





## 15-463 (15-862): Computational Photography

[Computer Science Department](#)  
[Carnegie Mellon University](#)

**INSTRUCTOR:** [Alexei \(Alyosha\) Efros](#) (Office hours: Thursdays 2:30-3:30, NSH 4207)

**TA:** [Jim McCann](#) (Office hours: Tuesdays 5-6, NSH 4228)

**UNIVERSITY UNITS:** 12

**SEMESTER:** Fall 2007

**NEWSGROUP:** [cmu.cs.class.cs463](#) (read this for important information!)

**WEB PAGE:** <http://graphics.cs.cmu.edu/courses/15-463/>

**LOCATION:** WeH 5312

**TIME:** T R 12:00–1:20 PM

### COURSE OVERVIEW:

Computational Photography is an emerging new field created by the convergence of computer graphics, computer vision and photography. Its role is to overcome the limitations of the traditional camera by using computational techniques to produce a richer, more vivid, perhaps more perceptually meaningful representation of our visual world.

The aim of this advanced undergraduate course is to study ways in which samples from the real world (images and video) can be used to generate compelling computer graphics imagery. We will learn how to acquire, represent, and render scenes from digitized photographs. Several popular image-based algorithms will be presented, with an emphasis on using these techniques to build practical systems. This hands-on emphasis will be reflected in the programming assignments, in which students will have the opportunity to acquire their own images of indoor and outdoor scenes and develop the image analysis and synthesis tools needed to render and view the scenes on the computer.

### TOPICS TO BE COVERED:

- Cameras, Image Formation
- Visual Perception
- Image and Video Processing (filtering, anti-aliasing, pyramids)
- Image Manipulation (warping, morphing, mosaicing, matting, compositing)
- Modeling and Synthesis using Lots of Data
- High Dynamic Range Imaging and Tone Mapping
- Image-Based Lighting
- Image-Based Rendering
- Non-photorealistic Rendering

### PREREQUISITES:

Programming experience and familiarity with linear algebra and calculus is assumed. Some background in computer graphics, computer vision, or image processing is helpful. This class does not significantly overlap with 15-462 and can be taken concurrently.

**Graduate Students:** a small number of graduate students will be allowed to take the graduate version of this course (15-862) with the permission of the instructor. Students taking 15-862 will be required to do more substantial assignments as well as a research-level final paper.

**Note:** if the system doesn't let you sign up, or puts you on the waitlist, do talk to me.

### PROGRAMMING ASSIGNMENTS:

- [Project 0: The Vertigo Shot](#)



[Results](#)

Class Choice Award Winner: [Lisa Chan](#)

- [Project 1: Images of the Russian Empire -- colorizing the Prokudin-Gorskii photo collection](#)



[Results](#)

Class Choice Award Winners: [Lisa Chan](#) and [Anna Michalska](#)

- [Project 2: Image Resizing by Seam Carving](#)



[Results](#)

Class Choice Award Winner: [Lisa Chan](#) (again!)

- [Project 3: Face morphing and modeling:](#)



[Results](#) [Class movie](#)

Class Choice Award Winner: [Ronit Slyper](#)

- [Project 4: Stitching Photo Mosaics \(including autostitching\)](#)

[Results](#)

Class Choice Award Winner: [Lisa Chan](#) (again!!)

- [Project 5: Single-View Reconstruction](#) (*Tour into the Picture*):

#### [Results](#)

Class Choice Award Winner: [Ronit Slyper](#) and [William Wedler](#)

## Final Projects!

[Online Face Labeler/Camera/Projector System](#)

[View Morphing](#)

[Recursive Image Mosaics](#)

[Creating Hockney's Joiners](#)

[Microstructural Grain Modeling](#)

[Infinite Panoramas](#)

[Seam-Carving in Web Pages](#)

[Image Deformation using Moving Least Squares](#)

[Flickrbooks: Flipbooks using millions of Flickr images](#)

[Story Telling with Markov Chains](#)

[Animating Texture Transfer](#)

### TEXT:

Since Computational Photography is such a new discipline, no comprehensive textbook exists for use in the class. Therefore, there is no required text. Various course notes and papers will be made available. Furthermore, there is an optional textbook that you might find helpful. It will be placed on reserve at the Wean Hall library:

Computer Vision: The Modern Approach, Forsyth and Ponce

There is a number of other fine texts that you can use for general reference:

Photography (8<sup>th</sup> edition), London and Upton, (*a great general guide to taking pictures*)  
 Vision Science: Photons to Phenomenology, Stephen Palmer (*great book on human visual perception*)  
 Digital Image Processing, 2nd edition, Gonzalez and Woods (*a good general image processing text*)  
 The Art and Science of Digital Compositing, Ron Brinkmann (*everything about compositing*)  
 Multiple View Geometry in Computer Vision, Hartley & Zisserman (*a bible on recovering 3D geometry*)  
 The Computer Image, Watt and Policarpo (*a nice "vision for graphics" text, somewhat dated*)  
 3D Computer Graphics (3rd Edition), Watt (*a good general graphics text*)  
 Fundamentals of Computer Graphics, Peter Shirley (*another good general graphics text*)  
 Linear Algebra and its Applications, Gilbert Strang (*a truly wonderful book on linear algebra*)

### CLASS NOTES

The instructor is extremely grateful to a large number of researchers for making their slides available for use in this course. [Steve Seitz](#) and [Rick Szeliski](#) have been particularly kind in letting me use their wonderful lecture notes. In addition, I would like to thank [Paul Debevec](#), [Stephen Palmer](#), [Paul Heckbert](#), [David Forsyth](#), [Steve Marschner](#) and others, as noted in the slides. The instructor gladly gives permission to use and modify any of the slides for academic and research purposes. However, please do also acknowledge the original sources where appropriate.

### CLASS SCHEDULE:

| CLASS DATE | TOPICS                                | Material                                                                                                                                                                                                                                                                                                          |
|------------|---------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Tu Aug 28  | Introduction                          | <ul style="list-style-type: none"> <li>• Slides (<a href="#">ppt</a>, <a href="#">pdf</a>)</li> <li>• <a href="#">Project #0 OUT</a></li> </ul>                                                                                                                                                                   |
| Th Aug 30  | The Camera                            | <ul style="list-style-type: none"> <li>• Slides (<a href="#">ppt</a>, <a href="#">pdf</a>)</li> <li>• Forsyth &amp; Ponce, Ch 1</li> </ul>                                                                                                                                                                        |
| Tu Sept 4  | Capturing Light... in man and machine | <ul style="list-style-type: none"> <li>• Slides (<a href="#">ppt</a>, <a href="#">pdf</a>)</li> <li>• Forsyth &amp; Ponce, Ch 6</li> <li>• <a href="#">Project #1 OUT</a></li> </ul>                                                                                                                              |
| Th Sept 6  | Sampling and Reconstruction           | <ul style="list-style-type: none"> <li>• Slides (<a href="#">ppt</a>, <a href="#">pdf</a>)</li> </ul>                                                                                                                                                                                                             |
| Tu Sept 11 | The Frequency Domain                  | <ul style="list-style-type: none"> <li>• Slides (<a href="#">ppt</a>, <a href="#">pdf</a>)</li> </ul>                                                                                                                                                                                                             |
| Th Sept 13 | Image Processing (Jim)                | <ul style="list-style-type: none"> <li>• N/A</li> </ul>                                                                                                                                                                                                                                                           |
| Tu Sept 18 | Image Blending and Compositing        | Slides ( <a href="#">ppt</a> , <a href="#">pdf</a> )<br><a href="#">Project #2 OUT</a><br>Additional Reading:<br>Burt and Adelson, <a href="#">A multiresolution spline with application to image mosaics</a> , ACM ToG (1983)<br>Agarwala et al, <a href="#">Interactive Digital Photomontage</a> , SIGGRAPH 200 |
| Th Sept 20 | Image Warping                         | Slides ( <a href="#">ppt</a> , <a href="#">pdf</a> )                                                                                                                                                                                                                                                              |

|                                  |                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|----------------------------------|-----------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Tu Sept 25                       | <b>Image Morphing</b>                                                                                     | Slides ( <a href="#">ppt</a> , <a href="#">pdf</a> )                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Th Sept 27                       | <b>Data-driven Methods: Faces</b>                                                                         | Slides ( <a href="#">ppt</a> , <a href="#">pdf</a> ) <ul style="list-style-type: none"> <li>Rowland and Ferrett, "<a href="#">Manipulating Facial Appearance through Shape and Color</a>", CG&amp;A, 1995</li> <li>Additional Reading:               <ol style="list-style-type: none"> <li>Blanz and Vetter, "<a href="#">A Morphable Model for the Synthesis of 3D Faces</a>", SIGGRAPH 1999</li> <li>Cootes, Edwards, and Taylor, "<a href="#">Active Appearance Models</a>", ECCV 1998</li> </ol> </li> </ul> |
| Friday Sept 28, 3:30pm, NSH 1305 | <b>Special Guest Lecture : <a href="#">From Images To Insights</a> (<a href="#">Wojciech Matusik</a>)</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Tu Oct 2                         | <b>Data-driven Methods: Video</b>                                                                         | <ul style="list-style-type: none"> <li><a href="#">Project #3 OUT</a></li> <li>Slides (<a href="#">ppt</a>, <a href="#">pdf</a>)</li> <li>Reading: <a href="#">Schold et al, Video Textures, 2000</a></li> </ul>                                                                                                                                                                                                                                                                                                  |
| Th Oct 4                         | <b>Data-driven Methods: Textures and Images</b>                                                           | <ul style="list-style-type: none"> <li>Slides (<a href="#">ppt</a>, <a href="#">pdf</a>)</li> <li>Reading: <a href="#">Efros &amp; Leung, Texture Synthesis by Non-parametric Sampling, 1999</a></li> <li>Additional reading:               <ol style="list-style-type: none"> <li><a href="#">Image Analogies</a></li> <li><a href="#">Scene Completion using Millions of Photographs</a></li> </ol> </li> </ul>                                                                                                 |
| Tu Oct 9                         | <b>Modeling Light</b>                                                                                     | <ul style="list-style-type: none"> <li>Slides (<a href="#">ppt</a>, <a href="#">pdf</a>)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                               |
| Th Oct 11                        | <b>Midterm review</b>                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Tu Oct 16                        | <b>Midterm Exam (Jim)</b>                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Th Oct 18                        | <b>Midterm Overview (Jim)</b>                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

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|---------------------------------------------|-------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Tu Oct 23                                   | <b>Homographies and Mosaics</b>                             | <ul style="list-style-type: none"> <li>Slides (<a href="#">ppt</a>, <a href="#">pdf</a>)</li> <li>Paul Heckbert, <a href="#">Projecting Mappings for Image Warping</a></li> <li><a href="#">Project #4 OUT</a></li> </ul>                                                                                                                                                                                                                                                                                                 |
| Th Oct 25                                   | <b>More Mosaic Madness</b>                                  | <ul style="list-style-type: none"> <li>Slides (<a href="#">ppt</a>, <a href="#">pdf</a>)</li> <li>Additional Reading: Rick Szeliski, <a href="#">Image Alignment and Stitching, A Tutorial (DRAFT)</a></li> </ul>                                                                                                                                                                                                                                                                                                         |
| Friday<br>Oct 26,<br>3:30pm,<br>NSH<br>1305 | <b>Special Guest Lecture : <a href="#">Paul Debevec</a></b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Tu Oct 30                                   | <b>Automatic Alignment</b>                                  | <ul style="list-style-type: none"> <li>Slides (<a href="#">ppt</a>, <a href="#">pdf</a>)</li> <li>Reading: <a href="#">Brown et al. "Multi-Image Matching using Multi-Scale Oriented Patches", CVPR 2005</a></li> <li>Reading: M. Brown and D. G. Lowe. Recognising Panoramas (<i>ICCV2003</i>) (<a href="#">pdf 820kb</a>)</li> <li>Reading: <a href="#">RANSAC</a></li> </ul>                                                                                                                                           |
| Th Nov 1                                    | <b>Multi-perspective Panoramas</b>                          | <ul style="list-style-type: none"> <li>Slides (<a href="#">ppt</a>, <a href="#">pdf</a>)</li> <li>Reading: <a href="#">Squaring the Circle in Panoramas</a></li> <li>Reading: <a href="#">Automating joiners</a></li> <li>Additional Reading: <a href="#">Photographing long scenes with multi-viewpoint panoramas</a></li> <li>Additional Reading: <a href="#">Scene Collages and Flexible Camera Arrays</a></li> <li>Flickr: <a href="http://flickr.com/groups/joiners">http://flickr.com/groups/joiners</a></li> </ul> |
| Tu Nov 6                                    | <b>Single View Reconstruction</b>                           | <ul style="list-style-type: none"> <li>Slides (<a href="#">ppt</a>, <a href="#">pdf</a>)</li> <li>Reading: Horry et al, <a href="#">"Tour into the Picture"</a>, SIGGRAPH '97</li> <li><a href="#">Project #5 OUT</a></li> </ul>                                                                                                                                                                                                                                                                                          |

- Slides ([ppt](#), [pdf](#))
- Additional Reading: [Single-view Reconstruction](#)

Slides ([ppt](#), [pdf](#))  
Reading: Debevec & Malik,  
“[Recovering High Dynamic Range  
Radiance Maps from Photographs](#)”,  
SIGGRAPH 1997

Slides ([ppt](#), [pdf](#))  
Reading: [Debevec, Rendering Synthetic Objects in Real Scenes, 1998](#)

Slides ([ppt](#), [pdf](#))  
Reading: [Debevec, Virtual Cinematography: Relighting Through Computation, IEEE Computer Aug. 2006](#)

Slides ([ppt](#), [pdf](#))  
Reading: [Y. Ke, X. Tang, and F. Jing, The Design of High-Level Features for Photo Quality Assessment, CVPR 2006.](#)

Slides ([ppt](#), [pdf](#))

|          |                                                                                                  |                                                      |
|----------|--------------------------------------------------------------------------------------------------|------------------------------------------------------|
| Tu Dec 4 | <b>Multi-view Geometry</b>                                                                       | Slides ( <a href="#">ppt</a> , <a href="#">pdf</a> ) |
| Th Dec 6 | <b>Navigating the World's Photographs (virtual guest lecture by <a href="#">Steve Seitz</a>)</b> | <a href="#">GoogleVideo link</a>                     |

**CAMERAS:**

Although it is not required, students are highly encouraged to obtain a digital camera for use in the course (one can get a [pretty good camera for under \\$150](#)). A camera might be available on loan from the instructor.

**METHOD OF EVALUATION:**

Grading will be based on a set of programming and written assignments (60%), an exam (20%) and a final project (20%). For the programming assignments, students will be allowed a total of 5 (five) late days per semester; each additional late day will incur a 10% penalty.

Students taking 15-862 will also be required to submit a conference-style paper describing their final project.

**COMPUTING FACILITIES:**

All students will have access to the graphics cluster in Wean Hall 5336. You will need to setup your Andrew account in the right way before you can login.

**MATLAB:**

Students will be encouraged to use Matlab (with the Image Processing Toolkit) as their primary computing platform. Besides being a great prototyping environment, Matlab is particularly well-suited for working with image data and offers tons of build-in image processing functions. Here is a link to some [useful Matlab resources](#)

**PREVIOUS OFFERINGS OF THIS COURSE:**

Previous offerings of this course can be found [here](#).

**SIMILAR COURSES IN OTHER UNIVERSITIES:**

- [Computational Photography SIGGRAPH Course](#) (Raskar & Tumblin)
- [Computational Photography](#) (Raskar, Northeastern)
- [Digital and Computational Photography](#) (Durand & Freeman, MIT)
- [Computational Photography](#) (Essa, Georgia Tech)
- [Computational Photography](#) (Levoy & Wilburn, Stanford)
- [Computer Vision](#) (Seitz & Szeliski, UWWashington)
- [Introduction to Visual Computing](#) and [Visual Modeling](#) (Kutulakos, UToronto)
- [Topics in Image-based Modeling and Rendering](#) (Kriegman, UCSD)
- [Symposium on Computational Photography and Video](#) (May 2005, MIT)

Page design courtesy of [Doug James](#)

