Sampling and Reconstruction of Visual Appearance

CSE 274 [Winter 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

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

Resurgence (2008 - )

- Eurographics 2015 STAR report by Zwicker et al. [former UCSD faculty]

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

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

Adaptive Wavelet Rendering

Overbeck et al 09

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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NO AUDIO

Recurrent Autoencoder Video (Chaitanya et al. 17)
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Motivation: Image-based Relighting

Sample Lighting Directions

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Motivation: Image-based Relighting

Sample Lighting Directions

Relight

16 Samples

Relight

64 Samples

Relight

256 Samples

Relight

256 Samples
Motivation: Image-based Relighting

Sample Lighting Directions

Relight

4096 Samples

Motivation: Image-based Relighting

Sample Lighting Directions

Relight

+10000 Samples

Motivation: Image-based Relighting

Sample Lighting Directions

Brute Force Capture Practically Impossible

+10000 Samples

Compressible / Sparseness

AI Coefficients

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Measurements

Canonical Domain

Measured Quanta

Wavelet Domain

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Measurements

Canonical Domain

Measure Quanta

Wavelet Domain

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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.

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

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

Results

Reference 1000 Measurement
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Light Field Rendering

Marc Levoy    Pat Hanrahan

Computer Science Department
Stanford University

Apple’s QuickTime VR

Outward    Inward
Generating New Views

Problem: fixed vantage point/center
One Solution: view interpolation
- Interpolating between range images (Chen and Willsky, 1993)
- Correspondences and epipole analysis (McMillan and Bishop, 1995)
  > Requires depths or correspondences
  must be extracted from acquired imagery
  relatively expensive and error-prone method

Light Fields

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

- 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

A degree-of-freedom gantry

Light Field as a 2D Array of Images

Camera Array

\[ L(r) = L(u, v, s, t) \]
Dual Interpretation of Light Field

Light fields

Resolution trade-off

Solution: angular super-resolution

Compression Example

Consumer light field cameras

Limited resolution
High angular
Low spatial

Kalantari et al.
**Straightforward solution**

- Model the process with a single CNN

**Single CNN’s result**

**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

**Our result**

**4D RGBD Light Fields from 2D Image**

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

**Light field video**

Lytro illum (3 fps video)
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.