CS543 / ECE549
Computer Vision
Spring 2020

Course webpage URL: https://s-gupta.github.io/ece549/

The goal of computer vision

- To extract “meaning” from pixels

What we see

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

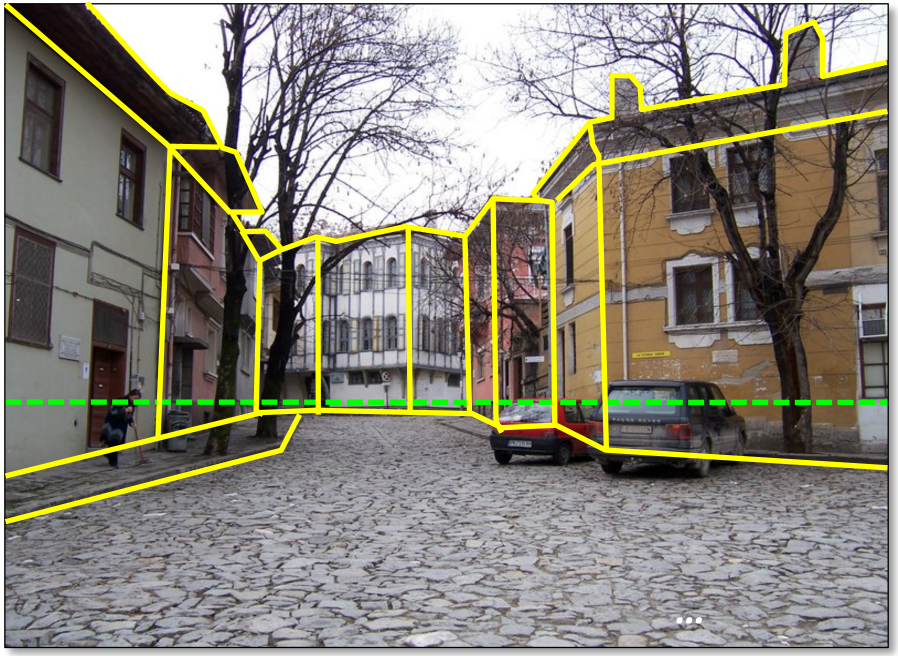
What a computer sees

Source: S. Narasimhan

What kind of information can be extracted from an image?

Source: L. Lazebnik

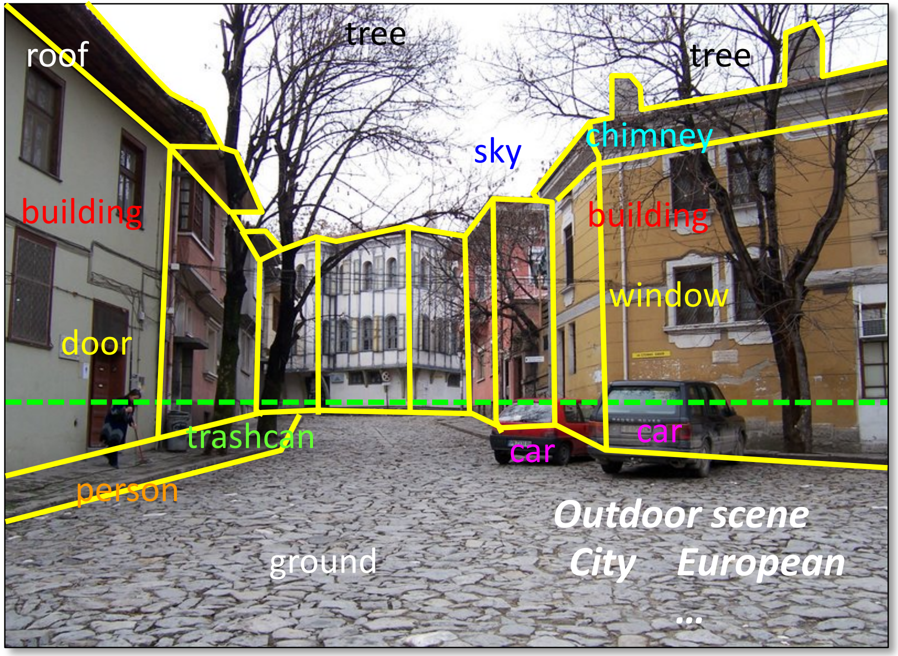
What kind of information can be extracted from an image?



Geometric information

Source: L. Lazebnik

What kind of information can be extracted from an image?

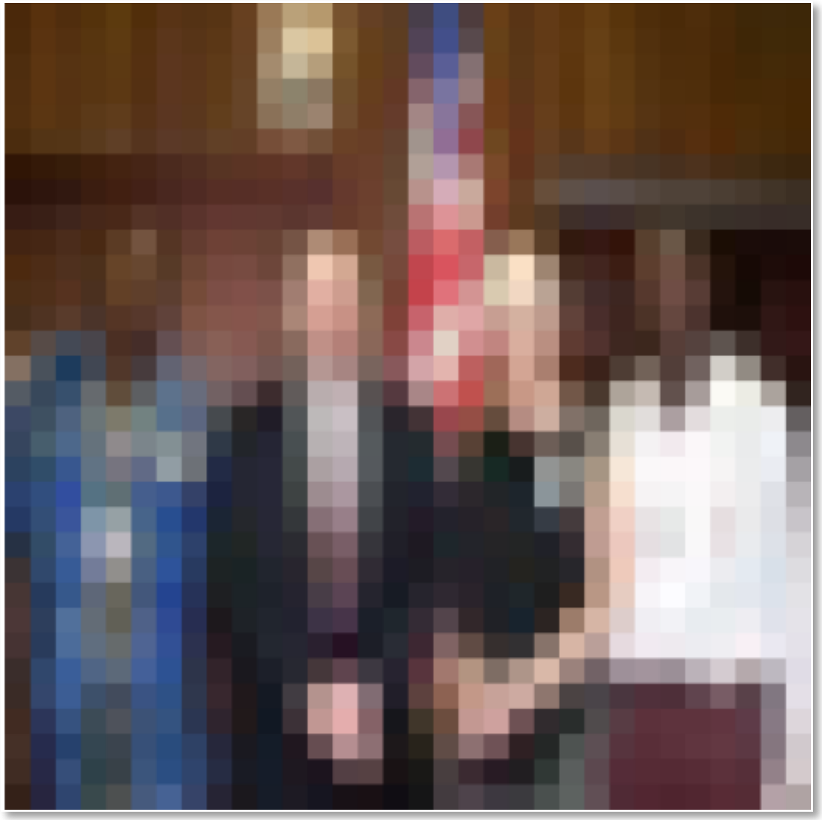


Geometric information

Semantic information

Source: L. Lazebnik

Vision is easy for humans



Source: L. Lazebnik

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

Vision is easy for humans

Attneave's Cat

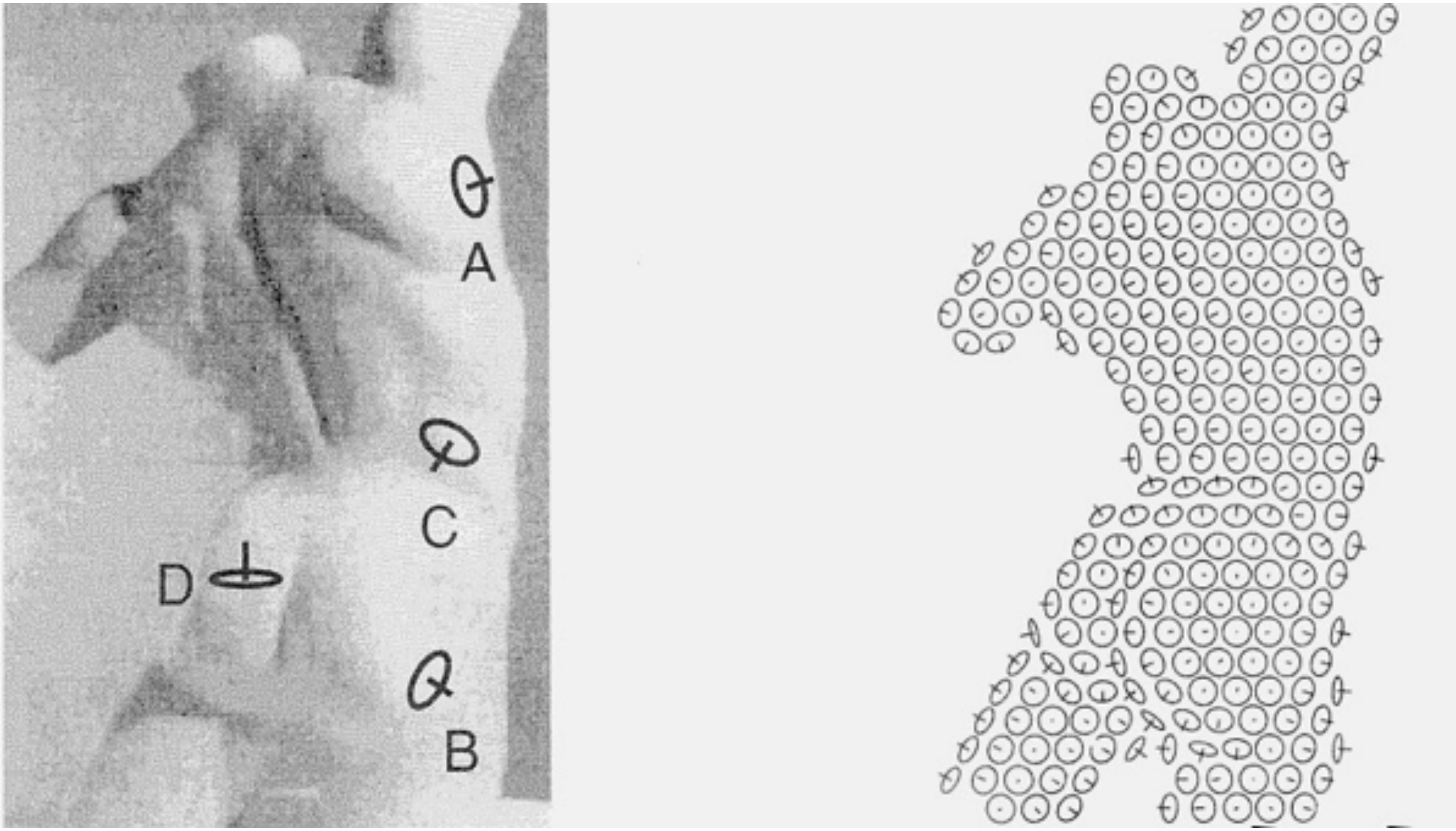
Source: B. Hariharan

Vision is easy for humans

Mooney Faces

Source: B. Hariharan

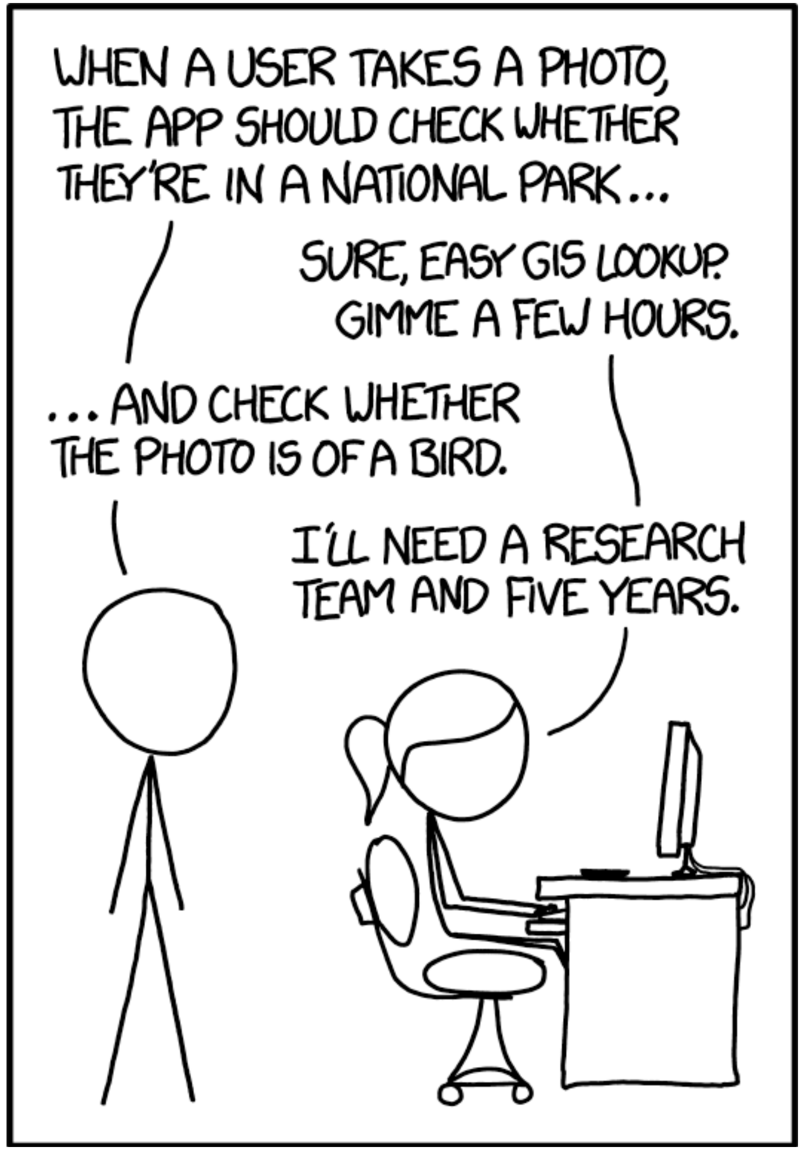
Vision is easy for humans



Surface perception in pictures. Koenderink, van Doorn and Kappers, 1992

Source: J. Malik

Remarkably Hard for Computers



Source: XKCD

Vision is hard: Images are ambiguous

Source: B. Hariharan

Vision is hard: Objects Blend Together

Source: B. Hariharan

Vision is hard: Objects Blend Together

Source: B. Hariharan

Vision is hard: Intra-class Variation

Viewpoint variation

Illumination

Scale

Source: B. Hariharan

Vision is hard: Intra-class Variation

Shape variation

Occlusion

Background clutter

Source: B. Hariharan

Vision is hard: Intra-class Variation

Source: B. Hariharan

Vision is hard: Concepts are subtle

Tenessee Warbler

Orange Crowned Warbler

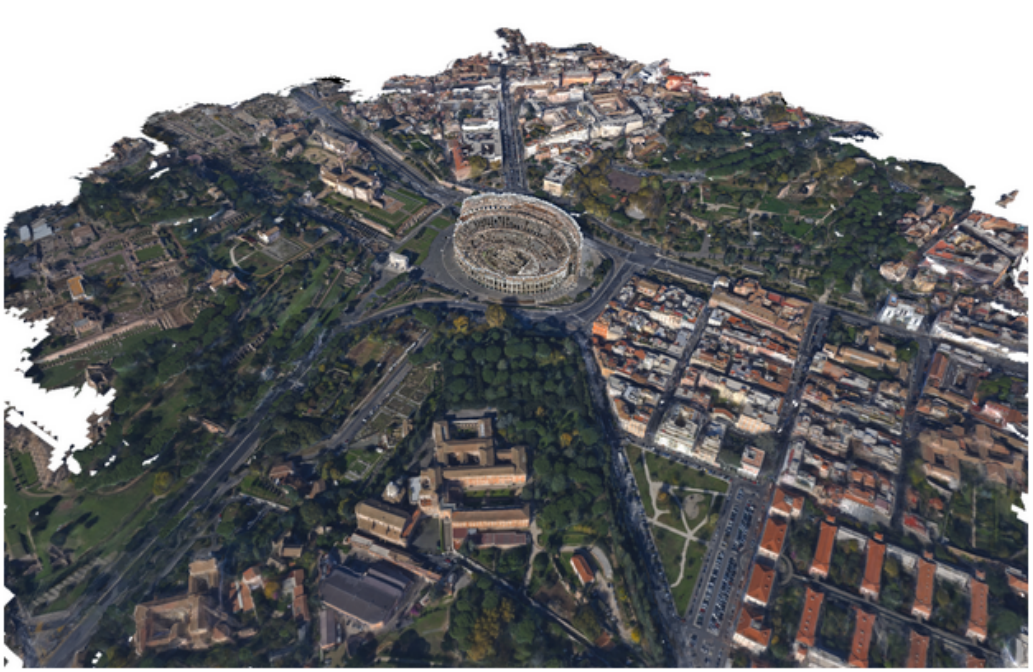
Source: B. Hariharan

https://www.allaboutbirds.org

What can computer vision do today?

Reconstruction: 3D from photo collections

Colosseum, Rome, Italy



San Marco Square, Venice, Italy

Q. Shan, R. Adams, B. Curless, Y. Furukawa, and S. Seitz, The Visual Turing Test for Scene Reconstruction, 3DV 2013

YouTube Video

Source: L. Lazebnik

Reconstruction: 4D from photo collections

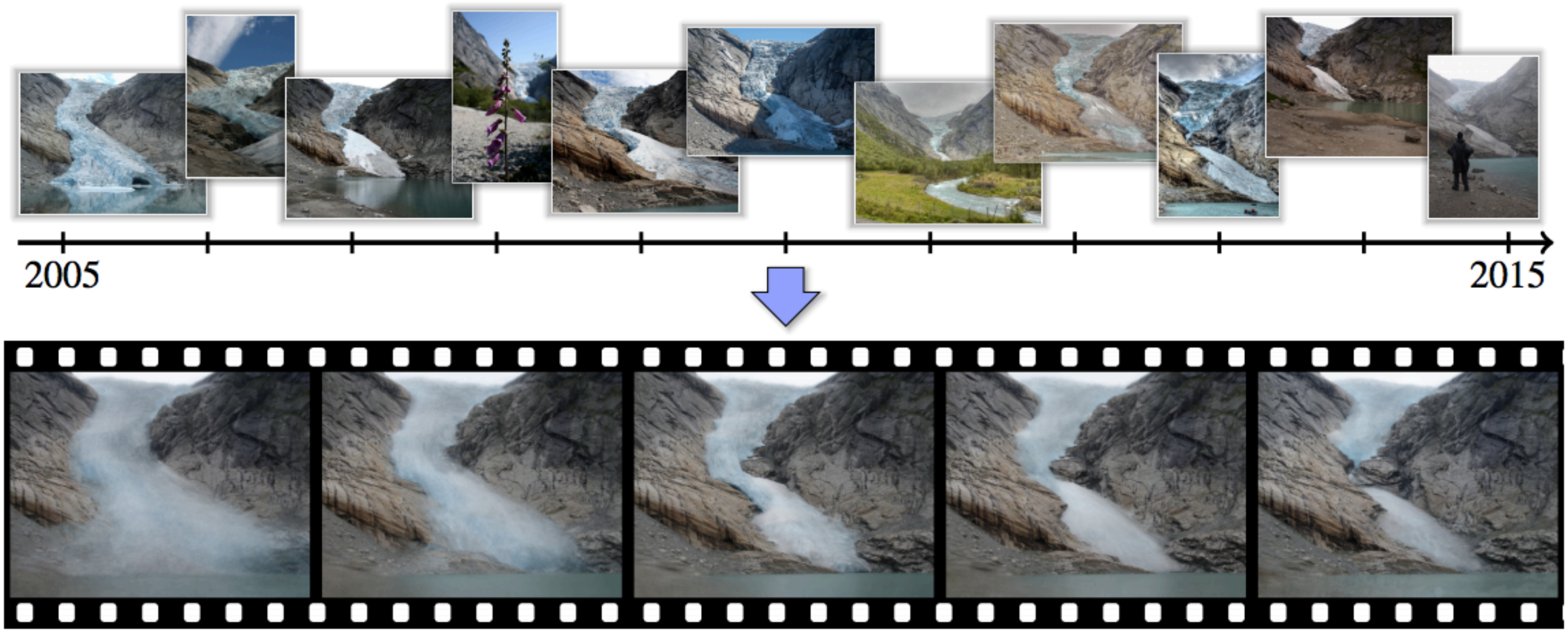


Figure 1: *We mine Internet photo collections to generate time-lapse videos of locations all over the world. Our time-lapses visualize a multitude of changes, like the retreat of the Briksdalsbreen Glacier in Norway shown above. The continuous time-lapse (bottom) is computed from hundreds of Internet photos (samples on top).* Photo credits: Aliento Más Allá, jirihnidek, mcxurxo, elka_cz, Juan Jesús Orío, Klaus Wißkirchen, Daikrieg, Free the image, dration and Nadav Tobias.

R. Martin-Brualla, D. Gallup, and S. Seitz, [Time-Lapse Mining from Internet Photos](), SIGGRAPH 2015

[YouTube Video]()

Source: L. Lazebnik

Reconstruction: 4D from depth cameras

Figure 1: Real-time reconstructions of a moving scene with DynamicFusion; both the person and the camera are moving. The initially noisy and incomplete model is progressively denoised and completed over time (left to right).

R. Newcombe, D. Fox, and S. Seitz, [DynamicFusion: Reconstruction and Tracking of Non-rigid Scenes in Real-Time], CVPR 2015

[YouTube Video]

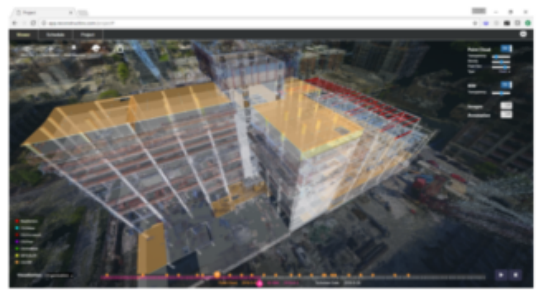
Source: L. Lazebnik

Reconstruction in construction industry

RECONSTRUCT INTEGRATES REALITY AND PLAN

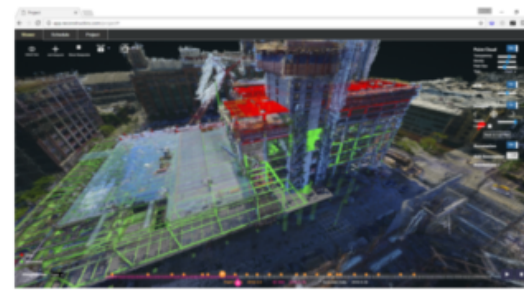
Visual Asset Management

Reconstruct 4D point clouds and organize images and videos from smartphones, time-lapse cameras, and drones around the project schedule. View, annotate, and share anywhere with a web interface.



4D Visual Production Models

Integrate 4D point clouds with 4D BIM, review "who does what work at what location" on a daily basis and improve coordination and communication among project teams.



Predictive Visual Data Analytics

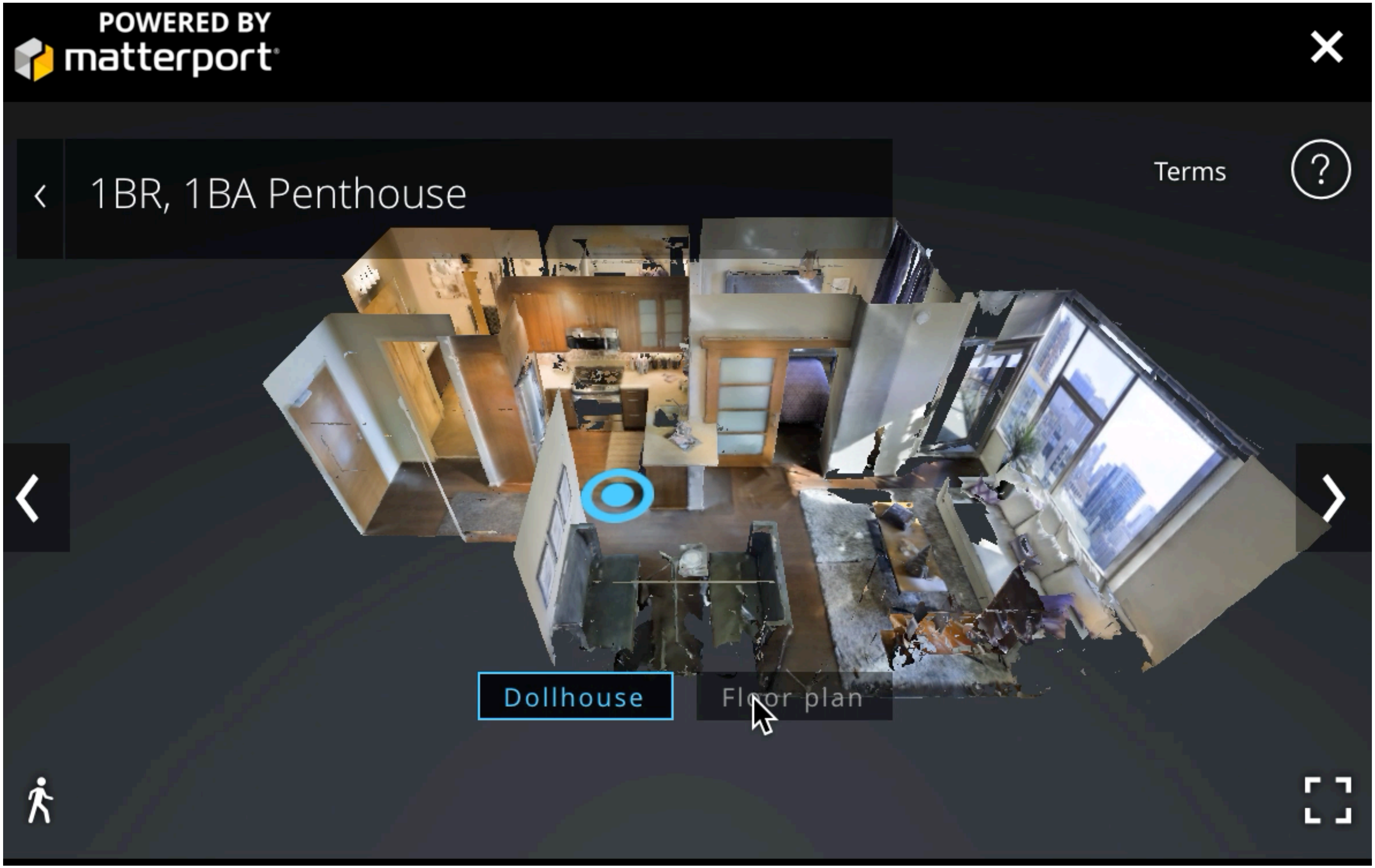
Analyze actual progress deviations by comparing Reality and Plan and predict risk with respect to the execution of the look-ahead schedule for each project location, to offer your project team with an opportunity to tap off potential delays before they surface on your jobsite.

reconstructinc.com

Source: L. Lazebnik

Source: D. Hoiem

Applications

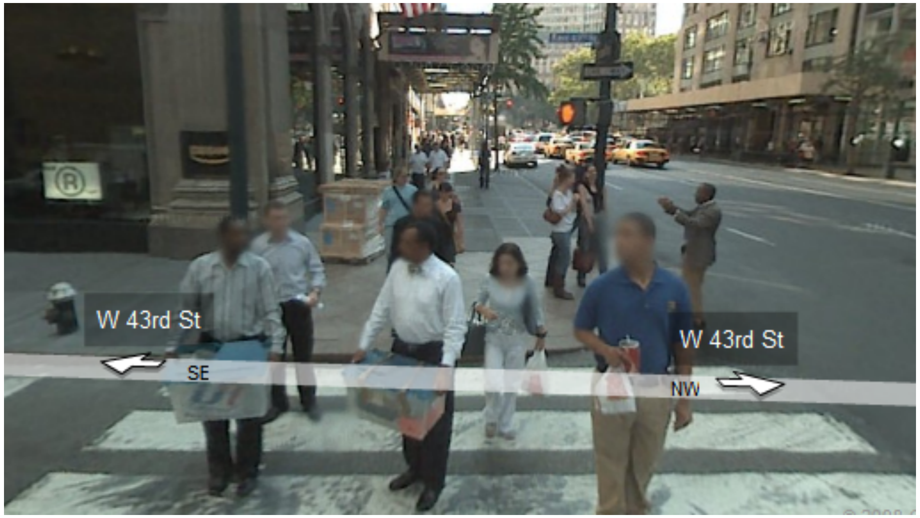


Source: N. Snavely

Recognition: “Simple” patterns

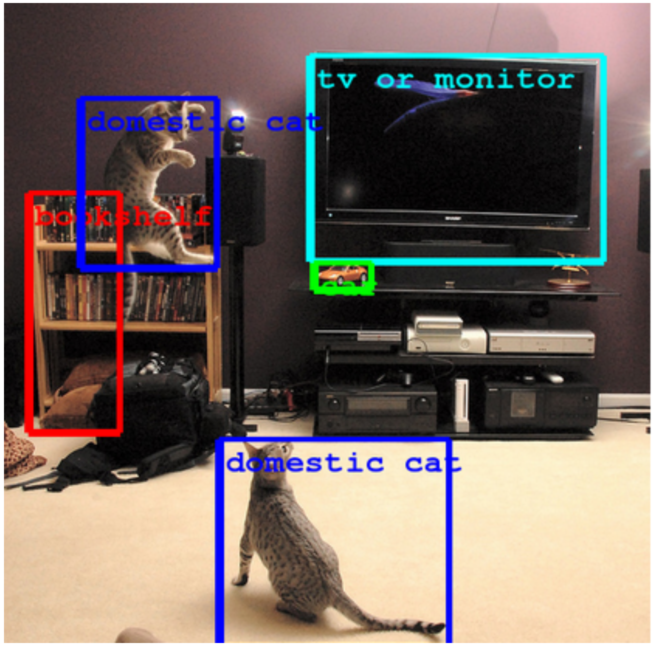
Source: L. Lazebnik

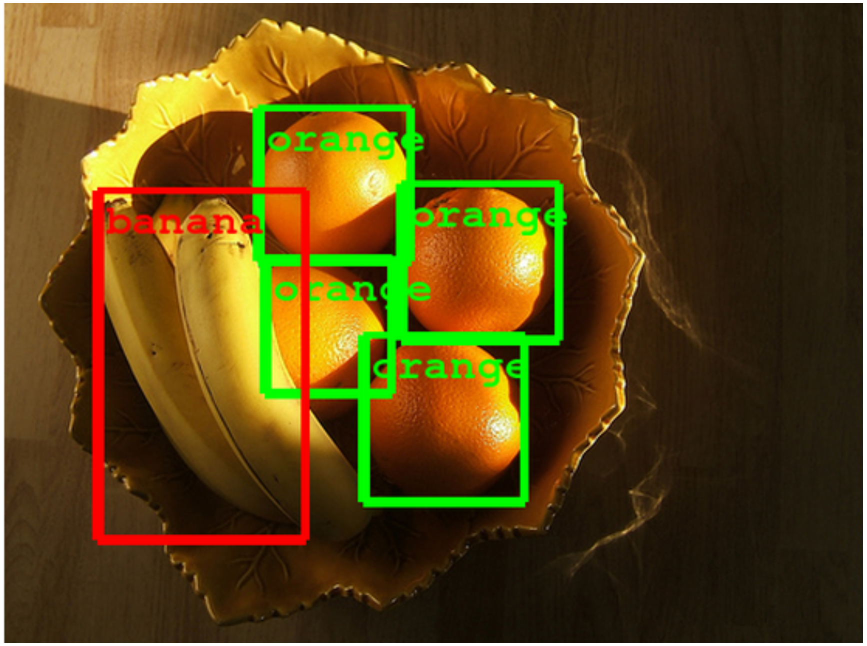
Recognition: Faces

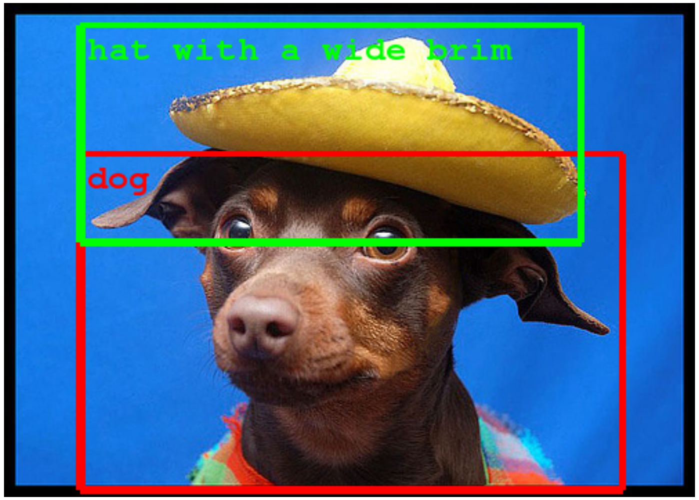


Source: L. Lazebnik

Recognition: General categories





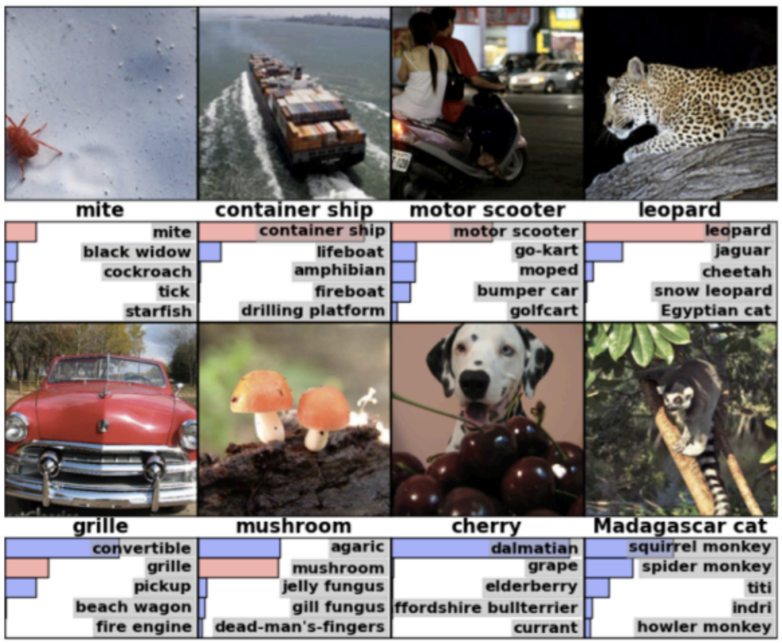


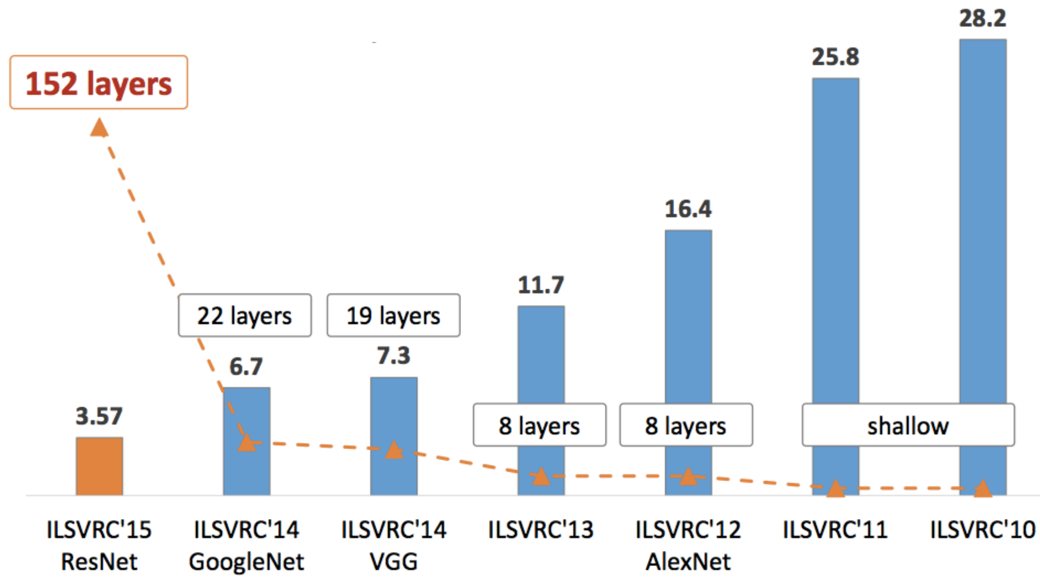
- Computer Eyesight Gets a Lot More Accurate, NY Times Bits blog, August 18, 2014
- Building A Deeper Understanding of Images, Google Research Blog, September 5, 2014

Source: L. Lazebnik

Recognition: General categories

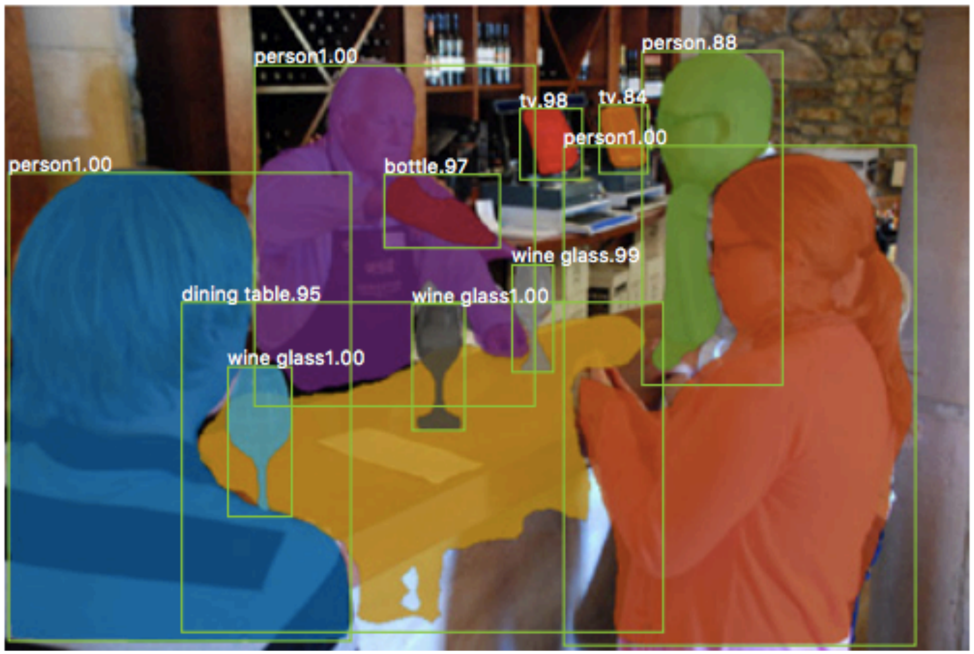
- ImageNet challenge

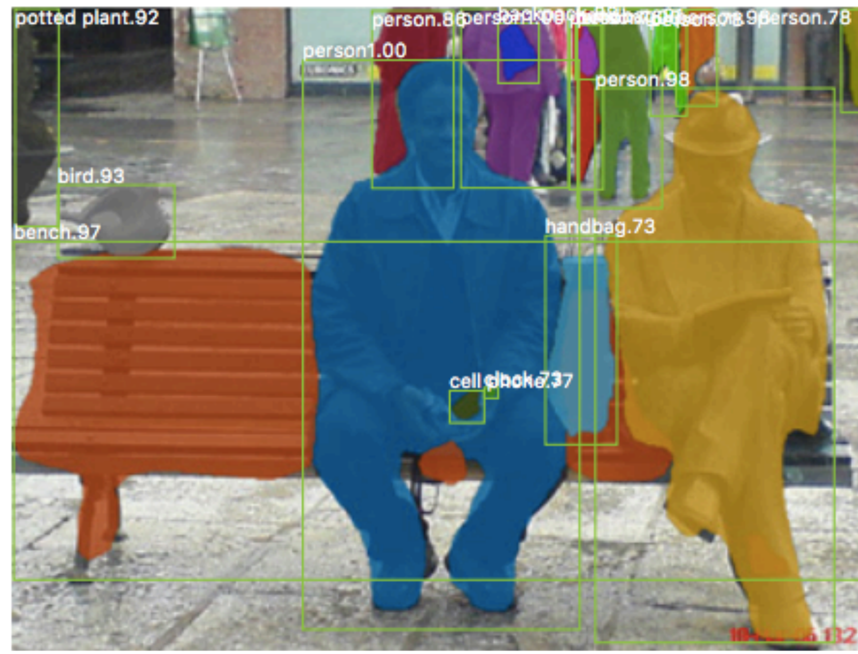




Source: L. Lazebnik

Object detection, instance segmentation





K. He, G. Gkioxari, P. Dollar, and R. Girshick, [Mask R-CNN](),
ICCV 2017 (Best Paper Award)

Source: L. Lazebnik

Image generation

- Faces: 1024x1024 resolution, CelebA-HQ dataset

T. Karras, T. Aila, S. Laine, and J. Lehtinen, Progressive Growing of GANs for Improved Quality, Stability, and Variation, ICLR 2018

Follow-up work

Source: L. Lazebnik

Image generation

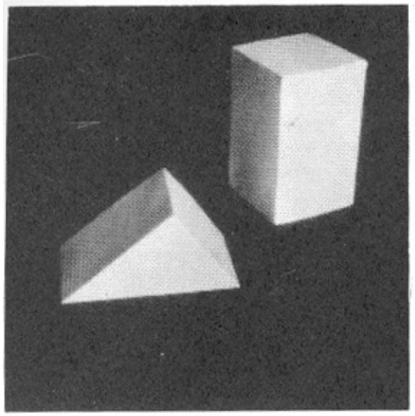
- BigGAN: 512 x 512 resolution, ImageNet

Easy classes Difficult classes

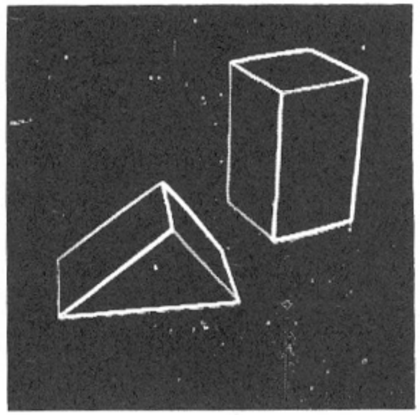
A. Brock, J. Donahue, K. Simonyan, Large scale GAN training for high fidelity natural image synthesis, arXiv 2018

Source: L. Lazebnik

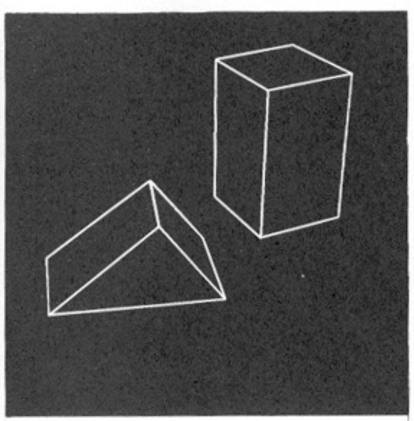
Origins of computer vision



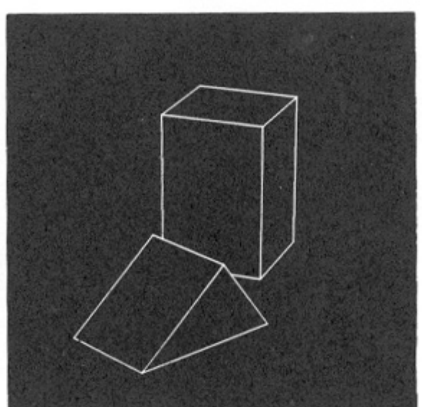
(a) Original picture.



(b) Differentiated picture.



(c) Line drawing.



(d) Rotated view.

L. G. Roberts *Machine Perception of Three Dimensional Solids*

Source: L. Lazebnik

Origins of computer vision

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PROJECT MAC

Artificial Intelligence Group July 7, 1966
Vision Memo. No. 100.

THE SUMMER VISION PROJECT

Seymour Papert

The summer vision project is an attempt to use our summer workers effectively in the construction of a significant part of a visual system. The particular task was chosen partly because it can be segmented into sub-problems which will allow individuals to work independently and yet participate in the construction of a system complex enough to be a real landmark in the development of "pattern recognition".

Source: L. Lazebnik

Six decades of computer vision

1960s: Beginnings in artificial intelligence, image processing and pattern recognition

1970s: Foundational work on image formation: Horn, Koenderink, Longuet-Higgins …

1980s: Vision as applied mathematics: geometry, multi-scale analysis, probabilistic modeling, control theory, optimization

1990s: Geometric analysis largely completed, vision meets graphics, statistical learning approaches resurface

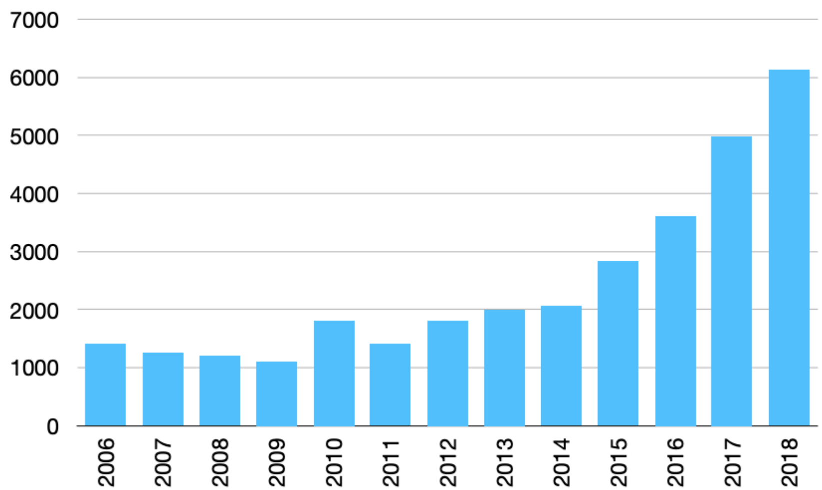
2000s: Significant advances in visual recognition

2010s: Progress continues, aided by the availability of large amounts of visual data and massive computing power. Deep learning has become pre-eminent

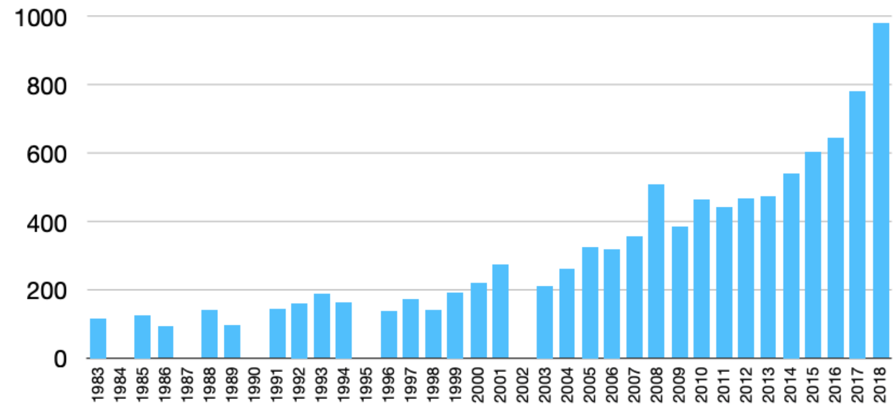
Source: J. Malik

Growth of the field

CVPR Attendance



CVPR Papers



Source

Long list of corporate sponsors

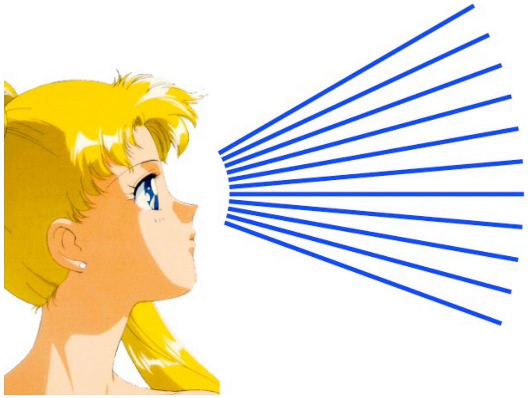
Source: L. Lazebnik

Course overview

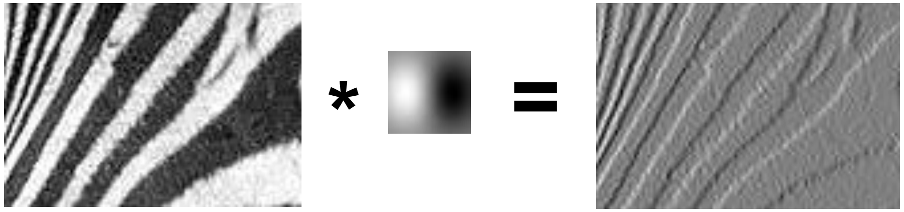
I. Early vision: Image formation and processing
II. Mid-level vision: Grouping and fitting
III. Multi-view geometry
IV. Recognition
V. Additional topics

I. Early vision

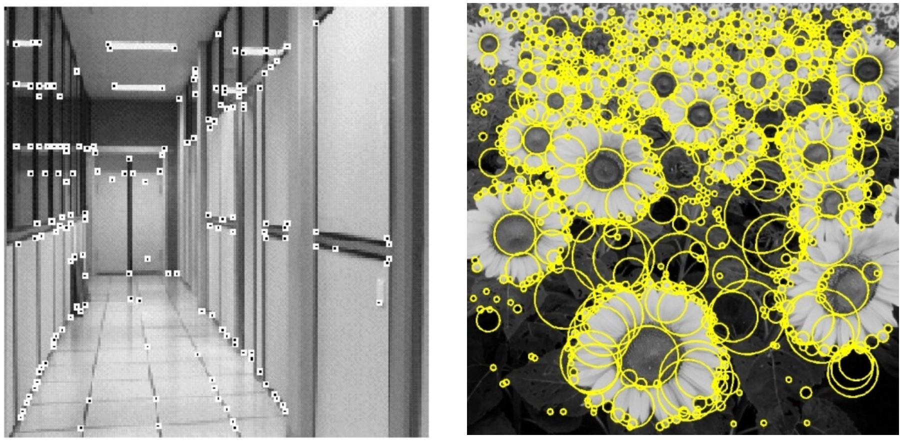
Basic image formation and processing



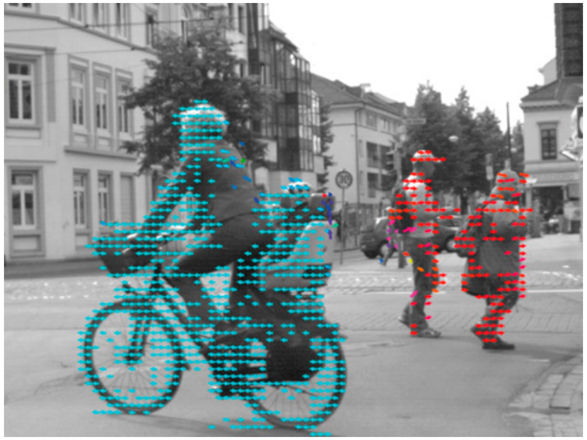
Cameras and sensors
Light and color



Linear filtering
Edge detection



Feature extraction

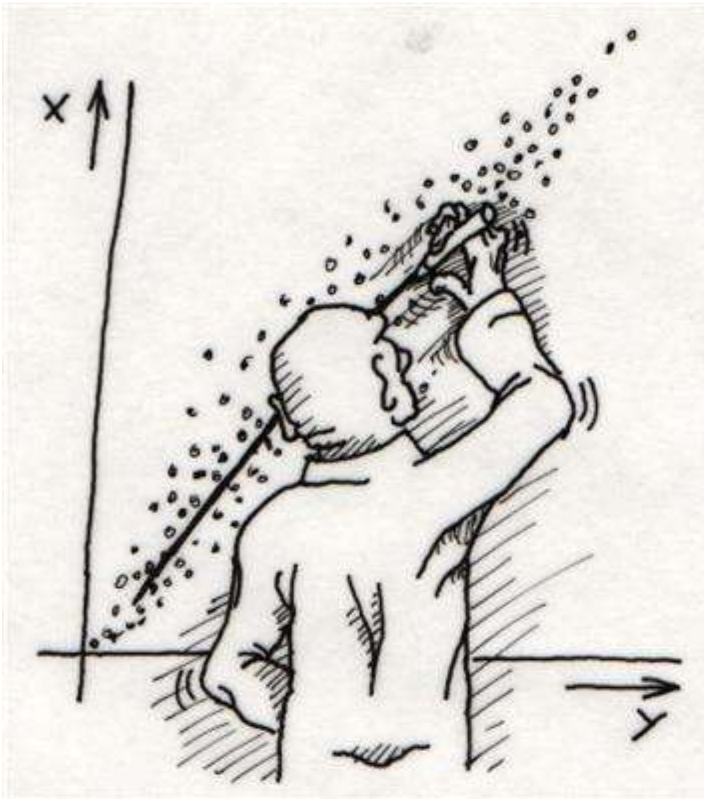


Optical flow

Source: L. Lazebnik

II. “Mid-level vision”

Fitting and grouping

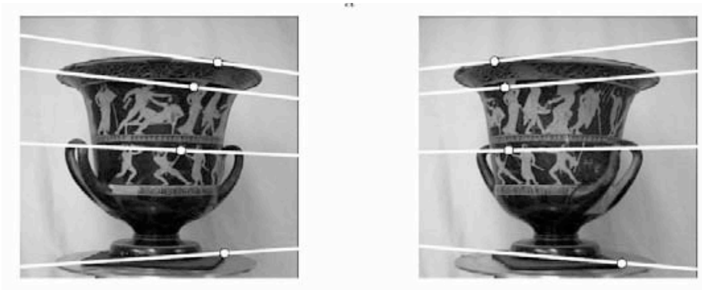


Fitting: Least squares
Voting methods

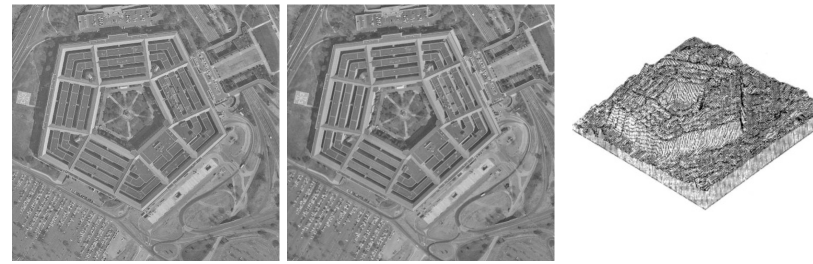
Alignment

Source: L. Lazebnik

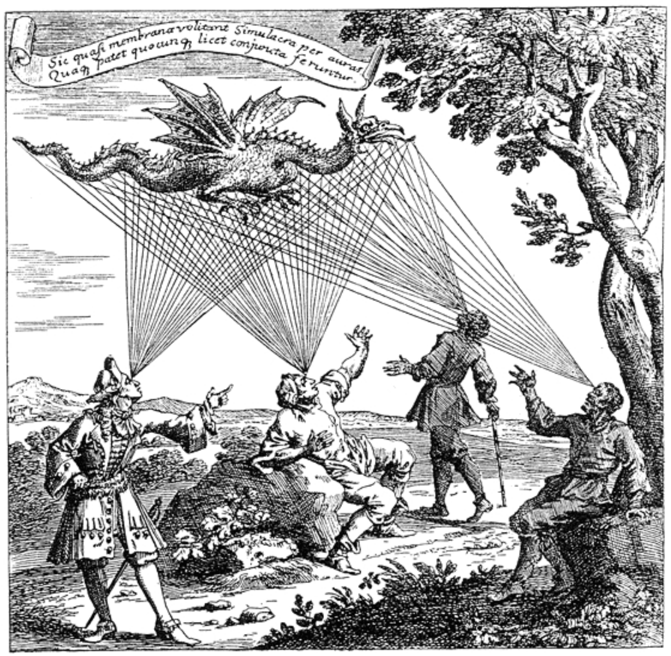
III. Multi-view geometry



Epipolar geometry

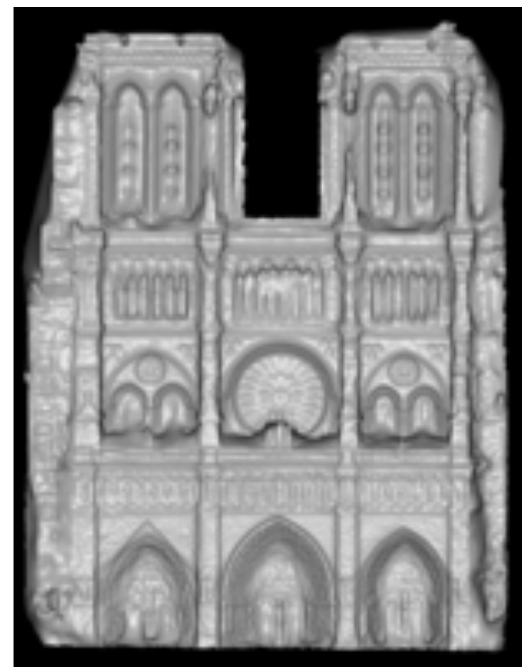


Two-view stereo



Драконъ, видимый подъ различными углами зрѣнія
По гравюрѣ на мѣди изъ „Oculus artificialis teledioptricus" Цана. 1702 года.

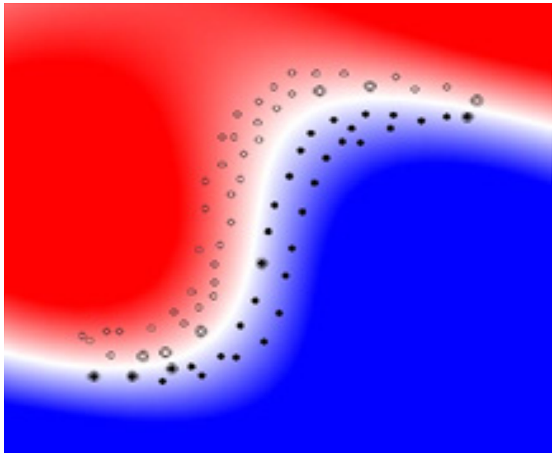
Structure from motion



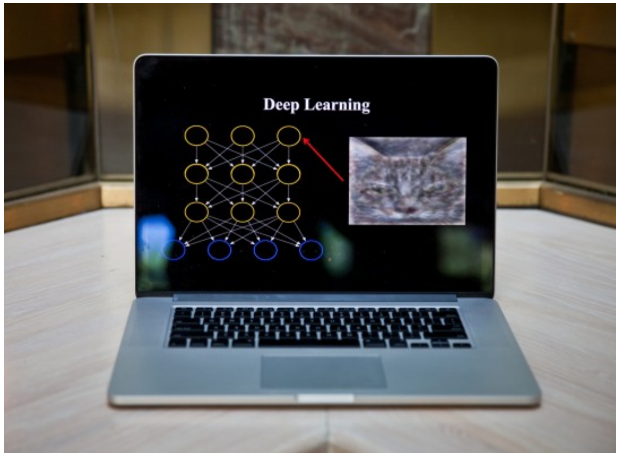
Multi-view stereo

Source: L. Lazebnik

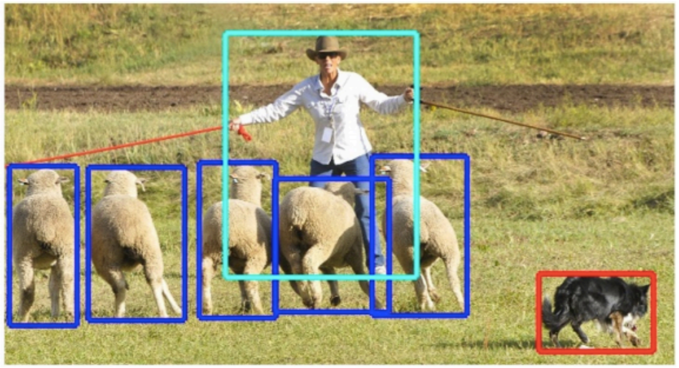
IV. Recognition



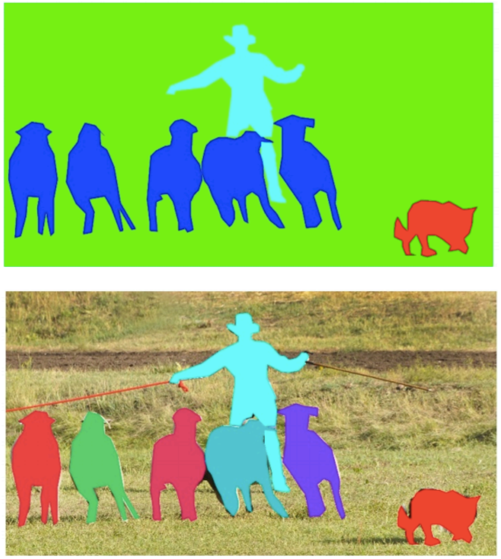
Basic classification



Deep learning



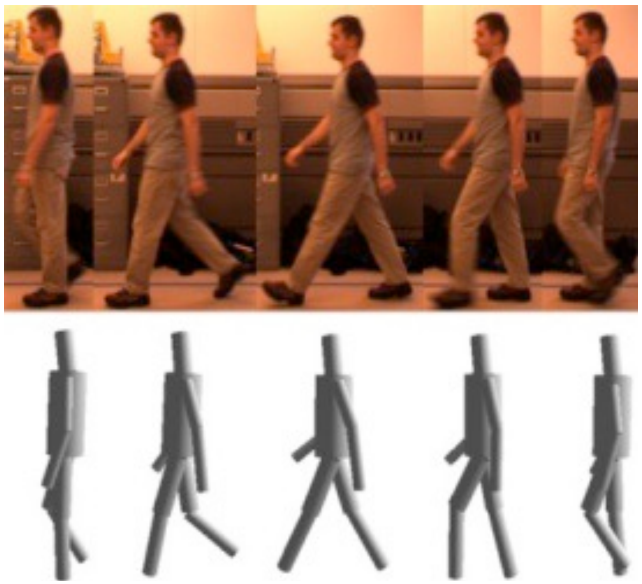
Object detection



Segmentation

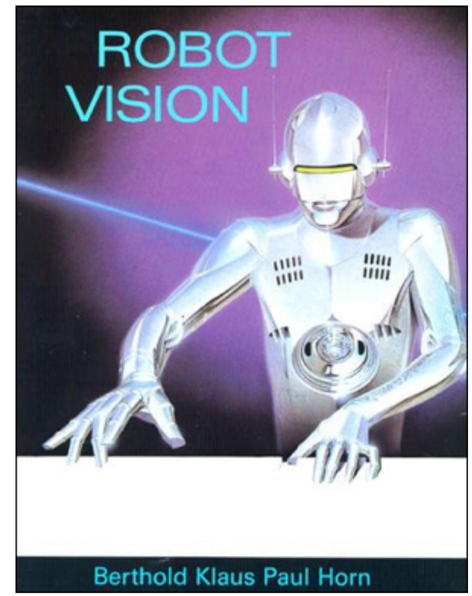
Source: L. Lazebnik

V. Additional Topics (time permitting)



Video

3D Scene Understanding



Vision and Robotics

Source: L. Lazebnik