Sampling and Reconstruction of Visual Appearance: From Denoising to View Synthesis

CSE 274 [Fall 2022], Lecture 9
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Applications
- Monte Carlo Rendering
- Light Transport Acquisition / Many Light Rendering
- Light Fields and Computational Photography
- View Synthesis
- Animation/Simulation (not covered in course)

Introduction 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

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Sample Lighting Directions

Relight 16 Samples

Sample Lighting Directions

Relight 256 Samples

Sample Lighting Directions

Relight 256 Samples

Sample Lighting Directions
Motivation: Image-based Relighting

Sample Lighting Directions

Relight

256 Samples

Relight

4096 Samples

Relight

+10000 Samples

Brute Force Capture Practically Impossible

Motivation: Image-based Relighting

Sample Lighting Directions

Relight

+10000 Samples

Relighting as a Matrix-Vector Multiply

Input Lighting (Cubemap Vector)

Output Image (Pixel Vector)

Precomputed Transport Matrix
Outline

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

Complex Illumination: A Challenge

Conversion to Many Lights

- Area, indirect, sun/sky
A Matrix Interpretation

Problem Statement

Pixels (2,000,000)

Lights (100,000)

- 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

- Compute rows (explore)
- How to choose columns and weights?
- Compute columns (exploit)
- Weighted sum

Reduced Matrix

Clustering Approach

Choose k clusters

Choose representative columns
### Reduced to Full

- **Representative columns**
- Use the same representatives for the full matrix
- **Weighted sum**

### Full Algorithm

1. **Compute rows (GPU)**
2. Assemble rows into reduced matrix
3. Cluster reduced columns
4. **Choose representatives**
5. **Compute columns (GPU)**
6. **Weighted sum**

### 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

- **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

- **Our result:** 16.9 sec (300 rows + 900 columns)
- **Reference:** 20 min (using all 100k lights)

### Results: Trees

- 328k polygons
- Complex incoherent geometry

- **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

Motivation: Image-based Relighting

Compressible / Sparseness

Measurements

Brute Force Capture Practically Impossible
+10000 Samples
Sample Lighting Directions
Compressive Sensing: A Brief Introduction

- **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.

\[
\begin{bmatrix}
A \\
\end{bmatrix}
\begin{bmatrix}
x \\
\end{bmatrix} = 
\begin{bmatrix}
b \\
\end{bmatrix}
\]

- Measurement Ensemble \( m \times n \), where \( m < n \)
- Signal \( n \times 1 \)
- Measurements \( m \times 1 \)
Compressive Sensing

Measurement Ensemble: $\Phi$

Sparse Signal: $x$

$N$

$M$

$y$

Compressive Sensing

Measurement Ensemble: $\Phi$

Sparse Signal: $x$

$y$

Compressive Sensing

Measurement Ensemble: $\Phi$

Sparse Signal: $x$

$y$

Compressive Sensing

Measurement Ensemble: $\Phi$

Sparse Signal: $x$

$y$
Compressive Sensing

\[ x = \text{argmin}_x \|x\|_1 \text{ s.t. } \Phi x = y \]

\[ M \sim K \log N \]

Brute Force: Result

Scene: Diffuse Sphere
Lighting Resolution: 128 x 128
Measurements: 1000 Normal Distributed Noise Light Conditions
Reconstruction: 100 Haar Wavelet Coefficients

Brute Force: Result

Scene: Diffuse Sphere
Lighting Resolution: 128 x 128
Measurements: 100 Normal Conditions
Reconstruction: 100 Haar Wavelet Coefficients

Multi-resolution Approach

Each pixel computed separately
Spatial Coherence not exploited
Inhomogeneous Participating Media
Volume densities rather than boundary surfaces. Efficiency in acquisition is critical, especially for time-varying participating media.

Drifting Smoke of Incense (532nm Camera)  
Mixing a Pink Drink with Water (1000fps Camera)

Video clips are from http://www.lucidmovement.com

Compressive Structured Light
- Projector: DLP, 1024x768, 360 fps
- Camera: Dragonfly Express 8bit, 320x140 at 360 fps
- 24 measurements per time instance, and thus recover dynamic volumes up to 360/24 = 15 fps
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

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Results (Participating Media)

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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
- Think about modern extensions with deep learning