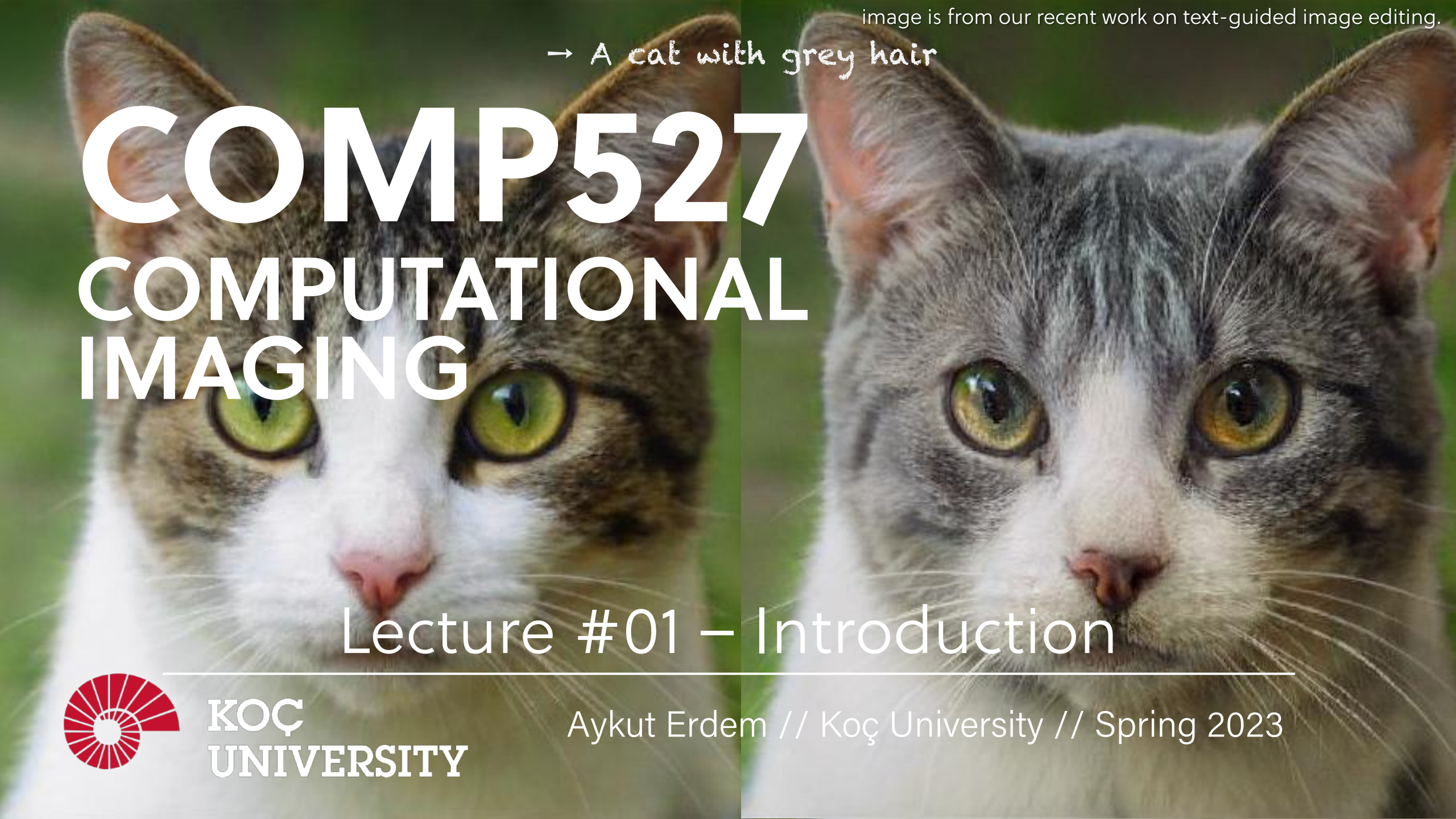


COMP527
COMPUTATIONAL IMAGING

Lecture #01 – Introduction

KOÇ UNIVERSITY

Aykut Erdem // Koç University // Spring 2023

Today's Lecture

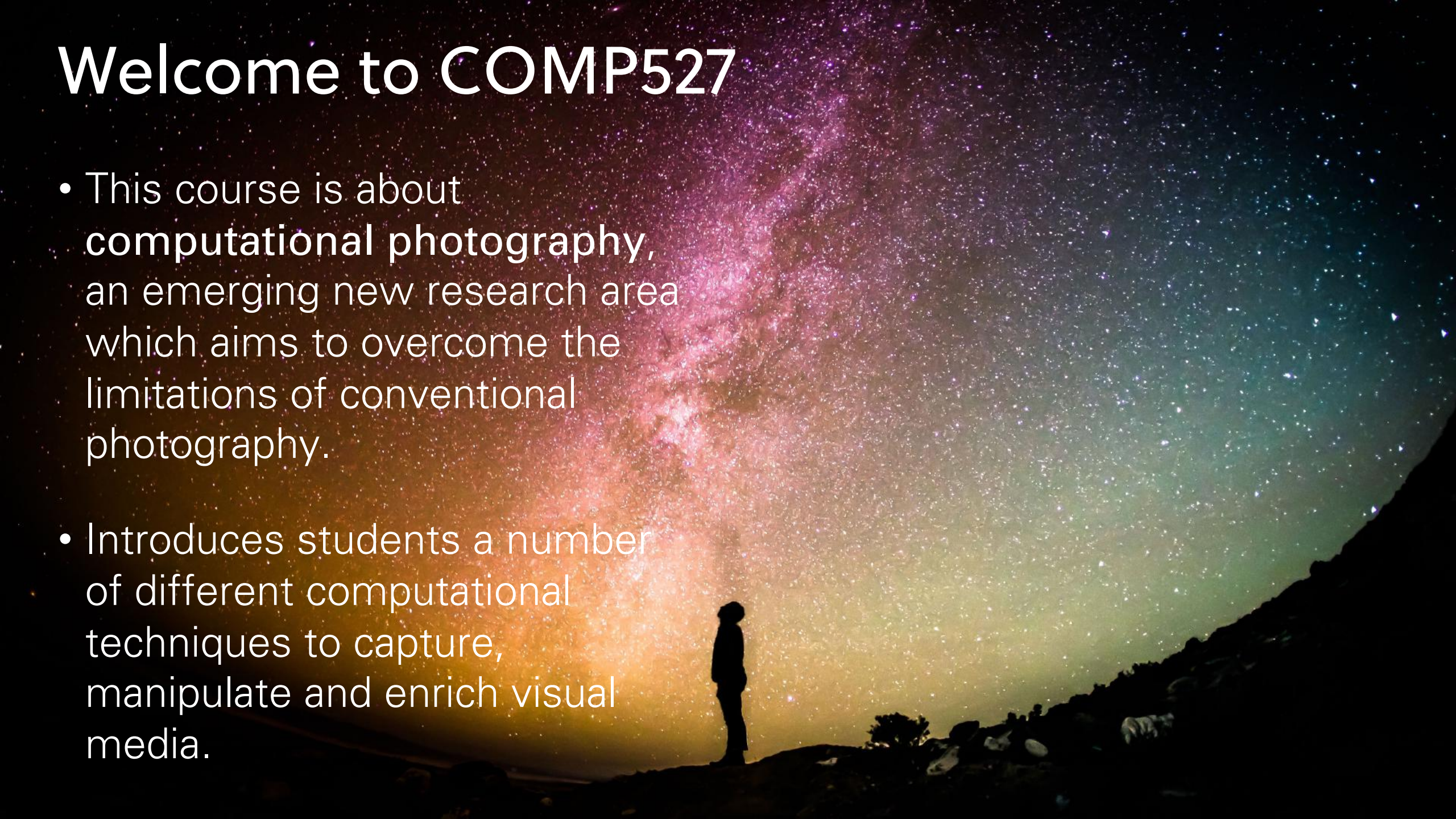
- Course info
- History of photography
- Limitations of traditional photography
- Recent accomplishments

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"

Today's Lecture

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

Welcome to COMP527



- This course is about **computational photography**, an emerging new research area which aims to overcome the limitations of conventional photography.
- Introduces students a number of different computational techniques to capture, manipulate and enrich visual media.

A little about me...

Koç University
Associate Professor
2020-now

Hacettepe University
Associate Professor
2010-2020

Universitá Ca' Foscari di Venezia
Post-doctoral Researcher
2008-2010

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

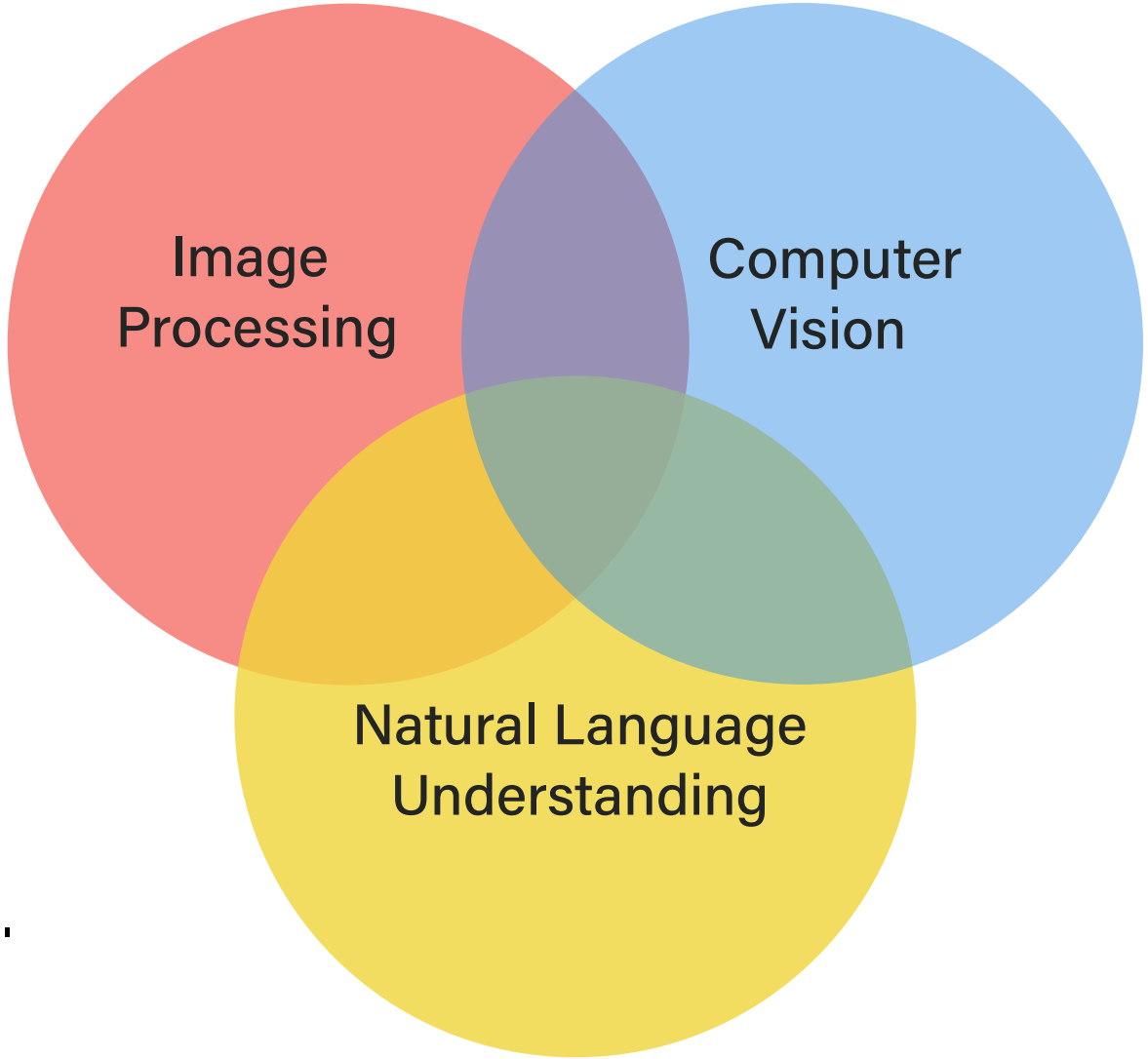
MIT
Fall 2007
Visiting Student

VirginiaTech
Visiting Research Scholar
Summer 2006

- I explore better ways to understand, interpret and manipulate 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.

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

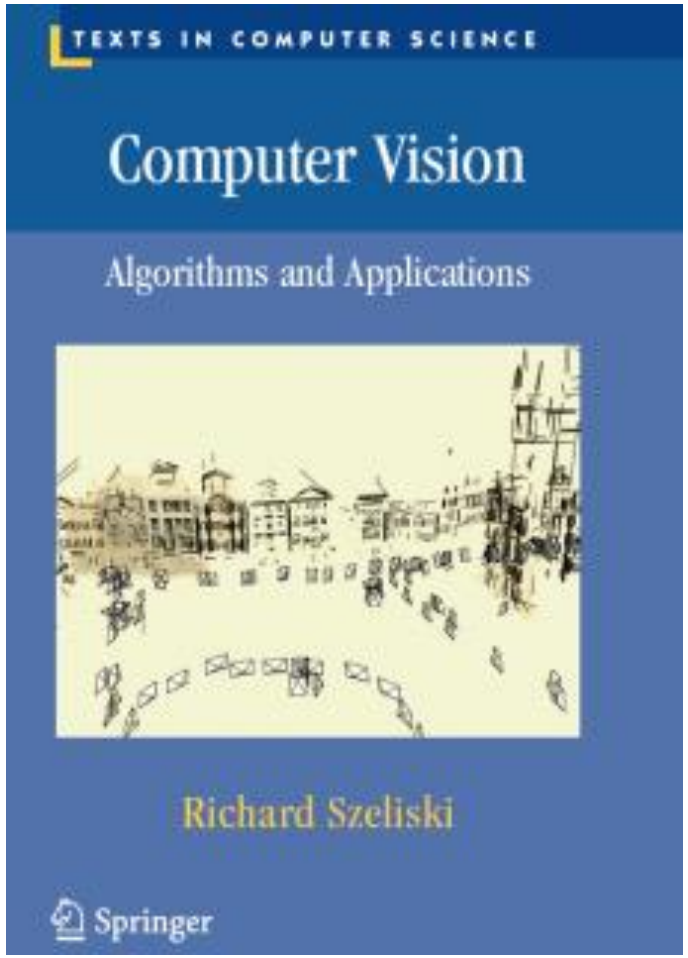
Lectures Monday and Wednesday 16:00-17:15 (SNA B119)

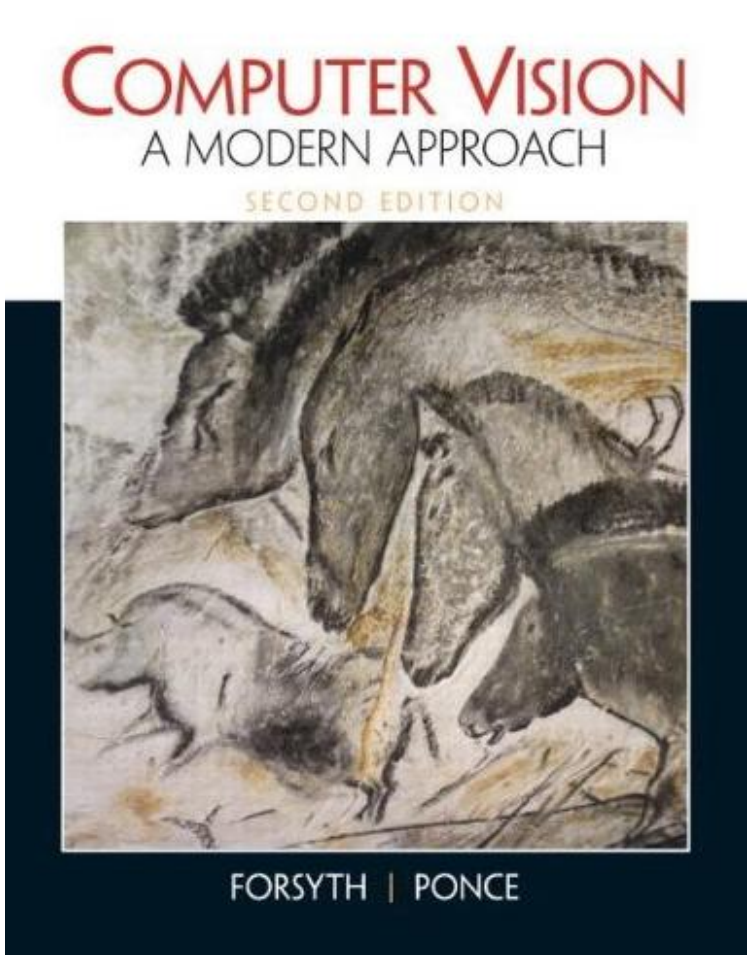
Instructor Aykut Erdem
TAs Canberk Baykal

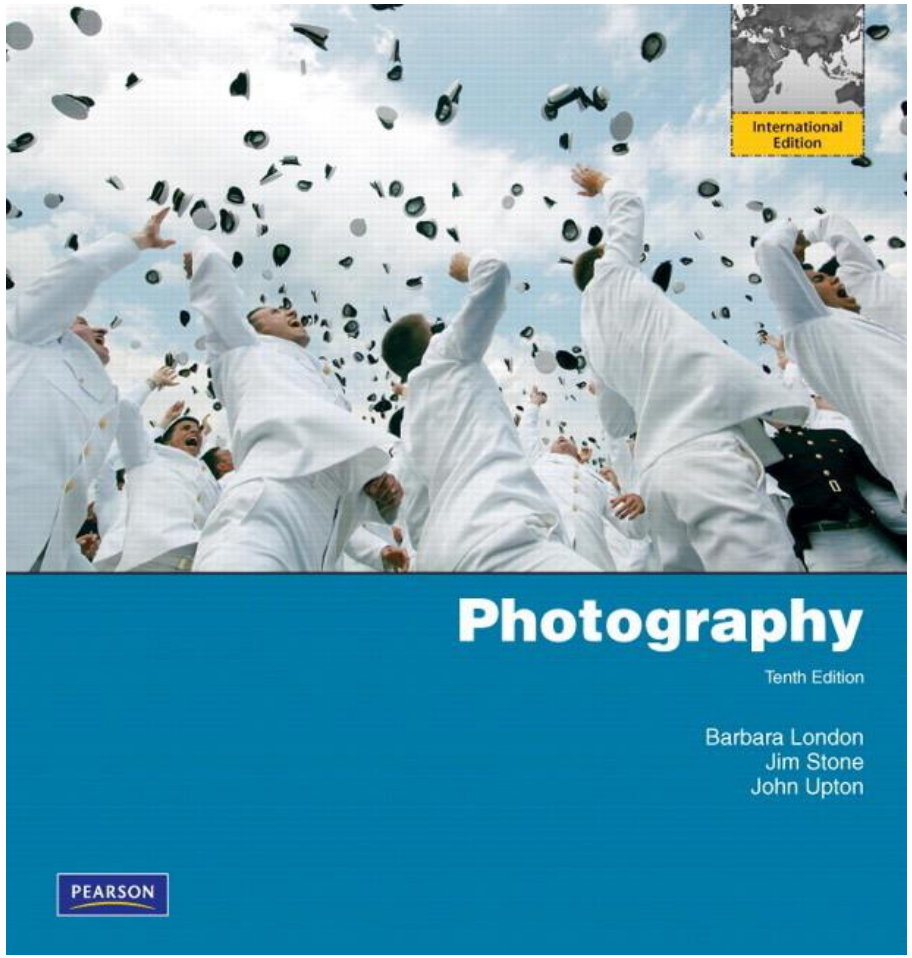
Website https://aykuterdem.github.io/classes/comp527.s23/

- Blackboard for course related announcements and collecting and grading your submissions

Reference Books







Prerequisites

- Good math (calculus, linear algebra, statistics) and programming skills.
- An introductory course on machine learning (ENGR 421) or deep learning (COMP 411/511 or COMP441/541) is highly recommended.

Grading

Programming Assignments	45% (5 assignments x 9% each)
Midterm Exam	20%
Course Project	30%
Class Participation	5%

Attendance

What foreign TV series are you watching now? Just specify the one that you are enjoying the most!

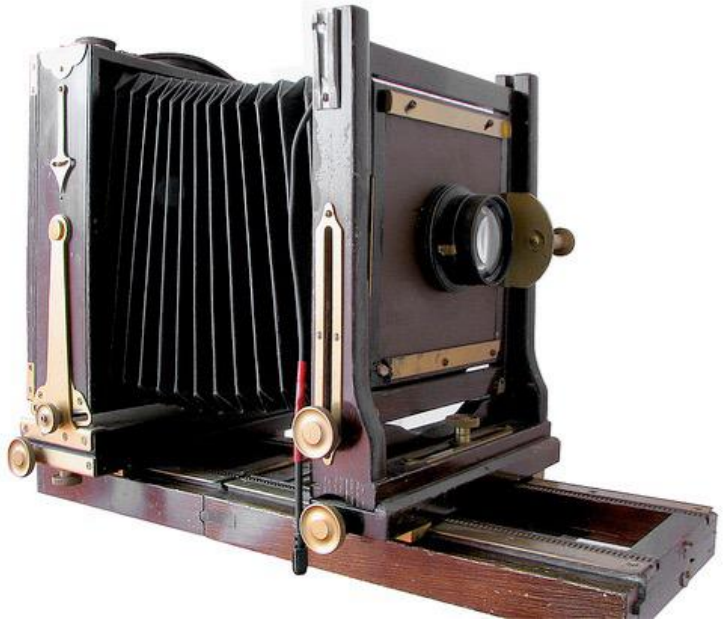
Schedule

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

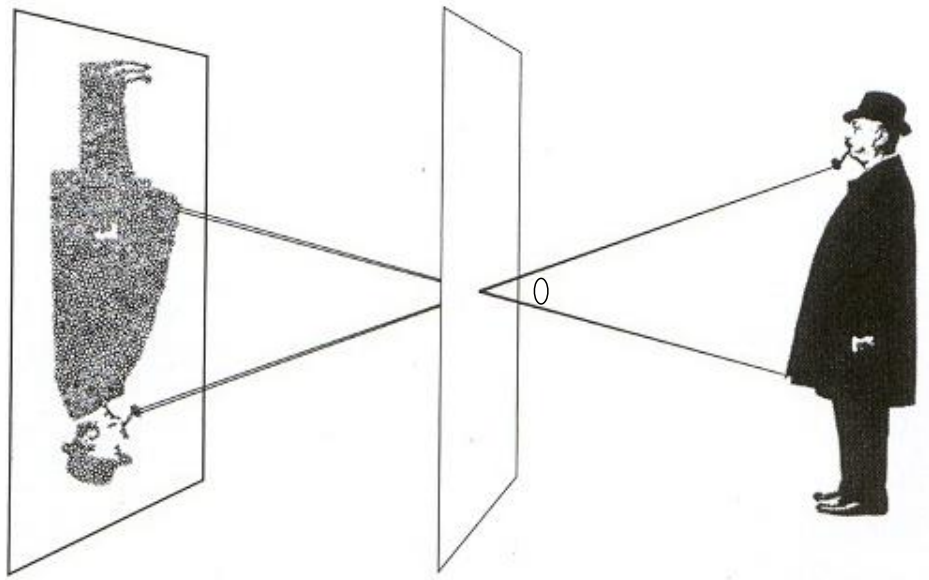
Schedule

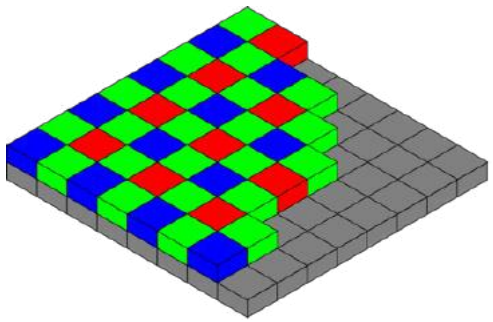
Week 8	*Spring Break*
Week 9	Deconvolution, Coded photography
Week 10	Convolutional Neural Networks
Week 11	Deep Generative Models and their applications
Week 12	Midterm Review
Week 13	Visual quality assessment
Week 14	Advanced topics, Course wrap-up
Week 15	Project presentations

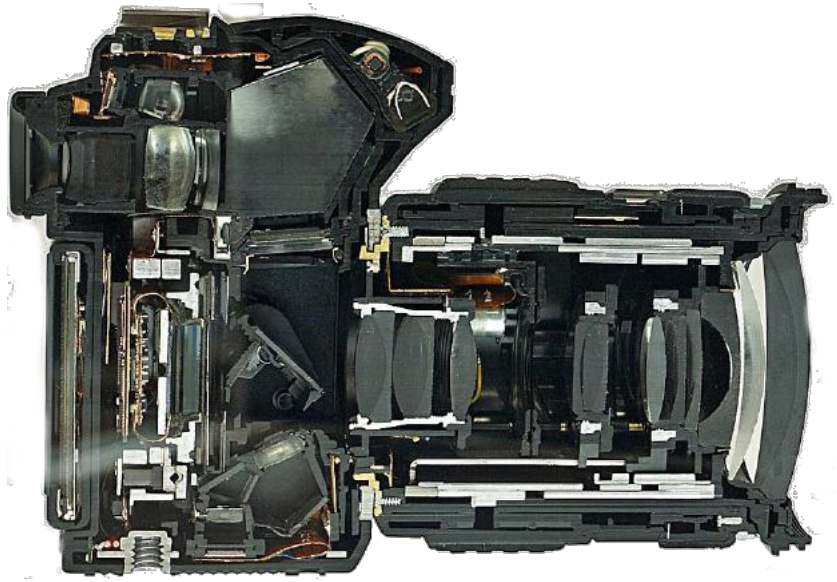
Lecture 1: Introduction to digital photography



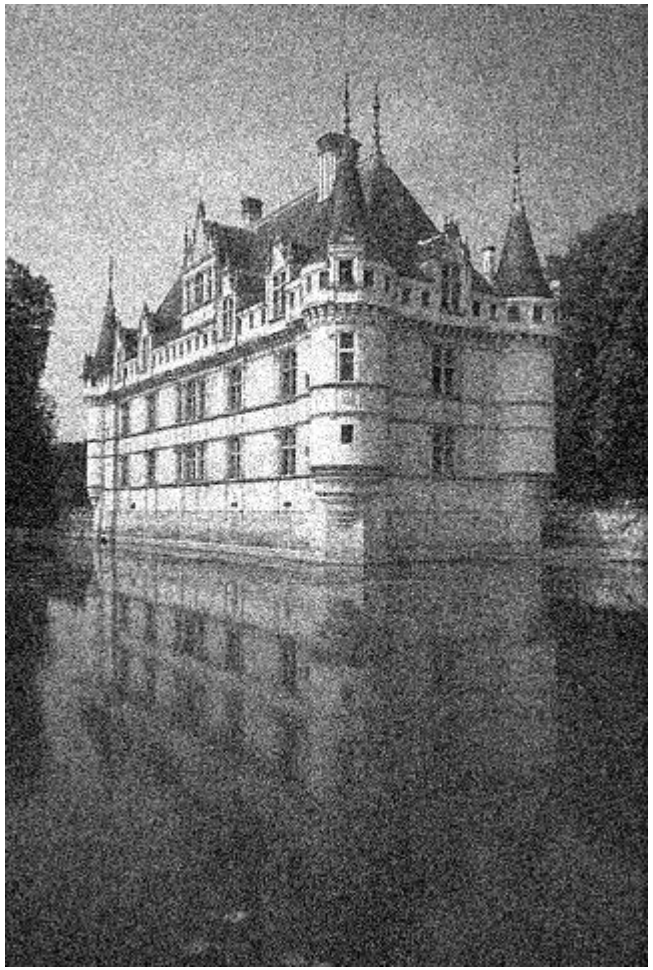
Lecture 2: Image formation

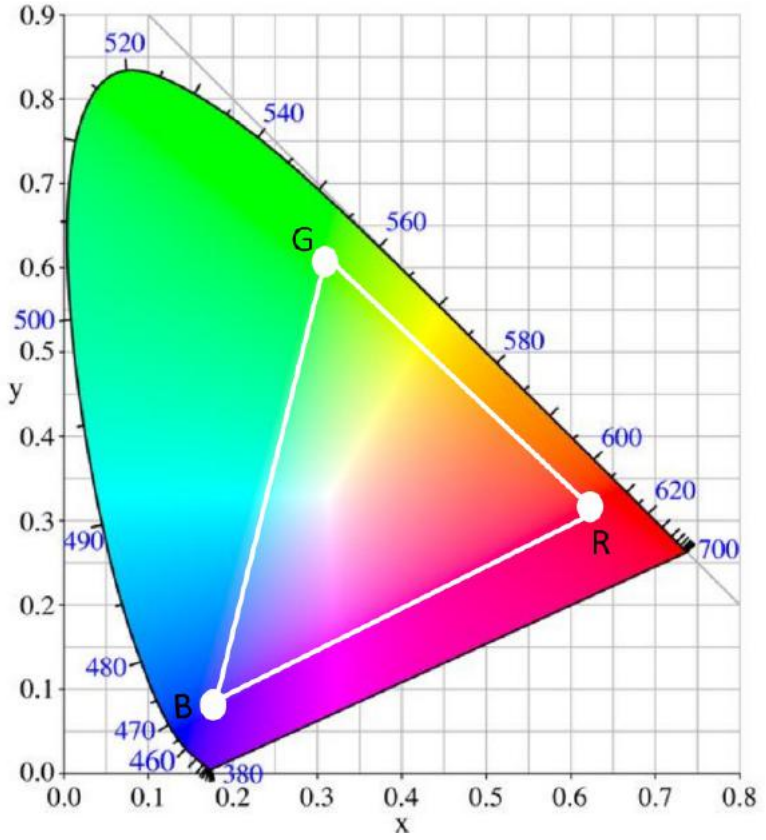






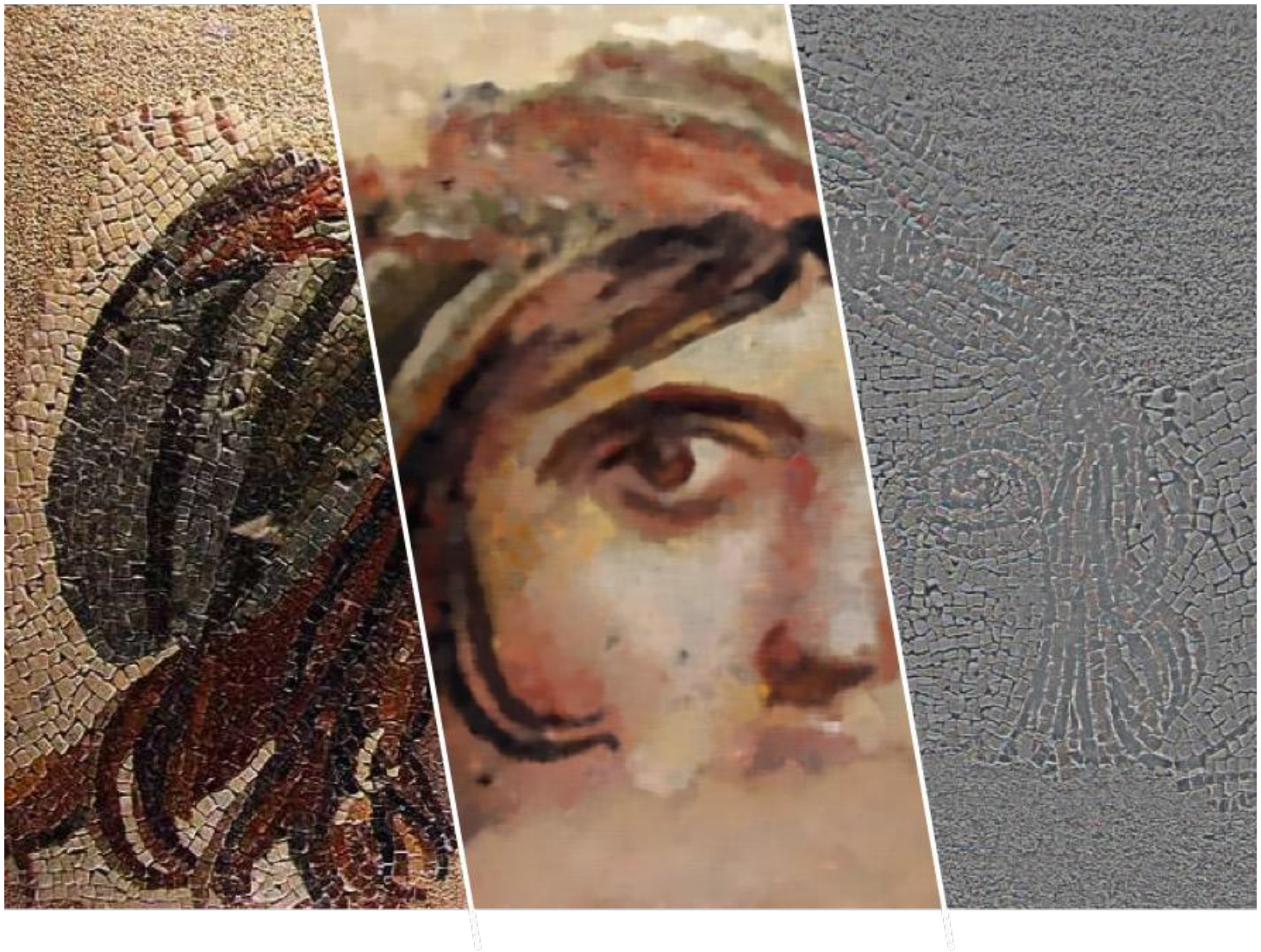
Lecture 3: Noise and Color



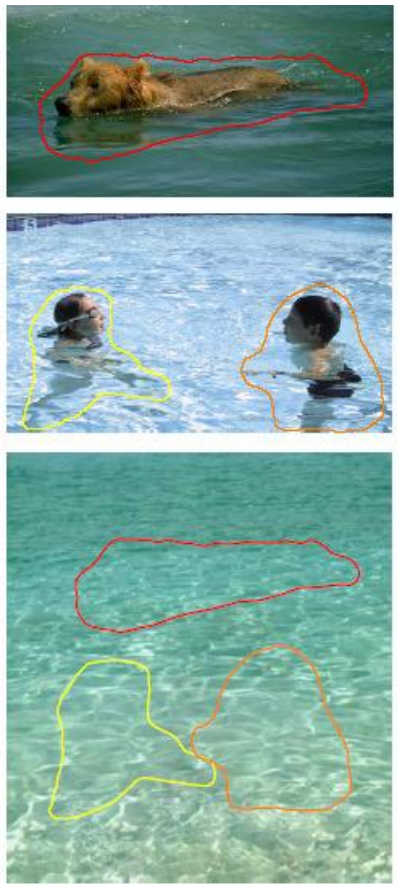


Lecture 4: Exposure and high-dynamic-range imaging

Lecture 5: Edge-aware filtering



Lecture 6: Gradient-domain image processing

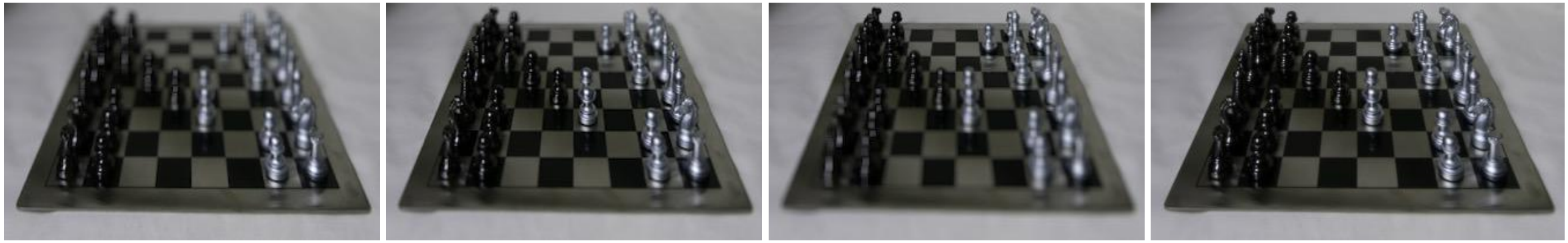


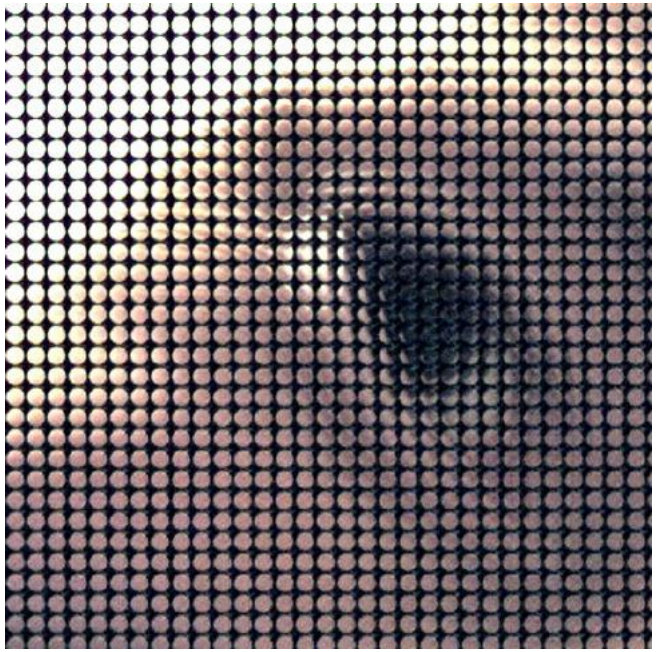
sources/destinations

cloning

seamless cloning

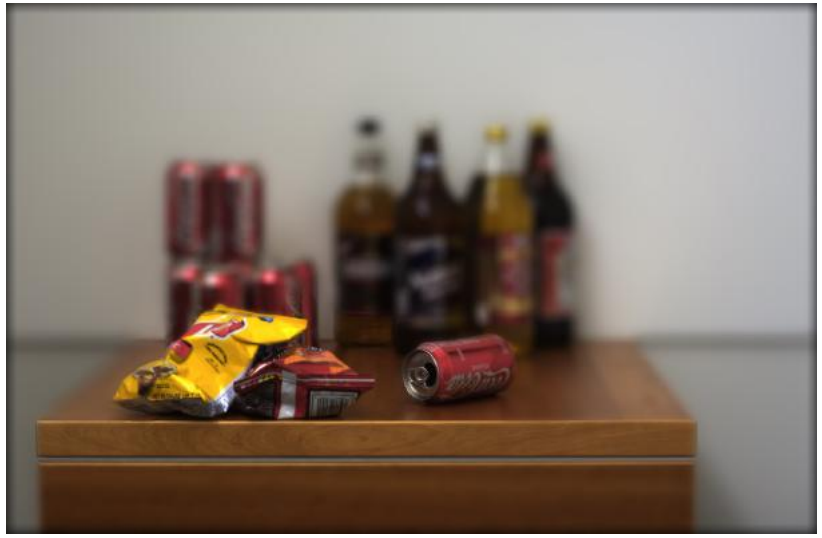
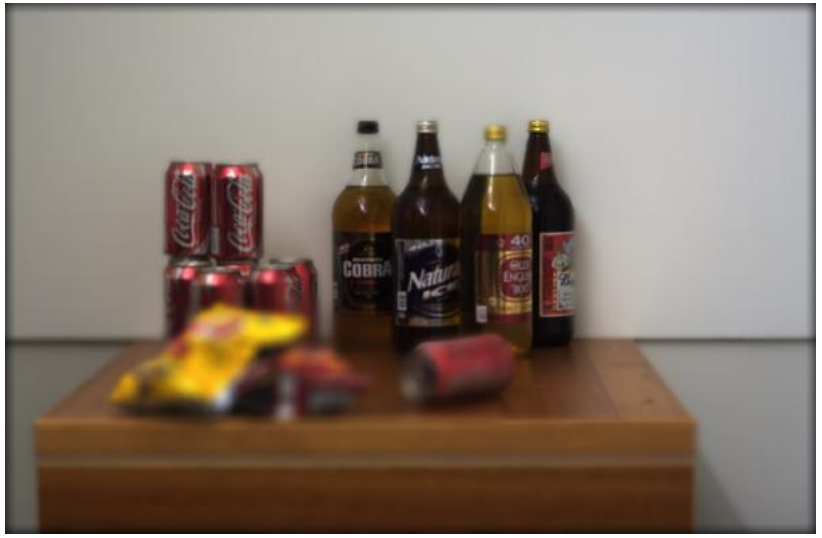
Lecture 7: Focal stacks and depth from (de)focus, Lightfields





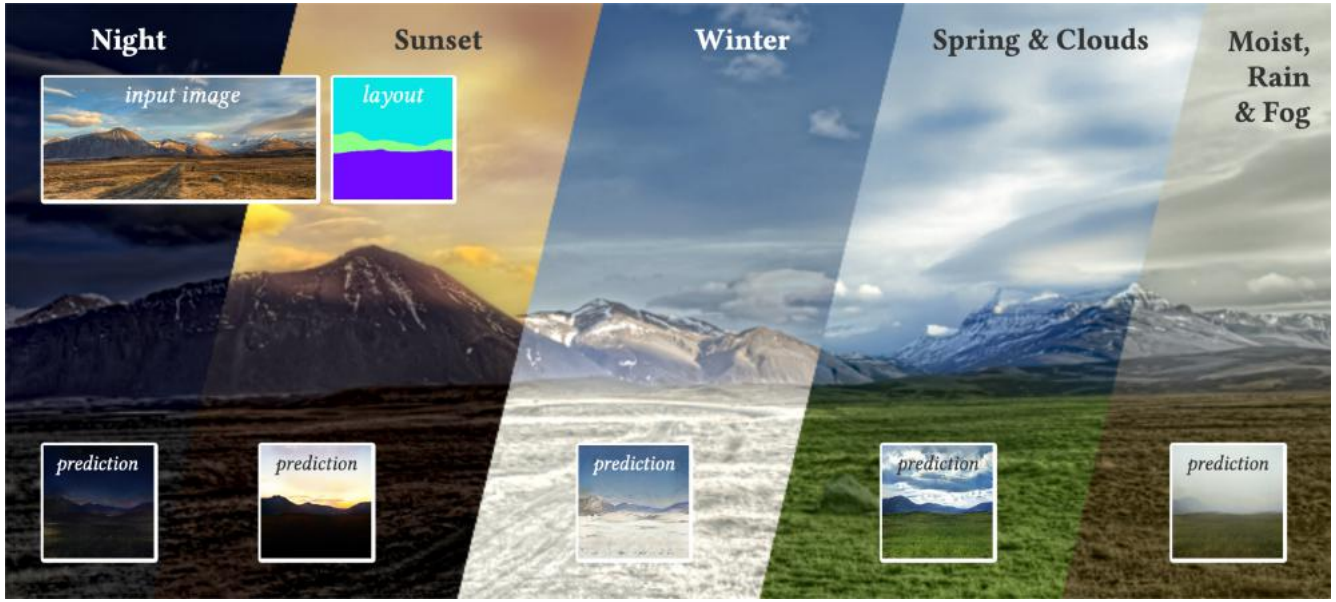
Lecture 8: Deconvolution, Coded photography



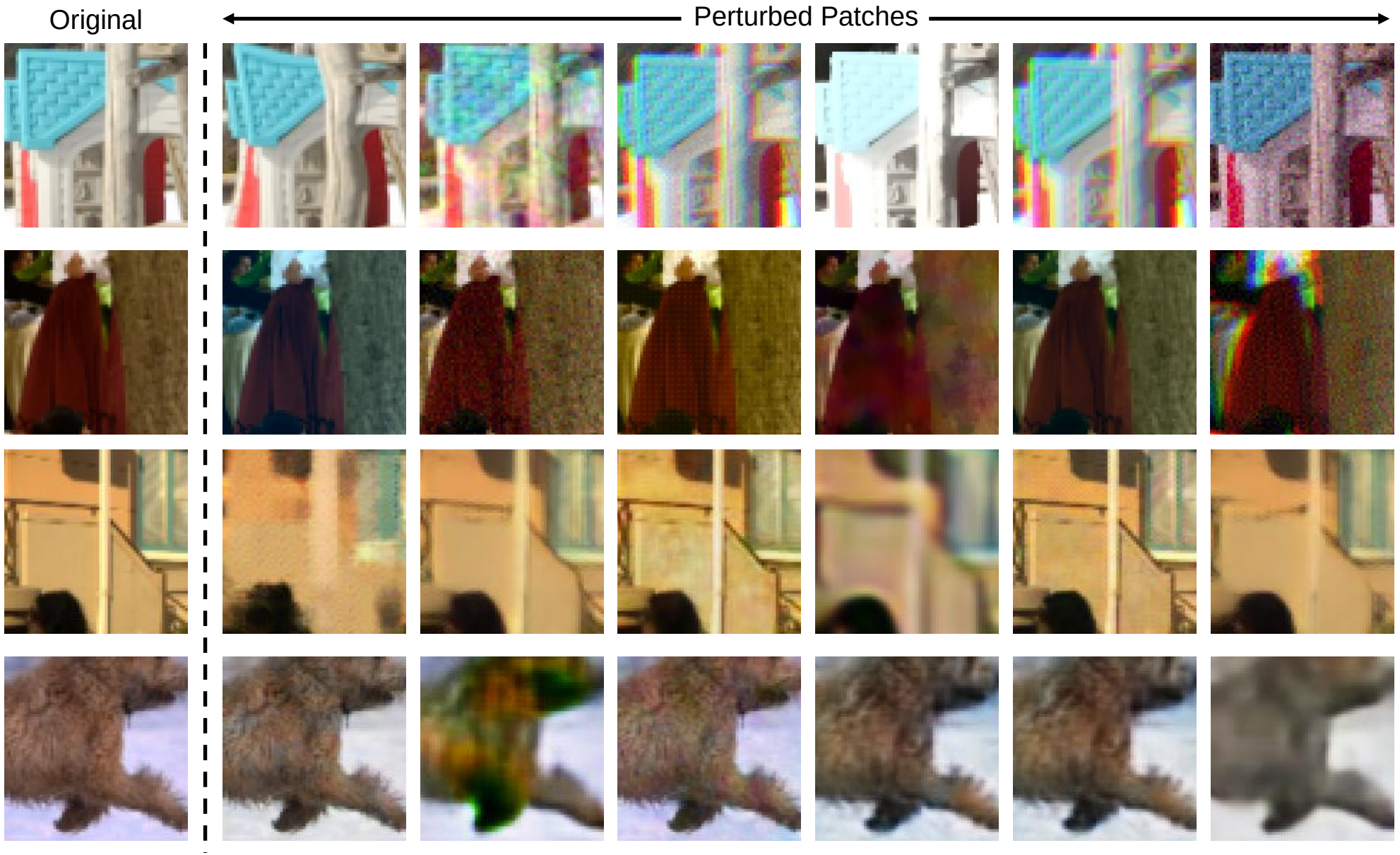




Lecture 9: Convolutional Neural Networks

Lecture 10: Deep Generative Models and their applications



Lecture 11: Visual quality assessment



Programming Assignments

- 5 programming assignments (9% 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 7 slip days in the semester.
  No submissions 2 days after the original deadline will be accepted!

- Tentative Dates
  - Assignment 1 out: March 16, in: March 30
  - Assignment 2 out: March 30, in: April 13
  - Assignment 3 out: April 13, in: May 4
  - Assignment 4 out: May 4, in: May 18
  - Assignment 5 out: May 18, in: June 1

Course project

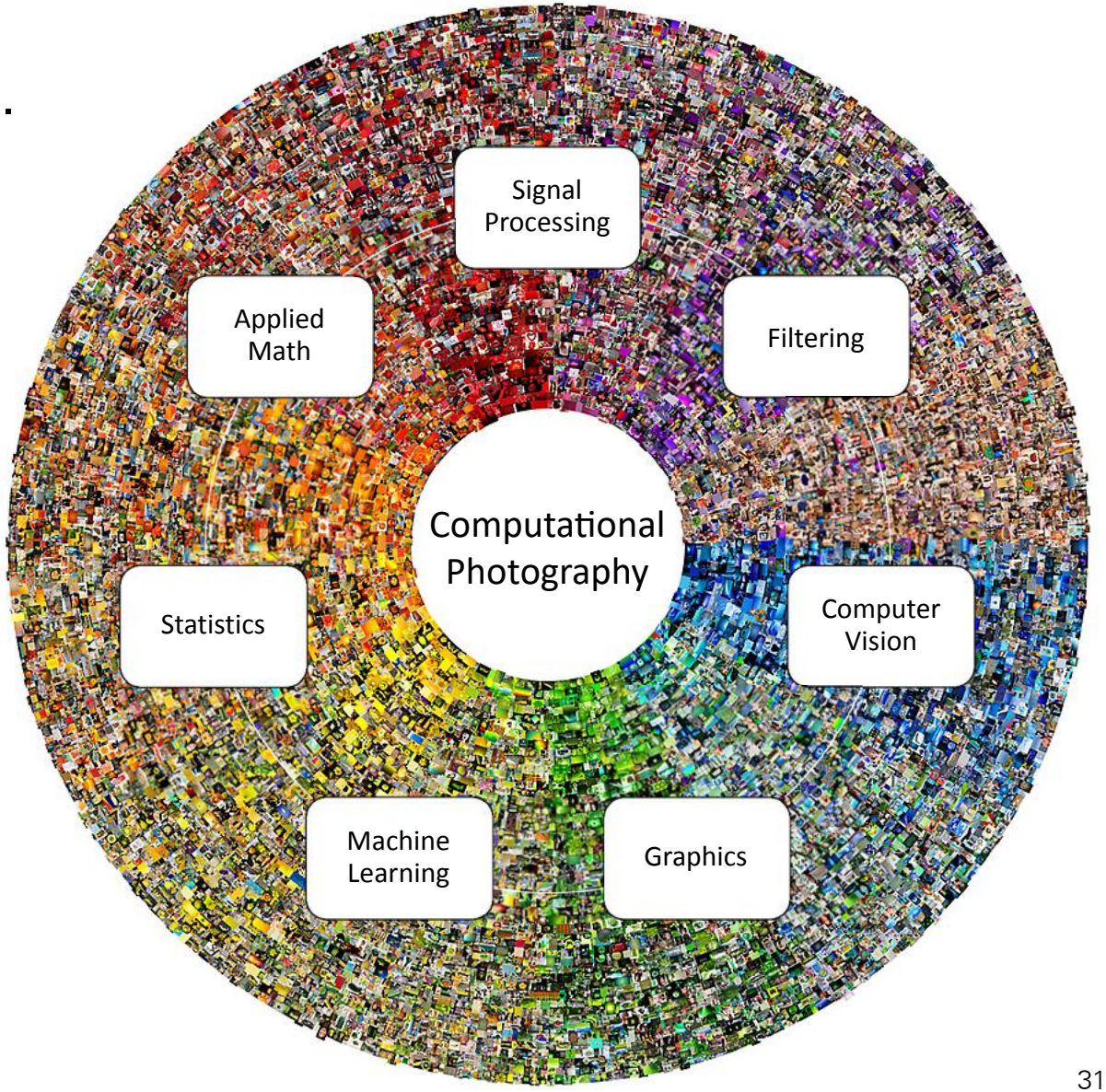
- The course project gives students a chance to apply the methods discussed in class to a research-oriented project.
- **The students should work in pairs**.
- The course project may involve
  - Design of a novel approach and its experimental analysis, or
  - An extension to a recent study of non-trivial complexity and its experimental analysis.
  - A comparative analysis of methods
- Deliverables
  - Proposals — March 31, 2023
  - Project progress reports — May 14, 2023
  - Final project presentations — June 5,7, 2023
  - Final reports — June 11, 2023

Today's Lecture

- Course info
- **History of photography**
- Limitations of traditional photography
- Recent accomplishments

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.

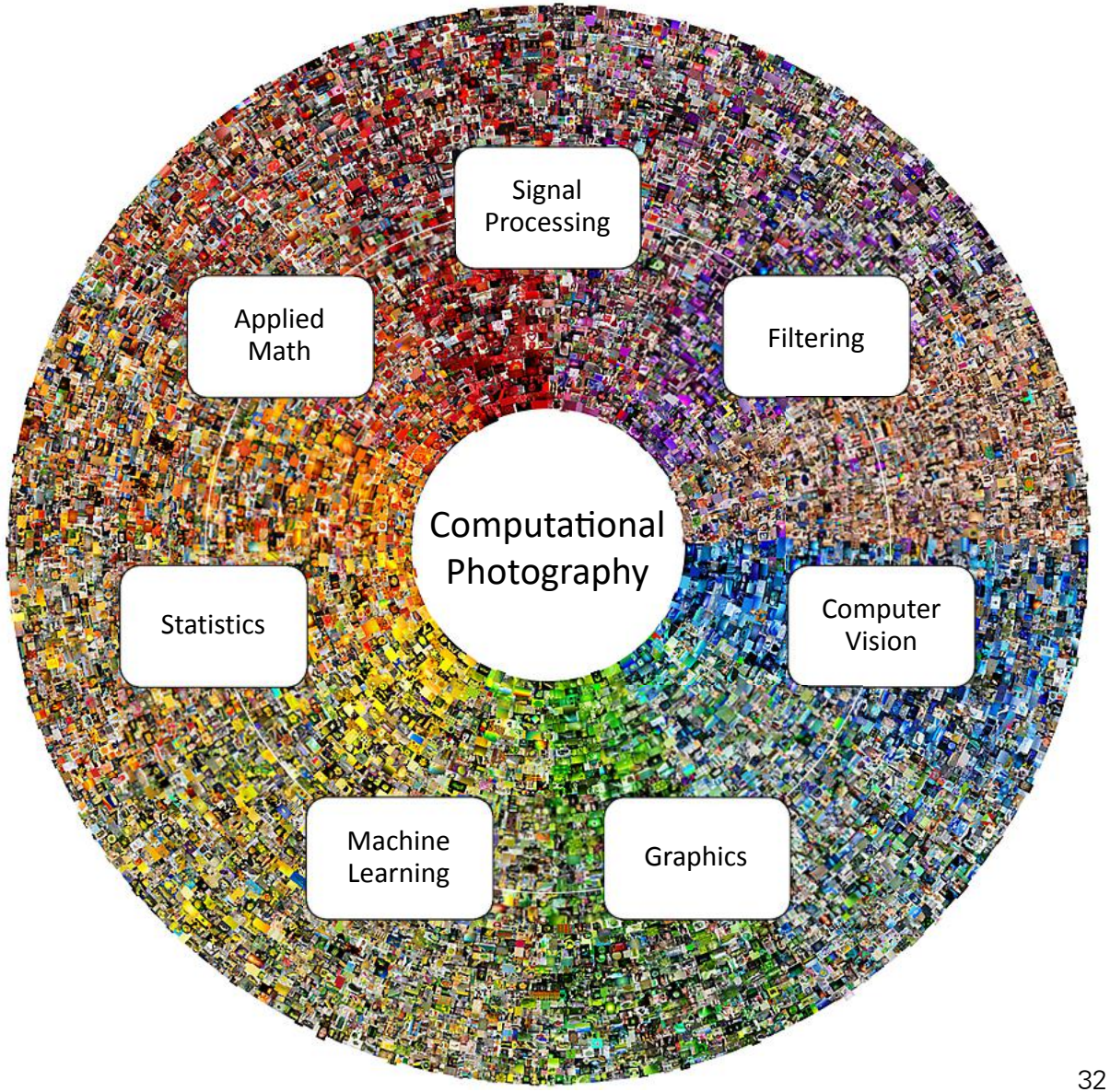


Slide adapted from P. Milanfar

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

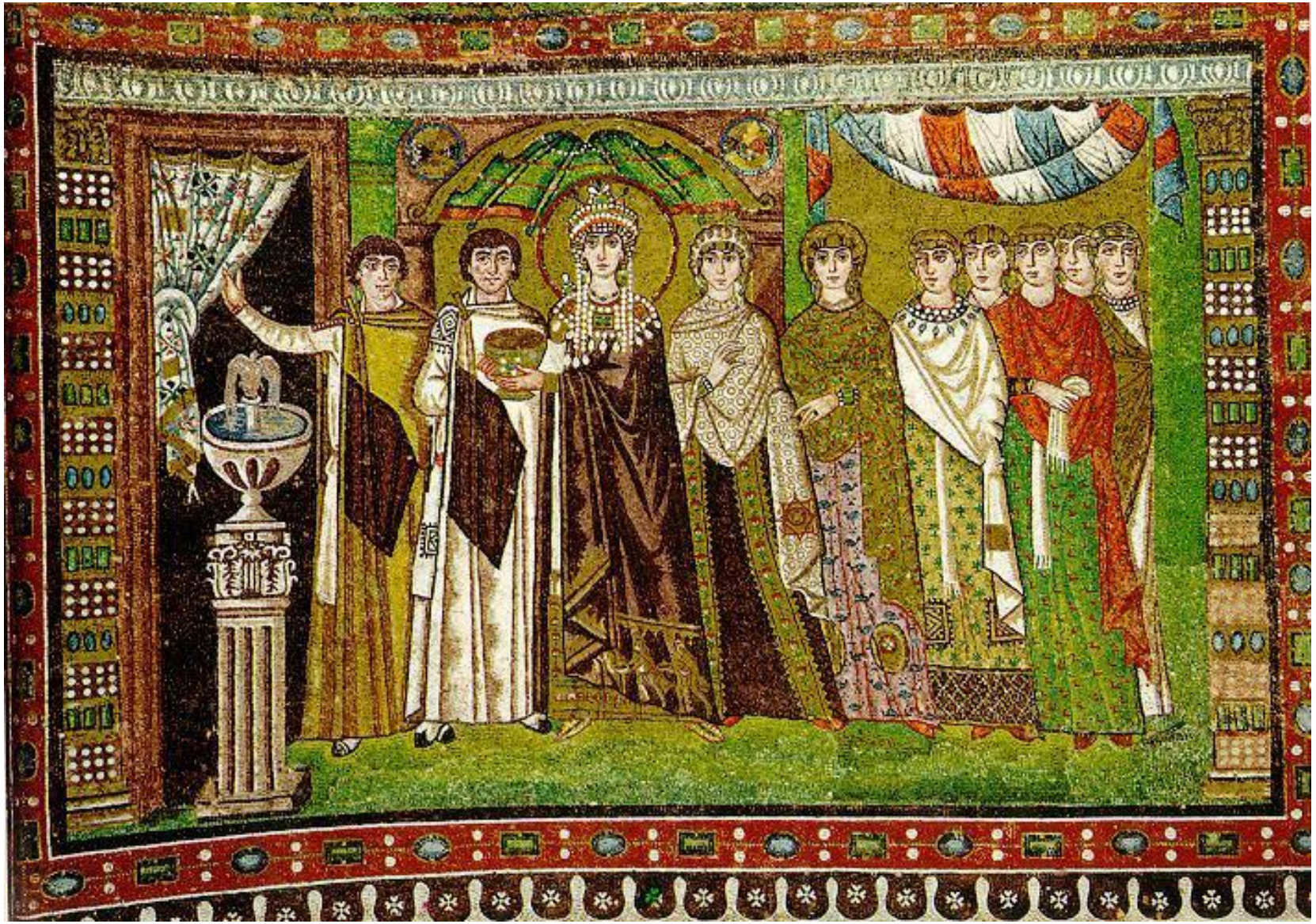
Film camera

Digital camera

Depicting Our World: Prehistory

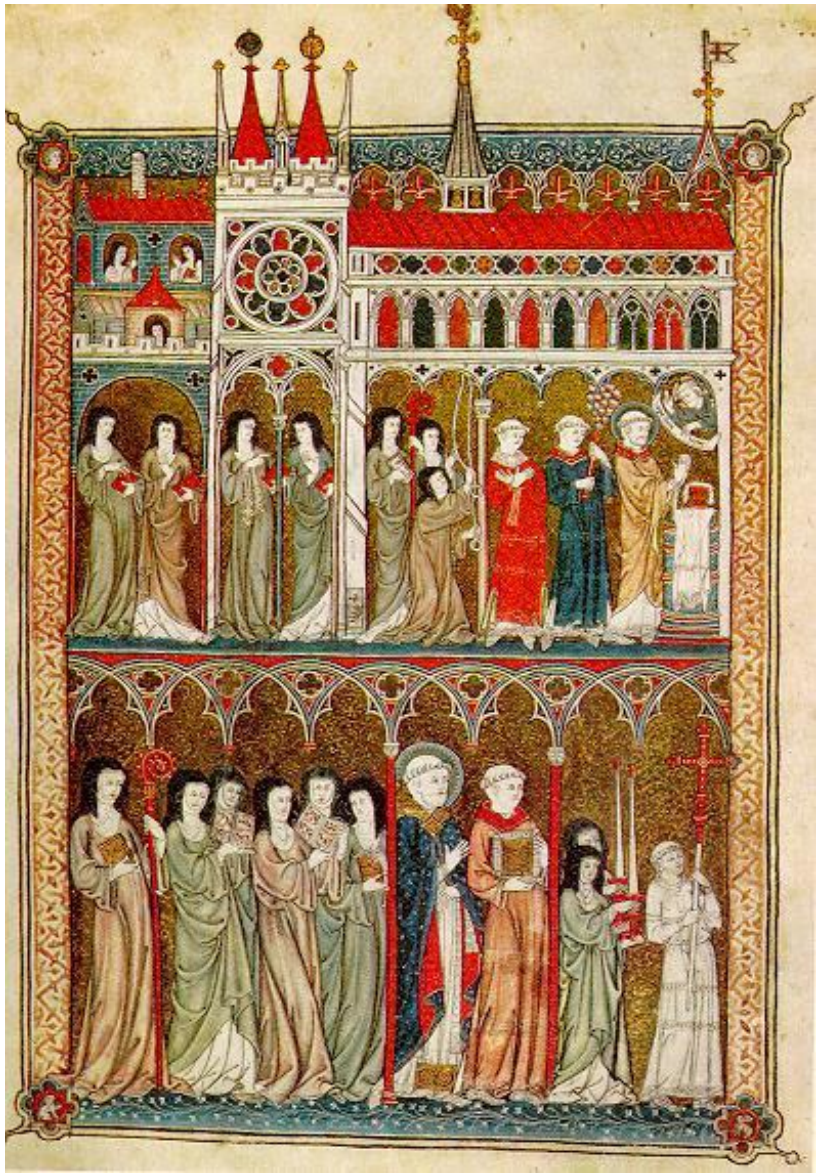
Prehistoric Painting, Lascaux Cave, France ~ 13,000 – 15,000 B.C.

Depicting Our World: Middle Ages



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

Depicting Our World: Middle Ages



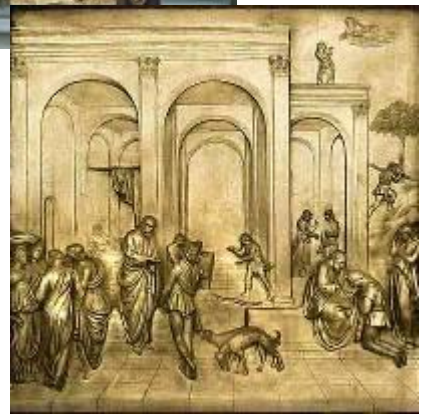
Nuns in Procession. French ms. ca. 1300.

Depicting Our World: Renaissance

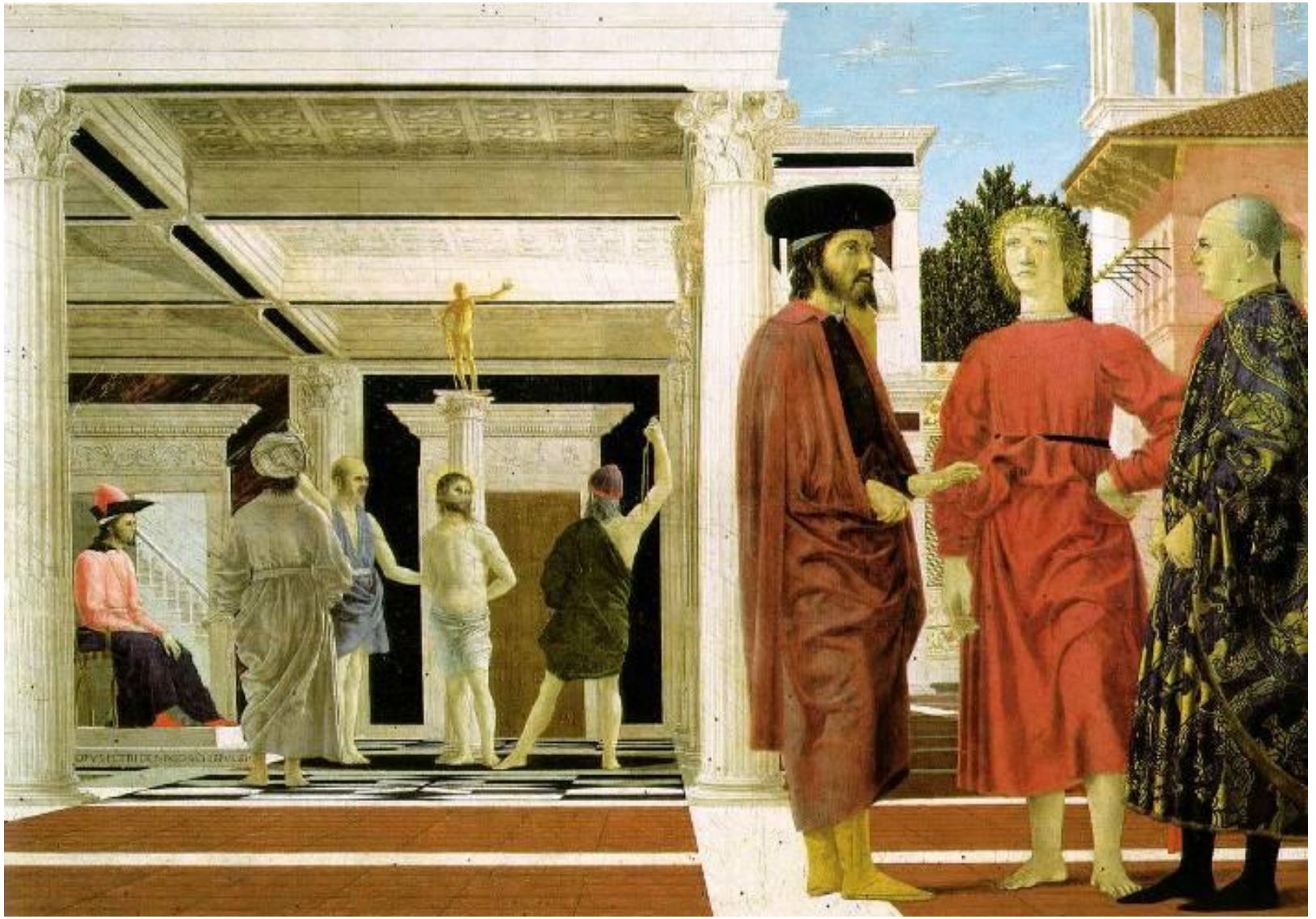
North Doors (1424)

Lorenzo Ghiberti (1378-1455)

East Doors (1452)



Depicting Our World: Renaissance

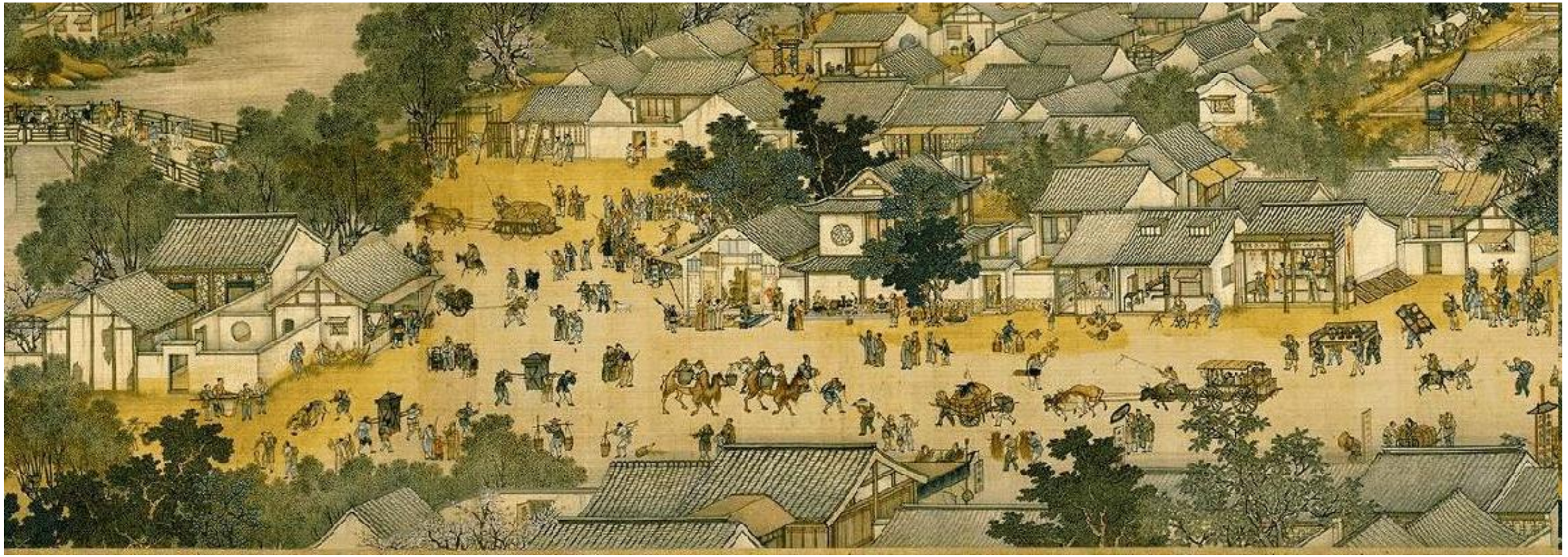


Piero della Francesca, The Flagellation (c.1469)

Depicting Our World: Renaissance

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

Depicting Our World: Song Dynasty (China)

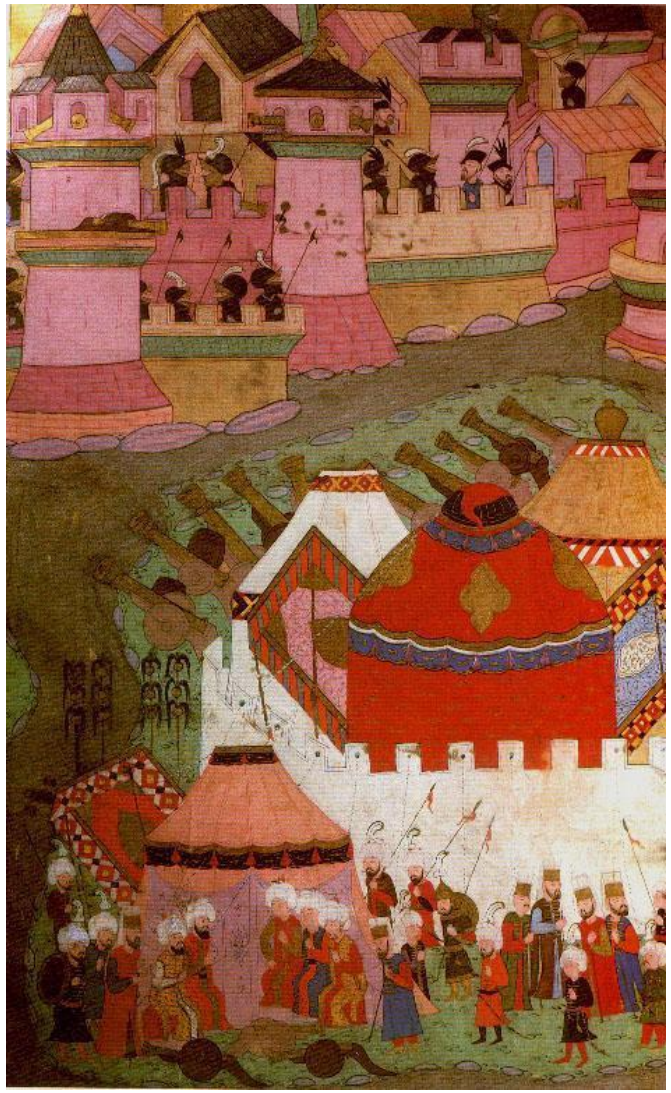


Qingming Festival by the Riverside, Zhang Zeduan ~900 AD

Depicting Our World: Edo Period (Japan)

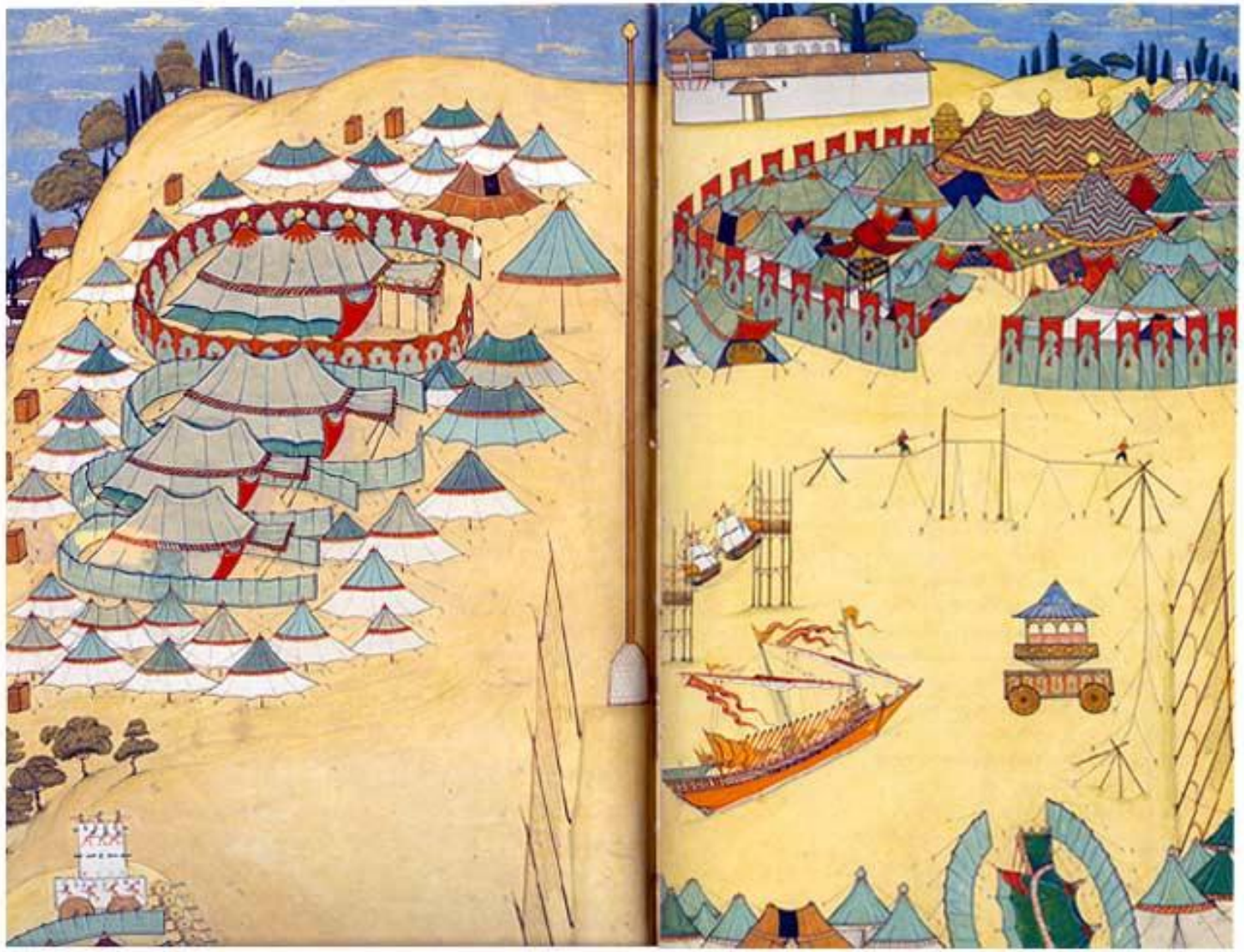
The Great Wave off Kanagawa, part of the series
Thirty-six Views of Mount Fuji, Hokusai (between 1826 and 1833)

Depicting Our World: Ottoman Miniatures



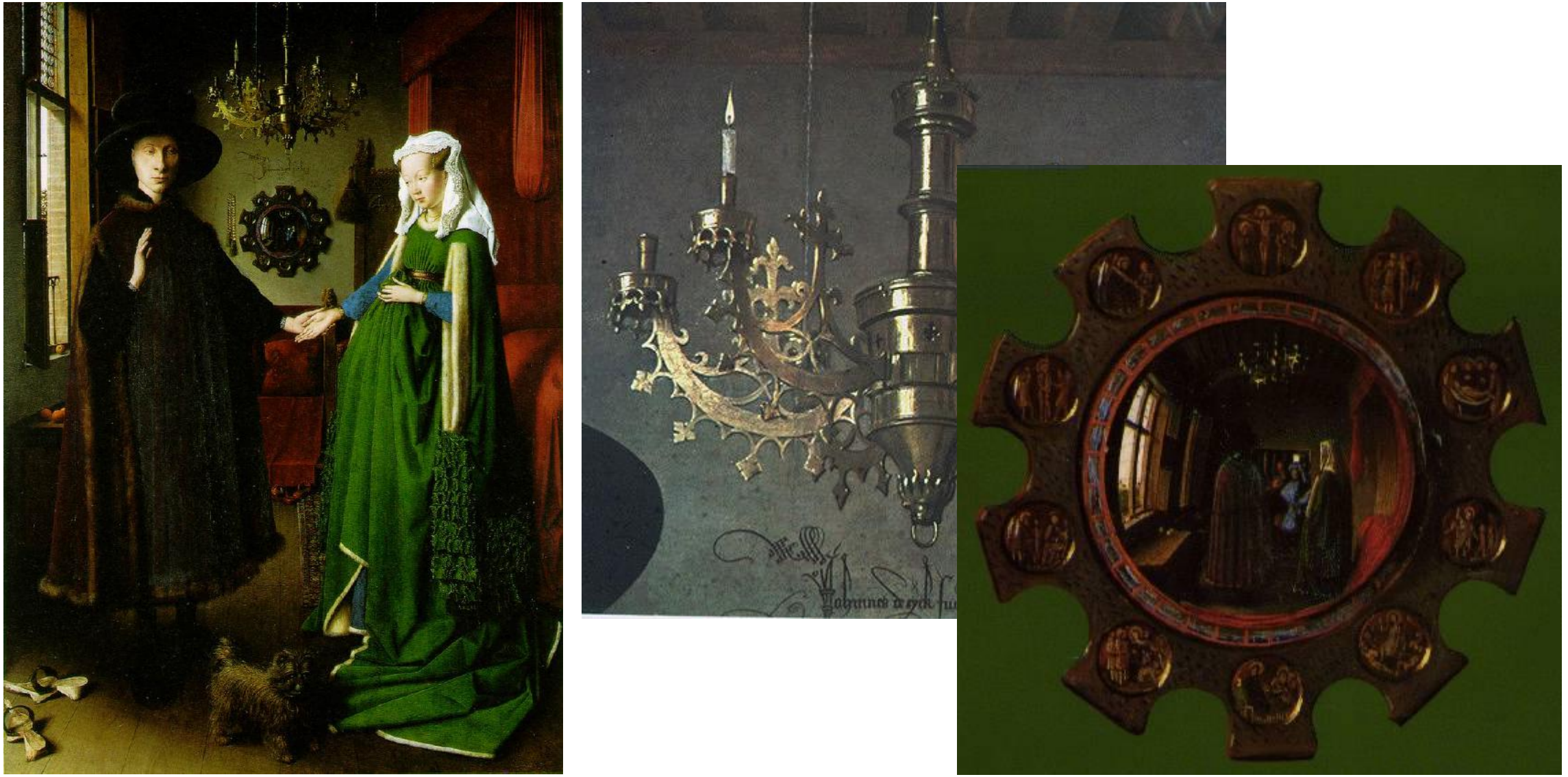
The Ottoman army besieging Vienna, from Huner-nama ('Book of Skills').
Nakkas Osman, 1588.

Depicting Our World: Ottoman Miniatures



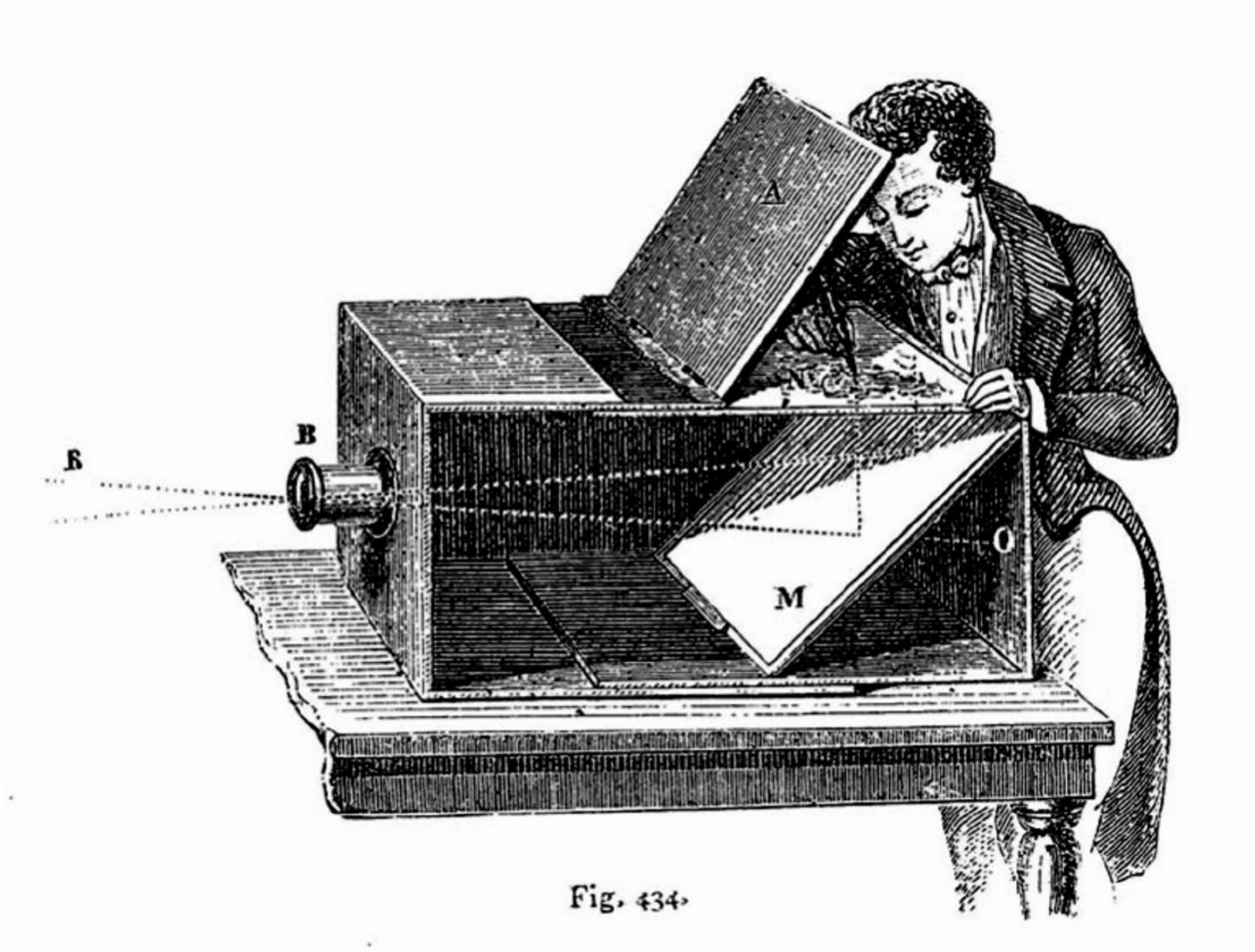
An Ottoman miniature from Surname-*ı* Vehbi, Abdulcelil Levni (1720)

Depicting Our World: Toward Perfection



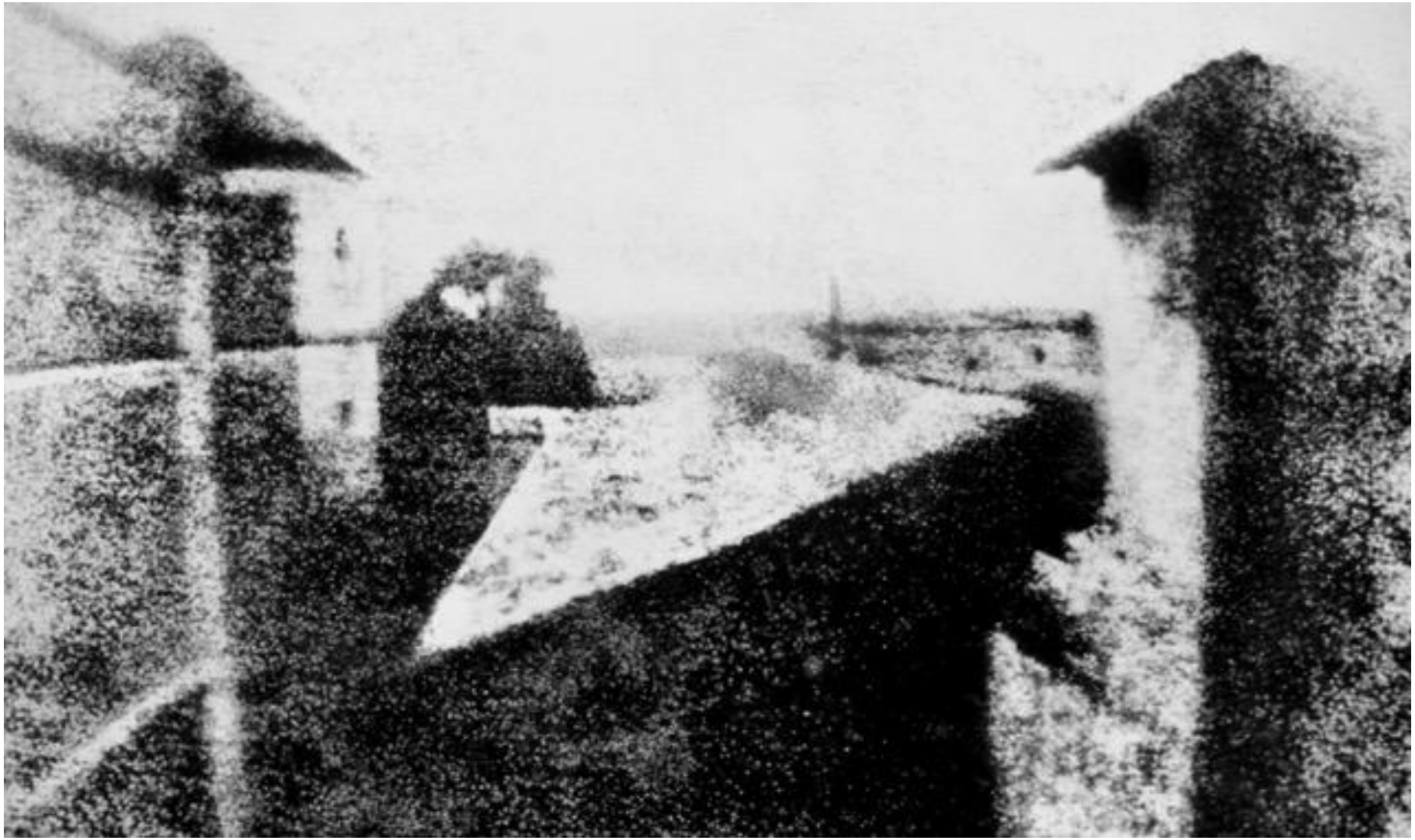
Jan van Eyck, The Arnolfini Marriage (c.1434)

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

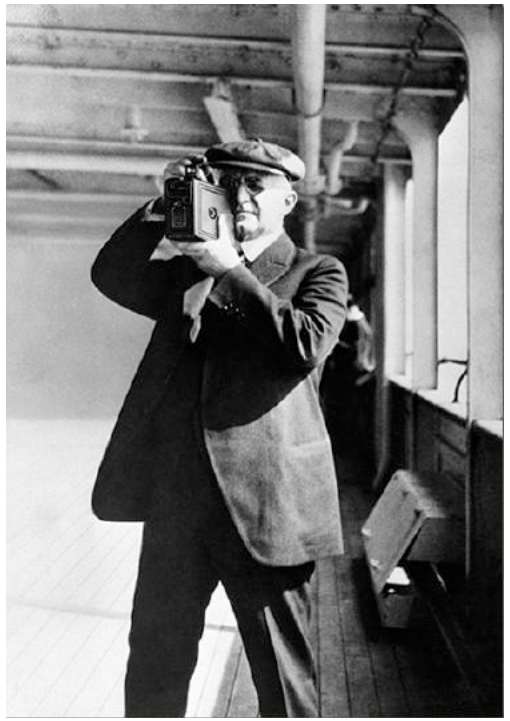
Single viewpoint

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 (mercury) vapor (yikes!) combines with Ag (silver) 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

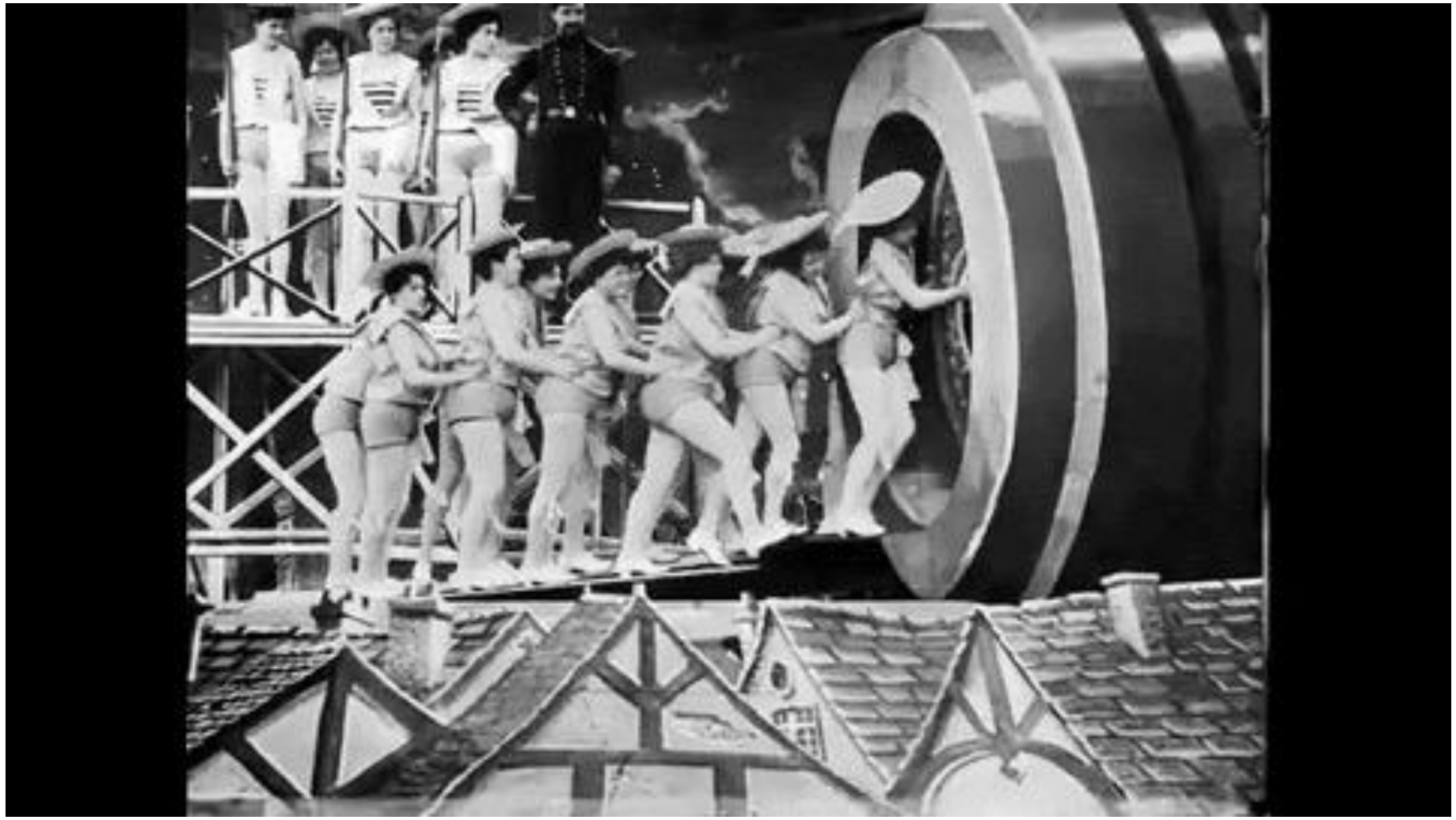
Motion pictures

- 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

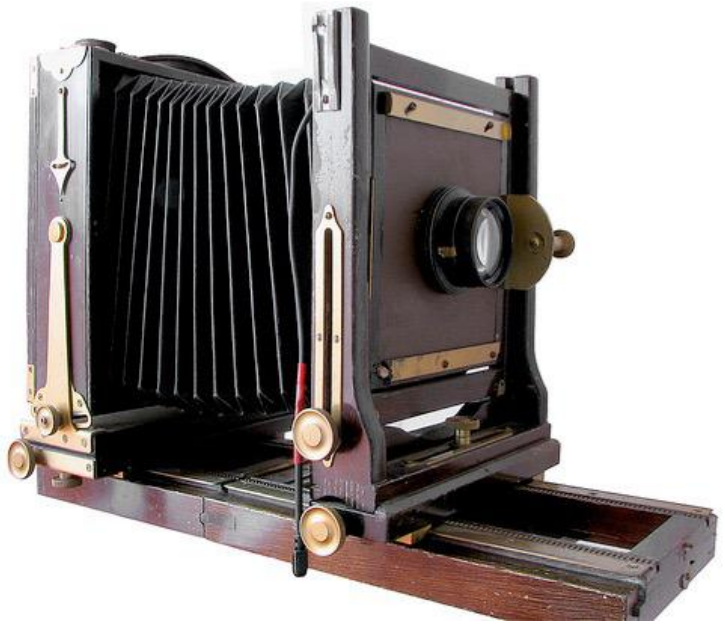
George Méliès



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

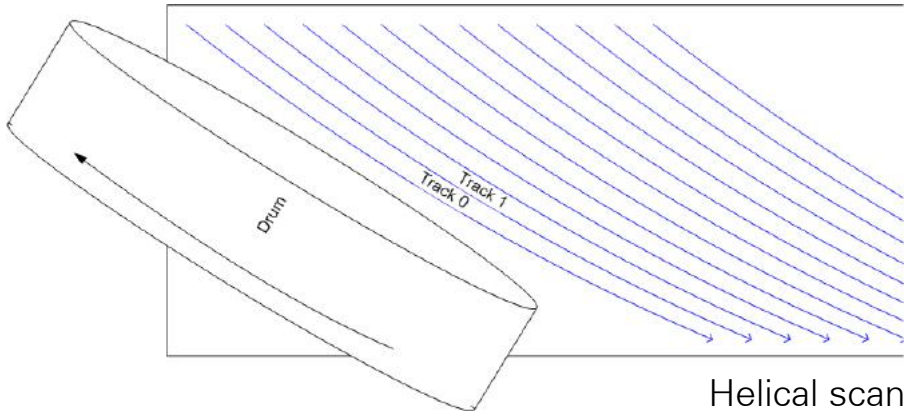
- Practical around 1927 (Farnsworth)
- Camera basically the same
  - imaging lens plus planar image sensor
- Recording is electronic
  - various early schemes
  - early winner: CRT image sensors (Orthicon, Vidicon, ...)
- Initially seems quite different from photography/cinematography
  - ephemeral output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



Helical scan

Wikipedia

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

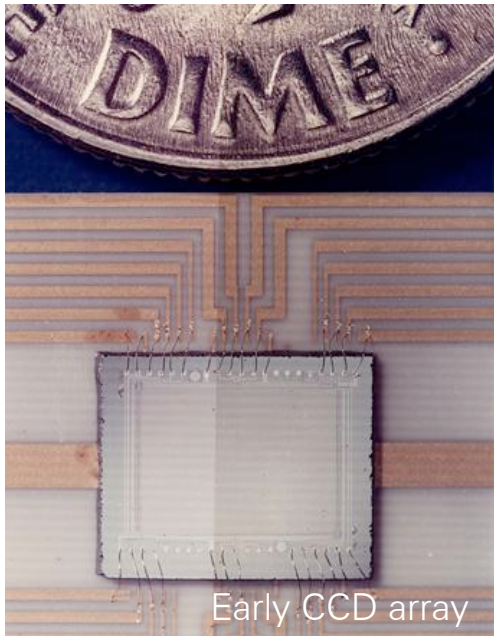
Meanwhile…

- **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

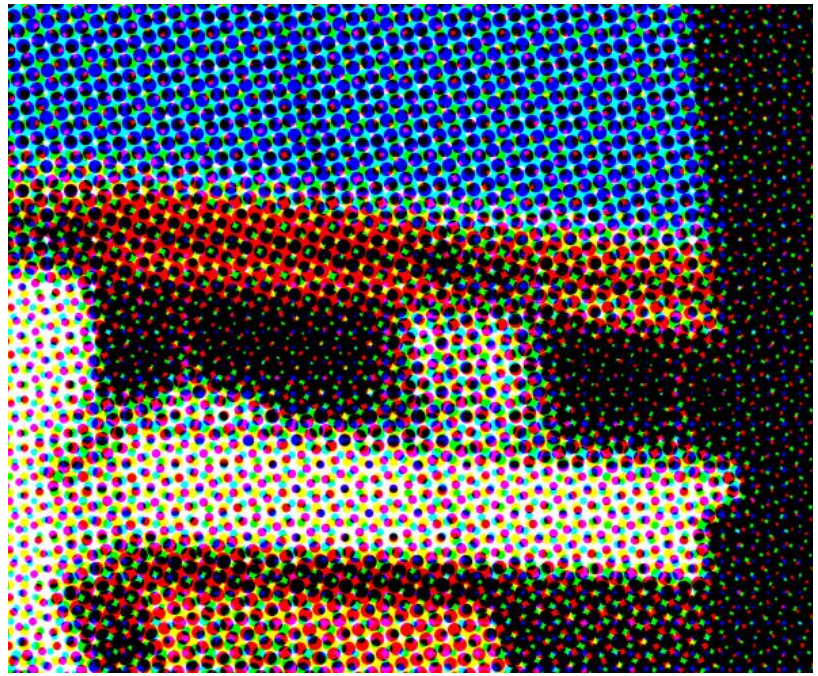
George Smith and Willard Boyle in 1970

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"

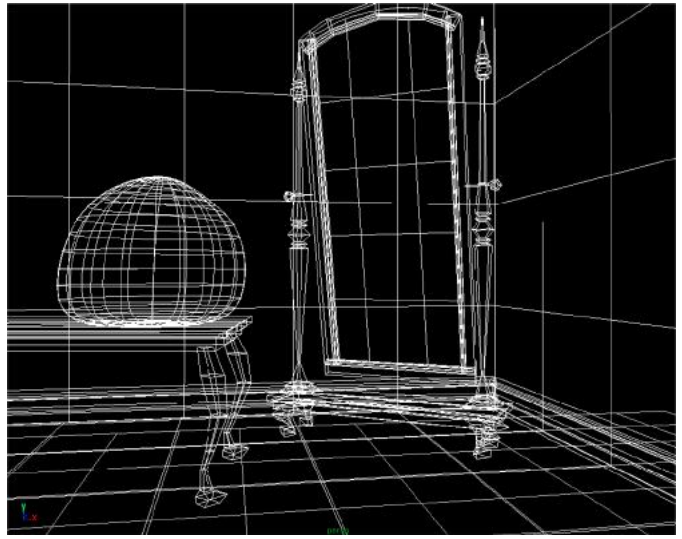
Digital photography today

- 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

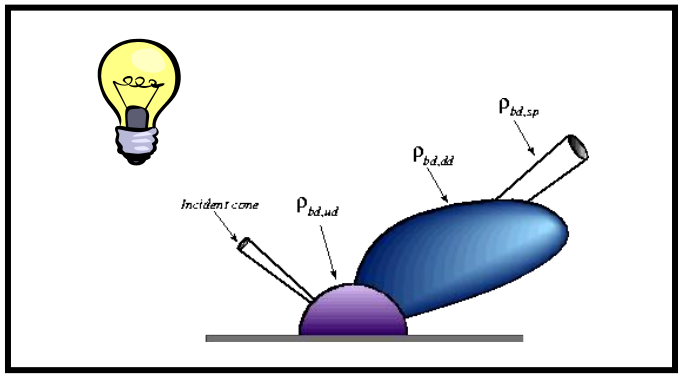
Computer Graphics?

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

Traditional Computer Graphics



3D geometry



physics

projection

Simulation

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

GenAI - Generative AI

- refers to the set of recent techniques (mostly based on deep learning) which employs existing content (like text, images, videos, speech, codes, etc.) to generate new plausible content.

- Many interesting applications, and application domains.

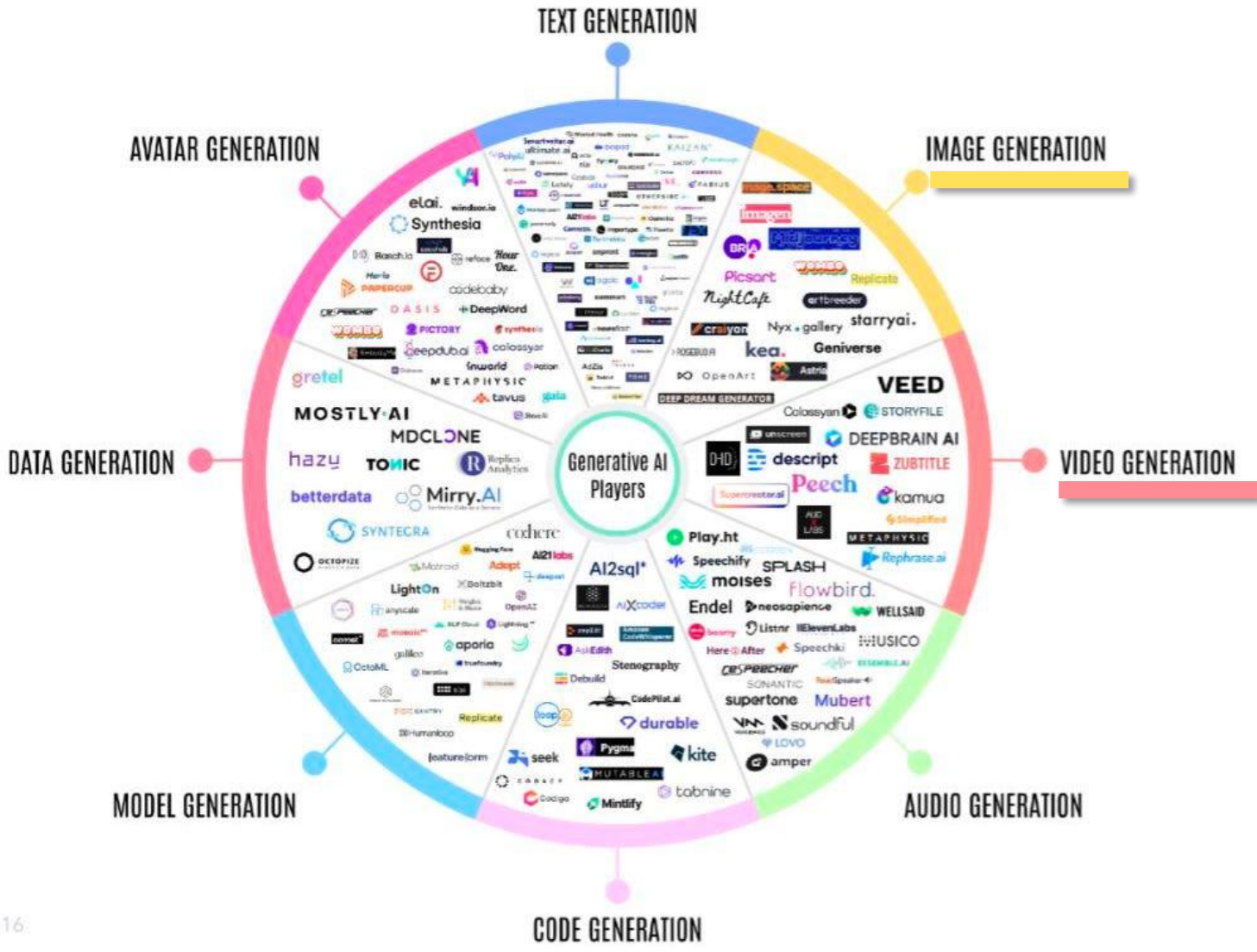


Image credit: B. Kaplan

GenAI - Generative AI

Image credit: B. Kaplan

GenAI - Generative AI

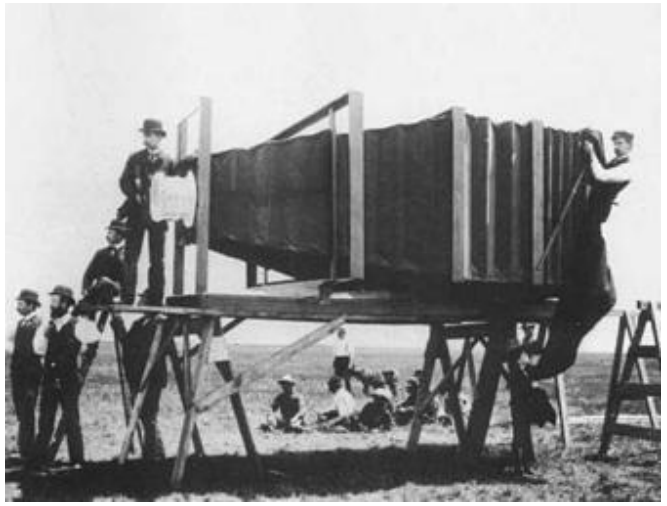
Image credit: Rombach et al., 2022

Today's Lecture

- Course info
- History of photography
- **Limitations of traditional photography**
- Recent accomplishments

The unfinished revolution

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

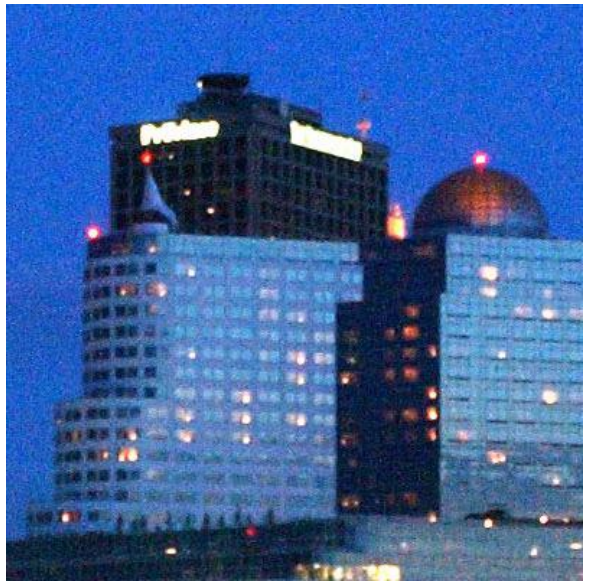


- Digital photography
  - optics focuses optical array onto sensor
  - digital sensor records final image

Slide credit: F. Durand

Limitations of traditional photography

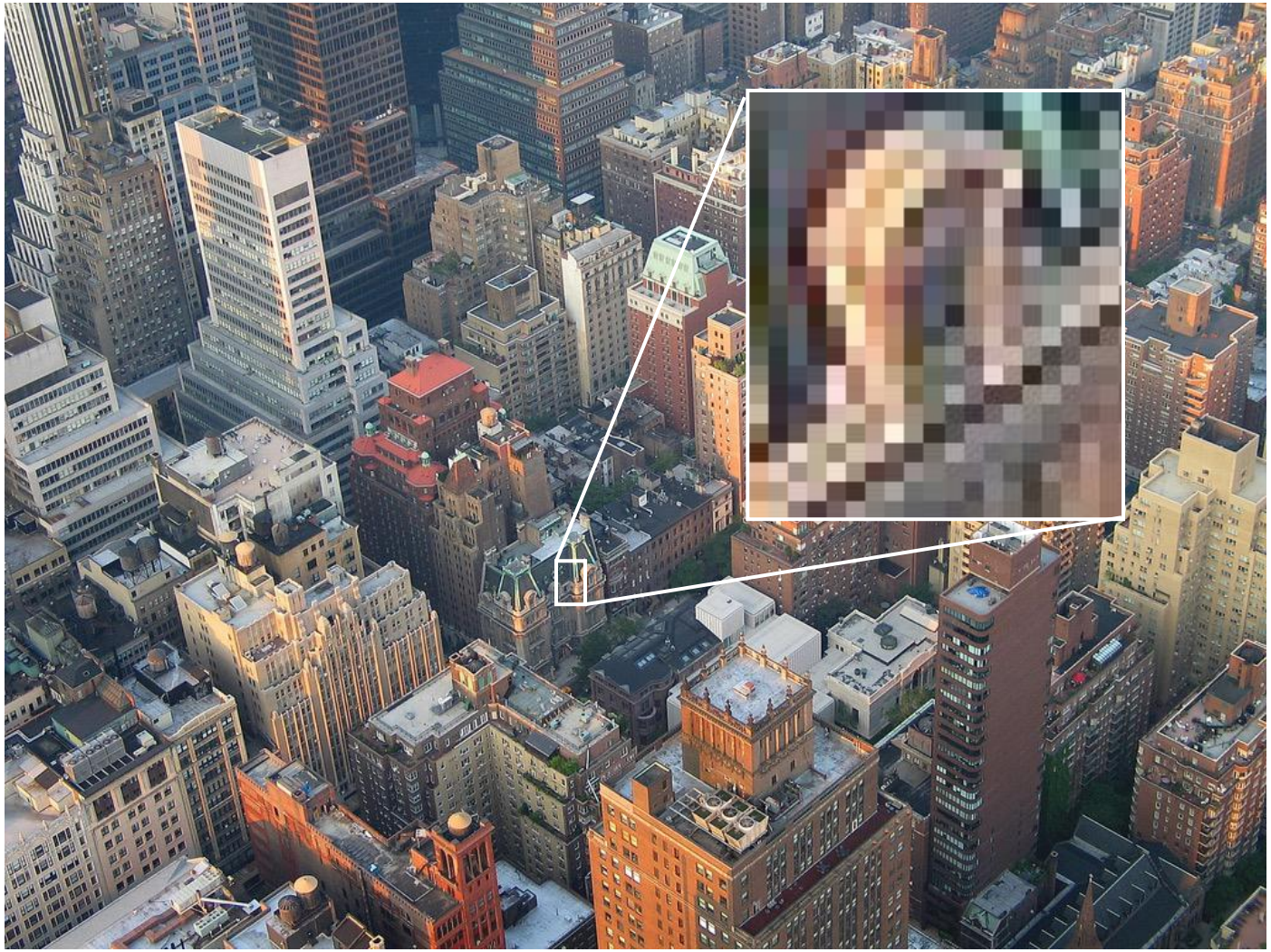
- Blur, camera shake, noise, damage



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

Slide credit: S. Lazebnik

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

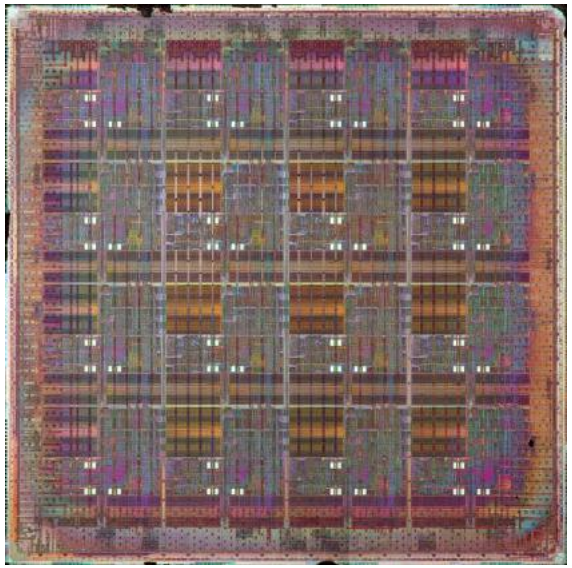
- very hard to manipulate objects or viewpoint

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



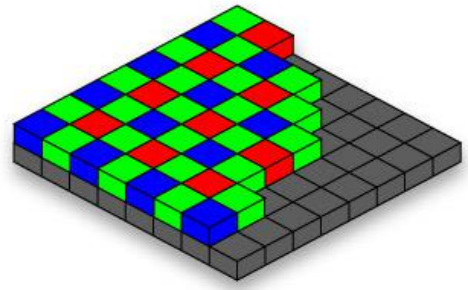
Lots of computation

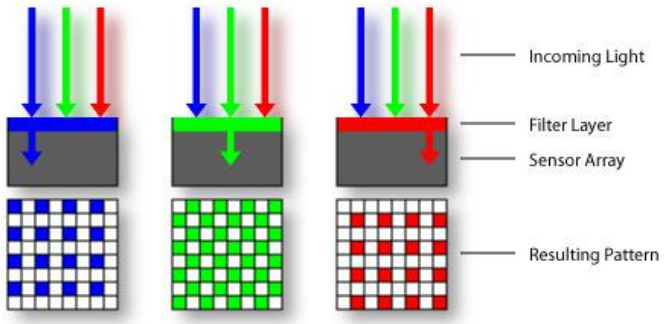
Final image

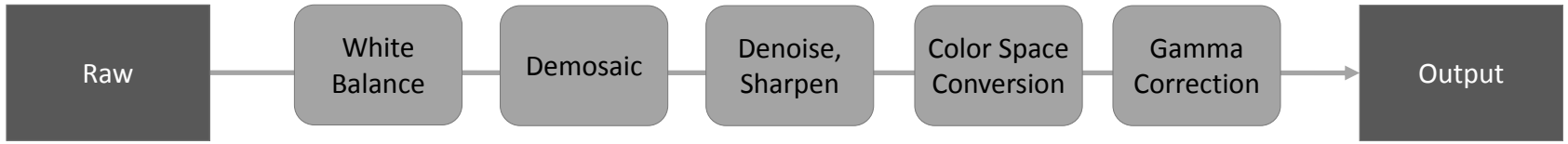
Slide credit: F. Durand

Computational Photography

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







Slide adapterd from 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

Today's Lecture

- Course info
- History of photography
- Limitations of traditional photography
- **Recent accomplishments**

Photo Style Transfer

Image credit: Ledig et al., 2017

Photo Style Transfer

Image credit: Ledig et al., 2017

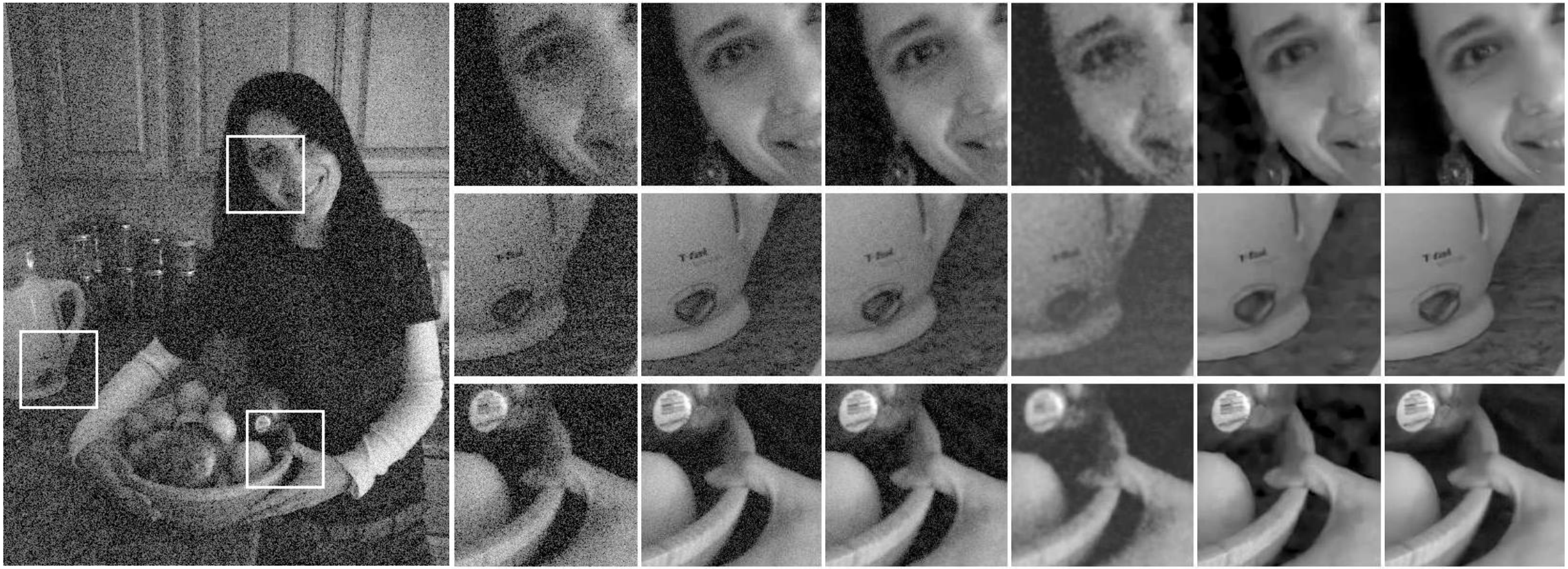
Image Relighting

(a) Input image and estimated lighting

(b) Rendered images from our method under three novel illuminations

Image credit: Sun et al., 2019

Image Denoising



Reference frame (a) Reference (b) Average (c) HDR+ (d) NLM (e) VBM4D (f) Ours (KPN)

Image credit: Mildenhall et al., 2018

Image Super Resolution

bicubic
(21.59dB/0.6423)

SRResNet
(23.53dB/0.7832)

SRGAN
(21.15dB/0.6868)

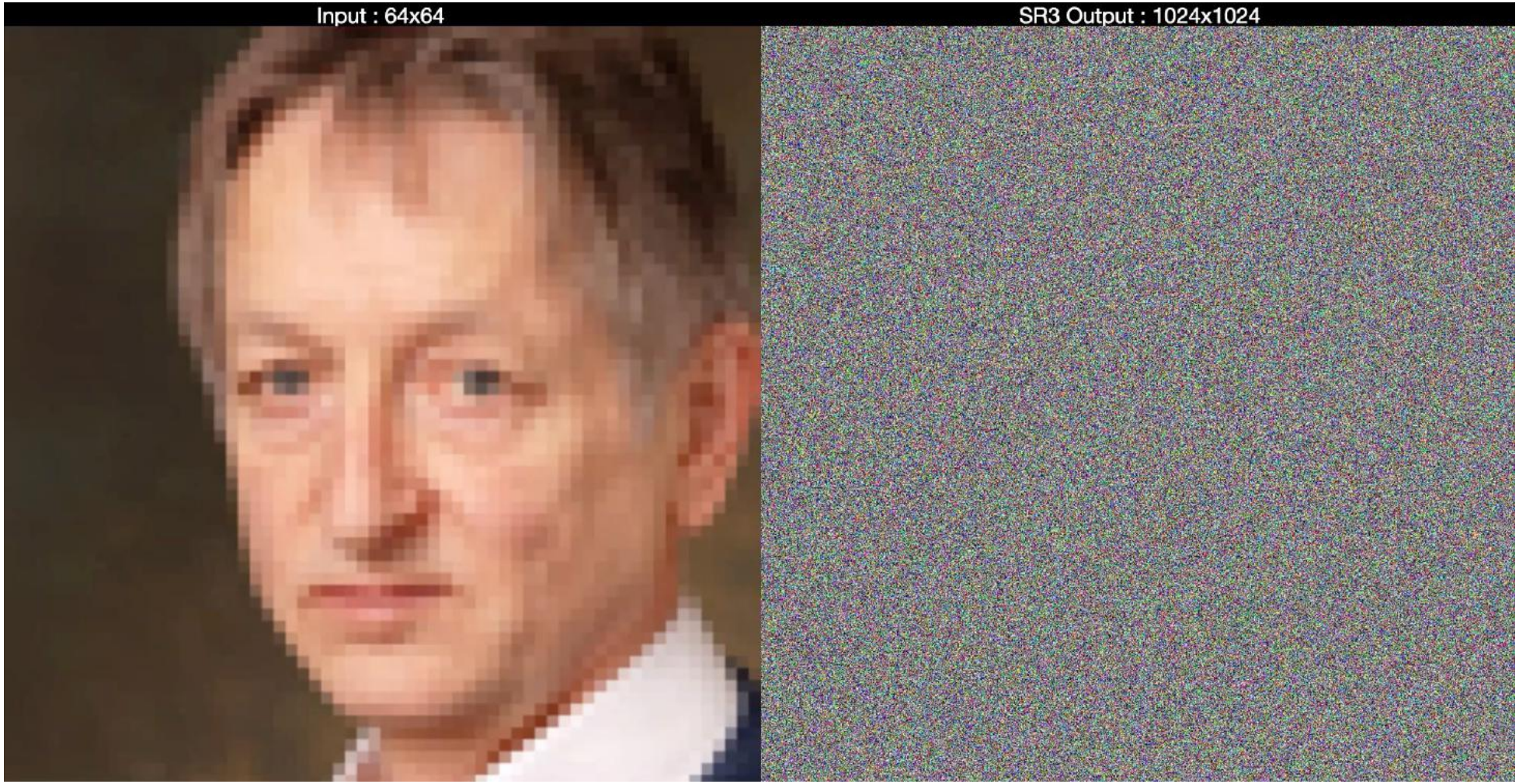
original

Image credit: Ledig et al., 2017

Image Super Resolution

Image credit: Liang et al., 2021

Image Super Resolution



Results of a SR3 model (64×64 → 512×512), trained on FFHQ, and applied to images outside of the training set.

Image credit: Saharia et al., 2021

Image Deblurring

Image credit: Kupyn et al., 2018

Image Deblurring

Image credit: Tu et al., 2022

Outdoors at night. Sony a7S II camera

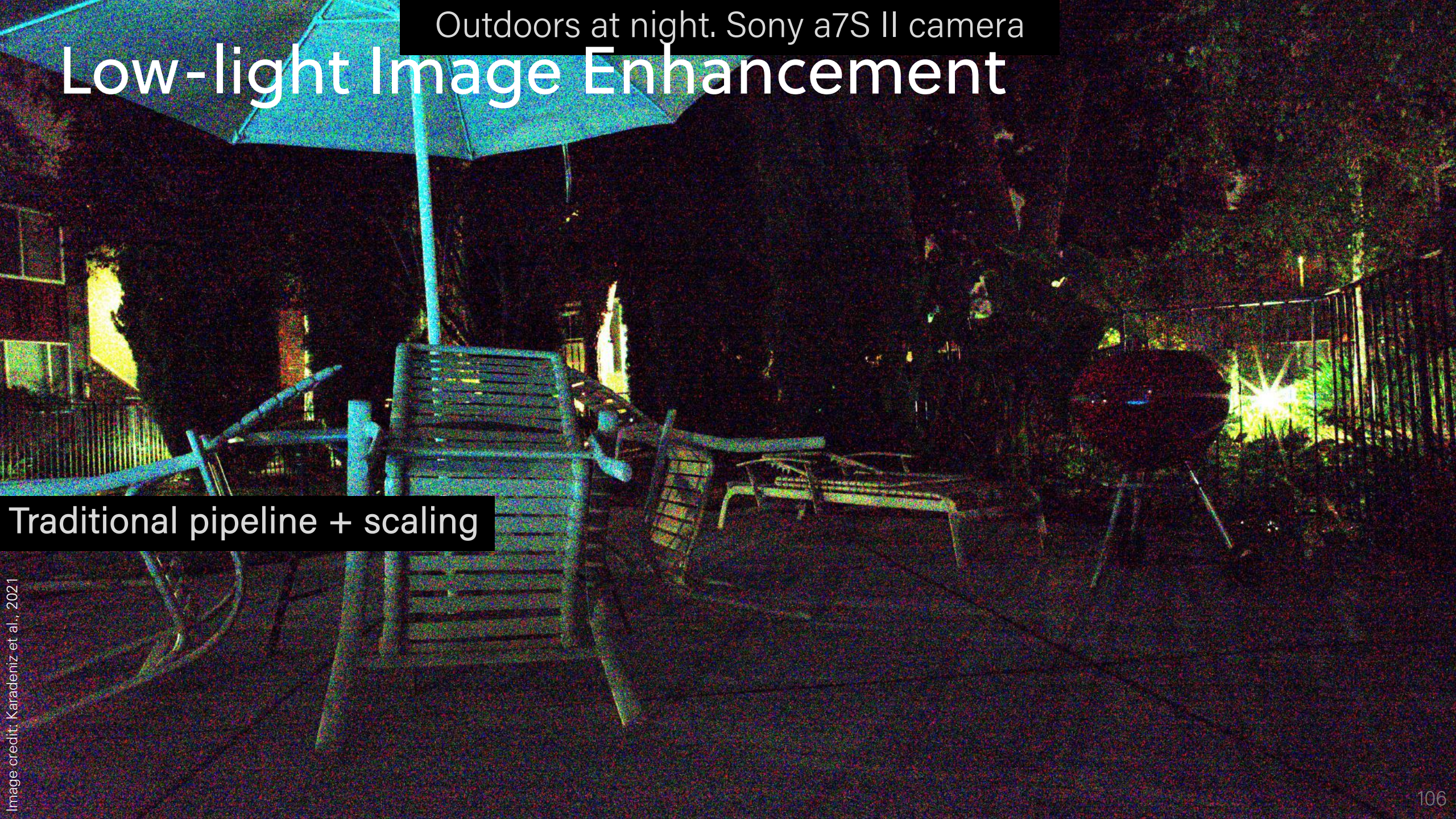
Low-light Image Enhancement

Traditional pipeline

Image credit: Karadeniz et al., 2021

Outdoors at night. Sony a7S II camera

Low-light Image Enhancement



Traditional pipeline + scaling

Image credit: Karadeniz et al., 2021

Low-light Image Enhancement

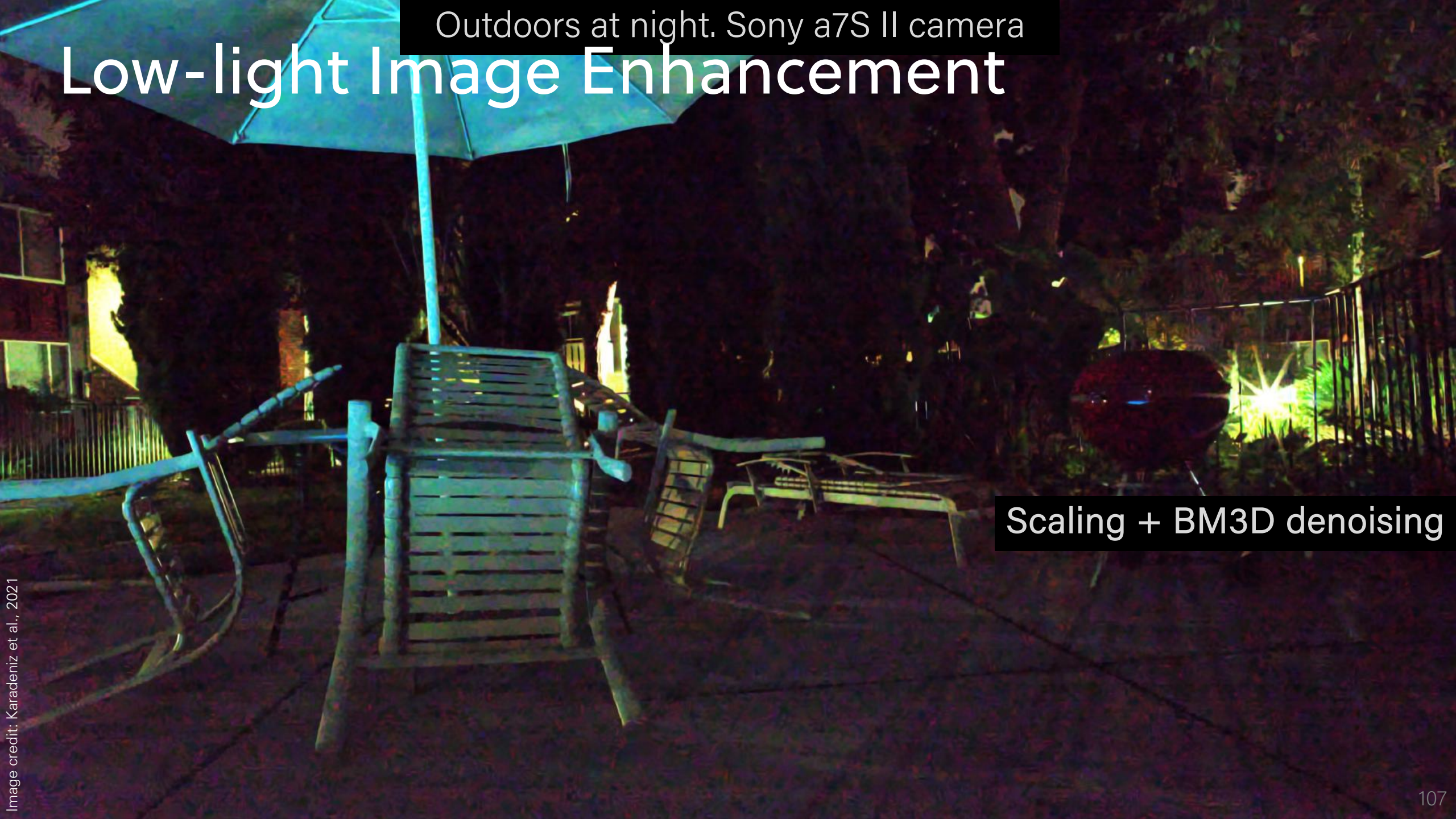
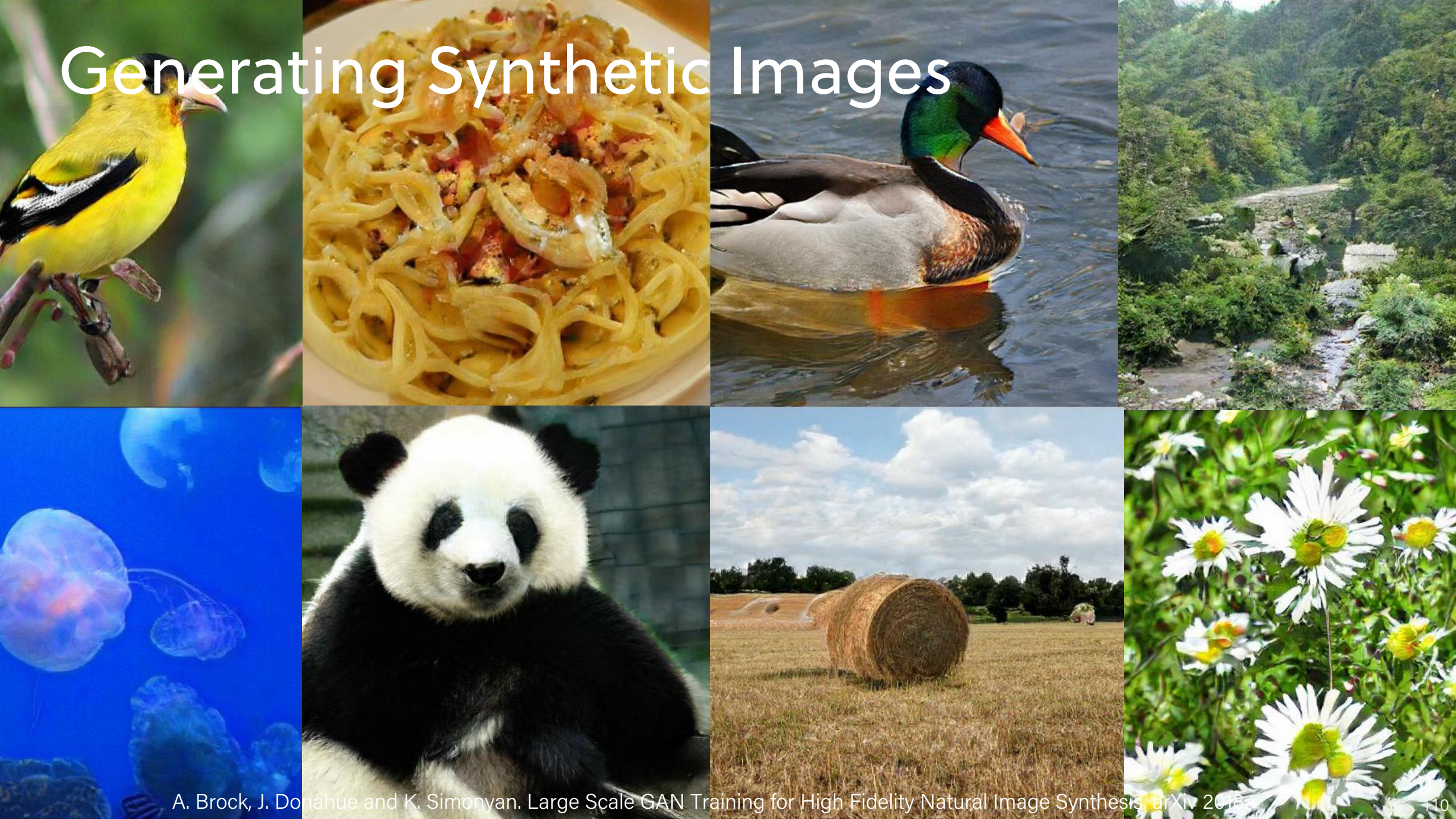


Image credit: Karadeniz et al., 2021


Outdoors at night. Sony a7S II camera
Low-light Image Enhancement
Our result
Scaling + BM3D denoising
Image credit: Karadeniz et al., 2021

Image credit: Karadeniz et al., 2021

Generating Synthetic Images



A. Brock, J. Donahue and K. Simonyan. Large Scale GAN Training for High Fidelity Natural Image Synthesis. arXiv 2018

Generating Synthetic Images

Image credit: Rombach et al., 2022

[Latent Diffusion, Rombach, Blattmann, Lorenz, Esser, Ommer, 2022]

Generating Images from Text

a teddy bear on a skateboard in times square

A photo of Michelangelo's sculpture of David wearing headphones djing

"A sea otter with a pearl earring" by Johannes Vermeer

3D render of a cute tropical fish in an aquarium on a dark blue background, digital art

Image credit: Ramesh et al., 2022

Generating Images from Text

"A sunset over a mountain, vector image"

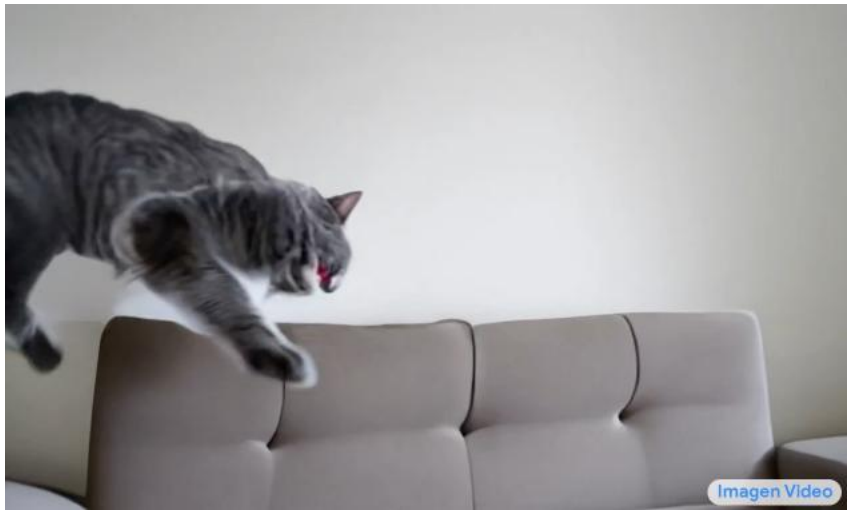
"a portrait of a cyberpunk rabbit, trending on artstation"

"A sunset over a mountain, oil on canvas"

Image credit: Rombach et al., 2022

Generating Videos from Text

A teddy bear
running in New York City



A british shorthair
jumping over a coach

A swarm of bees
flying around their hive

Image credit: Ho et al., 2022

[Ho et al., "Imagen Video", 2022]

Time-travel Rephotography

Image credit: Luo et al. 2021

Image Inpainting

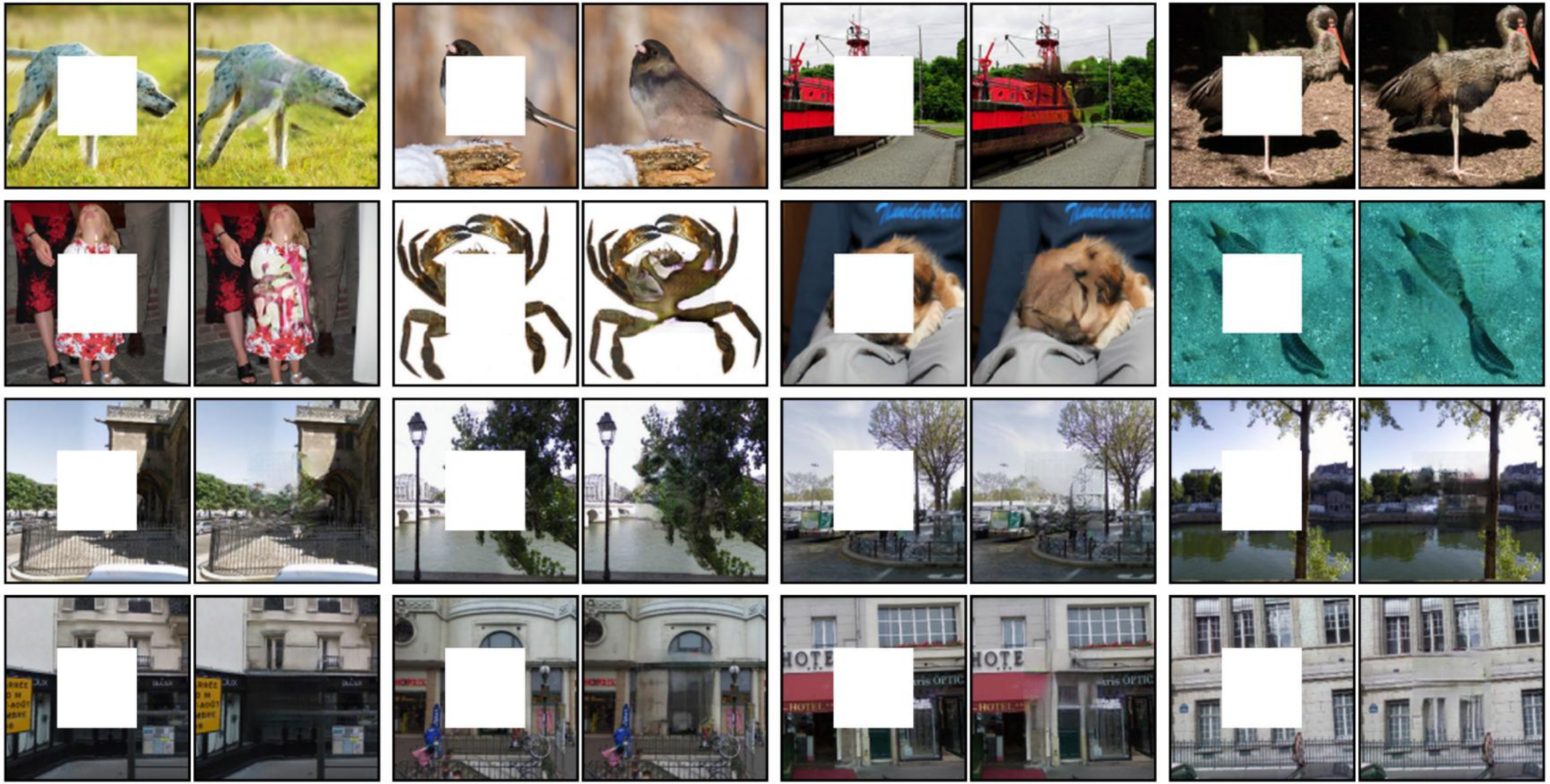
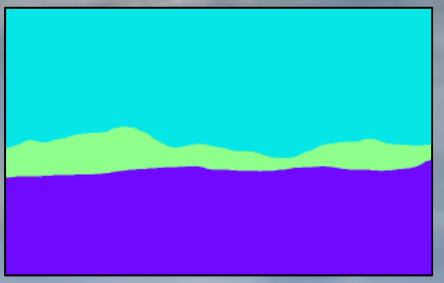


Image credit: Pathak et al., 2016

Image Inpainting

Image credit: Rombach et al., 2022

Semantic Image Editing



Semantic Layout

Image credit: Karacan et al., 2020

Semantic Image Editing

Winter

Prediction

Image credit: Karacan et al., 2020

Semantic Image Editing

Spring
+
Clouds

Prediction

Image credit: Karacan et al., 2020

Semantic Image Editing

Input image

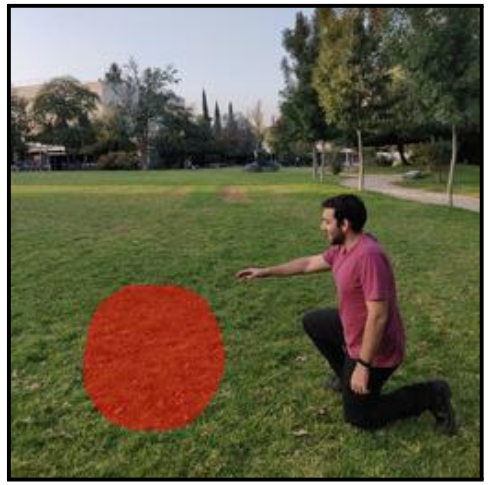
Input mask

“beach”

“big mountain”

“The Great Pyramid of Giza”

Input image



Input mask

“gravestone”

“toy truck”

“snake”

Image credit: Avrahami et al., 2022

Reading Assignments

- Brian Hayes, Computational Photography, American Scientist 96, 94-99, 2008
- Michael Johnston, Your Camera Roll Contains A Masterpiece, New Yorker, March 31, 2022

Next Lecture:
Image formation