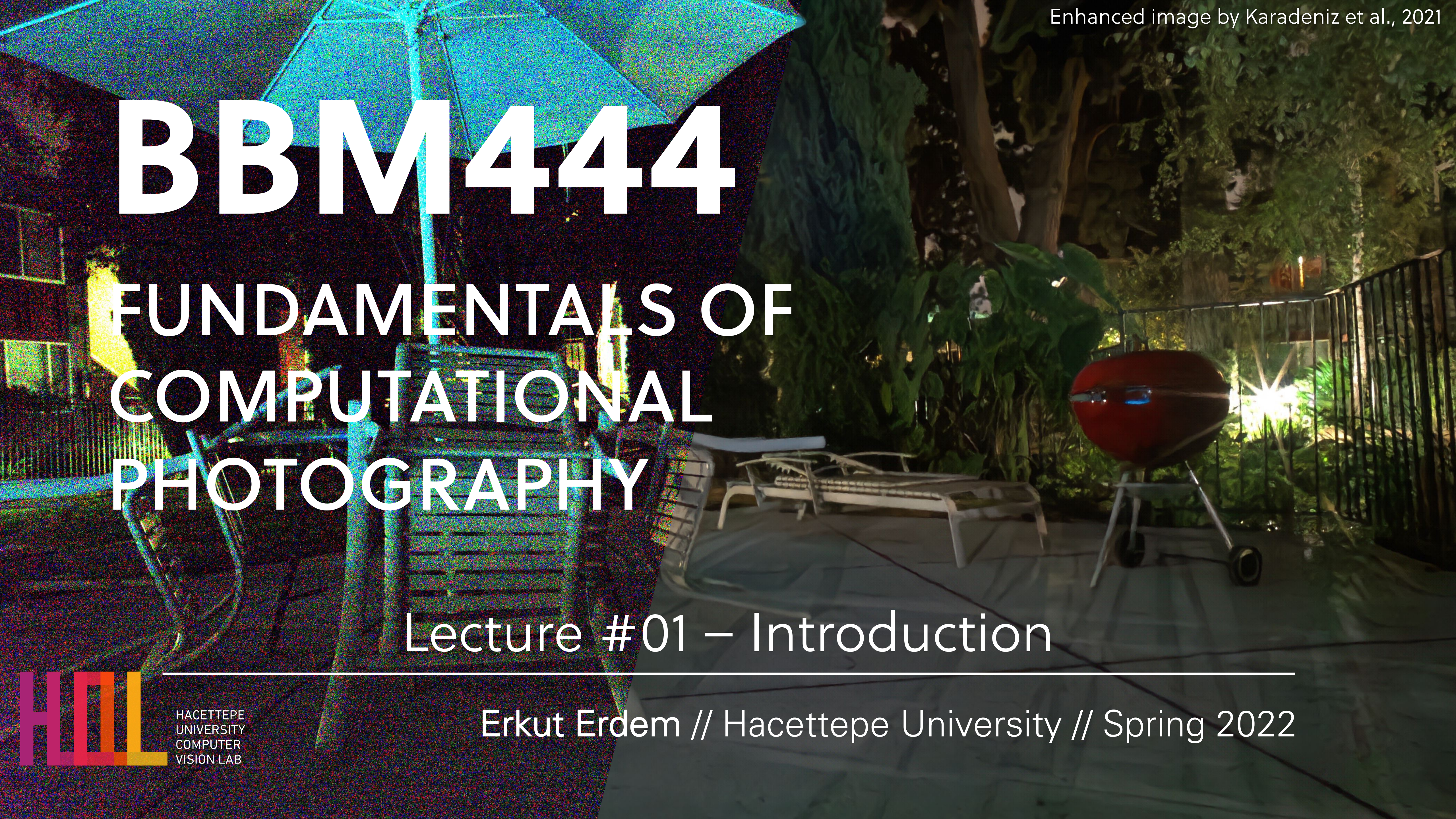

Enhanced image by Karadeniz et al., 2021

BBM444

FUNDAMENTALS OF COMPUTATIONAL PHOTOGRAPHY

Lecture #01 – Introduction

Erkut Erdem // Hacettepe University // Spring 2022

HACETTEPE UNIVERSITY COMPUTER VISION LAB

Today's Lecture

- Course info
- History of photography
- Limitations of traditional photography

Disclaimer: Some of the material and slides for this lecture were borrowed from

—Alexei Efros's CS194-26/294-26 "Intro to Computer Vision and Computational Photography" class

—Steve Marschner's CS6640 "Computational Photography" class

—Fredo Durand's slides on "The History of photography"

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Welcome to BBM444

- An advanced undergraduate course is about the fundamentals of computational photography

- Introduces students a number of different computational techniques to capture, manipulate and enrich visual media.

A little about me...

Koç University-İş Bank
Artificial Intelligence Center
Adjunct Faculty
2020-now

Hacettepe University
Associate Professor
2010-now

Télécom ParisTech
Post-doctoral Researcher
2009-2010

Middle East Technical University
1997-2008
Ph.D., 2008
M.Sc., 2003
B.Sc., 2001

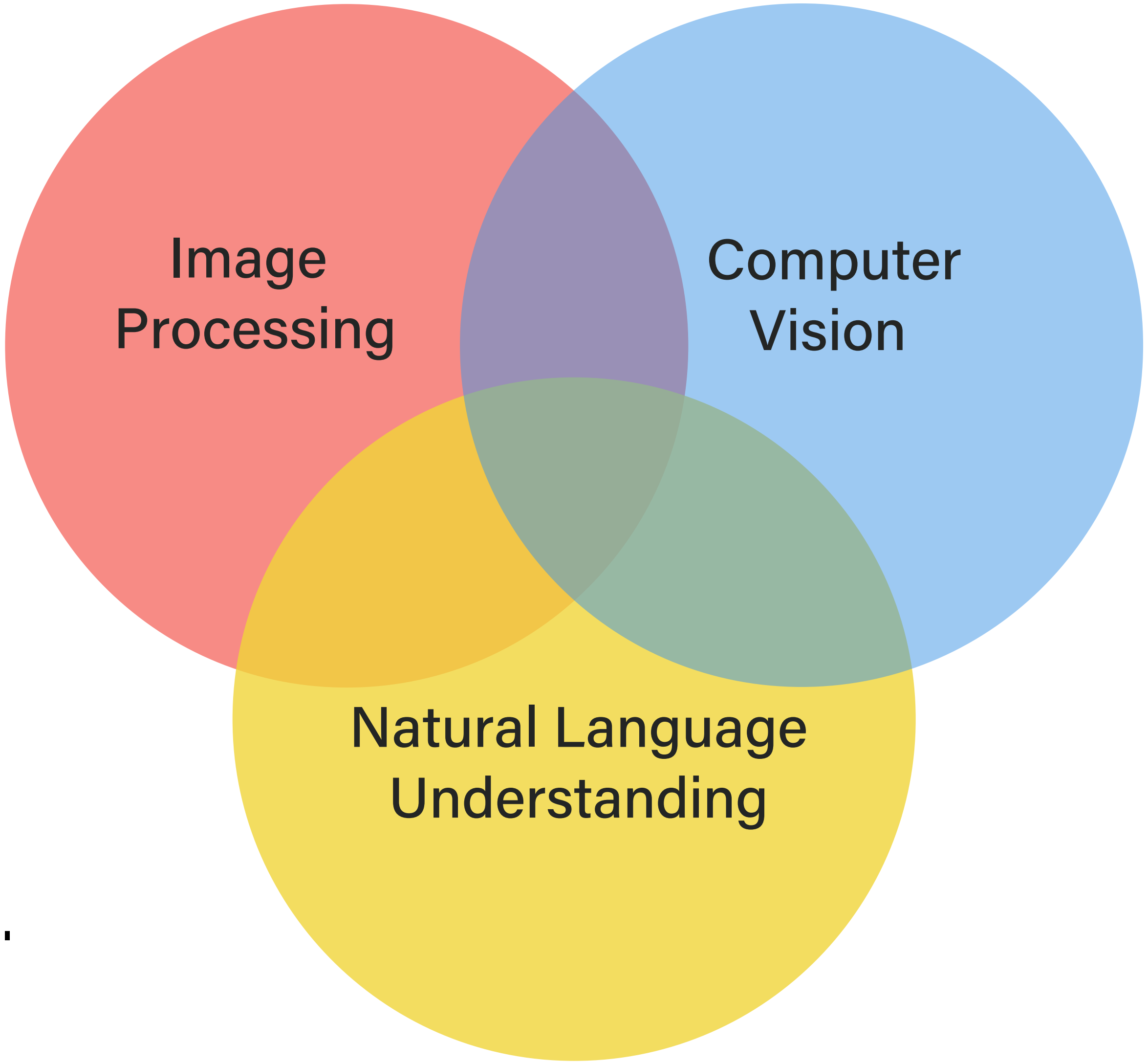
UCLA
Fall 2007
Visiting Student

VirginiaTech
Visiting Research Scholar
Summer 2006

http://web.cs.hacettepe.edu.tr/~erkut
@erkuterdem
erkut@cs.hacettepe.edu.tr

Research Interests

- I study better ways to understand and process visual data.
- My research interests span a diverse set of topics, ranging from image editing to visual saliency estimation, and to multimodal learning for integrated vision and language.



Course Logistics

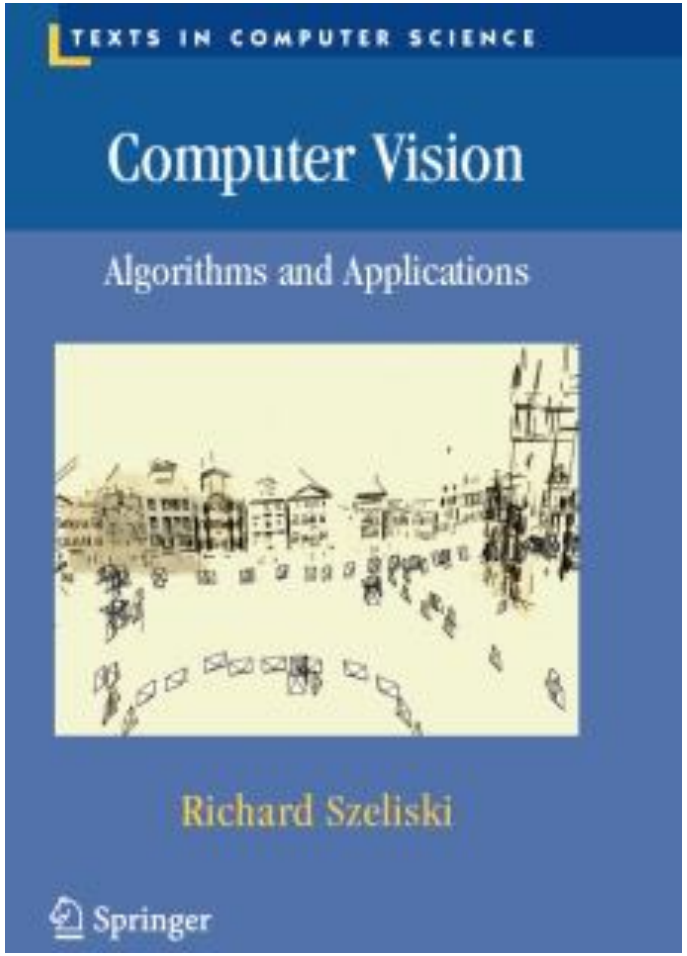
Course information

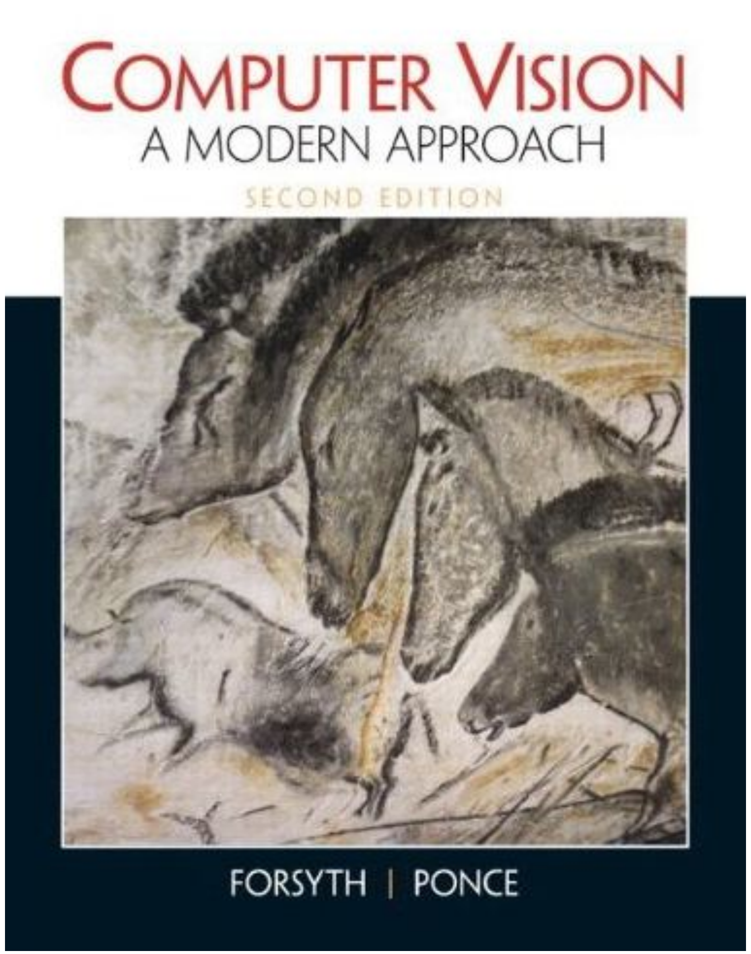
Time/Location	09:00-12:00pm Tuesday, Seminar Hall
Instructor	Erkut Erdem

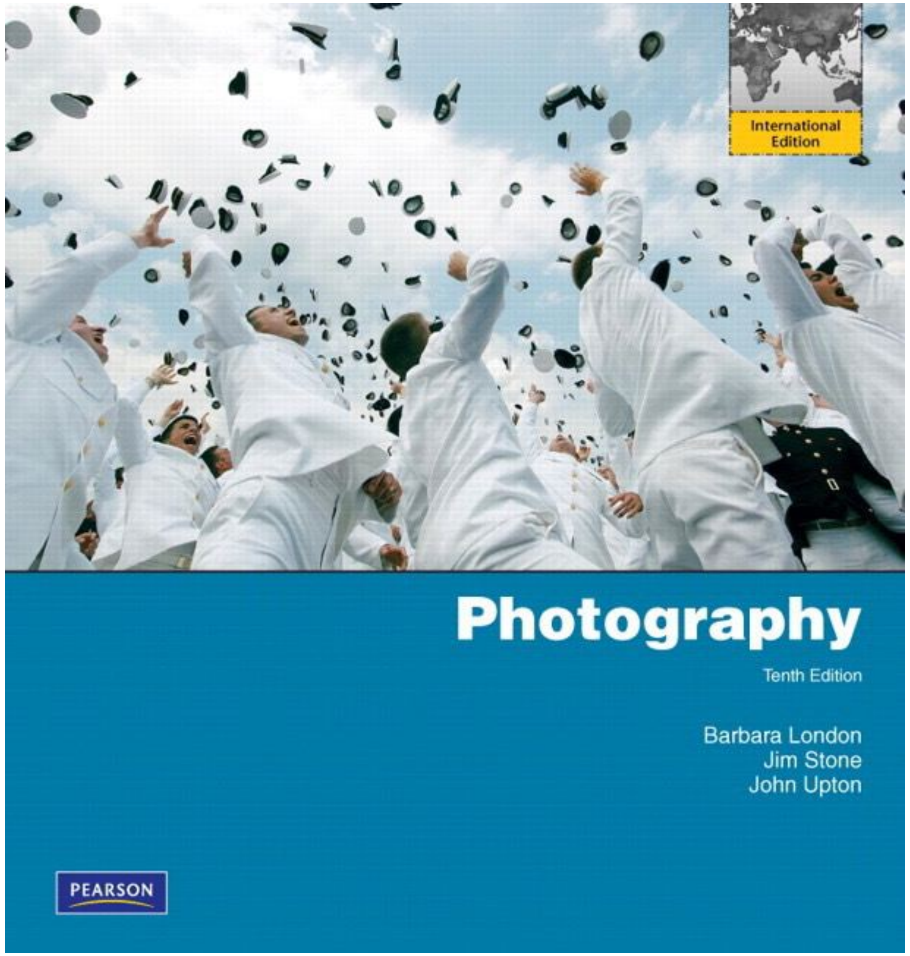
- piazza for course related announcements:
  https://piazza.com/hacettepe.edu.tr/spring2022/bbm444

- Course webpage:
  https://web.cs.hacettepe.edu.tr/~erkut/bbm444.s22/index.html

Reference Books







Prerequisites

- Good math (calculus, linear algebra, statistics) and programming skills.
- An introductory course in image processing (BBM413), and/or computer vision (BBM416) and/or machine learning (BBM406) is highly recommended.

Grading

- Grading for BBM444 will be based on
  - Class participation (5%),
  - Course project (done in pairs) (30%),
  - Midterm exam (30%), and
  - Final exam (35%).

- Grading for BBM446 will be based on
  - Four assignments (done individually) (25% each).

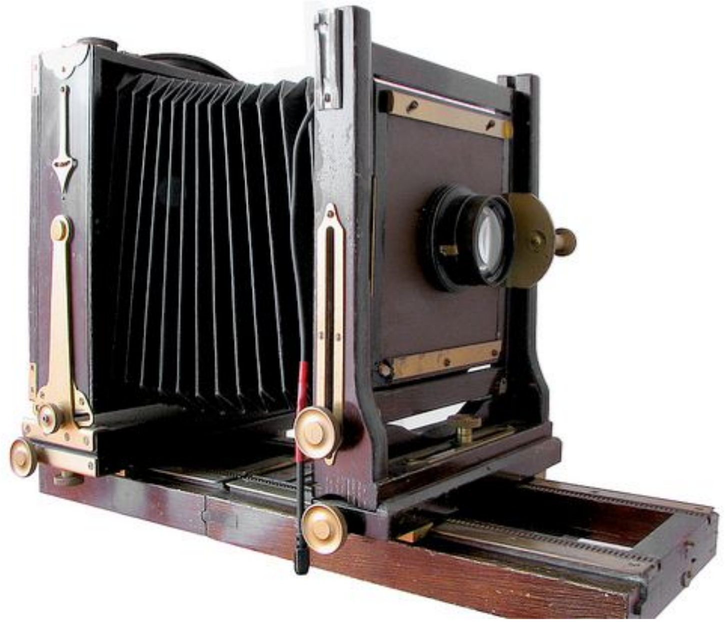
Schedule

Week 1	Introduction, Digital photography
Week 2	Image formation
Week 3	Exposure and high-dynamic-range imaging
Week 4	Noise and Color
Week 5	Edge-aware filtering, Gradient-domain image processing
Week 6	Focal stacks and depth from (de)focus, Lightfields
Week 7	Deconvolution, Coded photography

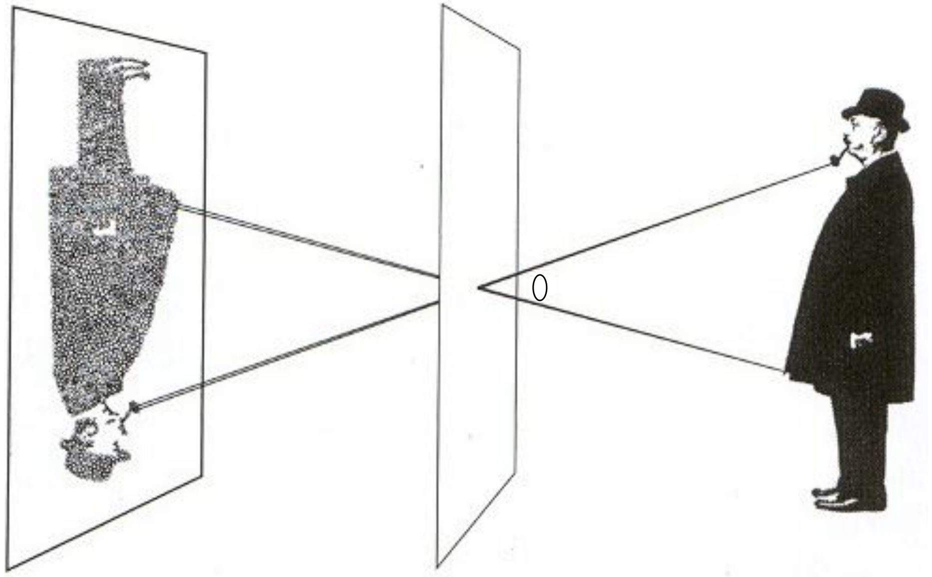
Schedule

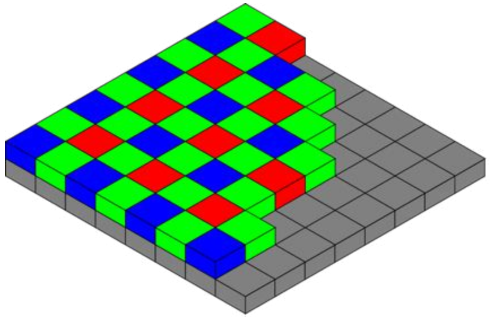
Week 8	Convolutional Neural Networks
Week 9	Deep Generative Models and their applications
Week 10	Midterm Exam
Week 11	Blending, compositing and matting
Week 12	Visual quality assessment
Week 13	Advanced topics
Week 14	Project presentations, Course wrap-up

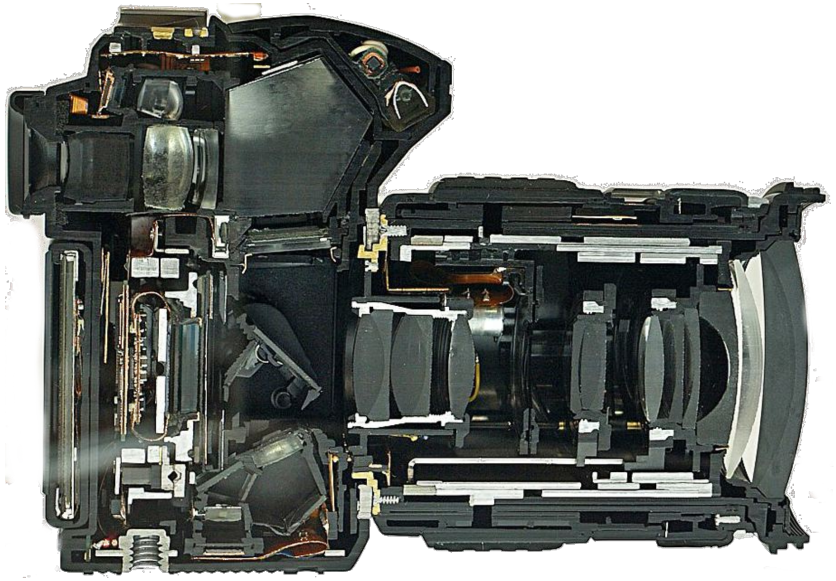
Lecture 1: Introduction to Digital photography



Lecture 2: Image formation

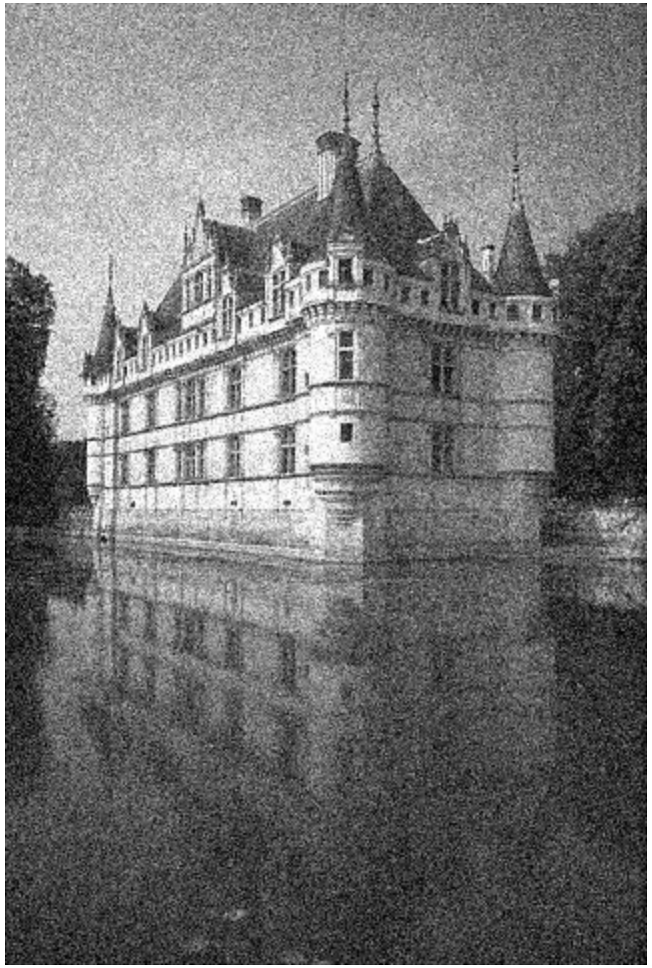


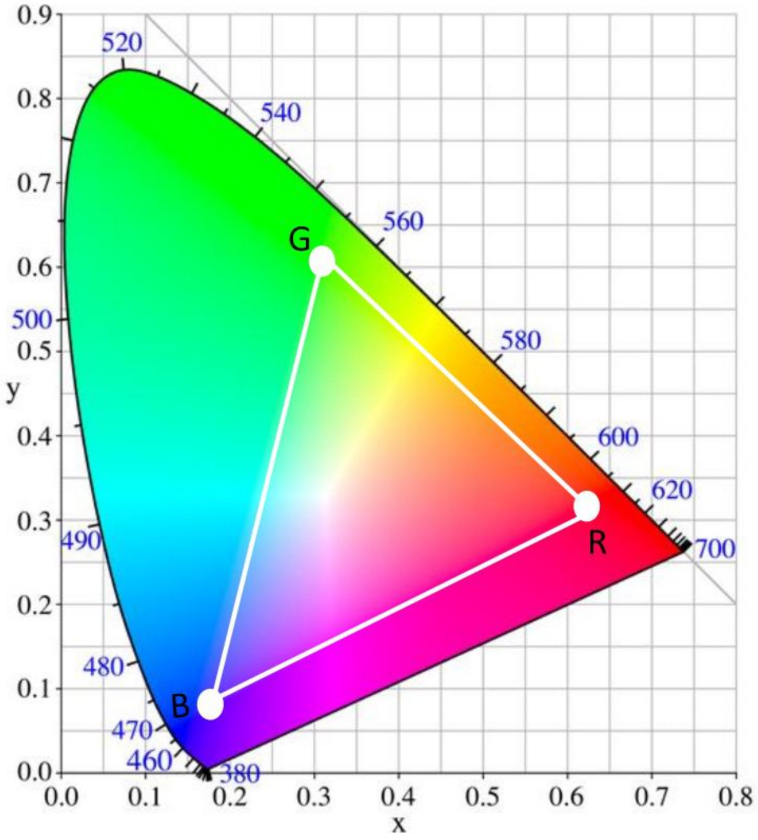




Lecture 3: Exposure and high-dynamic-range imaging

Lecture 4: Noise and Color





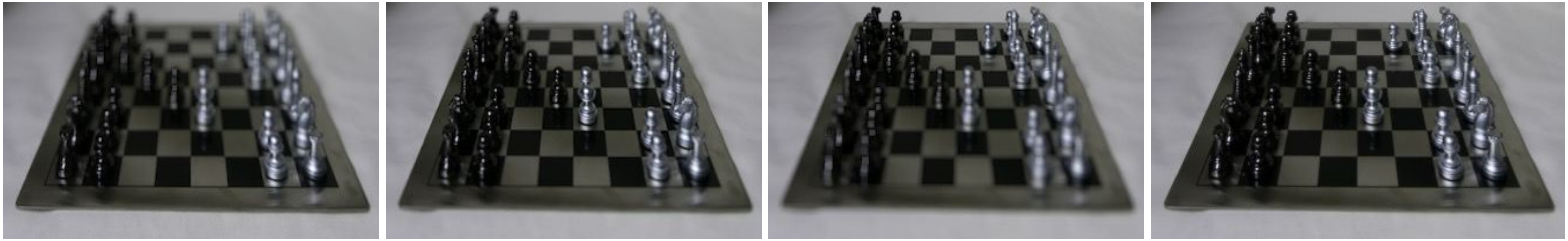
Lecture 5: Edge-aware filtering, Gradient-domain image processing

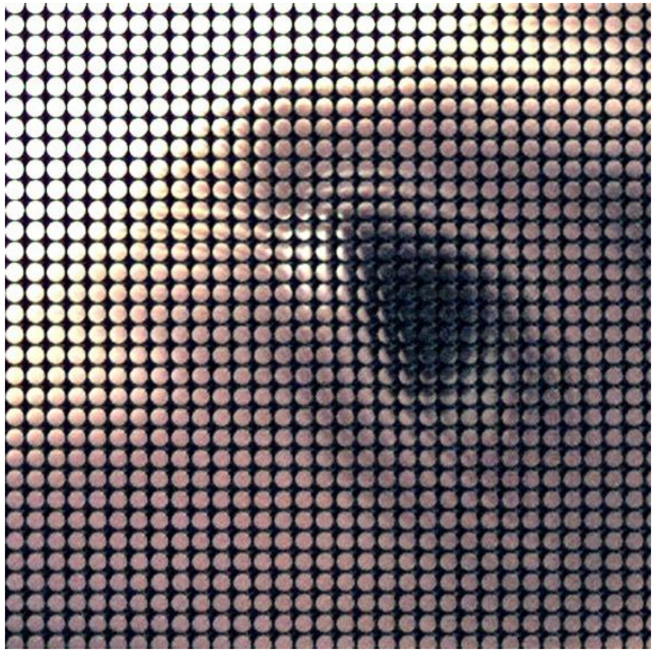
sources/destinations

cloning

seamless cloning

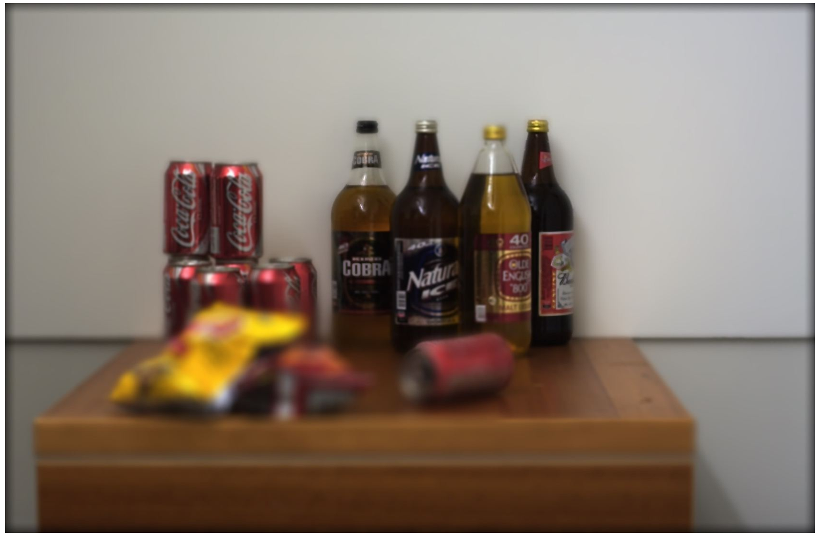
Lecture 6: Focal stacks and depth from (de)focus, Lightfields



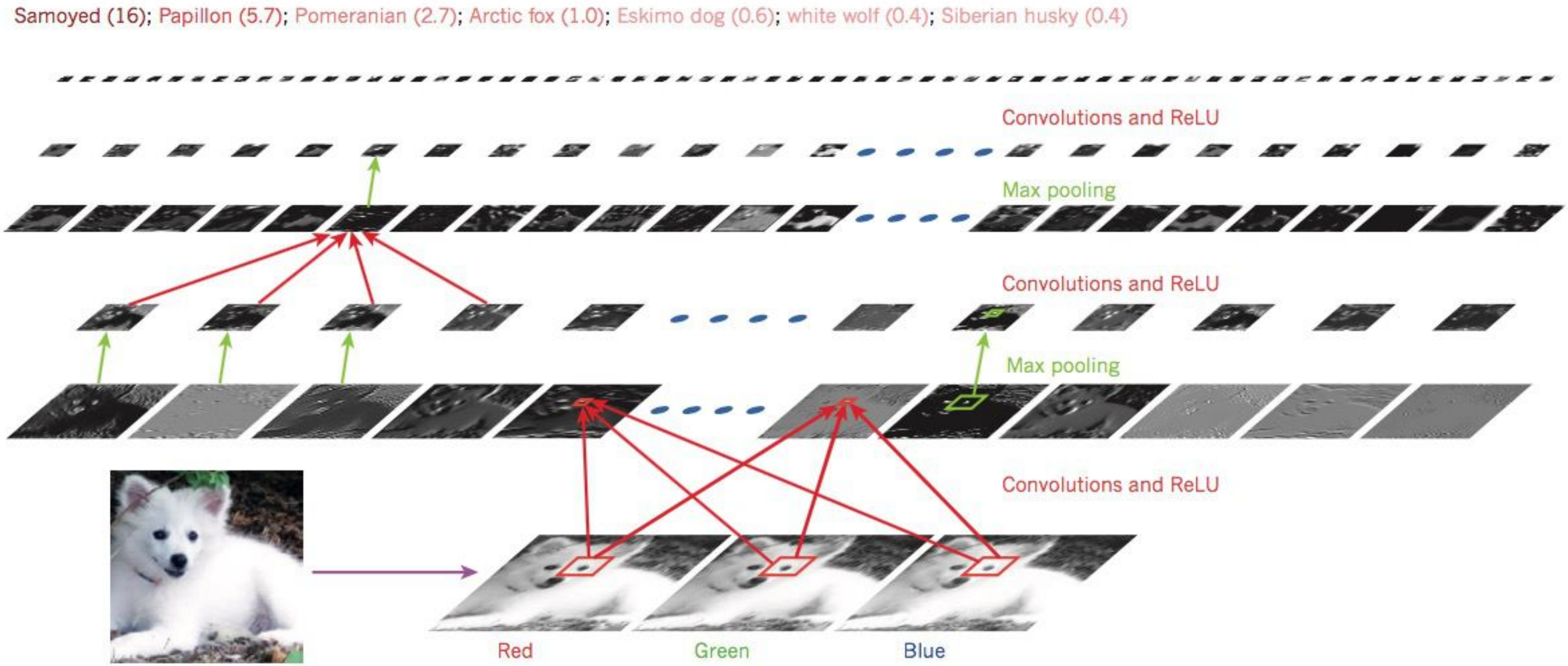


Lecture 7: Deconvolution, Coded photography

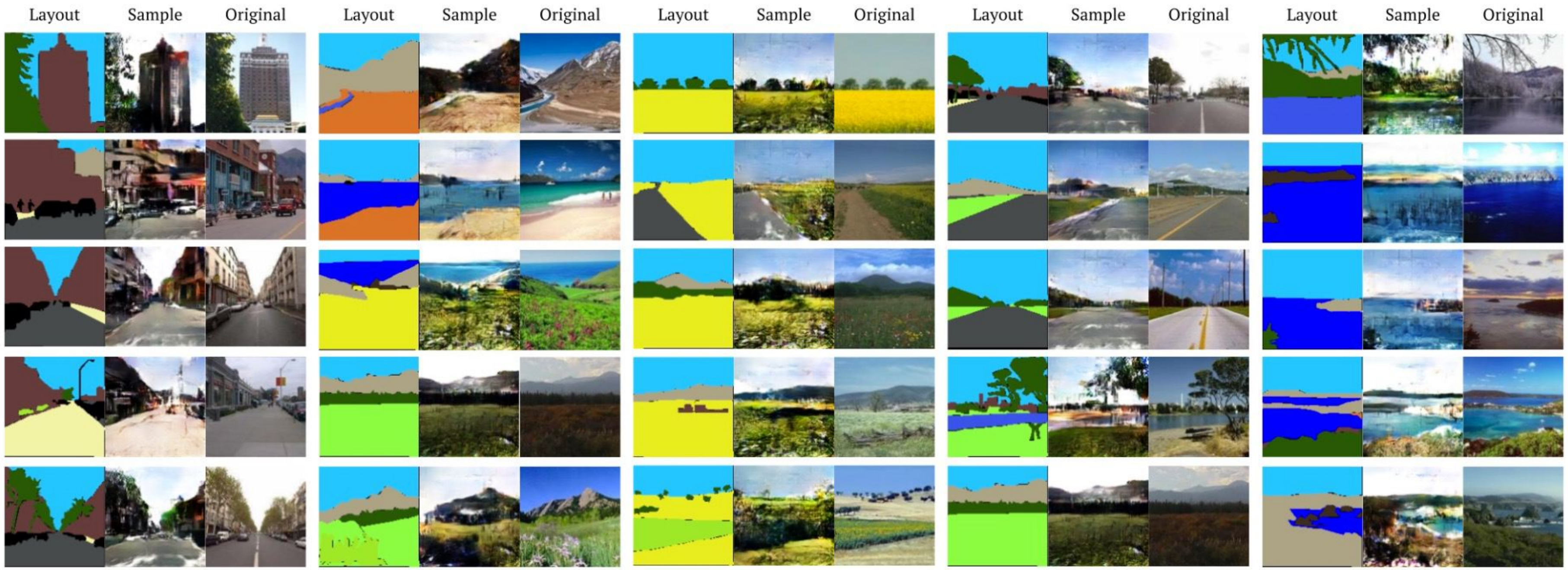


Lecture 8: Convolutional Neural Networks

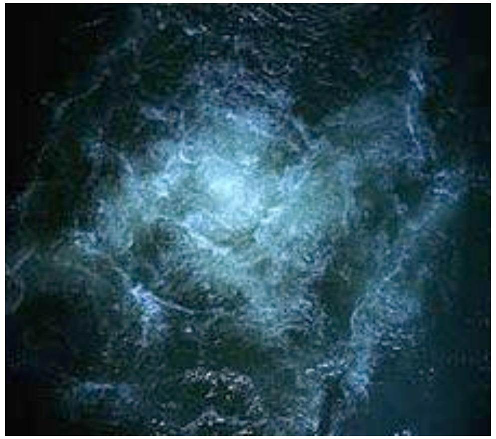
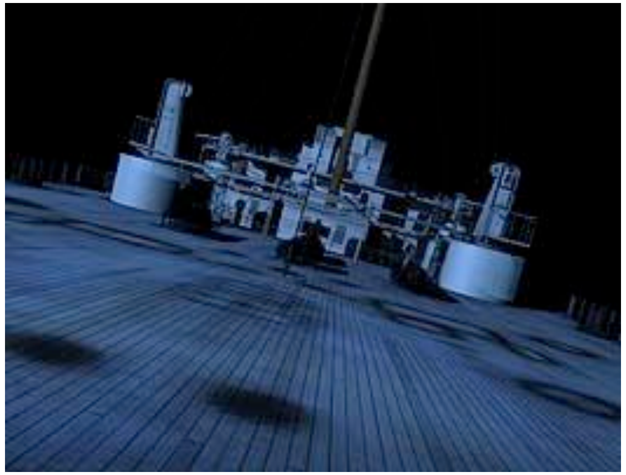


Lecture 9: Deep Generative Models and their applications



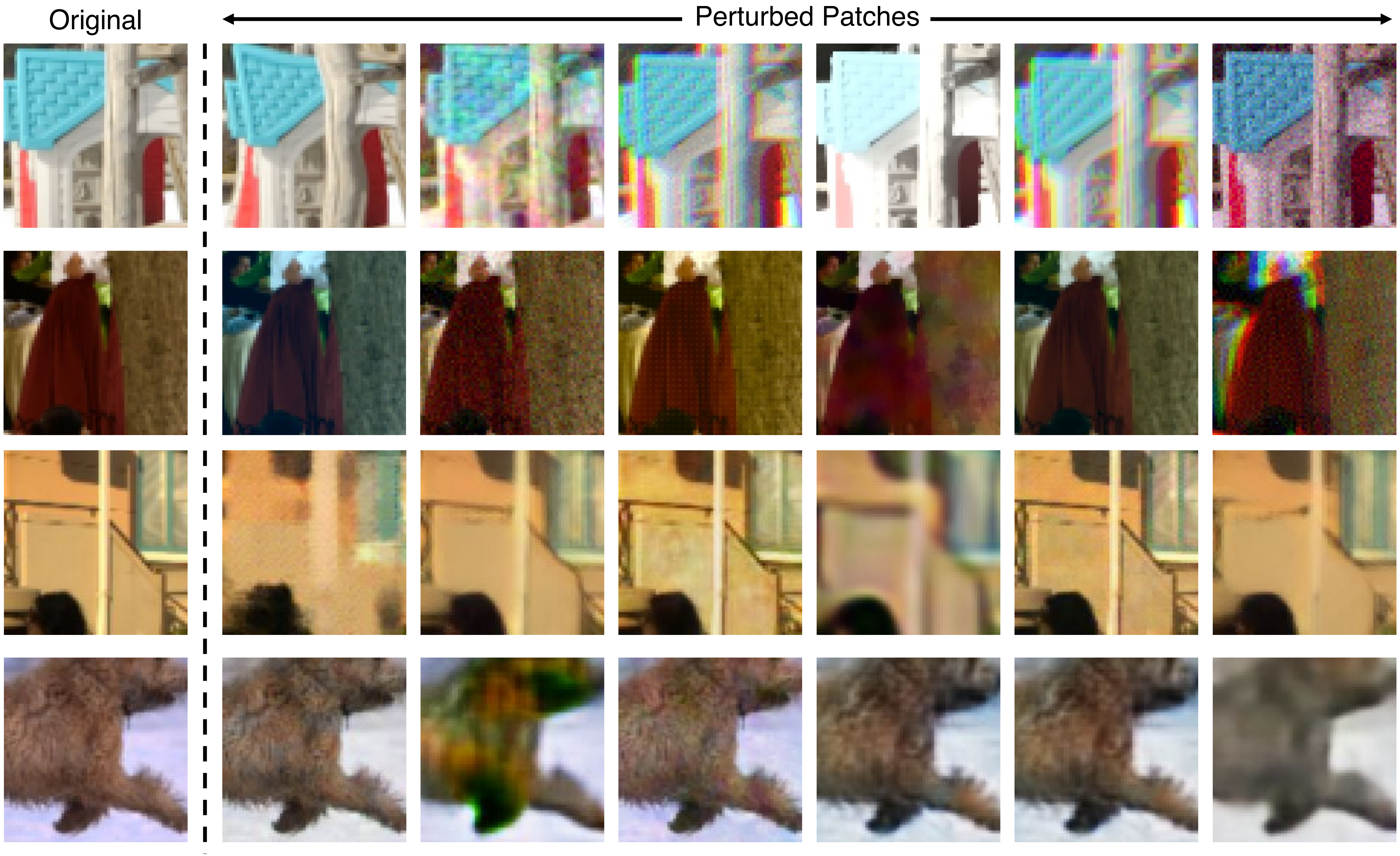
Lecture 10: Blending, compositing and matting



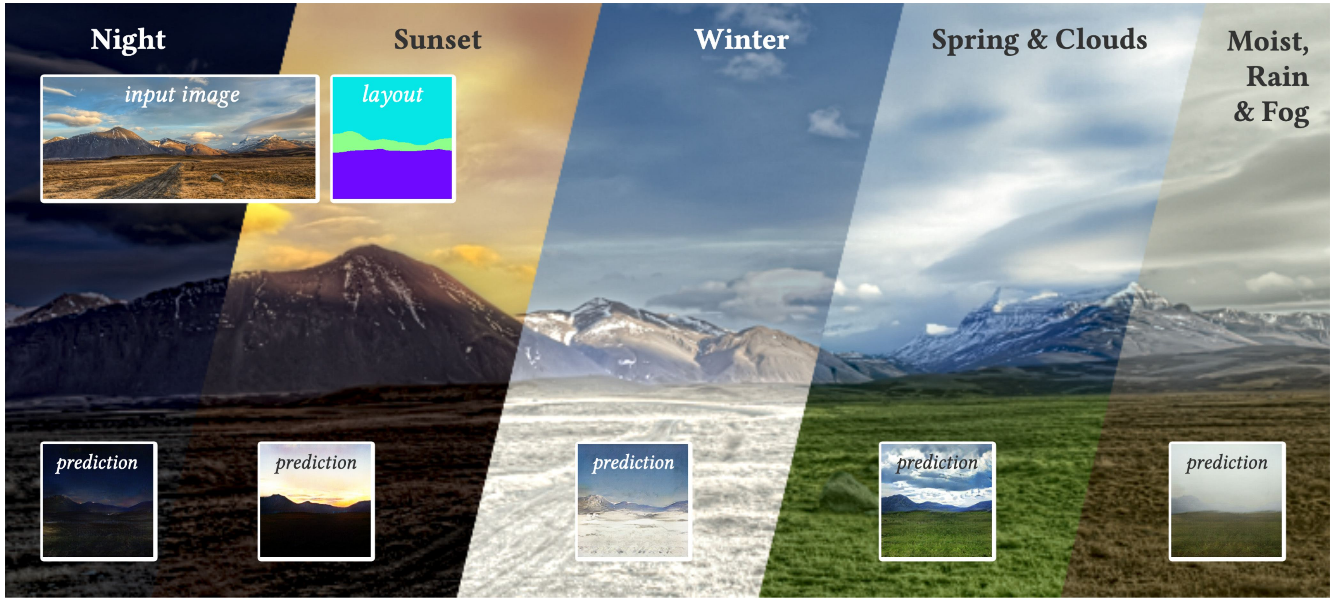




[*Titanic* ; DigitalDomain; vfxhq.com]

Lecture 11: Visual quality assessment



Lecture 12: Advanced topics



Programming Assignments

- 4 programming assignments (25% each)
- Should be done individually
- Involve implementing an algorithm, carrying out a set of experiments to evaluate it, and writing up a report on the experimental results.
- **Late policy:** You have 5 slip days in the semester.

- **Tentative** Dates
  - Assignment 1 Out: February 22nd, Due: March 8th
  - Assignment 2 Out: March 8th, Due: March 22nd
  - Assignment 3 Out: March 22nd, Due: April 5th
  - Assignment 4 Out: April 12th, Due: April 26th

Course project

The students who need GPU resources for the course project are advised to use Google Colab.

- The course project gives students a chance to apply the methods discussed in class to a research oriented project.
- The students can work in pairs.
- The course project may involve
  - Design of a novel approach and its experimental analysis, or
  - An extension to a recent study of non-trivial complexity and its experimental analysis.
  - A comparative analysis of methods
- Deliverables
  - Proposals — March 15, 2022
  - Project progress reports — Apr 19, 2022
  - Final project presentations — May 10, 2022
  - Final reports — May 15, 2022

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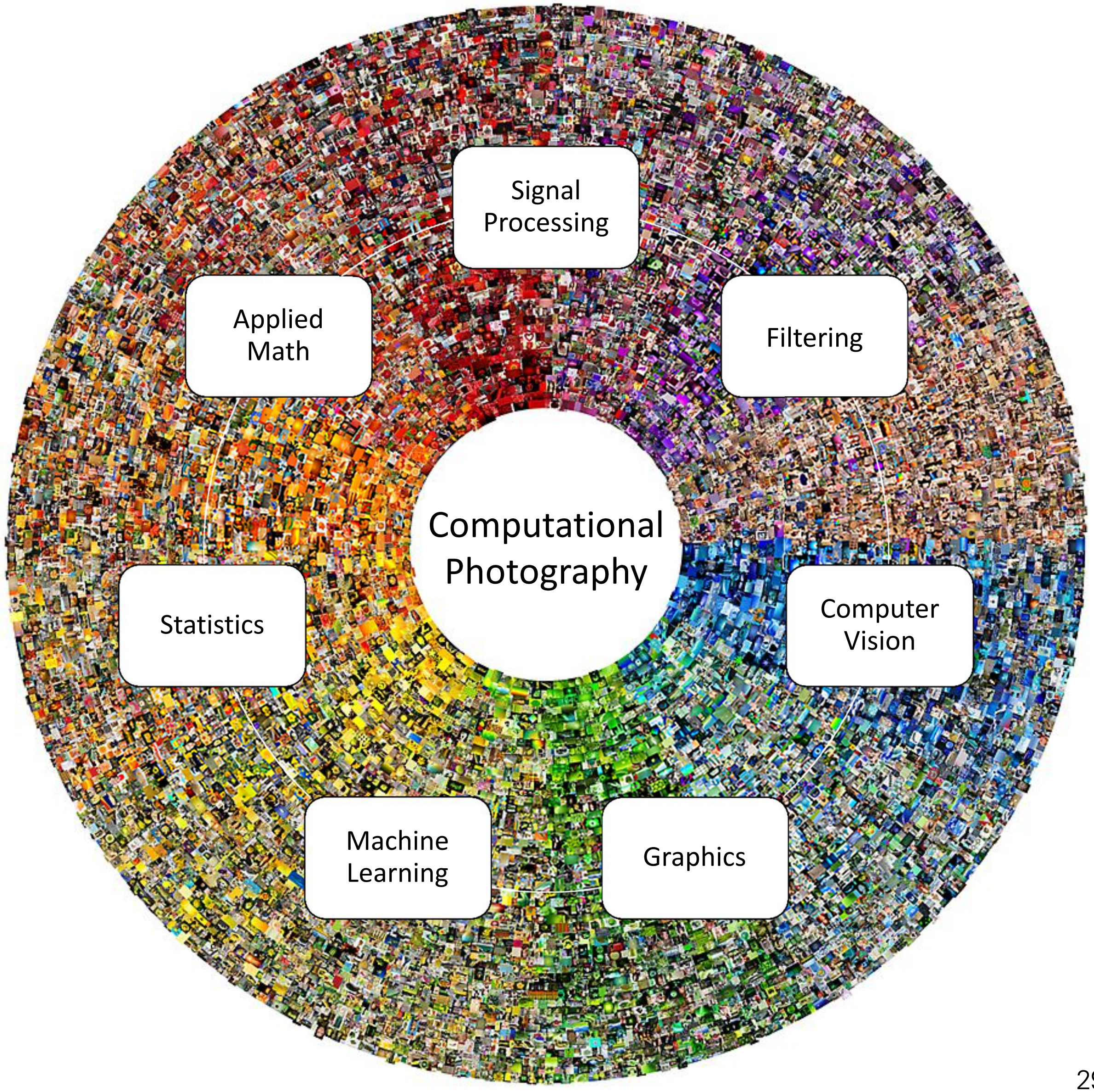
What is Computational Photography ?

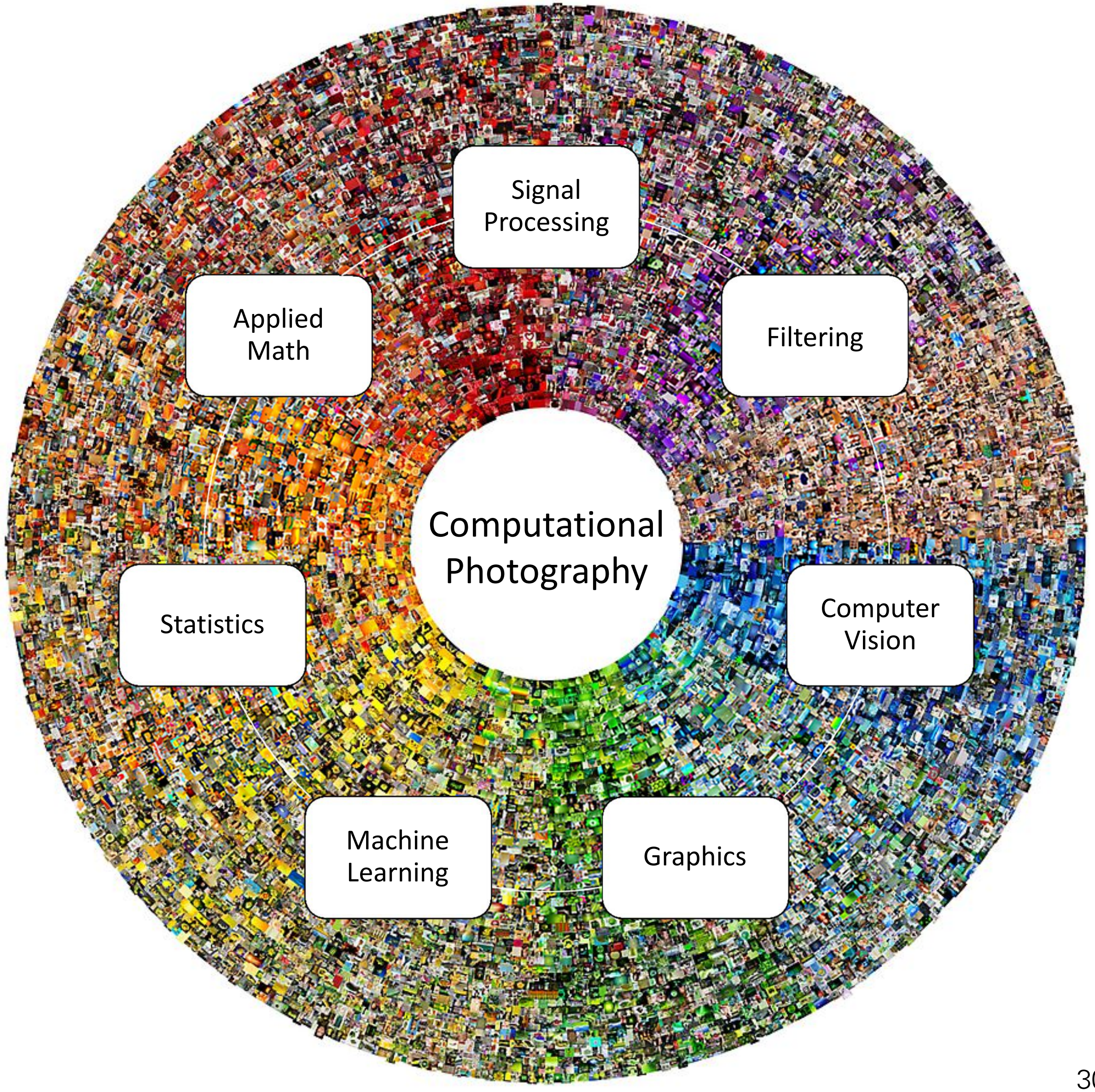
- It refers to an emerging new research area.
- It covers the set of methods used for capturing and processing digital images based on modern digital computation and algorithms instead of optical processes.
- It has changed the rules of photography, bringing to it new modes of capture, post-processing, storage, and sharing.



Slide adapted from P. Milanfar

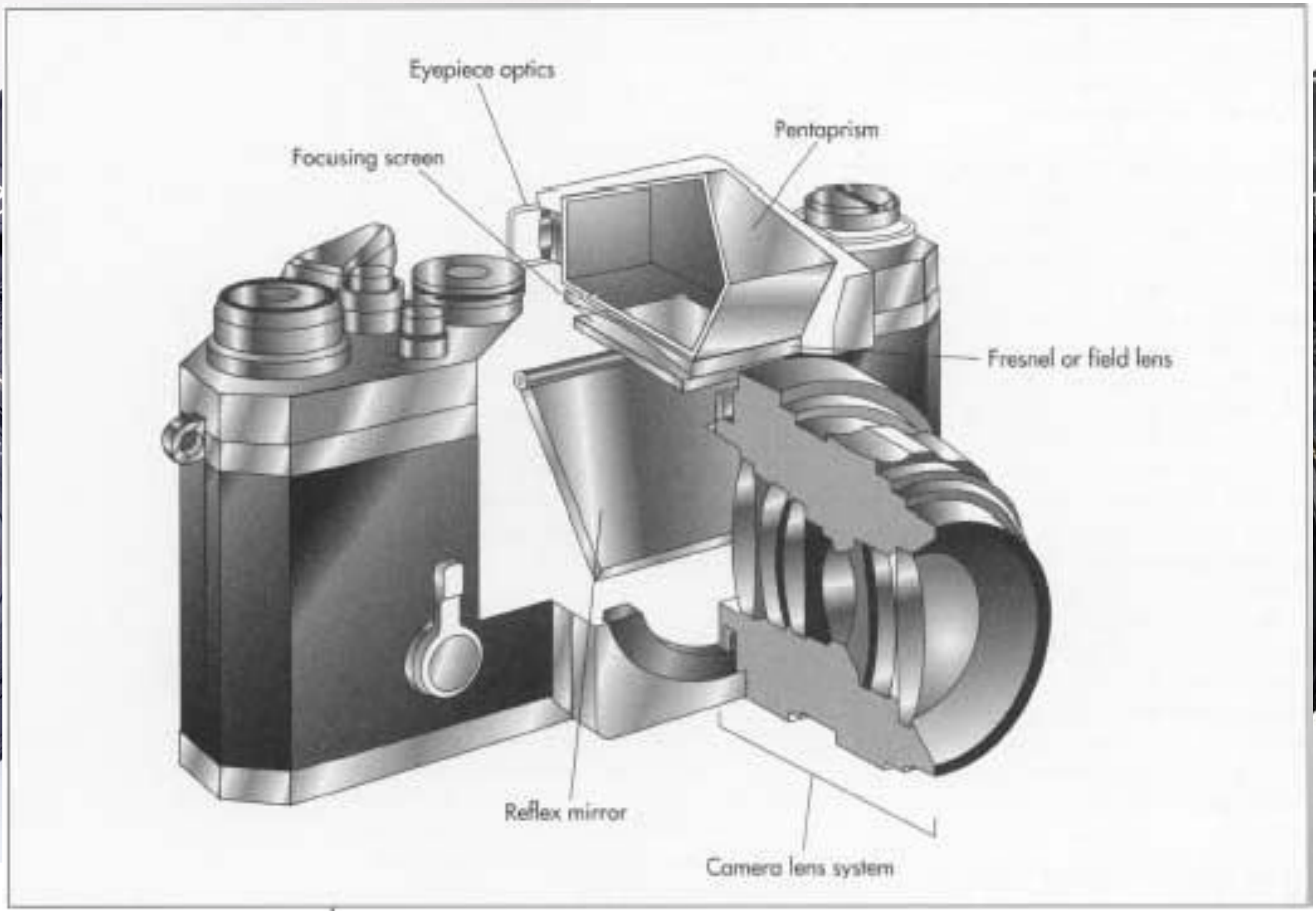
What is Computational Photography ?

- Digital photography:
  - Simply replaces traditional sensors and recording by digital technology
  - Involves only simple image processing
- Computational photography
  - More elaborate image manipulation, more computation
  - New types of media (panorama, 3D, etc.)
  - Camera design that take computation into account



Slide adapted from R. Fergus

Spot the difference



Film camera

Digital camera

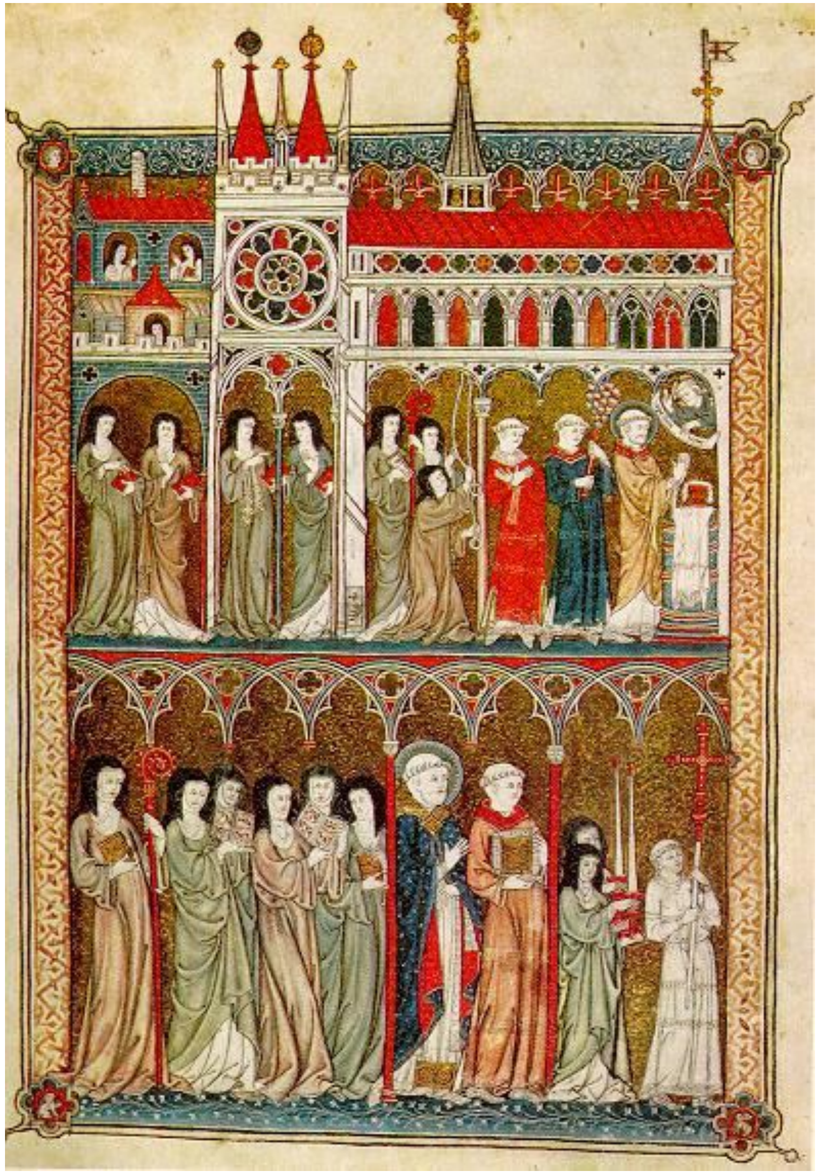
Depicting Our World: Prehistory

Prehistoric Painting, Lascaux Cave, France ~ 13,000 -- 15,000 B.C.

Depicting Our World: Middle Ages

The Empress Theodora with her court., Ravenna, St. Vitale 6th c.

Depicting Our World: Middle Ages



Nuns in Procession. French ms. ca. 1300.

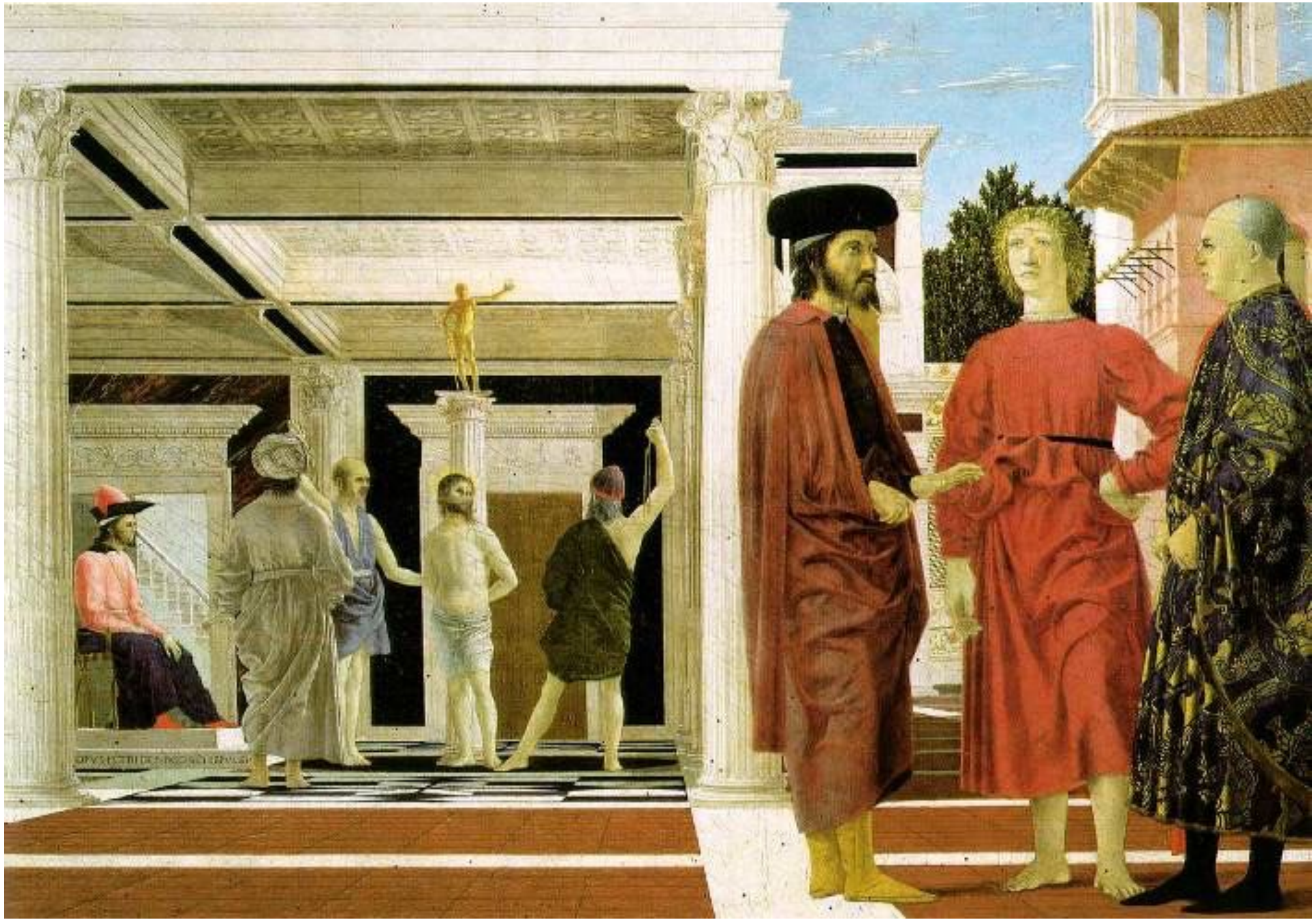
Depicting Our World: Renaissance

North Doors (1424)

Lorenzo
Ghiberti
(1378-1455)

East Doors (1452)

Depicting Our World: Renaissance

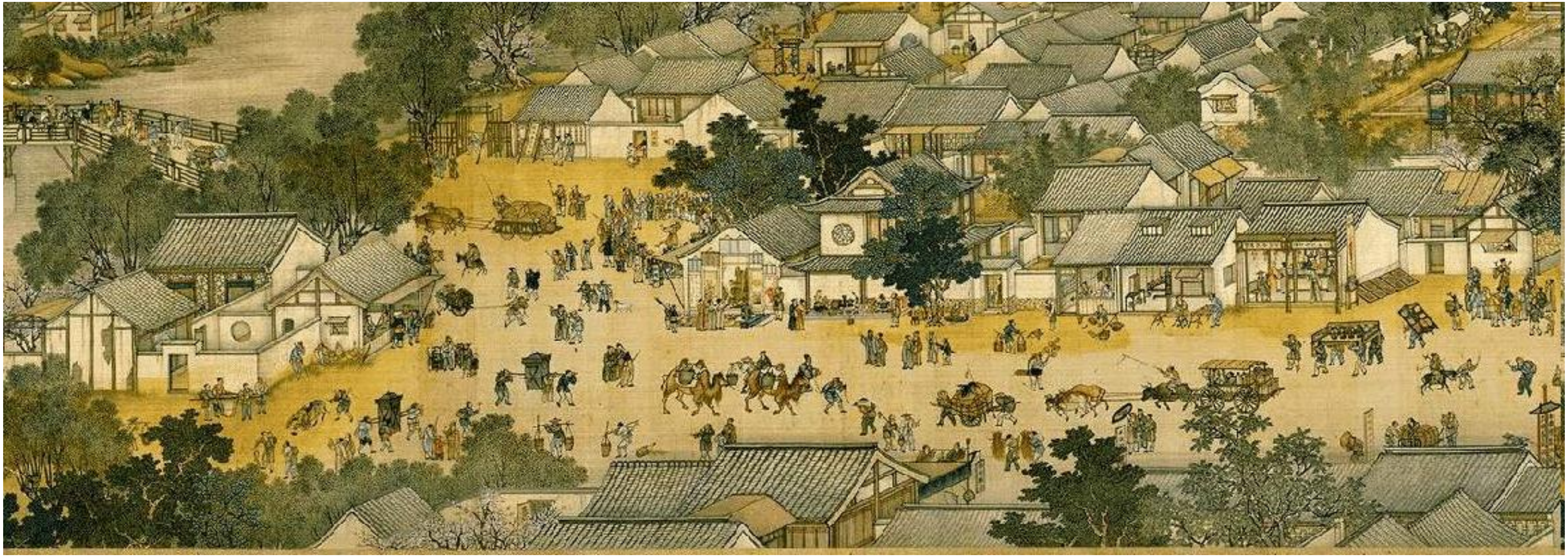


Piero della Francesca, The Flagellation (c.1469)

Depicting Our World: Renaissance

Paolo Uccello, Miracle of the Profaned Host (c.1467-9)

Depicting Our World: Song Dynasty (China)

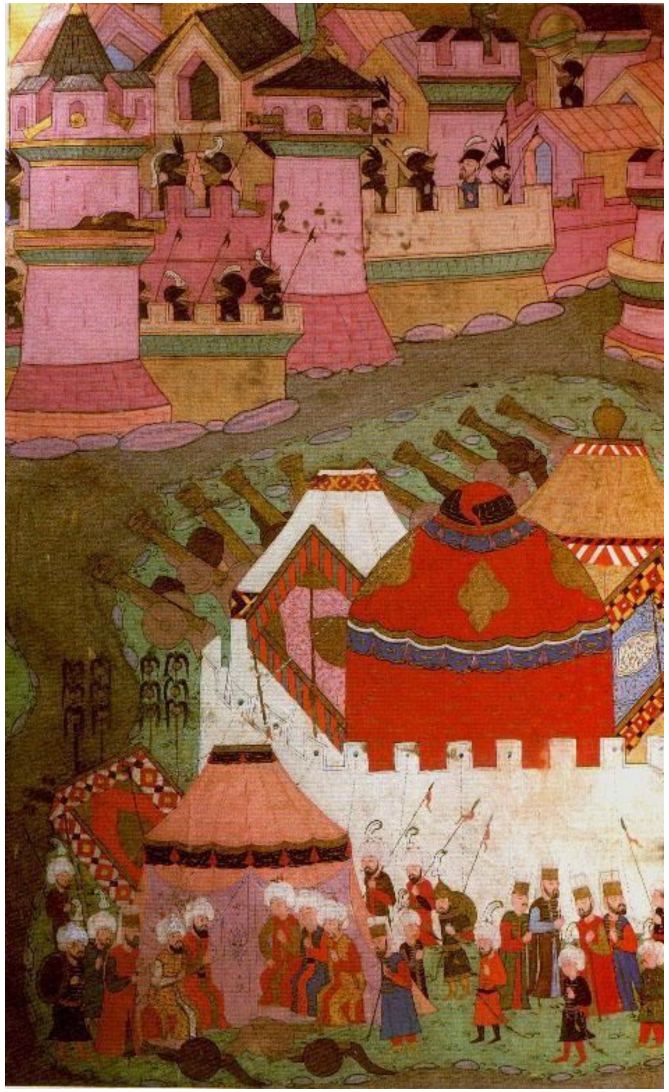


Qingming Festival by the Riverside, Zhang Zeduan ~900 AD

Depicting Our World: Edo Period (Japan)

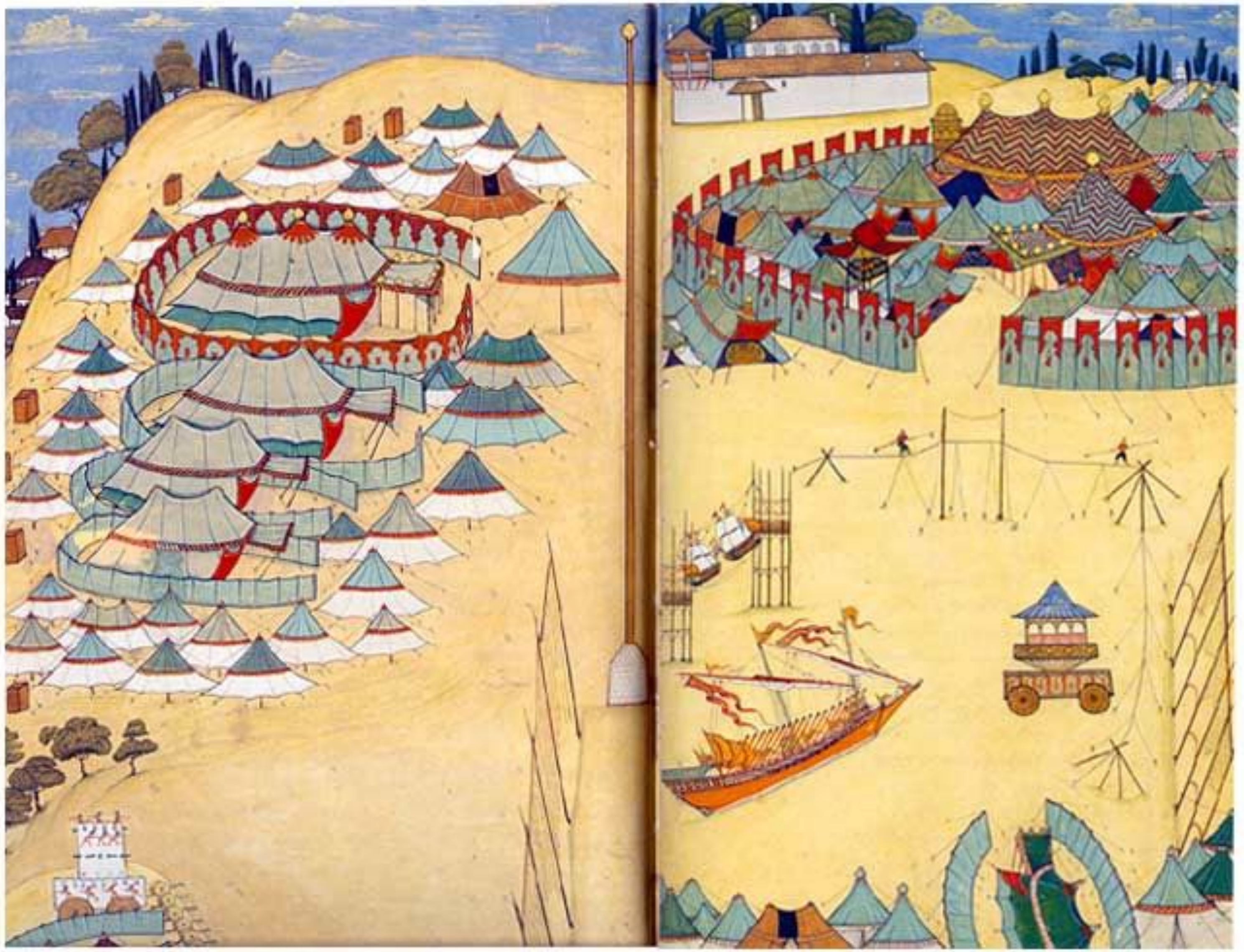
The Great Wave off Kanagawa, part of the series
Thirty-six Views of Mount Fuji, Hokusai (between 1826 and 1833)

Depicting Our World: Ottoman Miniatures



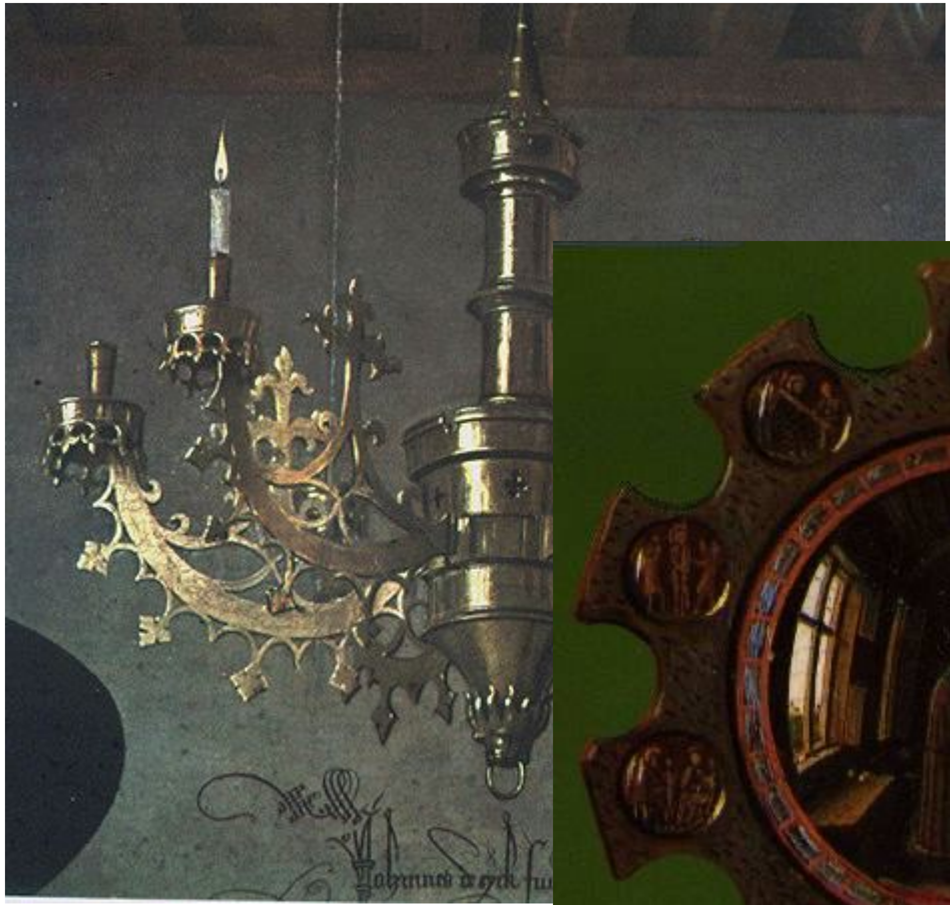
The Ottoman army besieging Vienna, from Huner-nama ('Book of Skills').
Nakkas Osman, 1588.

Depicting Our World: Ottoman Miniatures



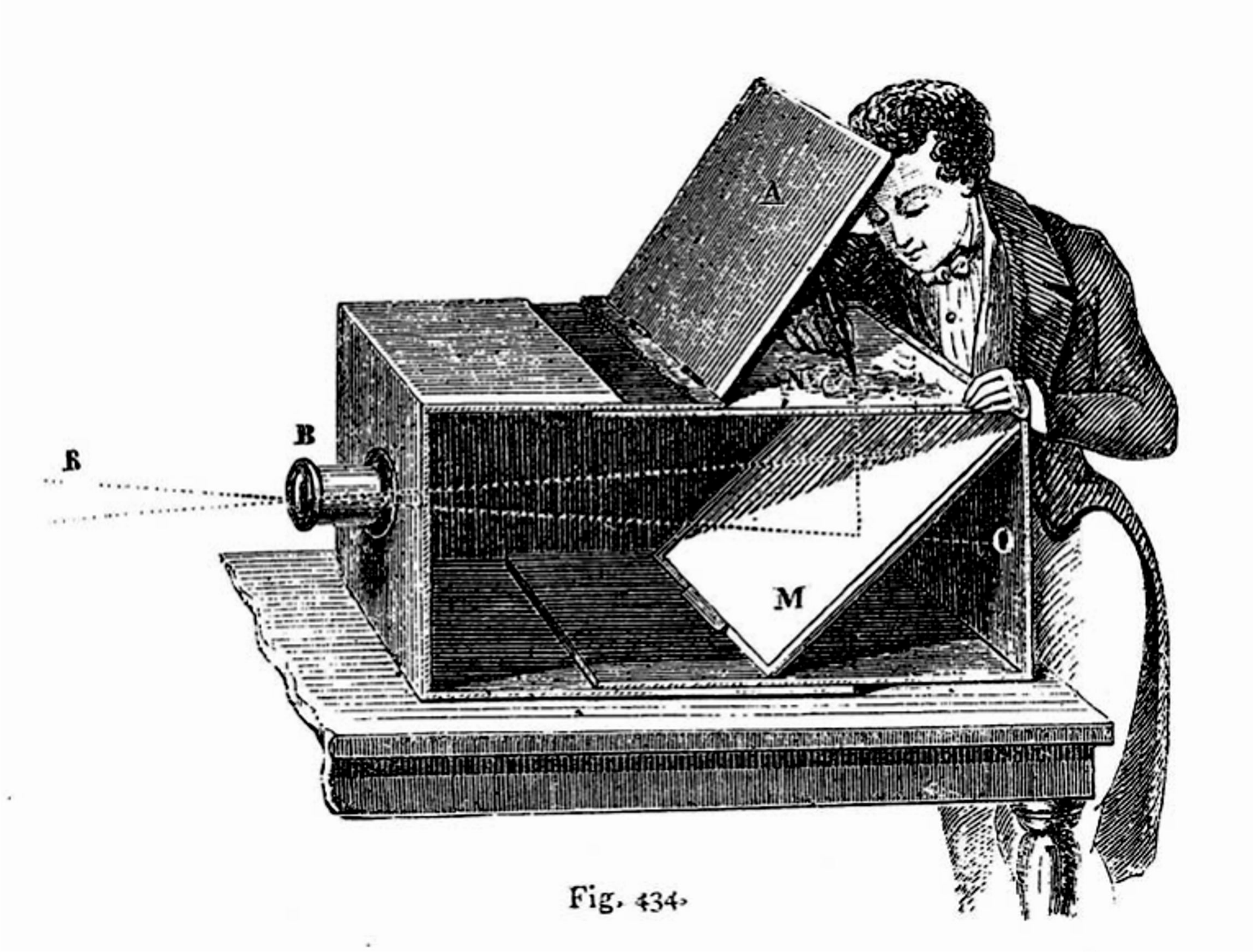
An Ottoman miniature from Surname-ı Vehbi, Abdulcelil Levni (1720)

Depicting Our World: Toward Perfection



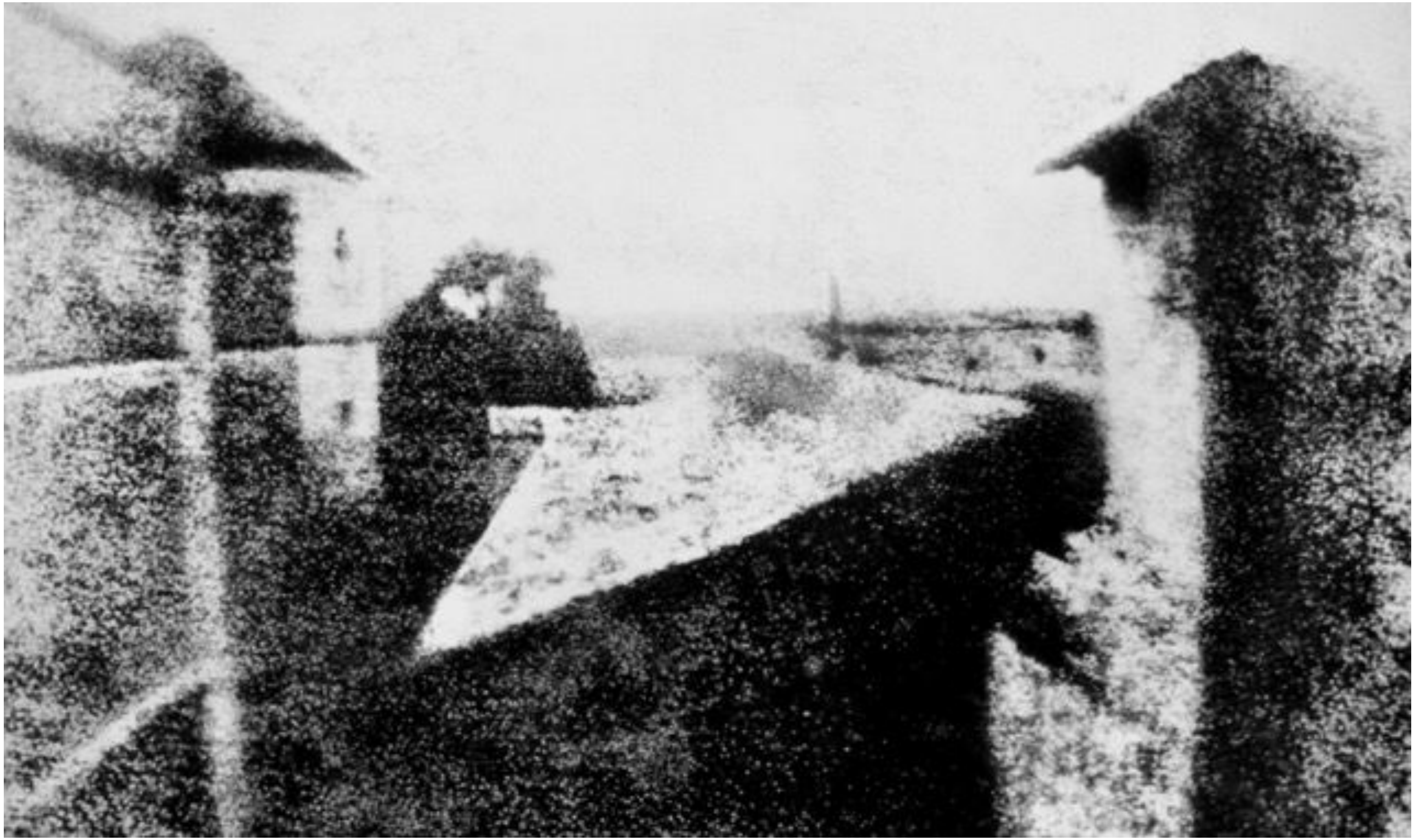
Jan van Eyck, The Arnolfini Marriage (c.1434)

Depicting Our World: Toward Perfection



Lens Based Camera Obscura, 1568

Depicting Our World: Perfection!

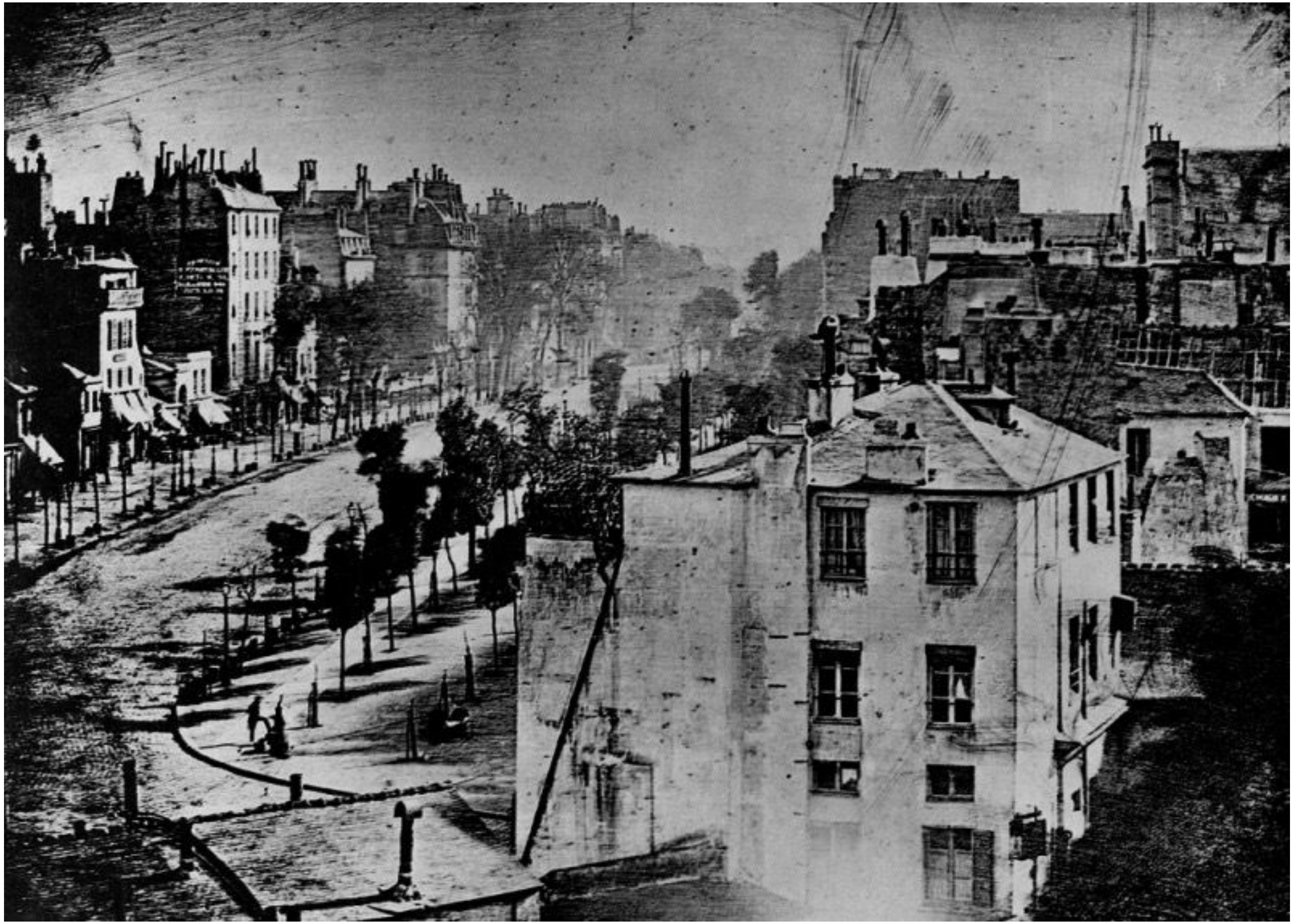


View from the Window at Le Gras, Joseph Nicéphore Niépce (1826)

Depicting Our World: Perfection!

Still Life, Louis Jaques Mande Daguerre, 1837

Depicting Our World: Perfection!



Boulevard du Temple, Louis Daguerre, 1838

After realism…

Monet, La rue Montorgueil

Depicting Our World: Ongoing Quest

Pablo Picasso

David Hockney

Depicting Our World: Ongoing Quest

David Hockney, Place Furstenberg, (1985)

Which one is right?

Multiple viewpoints

David Hockney,
Place Furstenberg, 1985

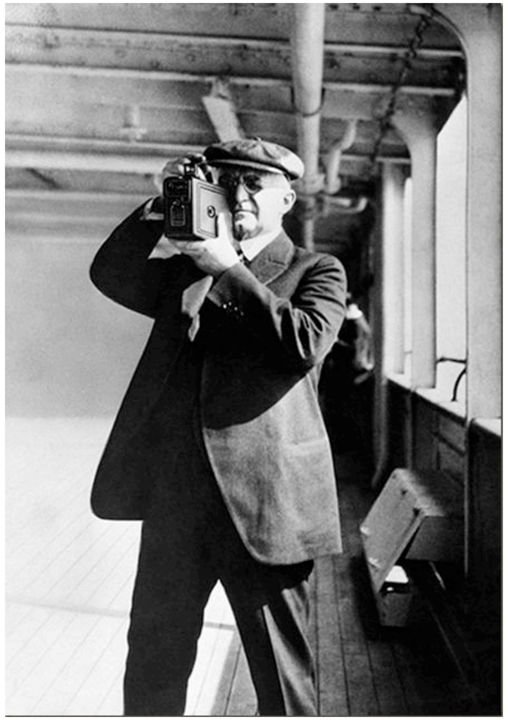
Single viewpoint

Alyosha Efros
Place Furstenberg, 2009

Recording images automatically

- Silver halide (AgCl, AgBr, AgI) salts are light sensitive
  - absorbed photons in halide ions cause free
  - electrons electrons combine with Ag+, producing metallic silver
- Daguerre: first practical and permanent photographic plate
  - Hg vapor (yikes!) combines with Ag to produce reflective amalgam Daguerrotypes were widely popular
- Indirect negative-plate processes
  - negative images on paper, glass allowed multiple copies to be printed
- Roll film: silver halide grains in gelatin on celluloid
  - introduced by Eastman in 1880s
  - portable, convenient, practical
  - sensitive ("fast") enough for moving subjects in daylight

Daguerrotype (1839)



George Eastman with his Kodak camera

Slide adapted from P. Milanfar

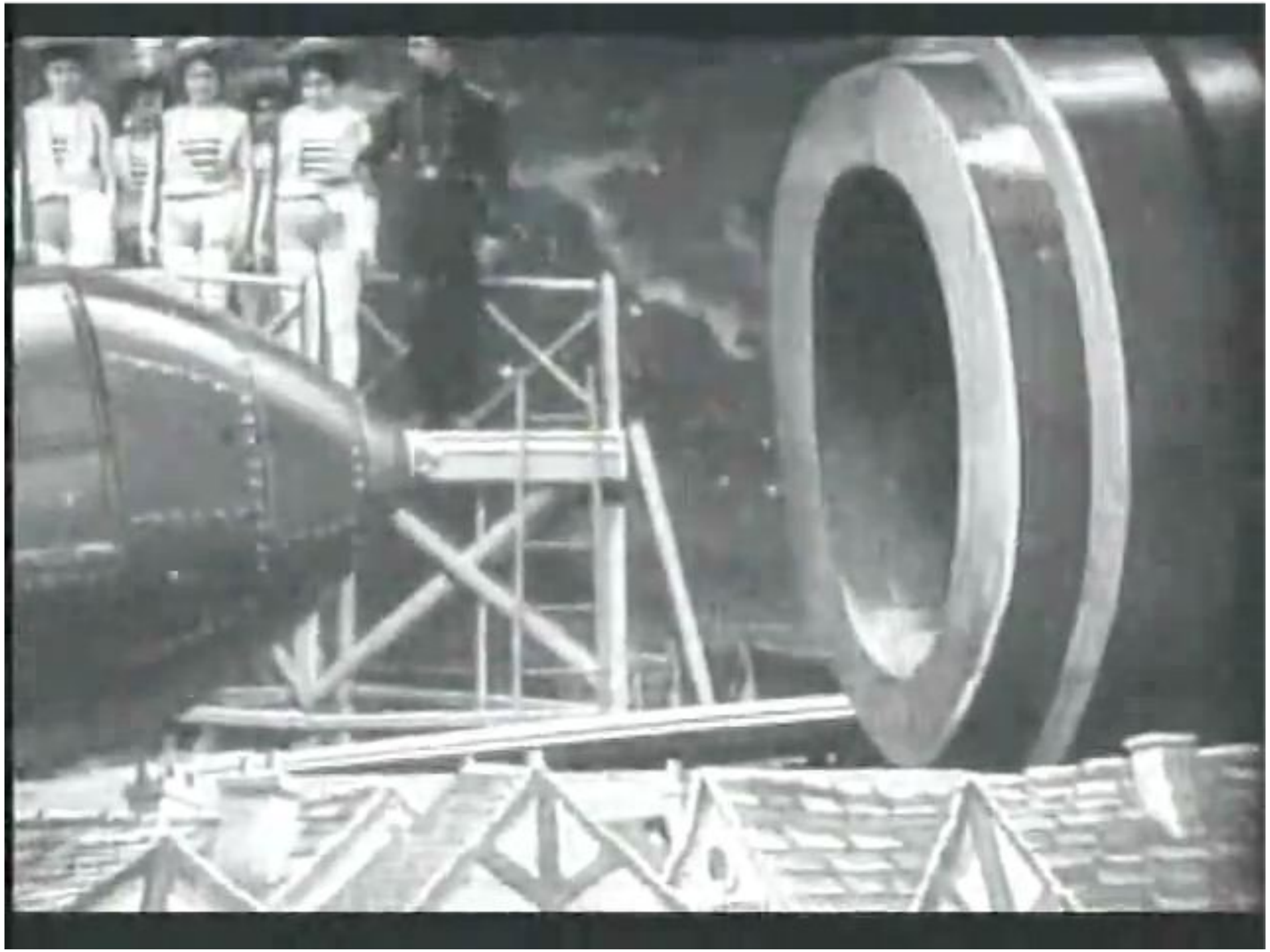
Motion pictures

- Sensitive roll film enables sampling in time
- 1890s - several cameras
  - Lumière brothers' Cinematographe
  - Edison's Kinescope

Cinématographe [Wikimedia commons]

George Eastman and Thomas Edison in 1928

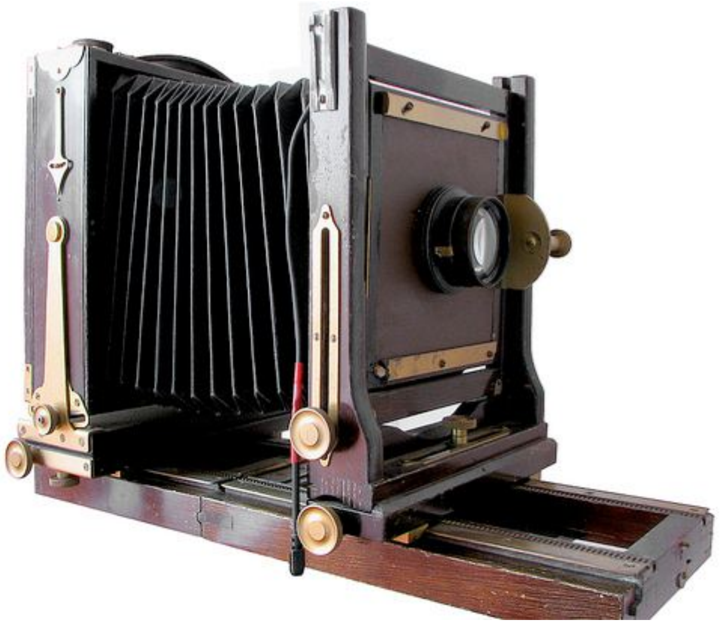
George Méliès



Georges Méliès, A Trip to the Moon, 1902

Improvements in cameras

- Size and portability
- Ease of use
- Automation



Improvements in film

- Sensitivity
  - enables photographs of faster subjects—“faster” film
- Dynamic range
  - higher quality images with detail in highlights and shadows
  - expanded “latitude” to mess up the exposure
- Resolution
  - enables smaller format cameras

Television

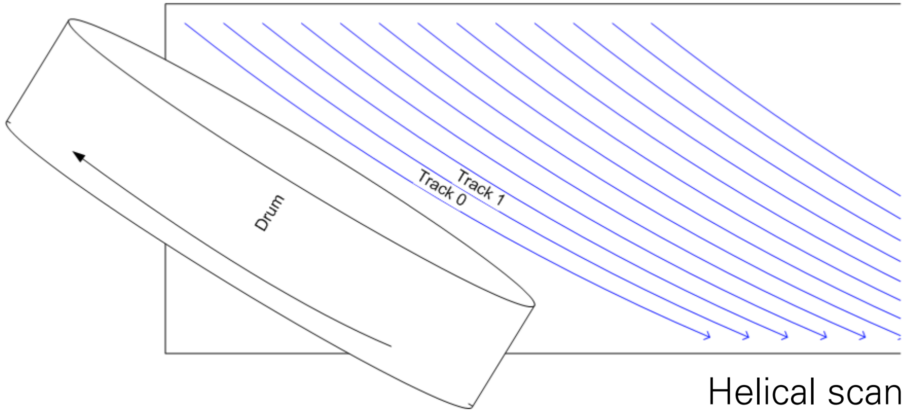
- Practical around 1927 (Farnsworth)
- Camera basically the same
  - imaging lens plus planar image sensor
- Recording is electronic
  - various early schemes
  - early winner: CRT image sensors (Orthicon, Vidicon, ...)
- Initially seems quite different from photography/cinematography
  - ephemeral output signal - live viewing only
  - low resolution, low dynamic range images

Farnsworth Archives

Philo Farnsworth, c. 1935

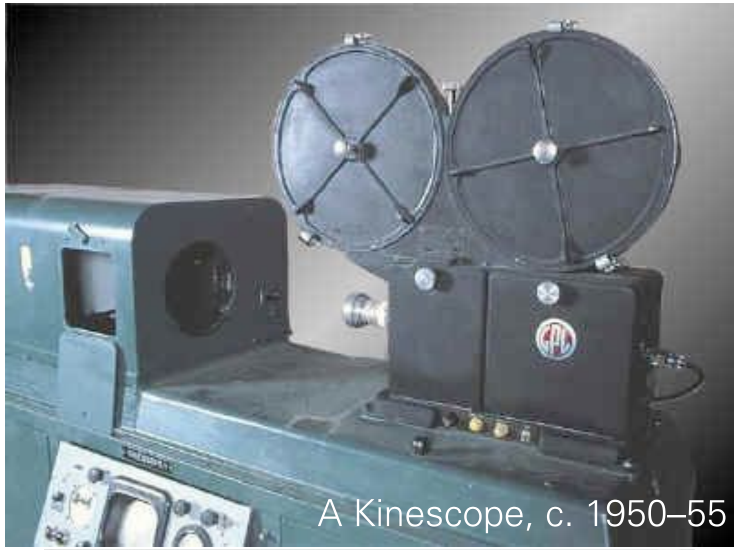
Recording video signals

- Kinescope (1940s)
  - photograph onto motion picture film re-photograph the film for replay
- Videotape (1956)
  - record signal on magnetic tape
  - very high head velocities required - transverse or helical scanning



Wikipedia

Helical scan



A Kinescope, c. 1950–55

Peter Lindell, Canada Science and Technology Museum

A 2-inch video tape recorder c.1970

Wikipedia

Imaging around 1950s–70s

- Technology improves incrementally
  - Film emulsions improve; very high quality attainable in large formats
  - Video technology improves; but standards keep resolution fixed
  - Lens designs improve, cameras become much more usable
- Usage is refined
  - Photography an established art form, widespread hobby
  - Cinematography develops as a storytelling medium
  - Television becomes dominant mass communication medium

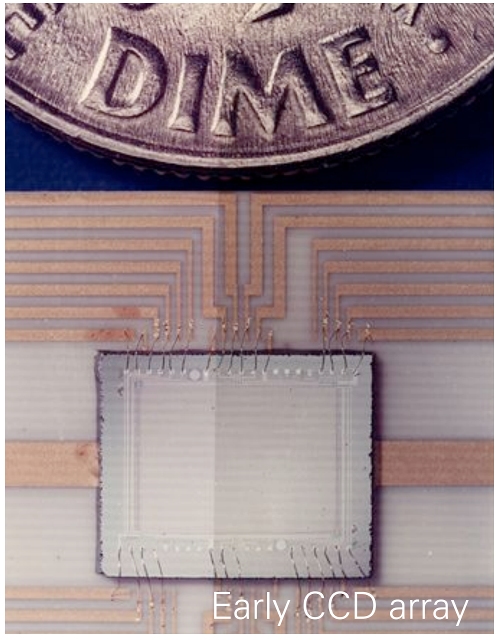
Meanwhile…

- Invention of CCD (1969)
  - solid-state, fundamentally discrete image sensor
  - quickly established in astronomy, space
  - by mid-80s, displaces tubes in video cameras (as drop-in replacement)
- Computing and computer graphics
  - sufficient memory to store images becomes available
  - first framebuffers developed 1972–74
- Digital signal transmission and processing
  - used for audio and telephone
- These set the stage for the next revolution

Photo: Alcatel-Lucent/Bell Labs

George Smith and Willard Boyle in 1970

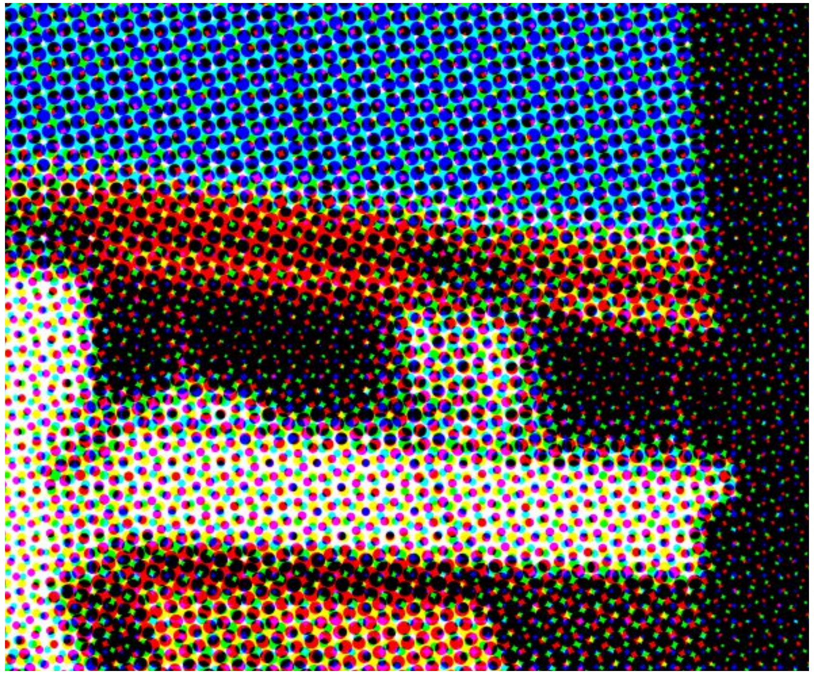
Photo: Alcatel-Lucent/Bell Labs

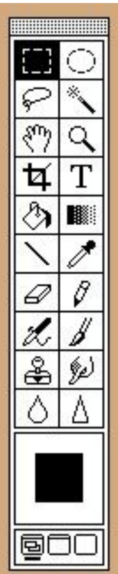


Early CCD array

Digital imaging

- Halftone printing of images
  - halftone process around for a while
  - complex, delicate optical procedure
  - moving images from place to place requires moving film or paper
- Digital imaging
  - scan images from film or paper
  - transmit images by phone
  - do processing (e.g. halftone separation) by computing print images using laser printer or laser film recorder
- Image editing
  - 1990—Adobe Photoshop 1.0
- Image compression algorithms
  - make image storage, transmission more practical





Photoshop toolbar from version 1.07

Digital photography

- Digital images are established
  - people can make use of them directly
- CCD sensors improve
  - Moore’s law makes pixels smaller
  - video cameras already recording images electronically
  - digital image capture used in scientific applications
- Analog electronic still camera (aka. still video camera)
  - is just a video camera that takes one frame at a time
  - several manufacturers made them
  - but high image quality expectations for stills delays acceptance

First microprocessor in a camera, Canon AE-1976

Canon RC-701 still video camera, 1986

Early digital cameras

- Important limitations
  - low image quality (relative to film) slow camera performance
  - large, heavy, clunky
  - limited, expensive image storage
- Important advantages
  - immediate availability of images
  - zero (well...) marginal cost per exposure
- First adopters: photojournalists
- Kodak DCS series
  - based on film camera bodies
  - early commercial success
  - storage: PCMCIA hard disks (mid 90s)

digicamhistory.com

Kodak DCS-100, 1991

Kodak DCS-100, 1991

Digital rivals film

- Key improvements
  - cameras become more compact
  - resolution and dynamic range improve
  - LCD displays for immediate image review
  - costs drop
- Meanwhile
  - computers with high-quality color displays become pervasive
- User experience
  - image review is a big change for users
  - sharing of digital images suddenly becomes easier than prints

Digital video

- Initially: improved recording medium
  - record the same old signal, but digitally best-quality medium for professional use
- Improvements
  - storage and bandwidth improve by orders of magnitude
  - video compression algorithms advance
  - digital formats become simpler/better than analog-derived
  - flexibility finally unlocks video resolution
- Digital recording becomes standard for video
  - basic experience similar
  - cost and quality greatly improved

Digital displaces film and video

- Move from convenience vs. quality to convenience and quality
- Digital slowly takes over for basically all users
  - advances in storage/transmission and compression algorithms
  - ecosystem for online sharing of photos, videos
  - declining use of printed images
- Last bastion: cinematography
  - delay: quality standards plus tradition
  - first took over low end because of film costs
  - now taking over high end because of superior quality/usability

Digital cameras today

- Digital SLRs
  - high-end product for professionals and enthusiasts
- Digital cinema
  - high-resolution cameras for big-budget film production
- HD video
  - medium resolution for low-end film and high-end TV production
- Mirrorless system cameras
  - smaller high-end cameras with electronic viewfinding
- Compact still cameras
  - inexpensive, auto-everything for day-to-day usage
- Tiny cameras in all cell phones
  - “The best camera is the camera that is with you”



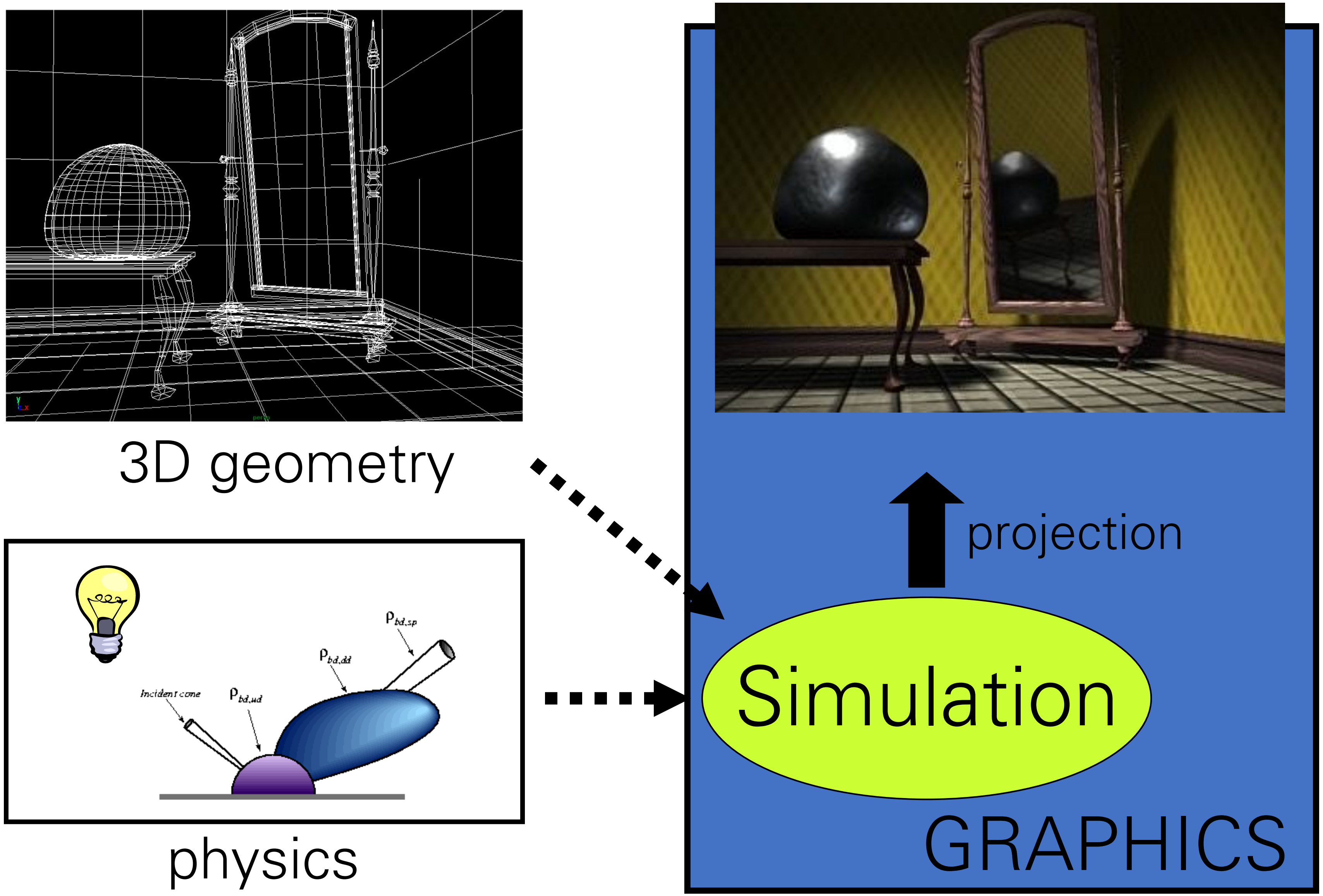
Digital photography today

- Video, photography, and cinema have converged
  - all using the same basic technology
  - all modern still cameras do video too (and many vice versa)
- Cameras becoming completely pervasive
  - film-equivalent quality possible in <1 cm^3
  - mobile applications driving much sensor/lens development
  - mobile cameras had eaten compact digicam market
- Computing power still rapidly advancing
  - more and more computation being done on images

Computer Graphics?

- Computers to create image
- Sketchpad, 1961, Ivan Sutherland's MIT PhD thesis

Traditional Computer Graphics



State of the Art

- Amazingly real
- But so sterile, lifeless, futuristic (why?)

The richness of our everyday world

Photo by Svetlana Lazebnik

Beauty in complexity

University Parks, Oxford

Which parts are hard to model?

Photo by Svetlana Lazebnik

People

From “Final Fantasy”

On the Tube, London

Today's Lecture

- Course info
- History of photography
- Limitations of traditional photography

Disclaimer: Some of the material and slides for this lecture were borrowed from

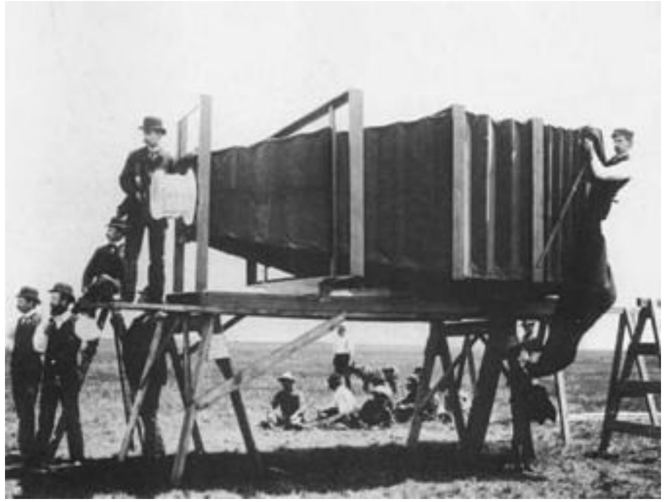
—Alexei Efros's CS194-26/294-26 "Intro to Computer Vision and Computational Photography" class

—Steve Marschner's CS6640 "Computational Photography" class

—Fredo Durand's slides on "The History of photography"

The unfinished revolution

- Traditional photography:
  - optics focuses optical array onto sensor
  - chemistry records final image
- Digital photography
  - optics focuses optical array onto sensor
  - digital sensor records final image



Slide credit: F. Durand

Limitations of traditional photography

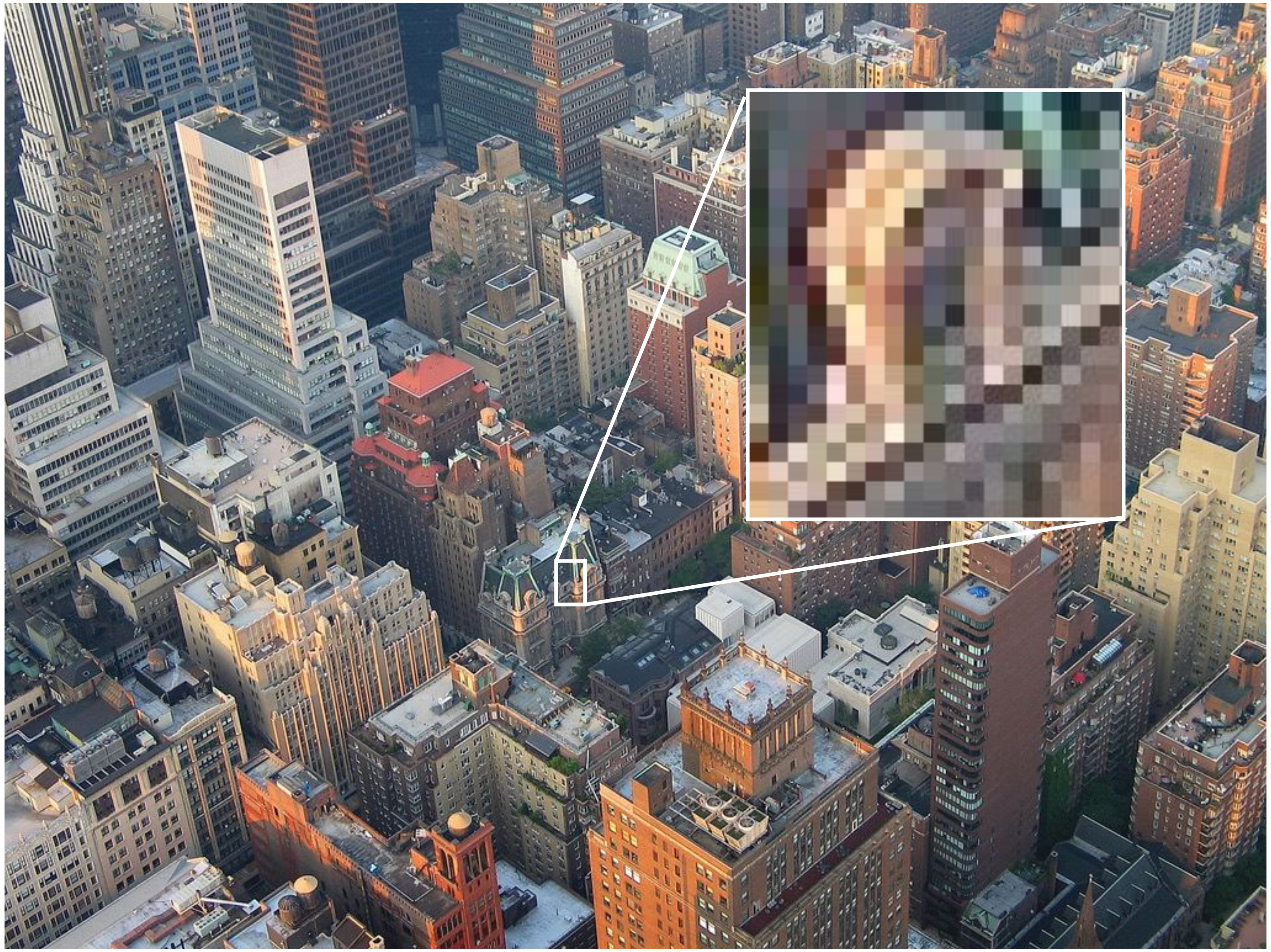
- Blur, camera shake, noise, damage




Slide credit: S. Lazebnik

Limitations of traditional photography

- Limited resolution



Slide credit: S. Lazebnik

Limitations of traditional photography

- Bad color / no color

Slide credit: S. Lazebnik

Limitations of traditional photography

- Unwanted objects

Slide credit: S. Lazebnik

Limitations of traditional photography

- Unfortunate expressions

Slide credit: S. Lazebnik

Limitations of traditional photography

- Limited dynamic range

Slide credit: S. Lazebnik

Limitations of traditional photography

- Single viewpoint, static 2D picture

Slide credit: S. Lazebnik

Limitations of traditional photography

- Single depth of focus

Creating Realistic Imagery

Computer Graphics

+ great creative possibilities

+ easy to manipulate objects or viewpoint

- tremendous expertise and effort to obtain realism

Computational Photography

Realism
Manipulation
Ease of capture

Photography

+ instantly realistic

+ easy to acquire

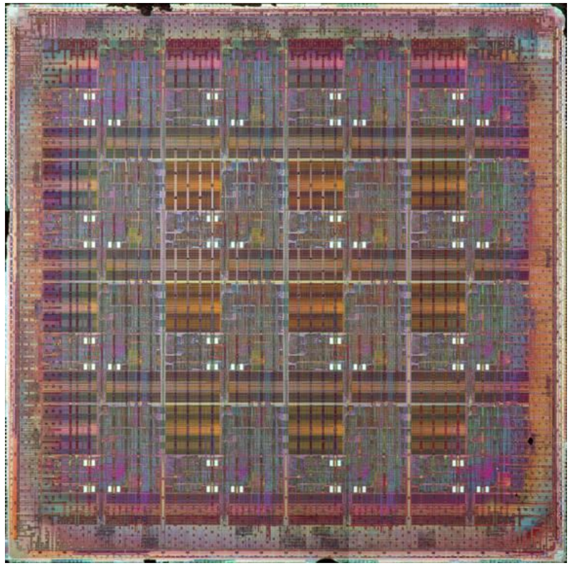
- very hard to manipulate objects or viewpoint

Slide credit: S. Lazebnik

Computational Photography

- Arbitrary computation between the optical array and the final image
- Data recorded by sensor is not the final image

Generalized imaging



Lots of computation

Final image

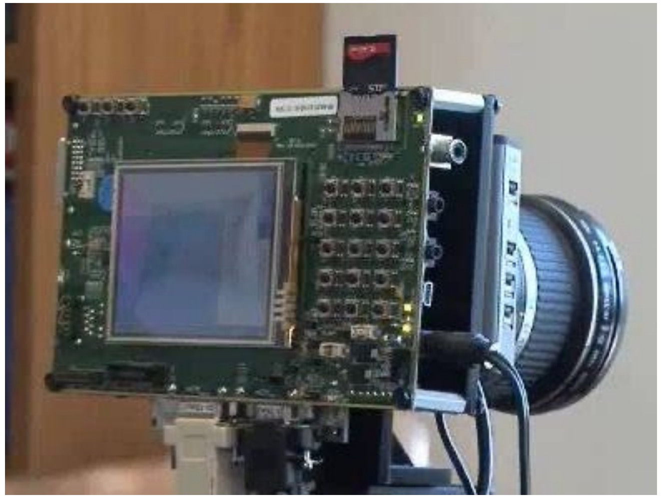
Slide credit: F. Durand

Computational Photography

- Arbitrary computation between the optical array and the final image
- Post-process after traditional imaging
  - a.k.a. image processing (maybe more interactive)
  - But also combine multiple images to overcome limits of traditional imaging (HDR, panorama)
- Design imaging architecture together with computation
  - Computational cameras, computational illumination, coded imaging, data-rich imaging
- Extract more than just 2D images
- New media (panorama, photo tourism)

Slide credit: F. Durand

Computational Photography



- How can I use computational techniques to capture light in new ways?
- How can I use computational techniques to breathe new life into the photograph?
- How can I use computational techniques to synthesize and organize photo collections?

Slide credit: F. Durand

Reading Assignment

- Brian Hayes, Computational Photography, American Scientist 96, 94-99, 2008

Next Lecture:
Image formation