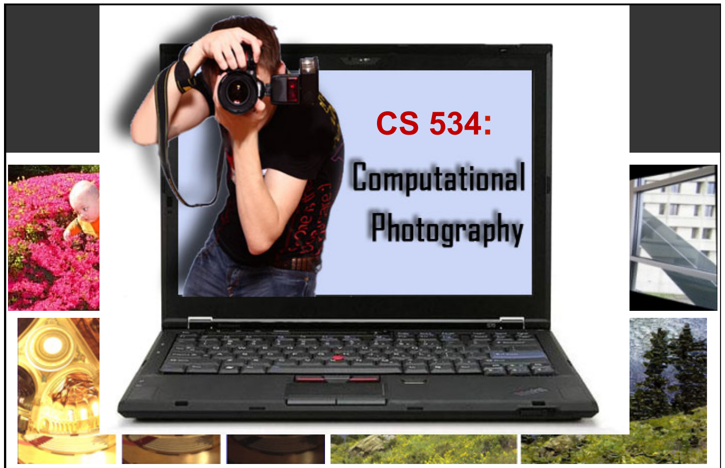


"You don't make a photograph just with a camera. You bring to the act of photography all the pictures you have seen, the books you have read, the music you have heard, the people you have loved."

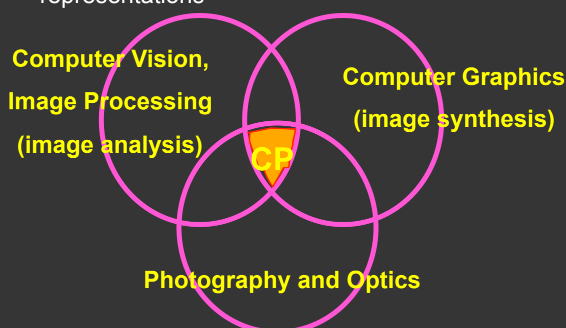
– Ansel Adams

"The camera is an instrument that teaches people how to see without a camera."

– Dorothea Lange

What is Computational Photography?

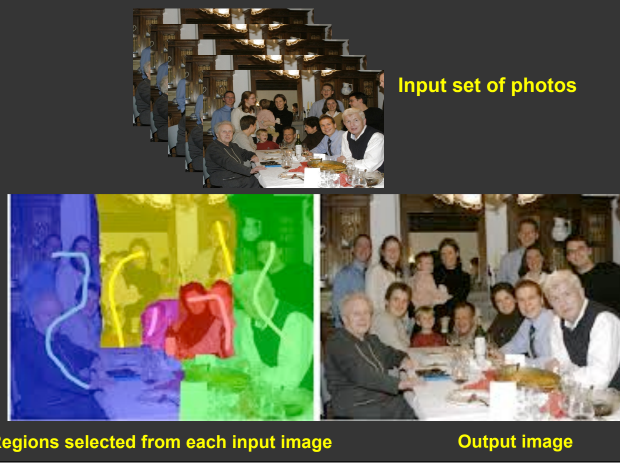
- An extension of traditional digital photography that uses computational techniques for **improving or augmenting image making** by producing new types of image or scene representations



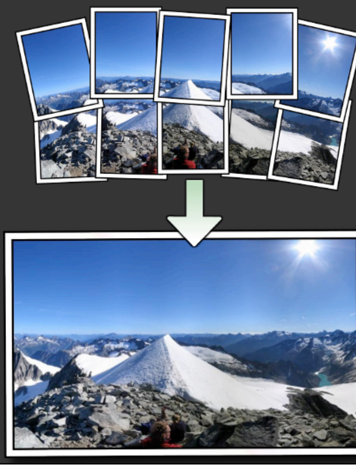
What is Computational Photography?

- Digital Photography
  - Simply replaced traditional film by digital technology
- Computational Photography
  - Image manipulation and computational techniques for capturing, analyzing, manipulating, combining, augmenting, searching, synthesizing, and using images for new applications (**software**)
  - Design new kinds of cameras (**hardware**)
  - Create new types of images, e.g., panoramas, 3D models, high dynamic range images

Example: Photomontage

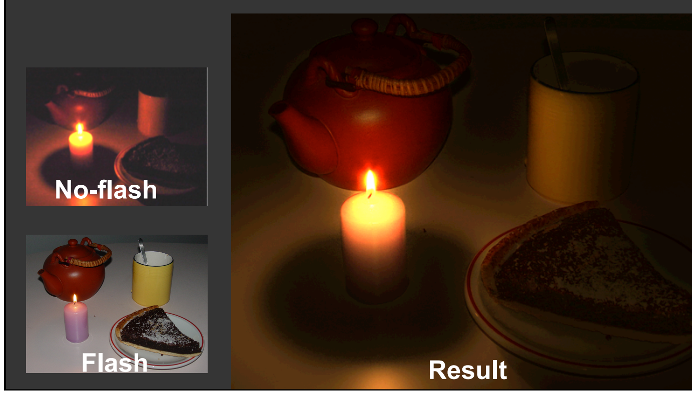


Example: Panoramic Images

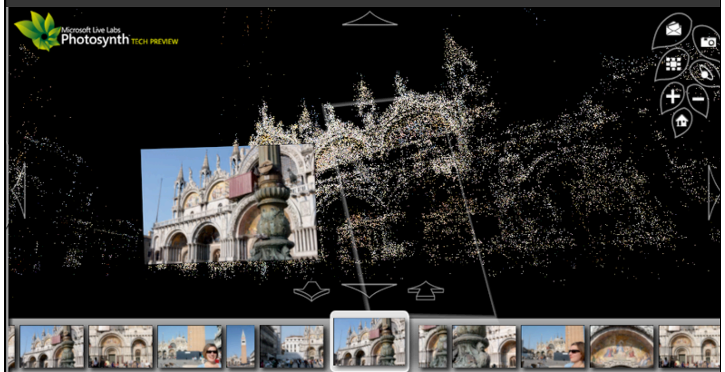


Example: High Dynamic Range Images

Example: Flash + No-Flash



Example: 3D Scene Reconstruction



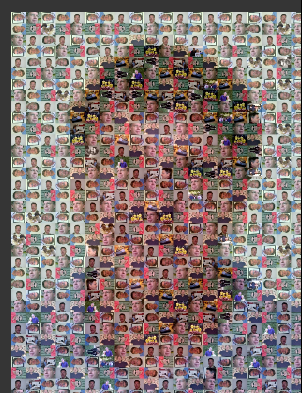
Course Information

http://pages.cs.wisc.edu/~cs534-1

- Pre-req: CS 367 (Matlab not assumed)
- Textbook: None. Readings from papers and some chapters in books (all online)
- Powerpoint slides
- **Piazza** web page for Q&A
- **Moodle** web page for homework electronic hand-in
- Alternative courses: CS 766: Computer Vision (Spring), CS 567: Medical Image Analysis (Spring)

Instructor

- Chuck Dyer
  - Chuck, Prof. Dyer, Dr. Dyer
  - 6379 CS
  - Office hours: MW 2 – 3
- Ph.D., University of Maryland
- M.S., UCLA
- B.S., Stanford
- Hometown: San Diego
- Research: Computer vision
- Hobby: Running (3:28 marathon in 2008, 4:22 mile in high school)



Teaching Assistant

- Qisi “Cheese” Wang
  - 1308 CS
  - Office Hours: TR 11:45 – 12:45
- CS graduate student
- B.S., Georgia Tech
- Hometown: Beijing, China

Course Requirements

- Class Attendance and Participation: about 5%
  - Come to class (attendance will be taken randomly)
  - Ask questions and make comments, including on Piazza (not anonymous)
  - Come to office hours
- Homework Assignments: probably 4, about 45%
  - Try out existing apps such as Photosynth and Photomatix
  - Implement some methods using **Matlab**
  - 3 free late days; late penalty: 1 day 10%, 2 days 25%, 3 days 50%, 4 days 100%
- Course Project: about 25%
  - Define, implement, experiment, write report, present in class
  - Grading is based primarily on effort, results and initiative – try to be creative!
  - **3-person teams**
- Midterm Exam: about 25%
  - **Tentatively Thursday, October 27**, 7:15 – 9:15 p.m.
- No Final Exam

Project Ideas and Grading

- "Straightforward" approach: Pick a paper, implement it, extend it in some ways, and perform experimental evaluation
- Pick a paper that's easy to understand and on a topic you're interested in
- Grading based on effort, initiative, creativity, coolness, difficulty, focus, depth, implementation, quality of experimental results, originality, project report write-up
- Best to pick a **narrower** topic and go **deeply** into it rather than pick a broad topic that is not very in-depth on any part

Class Presentation

- December 13 and 15
- ~5 minutes
- Conference-style "powerpoint" talk
- State problem, give motivation and example, background, description of method and main ideas of the approach, initial results, discussion of strengths and weaknesses of the method, possible future extensions

Course Overview

- Digital photography
- Image filtering
- Texture synthesis, image completion,
- Combining multiple images into panoramas
- Feature detection, warping, morphing
- Faces and places
- 3D scene reconstruction
- High dynamic range imaging and tone mapping
- Light fields, flash/no-flash photography
- Video processing (if time)

What will *Not* be Covered

- Photoshop
- New camera technologies (except briefly)
- Video (except briefly)
- Combining photographic imagery with standard graphics imagery ("augmented reality")

Things to Do

- Check out the course web page
  - pages.cs.wisc.edu/~cs534-1
- Activate your CS instructional Linux and Windows accounts
  - If you had a CS account in Spring or Summer, you do *not* need to re-activate your account; use same CS login
  - Otherwise, go to CSL web site and click "Activate Account" link
- Sign up on Piazza
  - piazza.com/wisc/fall2016/cs534/home

Things to Do

- Start learning or reviewing Matlab
  - In-class introduction to Matlab will be given
- Read introductory papers
- Start on HW #1 (due Thursday, September 15)
- Start thinking about possible course project ideas and possible 3-person team

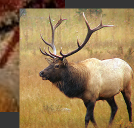
Today

Course overview and motivation

A *Very* Brief History of Image Making

- Painting
- Camera Obscura
- Film photography
- Digital photography
- Computational photography

Depicting Our World: The Beginning

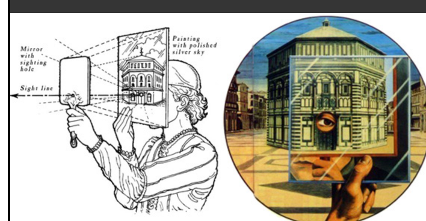


Prehistoric Painting, Lascaux Cave, France, 13,000 – 15,000 BCE

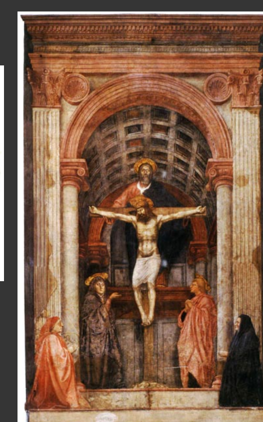
Cimabue, "Madonna in Majesty" 1295-1300

European artists in the Middle Ages did not depict 3D realism well

Linear Perspective Painting (15th century)

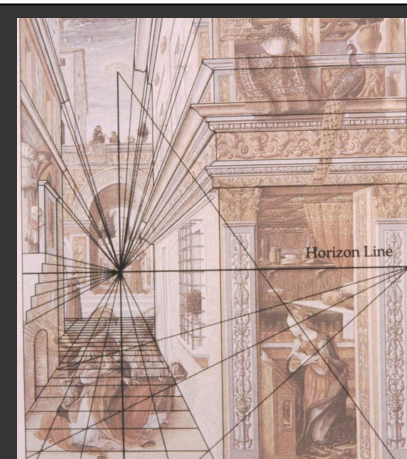


Brunelleschi (c. 1413)



Masaccio (c. 1427) *Trinity*, Florence

Carlo Crivelli (1486) *The Annunciation, with St. Emidius*

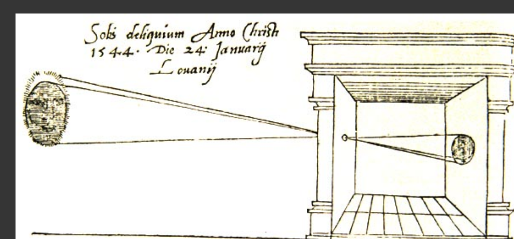


Perspective analysis of Crivelli's *Annunciation*

Selfie Invented 1523

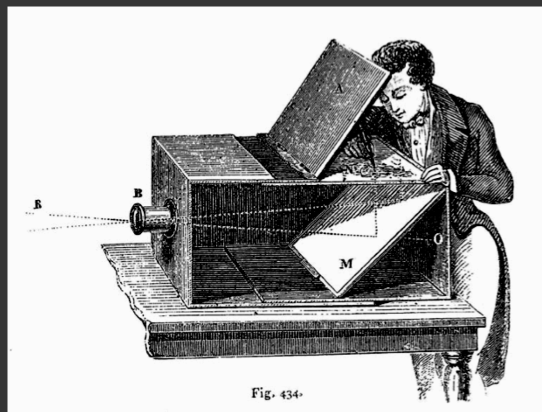
Camera Obscura

Written about by Mozi (China) in 400 BCE, Aristotle (Greece), Alhazen (Arabia), da Vinci (Italy), and others



R. Gemma Frisius (1545) ***Observing solar eclipse of 24 January, 1544.*** **Engraving from** ***De radio astronomico et geometrico liber.*** **Earliest known illustration of a camera obscura.**

Lens-based Camera Obscura (1568)



Film Camera (1825)

- Photography invented about 1825 by Joseph Niepce
  - 8 hour exposure time!

- William Henry Fox Talbot invents the *calotype* in 1834
- Louis Daguerre invents *daguerreotype* in 1837
- James Clerk Maxwell invents *color* photography in 1861

Consumer Cameras: Kodak Brownie

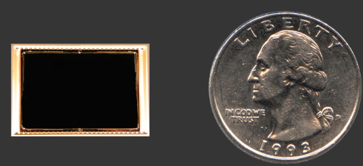
Brownie 127 (1952 – 1967)

1900

Consumer Cameras: Kodak Instamatic

Introduced in 1963; 60 million sold

Silicon Image Sensor (1973)



CCD chip with 100 x 100 pixels produced by Fairchild Semiconductor

First Digital Camera (Kodak, 1975)

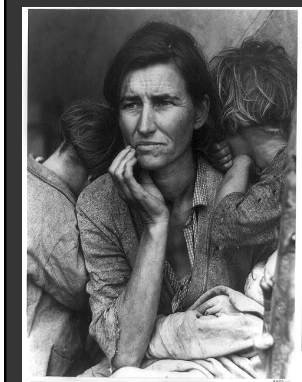
Steven Sasson

Digital Camera (1991)

Kodak DCS-100 introduced in 1991 with 1.3 MP

Traditional Photography

- Traditional photography, film or digital, focuses on the process of ***recording rays*** of light onto a permanent medium
- The ***art*** of photography is controlling the many settings (shutter speed, aperture, lighting, viewpoint, etc.) to obtain high-quality photographs
- But, what are photographs / images *for*?
- What we SEE is influenced by the Human Visual System, and what we often *want* is to **capture a representation of a *visual experience***



Dorothea Lange, 1936

Joe Rosenthal, 1945

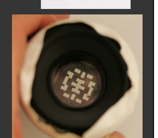
Ansel Adams, 1937

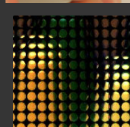
Image Making, *Not* Image Taking

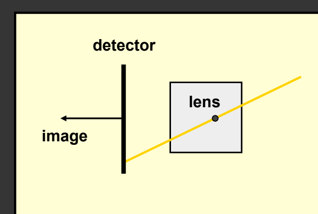
- Overcome limitations of traditional photography and enhance visual experiences
  1. Capture and combine *more light rays* from the “light field”
     - **New computational cameras** (optics + computation)
  2. **Improve image quality**
     - Deblur, refocus, relight, denoise, dehaze, different capture time
  3. Exploit the billions of images on web & social media
     - **Community photo collections / the Internet of Cameras**

What is Computational Photography?

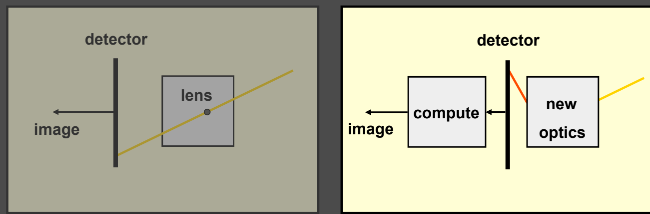
- Answer 1: Develop new hardware for capturing light rays: New cameras
  - Object side coding
    - Add optics in front of lens, e.g., mirror
  - Focal plane coding
    - Add optics close to sensor, e.g., microlens arrays
  - Illumination coding
    - Add lighting, e.g., multi-flash or projected light pattern
  - Camera clusters or arrays
- Goal: Optical coding followed by computational decoding to produce new types of images and scene representations







Traditional Camera



Traditional Camera
Computational Camera

3D Cameras

Fujifilm FinePix Real 3D W3
$500 (2015)

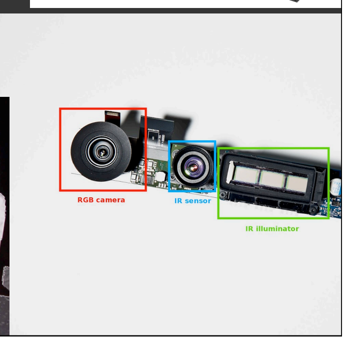
Sony HDR-TD30V camcorder
$2,500 (2015)

LG Optimus 3D Camera Phone
$600 (2015)

- 2 CCD sensors and 2 lenses
- Glasses-free 3D display

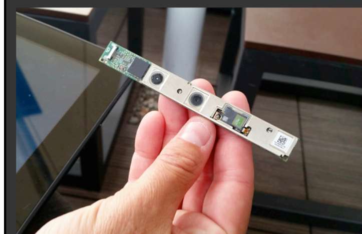
Depth Cameras

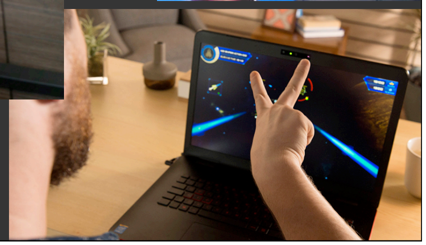
Microsoft Kinect for Xbox Sensor ("Kinect 2")
- Color video camera + infrared time-of-flight camera
- $150 (2015)



Depth Cameras

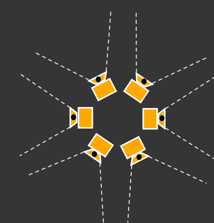
Intel RealSense 3D Camera





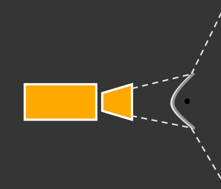
Wide-Angle Imaging

Multiple Cameras



Examples: Disney 55, McCutchen 91, Nalwa 96, Swaminathan & Nayar 99, Cutler et al. 02

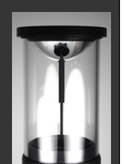
Catadioptric Imaging

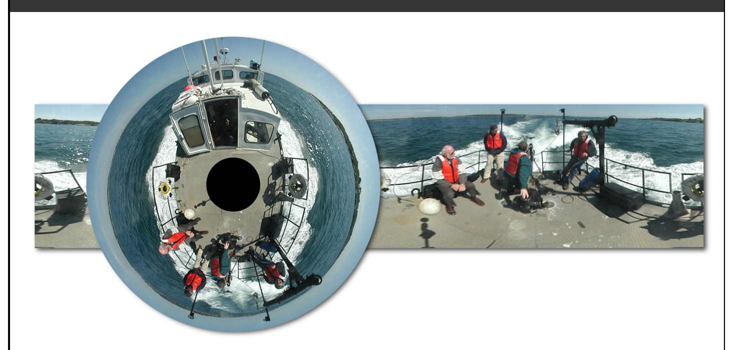


Examples: Rees 70, Charles 87, Nayar 88, Yagi 90, Hong 91, Yamazawa 95, Bogner 95, Nalwa 96, Nayar 97, Chahl & Srinivasan 97

360° Cameras

- RemoteReality OmniAlert 360
  - Camera w/ parabolic mirror
- Point Grey Ladybug3
  - 6 video cameras, stitched into 5400 x 2700 "spherical image" @ 15 fps ($15,000)





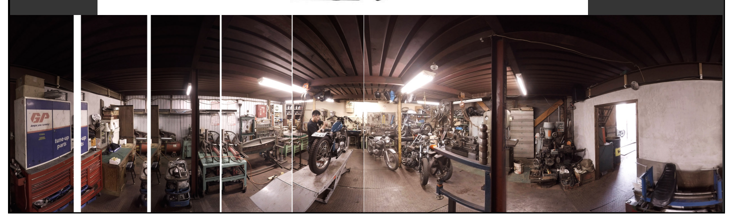
Kogeto Dot 360 Camera for iPhone

Point Grey Ladybug3

Ricoh Theta S Camera

- Two fisheye lenses back-to-back
- Images stitched in-camera into 14 MP 360° image
- Wi-Fi, integrated with Google's Street View app
- $350 (2015)

Google Jump

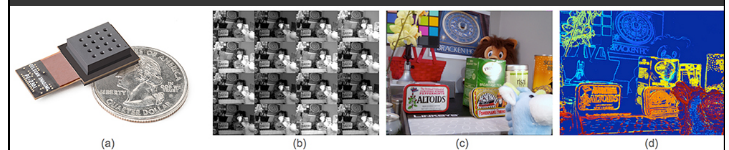


Array Cameras

- Point Grey ProFusion 25 (5 x 5 camera array)
  - 25 640 x 480 images at 25 fps
- Pelican Imaging array camera for mobile devices
  - 4 x 4 array, each 1000 x 750 pixels



Pelican Imaging PiCam



4 x 4 camera array | 16 1000 x 750 images | Parallax-corrected 8 MP image | 8 MP depth map

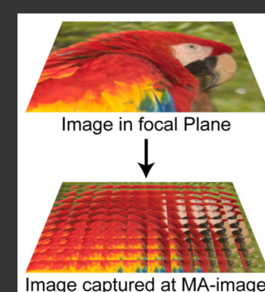
Linx Array Sensors Bought by Apple (2015)

Dual-camera rumored to be in iPhone 7

Light Field / Plenoptic Cameras

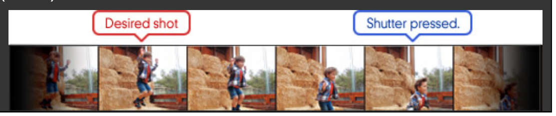
- Lytro Illum $329 (2016)
- Multiple, "synthetic apertures"
- Allows focusing ***after*** capture





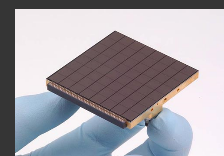
High-Speed Cameras

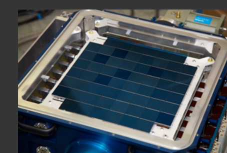
- Casio Exilim EX-ZR100
  - High-speed movie mode
    - 30 fps at 1980 x 1080 (HD)
    - 240 fps at 432 x 320
    - 1000 fps at 224 x 64
  - High-speed, continuous-shutter still image mode
    - Up to 30 10 MP images at 40 fps
    - Pre-record mode: half-press shutter to start continuously-refreshed buffer of images; full press records buffer contents
  - $300 (2011)



Gigapixel Cameras

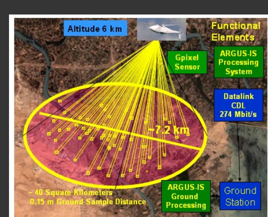
- Pan-STARRS GPC1
  - Custom-built camera for astronomical use
  - 64 x 64 array of CCD sensors, each 600 x 600 pixels, giving image with 1.4 gigapixels


8 x 8 array of sensors on a chip


56 cm diameter effective sensor

Gigapixel Cameras

- DARPA Argus-IS 1.8 gigapixel video camera (@15 fps) on Predator and Hummingbird unmanned aerial vehicles (UAVs) for airborne surveillance system called "Gorgon Stare"
  - Combines 4 cameras, each with 92 5 MP sensors



Gigapan Camera Mounts

Robotic camera mount + camera + stitching software + viewer

Example:

70,000 images stitched into 365 GP panorama of Mount Blanc

www.in2white.com

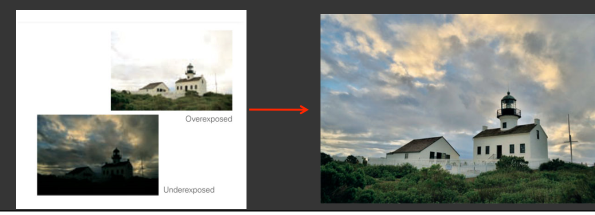
In-Camera Panoramas

- Fujifilm FinePix X100
- 120° or 180° “motion panorama” mode
- Up to 10 frames combined to produce 7680 x 2160 image
- $1,200 (2011)

by KopiOkaya, 2011

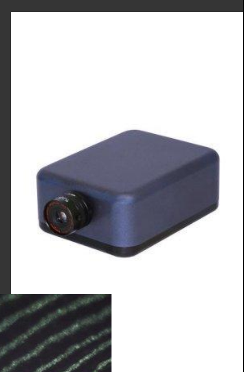
In-Camera HDR

- Nikon D5100
  - automatically combines multiple exposures to produce a single HDR image
- Casio EX-ZR100
- Apple iPhone (3 exposures)



Hyperspectral Cameras

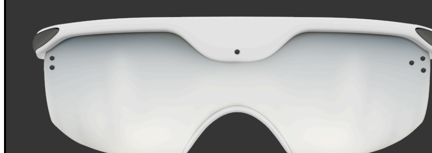
- Surface Optics SOC710
  - 128 “bands,” 400-1000 nm spectral range (visible light: 400-750 nm)
  - $20,000



Wearable Cameras

Looxcie wearable camcorder

Google Glass

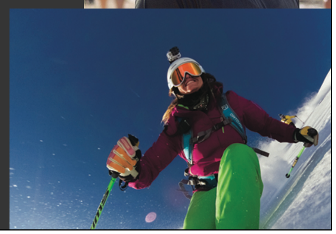


Pelican Imaging glasses

Wearable Cameras

GoPro Camera
- Waterproof, shockproof, video camera
- 12 MP images, 60 fps, Wi-Fi



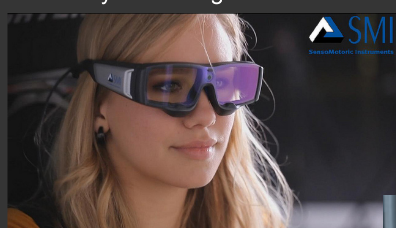


Wearable Cameras

Memoto Camera
- Auto captures 2 fps (adjustable)
- 5 MP images, GPS, timestamp, accelerometer
- $279 (2013)


Wearable Cameras

- SMI Eye Tracking Glasses



- SMI Head Tracking Glasses

Flyable Cameras

- DJI Phantom 2 Vision Quadcopter with integrated camera
- $1,200 (2014)

Camera with Tongue Display

- Wicab BrainPort (Middleton, WI)

20 x 20 electrode "image"

Phodographer

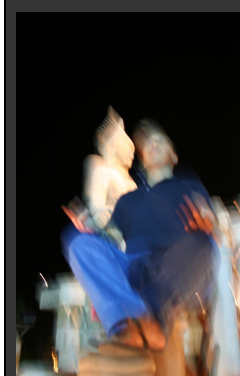
- **Heart rate monitor + camera**
- **When the dog's heartrate goes up, the camera snaps a picture**

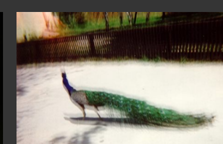
What is Computational Photography?

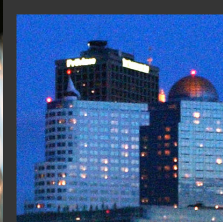
- Answer 2: Capture multiple images varying camera setting X (e.g., aperture, position, time) and combine them to produce a single image that exhibits better Y, overcoming limitations of traditional photography
  - Larger field of view (panoramic images)
  - Improve dynamic range (HDR images)
  - Improve lighting
  - Change focus
  - Video stabilization
- In-camera or off-camera processing

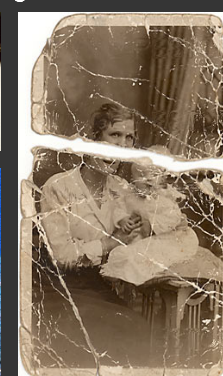
Image *Enhancement*: Overcome the Limitations of Traditional Photography

- Blur, camera shake, noise, damage



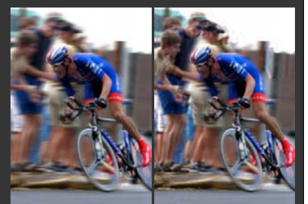






Removing Camera Shake and Motion Blur

Fergus et al. (2006)



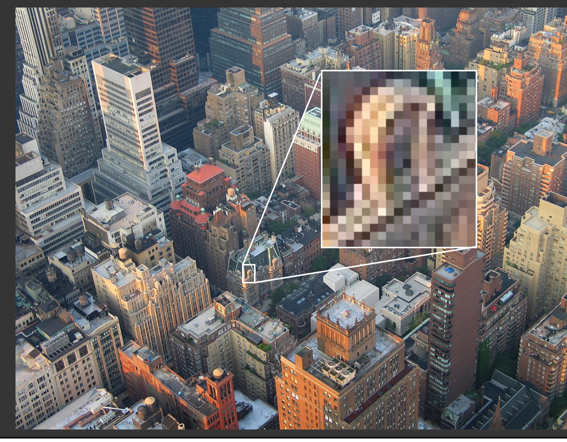
Levin (2006)

(a) blurred image (b) noisy image (c) enhanced noisy image (d) our deblurred result

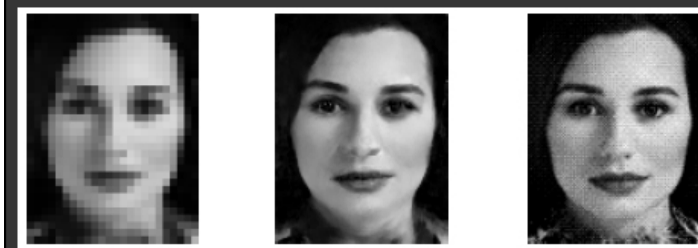
Yuan et al. (2007)

Limitations of Traditional Photography

- Limited resolution



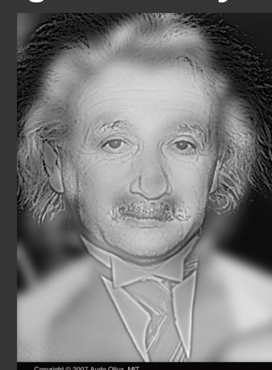
Hallucinating Faces



(a) Low-res input (b) Hallucinated by our system (c) Original high-res

C. Liu, H. Shum, and W. Freeman, Face Hallucination: Theory and Practice, *IJCV*, 2007

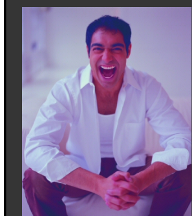
Combining Faces: Hybrid Images

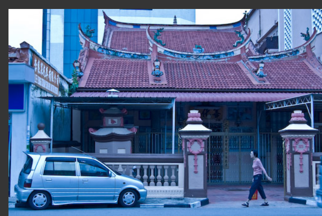


A. Oliva, A. Torralba, P.G. Schyns, "Hybrid Images," SIGGRAPH 2006

Limitations of Traditional Photography

- Bad color / no color



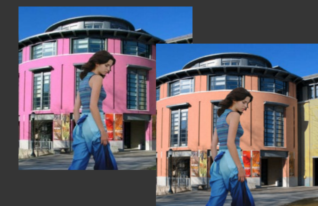


Color Image Manipulation

Colorization

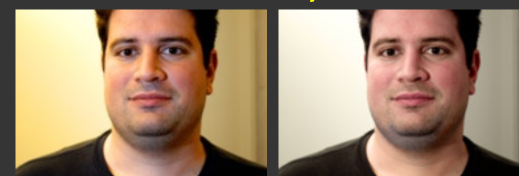
Levin et al. (2004)

Color Harmonization



Cohen-Or et al. (2006)

White Balance Adjustment

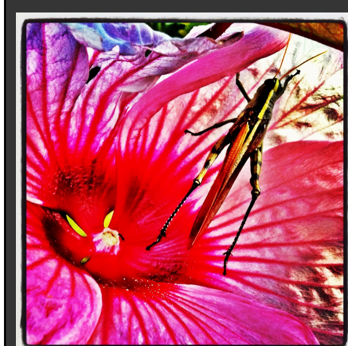


Hsu et al. (2008)

Image Manipulation for *Artistic* and Other Effects

- Many smartphone apps
  - Instagram
  - Snapseed
  - Shockmypic
  - Vignette
  - PhotoFX
  - ToonPaint
  - ArtistaOil
  - many, many more
- Most involve ***manual*** editing tools

Instagram

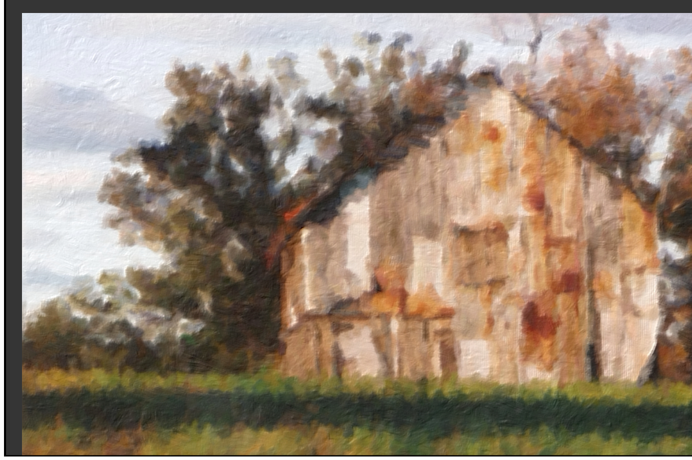


Photos by Sue Lyddon Hall

ToonPaint

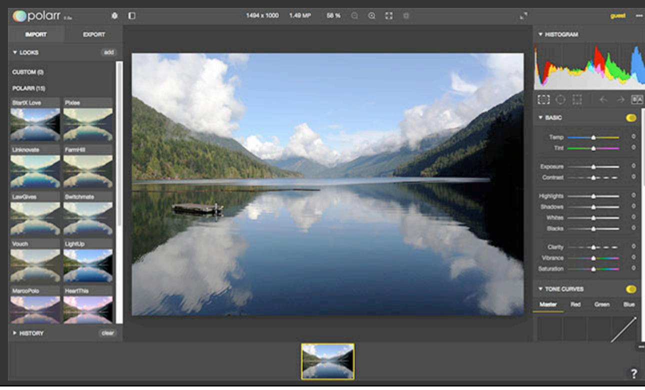
Snapseed

ArtistaOil



Polarr

Online photo editor started by former CS 534 student, Borui Wang

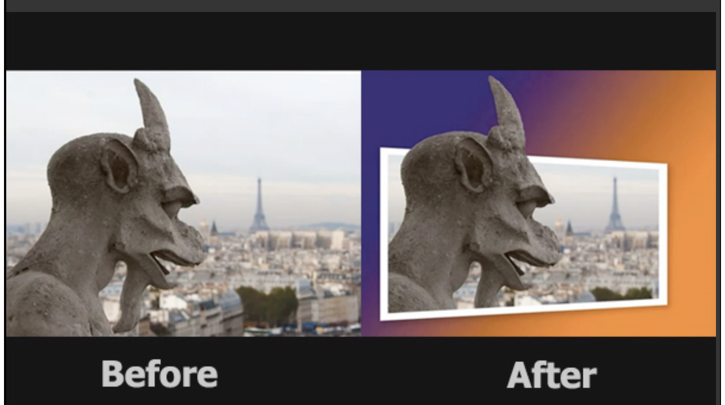


"Joiners"

David Hockney, Pearblossom Highway, April 1986

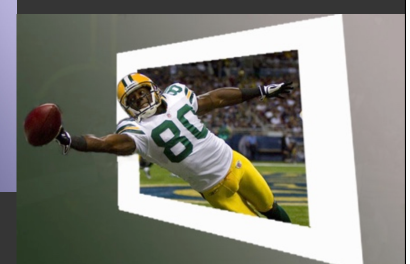
Kelsey Bloomquist, 2010

Out-of-Bounds Photographs



Out-of-Bounds Photographs

Ali Bramson, 2011



Stephanie Scherer-Johnson, 2011

Limitations of Traditional Photography

Bad expressions

Limitations of Traditional Photography

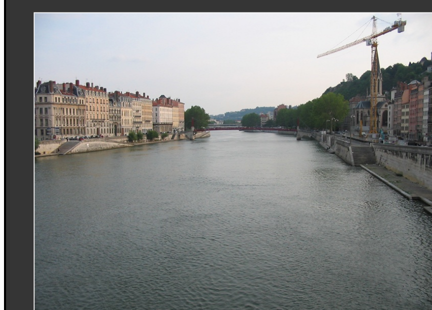
Limited dynamic range

Limitations of Traditional Photography

Single viewpoint, static 2D picture

Limitations of Traditional Photography

Unwanted objects

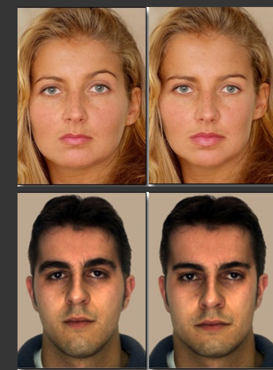


Background Replacement

(a) input (b) result 1 result 2

Sashi Kumar Penta

Face Beautification



Lots of "face beautification" apps

T. Leyvand, D. Cohen-Or, G. Dror and D. Lischinski, Data-Driven Enhancement of Facial Attractiveness, SIGGRAPH 2008

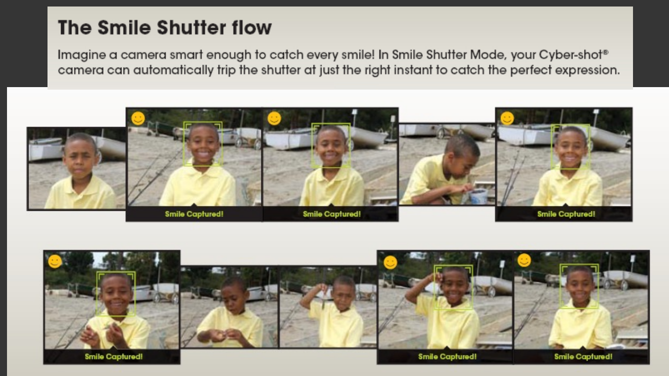
Limitations of Traditional Photography

Single focus and depth of field

Help Photographer Take Better Pictures: Face Detection

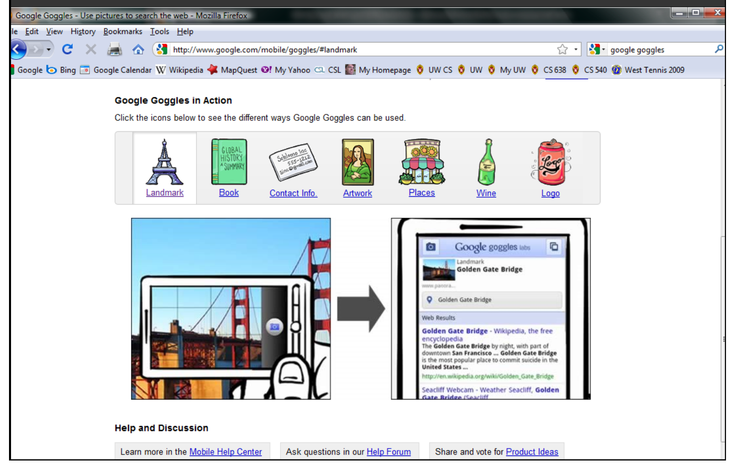
- Most digital cameras now detect faces for autofocus

Help Photographer Take Better Pictures: Smile Detection



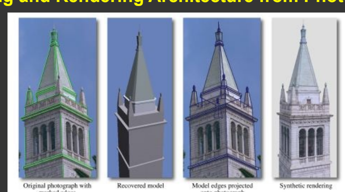
Sony Cyber-shot® T70 Digital Still Camera

Landmark Recognition



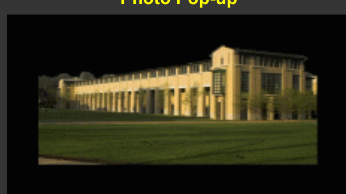
From 2D Image to 3D Scene

Modeling and Rendering Architecture from Photographs



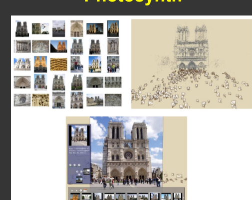
Debevec et al. (1996)

Photo Pop-up



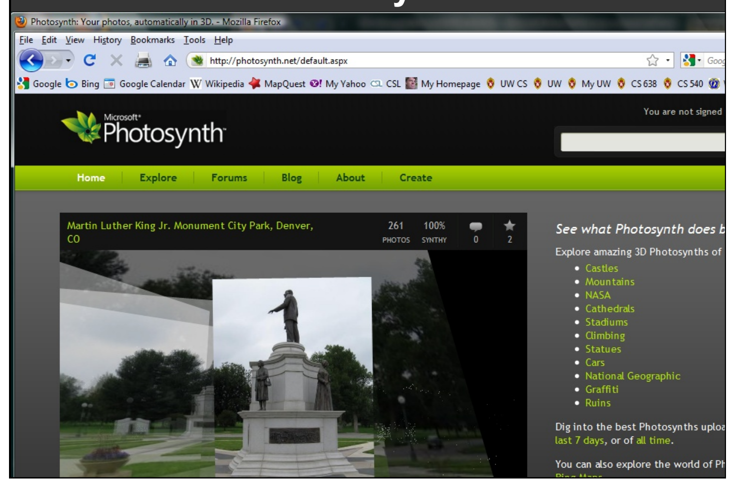
Hoiem et al. (2005)

Photosynth



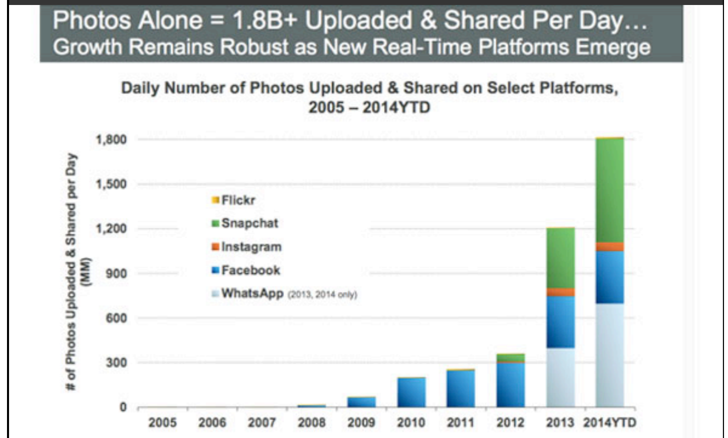
Snavely et al. (2006)

PhotoSynth



What is Computational Photography?

- Answer 3: Exploiting the billions of online images and videos in community photo collections and social media sites
  - Facebook users posted over 350 million images / day in 2014
  - Instagram users shared 40 million images / day in 2013
  - Snapchat users sent 700 million images / day in 2014
  - Sites such as Flickr, Picasa, Photobucket have billions of user-supplied images
- Mostly unorganized; few tagged or labeled
- How to search, index, organize, share, manipulate, combine, extract and use image content?



Source: M. Meeker Internet Trends report, 2014

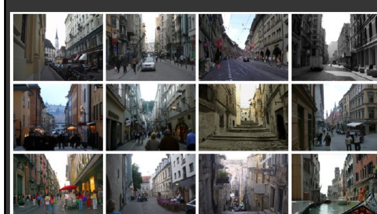
Subject-Specific Data

(especially people, faces, places)

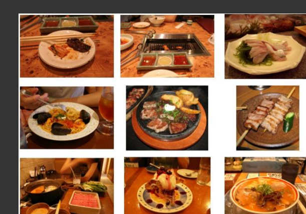
Photos of Coliseum

Portraits of Bill Clinton

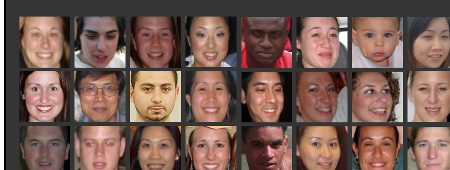
Generic Data



street scenes



Food plates



faces

pedestrians

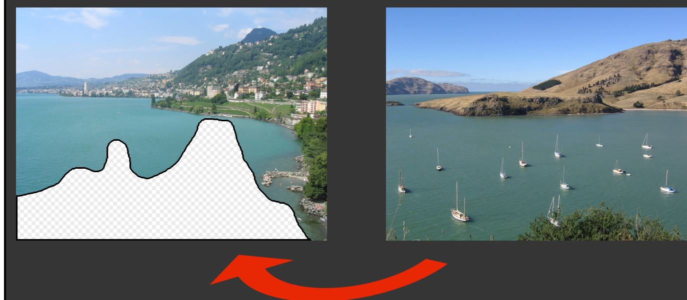
What are All the Photos on the Internet Good For?

Exploit the “unreasonable effectiveness of data” [Halevy, Norvig, Pereira 2009]:

With a large enough number of images, we have samples that are “similar to” almost any other image ever taken or to be taken,

so use them!

Appearance Transfer



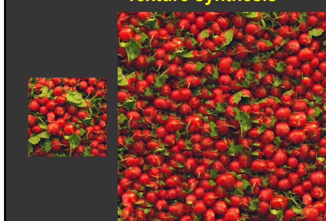
Find another image that has pixels with similar texture, color distribution, contrast, lighting, etc. and use to fill hole

Paste and Blend

Other Results

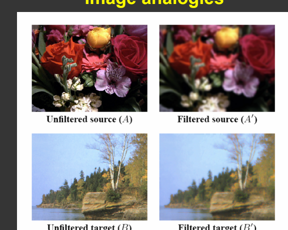
Data-driven Image Synthesis

Texture synthesis



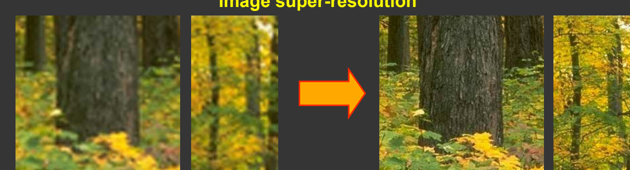
Efros & Leung (1999), Efros & Freeman (2001)

Image analogies

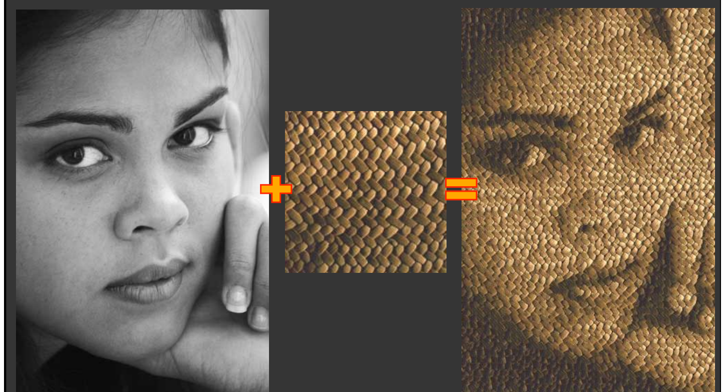


Hertzmann et al. (2001)

Image super-resolution



Texture Transfer



What are All the Photos on the Internet Good For?

Mobile social media provides near-real-time data about intentional or unintentional communities of users, which can be used for tasks such as surveillance and monitoring:

Social Media as Sensors

Example: Estimating Air Quality from Social Media Image Posts

Photography as Communication

- Photography + social networking ➔ photography is an increasingly important new "communication medium" and new form of dialogue between people
- "This is a watershed time where we are moving away from photography as a way of recording and storing a past moment, … and turning photography into a communication medium." --- Robin Kelsey, Harvard