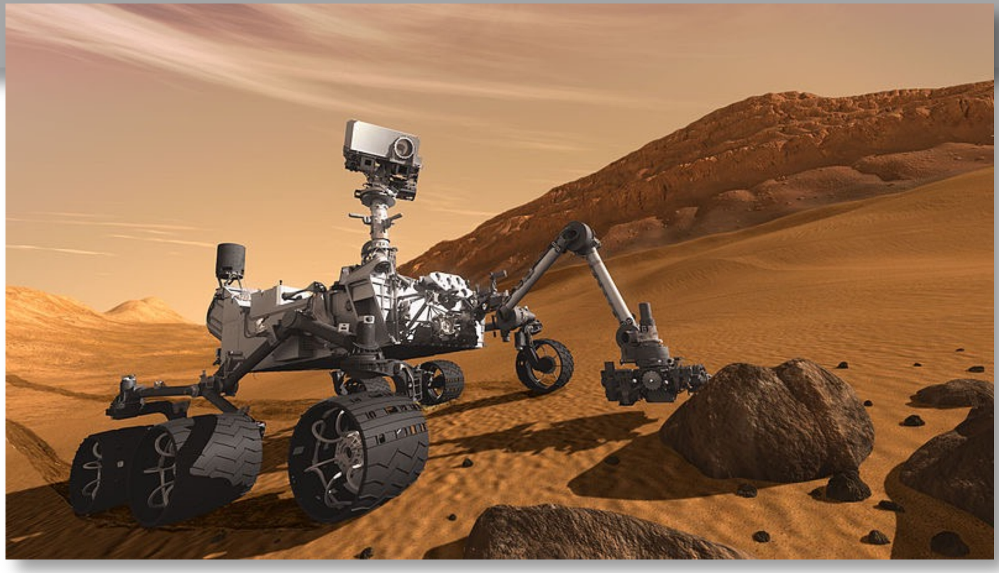
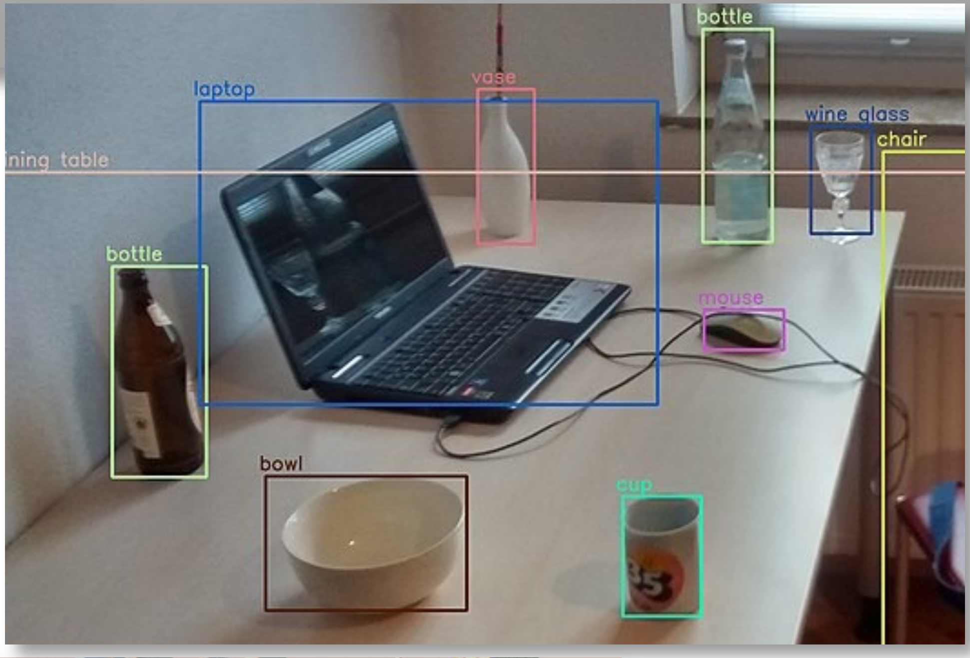
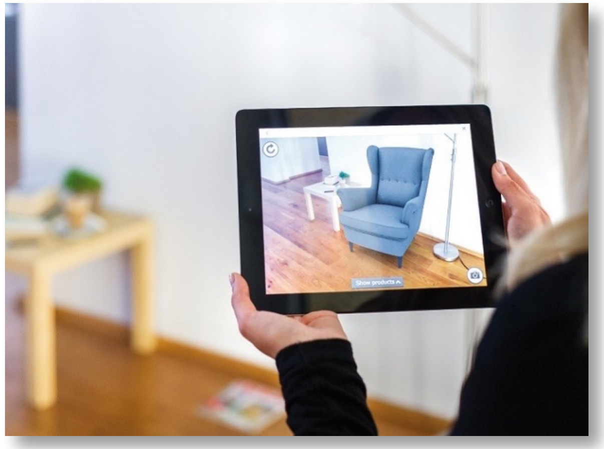
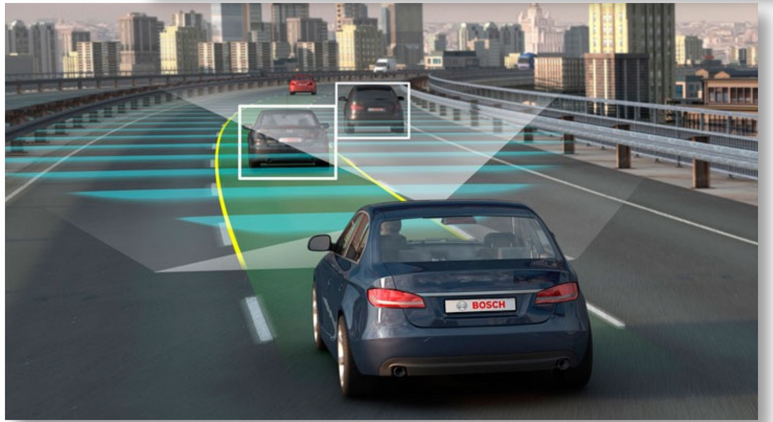
CS5670: Intro to Computer Vision (Cornell Tech)

Instructor: Noah Snavely









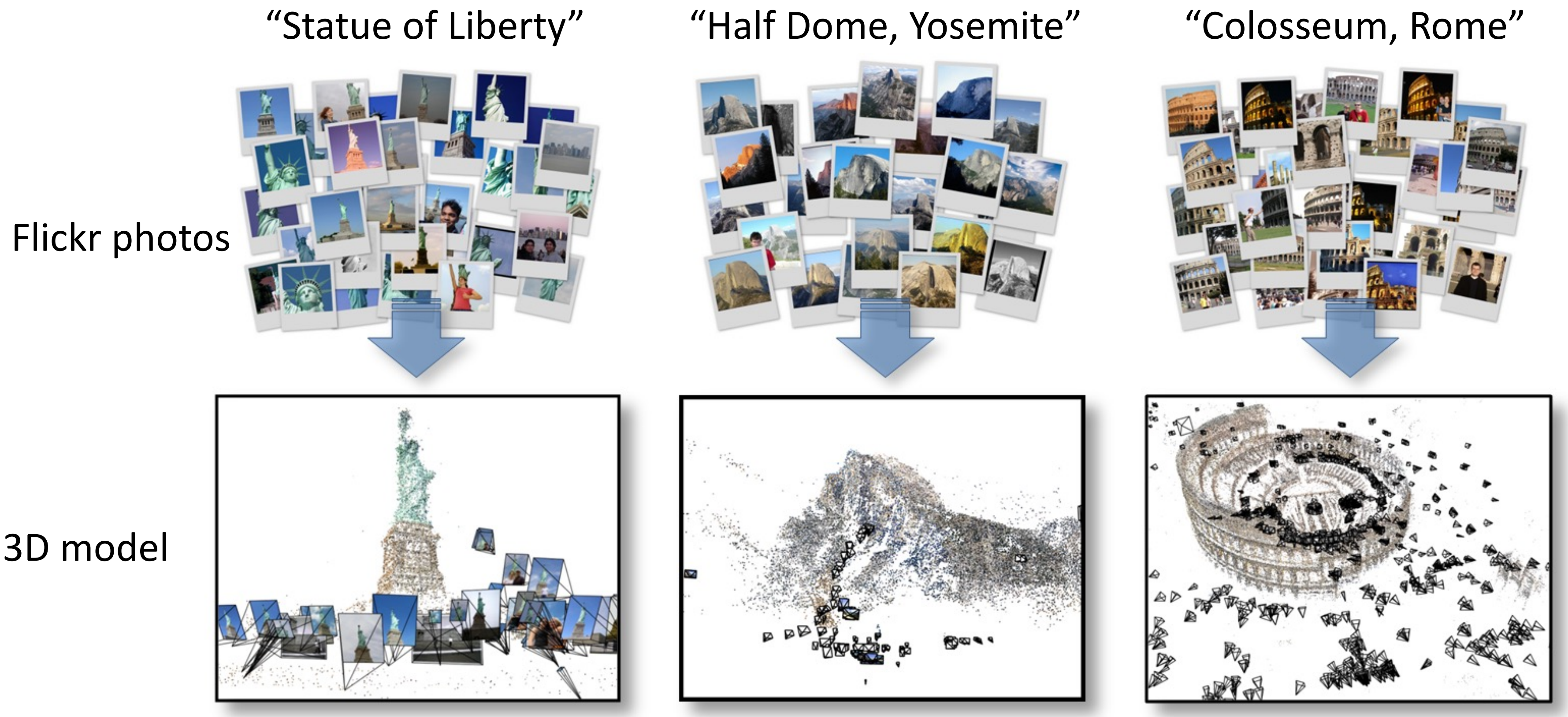
Instructor

- Noah Snavely (snavely@cs.cornell.edu)

- Research interests:
  - Computer vision and graphics
  - 3D reconstruction and visualization of Internet photo collections
  - Deep learning for computer graphics
  - Virtual and augmented reality

Noah’s work

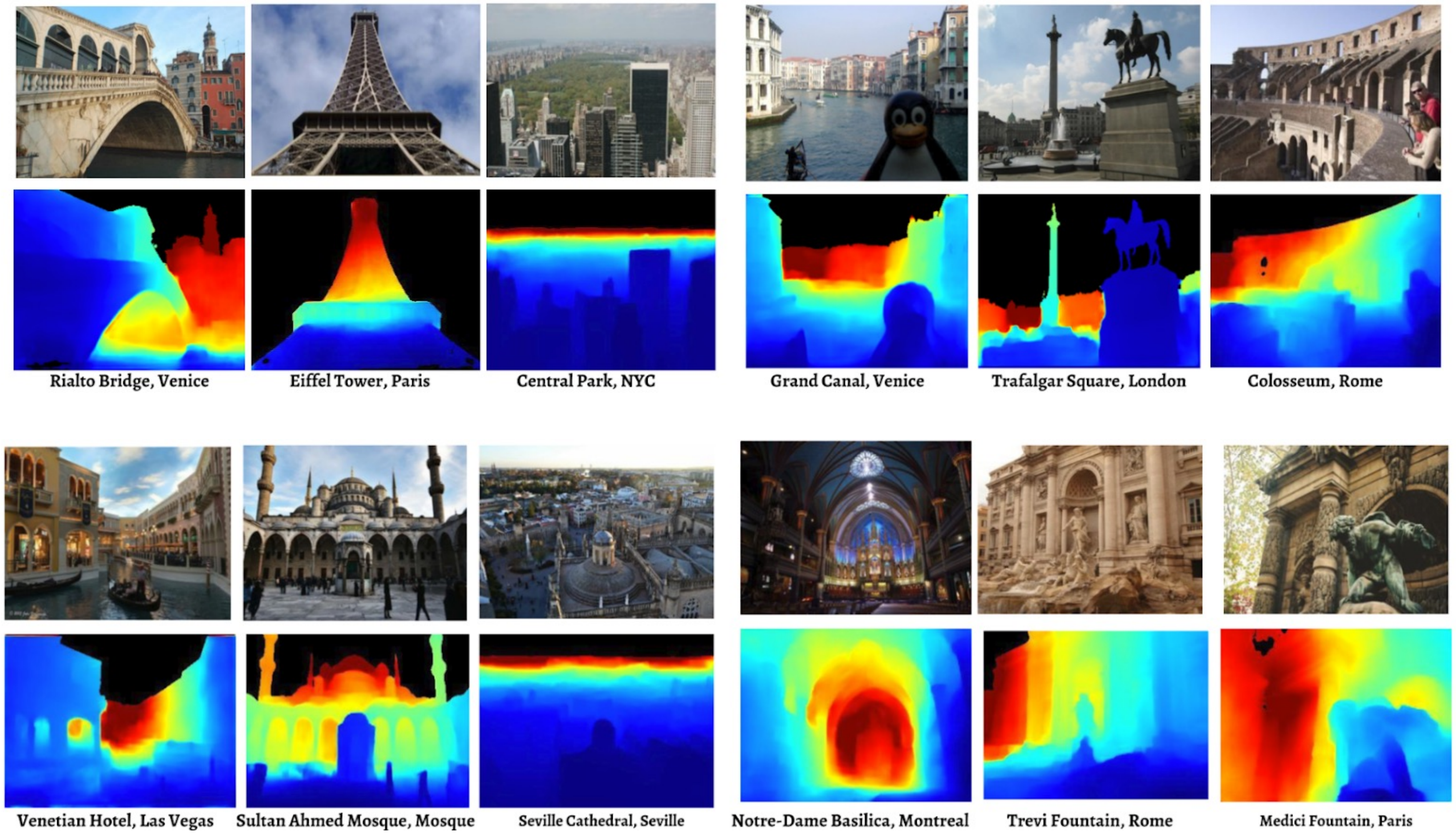
- Automatic 3D reconstruction from Internet photo collections



City-scale 3D reconstruction

Reconstruction of Dubrovnik, Croatia, from ~40,000 images

Depth from a single image



Visualizing scenes from tourist photos

Teaching assistants

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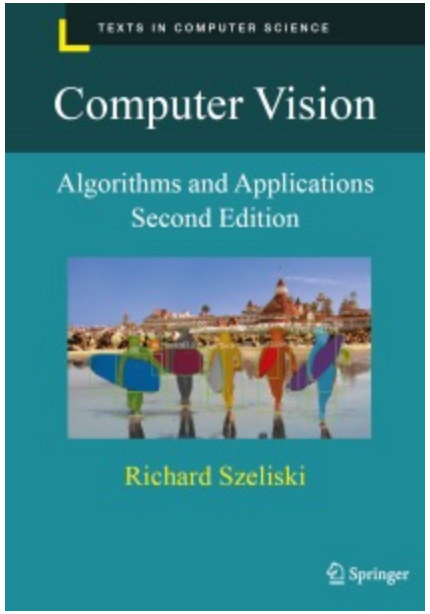
- Please check course webpage for office hours

https://www.cs.cornell.edu/courses/cs5670/2023sp/

Important information



- Textbook:

  Rick Szeliski, *Computer Vision: Algorithms and Applications* online at:

  http://szeliski.org/Book/

- Course webpage:

  http://www.cs.cornell.edu/courses/cs5670/2023sp/

- Canvas Page:

  https://canvas.cornell.edu/courses/49751

- Announcements/discussion via Ed Discussions (via Canvas)

- Assignment turnin via GitHub Classroom and CMSX:

  https://cmsx.cs.cornell.edu

Today

1. What is computer vision?
2. Why study computer vision?
3. Course overview
4. Images & image filtering [time permitting]

Today

- Readings
  - Szeliski, Chapter 1 (Introduction)

Every image tells a story

- Goal of computer vision: perceive the "story" behind the picture
- Compute properties of the world
  - 3D shape
  - Names of people or objects
  - What happened?

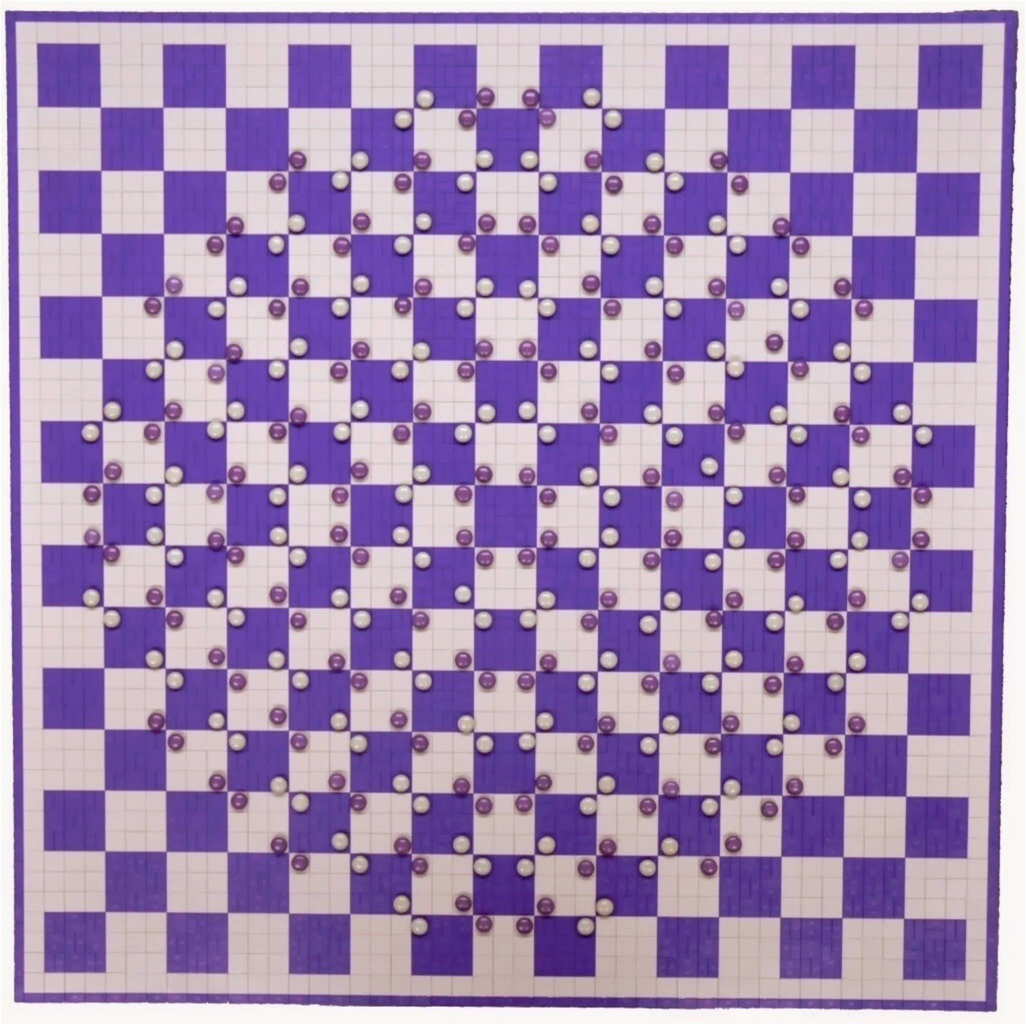
The goal of computer vision

0	3	2	5	4	7	6	9	8
3	0	1	2	3	4	5	6	7
2	1	0	3	2	5	4	7	6
5	2	3	0	1	2	3	4	5
4	3	2	1	0	3	2	5	4
7	4	5	2	3	0	1	2	3
6	5	4	3	2	1	0	3	2
9	6	7	4	5	2	3	0	1
8	7	6	5	4	3	2	1	0

Can computers match human perception?

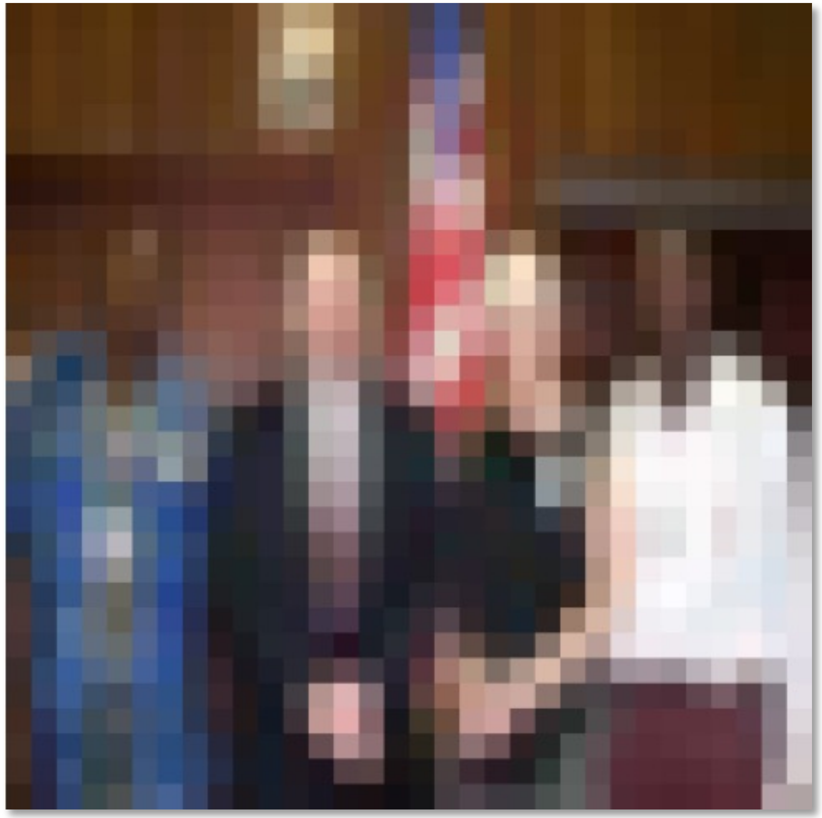
- Yes and no (mainly no)
  - computers can be better at "easy" things
  - humans are better at "hard" things
- But huge progress
  - Accelerating in the last five years due to deep learning
  - What is considered "hard" keeps changing

Human perception has its shortcomings



https://twitter.com/pickover/status/1460275132958662657/

But humans can tell a lot about a scene from a little information…



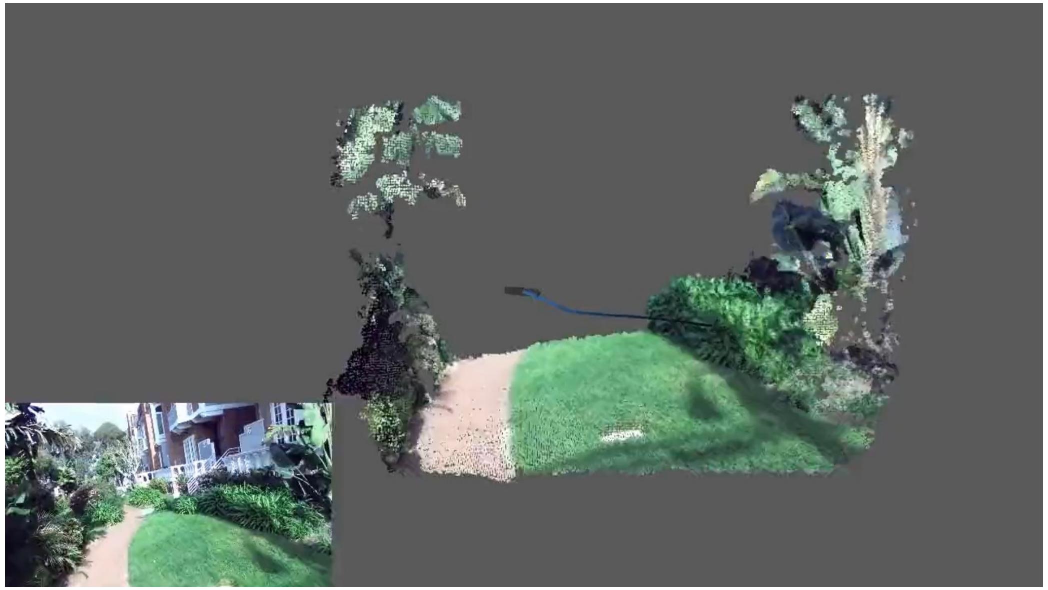
Source: “80 million tiny images” by Torralba, et al.

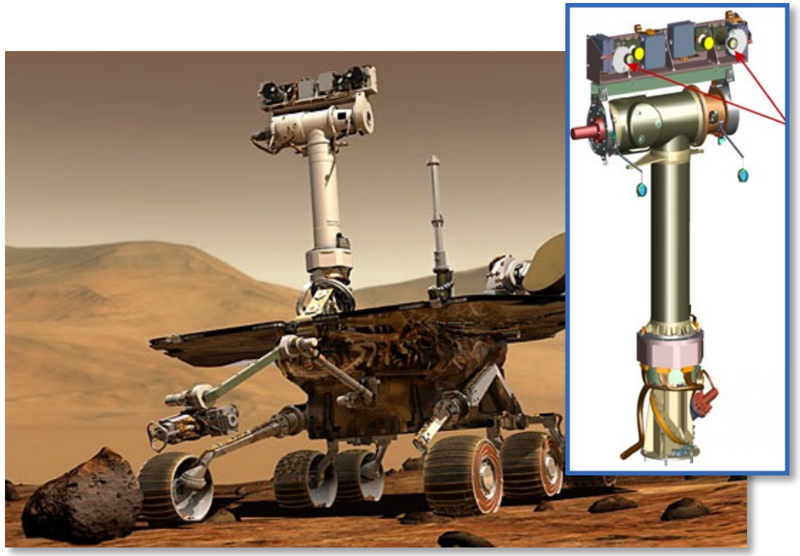
The goal of computer vision

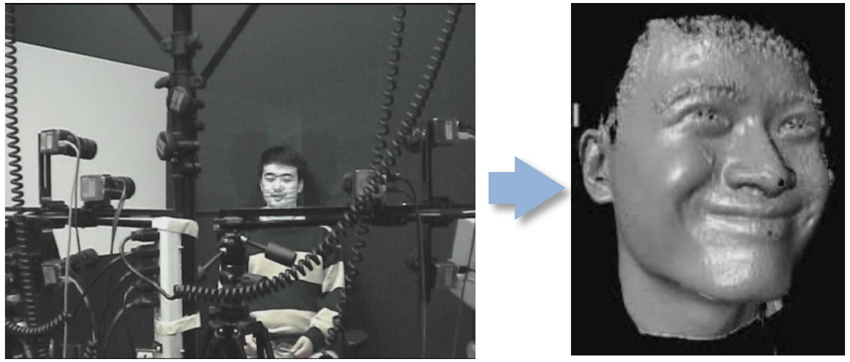
The goal of computer vision

- Compute the 3D shape of the world

ZED 2i Camera

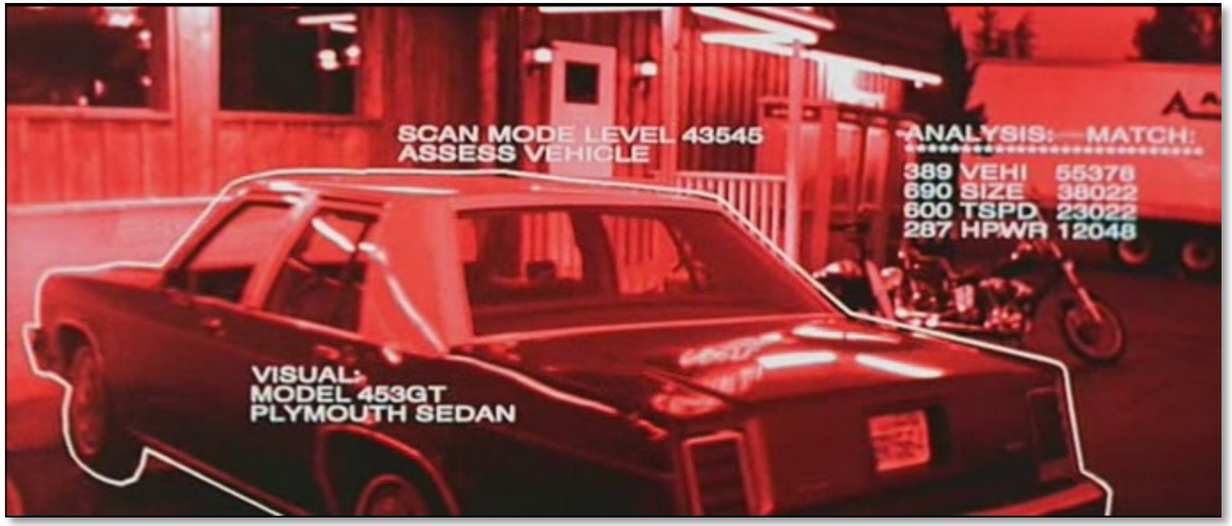






The goal of computer vision

- Recognize objects and people



Terminator 2, 1991


中华人民 和国万岁
世界 民大团结万岁


sky
building
flag
face
banner
wall
street lamp
bus
bus
cars
slide credit: Fei-Fei, Fergus & Torralba

The goal of computer vision

- “Enhance” images

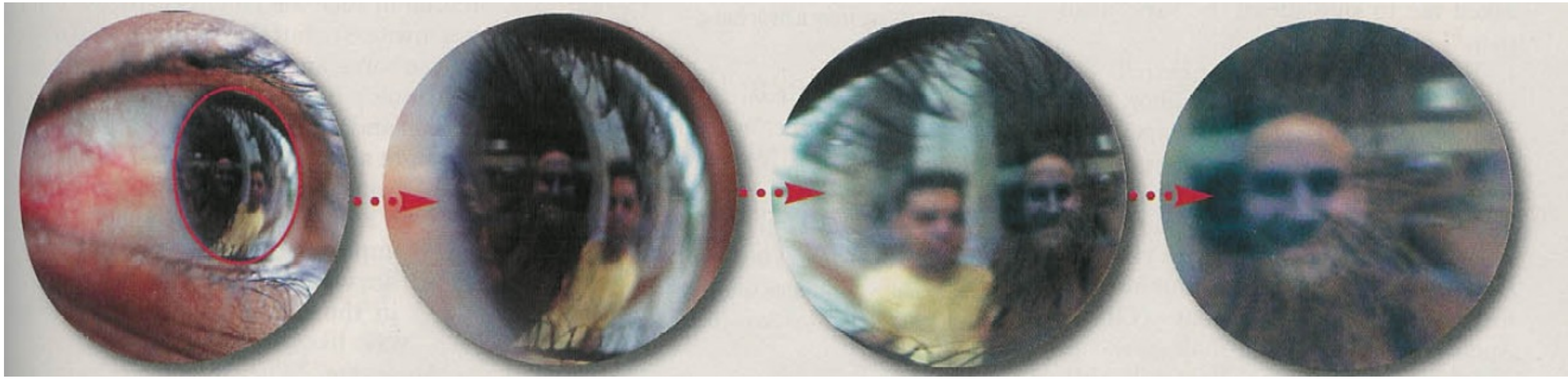

CSI:NY

The goal of computer vision

- Forensics

Source: Nayar and Nishino, "Eyes for Relighting"


Source: Nayar and Nishino, “Eyes for Relighting”

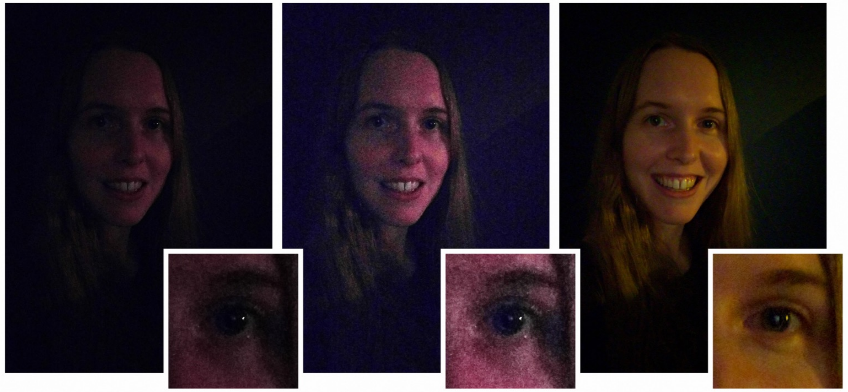


Source: Nayar and Nishino, “Eyes for Relighting”

The goal of computer vision

- Improve photos ("Computational Photography")

Super-resolution (source: 2d3)



Low-light photography
(credit: Hasinoff et al., SIGGRAPH ASIA 2016)

Depth of field on cell phone camera
(source: Google Research Blog)

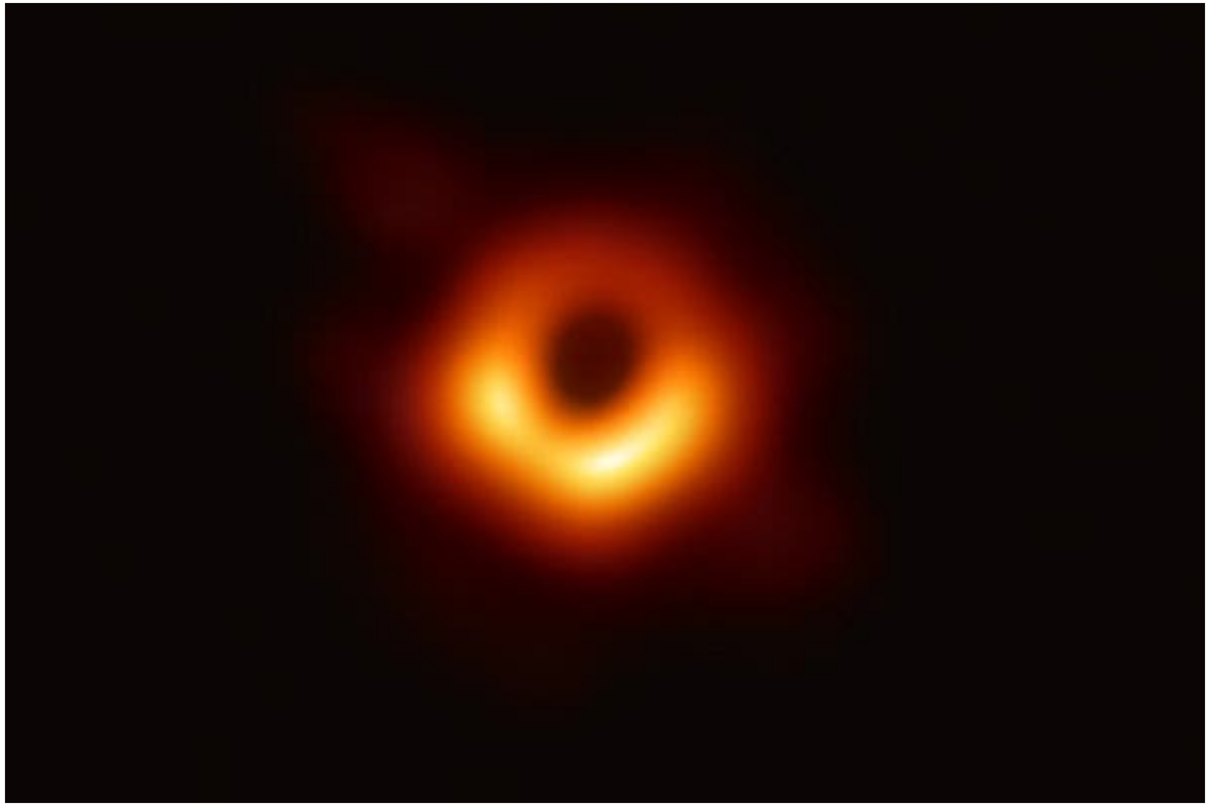
Removing objects
(Google Magic Eraser)

The New York Times

Darkness Visible, Finally: Astronomers Capture First Ever Image of a Black Hole

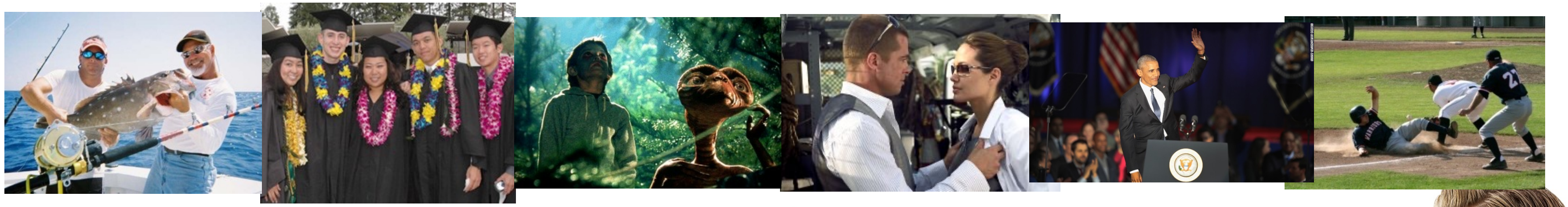
Astronomers at last have captured a picture of one of the most secretive entities in the cosmos.

April 10, 2019

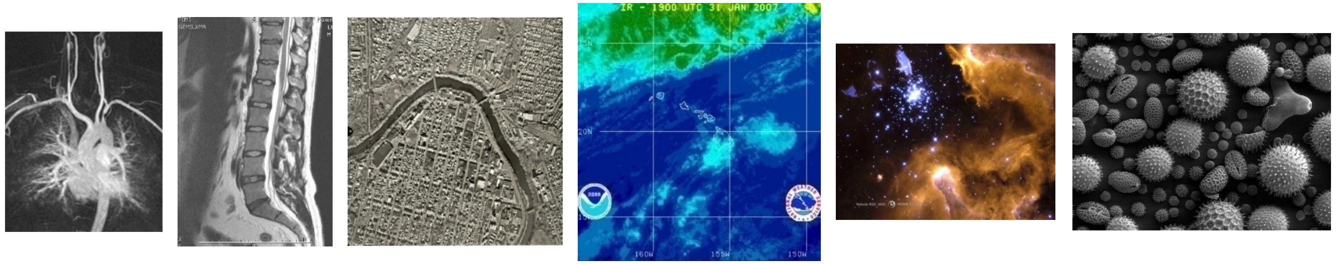


Why study computer vision?

- Billions of images/videos captured per day



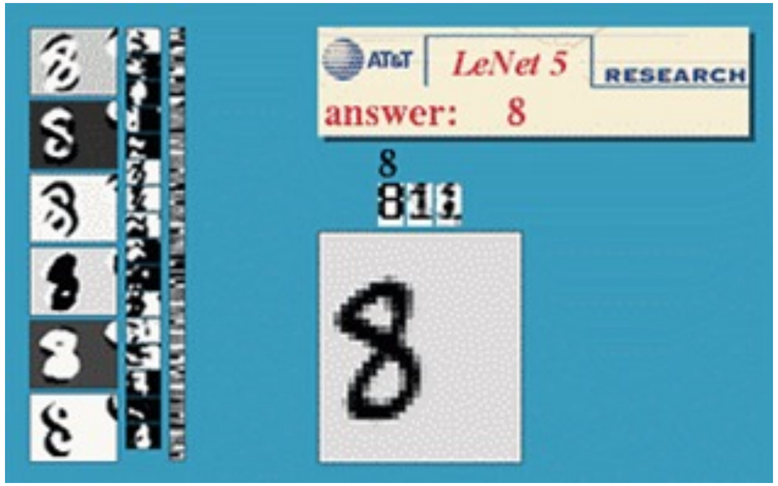
flickr YouTube Google Photos TikTok



- Huge number of potential applications
- The next slides show the current state of the art

Optical character recognition (OCR)

- If you have a scanner, it probably came with OCR software



Digit recognition, AT&T labs (1990's)
http://yann.lecun.com/exdb/lenet/

License plate readers
http://en.wikipedia.org/wiki/Automatic_number_plate_recognition

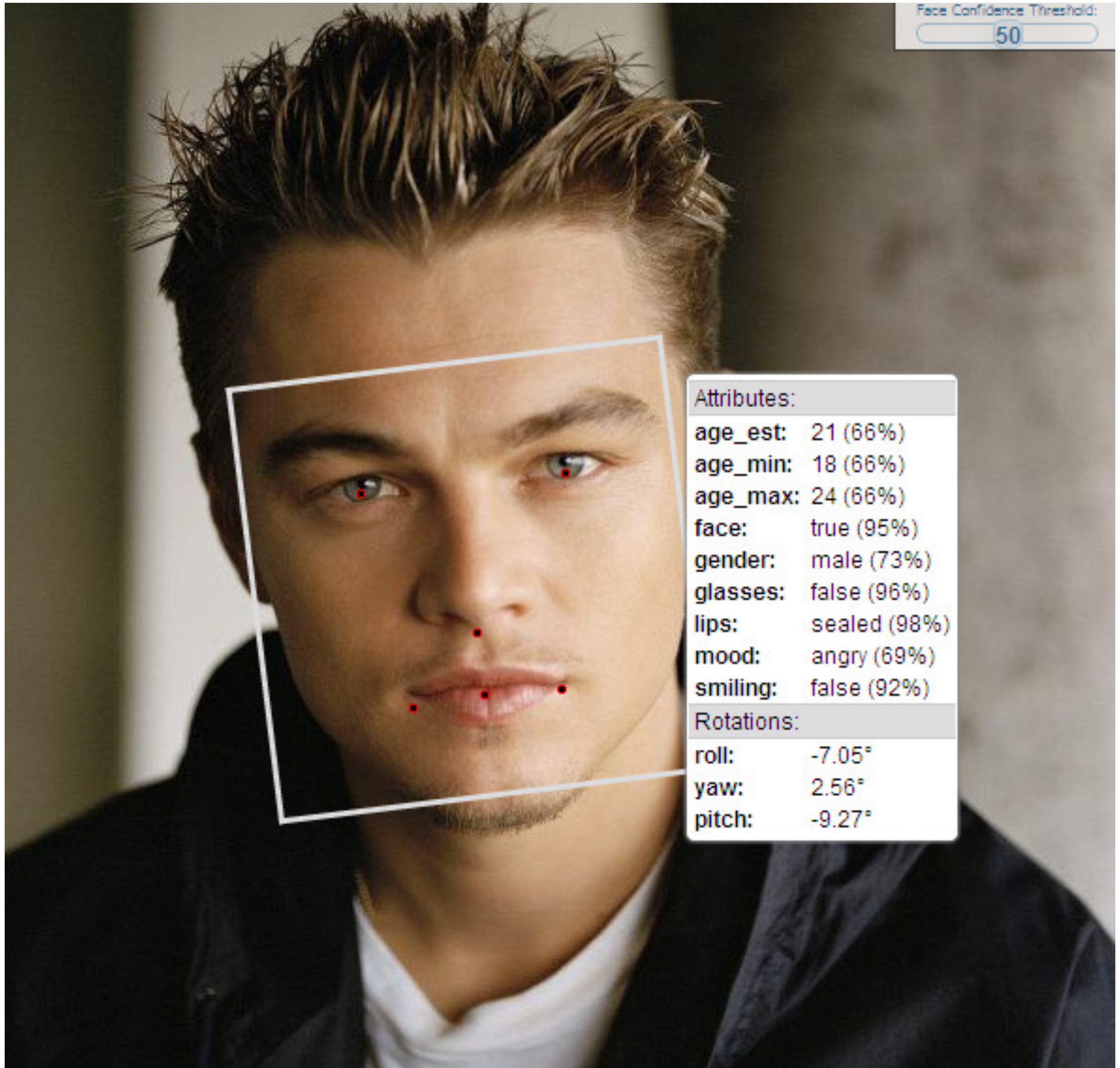
Automatic check processing

Sudoku grabber
http://sudokugrab.blogspot.com/

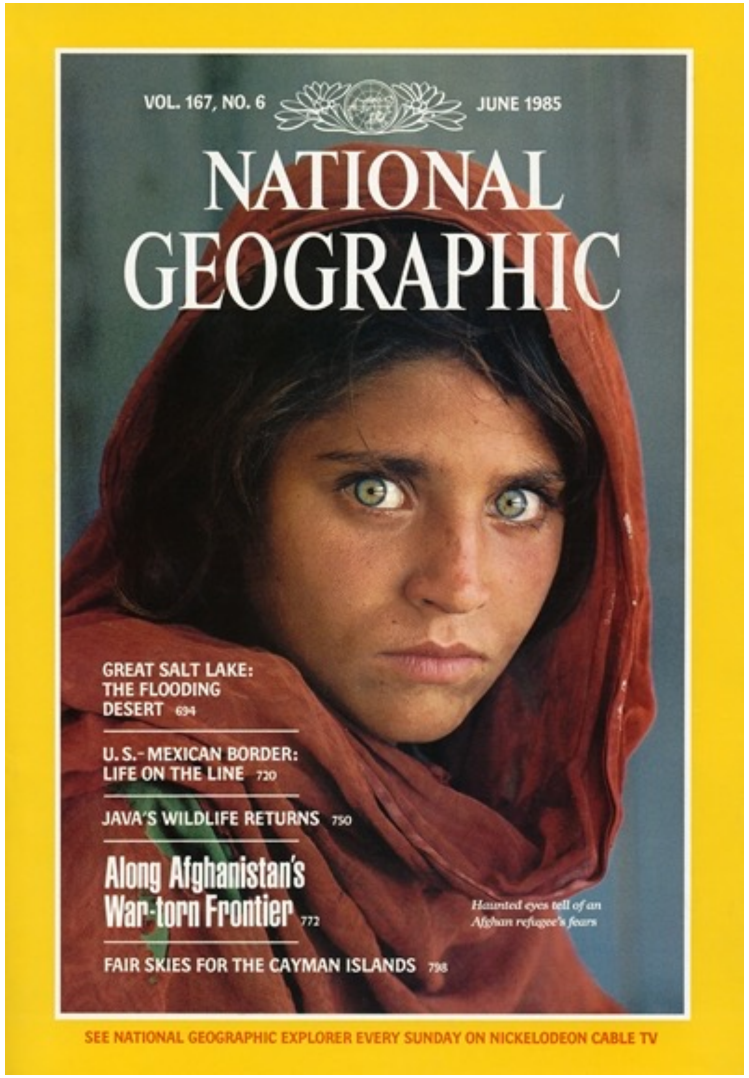
Face detection

- Nearly all cameras detect faces in real time
  - (Why?)

Face analysis and recognition



Vision-based biometrics

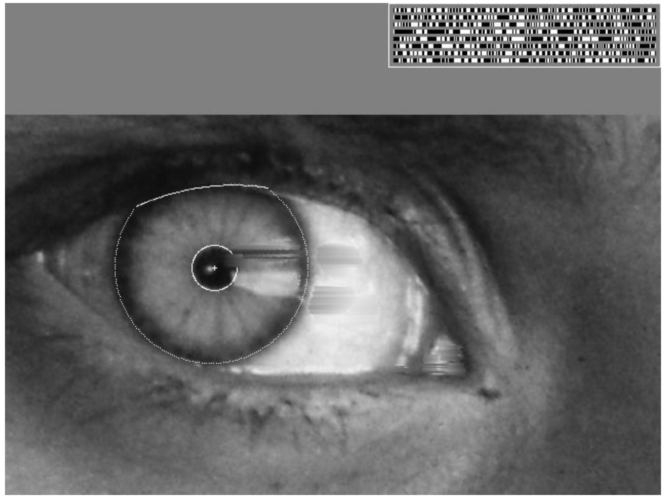


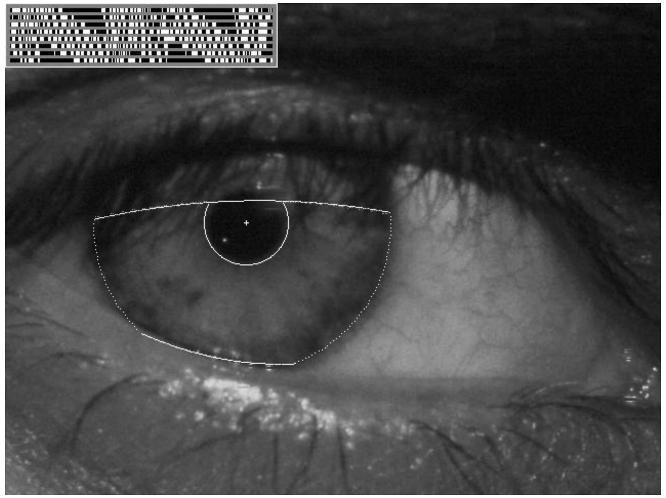
Who is she?

Source: S. Seitz

Vision-based biometrics

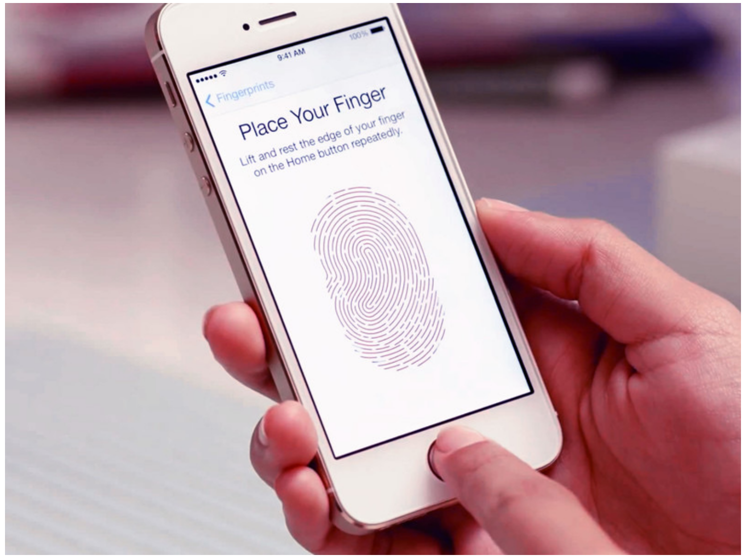
"How the Afghan Girl was Identified by Her Iris Patterns" Read the story





Source: S. Seitz

Login without a password



Fingerprint scanners on
many new smartphones
and other devices

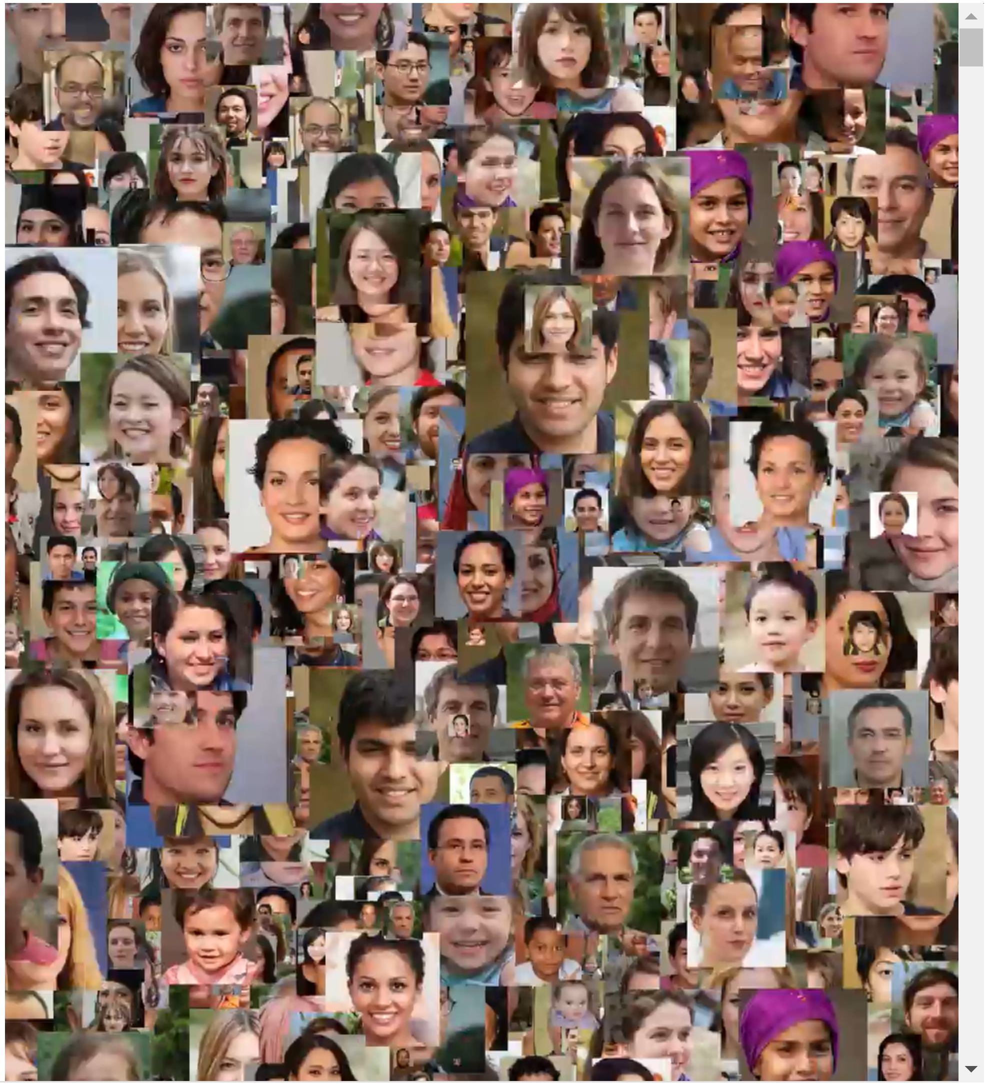
Face unlock on Apple iPhone X
See also http://www.sensiblevision.com/

The New York Times

Account

The Secretive Company That Might End Privacy as We Know It

A little-known start-up helps law enforcement match photos of unknown people to their online images — and "might lead to a dystopian future or something," a backer says.



New York Times, Jan. 18, 2020
by Kashmir Hill

Researchers warn peace sign photos could expose fingerprints

But the likelihood of anyone actually using images to recreate prints is pretty slim.

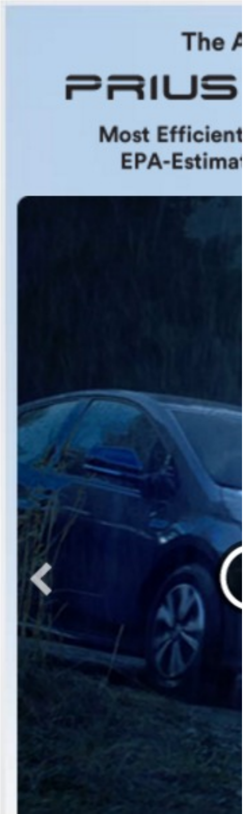
Jamie Rigg, @jmerigg
01.13.17 in Security

Comments

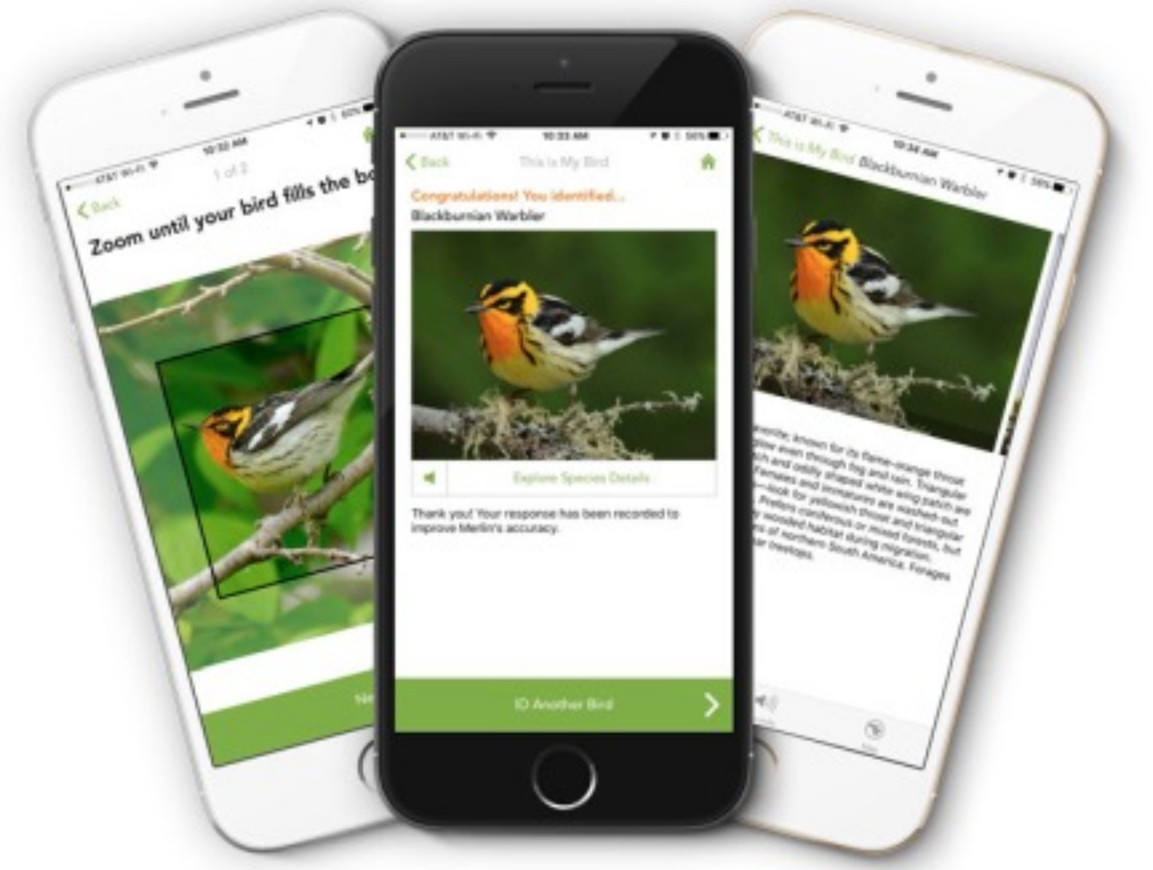
1721
Shares

f

Getty



Bird identification



Merlin Bird ID (based on Cornell Tech technology!)

Special effects: shape capture

The Matrix movies, ESC Entertainment, XYZRGB, NRC

Source: S. Seitz

Special effects: motion capture

Pirates of the Carribean, Industrial Light and Magic

Source: S. Seitz

Los Angeles Times

MOVIES

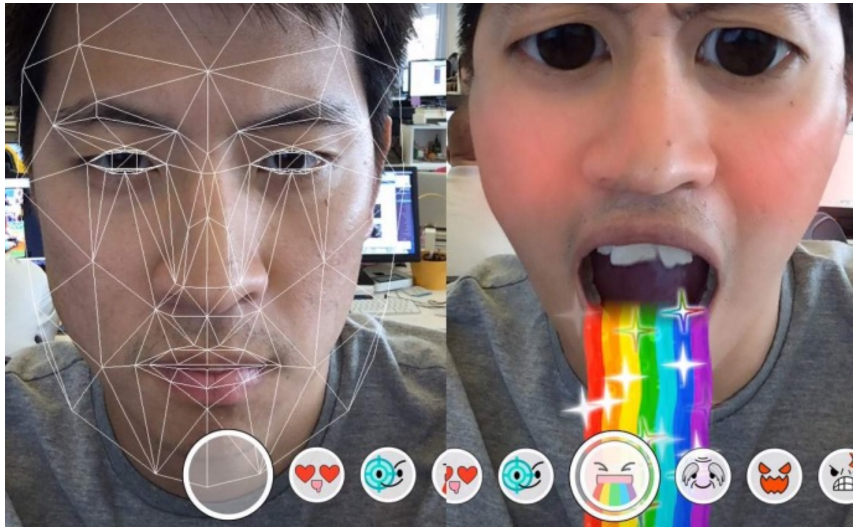
Robert De Niro said no green screen. No face dots. How ‘The Irishman’s’ de-aging changes Hollywood

Makeup and wig work got Robert De Niro partway to his character, Frank Sheeran, at 41, left. It took a specially built camera and visual artists to get all the way there, as before-and-after images show. (Netflix)

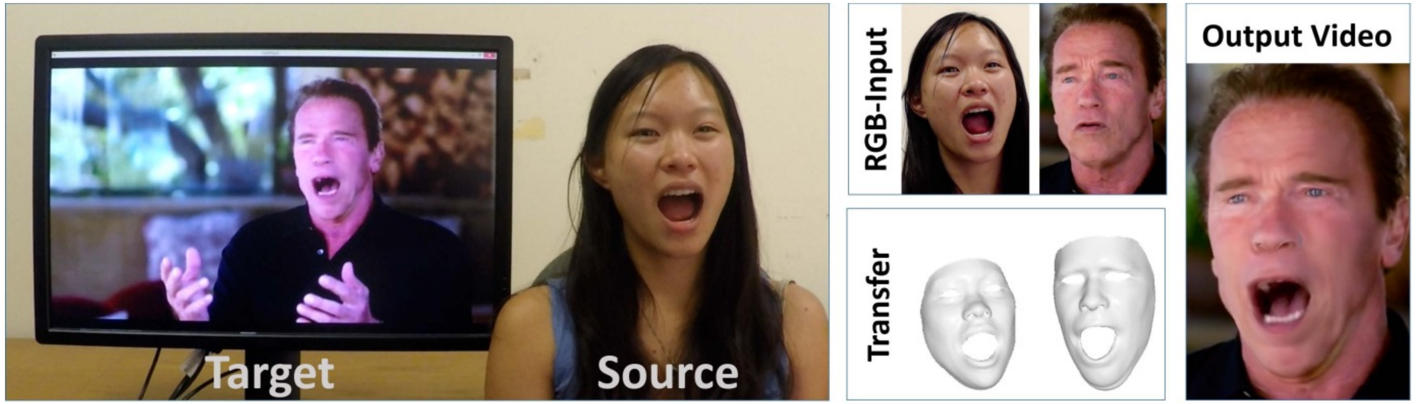
By JOSH ROTTENBERG | STAFF WRITER JAN. 2, 2020

Los Angeles Times

3D face tracking w/ consumer cameras



Snapchat Lenses



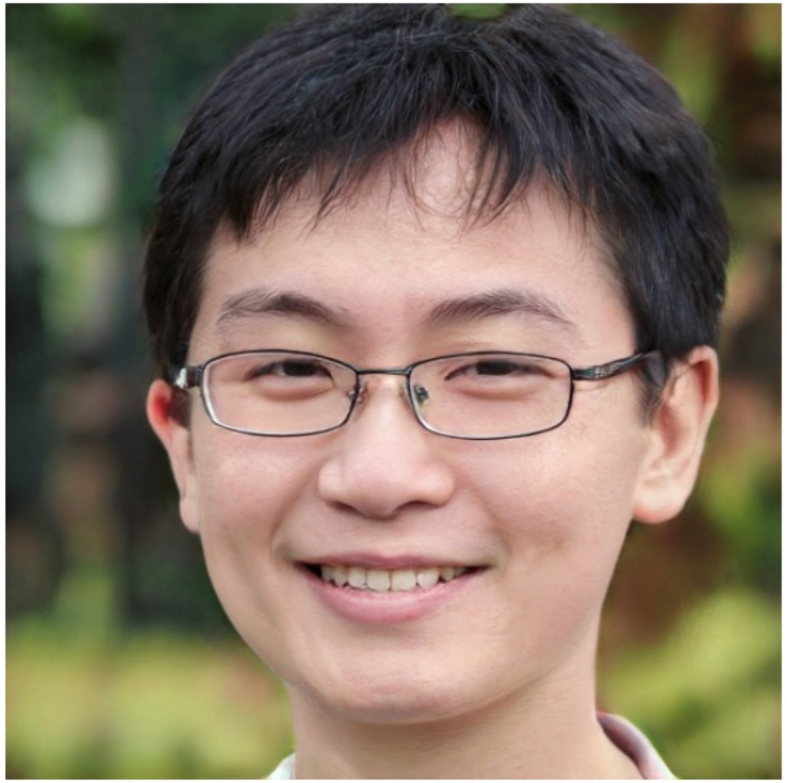
Face2Face system (Thies et al.)

Image synthesis

Karras, et al., *Progressive Growing of GANs for Improved Quality, Stability, and Variation*, ICLR 2018

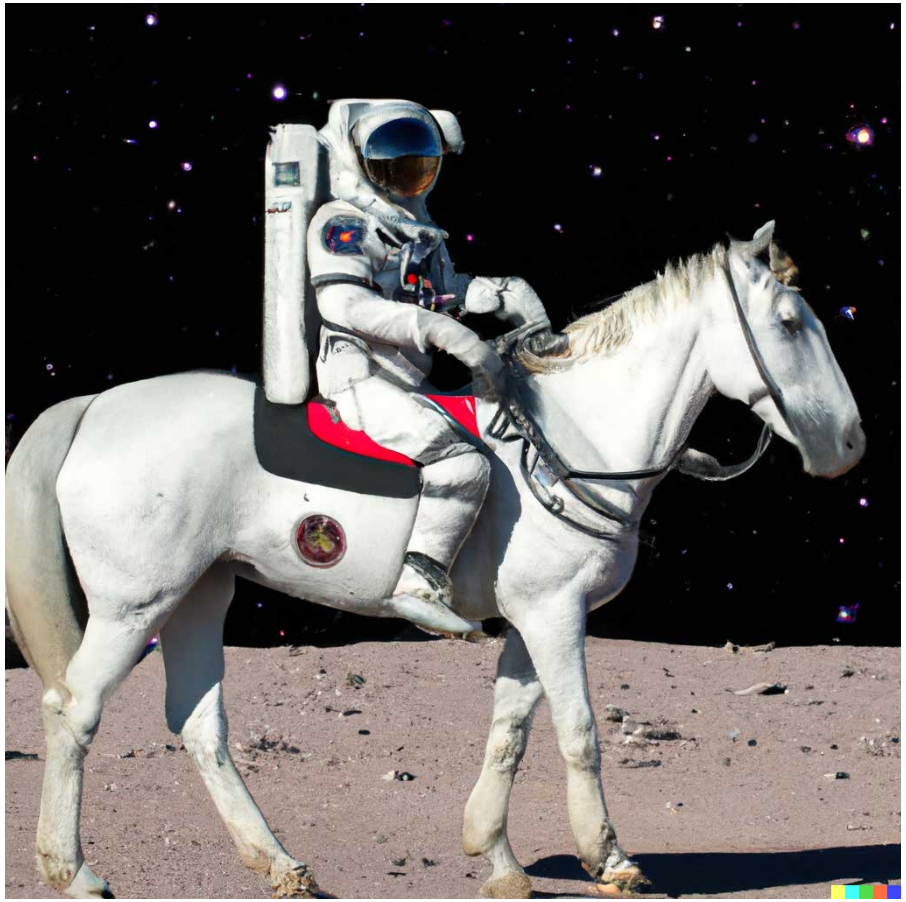
Which face is real?

Click on the person who is real.

https://www.whichfaceisreal.com/

Image synthesis



"An astronaut riding a horse in a photorealistic style" – DALL-E 2

"A photo of a Corgi dog riding a bike in Times Square. It is wearing sunglasses and a beach hat" – Imagen

Sports

Sportvision first down line
Explanation on www.howstuffworks.com

Source: S. Seitz

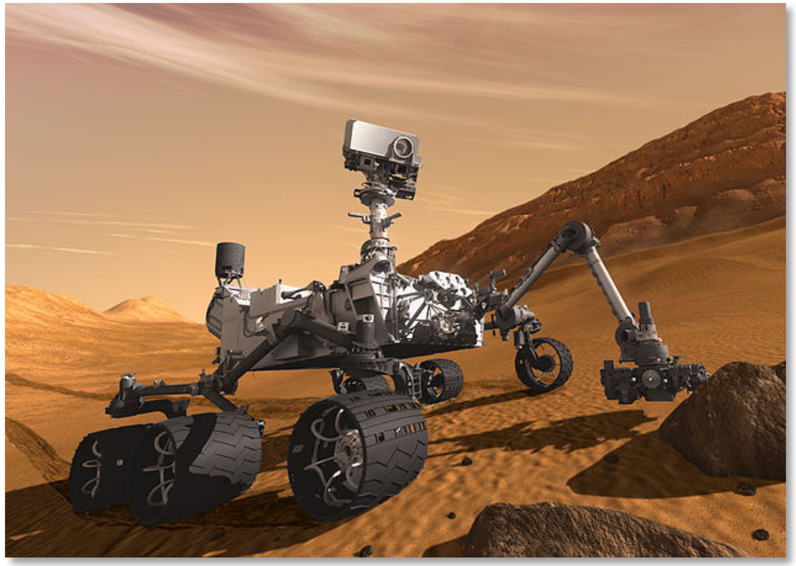
Smart cars

- [Mobileye](#)
- Tesla Autopilot
- Safety features in many cars

Self-driving cars

Waymo

Robotics



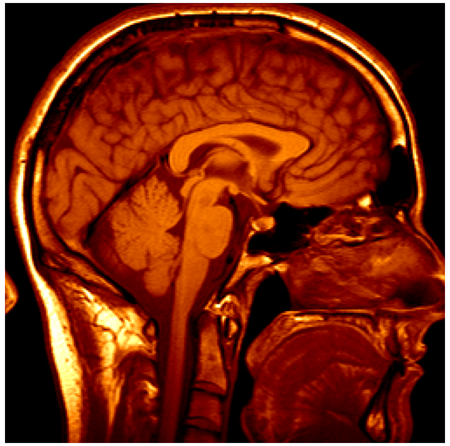
NASA's Mars Curiosity Rover
https://en.wikipedia.org/wiki/Curiosity_(rover)

Amazon Picking Challenge
http://www.robocup2016.org/en/events/amazon-picking-challenge/

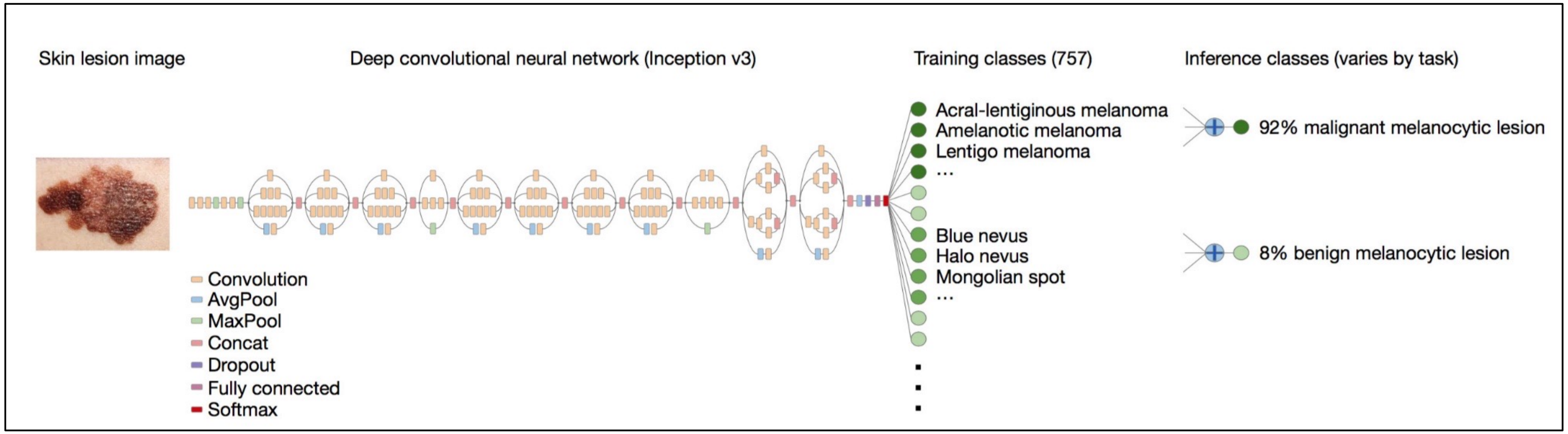
Amazon Prime Air

Amazon Scout

Medical imaging



3D imaging
(MRI, CT)



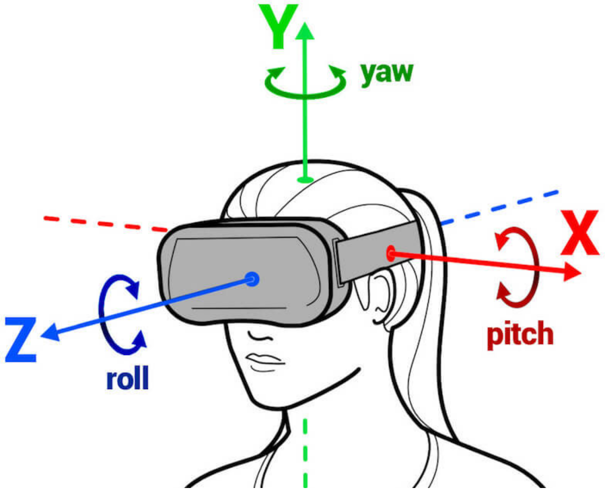
Skin cancer classification with deep learning
https://cs.stanford.edu/people/esteva/nature/

INVESTING 3/25/2014 @ 5:43PM | 70,399 views

Facebook Buys Oculus, Virtual Reality Gaming Startup, For $2 Billion

+ Comment Now + Follow Comments

Virtual & Augmented Reality



6DoF head tracking

Hand & body tracking

3D scene understanding

3D-360 video capture

Current state of the art

- You just saw many examples of current systems.
  - Many of these are less than 5 years old
- Computer vision is an active research area, and rapidly changing
  - Many new apps in the next 5 years
  - Deep learning powering many modern applications
- Many startups across a dizzying array of areas
  - Deep learning, robotics, autonomous vehicles, medical imaging, construction, inspection, VR/AR, …

Why is computer vision difficult?

Viewpoint variation

Illumination

Scale

Why is computer vision difficult?

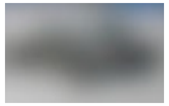
Intra-class variation

Motion (Source: S. Lazebnik)

Background clutter

Occlusion

Challenges: local ambiguity



slide credit: Fei-Fei, Fergus & Torralba

But there are lots of visual cues we can use…

Source: S. Lazebnik

Bottom line

- Perception is an inherently ambiguous problem
  - Many different 3D scenes could have given rise to a given 2D image

Artist Julian Beever with his anamorphic Coke bottle

  - We often must use prior knowledge about the world's structure

Andrej Karpathy blog

The state of Computer Vision and AI: we are really, really far.

Oct 22, 2012

The picture above is funny.

But for me it is also one of those examples that make me sad about the outlook for AI and for Computer Vision. What would it take for a computer to understand this image as you or I do? I challenge you to think explicitly of all the pieces of knowledge that have to fall in place for it to make sense. Here is my short attempt:

- You recognize it is an image of a bunch of people and you understand they are in a hallway
- You recognize that there are 3 mirrors in the scene so some of those people are "fake" replicas from different viewpoints.
- You recognize Obama from the few pixels that make up his face. It helps that he is in his suit and that he is surrounded by other people with suits.
- You recognize that there's a person standing on a scale, even though the scale occupies only very few white pixels that blend with the background. But, you've used the person's pose and knowledge of how people interact with objects to figure it out.
- You recognize that Obama has his foot positioned just slightly on top of the scale. Notice the language I'm using: It is in terms of the 3D structure of the scene, not the position of the leg in the 2D coordinate system of the image.
- You know how physics works: Obama is leaning in on the scale, which applies a force on it. Scale measures force that is applied on it, that's how it works => it will over-estimate the weight of the person standing on it.
- The person measuring his weight is not aware of Obama doing this. You derive this because you know his pose, you understand that the field of view of a person is finite, and you understand that he is not very likely to sense the slight push of Obama's foot.
- You understand that people are self-conscious about their weight. You also understand that he is reading off the scale measurement, and that shortly the over-estimated weight will confuse him because it will probably be much higher than what he expects. In other words, you reason about implications of the events that are about to unfold seconds after this photo was taken, and especially about the thoughts and how they will develop inside people's heads. You also reason about what pieces of information are available to people.
- There are people in the back who find the person's imminent confusion funny. In other words you are reasoning about state of mind of people, and their view of the state of mind of another person. That's getting frighteningly meta.
- Finally, the fact that the perpetrator here is the president makes it maybe even a little more funnier. You understand what actions are more or less likely to be undertaken by different people based on their status and identity.

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CS5670: Introduction to Computer Vision

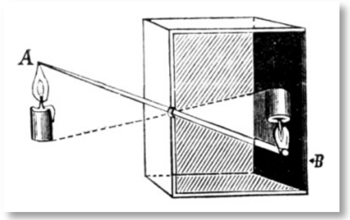
- Project-based course whose goal is to teach you the basics of computer vision – image processing, geometry, recognition – in a hands-on way

Course requirements

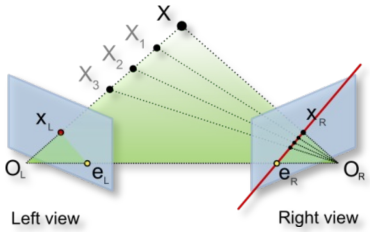
- Prerequisites
  - Data structures
  - Good working knowledge of Python programming
  - Linear algebra
  - Vector calculus

- Course does ***not*** assume prior imaging experience
  - computer vision, image processing, graphics, etc.

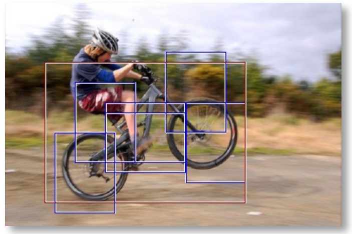
Course overview (tentative)



1. Low-level vision
   – image processing, edge detection, feature detection, cameras, image formation



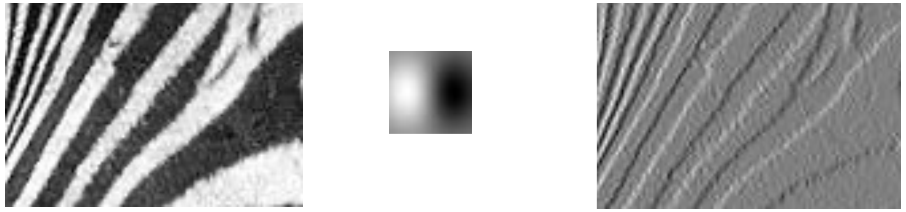
2. Geometry and algorithms
   – projective geometry, stereo, structure from motion, optimization



3. Recognition
   – face detection / recognition, category recognition, segmentation

1. Low-level vision

- Basic image processing and image formation



Filtering, edge detection

Feature extraction

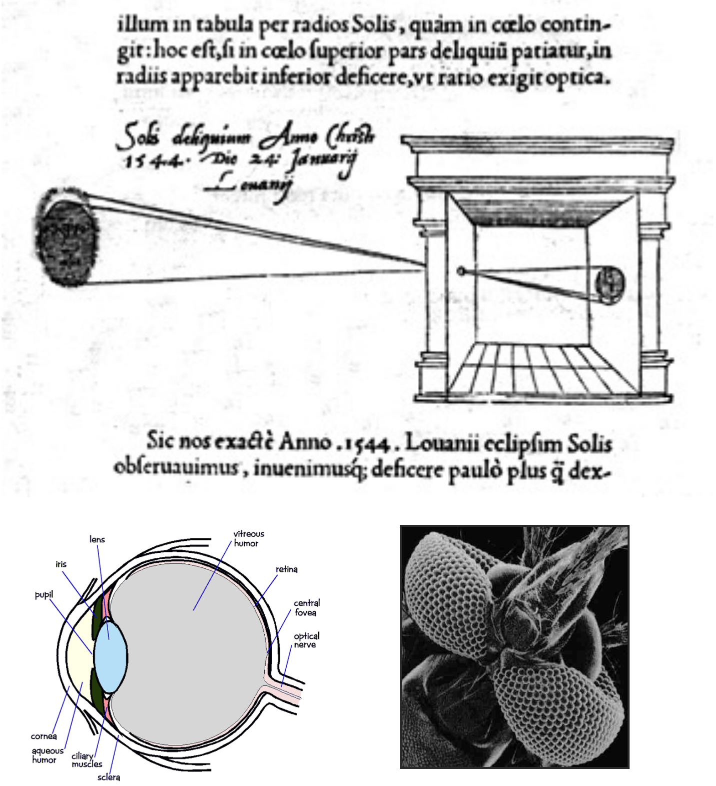
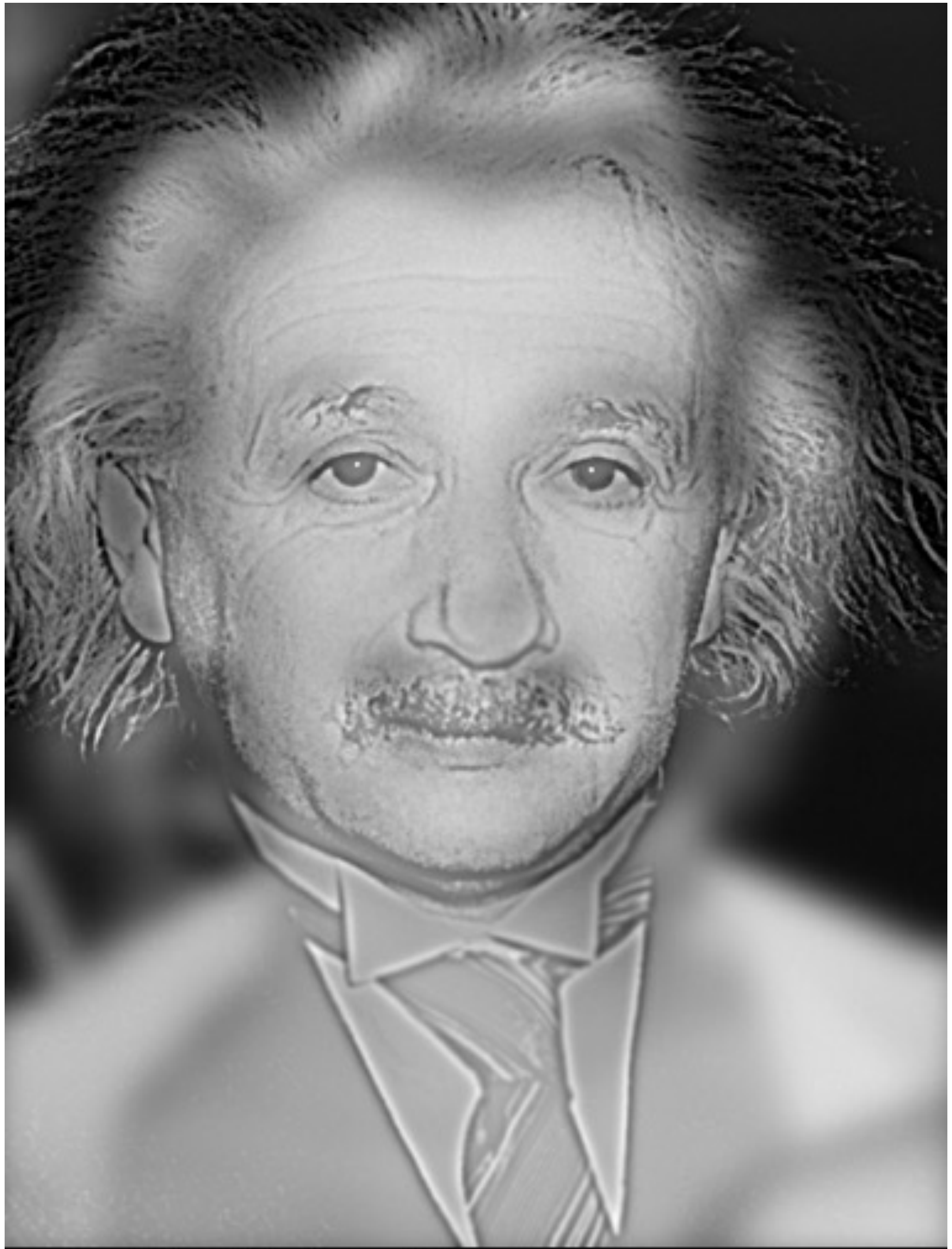


Image formation

Project: Hybrid images



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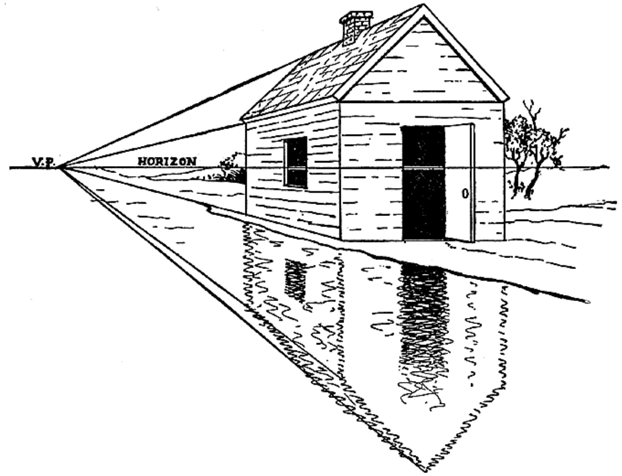
Project: Feature detection and matching

2. Geometry



Projective geometry

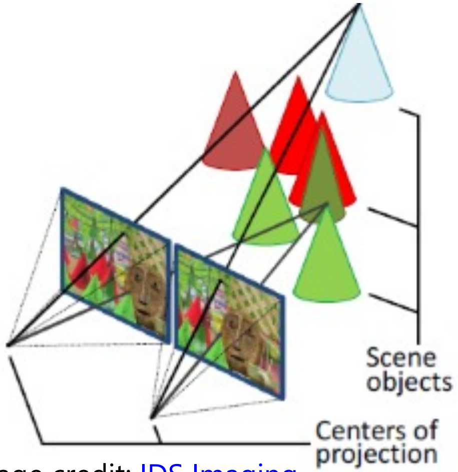
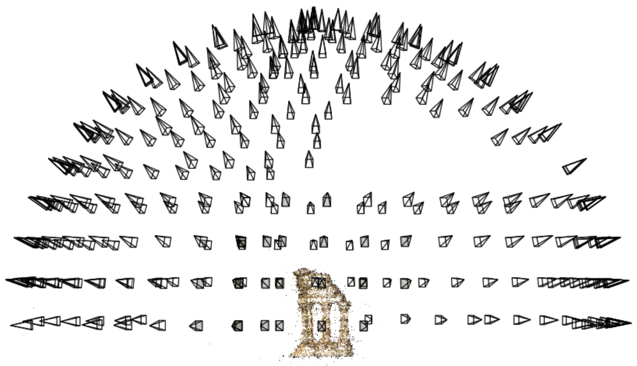


Image credit: [IDS Imaging]

Stereo vision

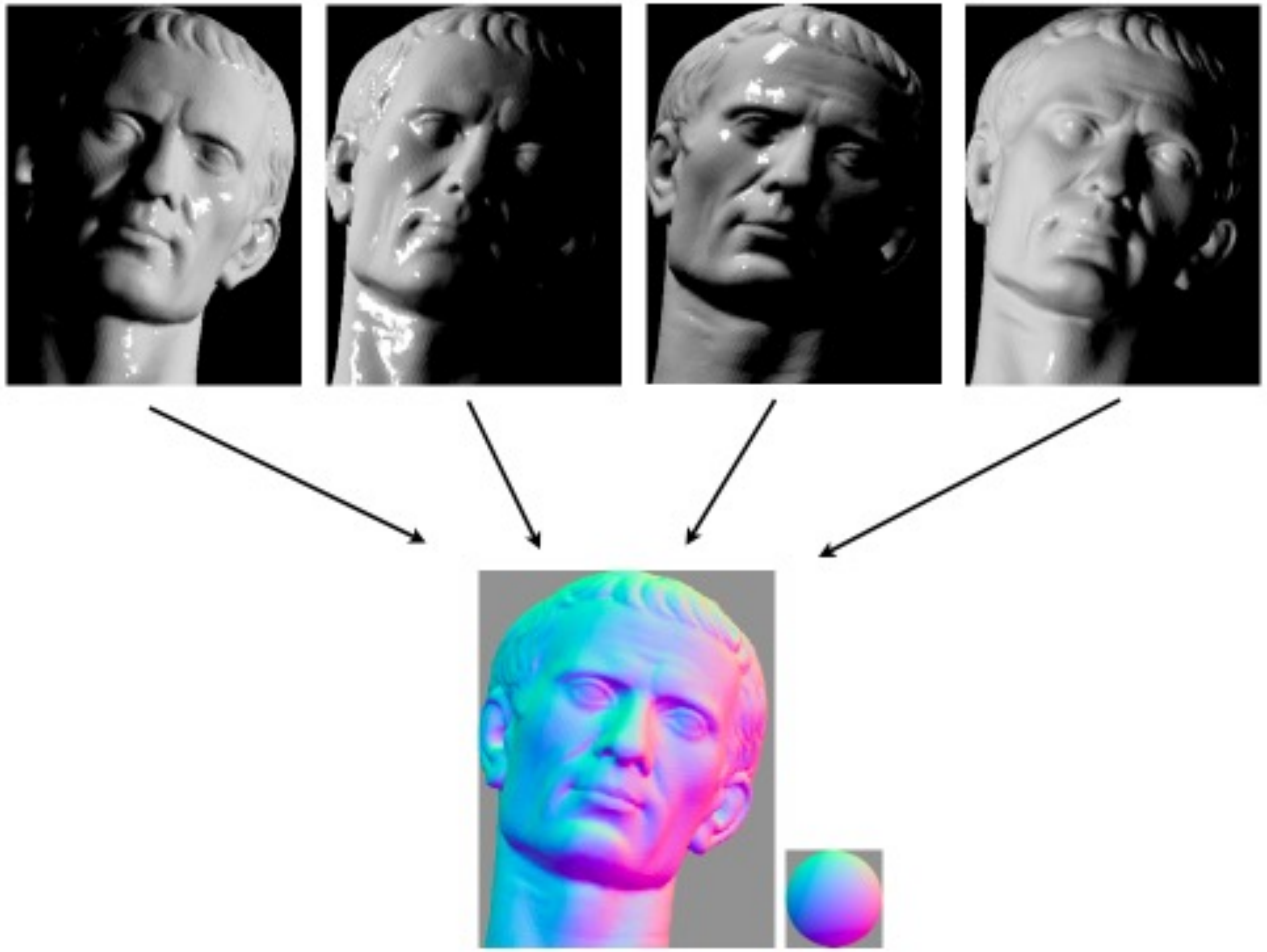


Multi-view stereo

Structure from motion

Project: Creating panoramas

Project: 3D reconstruction



3. Recognition

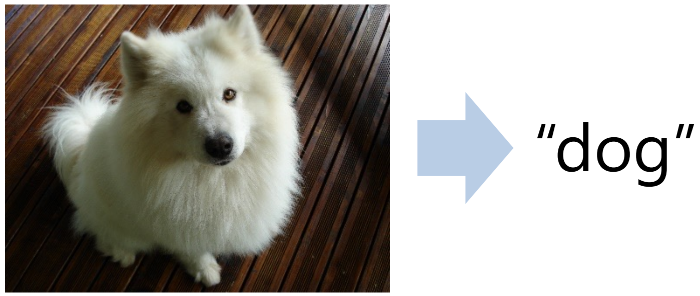
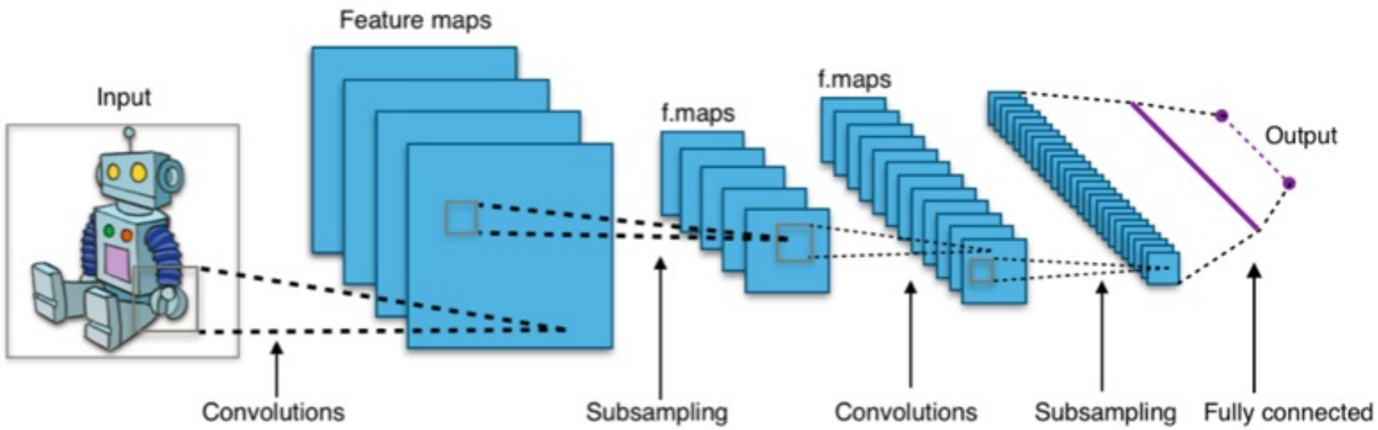


Image classification

Object detection



Convolutional Neural Networks

Project: Neural Radiance Fields (NeRFs)

Lectures

- Lectures will be held in person in Bloomberg 131
- If there is an instance where you need to attend lecture remotely, please reach out to the instructor for approval

Grading

- Approximately weekly short quizzes (typically at the beginning of class on Thursdays)
- One midterm (take-home), one final exam (in class)

- Grade breakdown (subject to minor tweaks):
  - Quizzes: 5% (lowest quiz grade dropped)
  - Midterm: 16%
  - Programming projects: 63%
  - Final exam: 16%

Late policy

- Four free “slip days” will be available for the semester
- A late project will be penalized by 10% for each day it is late (excepting slip days), and no extra credit will be awarded

Academic Integrity

- Assignments will be done solo or in pairs (we'll let you know for each project)
- Please do not leave any code public on GitHub (or the like) at the end of the semester!
- We will follow the Cornell Code of Academic Integrity (http://cuinfo.cornell.edu/aic.cfm)
- We reserve the right to run MOSS (automated code copying service) on submitted code

Questions?