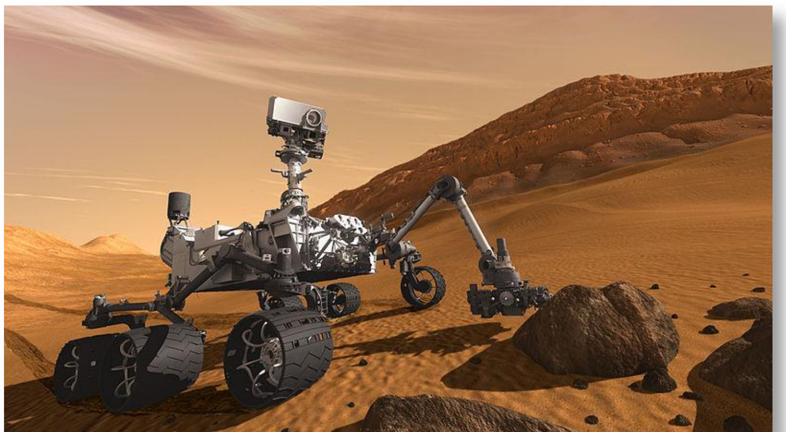
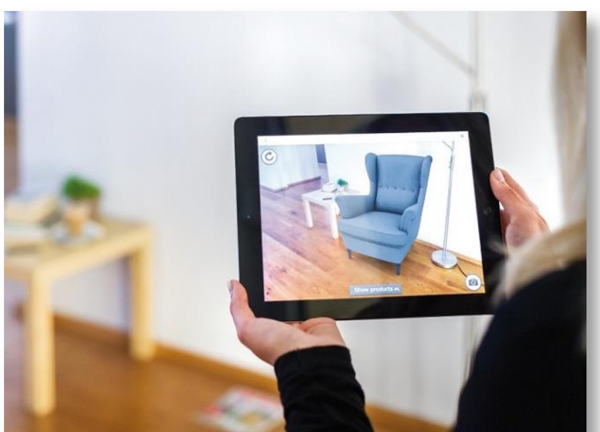
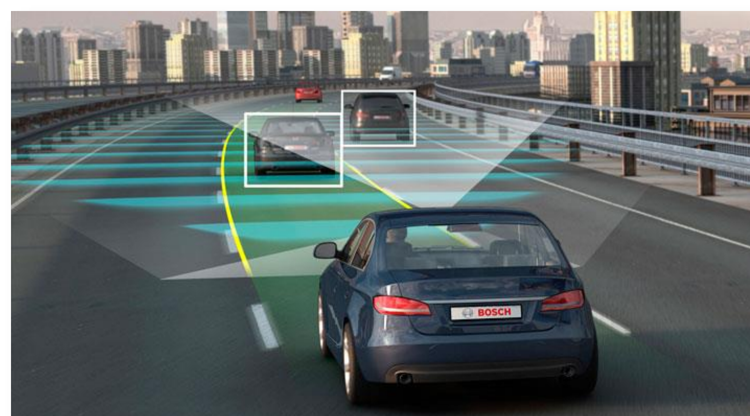
CS5670: Intro to Computer Vision

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

Teaching Assistants

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- Please check course webpage for office hours

Today

1. What is computer vision?
2. Course overview
3. Image filtering

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 the computer match human perception?

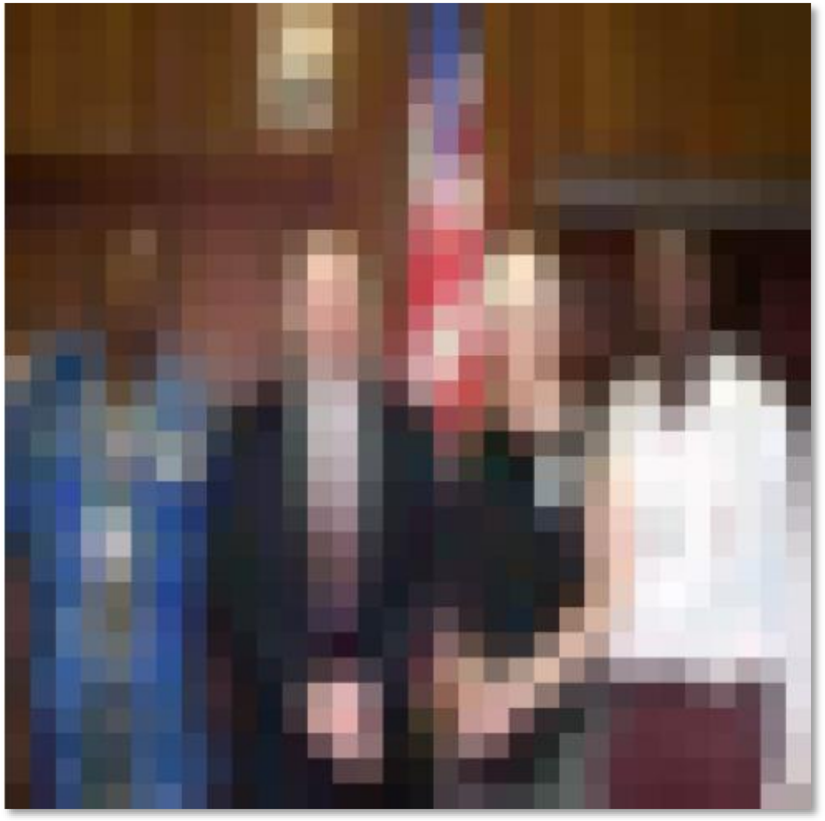
- Yes and no (mainly no)
  - computers can be better at "easy" things
  - humans are much better at "hard" things
- But huge progress has been made
  - Accelerating in the last 4 years due to deep learning
  - What is considered "hard" keeps changing

Human perception has its shortcomings

[Sinha and Poggio, *Nature*, 1996](#)

("The Presidential Illusion")

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

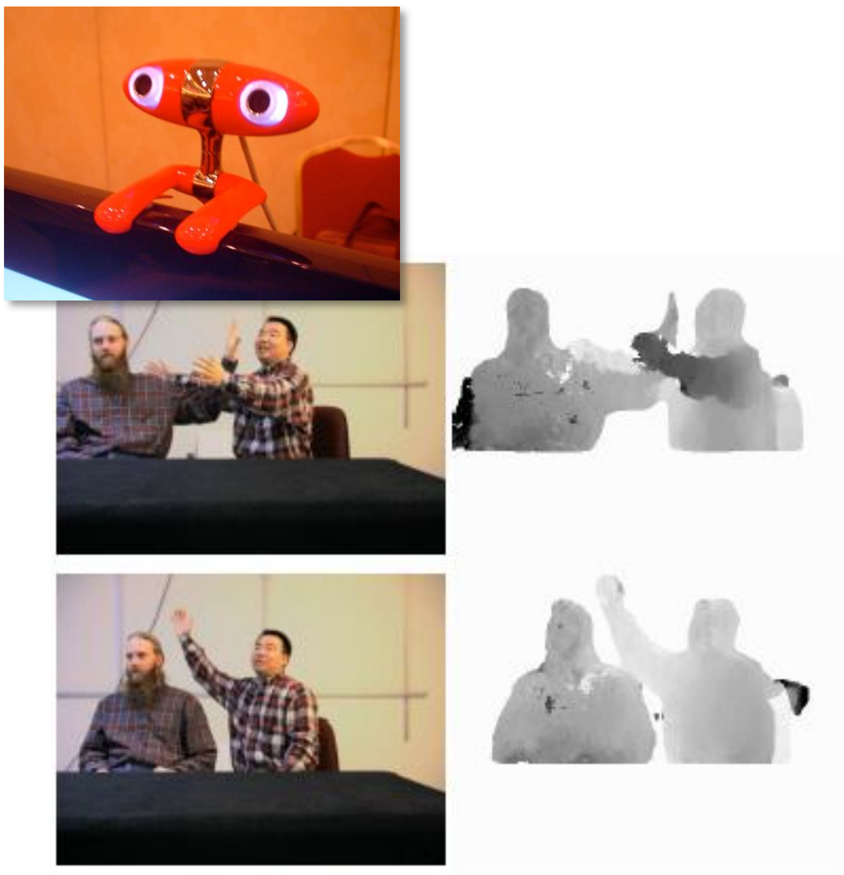


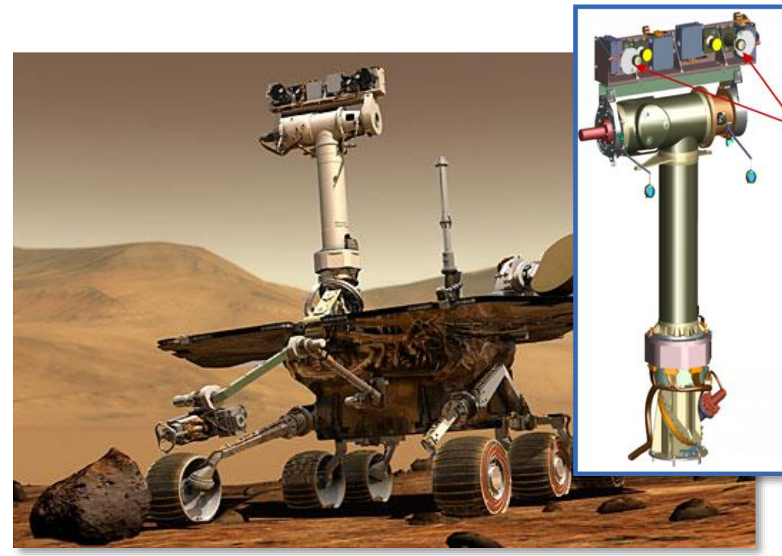
Source: “80 million tiny images” by Torralba, et al.

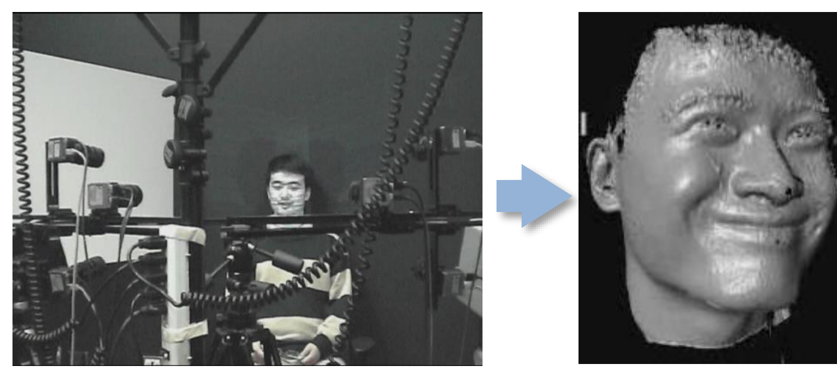
The goal of computer vision

The goal of computer vision

- Compute the 3D shape of the world

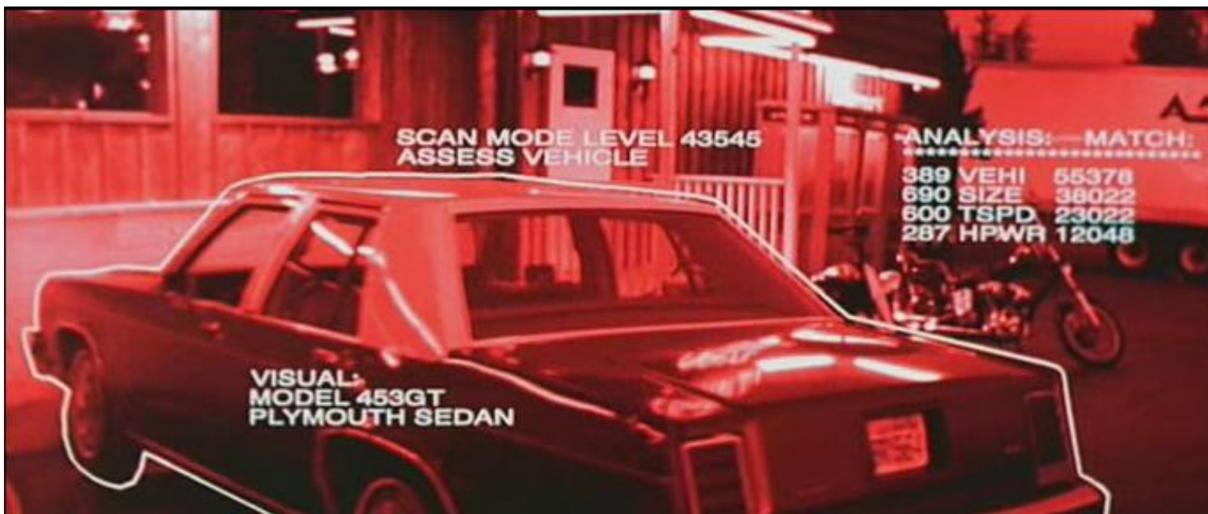






The goal of computer vision

- 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”

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

The goal of computer vision

- Improve photos ("Computational Photography")

Super-resolution (source: 2d3)

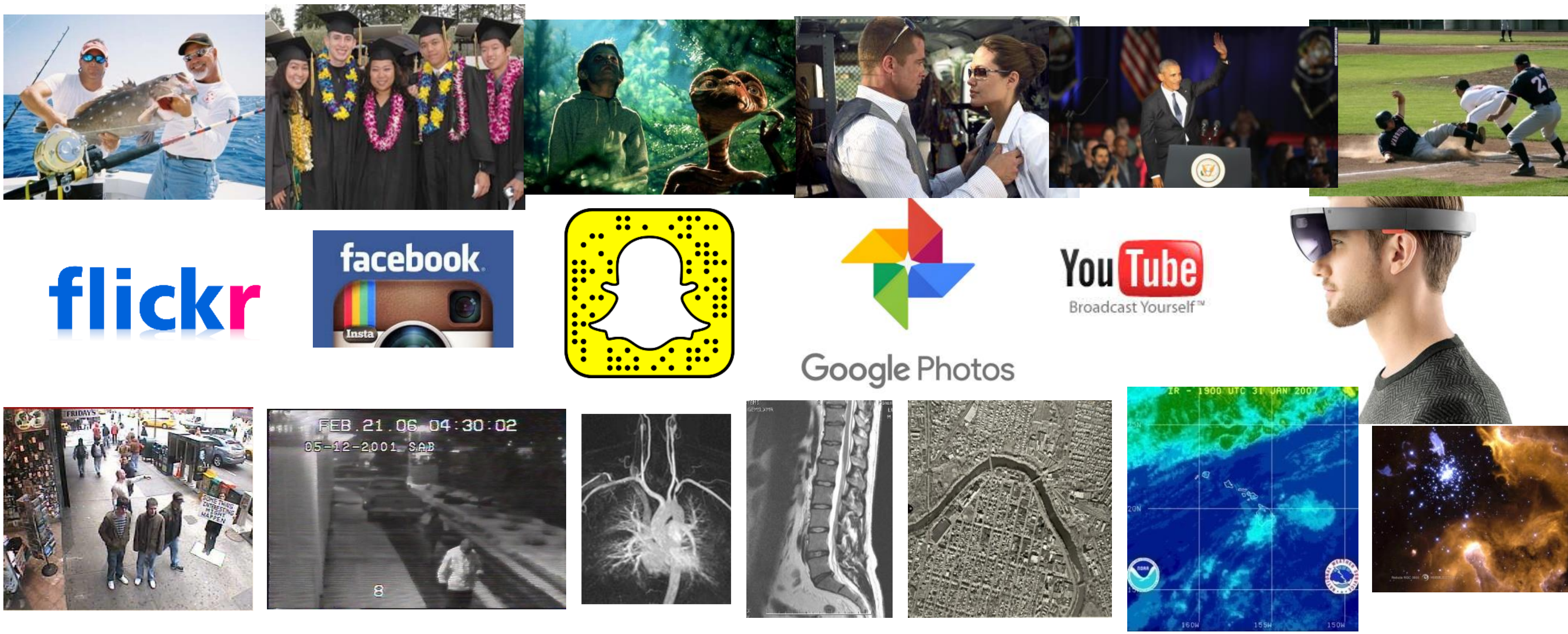
Low-light photography
(credit: Hasinoff et al., SIGGRAPH ASIA 2016)

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

Inpainting / image completion
(image credit: Hays and Efros)

Why study computer vision?

- Billions of images/videos captured per day



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

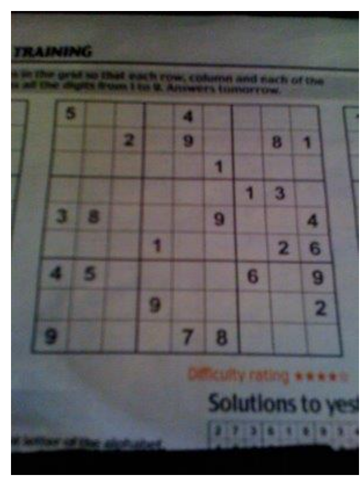
Optical character recognition (OCR)

- 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



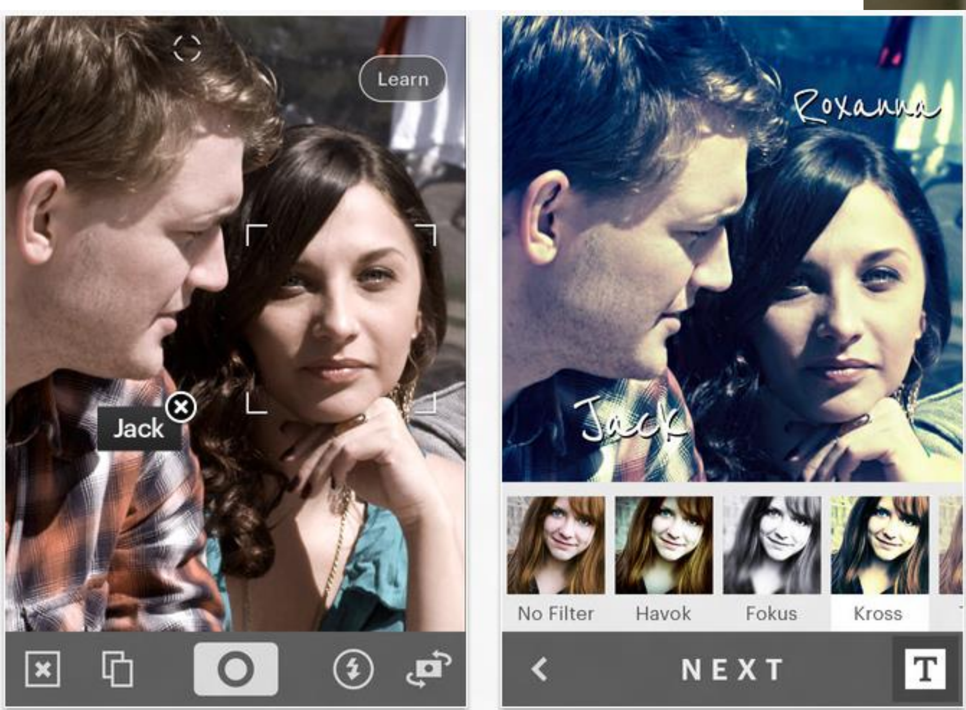
Sudoku grabber
http://sudokugrab.blogspot.com/

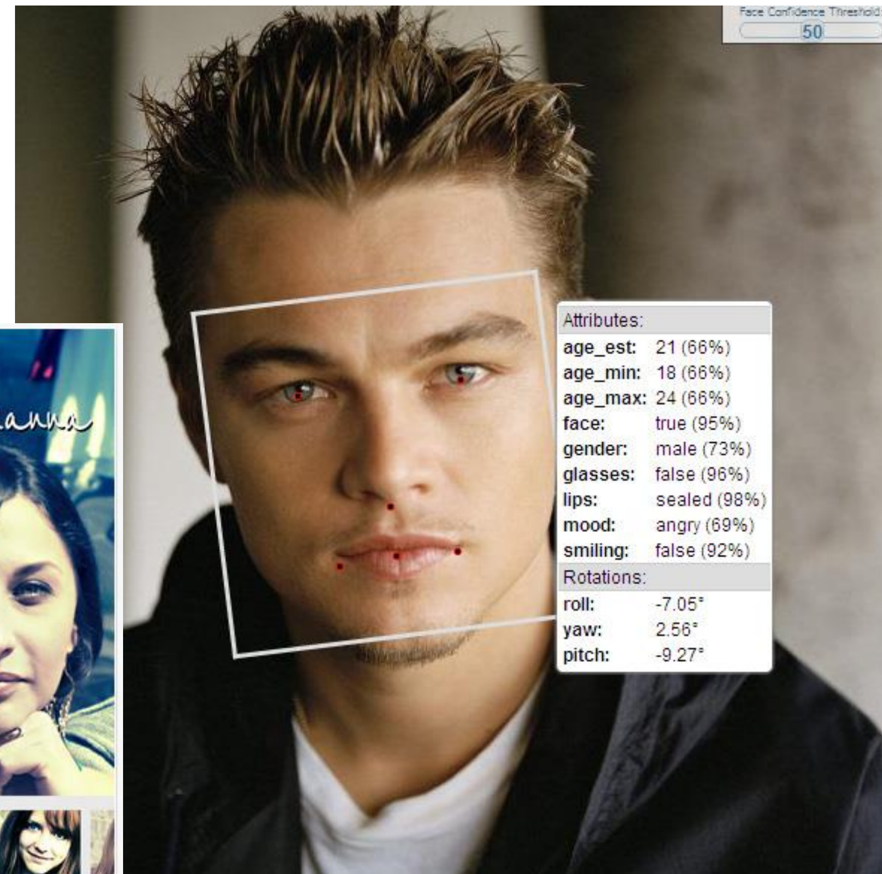
Face detection

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

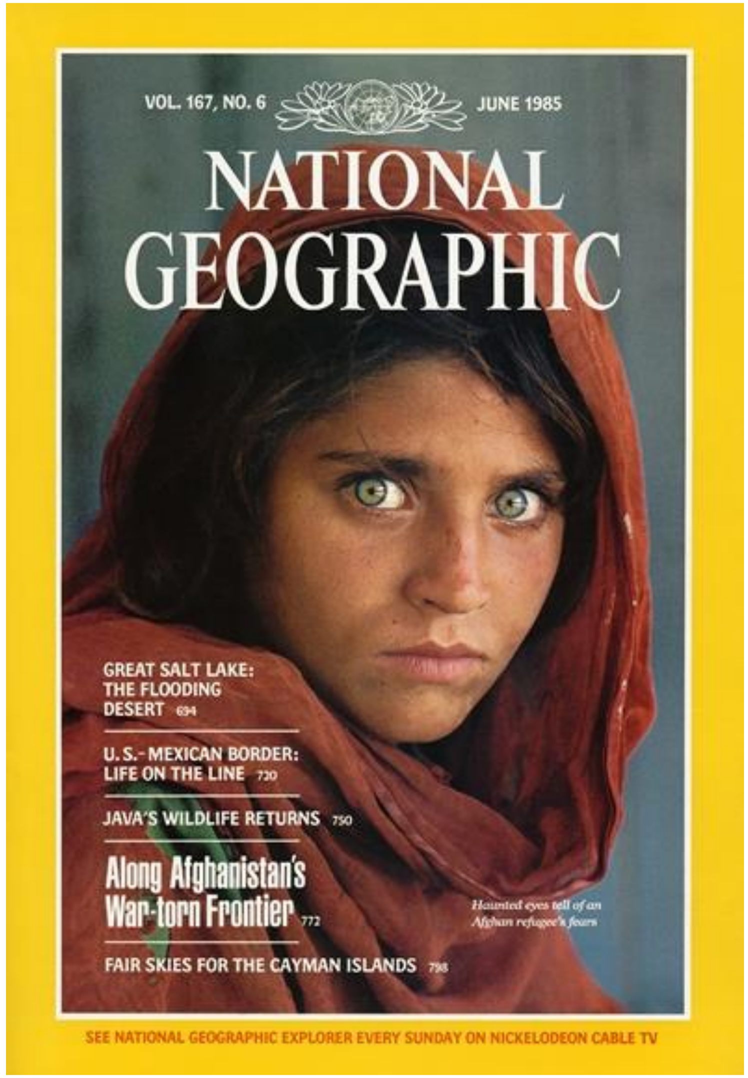
Face Recognition

FACE++





Face recognition

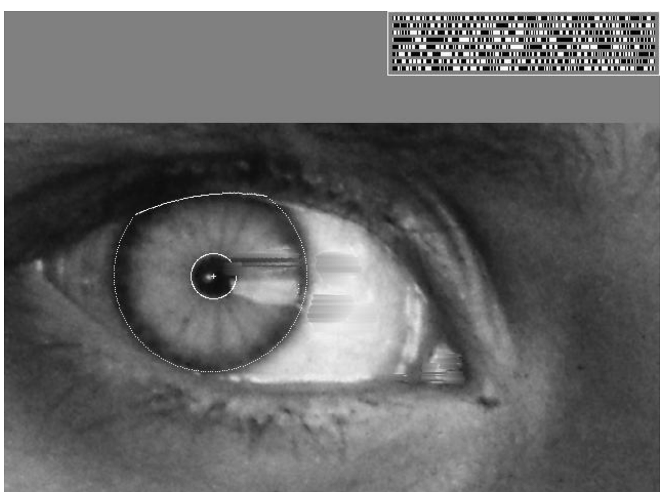


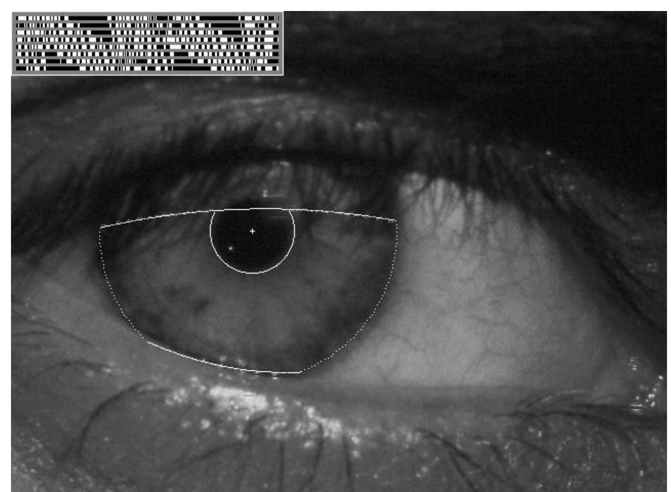
Who is she?

Source: S. Seitz

Vision-based biometrics

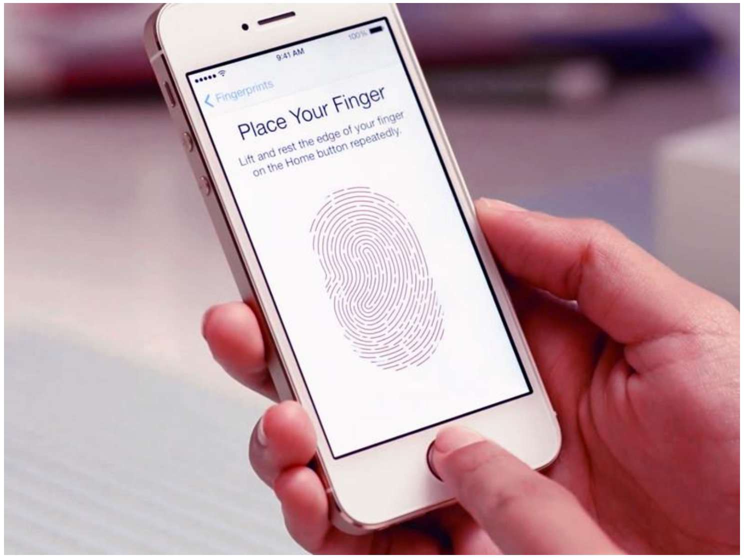
"*How the Afghan Girl was Identified by Her Iris Patterns*" Read the [story]





Source: S. Seitz

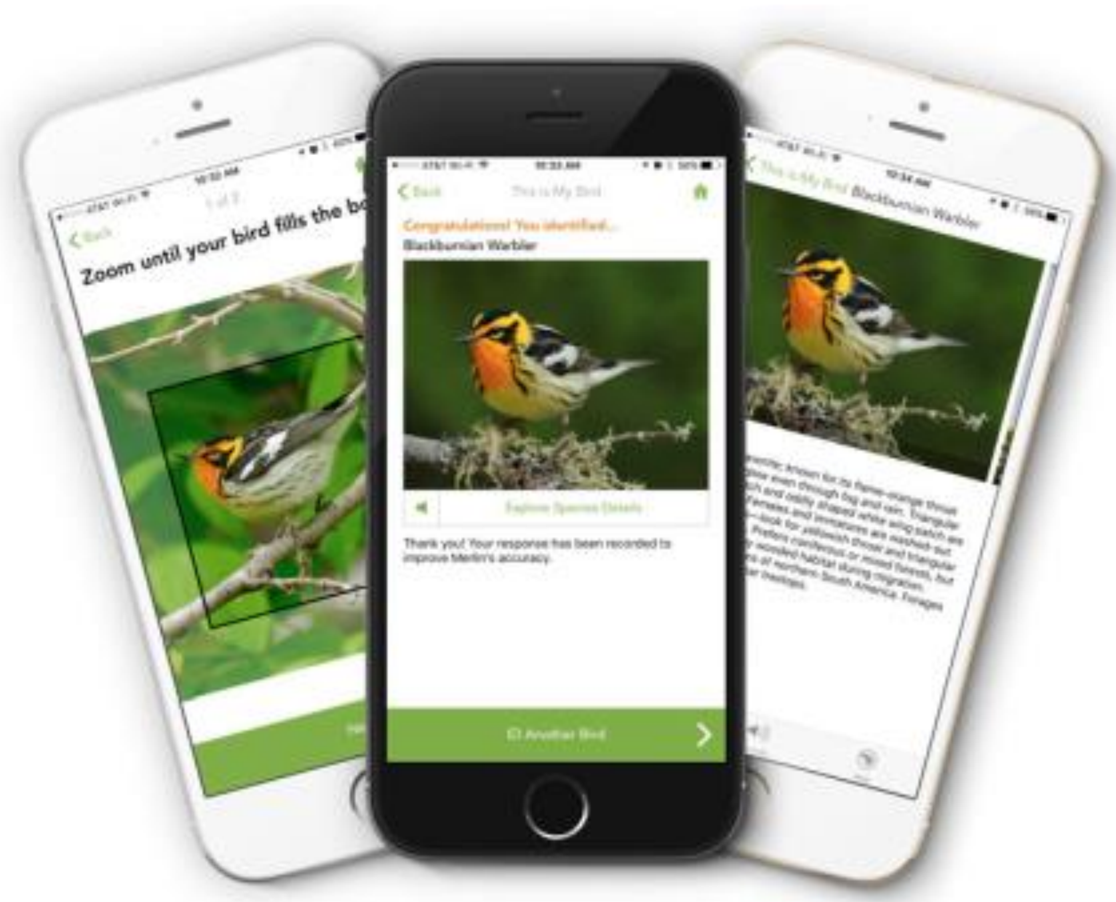
Login without a password



Fingerprint scanners on
many new smartphones
and other devices

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

Bird Identification



Merlin Bird ID (based on Cornell Tech technology!)

Special effects: camera tracking

Boujou, 2d3

Special effects: shape capture

The Matrix movies, ESC Entertainment, XYZRGB, NRC

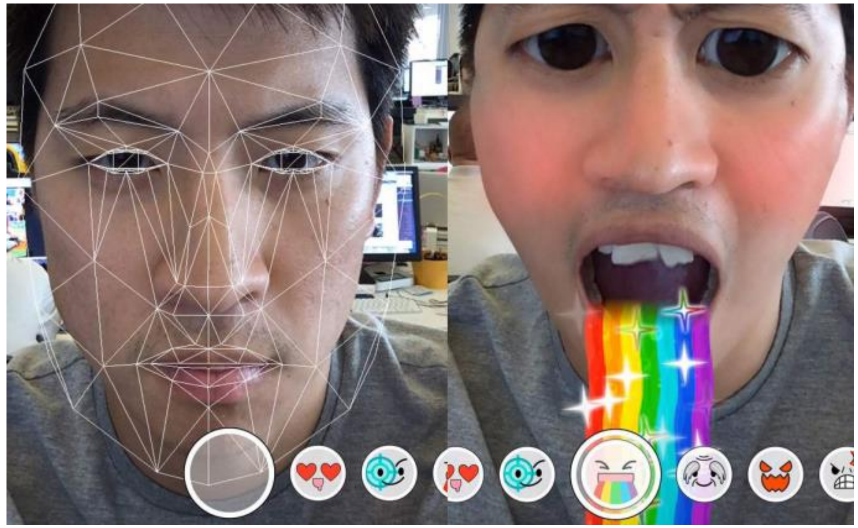
Source: S. Seitz

Special effects: motion capture

Pirates of the Carribean, Industrial Light and Magic

Source: S. Seitz

3D face tracking w/ consumer cameras



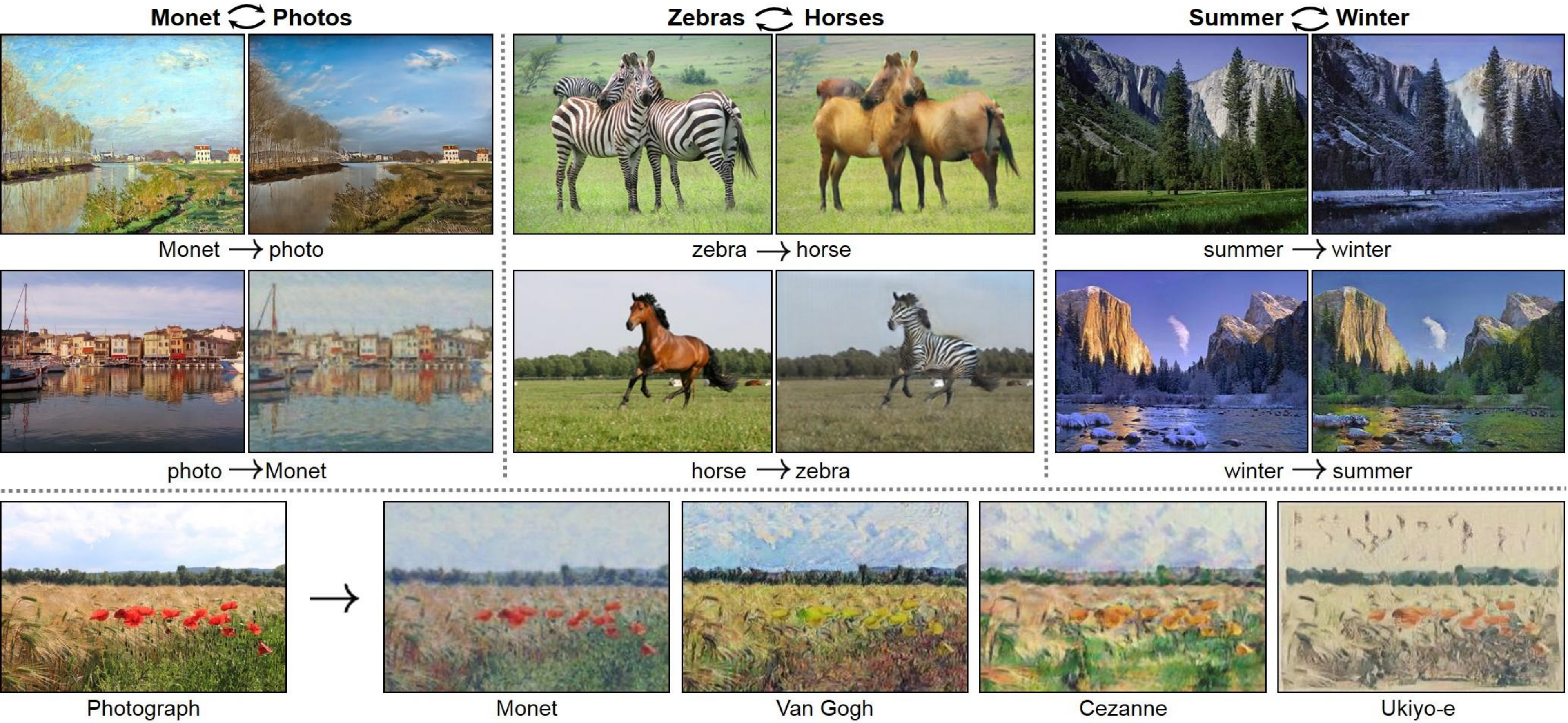
Snapchat Lenses

Face2Face system (Thies et al.)

Image synthesis

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

Image synthesis



Zhu, et al., *Unpaired Image-to-Image Translation using Cycle-Consistent Adversarial Networks*, ICCV 2017

Sports

Sportvision first down line
Nice [explanation]() on www.howstuffworks.com

Source: S. Seitz

Smart cars

- [Mobileye]
- Tesla Autopilot
- Safety features in many high-end cars

Self-driving cars

Google Waymo

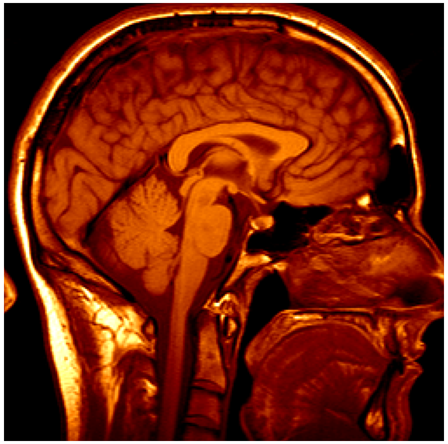
Robotics

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

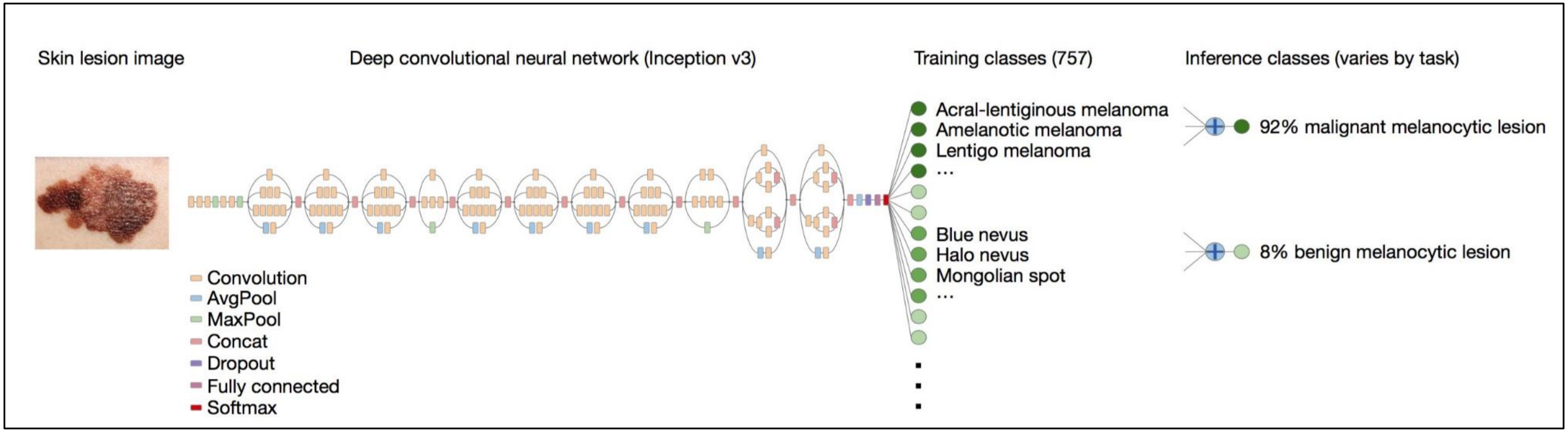
Amazon Picking Challenge
http://www.robocup2016.org/en/events/amazon-picking-challenge/

Amazon Prime Air

Medical imaging



3D imaging
(MRI, CT)



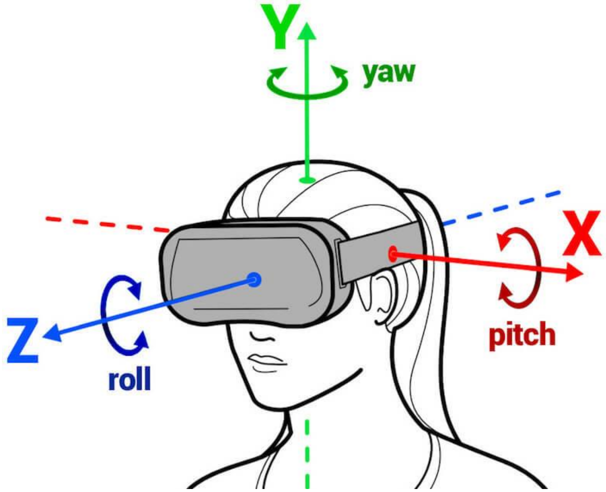
Skin cancer classification with deep learning
https://cs.stanford.edu/people/esteva/nature/

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

My own work

- Automatic 3D reconstruction from Internet photo collections

"Statue of Liberty" "Half Dome, Yosemite" "Colosseum, Rome"

Flickr photos

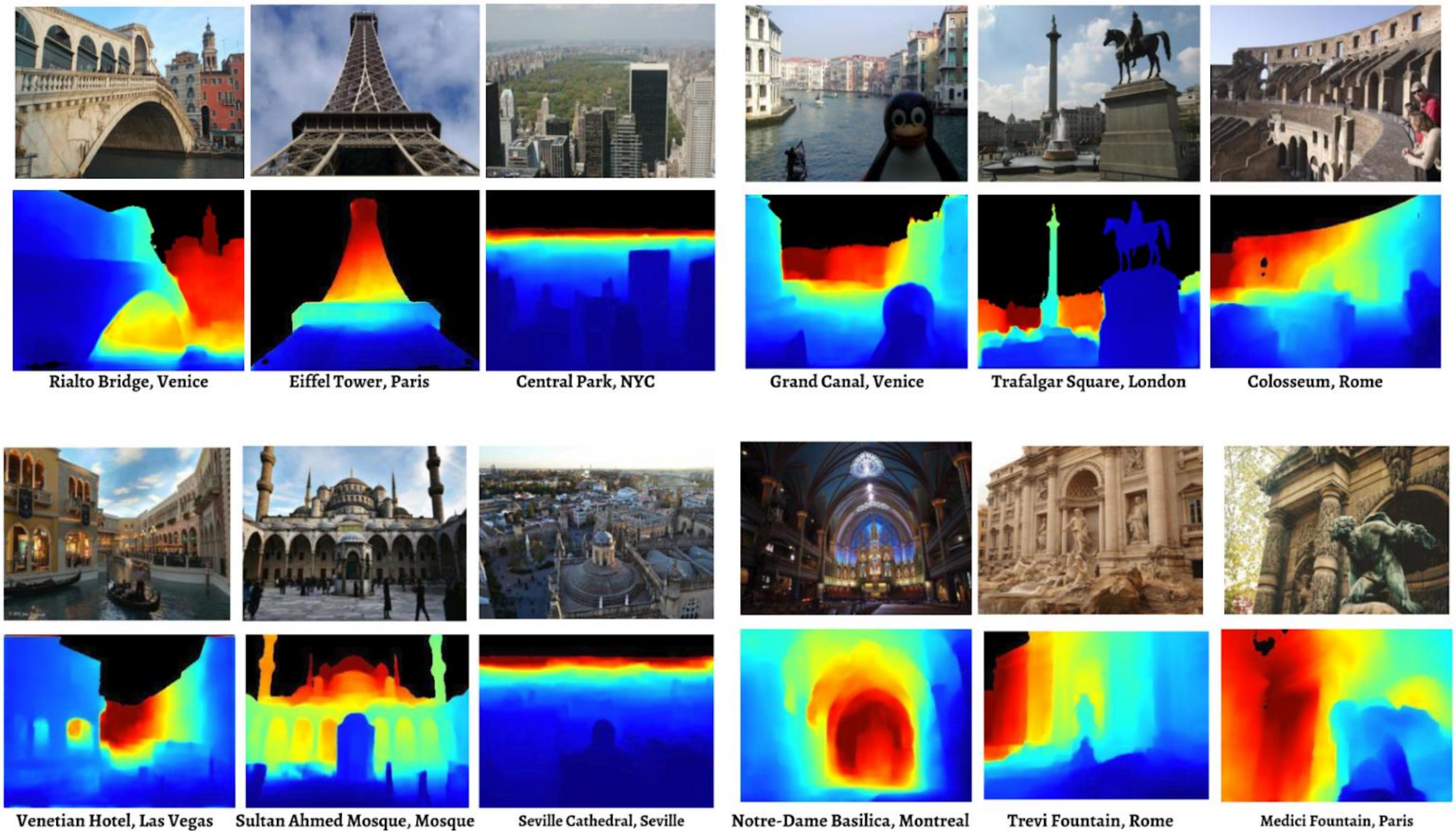
3D model

Photosynth

City-scale reconstruction

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

Depth from a single image



Current state of the art

- You just saw many examples of current systems.
  - Many of these are less than 5 years old
- This is a very 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?

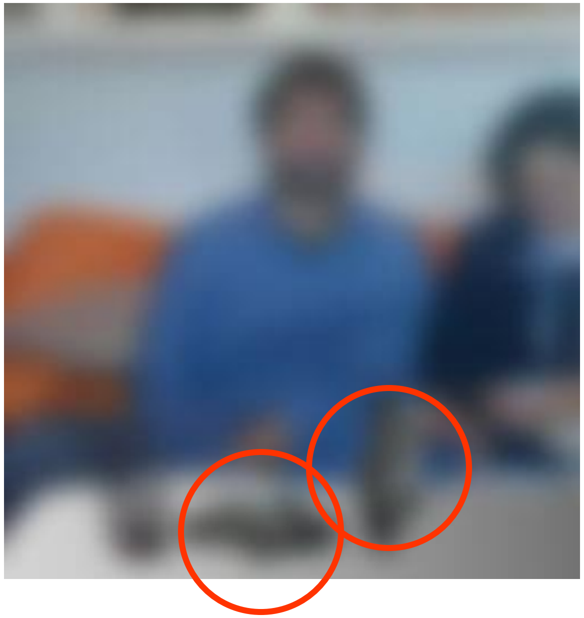
Intra-class variation

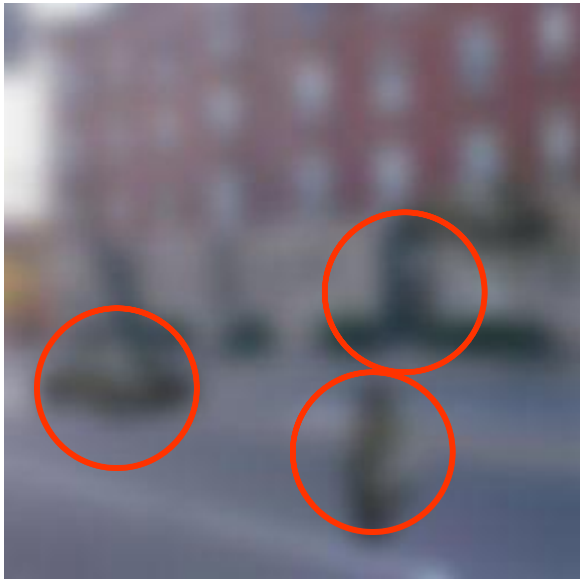
Motion (Source: S. Lazebnik)

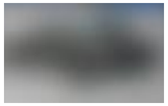
Background clutter

Occlusion

Challenges: local ambiguity







slide credit: Fei-Fei, Fergus & Torralba

But there are lots of cues we can exploit…

Source: S. Lazebnik

Bottom line

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

  - We often need to use prior knowledge about the structure of the world

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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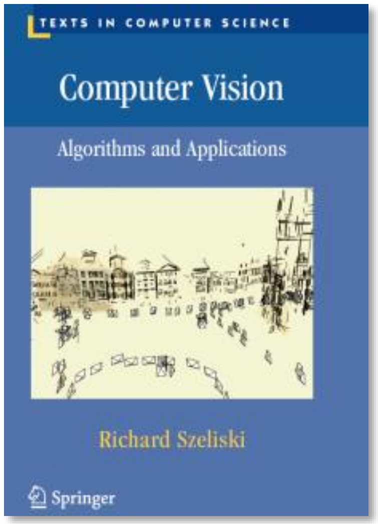
CS5670: Introduction to Computer Vision

Important notes



- Textbook:

  Rick Szeliski, *Computer Vision: Algorithms and Applications*

  online at: http://szeliski.org/Book/

- Course webpage:

  http://www.cs.cornell.edu/courses/cs5670/2018sp/

- Announcements/grades via Piazza/CMS

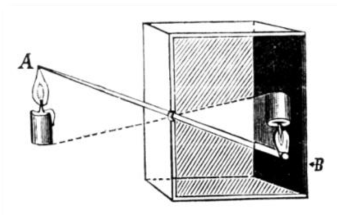
  https://piazza.com/cornell/spring2018/cs5670

  https://cmsx.cs.cornell.edu

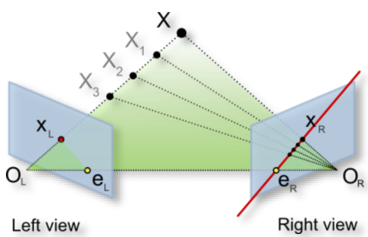
Course requirements

- Prerequisites—*these are essential*!
  - Data structures
  - A good working knowledge of Python programming
  - Linear algebra
  - Vector calculus
- Course does ***not*** assume prior imaging experience
  - computer vision, image processing, graphics, etc.

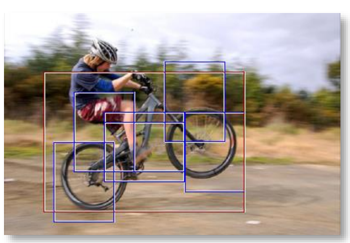
Course overview (tentative)



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



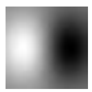
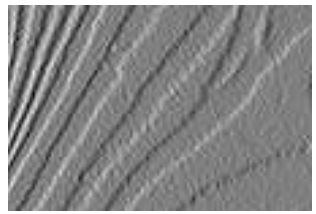
2. Geometry and algorithms
   – projective geometry, stereo, structure from motion, optimization



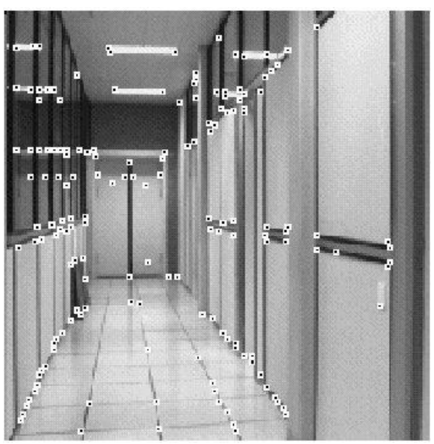
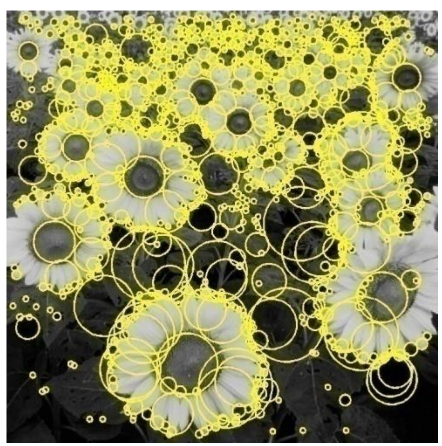
3. Recognition
   – face detection / recognition, category recognition, segmentation

1. Low-level vision

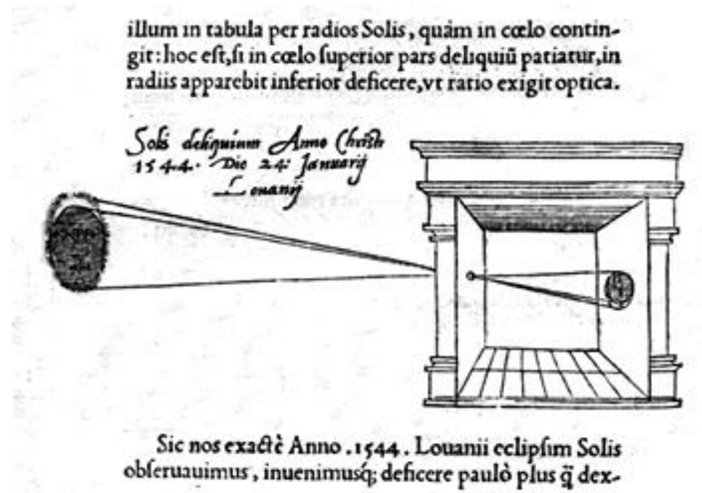
- Basic image processing and image formation

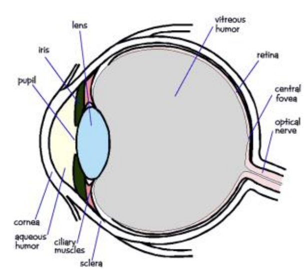




Filtering, edge detection

Feature extraction





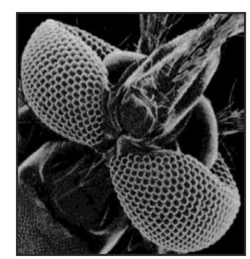
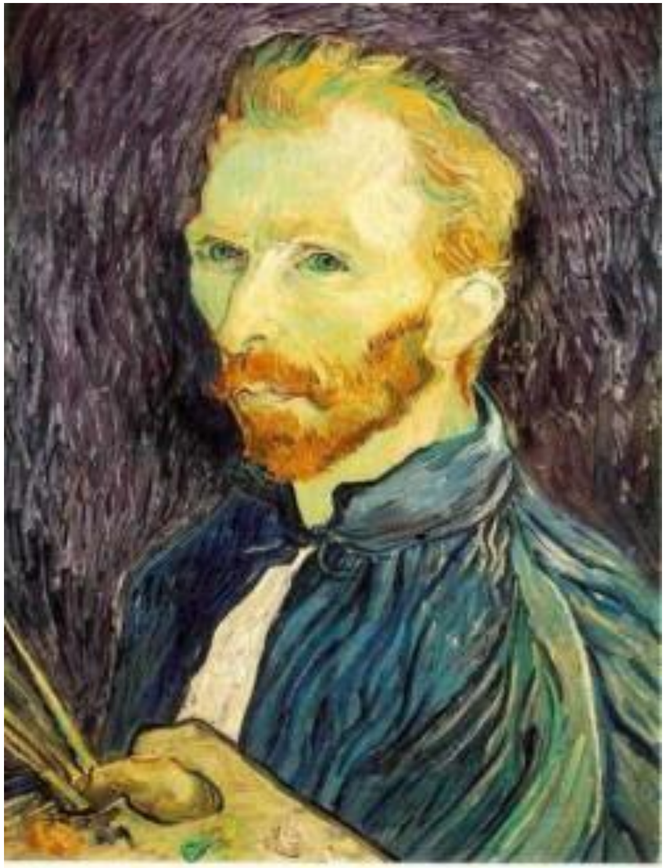


Image formation

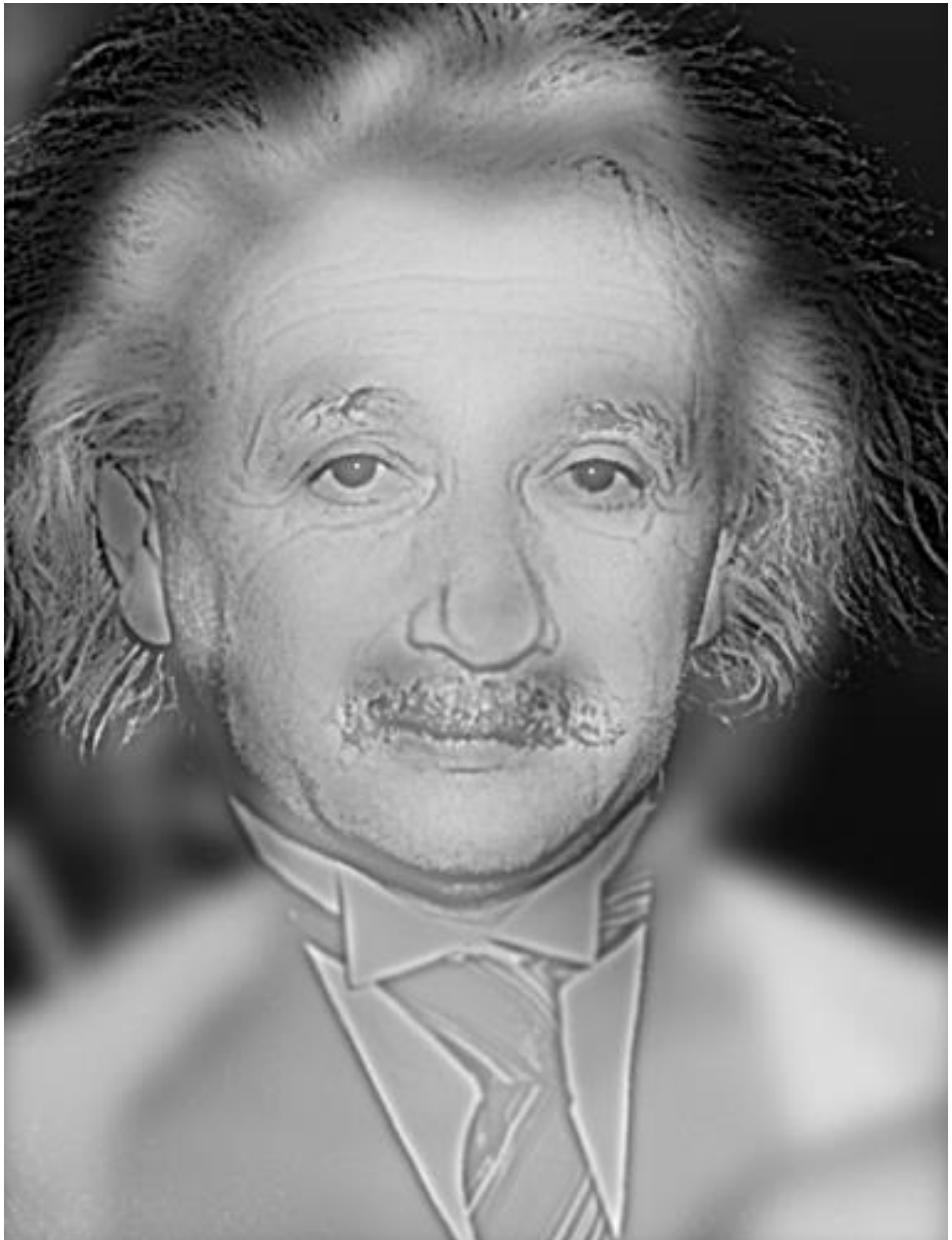
Project: Hybrid images from image pyramids



Gaussian 1/2

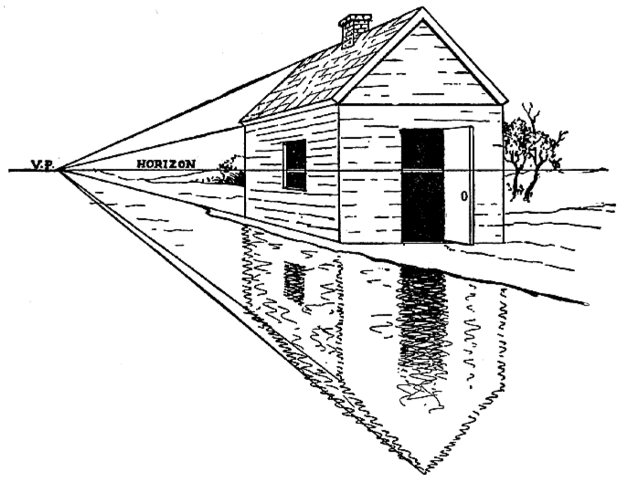
G 1/4

G 1/8

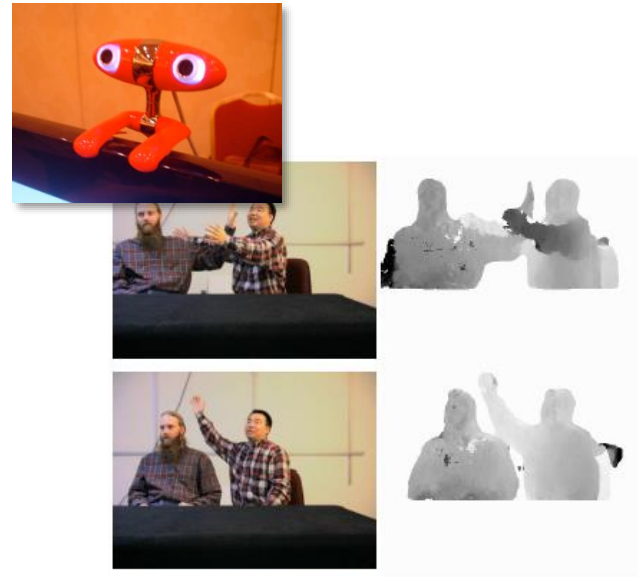


Project: Feature detection and matching

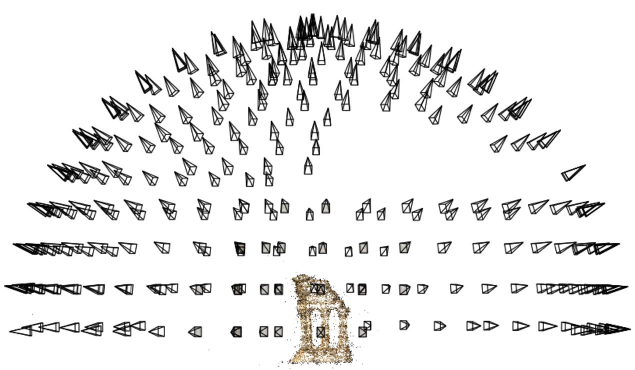
2. Geometry



Projective geometry



Stereo

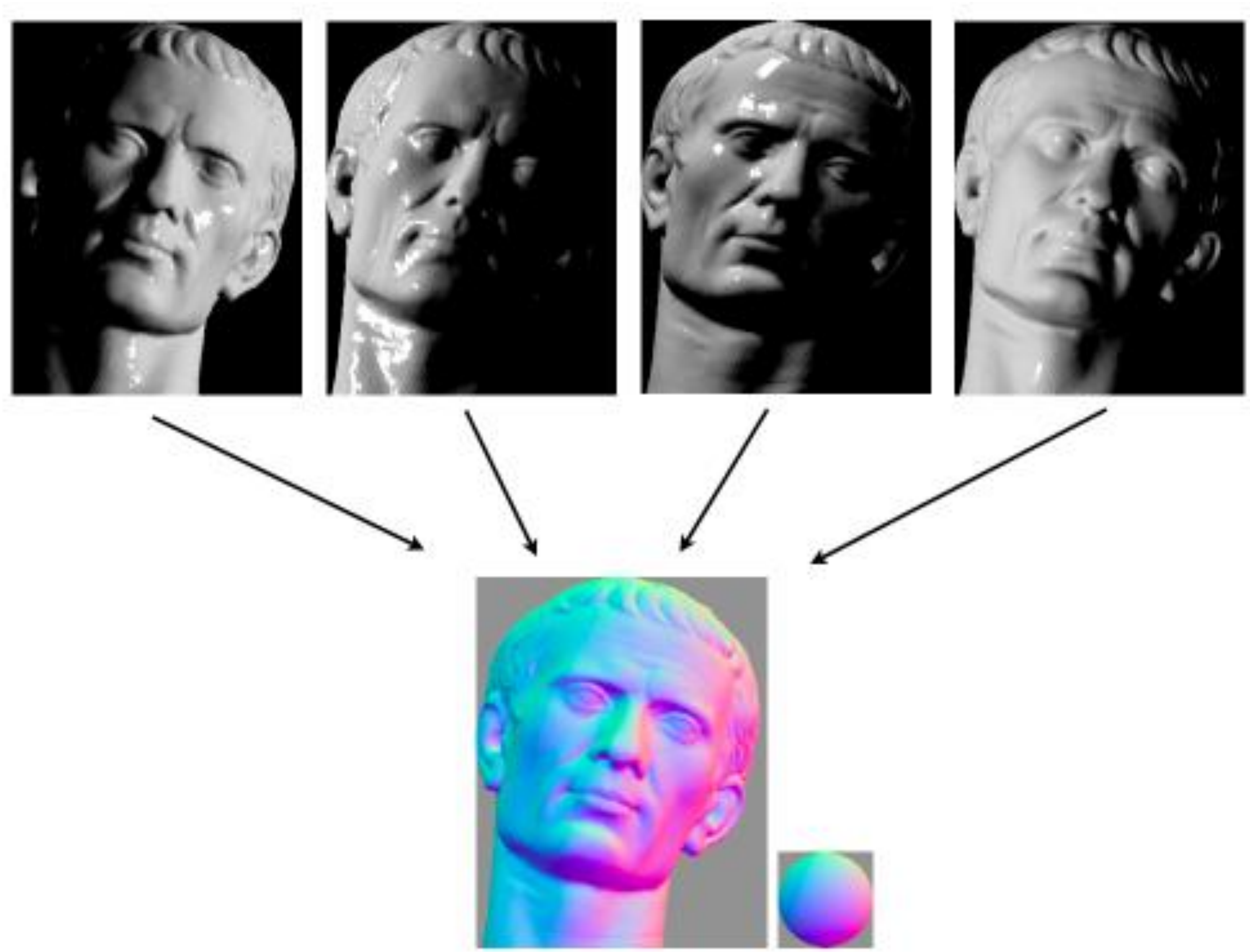


Multi-view stereo

Structure from motion

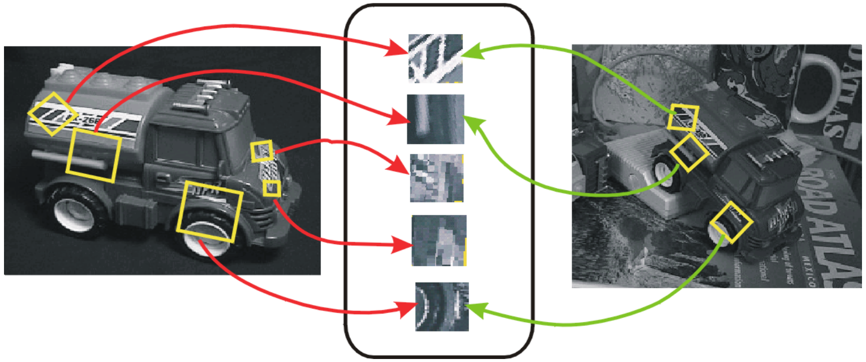
Project: Creating panoramas

Project: Photometric Stereo



3. Recognition

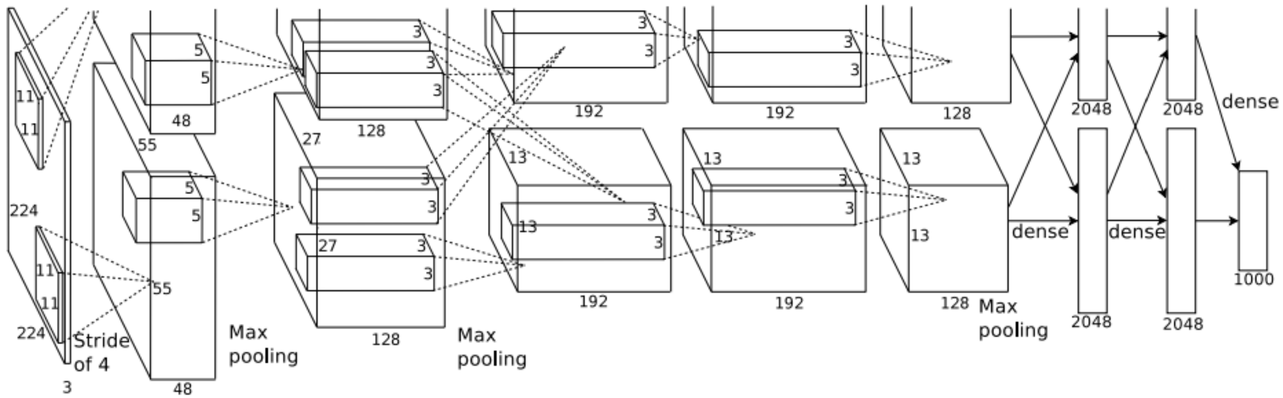
Face detection and recognition

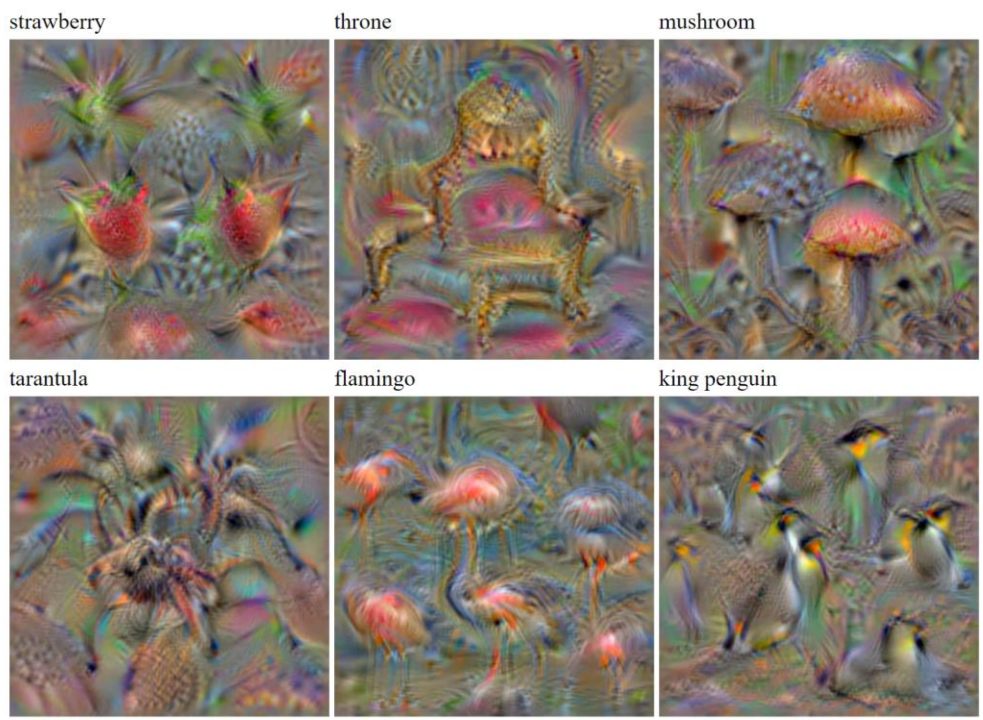


Single instance recognition

Category recognition

Project: Convolutional Neural Networks





Grading

- Occasional quizzes (at the beginning of class)
- One prelim, one final exam

- Grade breakdown (subject to minor tweaks):
  - Quizzes: 5%
  - Midterm: 15-18%
  - Programming projects: 60-65%
  - Final exam: 15-18%

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?