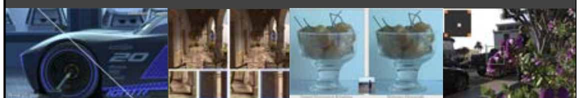
Sampling and Reconstruction of Visual Appearance

CSE 274 [Fall 2018], Lecture 1

Ravi Ramamoorthi

http://www.cs.ucsd.edu/~ravir



Motivation: High-Dim. Appearance

Appearance in vision/graphics involves high-dimensional data

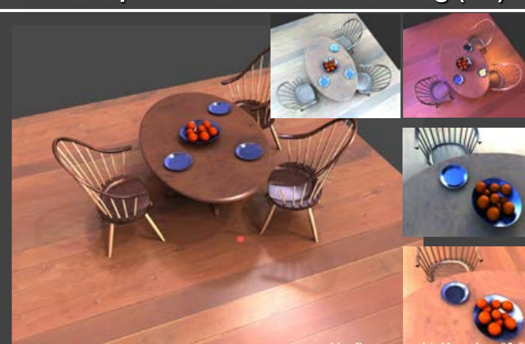
- **(Precomputed) Real-Time Rendering:** Light transport matrix stores variation across surface, light, view (4D-6D)
- **Monte Carlo Rendering:** Need to sample across time, light source, depth of field for each pixel (3D-7D)
- **Appearance Acquisition:** Acquire reflectance functions and light transport (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)



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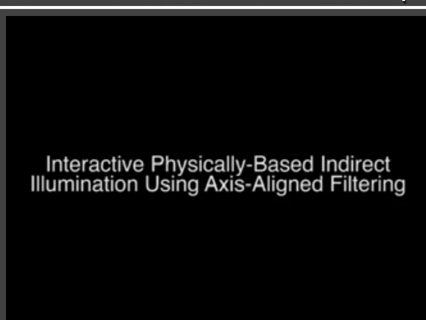
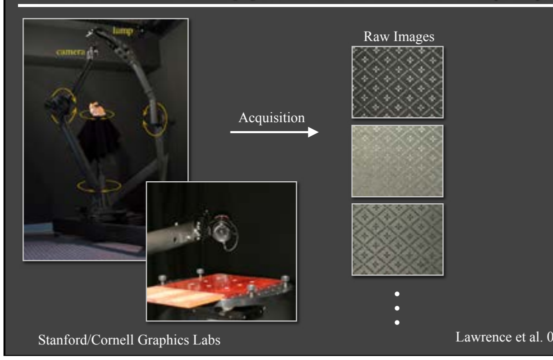
Real-Time Global Illumination (4D)



[Mehta, Wang, Ramamoorthi, Durand13]

Data-Driven Appearance Models (6D)



Stanford/Cornell Graphics Labs

Lawrence et al. 06

Volumetric Materials (Gigavoxels)

[Hasan and Ramamoorthi 13]

Lighting-Insensitive Recognition

Illuminate subject from many incident directions
Understand space of images as lighting is varied
Low Dimensional Subspace [Ramamoorthi 02]

Debevec *et al.* 00

Sparse Sampling, Reconstruction

- Same algorithm as offline Monte Carlo rendering
- But with smart sampling and filtering (current work)

Sparse Sampling, Reconstruction

Overview

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 Rendering, Physics-Based Vision, Animation, …

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

Outline of Lecture

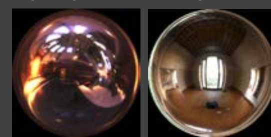
- Motivation, sampling and reconstruction visual appearance
- *Historical Development and Overview of Applications*
- Logistics of course

(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]

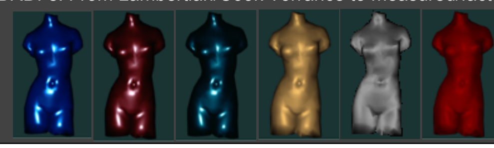
Types of Measured Visual Appearance

- Lighting: From point lights to environment maps and beyond



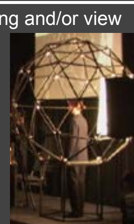
Grace Cathedral and Kitchen light probes
Courtesy Paul Debevec www.debevec.org

- 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)



Time-Varying Appearance: Video

General Plenoptic Function

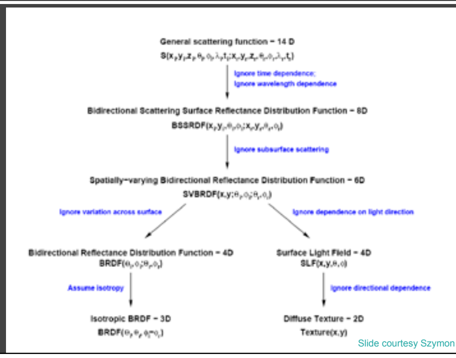
- All knowledge of light in scene [Adelson 91]
- Anywhere in space (x, y, z)
- In any direction (θ, ϕ)
- At any time instant (t)
- For any wavelength of light (λ)
- Function of 7 variables, therefore 7D function
- We care about taxonomy of *scattering functions*
  - *General Scattering Function is 14D (bet. two plenoptics)*

$$f(x_i, y_i, z_i, \theta_i, \phi_i, \lambda_i, t_i \,;\, x_o, y_o, z_o, \theta_o, \phi_o, \lambda_o, t_o)$$

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) $f(x_i, y_i, \theta_i, \phi_i ; x_o, y_o, \theta_o, \phi_o)$

Taxonomy of Appearance

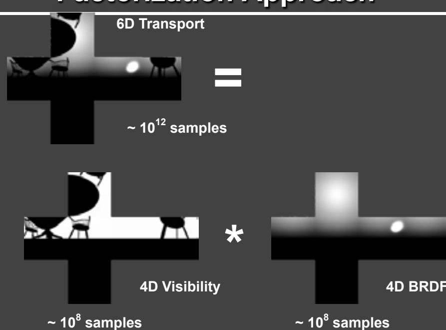


Slide courtesy Szymon Rusinkiewicz

(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, …]

Factorization Approach



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Triple Product Integral Relighting

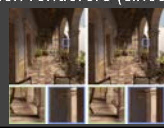
Relit Images (3-5 sec/frame)

(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 (old CSE168)
  - 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)*



Fast Sheared Filtering

Multiple Effects in Real Time

Multiple Axis-Aligned Filters for Rendering of Combined Distribution Effects

Lifan Wu[1] Ling-Qi Yan[2] Alexandr Kuznetsov[1] Ravi Ramamoorthi[1]

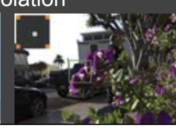
[1]University of California, San Diego [2]University of California, Berkeley

NO AUDIO

Recent commercial product release: NVIDIA Optix 5 with denoising: https://www.youtube.com/watch?v=l-5NVNgT70U

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
  - Video ; TuringRT 10G rays/second: Video
- Fast precomputation of light transport matrices
  - Precomputed rendering widely used in games etc.
- Sparse acquisition of Light Transport
- Light Field Imaging, Interpolation

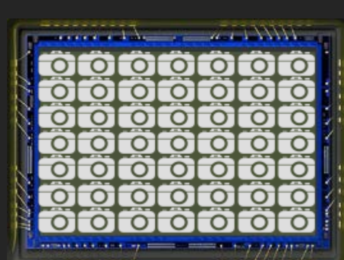


Resolution trade-off

Limited resolution

High angular

Low spatial

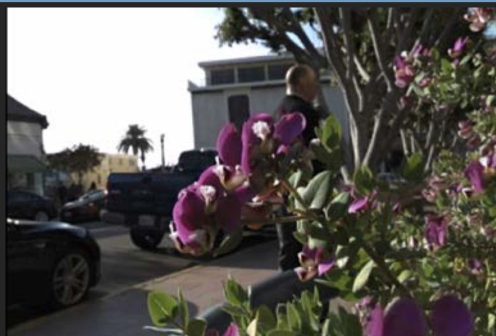


UC San Diego Kalantari et al.

Solution: angular super-resolution

UC San Diego Kalantari et al.

Our result



UC San Diego 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
  - *Convergence real-time, offline rendering, machine learning*
- 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
- Also basics of rendering to cover for CSE 168
- UCSD is the best place for this!!
- Format: Alternate lectures, student presentations of papers
- Website: http://viscomp.ucsd.edu/classes/cse274/fa18/274.html

Course Logistics

- No textbooks. Required readings are papers available online (and some handouts for books)
  - Handouts at http://viscomp.ucsd.edu/classes/cse274/fa18/readings
- Office hours: after class or email. My contact info is on my webpage: http://www.cs.ucsd.edu/~ravir
- TA: Jiyang Yu (jiy173@eng.ucsd.edu) Office hours in CSE 4150 from W 11-12pm or email for another time.
- 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)
  - If class is large, groups of 2 can present 1 paper
  - 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 not required; first few weeks will cover basic background (CSE 168)
- 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/Llack 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")

Questions?