Theory and Methods of Radiance Photography

Todor Georgiev
Adobe Systems
tgeorgie@adobe.com

Andrew Lumsdaine
Indiana University
lums@cs.indiana.edu

Abstract

Computational photography is based on capturing and processing discrete representations of all the light rays in the 3D space. Compared to conventional photography, which captures 2D images, computational photography captures the entire 4D "lightfield", i.e., the full 4D radiance. To multiplex the 4D radiance onto conventional 2D sensors, light-field photography demands sophisticated optics and imaging technology. At the same time, 2D image creation is based on creating 2D projections of the 4D radiance.

This tutorial presents light-field analysis in a rigorous mathematical way, which often leads to surprisingly direct solutions. The mathematical foundations will be used to develop computational methods for lightfield processing and image rendering, including digital refocusing and perspective viewing. While emphasizing theoretical understanding, we also explain practical approaches and engineering solutions.

As part of the course, we will demonstrate a number of working light-field cameras that implement different methods for radiance capture, including the microlens approach of Lippmann and the plenoptic camera; the MERL mask enhanced camera; the Adobe lens-prism camera; and a new camera using a "mosquito net" mask. Various computational techniques for digital refocusing and rendering will also be presented, including Ng's Fourier slice algorithm and the MERL heterodyned light-field approach. We demonstrate rendering the lightfield at full resolution.

Tutorial Syllabus

Background and Motivation

In the 170 year history of photography, photographers have inevitably wanted to edit their pictures after they have been taken. With the introduction of digital imaging and programs such as Photoshop, pixel-level corrections to images have become routine. However, traditional photographs are completely rendered when they are captured, in the sense that parameters like camera viewpoint and focus are fixed. As a result, there are limits to the manipulations that even the most sophisticated image processing programs can apply. By capturing the four-dimensional radiance in a scene, rather than a fixed photograph, image rendering can be deferred until the editing process, making a richer variety of image processing possible.

Radiance Theory and Modeling

The theory and practice of radiance photography requires a precise mathematical model of the radiance function and of the basic transformations that can be applied to it. This portion of the tutorial will cover:

- Physics of radiance
- Mathematical models and parameterizations
  - two plane
  - spatio-angular
  - others
- Transformations
  - translation in space
  - thin lens
- Conservation principles
- Matrix optics
- Traditional 2D photography from the radiance perspective

Capturing Radiance with Radiance Cameras

Radiance photography requires recording the optical description of a scene as a 4D radiance function. This portion of the tutorial will cover how conventional 2D sensor technologies are used to capture the 4D radiance in a scene. Specific topics include:

- Capturing radiance: Taking a "fingerprint of light"
- Sensor technology: Creating a 2D flat representation (image) of the 4D radiance function
- Lens and camera systems
  - Camera
  - "2F"
  - Traditional 2D systems from the radiance camera perspective
- Particular camera systems
  - Ives' camera
  - Lippmann's camera
- Apertures and focusing
  - Low and fixed F/Number
  - Fixed focusing parameter (no focusing needed during capture)

Hands-On with Radiance Cameras

A number of different working radiance cameras will be demonstrated and different particular approaches to radiance capture will be highlighted. Tutorial participants will have hands-on with the following radiance cameras:

- Microlens approach of Lippmann (showing working microlens arrays)
- Plenoptic camera (demonstrating plenoptic camera in action)
- MERL mask enhanced cameras (showing masks and coding approaches)
- Adobe lens-prism camera (showing the lenses)
- "Mosquito net" mask camera

Computation with Radiance

Radiance photography has been made practical by the availability of computational techniques that can perform 2D image rendering from the 4D radiance function. The following computational issues will be discussed during this portion of the tutorial:

- Sensors, pixels, digital image representations
- Image rendering
- Space multiplexing
- Frequency multiplexing ("heterodyning")
- New capabilities

Fourier Slice Refocusing

As a particular case of a radiance-based algorithm, we will study the Fourier slice refocusing algorithm of Ng.

- Fourier representation of 4D radiance function
- Rendering
- Fourier slice algorithm
- Editing and displays of the images

Conclusion

Reading list / Bibliography

About the Presenters

Todor Georgiev is a researcher at Adobe Systems, working closely with the Photoshop group. Having extensive background in theoretical physics, he concentrates on applications of mathematical methods taken from physics to image processing, graphics, and vision. He is the author of the Healing Brush tool in Photoshop (2002), the method better known as Poisson image editing. He has published several articles on applications of the mathematics of covariant derivatives in image processing and vision. He is working on a wide range of theoretical and practical ideas in optics, light field cameras and capture/manipulations of the optical field. His recent work concentrates on radiance camera designs. He has a number of papers and patents in these and related areas.

Andrew Lumsdaine received the PhD degree in electrical engineering and computer science from the Massachusetts Institute of Technology in 1992. He is presently a professor of computer science at Indiana University, where he is also the director of the Open Systems Laboratory. His research interests include computational science and engineering, parallel and distributed computing, mathematical software, numerical analysis, and radiance photography. He is a member of the IEEE, the IEEE Computer Society, the ACM, and SIAM.