Sampling and Reconstruction of Visual Appearance
CSE 274 [Winter 2018], Lecture 1
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Motivation: High-Dim. Appearance
Appearance in vision/graphics involves high-dimensional data
- (Precomputed) Real-Time Rendering: Light transport matrix stores variation across surface, light, view (4D-6D)
- Monte Carlo Rendering: Need to sample across time, light source, depth of field for each pixel (3D-7D)
- Appearance Acquisition: Acquire reflectance functions and light transport (4D-8D)
- Computer Vision: Effect of lighting on images (4D)
Consider real-time rendering (6D): With ~100 samples/dimension ~ 10^12 samples total!!: Intractable computation, rendering

Fast Motion Blur Rendering (3D)
Garfield: A Tail of Two Kitties
Rhythm & Hues Studios
Twentieth Century-Fox Film Corporation

Precomputed Real-Time Rendering (6D)
Ng, Ramamoorthi, Hanrahan 03,04

Real-Time Global Illumination (4D)
Interactive Physically-Based Indirect Illumination Using Axis-Aligned Filtering

Data-Driven Appearance Models (6D)
Lawrence et al. 06
Many problems in graphics, vision are hard to solve directly
- **Visual appearance** is high-dimensional
- High sampling rate, computational cost
- Often prohibitive to even sample before compression

Mathematical and signal-processing approach
- Treat illumination and reflection functions as signals
- Exploit “sparsity” for acquisition of light transport and appearance
- Reduces to efficient **sampling and high quality reconstruction**

Large range of applications in graphics, vision
- Monte Carlo Rendering (order-of-mag. advances classical problem)
- Appearance Acquisition and Editing
- Imaging and Computational Photography
- Precomputed Renderings, Physics-Based Vision, Animation, …

Much recent work (esp at UCSD): CSE 274 Topics in Graphics: Sampling and Reconstruction of Visual Appearance
(My lens on) History

- Data-Driven Visual Appearance [-1993 - ]
  - Image-Based Rendering
  - Sampled Representations (in many areas)
  - Even for synthetic relighting [Nimeroff 94, Sloan 02]

Types of Measured Visual Appearance

- Lighting: From point lights to environment maps and beyond
  - Grace Cathedral and Kitchen light probes
  - Courtesy Paul Debevec www.debevec.org
- BRDFs: From Lambertian/Cook Torrance to measured/factored

Types of Measured Visual Appearance

- "Reflectance Fields": Variation with lighting and/or view
- Subsurface and Volumetric Scattering
- Time-Varying Surface Appearance
- BTFs or Bi-Directional Texture Functions
- And many more (full taxonomy next)

General Plenoptic Function

- All knowledge of light in scene [Adelson 91]
- Anywhere in space \((x, y, z)\)
- In any direction \((\theta, \phi)\)
- At any time instant \((t)\)
- For any wavelength of light \((\lambda)\)
- Function of 7 variables, therefore 7D function

We care about taxonomy of scattering functions

- General Scattering Function is 14D (bet. two plenoptics)
- \(f(x, y, \tau, \theta, \phi, \lambda, t_i; x, y, \tau, \theta, \phi, \lambda, t_o)\)

Time-Varying Appearance: Video

Common Assumptions

- Ignore time dependence (no phosphorescence or time-varying BRDF properties)
- Ignore wavelength (no fluorescence, assume RGB)
- Travel in free space, parameterize on surfaces (no \(z\))
  - Alternative for light fields: 4D space of rays (intersections in 2 planes)
- Each of these removes 1D of plenoptic, 2D of scattering
- Left with 8D function of greatest importance for class
- 8D Bi-Directional Surface Scattering Distribution Function (BSSRDF)
  \(f(x, y, \tau, \theta, \phi; x, y, \tau, \theta, \phi)\)
**Taxonomy of Appearance**

- General scattering function
- Bi-directional scattering
- Surface reflectance distribution function
- Surface light field
- Triple product integral relighting

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**Factorization Approach**

\[ 6D \text{ Transport} \approx 10^{12} \text{ samples} \]

\[ \approx 10^8 \text{ samples} \times \approx 10^8 \text{ samples} \]

- 4D Visibility
- 4D BRDF

Ng, Ramamoorthi, Hanrahan 04

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**Triple Product Integral Relighting**

Relit Images (3-5 sec/frame)

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**My lens on) History**

- Data-Driven Visual Appearance [~1993 - ]
  - Image-Based Rendering
  - Sampled Representations (in many areas)
  - Even for synthetic relighting [Nimeroff 94, Sloan 02]
- Mathematical and Computational Fundamentals [~2000 - ] (my term, topic of my Career Award)
  - Lower-Dimensional Factorizations [e.g. 6D -> 4D]
  - Efficient Mathematical Representations [spherical harmonics, wavelets, radial basis functions]
  - New Computational Methods [analytic formulae, convolution, triple products, Nystrom, …]

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**My lens on) History and Future**

- Data-Driven Visual Appearance [~1993 - ]
  - Sampled representations and real-world data
  - How do we make the data practical and usable?
- Mathematical and Computational Fundamentals [~2000 - ] (my term, topic of my Career Award)
  - Lower-Dimensional Factorizations [e.g. 6D -> 4D]
  - Data still is acquired or precomputed by brute force
- Sampling Theory of Appearance [~2007 - ]
  - How many samples do we need for final representation?
  - Theory and efficient acquisition/computation strategies
  - Really a core signal-processing problem (Chai et al 00)
  - Newest approaches based on machine learning
  - Sampling and Reconstruction of Visual Appearance
Applications and Context

- Monte Carlo global illumination rendering (CSE 168)
  - Main application area discussed in course.
  - Often perceived as mature: "rendering is a solved problem"
  - But not widely used in production rendering until 2011

- Production Rendering is now Physically-Based
  - Sea change since 2011. Ad-hoc methods gone. MC used.
  - Sampling and Reconstruction (denoising) is key
  - Leads to 1-2 order of magnitude speedup in mature area
  - Essential part of today's production renderers (since ~2014)

Applications and Context

- Fast enough for real-time rendering
  - Sample and reconstruct for real-time started ~2012
  - Latest papers machine learning + 1 sample per pixel

- Fast precomputation of light transport matrices
  - Precomputed rendering widely used in games etc.

- Sparse acquisition of light transport

- Light field imaging, interpolation

Multiple Effects in Real Time

Multiple Axis-Linked Filters for Rendering of Combined Distribution Effects

Lili Wu, Ling-Oi Yen, Alexandre Kuznetsov, Ravi Ramamoorthi

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

NO AUDIO

Resolution trade-off

Limited resolution
High angular
Low spatial

Solution: Angular super-resolution
Kalantari et al.

Relation to Signal Processing, Learning

- Signal processing itself undergoing revolution
  - From Nyquist to compressive to sparse low rank
  - Will cover these topics briefly where relevant
  - Exciting time to work in this area
  - *Unified Sampling Theory of Appearance?*
- Newest advances in machine learning
  - Deep Convolutional Neural Networks (CNNs)
  - Introduced for computer vision but many exciting applications for image synthesis
  - Latest denoising methods leverage CNNs
- This is a graphics course, but we will touch on above methods as needed. Exciting convergence.

Outline of Lecture

- Motivation, sampling and reconstruction visual appearance
- Historical Development and Overview of Applications
- *Logistics of course*

Course Goals, Format

- Goal: Background and current graphics research
  - Topic: Sampling and Reconstruction of Visual Appearance
  - Need to cover a lot of background research papers
  - Then discuss current frontiers in the field
- UCSD is the best place for this!!
- Format: Alternate lectures, student presentations of papers
- Website: [http://www.cs.ucsd.edu/~ravir/274/18/274.html](http://www.cs.ucsd.edu/~ravir/274/18/274.html)

Course Logistics

- No textbooks. Required readings are papers available online (and some handouts for books)
  - Handouts at [http://www.cs.ucsd.edu/~ravir/274/18/readings](http://www.cs.ucsd.edu/~ravir/274/18/readings)
- Office hours: after class or email. My contact info is on my webpage: [http://www.cs.ucsd.edu/~ravir](http://www.cs.ucsd.edu/~ravir)
- Should count for PhD, MS, BS electives in graphics and vision, see me if there is a problem or you need a certification

Requirements

- **Pass-Fail (2 units)**
  - Show up to class regularly
  - Present 1 or 2 paper(s) if needed
  - Prefer you do this rather than just sit in
- **Grades (4 units)**
  - Attend class, participate in discussions
  - Present 1 or 2 papers (please do this well)
  - Project (key part of grade)
**Project**

- Wide flexibility if related to course. Can be done groups of 2
  - Default: Implement (part of) one of papers and produce an impressive demo for real-time or offline rendering
  - See/e-mail me re ideas
  - Best projects will go beyond simple implementation (try something new, some extensions)

- Alternative (less desirable): Summary of 3+ papers in an area
  - Best projects will explore links/framework not discussed by authors, and suggest future research directions

**Prerequisites**

- Strong interest in graphics, rendering
- Computer graphics experience (167 or equivalent)
- What if lacking prerequisites? Next slide
- Experience with rendering (CSE 168) not required
- Course will move quickly
  - Covering recent and current active research
  - Some material quite technical
  - Considerable background material is covered
  - Assume some basic knowledge
  - Many topics. Needn’t fully follow each one, but doing so will be most rewarding.

**If in doubt/Lack prerequisites**

- Material is deep, not broad
  - May be able to pick up background quickly
  - Course requirements need you to really fully understand only one/two areas (topics)
  - But if completely lost, won’t be much fun

- If in doubt, see if you can more or less follow some of papers after background reading

- Ultimately, your call

**Assignment this week**

- E-mail me (ravir@cs.ucsd.edu)
  - Name, e-mail, status (Senior, PhD etc.)
  - Will you be taking course grades or P/F
  - Background in graphics/any special comments
  - Optional: Papers you’d like to present FCFS (only those that say “presented by students”)
  - Paper presenters for [first set of papers]

**Questions?**