

## Sampling and Reconstruction of Visual Appearance

CSE 274 [Winter 2018], Lecture 10

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## Applications

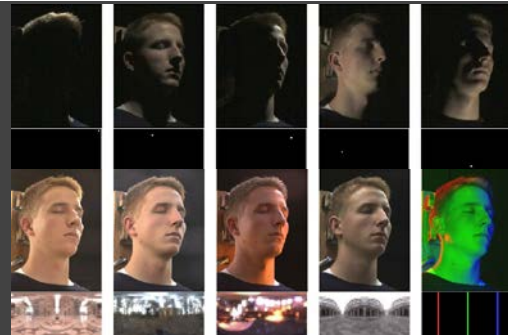
- Monte Carlo Rendering (biggest application)
  - *Light Transport Acquisition / Many Light Rendering*
  - Light Fields and Computational Photography
  - Animation/Simulation (not covered in course)
- 
- Introduce concepts of sparsity, coherence, compressive sensing for reconstruction

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

Illuminate subject from many incident directions



## Example Images



## Motivation: Image-based Relighting

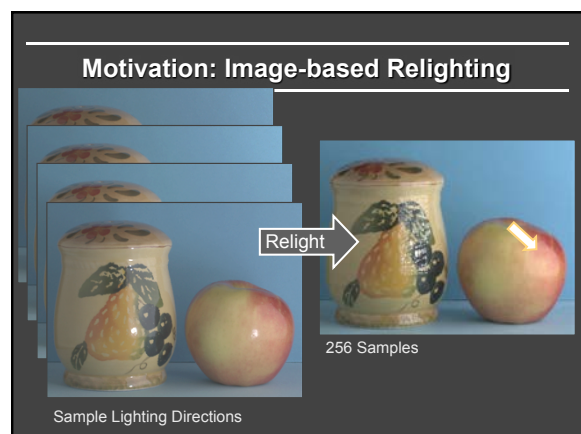
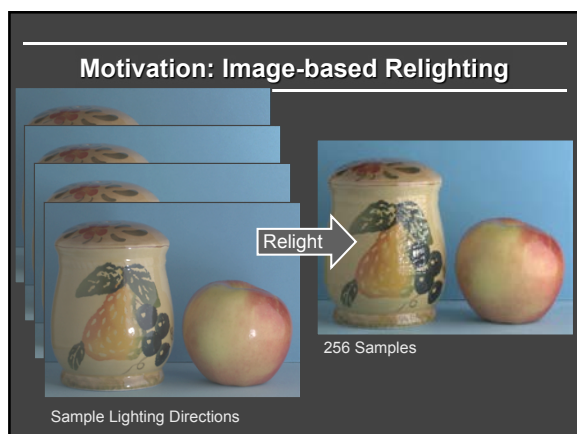
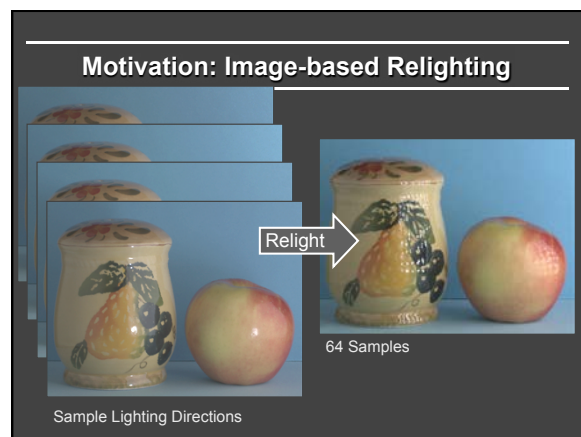
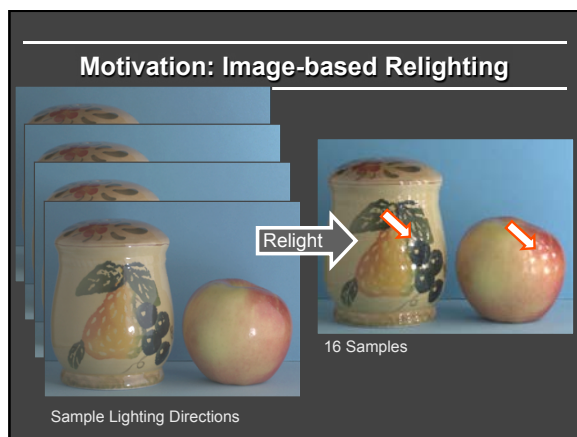
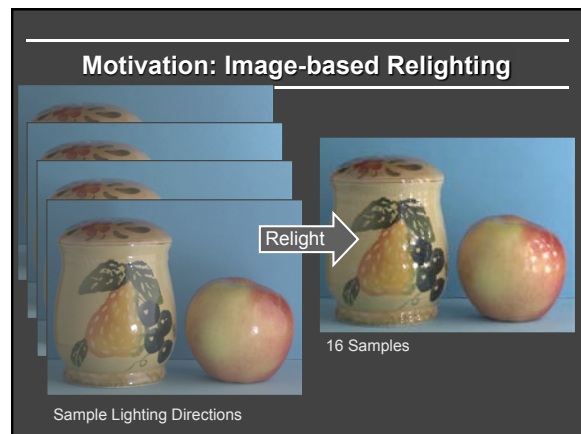
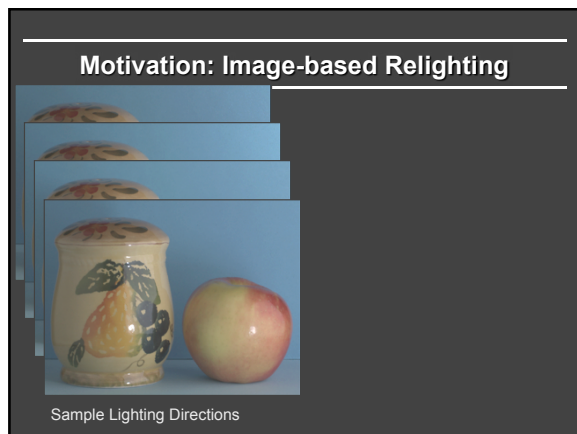


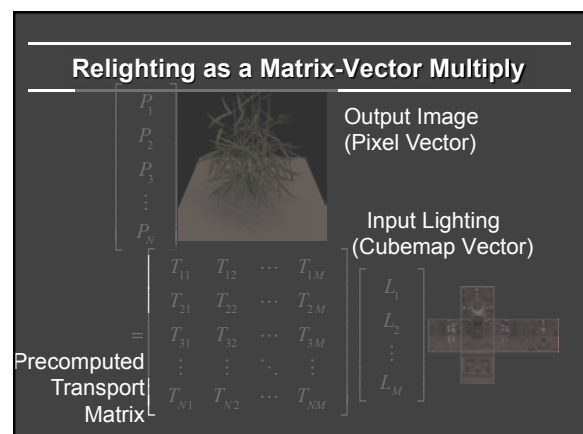
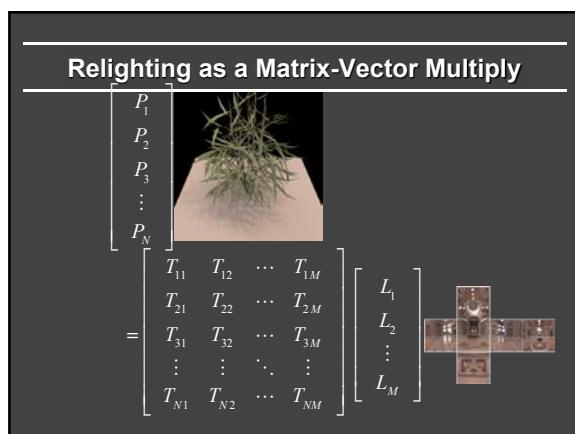
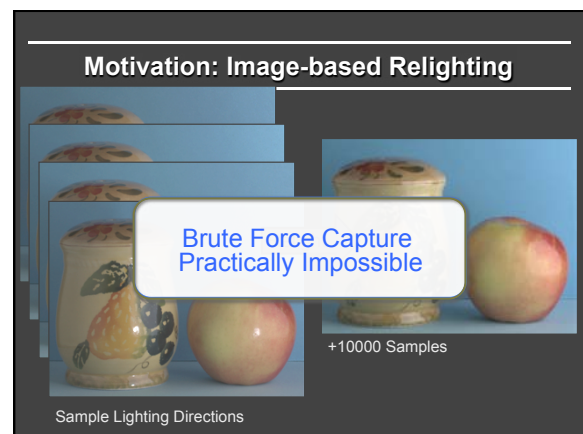
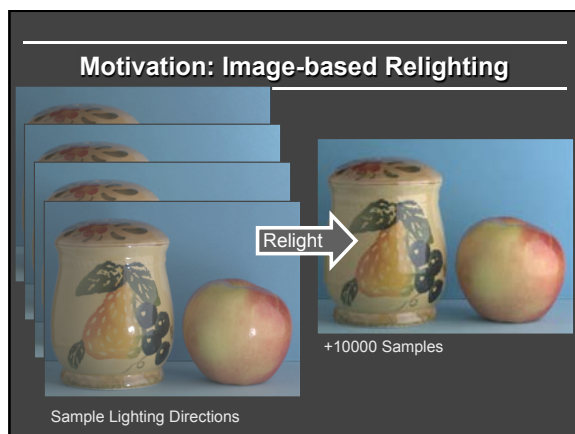
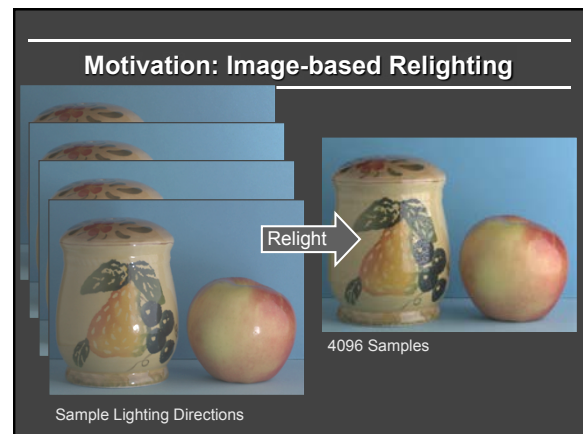
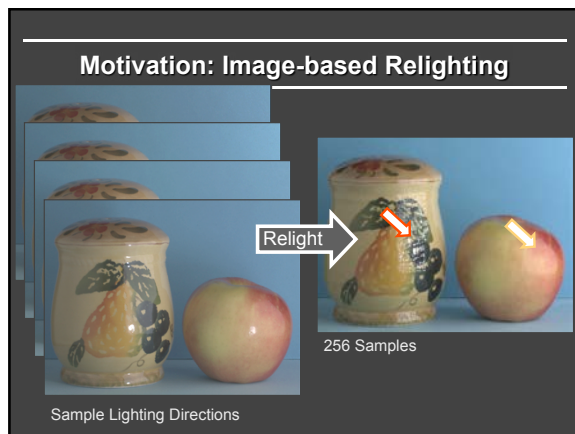
Sample Lighting Directions

## Motivation: Image-based Relighting



Sample Lighting Directions





### Matrix Columns (Images)

$$\begin{bmatrix} T_{11} & T_{12} & \cdots & T_{1M} \\ T_{21} & T_{22} & \cdots & T_{2M} \\ T_{31} & T_{32} & \cdots & T_{3M} \\ \vdots & \vdots & \ddots & \vdots \\ T_{N1} & T_{N2} & \cdots & T_{NM} \end{bmatrix}$$



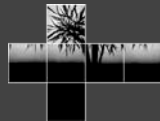
### (Pre)compute: Ray-Trace Image Cols

$$\begin{bmatrix} T_{11} & T_{12} & \cdots & T_{1M} \\ T_{21} & T_{22} & \cdots & T_{2M} \\ T_{31} & T_{32} & \cdots & T_{3M} \\ \vdots & \vdots & \ddots & \vdots \\ T_{N1} & T_{N2} & \cdots & T_{NM} \end{bmatrix}$$



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

$$\begin{bmatrix} T_{11} & T_{12} & \cdots & T_{1M} \\ T_{21} & T_{22} & \cdots & T_{2M} \\ T_{31} & T_{32} & \cdots & T_{3M} \\ \vdots & \vdots & \ddots & \vdots \\ T_{N1} & T_{N2} & \cdots & T_{NM} \end{bmatrix}$$

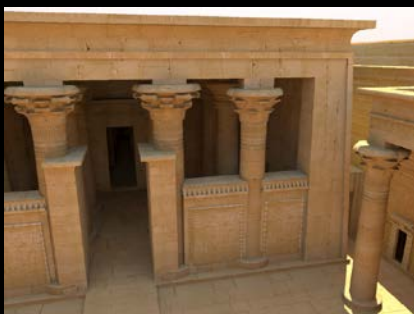


### Outline

- 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



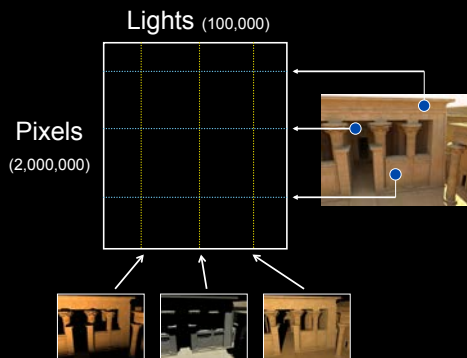
### Conversion to Many Lights

- Area, indirect, sun/sky



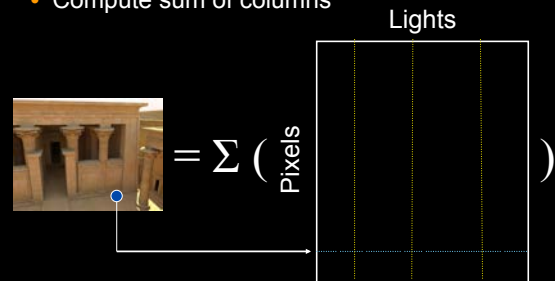
Courtesy Walter et al., Lightcuts, SIGGRAPH 05/06

## A Matrix Interpretation



## Problem Statement

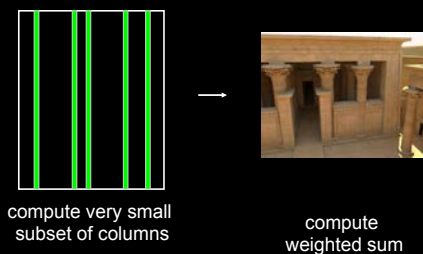
- Compute sum of columns



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

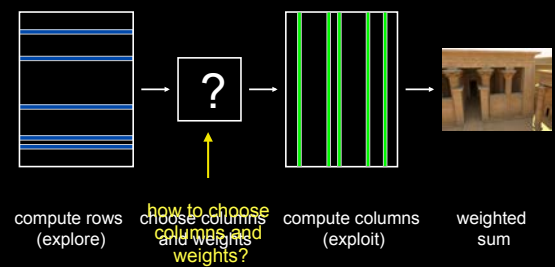
## Image as a Weighted Column Sum

- The following is possible:

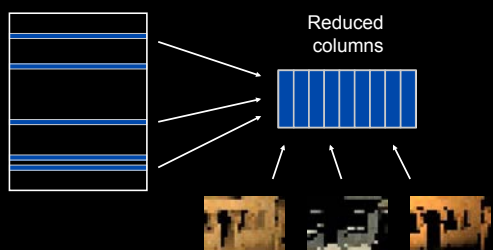


- Use rows to choose a good set of columns!

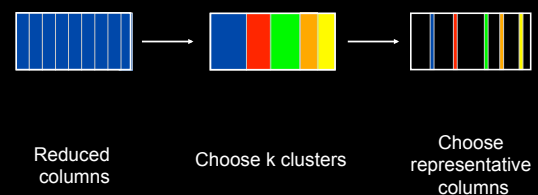
## Exploration and Exploitation



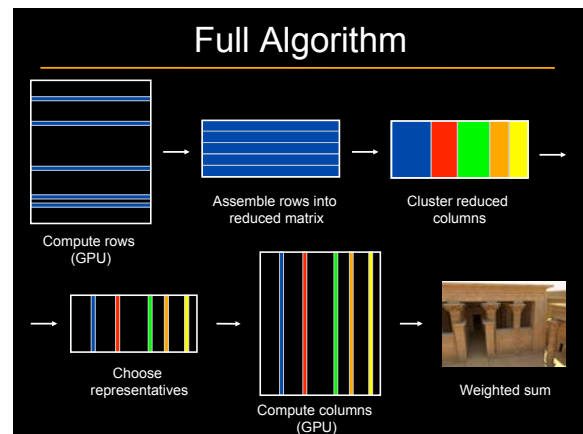
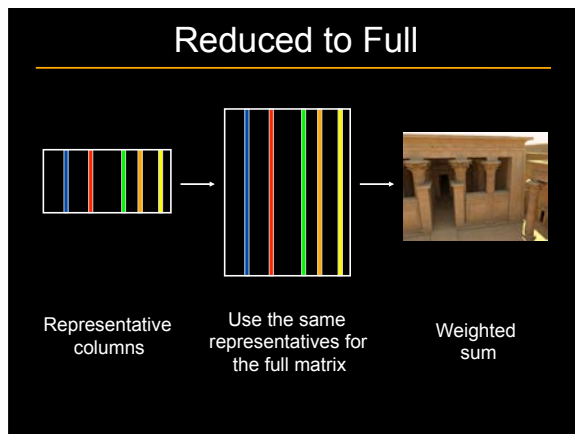
## Reduced Matrix



## Clustering Approach







## Results

- We show 5 scenes:

Kitchen Temple Trees Bunny Grand Central

- Show reference and 5x difference image
- All scenes have 100,000+ lights
- Timings
  - NVidia GeForce 8800 GTX
  - Light / surface sample creation not included

## Results: Kitchen

- 388k polygons
- Mostly indirect illumination
- Glossy surfaces
- Indirect shadows

5x diff

Our result: 13.5 sec  
(432 rows + 864 columns)

Reference: 13 min  
(using all 100k lights)

## Results: Temple

- 2.1m polygons
- Mostly indirect & sky illumination
- Indirect shadows

5x diff

Our result: 16.9 sec  
(300 rows + 900 columns)

Reference: 20 min  
(using all 100k lights)

## Results: Trees

- 328k polygons
- Complex incoherent geometry


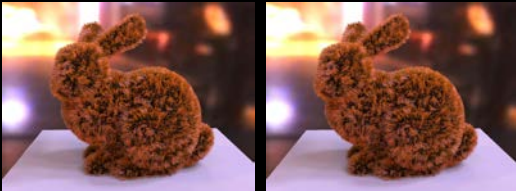
5x diff

Our result: 2.9 sec  
(100 rows + 200 columns)

Reference: 14 min  
(using all 100k lights)

### 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)

### Results: Grand Central

- 1.5m polygons
- Point lights between stone blocks

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

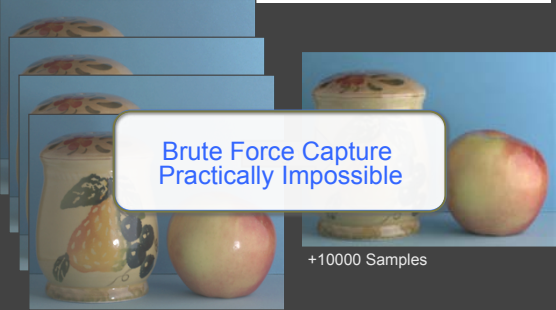
Reference: 44 min  
(using all 100k lights)

### 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

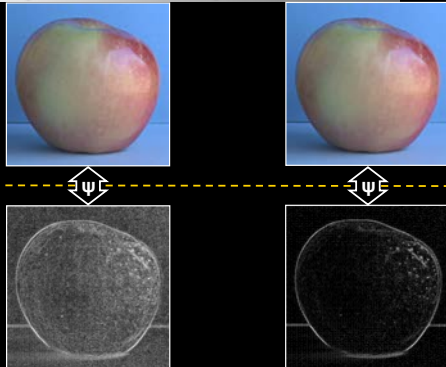


Brute Force Capture  
Practically Impossible

+10000 Samples

Sample Lighting Directions

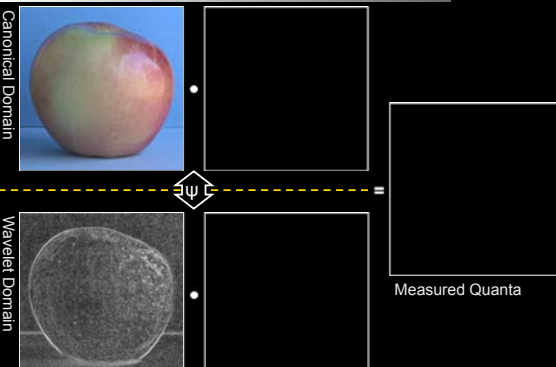
### Compressible / Sparseness



All Coefficients

5% Largest Coeff.

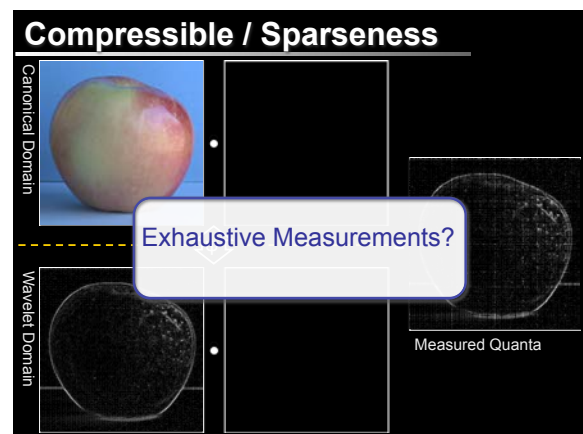
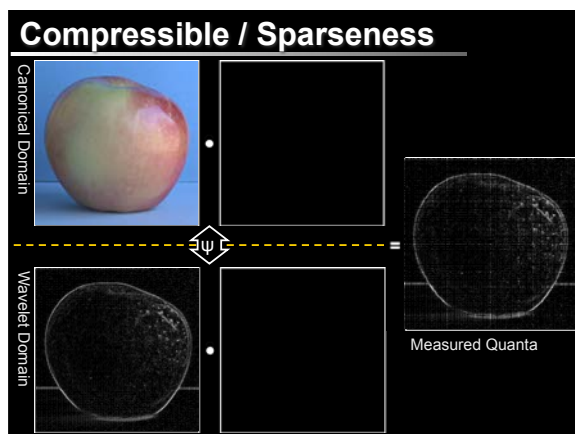
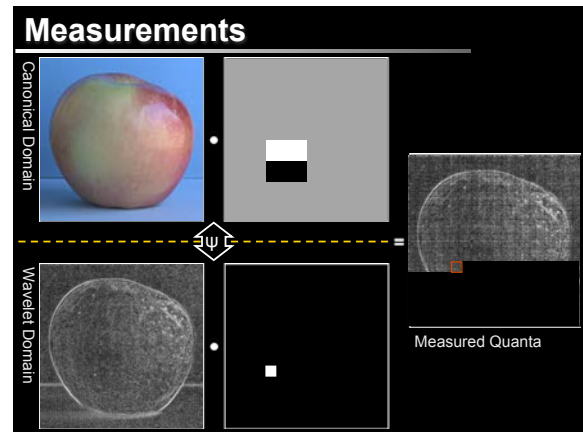
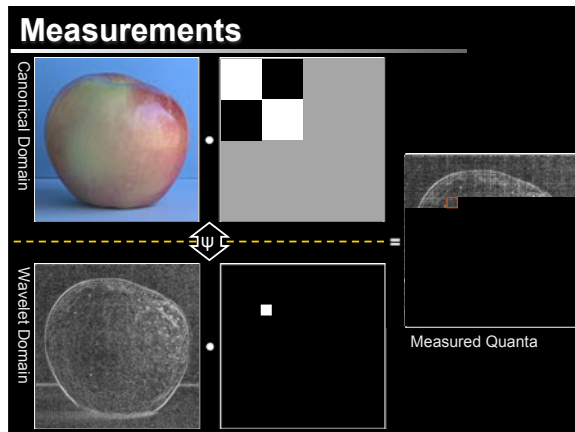
### Measurements



Canonical Domain

Wavelet Domain

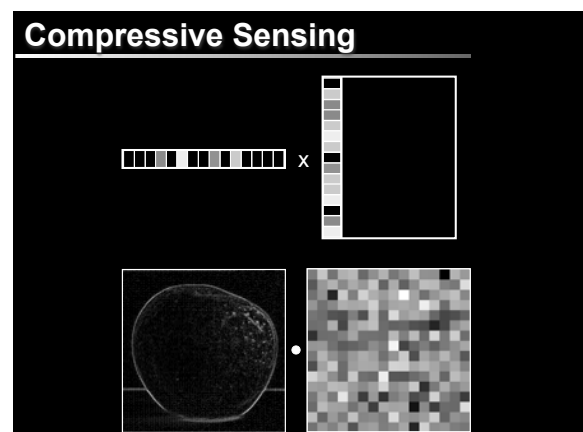
Measured Quanta



### Compressive Sensing: A Brief Introduction

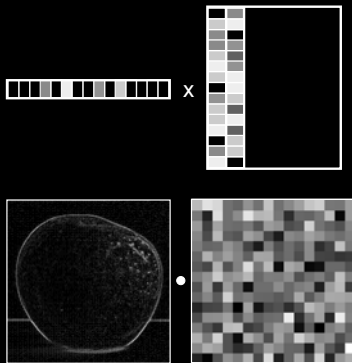
[Candes et al., 06][Donoho, 06]...

- 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**.

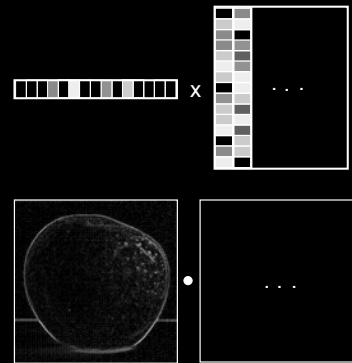
$$A \begin{bmatrix} \text{Measurement Ensemble} \\ m \times n, \text{ where } m < n \end{bmatrix} \begin{bmatrix} \text{Signal} \\ n \times 1 \end{bmatrix} x = \begin{bmatrix} \text{Measurements} \\ m \times 1 \end{bmatrix} b$$




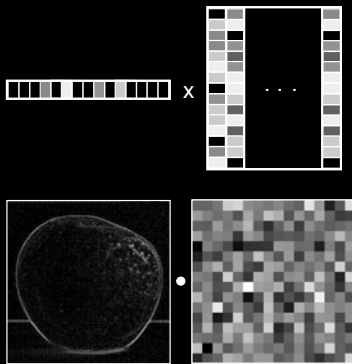
## Compressive Sensing



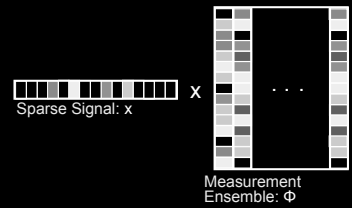
## Compressive Sensing



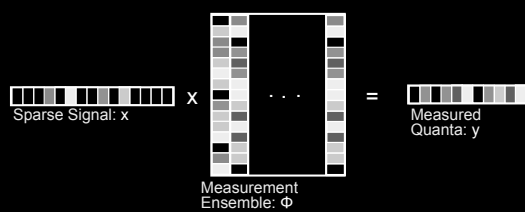
## Compressive Sensing



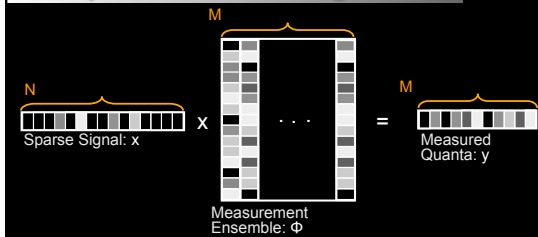
## Compressive Sensing



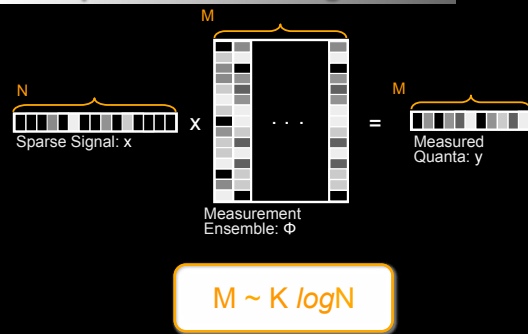
## Compressive Sensing



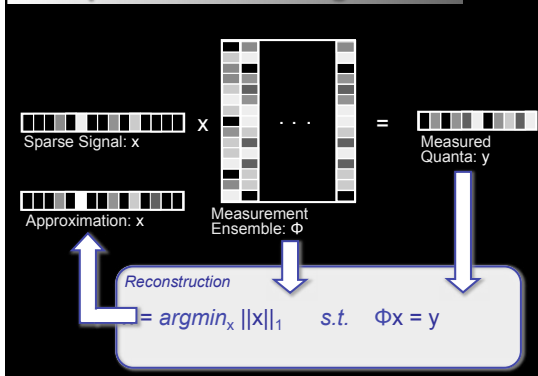
## Compressive Sensing



## Compressive Sensing



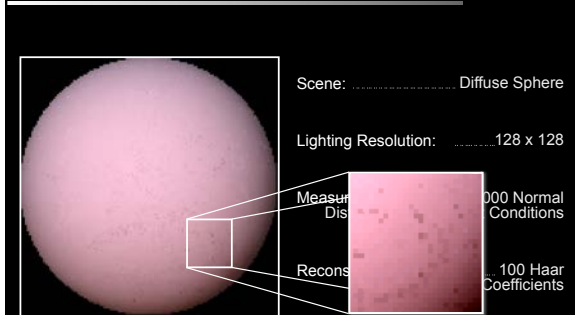
## Compressive Sensing



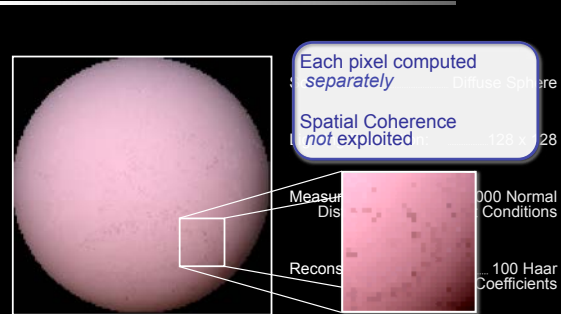
## Brute Force: Result



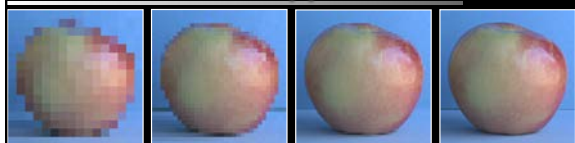
## Brute Force: Result



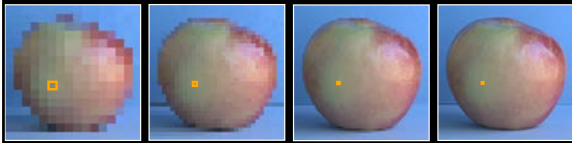
## Brute Force: Result



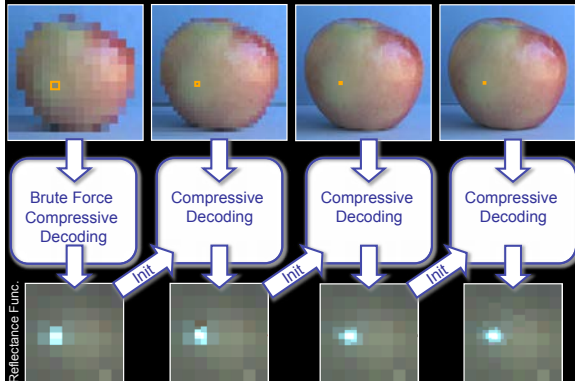
## Multi-resolution Approach



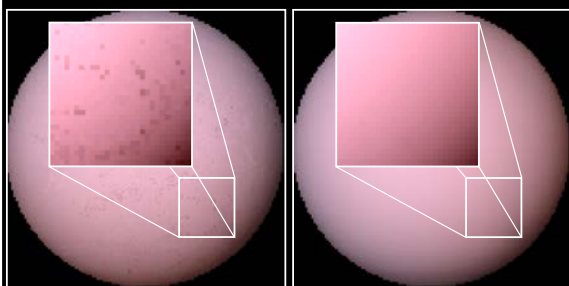
## Multi-resolution Approach



## Multi-resolution Approach



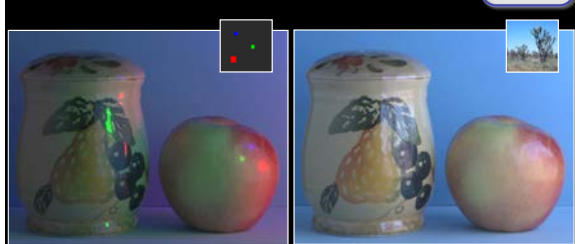
## Results



Brute Force Algorithm

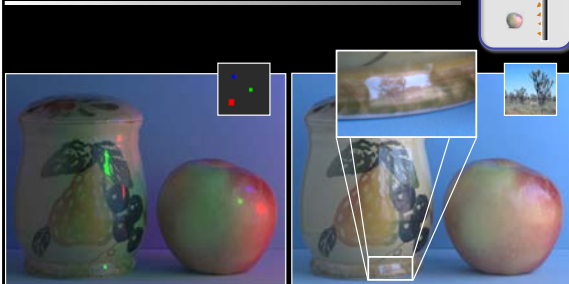
Hierarchical Algorithm

## Resolution



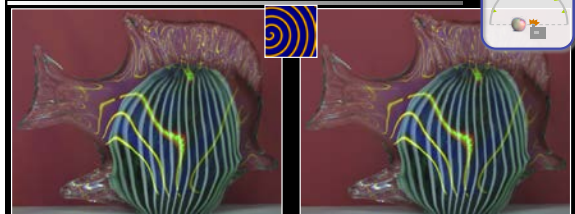
1000 Measurements  
128 x 128 Lighting Resolution  
128 Haar Wavelet Coefficients

## Resolution



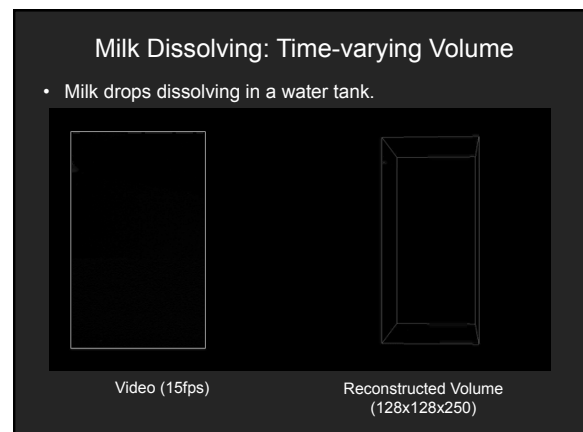
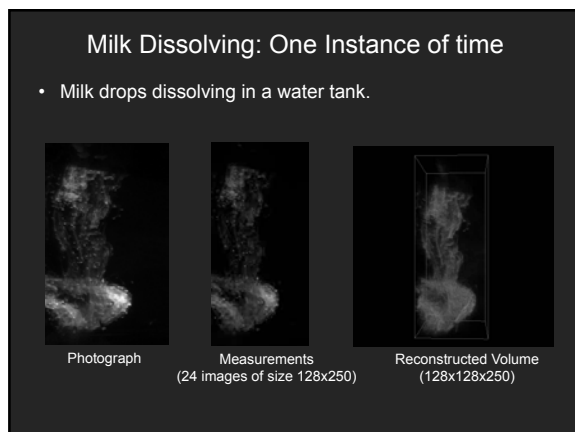
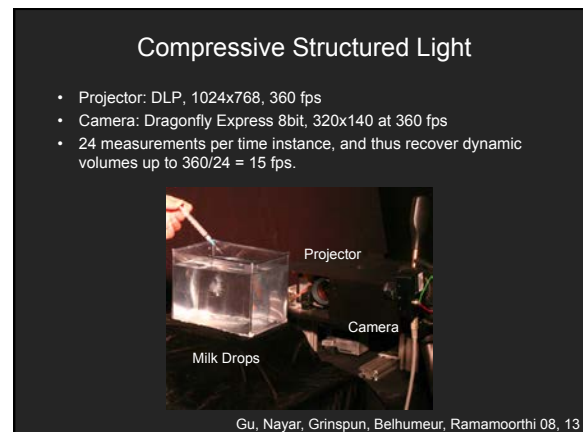
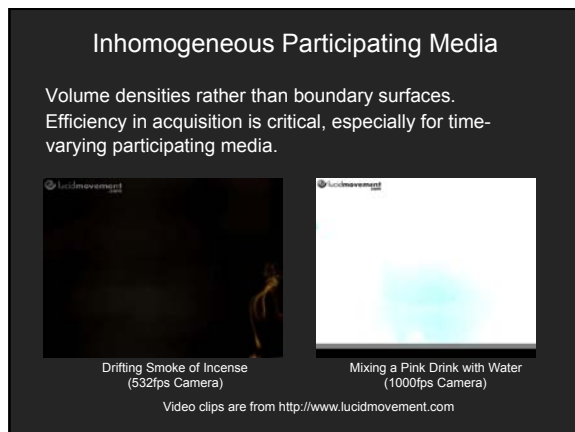
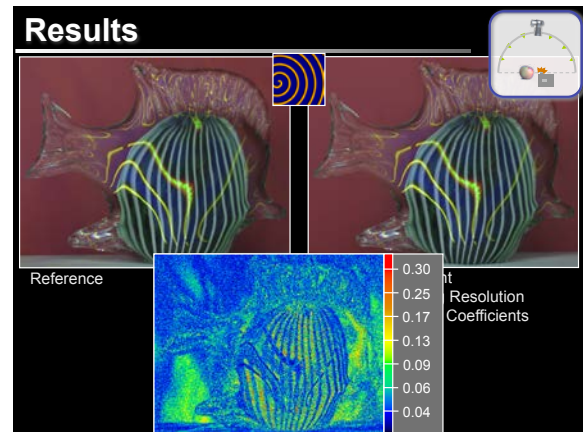
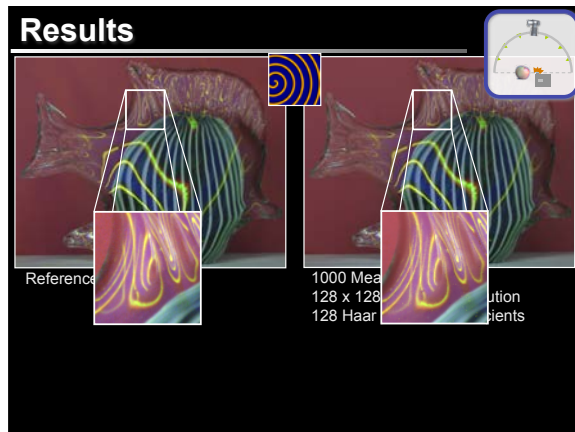
1000 Measurements  
128 x 128 Lighting Resolution  
128 Haar Wavelet Coefficients

## Results



Reference

1000 Measurement  
128 x 128 Lighting Resolution  
128 Haar Wavelet Coefficients



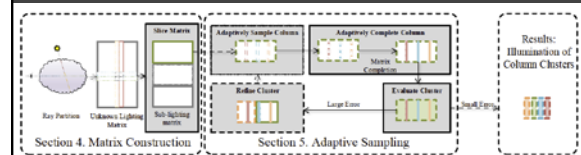
## Outline

- 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

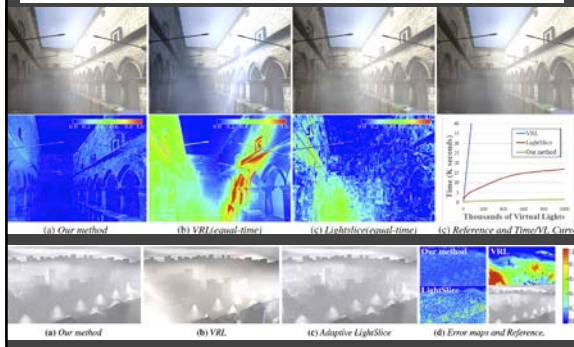
## Outline

- 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