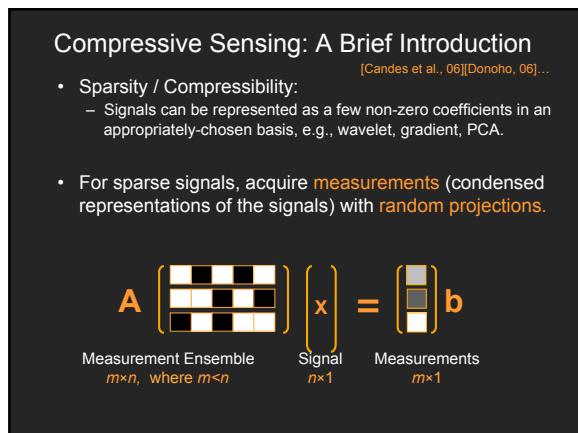
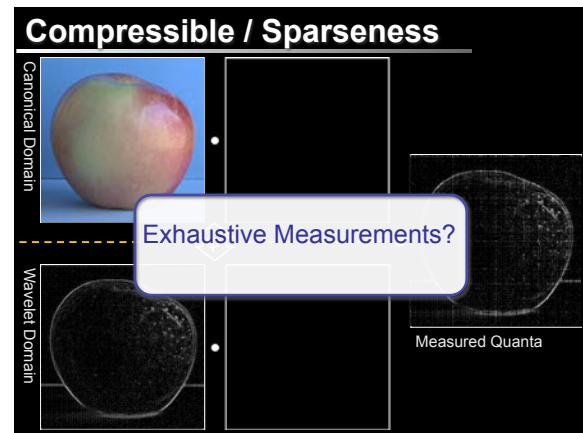
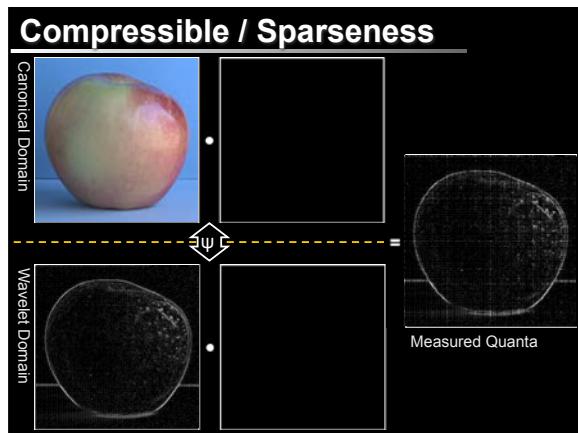
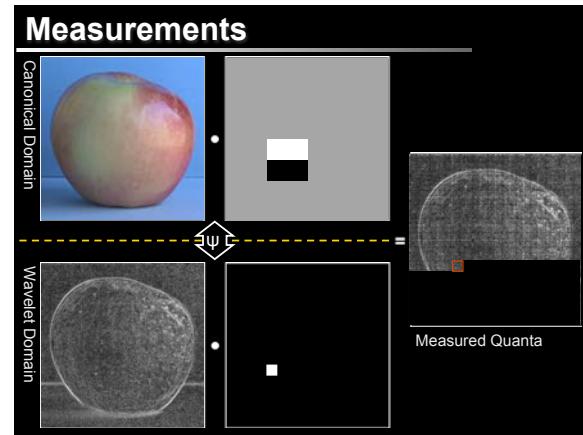
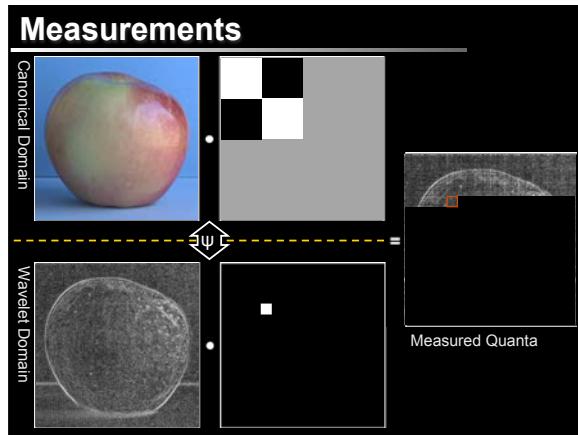
Measured Quanta

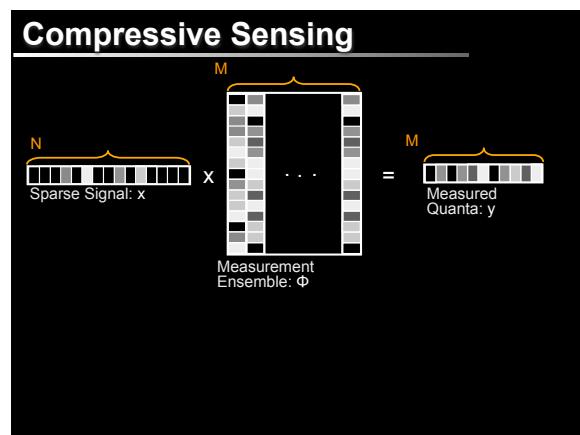
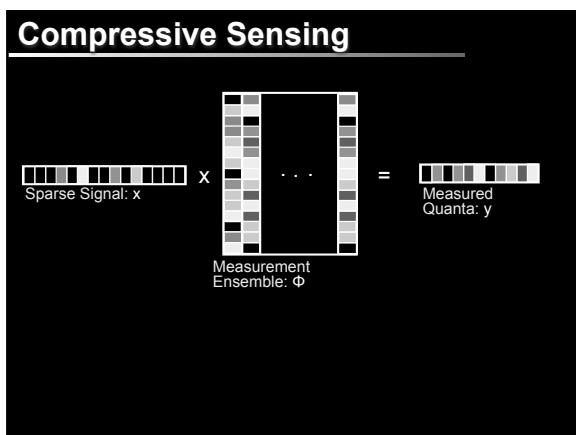
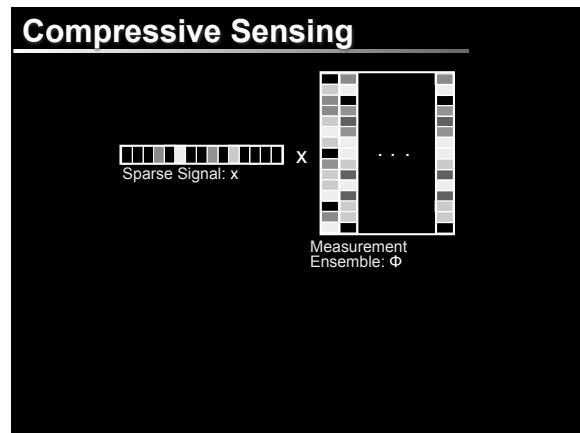
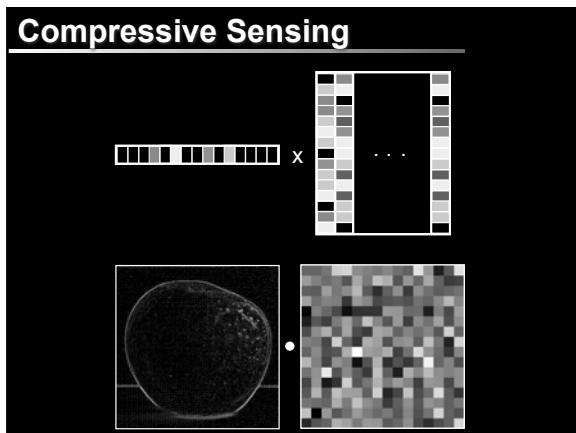
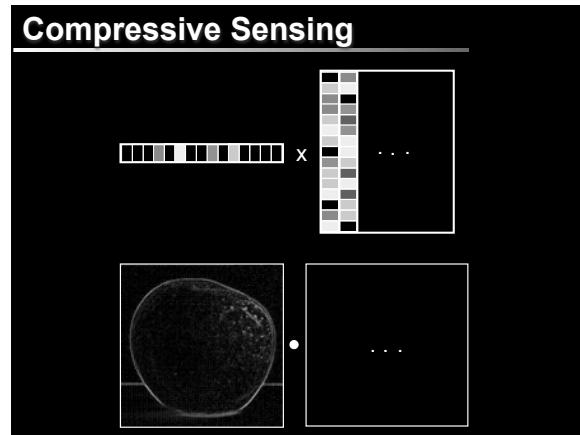
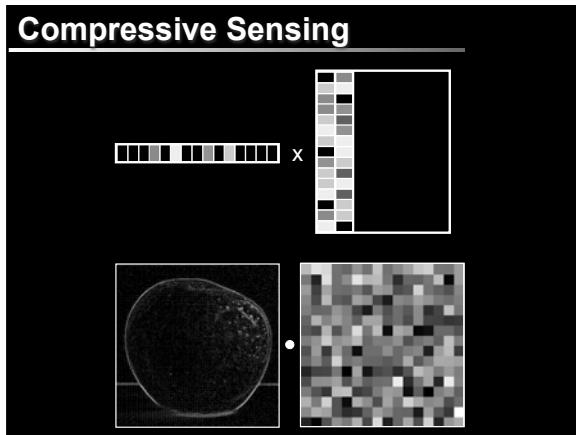
Wavelet Domain

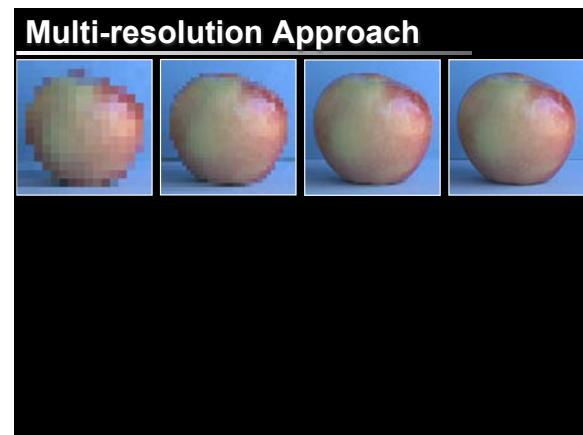
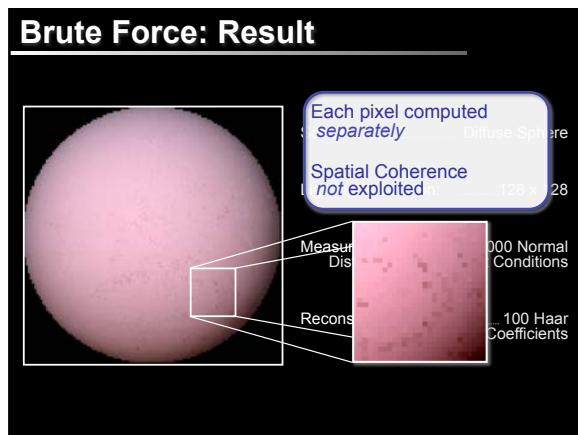
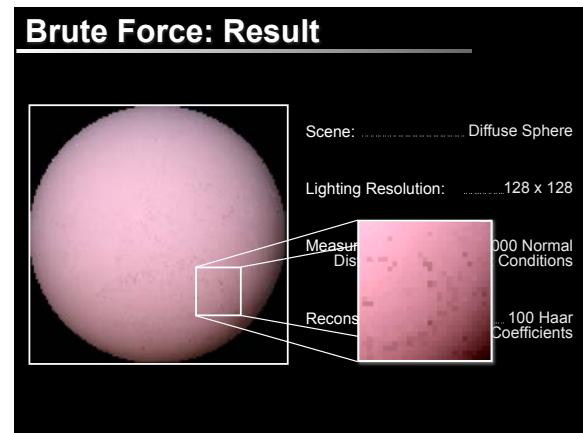
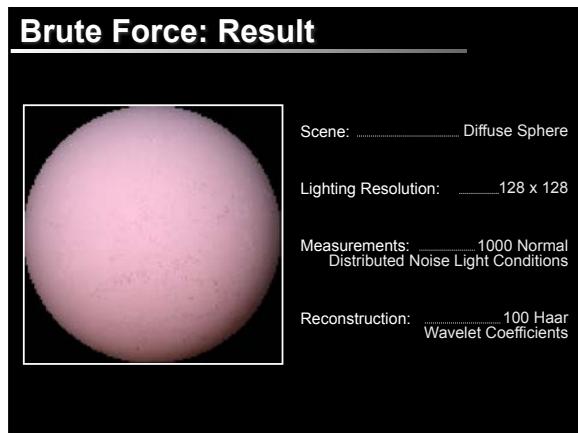
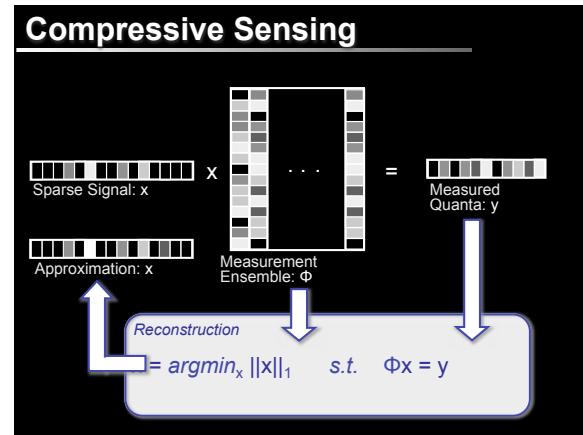
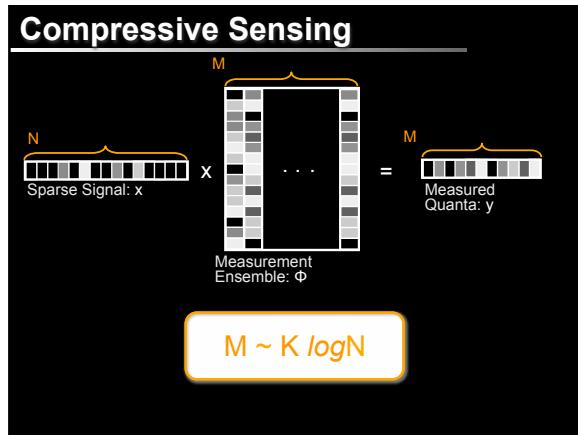


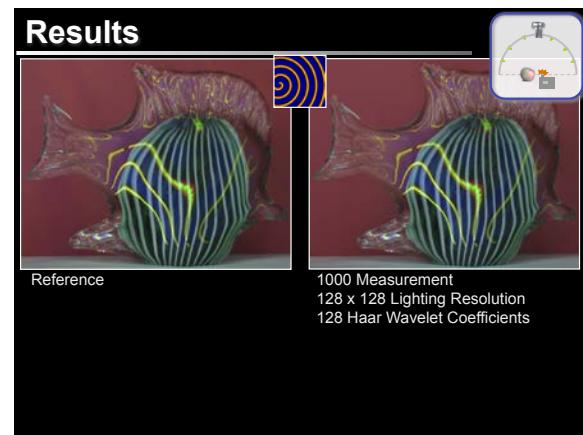
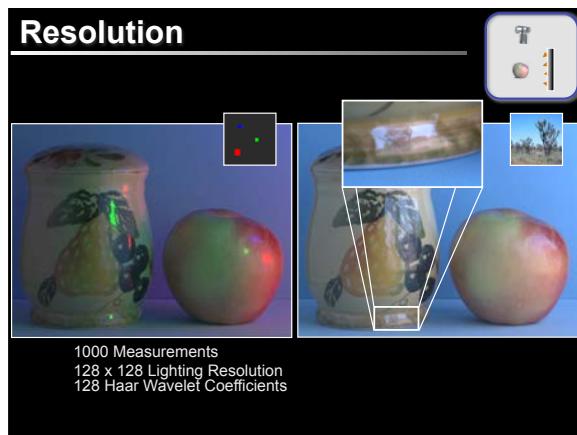
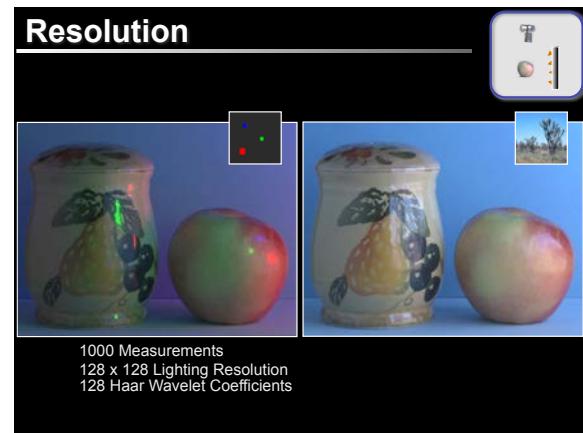
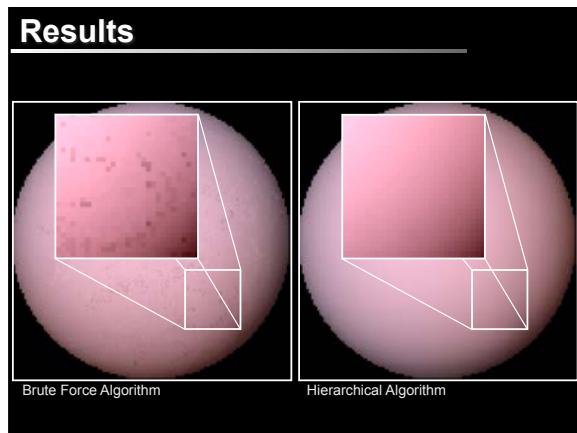
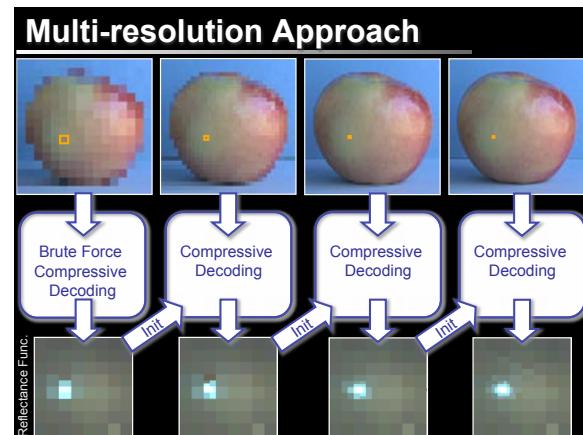
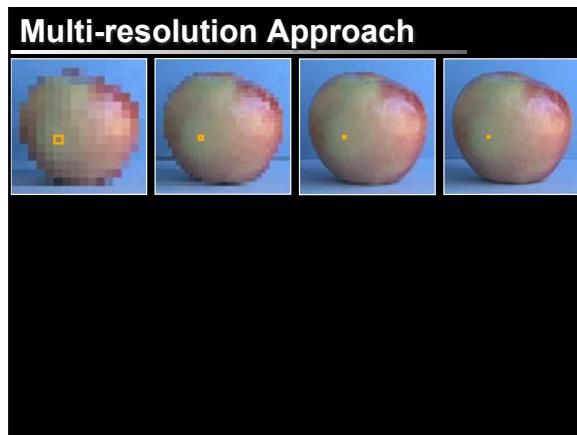
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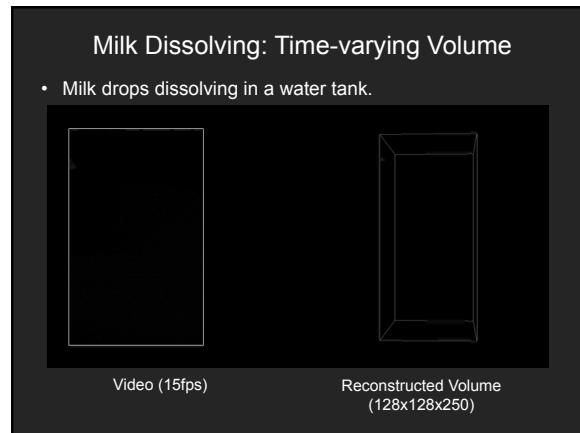
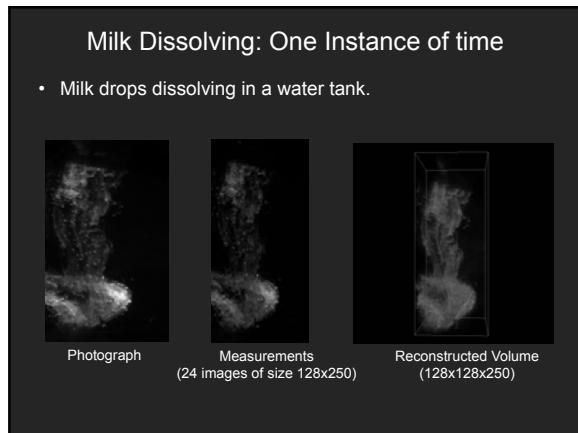
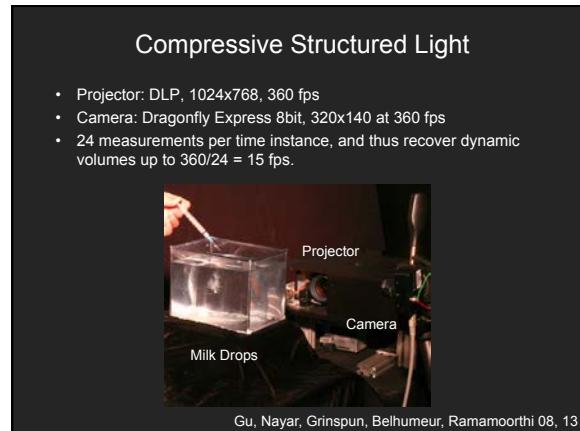
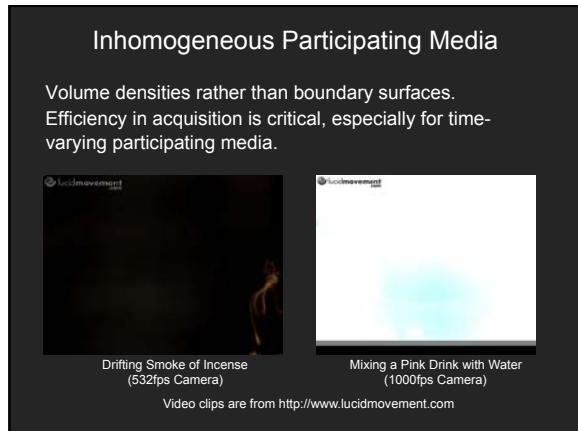
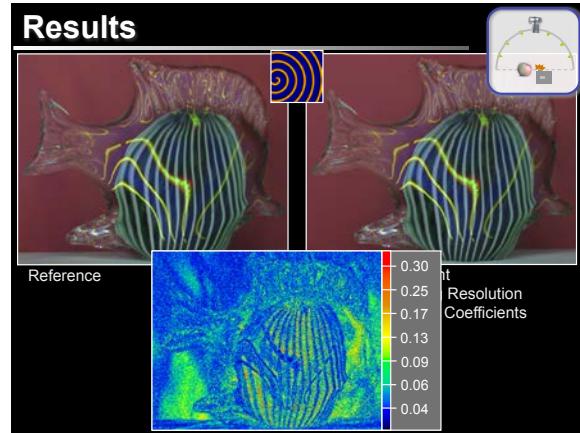
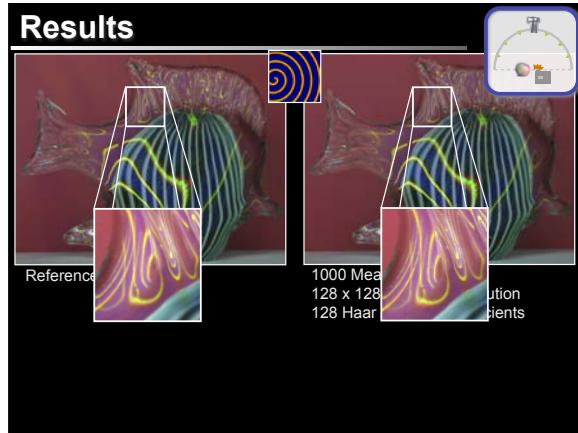












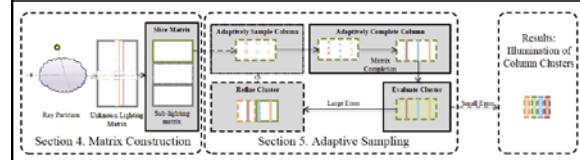
## Outline

- Matrix Row-Column Sampling (Many Lights)  
(clustering for matrix completion of light transport)
- Compressive Sensing for Light Transport
- *Matrix Completion*
  - Extension to compressive sensing: Low rank matrices
  - Minimize matrix norm (rank), given some entries
  - Combine many ideas seen previously

Huo et al. SIGGRAPH Asia 16

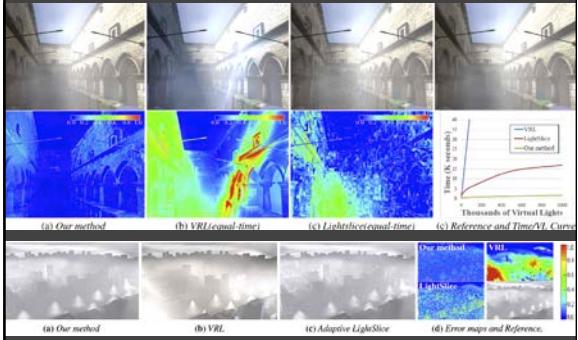
## Outline

- *Matrix Completion*
  - Extension to compressive sensing: Low rank matrices
  - Minimize matrix norm (rank), given some entries
  - Combine many ideas seen previously



Huo et al. SIGGRAPH Asia 16

## Results (Participating Media)



## Summary

- Light Transport for Acquisition, Many Light Rendering
- Compressive Sensing for projected patterns
- Matrix Completion for many light rendering
- Leverages popular ideas in applied math
- Consider all forms of coherence