Computational Photography

* Study the basics of computation and its impact on the entire workflow of photography, from capturing, manipulating and collaborating on, and sharing photographs.

Georgia Tech College of Computing

Introduction to the Course

* Instructor Introductions
* Overview of the Course Structure
* What to Expect?

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Instructor Introductions

Irfan Essa
Professor of Computing
Georgia Institute of Technology
PhD MIT 1995
http://prof.irfanessa.com

Julia Deeb
PhD CS Student
Georgia Institute of Technology
BS GA Tech 2014

Overview of the Course Structure

* CS 6475: Computational Photography
* Video lectures, quizzes, weekly homework assignments (coding / peer feedback), exam, final project
* Learn about imaging and computing concepts as applied to Computational Photography with <u>hands-on</u> experimentation

Requirements

- Mathematics (Linear Algebra, Calculus, Probability)
- Computing
  - OpenCV / Python / C++ OR
  - Matlab / Octave
- Camera
  - Could be useful (nothing advanced)
  - Images will be provided

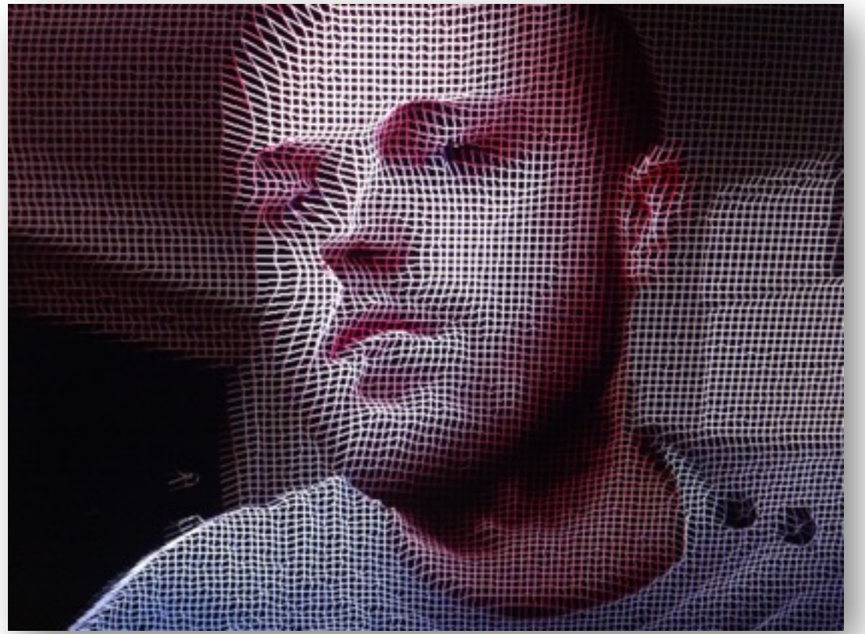
Module 1: Introduction

* What is Computational Photography?
* Examples of Computational Photography to provide context
* Overview of the scope of Computational, with respect to other disciplines, and its potential impact
* Assignment: Getting set up and sharing some pictures!

Camera 2.0, Marc Levoy

Module 2: Image Processing and Analysis

* Digital Image Representation
* Pixel/Point Processes for Images
* Smoothing and Filtering methods for Images
* Extracting Features from Images
* Assignments: Experiments with Image Filtering, Features Detection



http://www.flickr.com/photos/markcph/5137142884/

Module 3: Cameras, Optics and Sensors

* Pin-Hole Camera
* Importance of Optics
* How does a Camera work?
* Sensors
* Assignments: Epsilon Photography & make your own Camera Obscura!

wikimedia.org/wiki/File:Cameras.jpg

wikimedia.org/wiki/File:Byelorussky_Station-_a_pinhole_photograph.jpg

Module 4: Image Blending/Merging

* Sampling and Frequencies
* Image Blending
* Image Features
* Homework: Exercise on Image Blending

Irfan Essa, gatech.edu

Irfan Essa, gatech.edu

Module 5: Doing Computational Photography

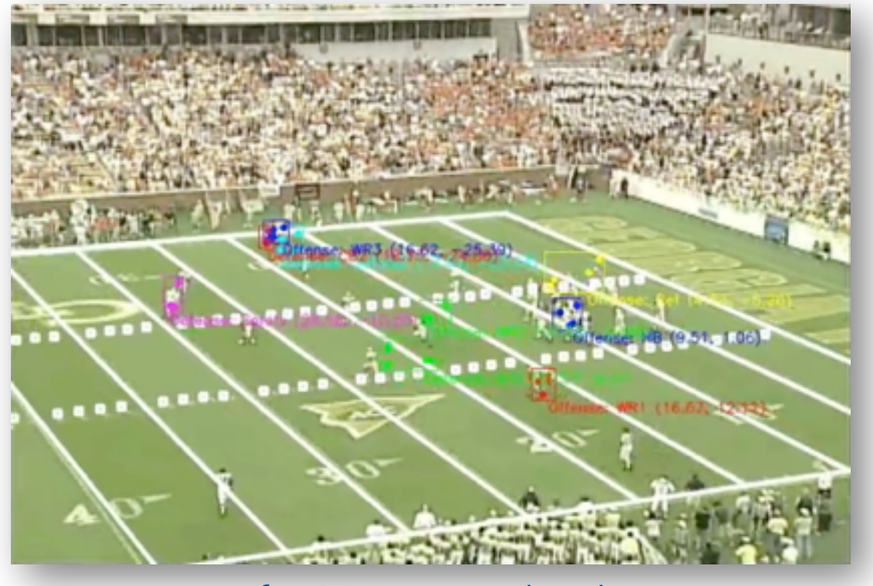
* Panoramas
* HDR
* Image Editing
* Assignment: Experiments with HDR/Panoramas

Irfan Essa

Irfan Essa

Module 6: Extending to Video

* Video
  * Video Textures
  * Video Stabilization
* Homework Assignment: Experiments with Video Textures



Irfan Essa, gatech.edu

wikipedia.org/wiki/Quadcopter

Module 7: Computational Cameras

* Computational Cameras
  * Light field Cameras
* Multi-view
* Projector Camera Systems

pelicanimaging.com

lytro.com

Programmable Automotive Headlights,
Srinivasa Narasimhan, CMU

Module 8: Advanced Topics. Special Cases

- Newer camera technologies
- Blur/Deblur
- Social/Crowd Photography
- Final Project
  - Select a topic of your choosing and make it work for real

Paul Debevec, USC and whitehouse.gov

What to Expect?

* Not a photography class
  * Technology-related content
* A hands-on activities class
  * You will <u>learn</u> by doing, by yourself and with the class


NEW WORK BY MR. CHARLES DICKENS.

In No. 84 of ALL THE YEAR ROUND, TO BE PUBLISHED ON SATURDAY, DECEMBER THE FIRST, will be commenced

GREAT EXPECTATIONS,

BY CHARLES DICKENS,

A NEW SERIAL STORY,

To be continued from week to week until completed in about EIGHT MONTHS.

THE EXTRA CHRISTMAS NUMBER WILL BE PUBLISHED EARLY IN DECEMBER.

Computational Photography

* Study the basics of computation and its impact on the entire workflow of photography, from capturing, manipulating and collaborating on, and sharing photographs.

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Next

* Deeper dive into what Computational Photography is, and
* What aspects (and frameworks) of Computational Photography we need to study

Computational Photography

* Study the basics of computation and its impact on the entire workflow of photography, from capturing, manipulating and collaborating on, and sharing photographs.

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What is Computational Photography? (Part 1 of 3)

* Computational Photography and its comparison to traditional photography and digital photography.

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1. What is Computational Photography?

2. Fundamental elements of computational photography

What is Photography?

Photography is the science, art and practice of creating durable images by recording light or other electromagnetic radiation, either electronically by means of an image sensor, or chemically by means of a light-sensitive material such as photographic film.[1]

Typically, a lens is used to focus the light reflected or emitted from objects into a real image on the light-sensitive surface inside a camera during a timed exposure. With an electronic image sensor, this produces an electrical charge at each pixel, which is electronically processed and stored in a digital image file for subsequent display or processing. The result with photographic emulsion is an invisible latent image, which is later chemically "developed" into a visible image, either negative or positive depending on the purpose of the photographic material and the method of processing. A negative image on film is traditionally used to photographically create a positive image on a paper base, known as a print, either by using an enlarger or by contact printing.

Lens and mounting of a large-format camera

Photography is employed in many fields of science, manufacturing (e.g. photolithography) and business, as well as its more direct uses for art, recreational purposes, and mass communication.

http://en.wikipedia.org/wiki/Photography?

(Accessed, December 2014)

What is Computational Photography?

+

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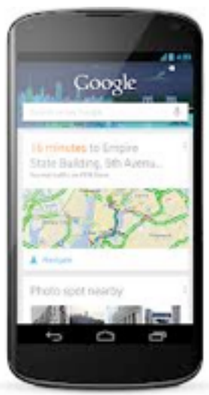
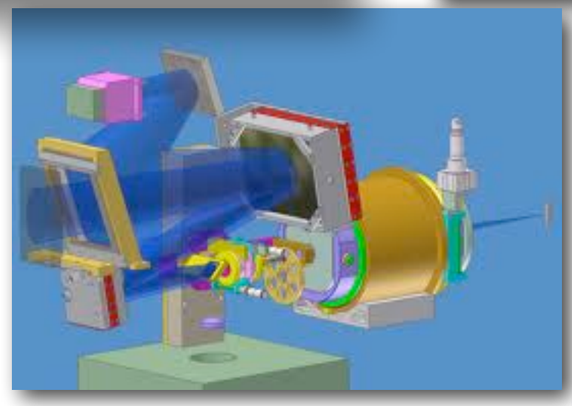
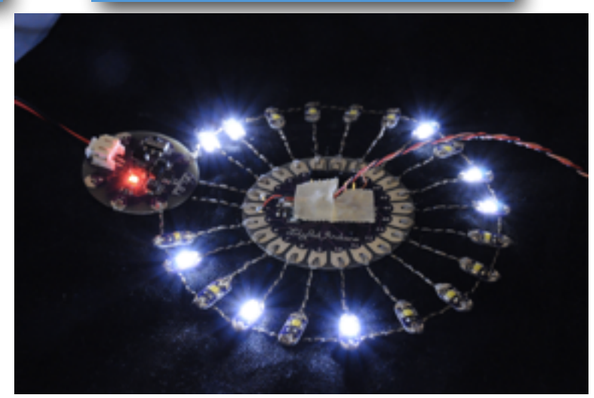
Camera 2.0
(Frankencamera)
Adams et al., 2010



Computational Photography Combines

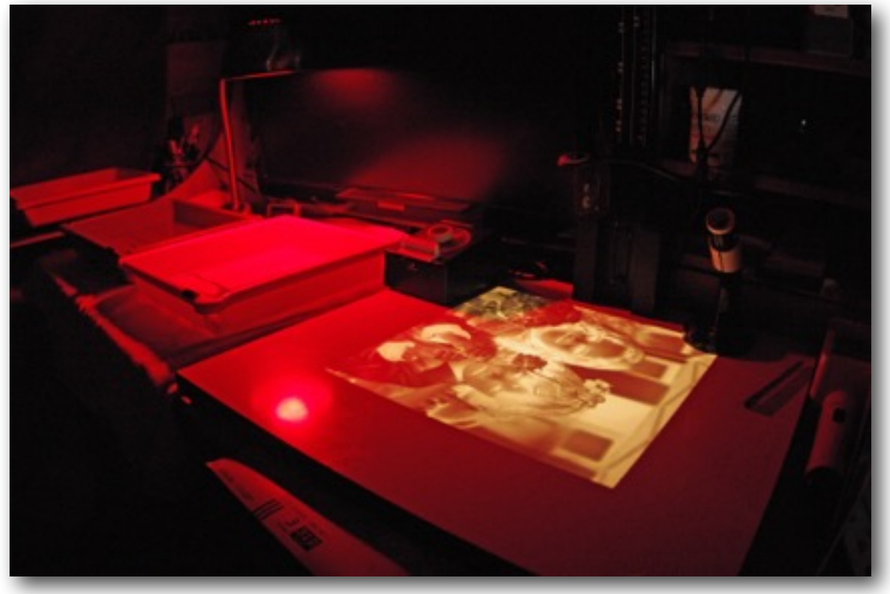
- Computing
- Digital Sensors
- Modern Optics
- Actuators
- Smart Lights
- To "escape" the limitations of traditional film cameras





Limitations of Traditional Film Cameras

* Debatable, but . . .
  * Chemicals / Darkroom
* 12-24-36 pictures / roll
* No instant gratification
* Sensitivity of film



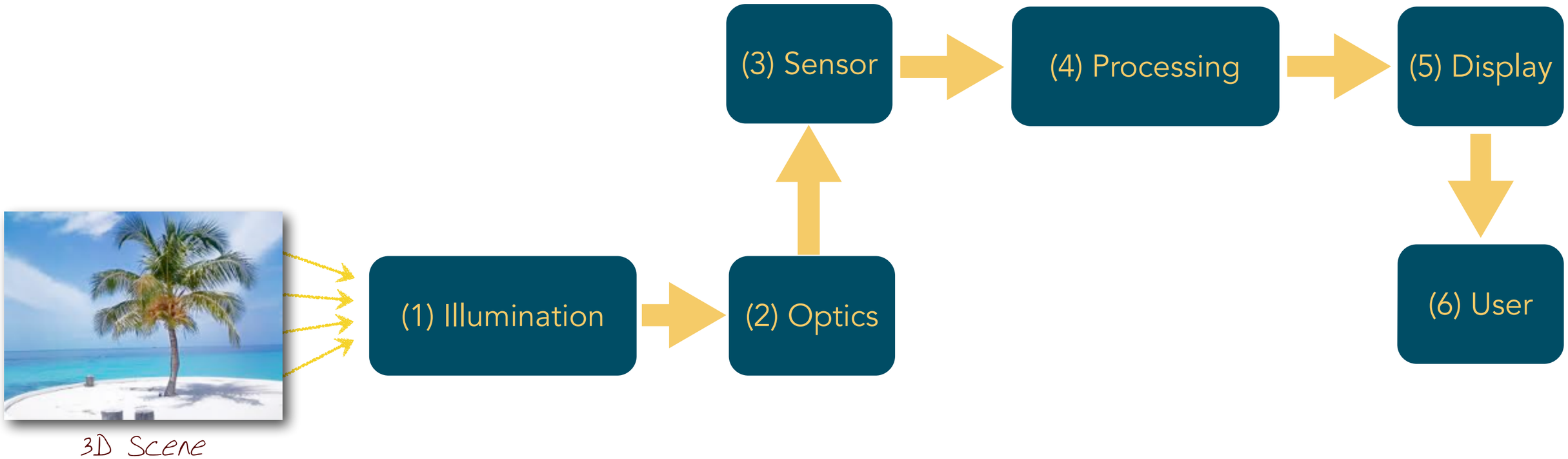
Computational Photography Enables Imaging

* Unbounded Dynamic Range
* Variable
  * Focus
  * Depth of Field
  * Resolution
  * Lighting
  * Reflectance

* Supports and Enhances the Medium of Photography

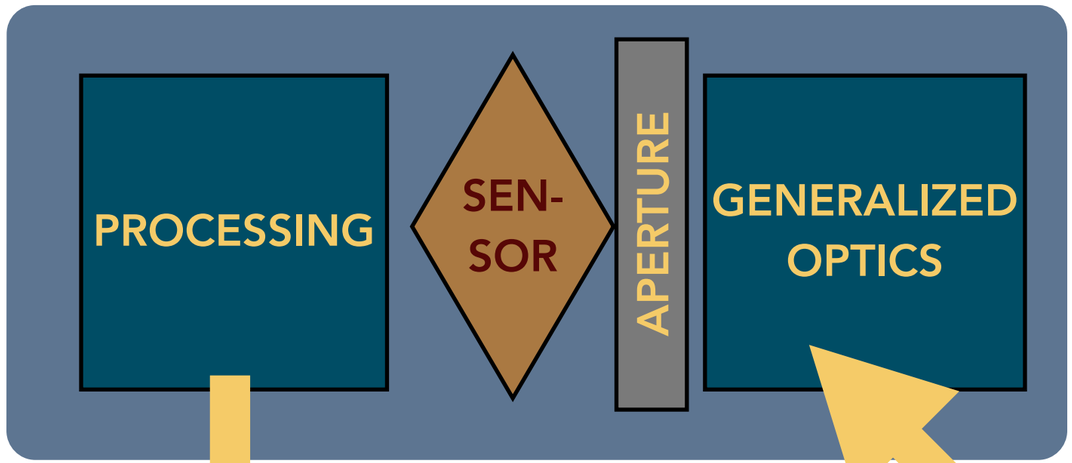
Elements of Computational Photography

Computation can be embedded in all aspects of these elements to support photography



Computational Photography (Rays to Pixels)

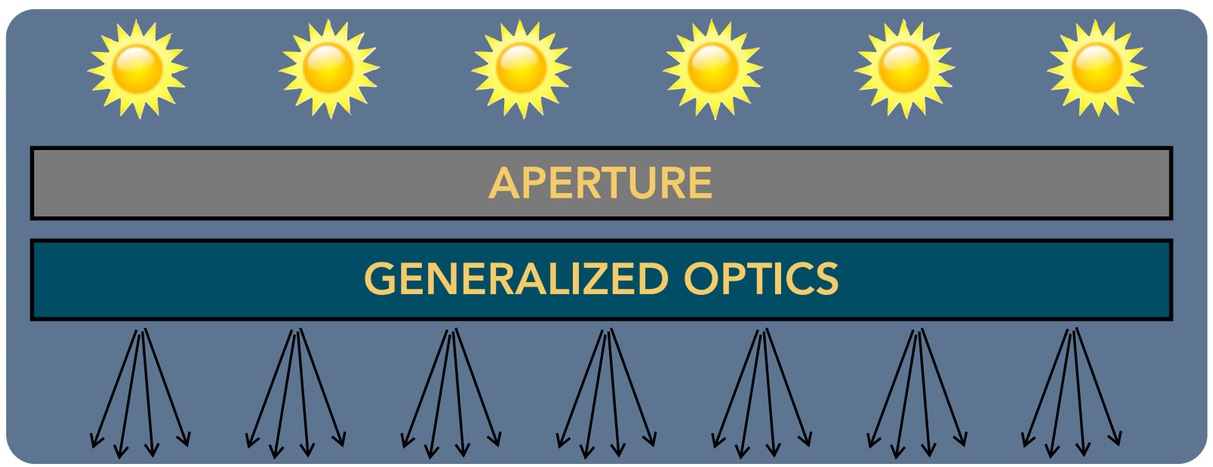
Novel Camera



Pixels

Rays

Novel Illumination



Rays

3D Scene

Schematic motivated by Nayar and Raskar

Summary

1. Computational Photography "computationalizes" the entire workflow of photography
2. Rays to pixels
3. Generalizing control (actuation) of elements: illumination, optics/aperture, sensor, processing, display, and sharing
4. "Enhances" the photographic process

Next Class

* Look at a specific example of Computational Photography
* A deeper dive, with brief details about how "computationalizing" the different elements of Computational Photography can generate novel images

Credits

* Adams, Talvala, Park, Jacobs, Ajdin, Gelfand, Dolson, Vaquero, Baek, Tico, Lensch, Matusik, Pulli, Horowitz, Levoy (2010) "The Frankencamera: An Experimental Platform for Computational Photography", In SIGGRAPH 2010
* Some schematics motivated by Shree Nayar, Ramesh Raskar, and Jack Tumblin

Computational Photography

* Study the basics of the impact of computation on the entire workflow of photography, from how images are captured, manipulated and collaborated on, and shared.

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Computational Photography

* Study the basics of computation and its impact on the entire workflow of photography, from capturing, manipulating and collaborating on, and sharing photographs.

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What is Computational Photography? (Part 2 of 3)

* Dual Photography, a specific example of Computational Photography

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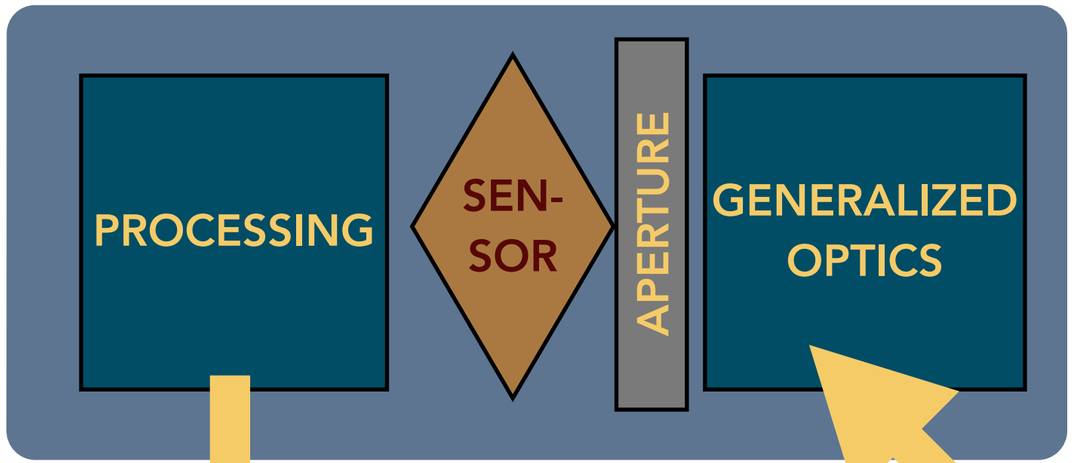
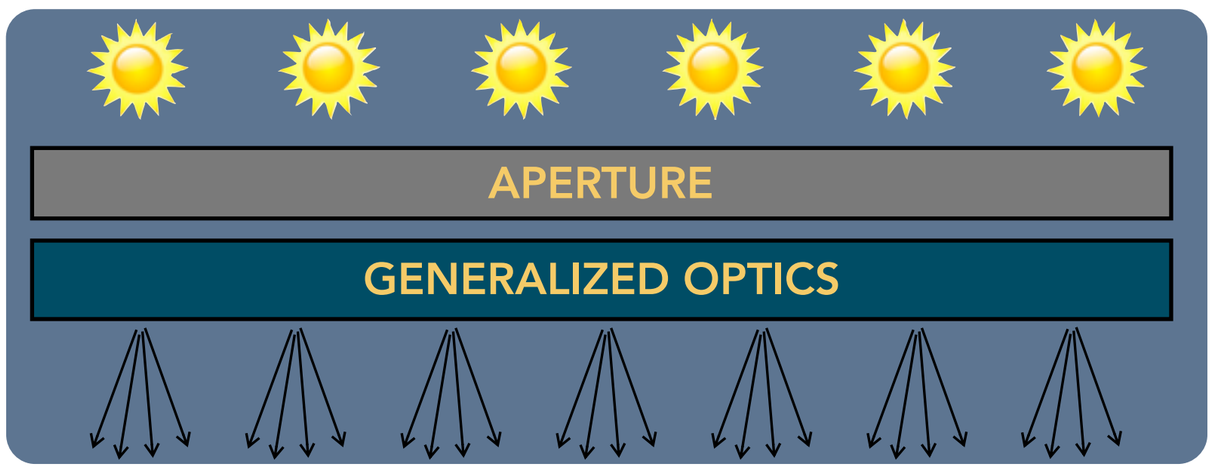
1. An example of computational photography
2. The concept of "dual photography"

Recall: Computational Photography (Rays to Pixels)

Novel Camera



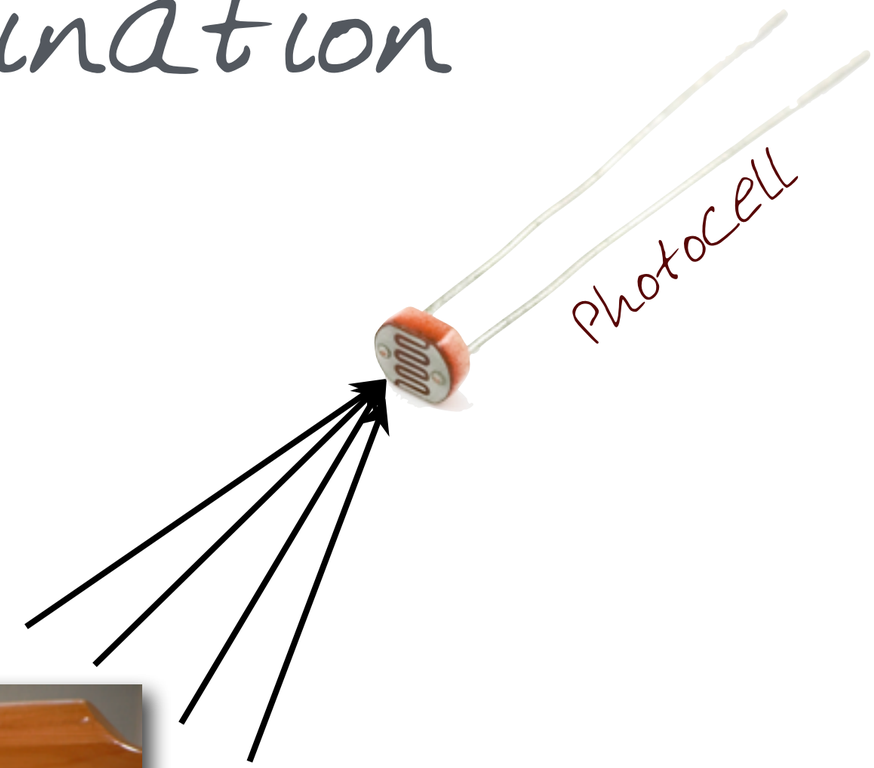
Novel Illumination



Schematic motivated by Nayar and Raskar

Novel Illumination

Modulator
(Controllable
Aperture)

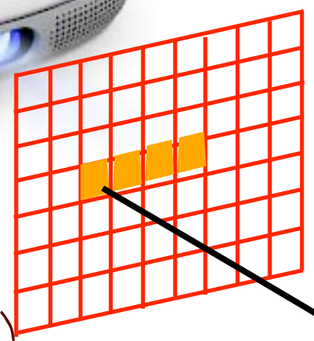


3D Scene

Schematic motivated by Shree Nayar, Ramesh Raskar, and Jack Tumblin

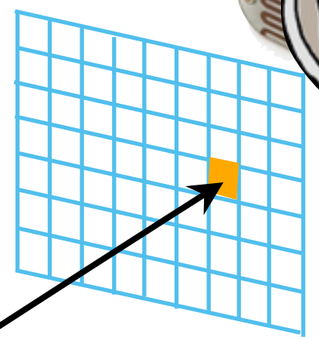
Novel Illumination

Projector
(Controllable
Light Source)



Modulator
(Controllable
Aperture)

3D Scene

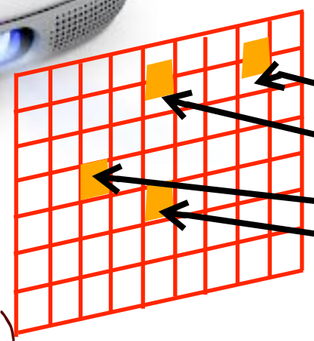


Modulator
(Controllable
Aperture)

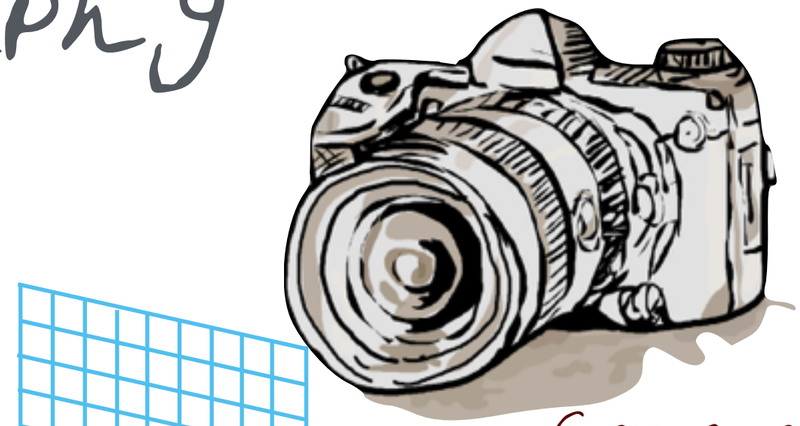
Camera

Dual Photography

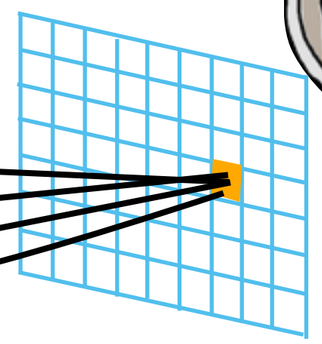
Projector
(Controllable
Light Source)



Modulator
(Controllable
Aperture)



Camera

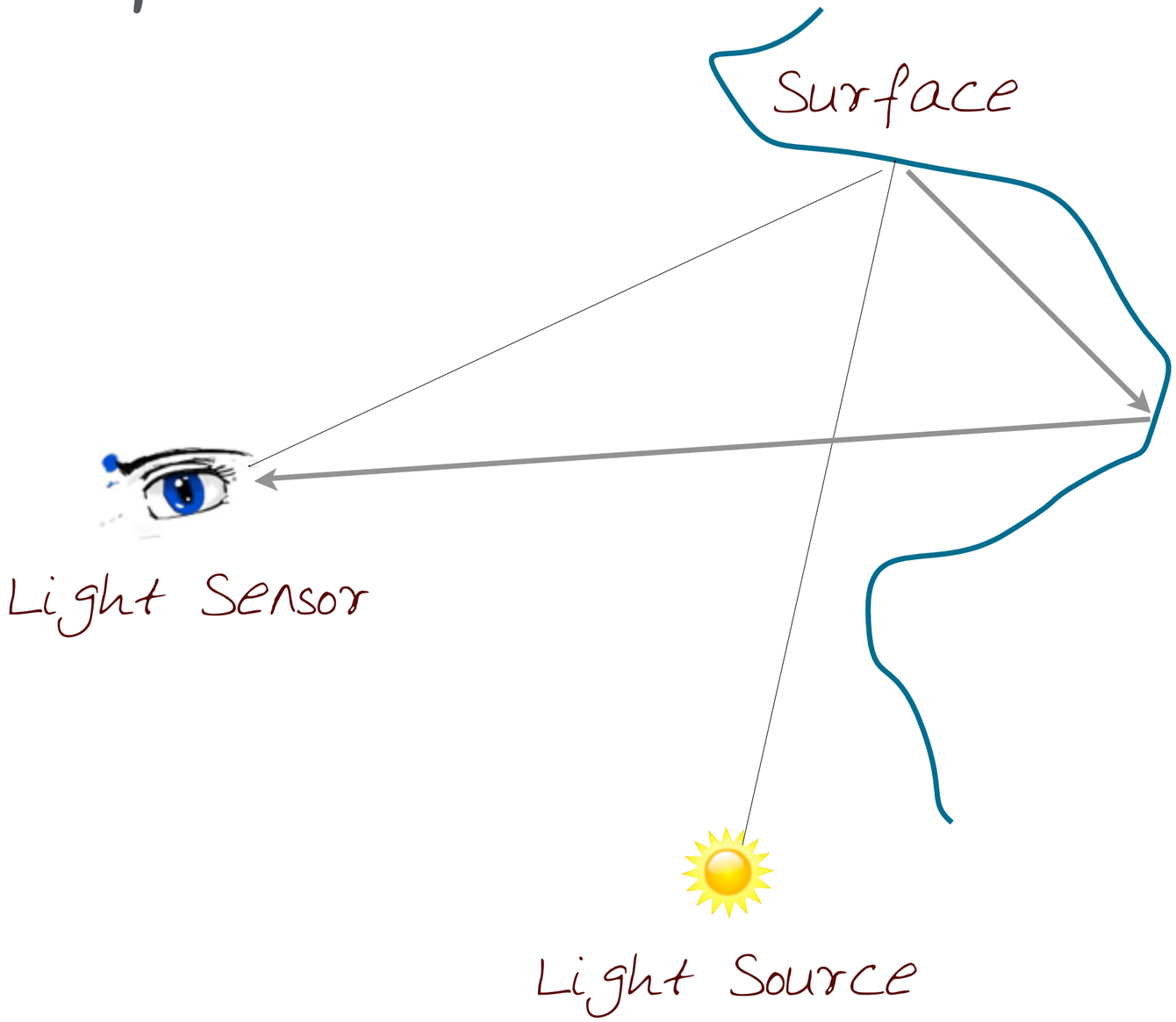


Modulator
(Controllable
Aperture)

3D Scene

Dual Photography, Sen et al. SIGGRAPH 2005

Reflective properties of ray of light



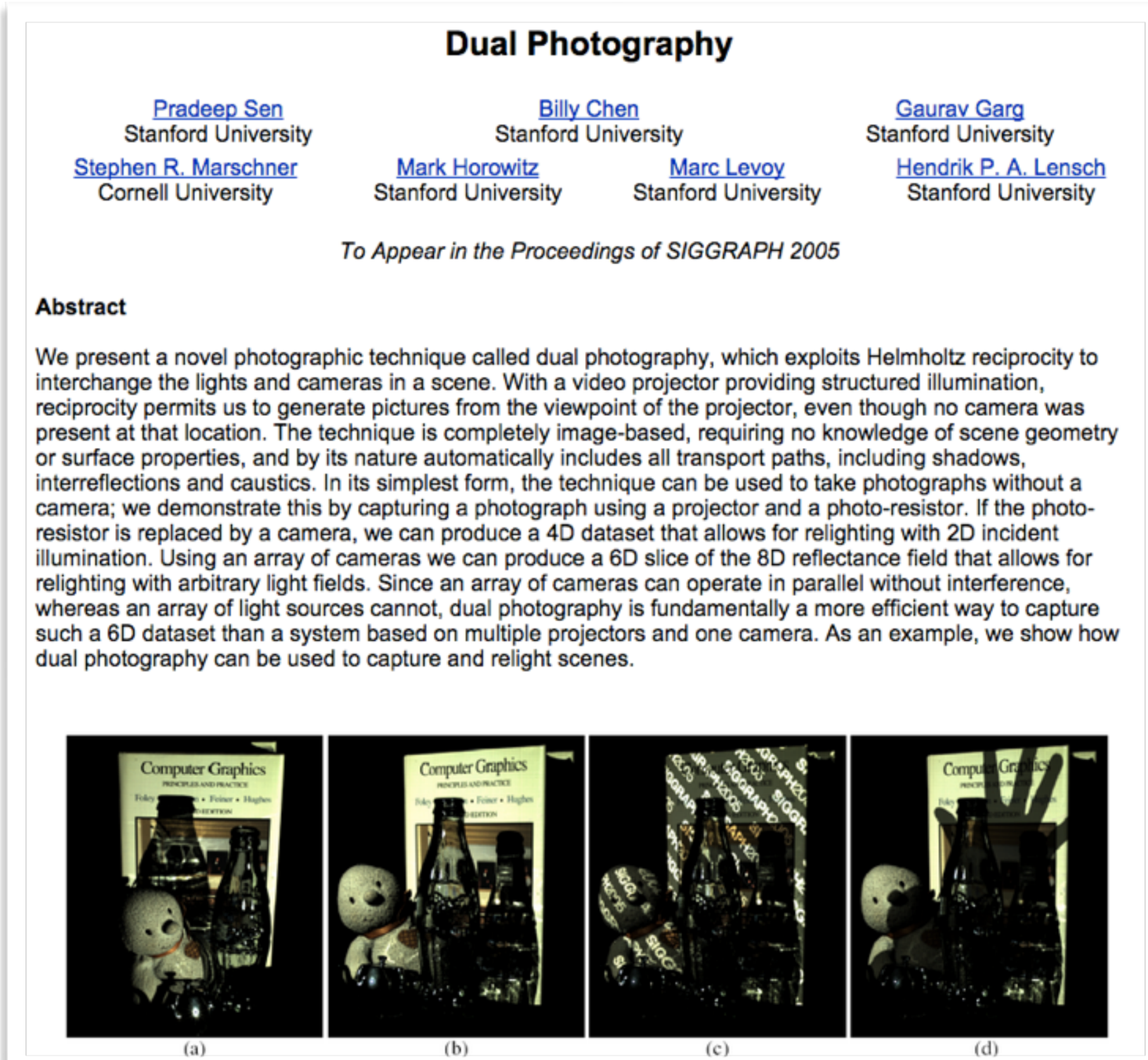
Reflection of light depends on the kind of surface:

Specular (mirror)

Diffuse (matte)

Pradeep Sen, Billy Chen, Gaurav Garg, Stephen R. Marschner, Mark Horowitz, Marc Levoy, and Hendrik P. A. Lensch. 2005. Dual photography. ACM Trans. Graph. 24, 3 (July 2005), 745-755. DOI=10.1145/1073204.1073257 http://doi.acm.org/10.1145/1073204.1073257

http://graphics.stanford.edu/papers/dual_photography/



Dual Photography

Pradeep Sen
Stanford University

Billy Chen
Stanford University

Gaurav Garg
Stanford University

Stephen R. Marschner
Cornell University

Mark Horowitz
Stanford University

Marc Levoy
Stanford University

Hendrik P. A. Lensch
Stanford University

To Appear in the Proceedings of SIGGRAPH 2005

Abstract

We present a novel photographic technique called dual photography, which exploits Helmholtz reciprocity to interchange the lights and cameras in a scene. With a video projector providing structured illumination, reciprocity permits us to generate pictures from the viewpoint of the projector, even though no camera was present at that location. The technique is completely image-based, requiring no knowledge of scene geometry or surface properties, and by its nature automatically includes all transport paths, including shadows, interreflections and caustics. In its simplest form, the technique can be used to take photographs without a camera; we demonstrate this by capturing a photograph using a projector and a photo-resistor. If the photo-resistor is replaced by a camera, we can produce a 4D dataset that allows for relighting with 2D incident illumination. Using an array of cameras we can produce a 6D slice of the 8D reflectance field that allows for relighting with arbitrary light fields. Since an array of cameras can operate in parallel without interference, whereas an array of light sources cannot, dual photography is fundamentally a more efficient way to capture such a 6D dataset than a system based on multiple projectors and one camera. As an example, we show how dual photography can be used to capture and relight scenes.

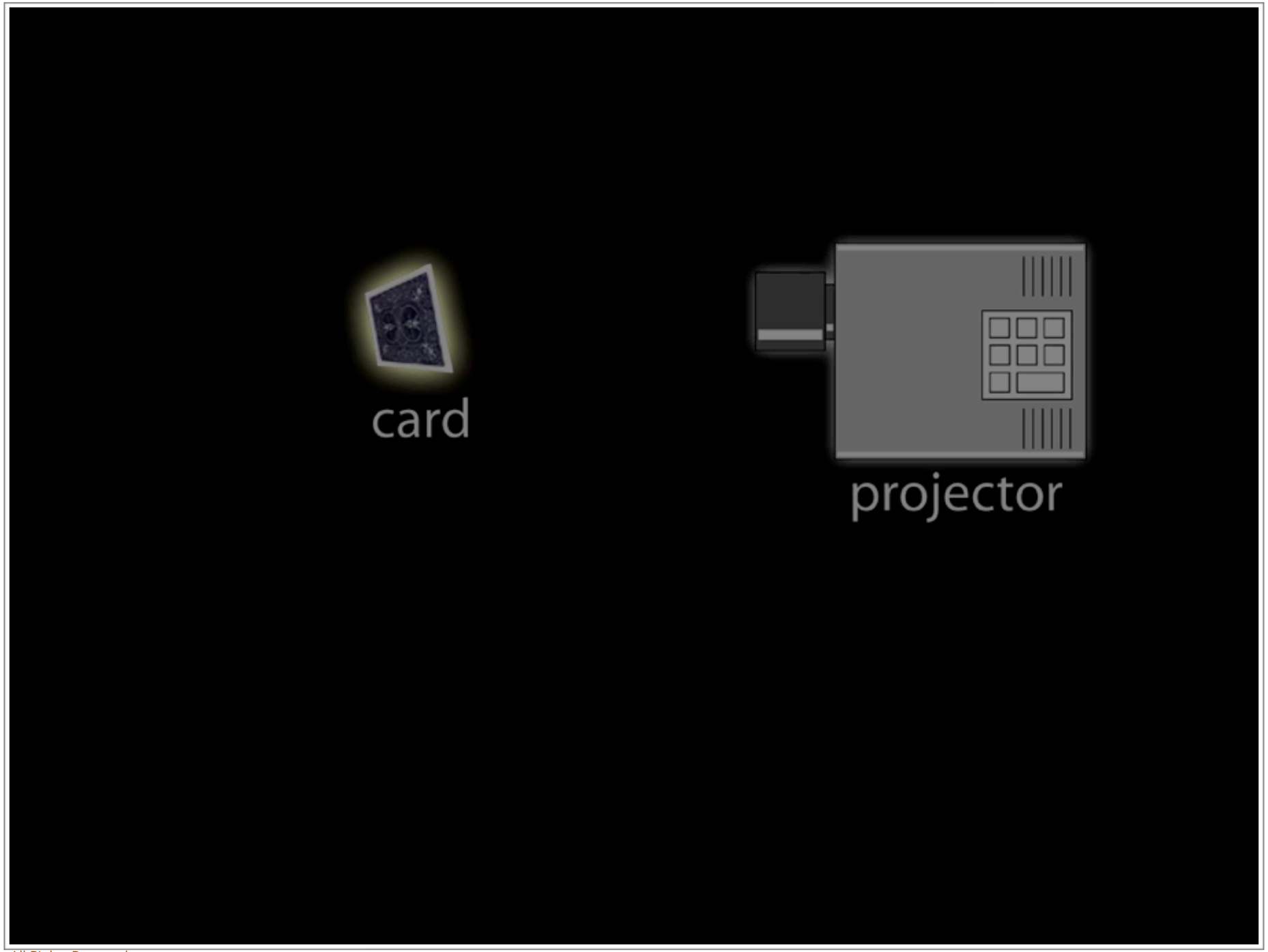
(a) (b) (c) (d)

Dual Photography

Pradeep Sen* Billy Chen* Gaurav Garg* Stephen R. Marschner†
Mark Horowitz* Marc Levoy* Hendrik P.A. Lensch*

*Stanford University †Cornell University

SIGGRAPH2005



Summary

* Introduced computational photography terms' novel illumination, novel cameras, generalized optics, aperture, sensors, rays, and pixels
* Studied a core computational photography example (Dual Photography)

Next Class

* Another example of Computational Photography

* Panorama

  * How to stitch multiple images to generate a "larger" image?

Credits

* References
  * Sen et al. (2005), "Dual Photography" SIGGRAPH 2005
* Some schematics adapted from Shree Nayar and Ramesh Raskar

Computational Photography

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Computational Photography

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What is Computational Photography? (Part 3 of 3)

* Panorama: Another Example of Computational Photography

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Lesson Objectives

1. Steps required to make a panoramic image
2. Identify the five elements of computational photography that are used in making a Panorama

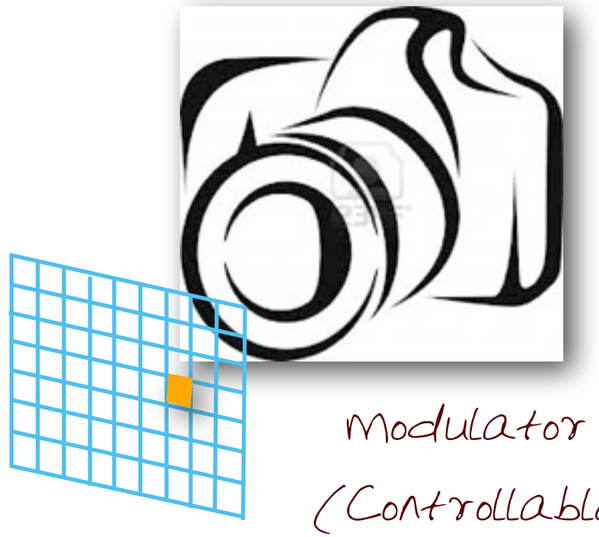
Dual Photography

- 3D Scene
- Illumination
- Optics
- Sensor
- Processing
- Display
- User

Projector (Controllable Light Source)

Modulator (Controllable Aperture)

3D Scene



Camera

Modulator (Controllable Aperture)

Dual Photography, Sen et al. SIGGRAPH 2005

3D Scene

Illumination

Optics

Sensor

Processing

Display

User

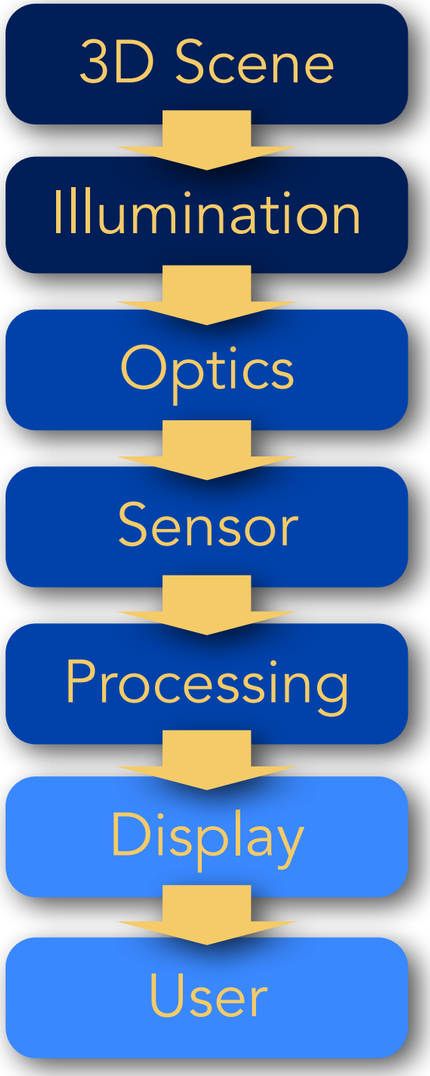
7 Pictures, / 3,072 × 2,304 (7.1MP)

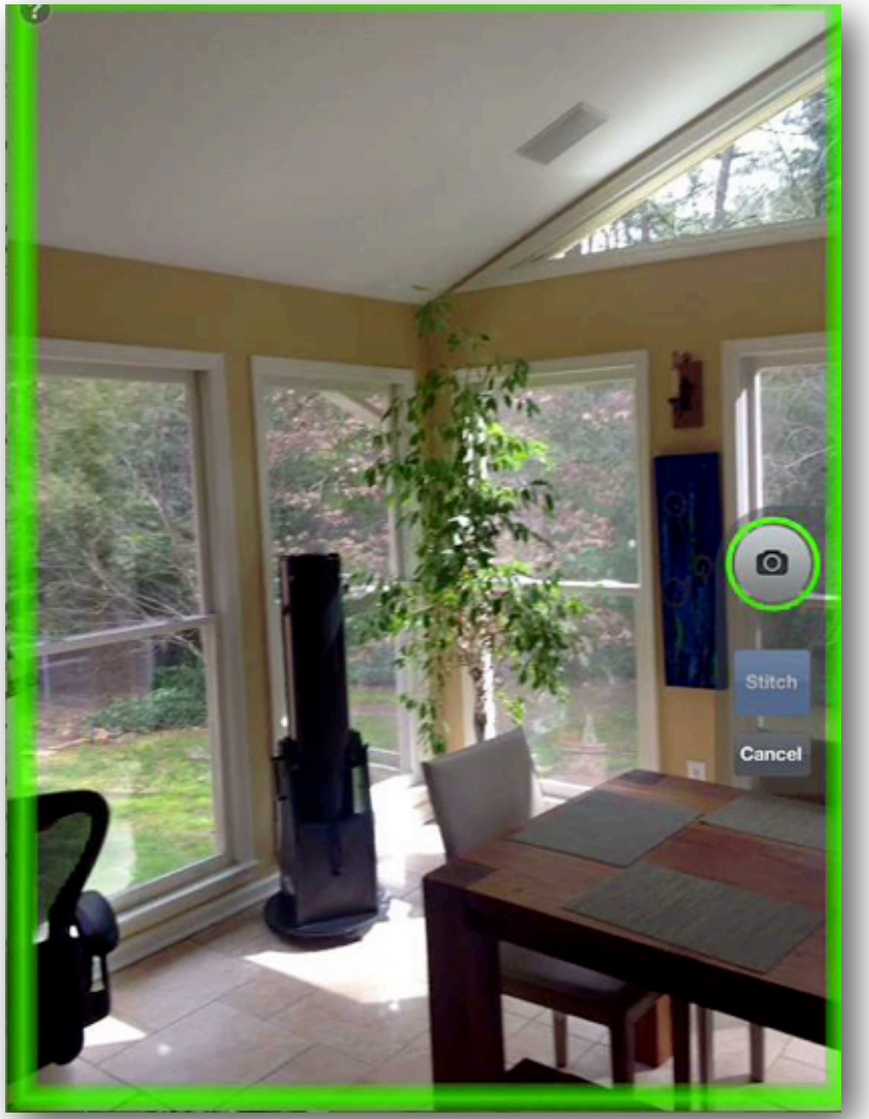
11,262 × 2,691 / (31 MP) / FOV=151.72 × 24.46

Step 1: Taking Pictures

gigapan.com

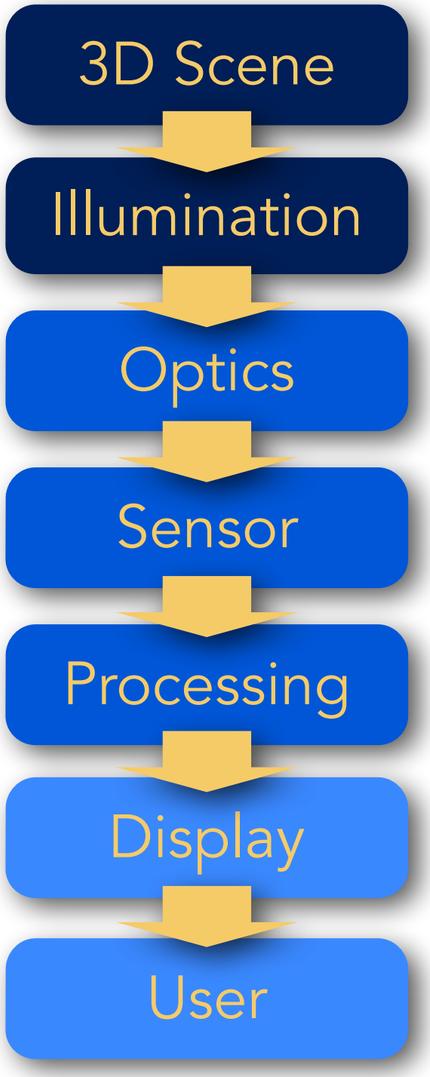
Step 1: Taking Pictures

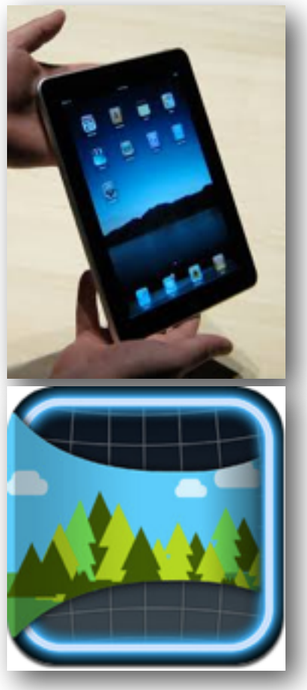


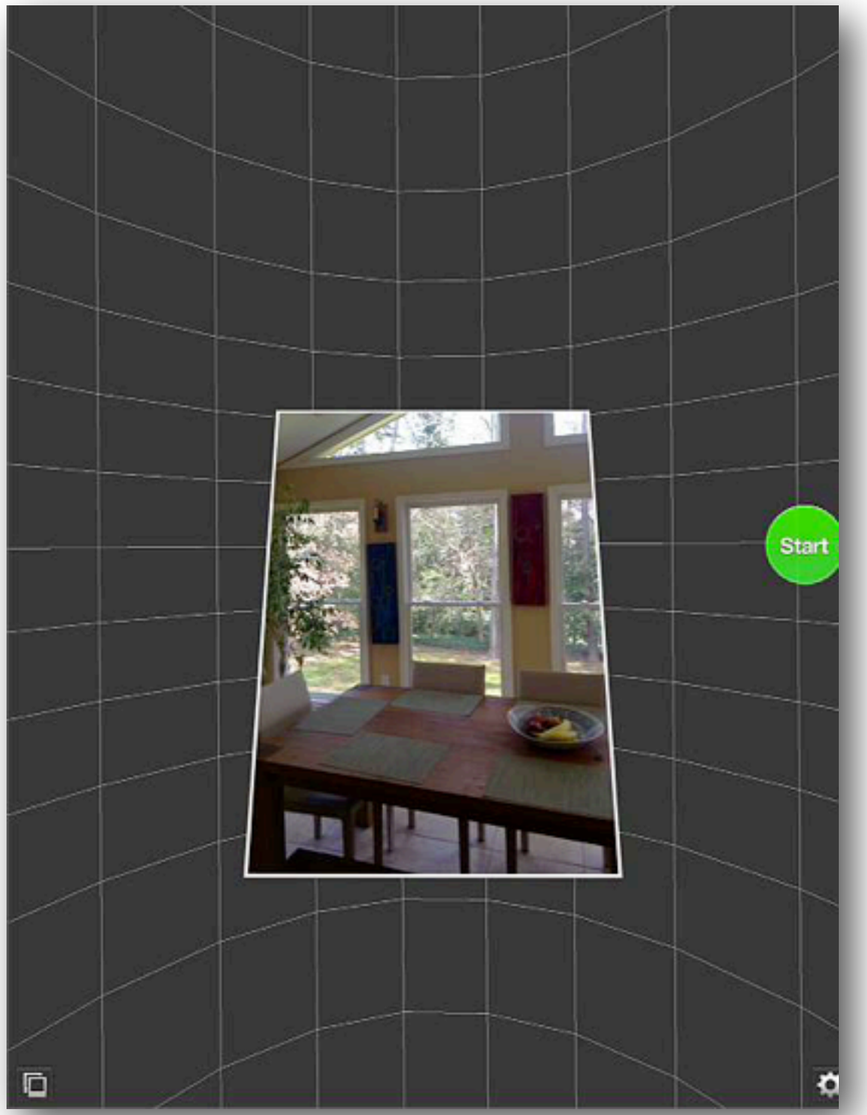


autostitch by Cloudburst Research

Step 1: Taking Pictures

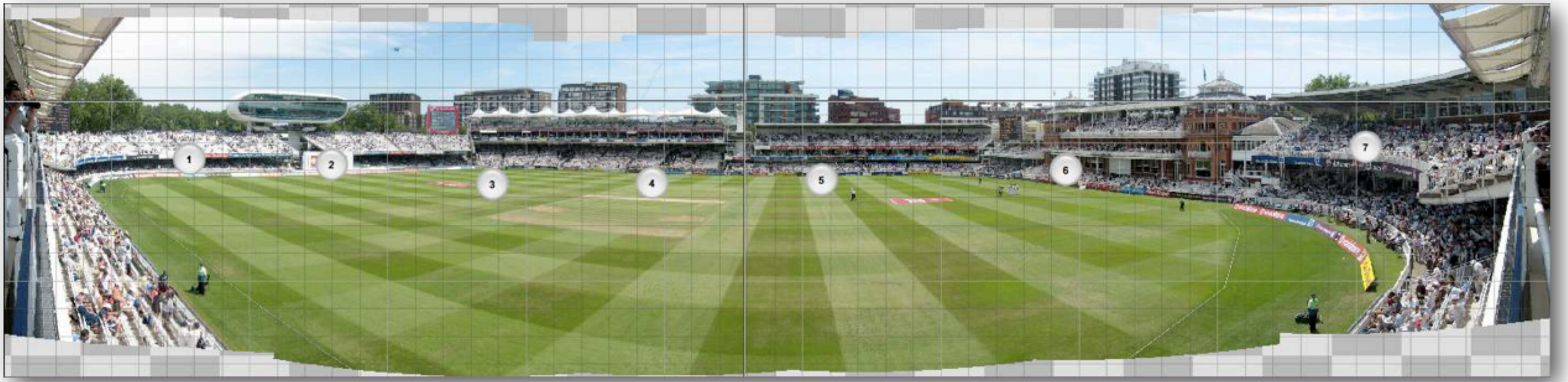






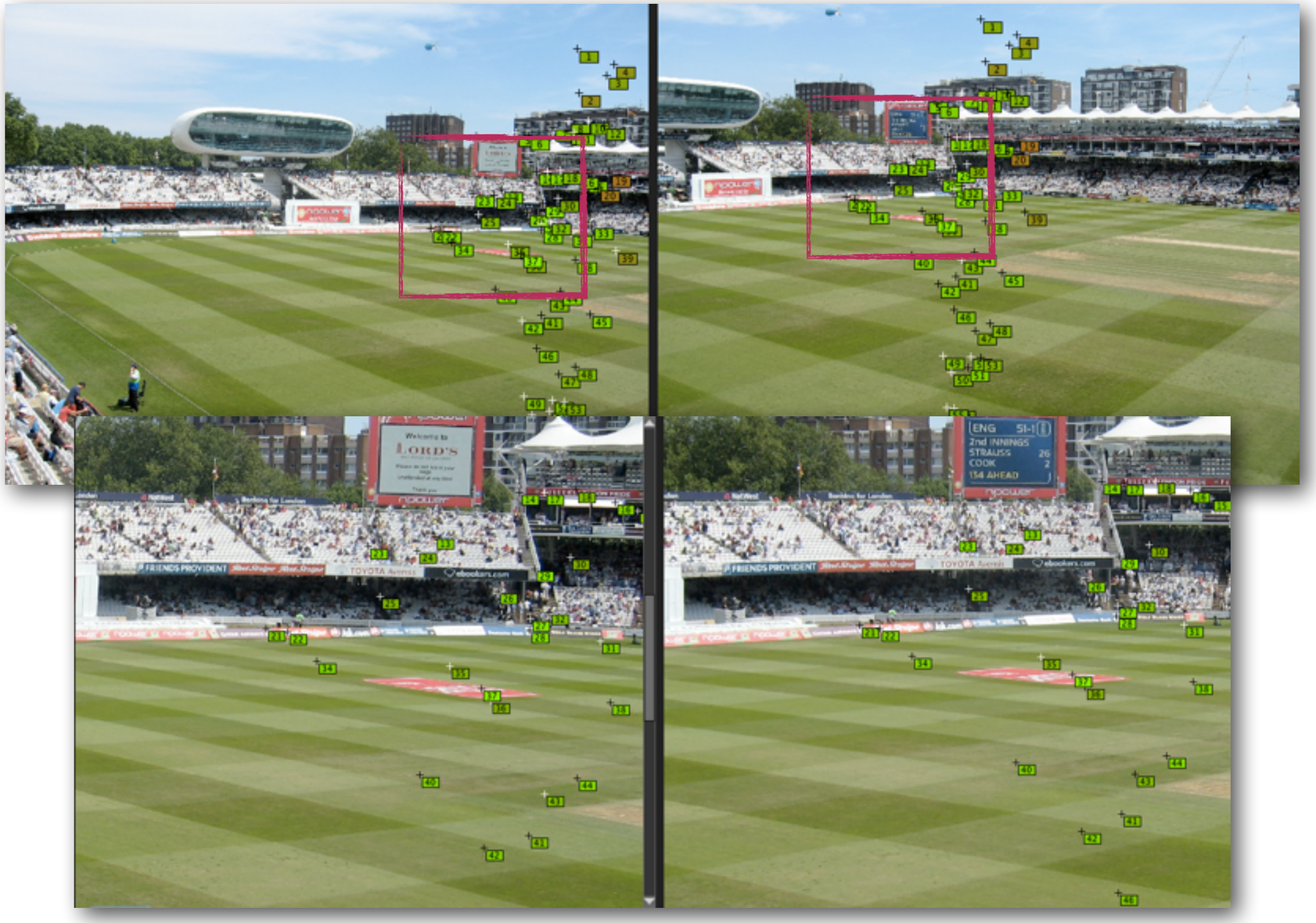
360 Panorama by Occipital

Consider the steps following Capture: Matching to Warping

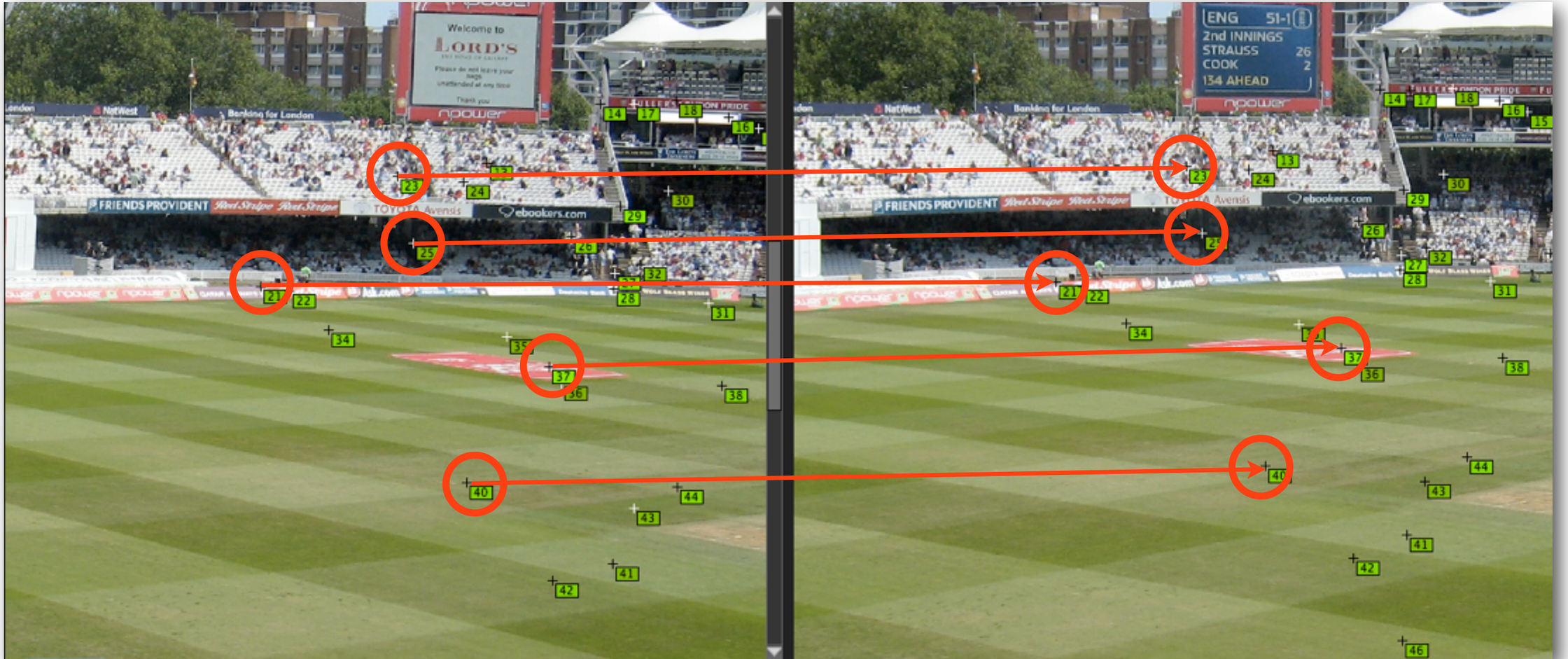


Using kolor autopano giga v3

Step 2: Detection and Matching



Step 2: Detection and Matching



Step 3: Warping








Step 3: Warping

Step 4: Fade, Blend, or Cut

Now we need to choose which pixels from which of the images should be visible

Step 5: Crop (Optional)

5 Steps to Make a Panorama

1. Capture Images
2. Detection and matching
3. Warping
4. Blending, Fading, Cutting
5. Cropping (Optional)

(Lords Cricket Ground, London, UK, by I. Essa)

Summary

* Introduced the concept of a Panorama
* Presented the steps required to make a Panorama
* Related the steps of building a Panorama to the basic elements of Computational Photography

Next Class

- Why study Computational Photography?
- Overview of Computational Photography
- How it relates to other disciplines?
- How it extends traditional and digital photography?

Credits

* Softwares used
* Autopano Giga 3.0 by kolor for macOS
* Autostitch by Cloudburst Research for iOS
* 360 Panorama by Occipital for iOS

Computational Photography

* Study the basics of computation and its impact on the entire workflow of photography, from capturing, manipulating and collaborating on, and sharing photographs.

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Computational Photography

* Study the basics of computation and its impact on the entire workflow of photography, from capturing, manipulating and collaborating on, and sharing photographs.

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Why Study Computational Photography?

* The Context of the Field of Computational Photography and Its Future

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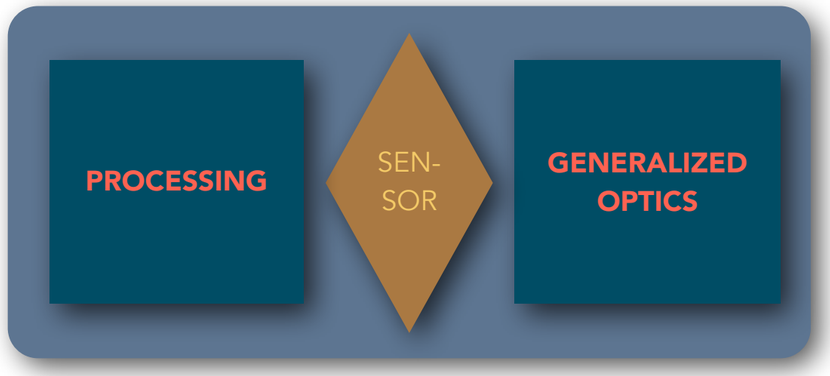
Lesson Objectives

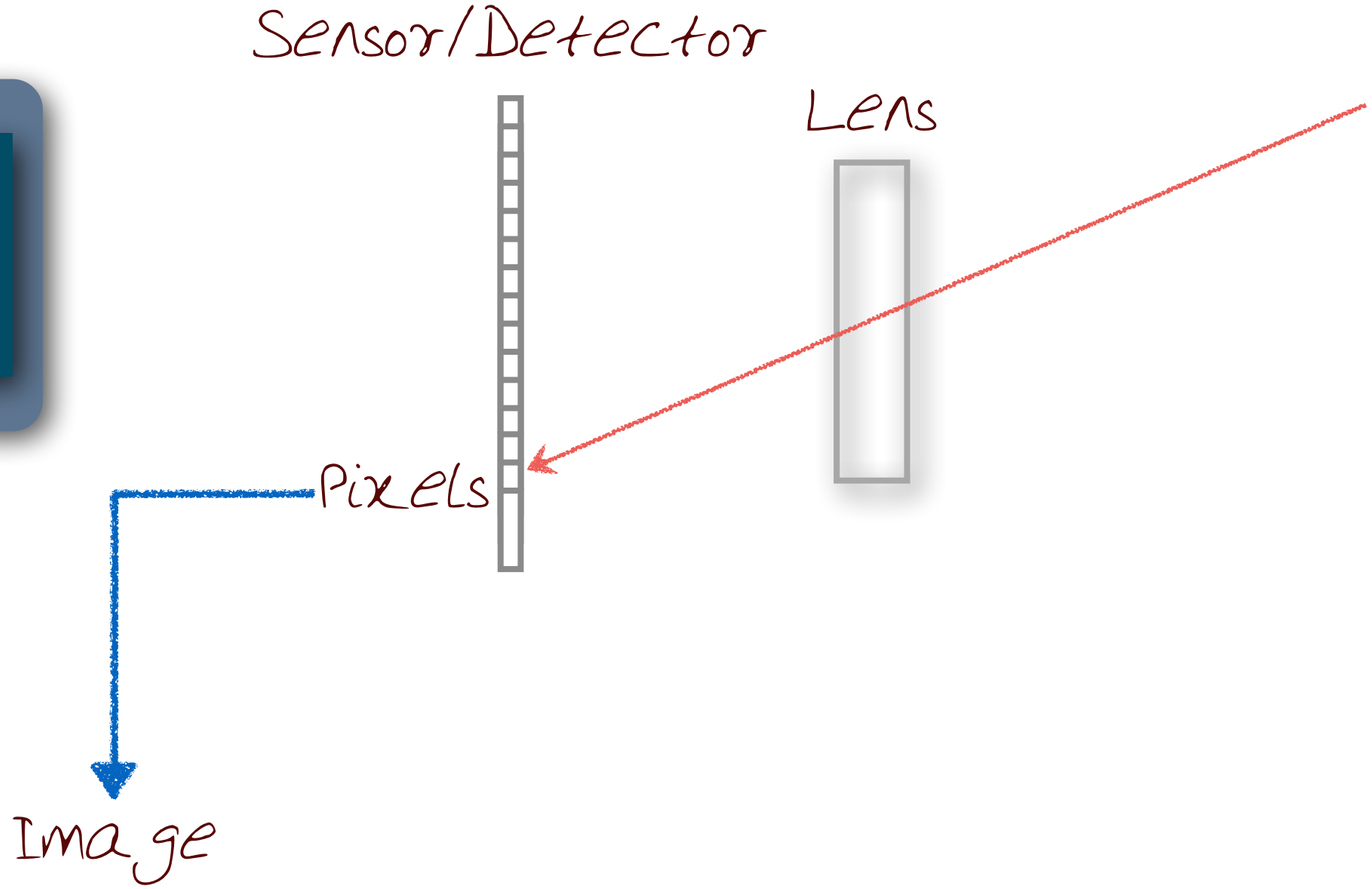
1. Pervasiveness of Photography
2. Computational photography as it relates to other disciplines
3. Computational photography vs. photography

Traditional Film/Digital Camera Processes



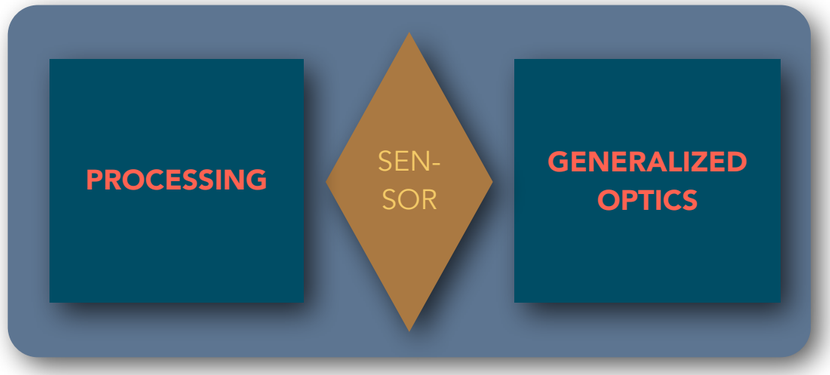
Novel Camera

Not sure what this diagram indicates, and why does it need to disappear?

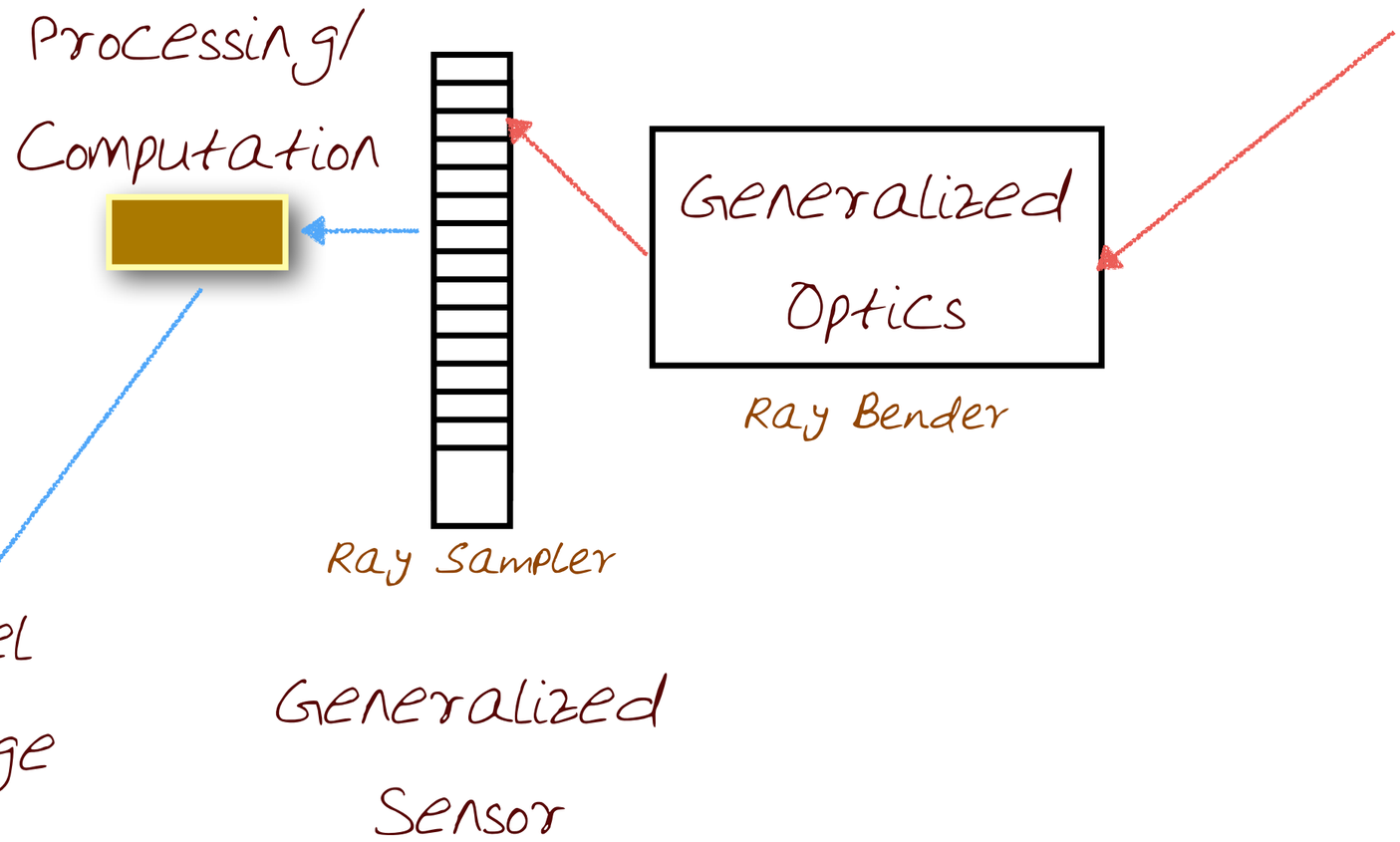


Schematic Similar to one used by Shree Nayar and Ramesh Raskar

Computational Camera Process



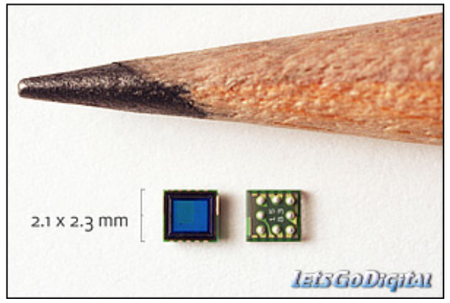
Novel Camera



Slide schematic based on slides by Raskar and Tumblin

So Why Study Cameras?

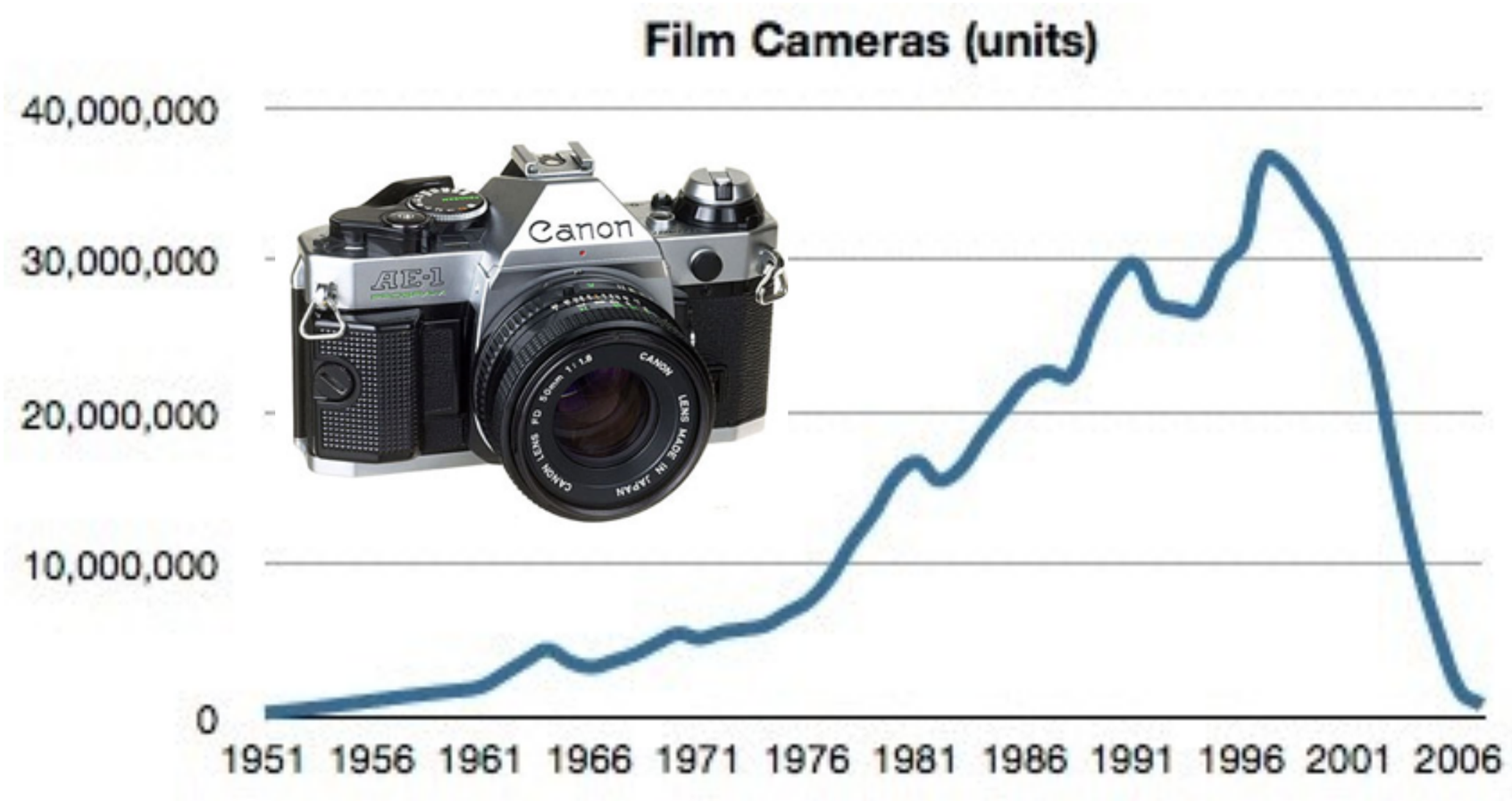
- Almost Everyone has a Camera
  - e.g., Smaller, Ubiquitous
- Significant Improvements in Optics
  - Field of Applied Optics has studied every aspect of the Lens
- Better, Cheaper Sensors (CCD/CMOS)
  - Sensor Electronics has its own Field



Cameras are Everywhere

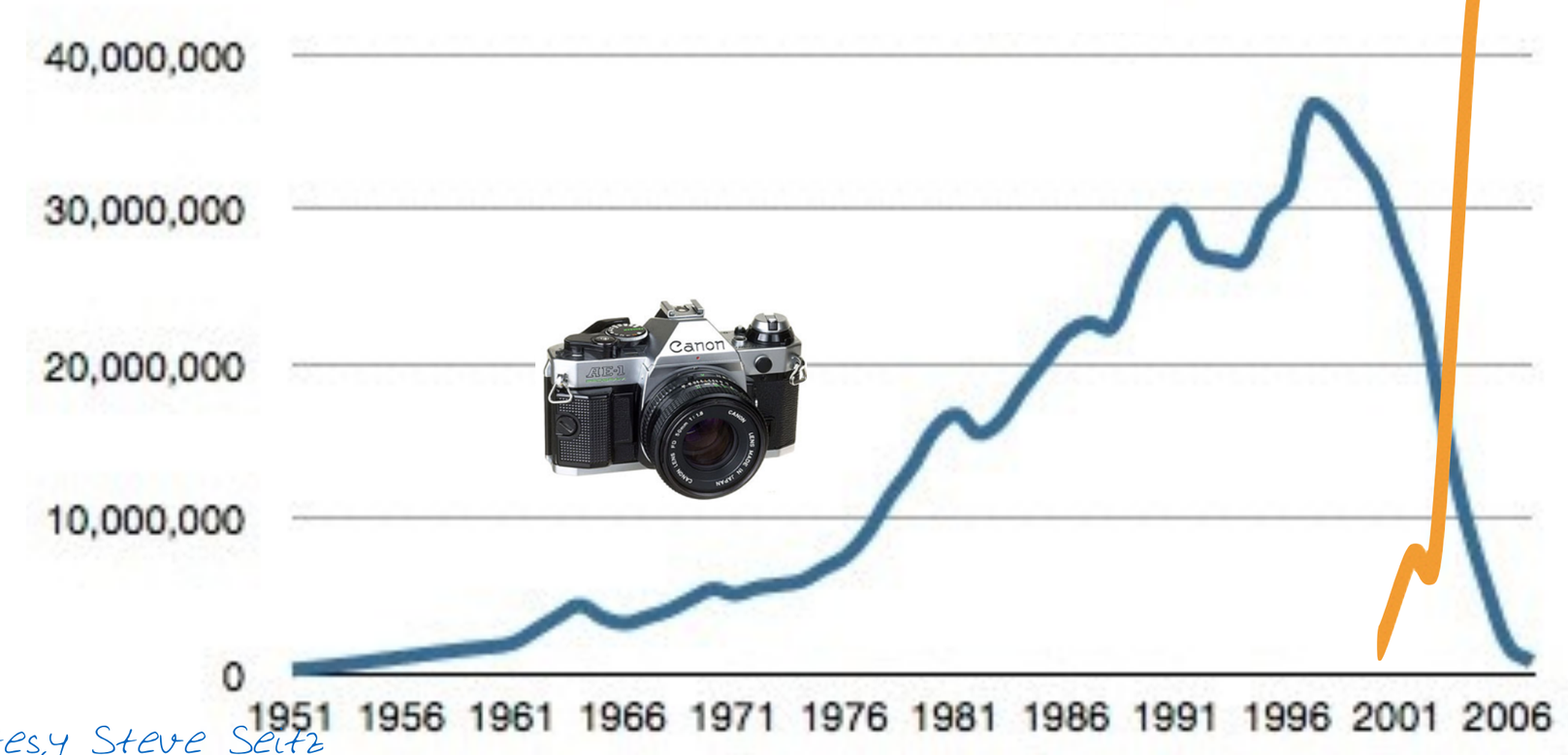
- Camera phones
  - Widest selling electronic platform
- Further expanded by new platforms:
  - Google Earth, YouTube, Flickr . . .
  - Text, Speech, Music, Images, Video, 3D, . . .
- Key element for art, research, products, social-computing . . .

SLR (film)



Slide: Courtesy Steve Seitz

SLR (film)

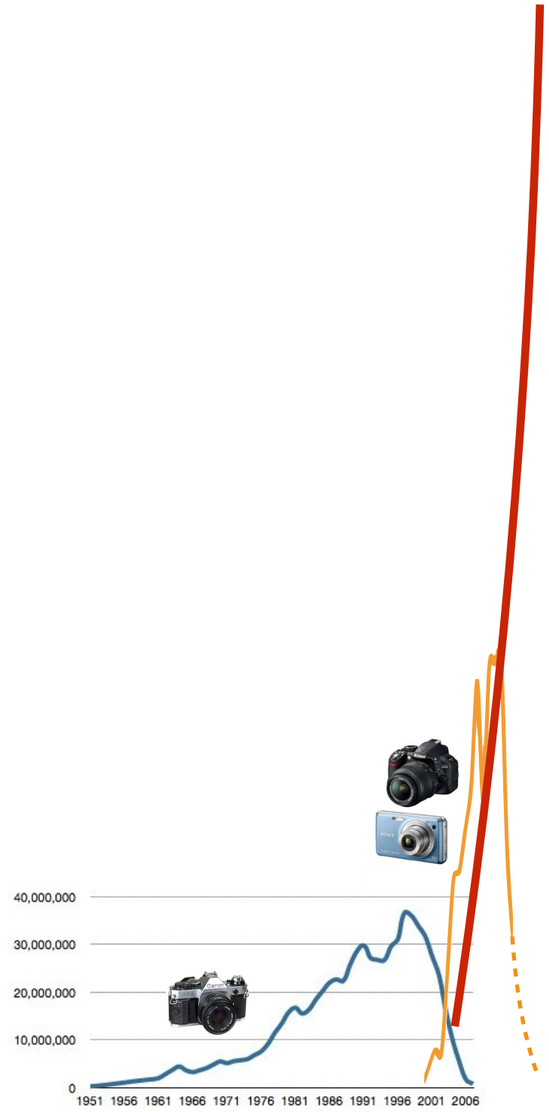


Slide: Courtesy Steve Seitz

Digital Camera

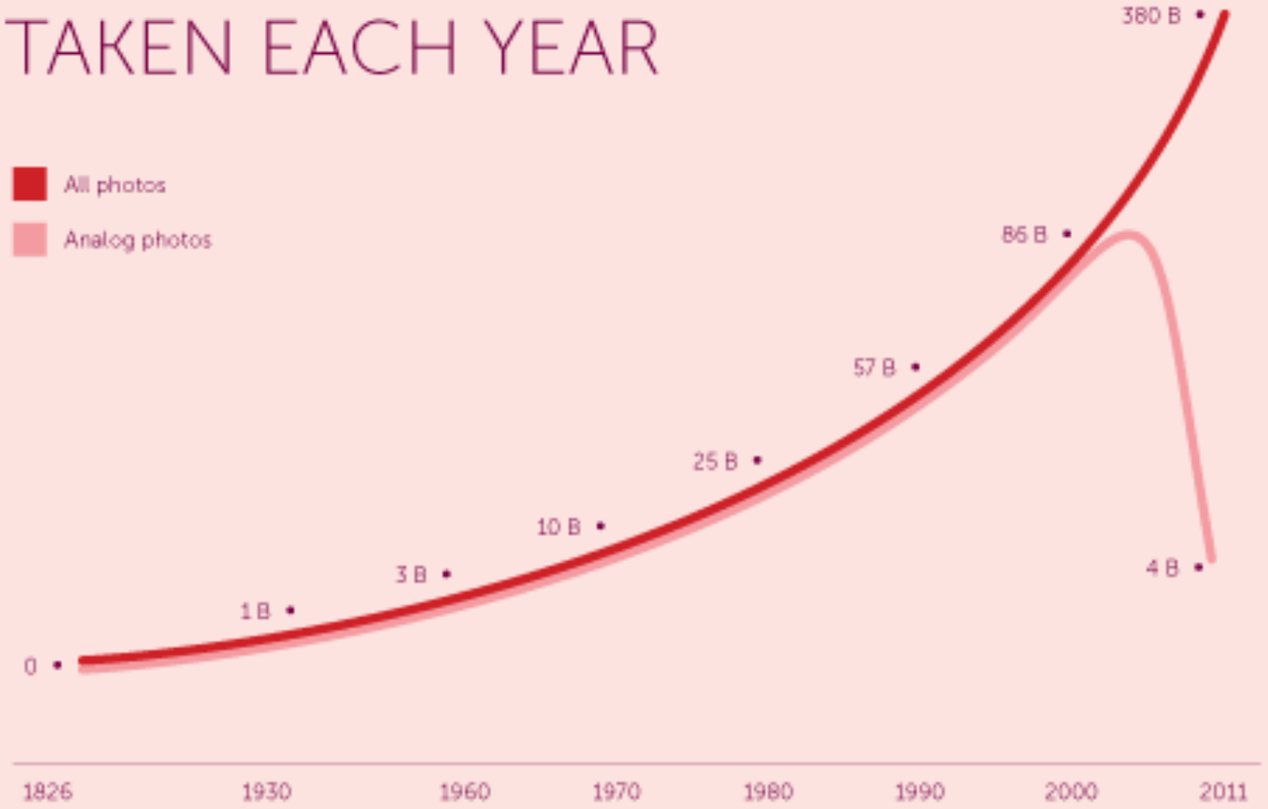
Slide: Courtesy Steve Seitz

Smart Phone Camera



Slide: Courtesy Steve Seitz

NUMBER OF PHOTOS TAKEN EACH YEAR



1000memories.com, Sep 2011

SLR to Camera Phones?

* <u>DSLR advantages</u>
  * more light
  * depth of field
  * shutter lag
  * control field of view
  * better glass
  * others (flash, man. modes, ...)

* <u>phone advantages</u>
  * computation
  * data
  * programmers

Comparison of Film and Digital Cameras/Photography

* Film and Digital Cameras have roughly the same Features and Controls:

* Zoom and Focus
* Aperture and Exposure
* Shutter Release and Advance
* One Shutter Press = One Snapshot

Computational Photography Extends FP/DP

* For FP/DP we can USE, but CP allows us to CHANGE!

* Optics, Illumination, Sensor, Movement
* Exploit Wavelength, Speed, Depth, Polarization, etc.
* Probes, Actuators, Network

Computational Photography Extends FP / DP

* Compared to FP/DP, CP has Better Specification and Support for:
  * Dynamic Range
  * Vary Focus Point-by-Point
  * Field of View vs. Resolution
  * Exposure Time and Frame Rate
  * Bursts

Evolution of the Cameras I

1839

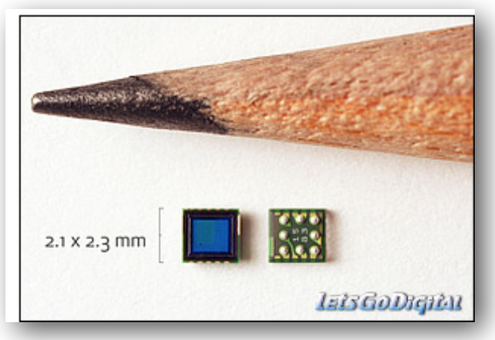
1907

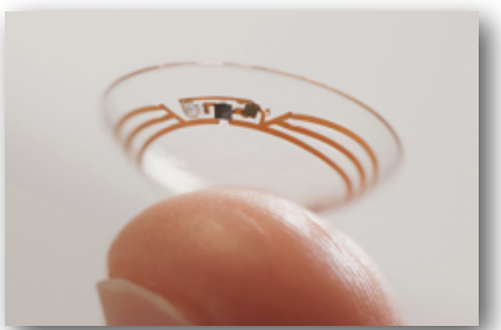
1948

1986

1991

2000





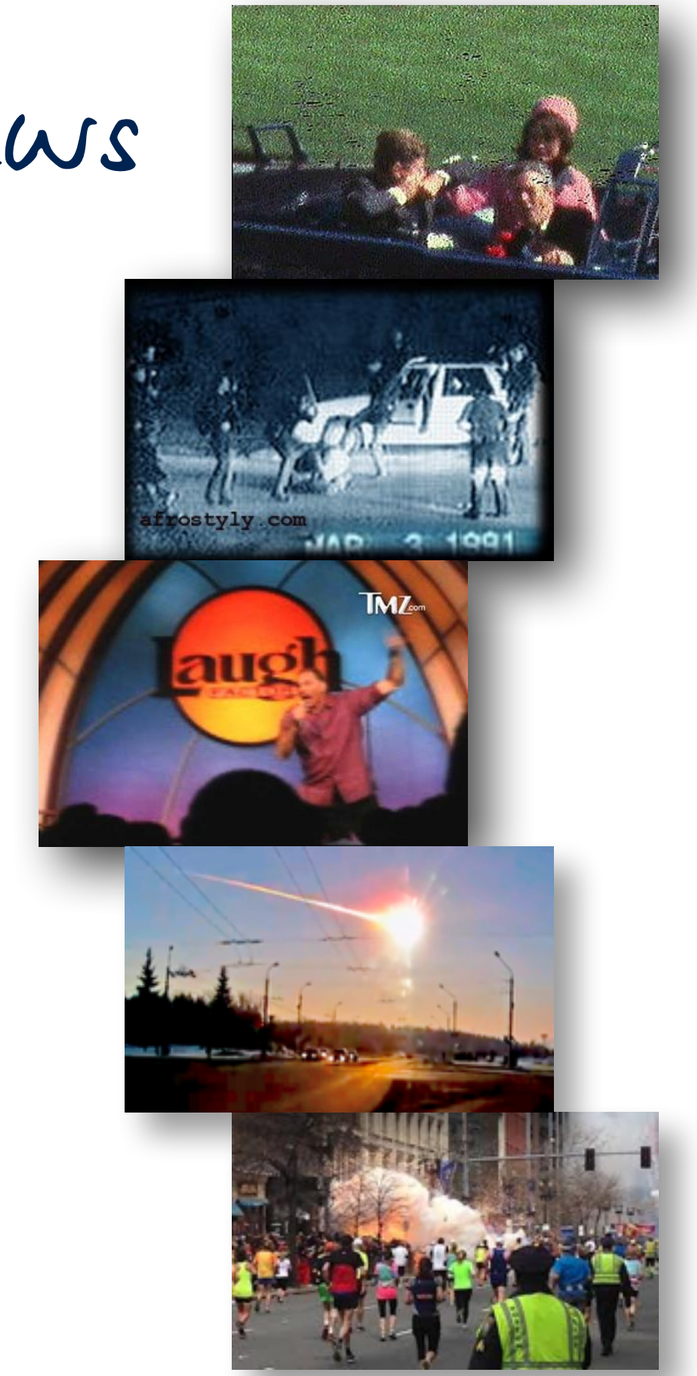
http://ericwilliamcarroll.com/blog/?p=23
http://simplevideoproduction.blogspot.com/
http://webdesign.njit.edu/2012/248/evolution.html

Evolution of the Cameras II

Evolution of the Cameras III

Joaquin Phoenix in Her (2013) by Annapurna Pictures

Images in News



- Kennedy Assassination (Zapruder Film)
- Rodney King Beatings in LA
- 9/11 Images
- 7/7 London Bombings
- Virginia Tech
- Michael Richards . . .
- Russian Meteor
- Boston Bombings . . .
- Beast with a Billion eyes (Literally!)

What kinds of IMAGES are out there?

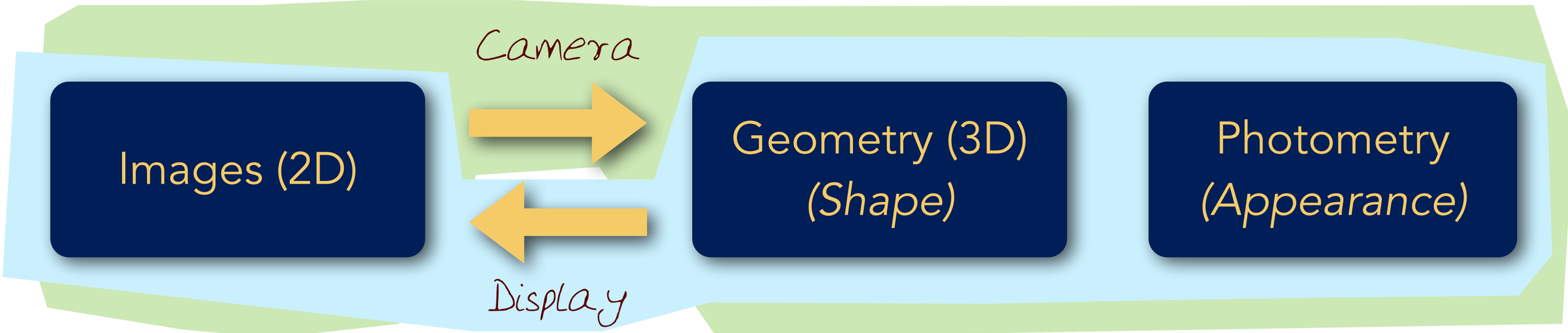
- Participatory Data
  - Handheld, citizen, etc.

- Institutional Imagery
  - Satellite, Airborne, Recon, UAV etc.

- Incidental
  - Security cameras, ATMs, etc.

http://www.ebay.com/itm/270804690527?
http://www.crishammond.com/
http://en.wikipedia.org/wiki/Photo_manipulation

Computer Vision and Computer Graphics



Computer Graphics

Computer Vision

Image Processing and Optics/Sensors

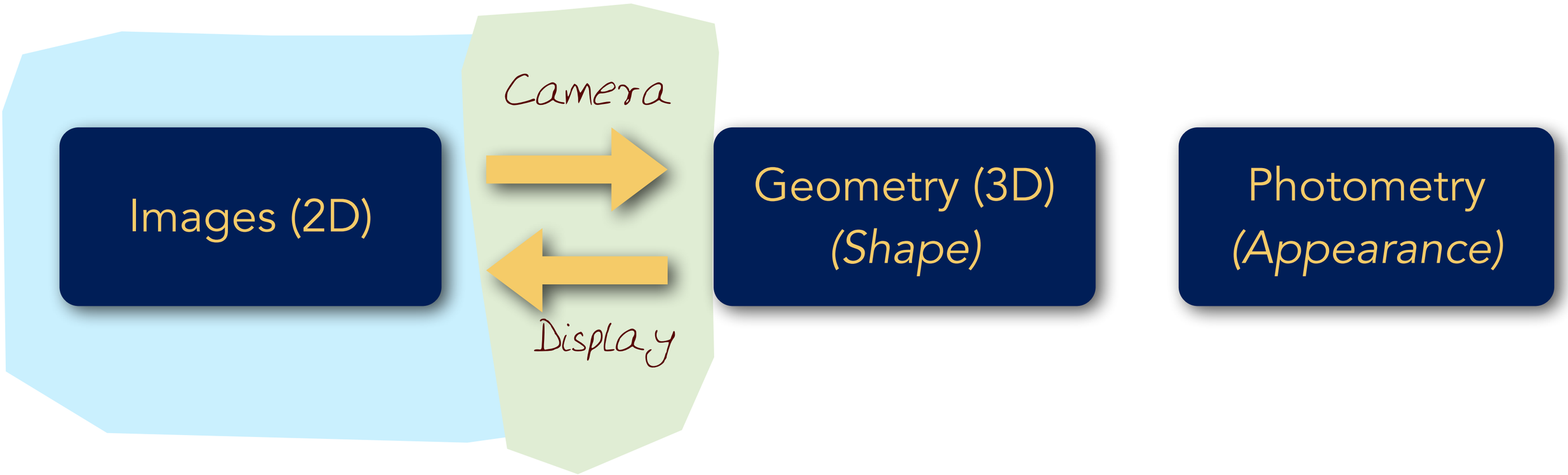
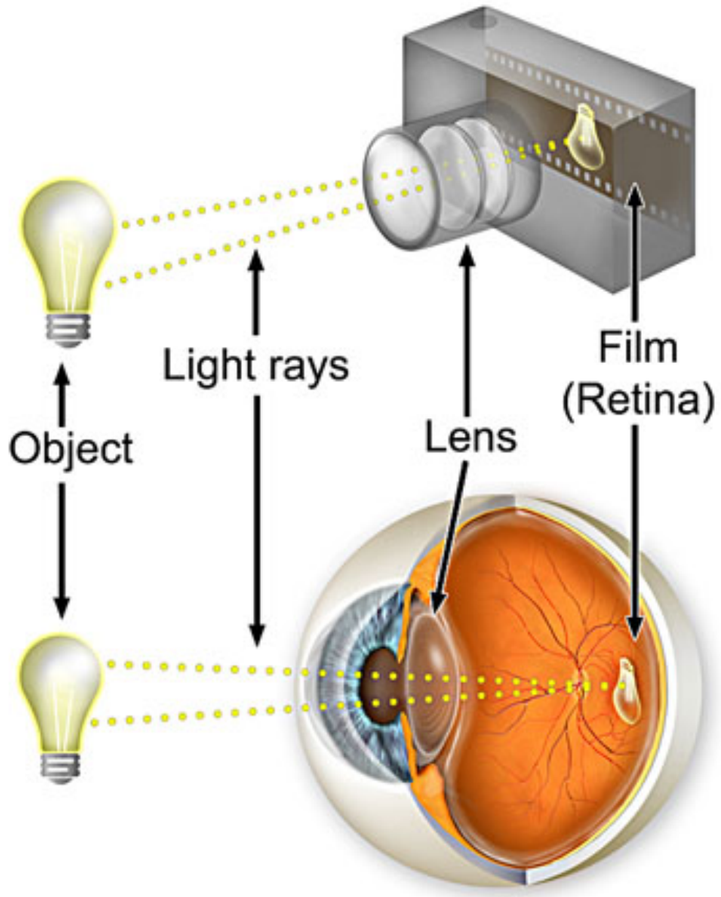


Image Processing

Optics / Sensors

Ultimate Camera?



Emerging Field of Computational Photography

* What will a camera look like in 10 years? 20 years?
* What novel images can we get? What are their Uses?
* How will the next billion cameras change the social culture?
* How can we augment the camera to support best "image search" ?

Emerging Field of Computational Photography

* How will ultra-high-speed/resolution imaging change our usage?
* How will autonomous and robotic cameras impact the photographic pipeline
* What are the opportunities in pervasive, experiential recording?
* How should we change cameras for movie-making, news reporting?

Summary

* Pervasiveness of Cameras
* Computational Photography in the context of computer graphics, computer vision, image processing and optics/sensors
* Computational Photography vs. traditional photography and digital photography
* A need to study Computational Photography

Next Class

* What is an Image?
* Creation of Digital Representation of Images.
* To compute with them
* To process them

Computational Photography

* Study the basics of computation and its impact on the entire workflow of photography, from capturing, manipulating and collaborating on, and sharing photographs.

Georgia Tech College of Computing