Computer Vision

AI3604

Instructor

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AI Institute, Shanghai Jiao Tong University

Welcome to AI3604 Computer Vision

- Course organization
- What is computer vision?
- Course overview

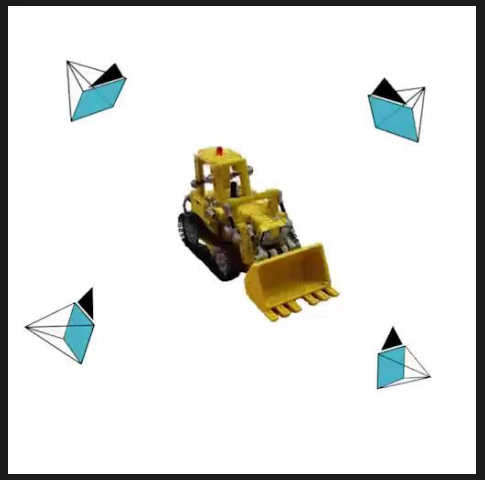
A Bit About My Research

We are interested in pioneering research at the intersection of …

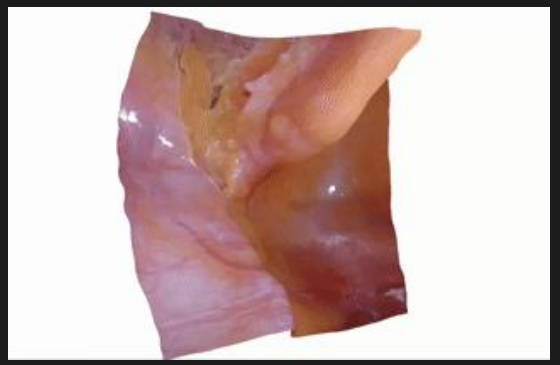
- Computer Vision,
- Machine Learning,
- Medical Imaging Analysis,

Image Segmentation

3D Reconstruction



Medical Imaging



Check out my homepage: https://shenwei1231.github.io/

Class organization

Course information (1)

- Introductory course
  - Audience: undergraduate
- Required background
  - Programming fundamentals, in particular data structures and Python experience desirable
  - Linear algebra
  - Basic probability
  - Calculus

Learning Objectives

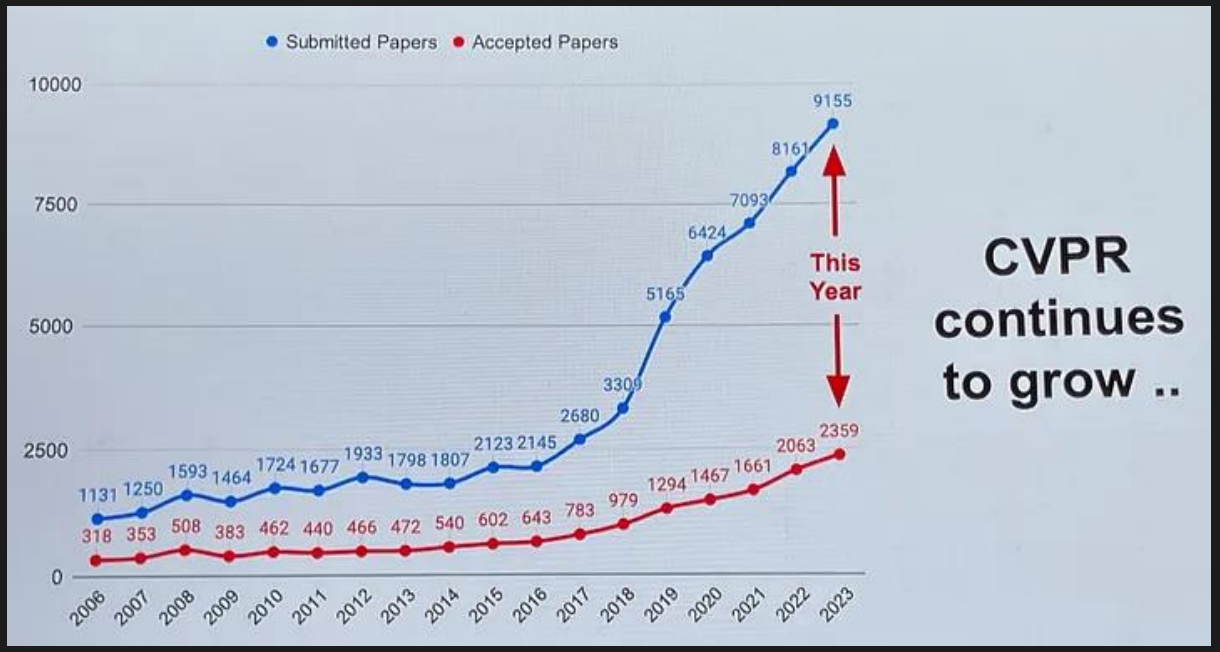
- Understand the techniques and algorithms of computer vision
- Know how to use them to address vision problems
- Fearlessly design, build, your vision methods,…
  … and reason about pitfalls and design choices
- Gain intuition,…

… but realize you will not become an expert in one course

Learning Objectives

- This is an introductory course to computer vision
- While we will try to cover everything important…
- … it is impossible to cover everything!

→Set you up for further research/work in this area

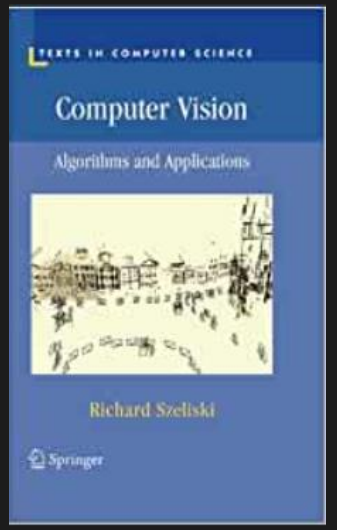


Course information (2)

- Organization
  - Two assignments, Final Project, Final Exam
- Office hours:
  - Friday afternoon or make an appointment
- Course updates:
  - Announcements/material/assignments : CANVAS

Course information (3)

- Grading
  - 10% Quiz + Q&A in class
  - 20% Homework
  - 35% Course Project + Presentation
  - 35% Final Exam



- References:
  - Optional: R. Szeliski, Computer Vision, Springer (2011).
  - Optional: Forsyth and Ponce, Computer Vision: A Modern Approach, Prentice Hall (2002).
  - Optional: Hartley and Zisserman, Multiple View Geometry in Computer Vision, Cambridge University Press (2010).

Homework

- Homework comes in two flavors
  - Written assignments
  - Programming assignments

- Late assignment submissions:
  - You have 3 late days (smallest quantity: “ 1 day ”, largest quantity: 3 days
  - You need to request late submission before the deadline!

Final Project

- Teamwork of 4 students
- I will give a topic

Deliverables for each team:

- Give a presentation
- Submit a structured (brief!) final report

More details about the project will be provided on a final project description

Final Exam

- Take it easy
- But remember to flip classroom documents after class.

Programming resources

- Python tools (see TA for help)
  - Numpy
  - Pytorch
  - Matplotlib

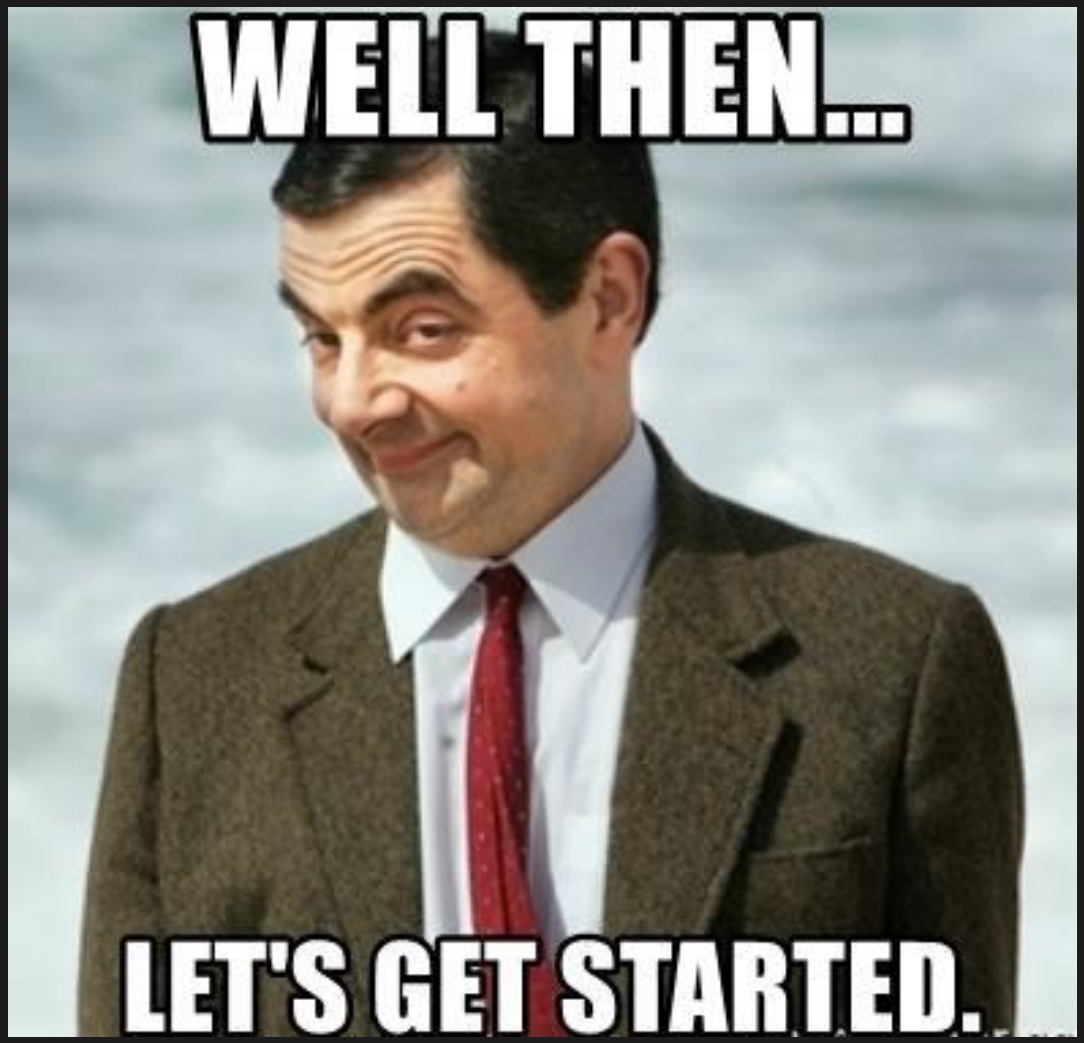
  Google Colaboratory

  https://colab.research.google.com/notebooks/welcome.ipynb#recent=true

  Kaggle

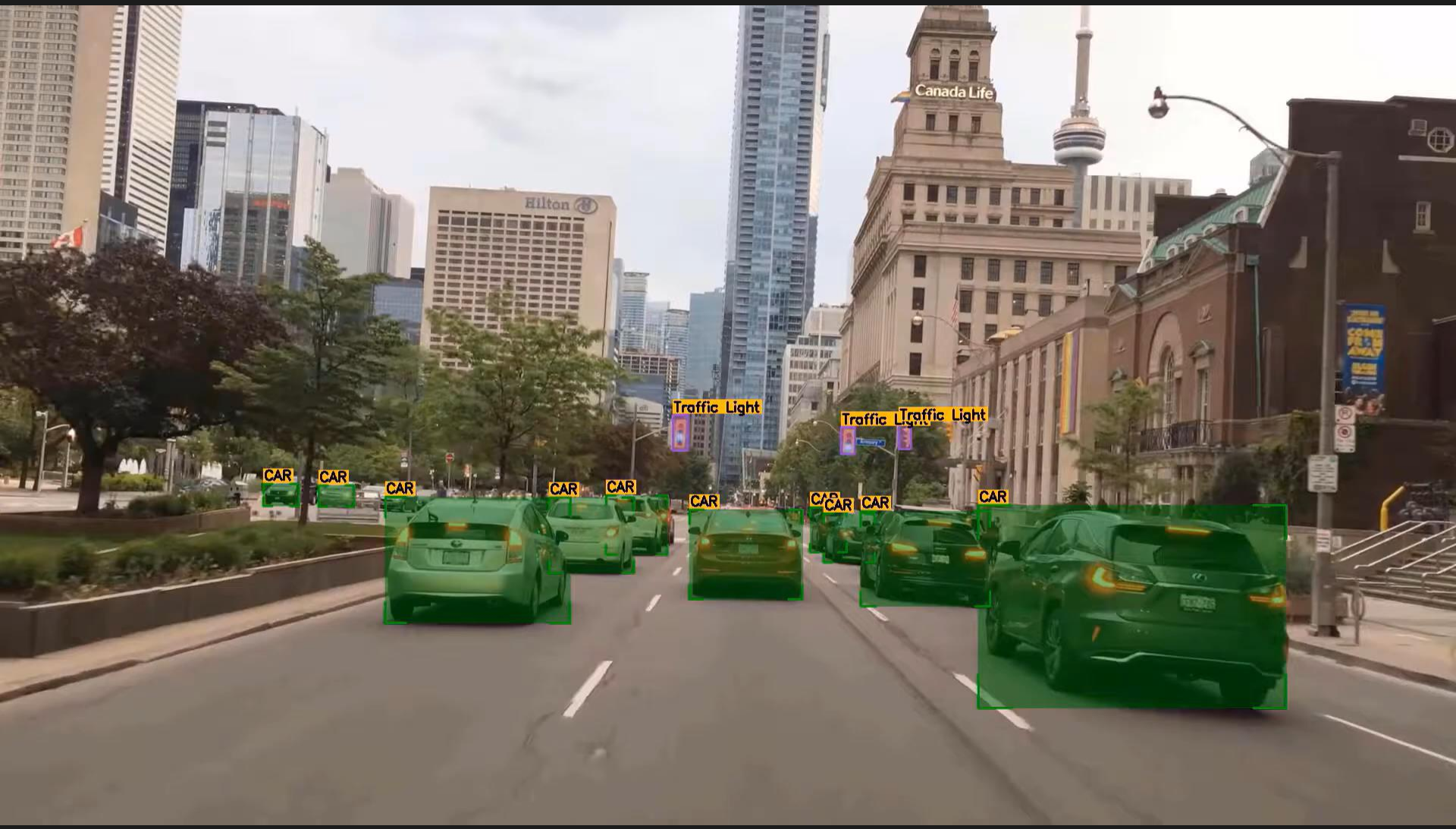
- OpenCV

Let’s start our course!



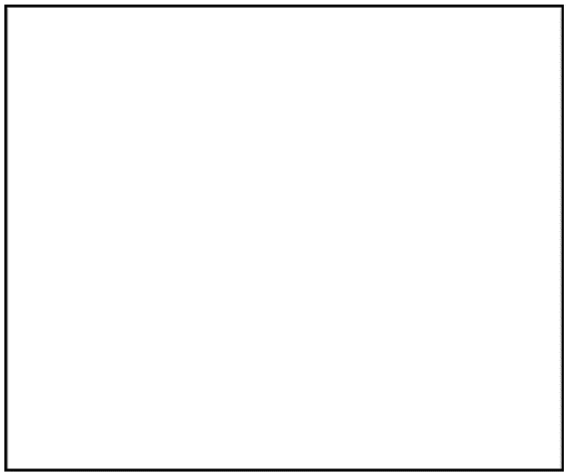
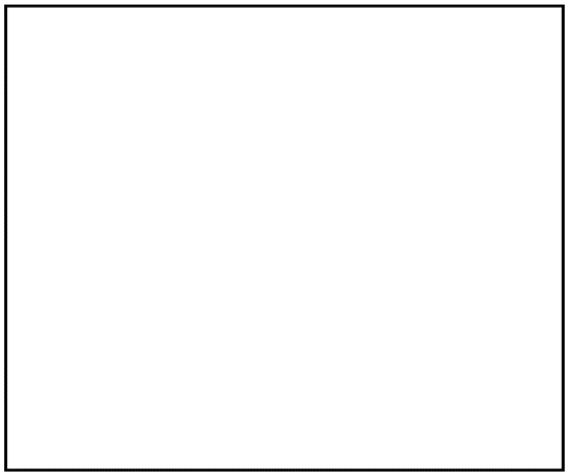
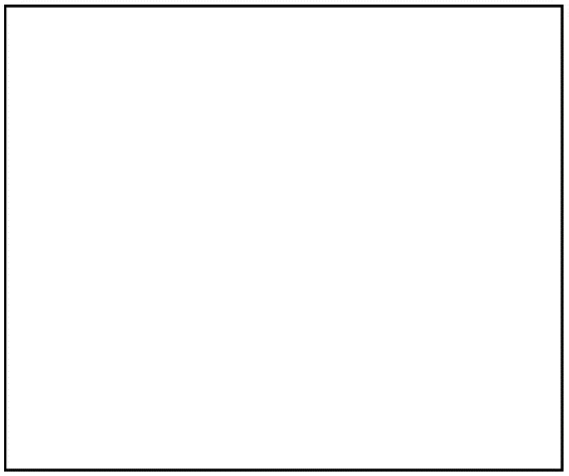
What is Computer Vision?

What is Computer Vision?

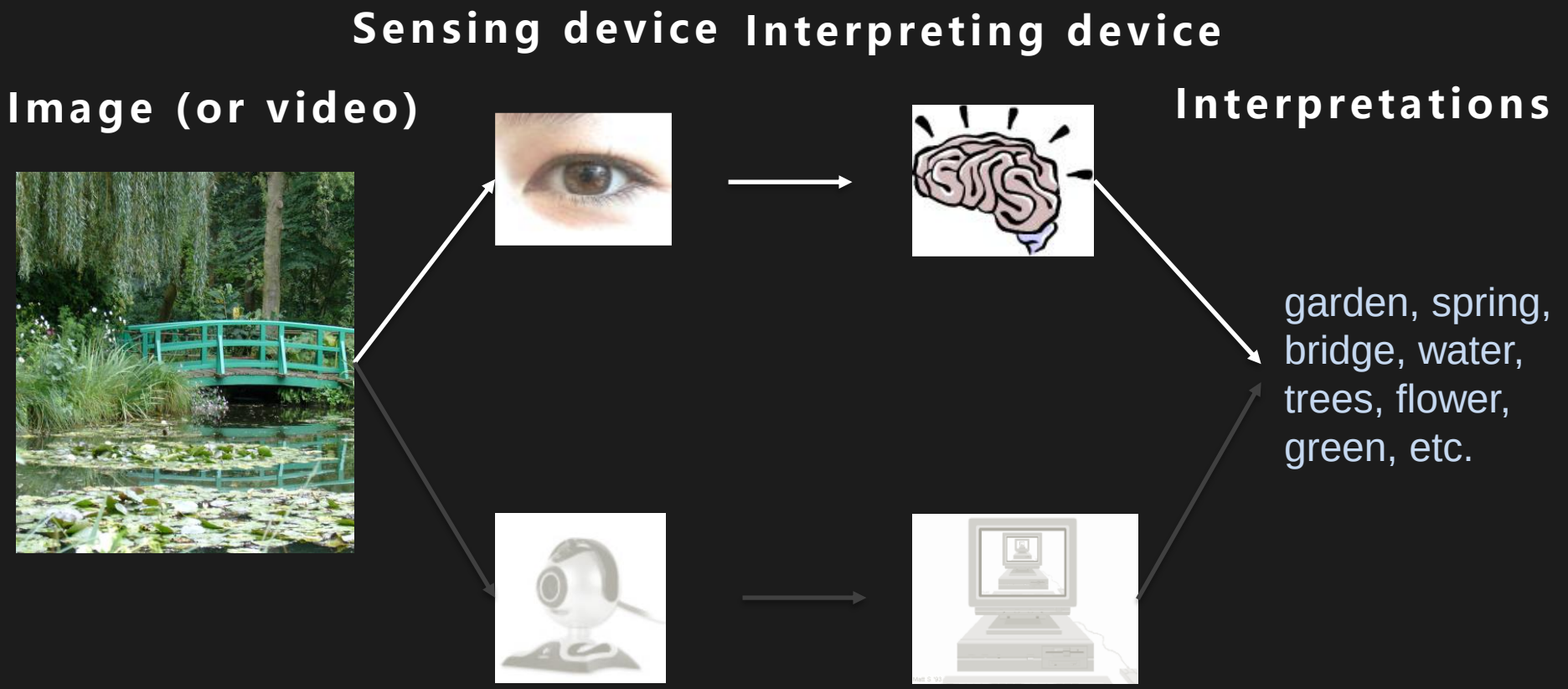


What is Computer Vision?

Input 3 images

What is (Computer) Vision?



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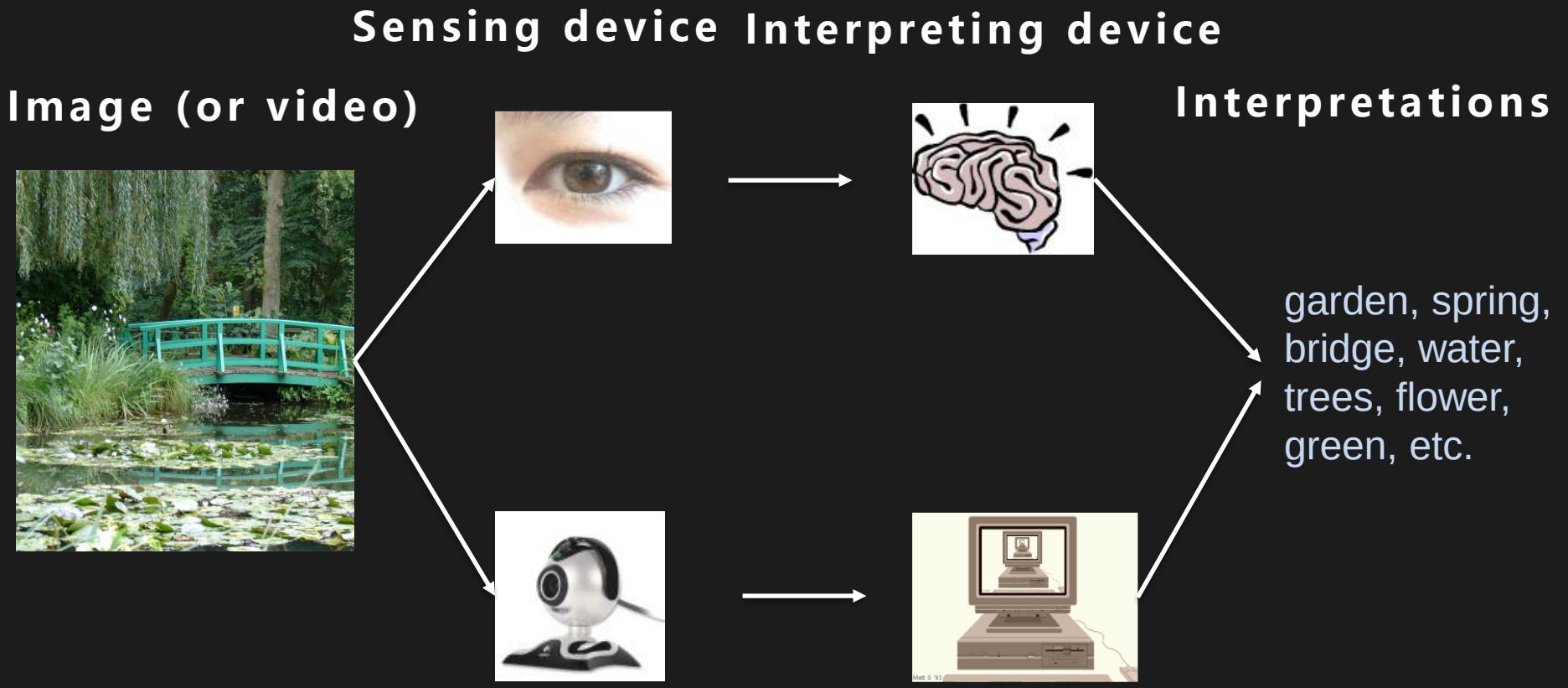
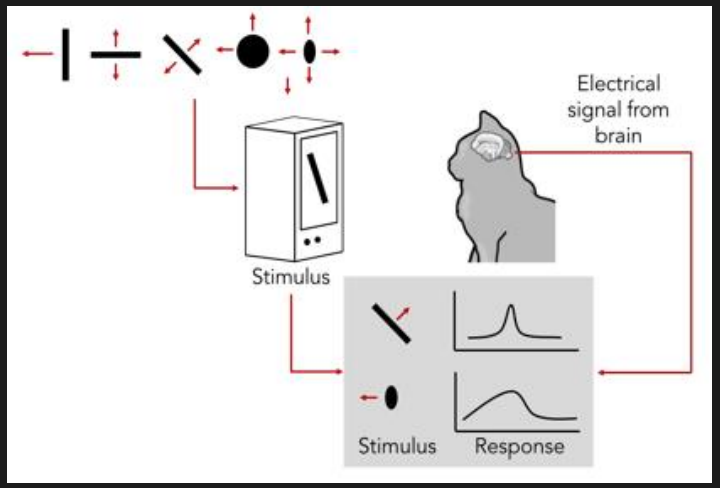


A bit of history

Biological Vision



David Hubel (1926-2013) Torsten Wiesel (1924-)

1981: Nobel Prize In medicine

David Hubel and Torsten Wiesel. Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. JOURNAL OF PHYSIOLOGY-LONDON, no. 1 (1962).

The First Digital Image

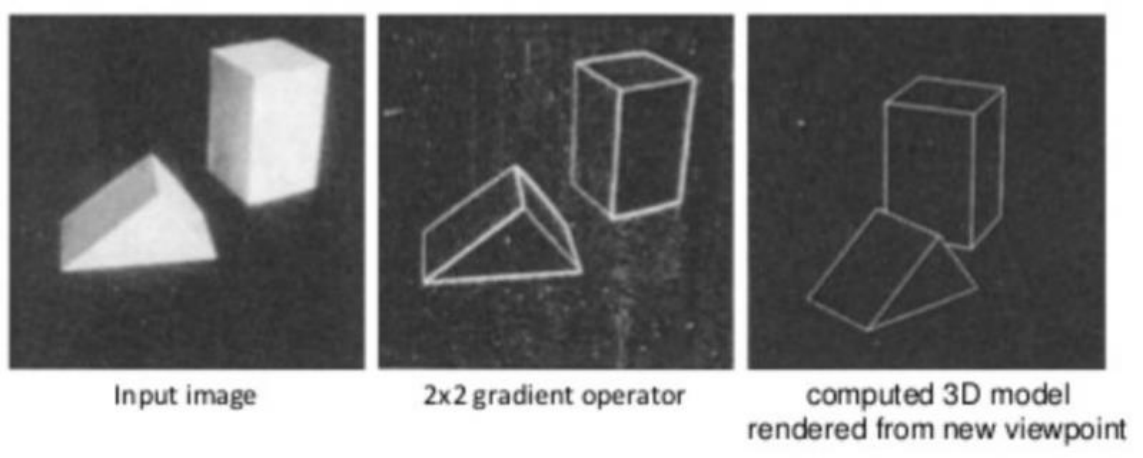
5cm by 5cm

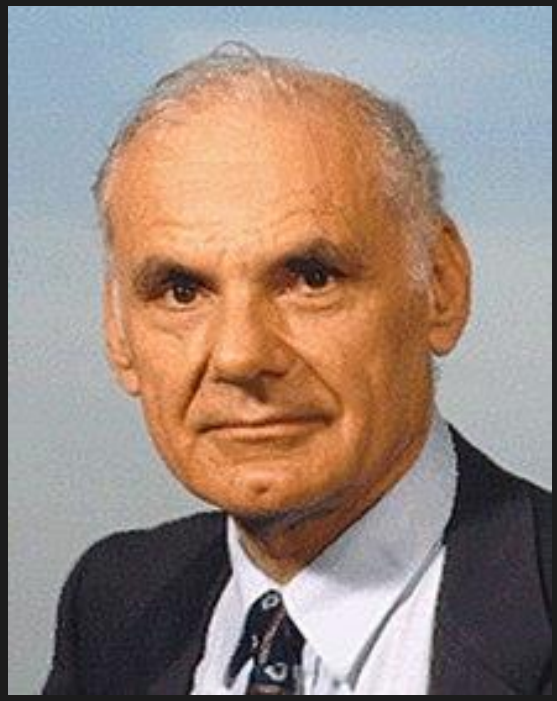
30,976 pixels

Russell Kirsch (1929-2020)

The First Thesis for Computer Vision

Machine Perception of Three-Dimensional Solids





Lawrence Roberts
(1937-2018)

The First Project for Computer Vision

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
PROJECT MAC

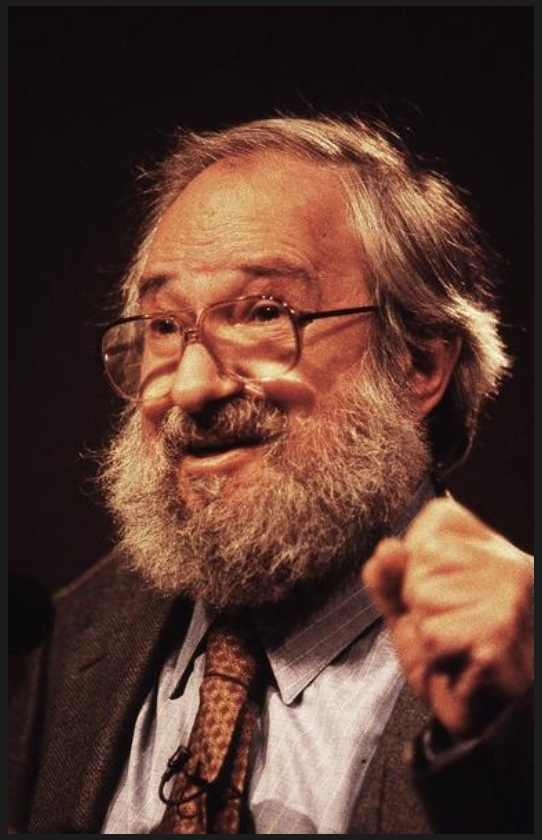
Artificial Intelligence Group
Vision Memo. No. 100.

July 7, 1966

THE SUMMER VISION PROJECT

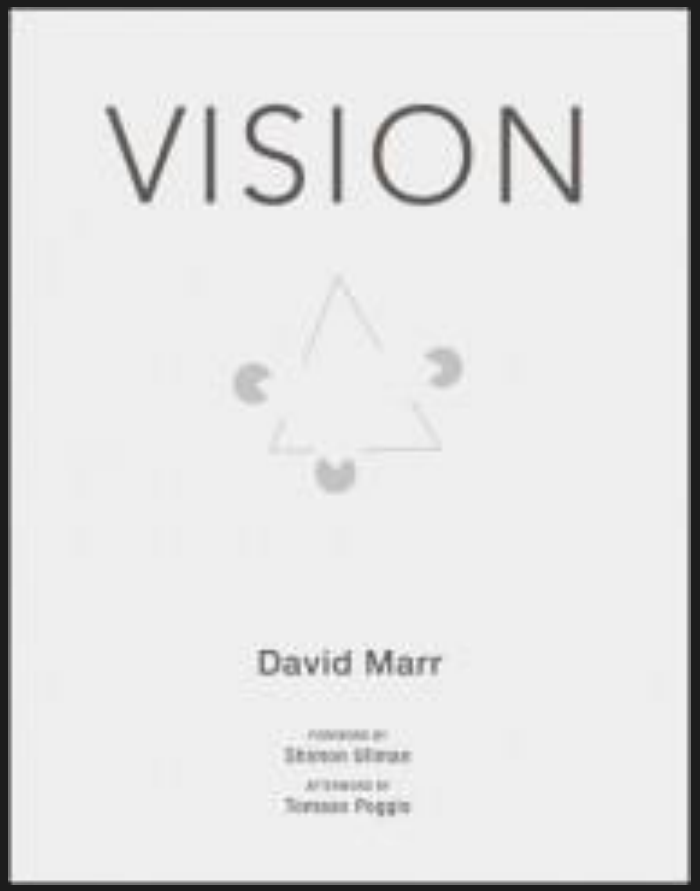
Seymour Papert

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".



Seymour Papert
(1928-2016)

David Marr
1945-1980
Professor of
Psychology at MIT



A general framework for understanding visual perception

Vision as Information Processing

Marr's Tri-Level Hypothesis:

Computational theory	Representation and algorithm	Hardware implementation
What is the goal of the computation, why is it appropriate, and what is the logic of the strategy by which it can be carried out?	How can this computational theory be implemented? In particular, what is the representation for the input and output, and what is the algorithm for the transformation?	How can the representation and algorithm be realized physically?

Vision as Information Processing

A two-dimensional visual array

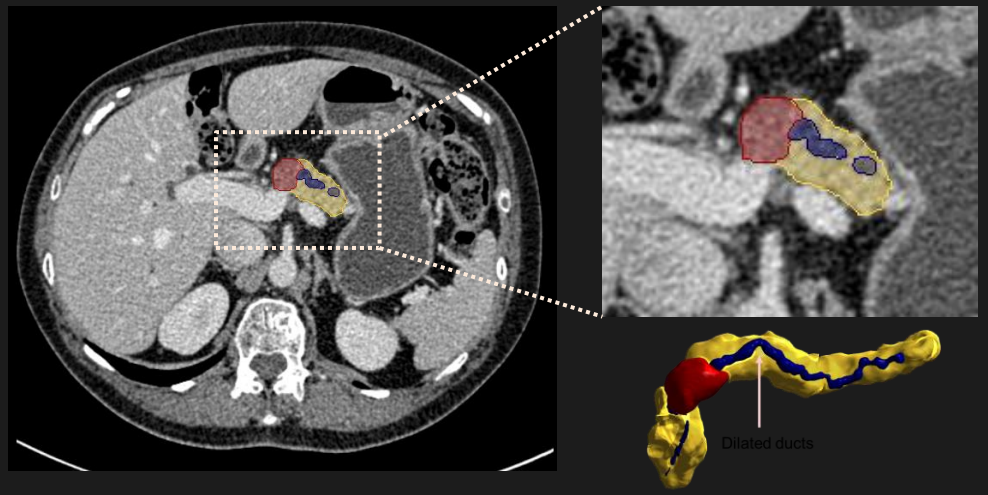
A three-dimensional description of the world as output

1. a ***primal sketch*** of the scene, based on feature extraction of fundamental components of the scene, including edges, regions, etc
2. a ***2.5D sketch*** of the scene, where textures are acknowledged
3. a ***3D model***, where the scene is visualised in a continuous, 3-dimensional map.

Computer vision?

- Recovering properties from the real world using images
  - Examples:
    - Detecting/recognizing objects in a scene
    - Reconstructing a 3D model of the imaged buildings

- Overlaps with a few other areas from computer Science, e.g.
  - Image processing
  - Machine learning/pattern recognition
  - Graphics



But What Really Is Computer vision?

- Vision is
  - … automating human visual processes
  - … an information processing task
  - … inverting image formation
  - … inverse graphics
  - … really useful!

So Why Is It So Hard?

- The Human Visual System has no problem interpreting subtle variations and correctly segmenting the object from the background

So Why Is It So Hard?

- The Human Visual System has no problem interpreting subtle variations and correctly segmenting the object from the background

What can we infer?

- It's a flower.
- The flower is pink.
- There are water droplets on the flower. Perhaps it rained earlier?
- It's daytime and sunny.
- …

So Why Is It So Hard?

- The Human Visual System has no problem interpreting subtle variations and correctly segmenting the object from the background

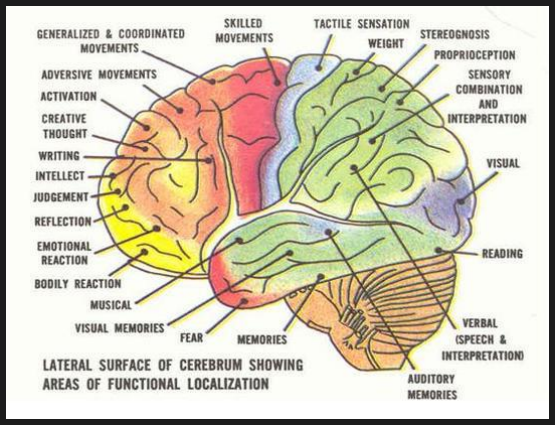
What can the machine infer?

- It's a flower.
- …
- That's mostly it!

Why is vision challenging…?

- When you see an image, you see:
  - The objects in the image
  - The context of the scene
  - Your prior knowledge and experiences automatically apply to what you see to deduce meaning
  - …and much much more…

- When a machine sees an image, it sees:
  - Numbers
  - …and…
  - …well…
  - That's it



- Approx. 10^{11} Neurons
- Approx. 10^{14} Synapses
- Firing rates 100-1000 Hz
- Asynchronous, distributed
- Consumes 20W
- Diverse (everyone is different!)

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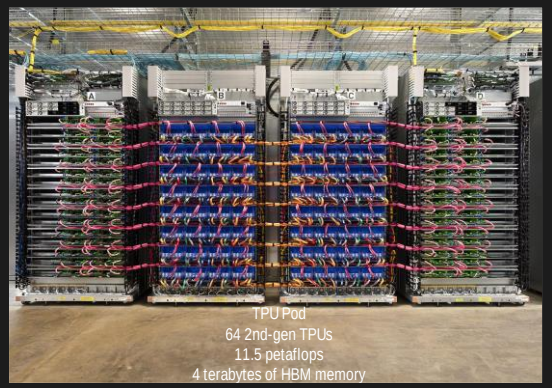
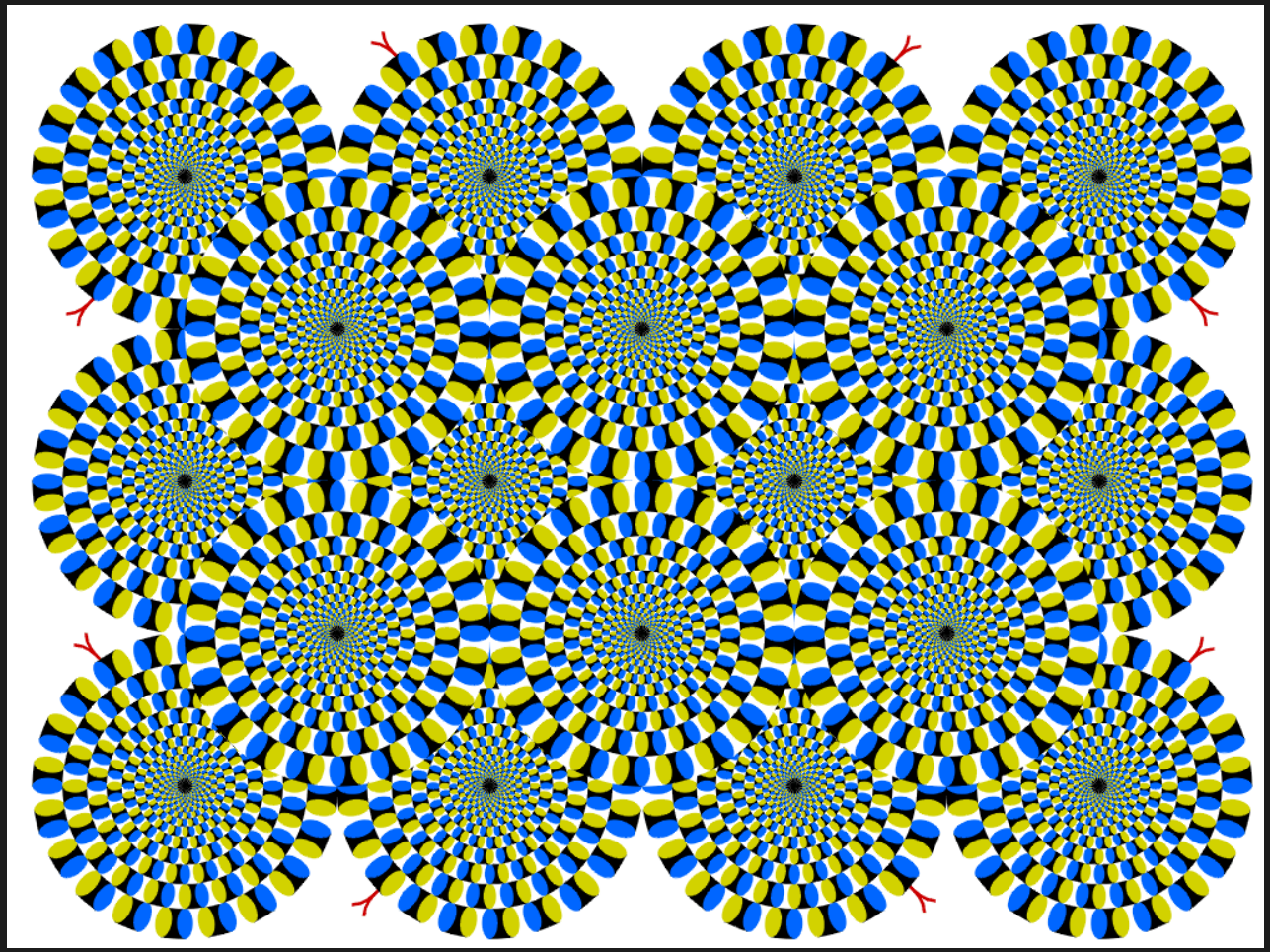


- 11.5x 10^{15} floating point ops
- 4 x 10^{12} memory locations
- Gigahertz clock
- Synchronous
- Consumes hundreds of kilowatts
- Each is exactly the same

So Why Is It So Hard?

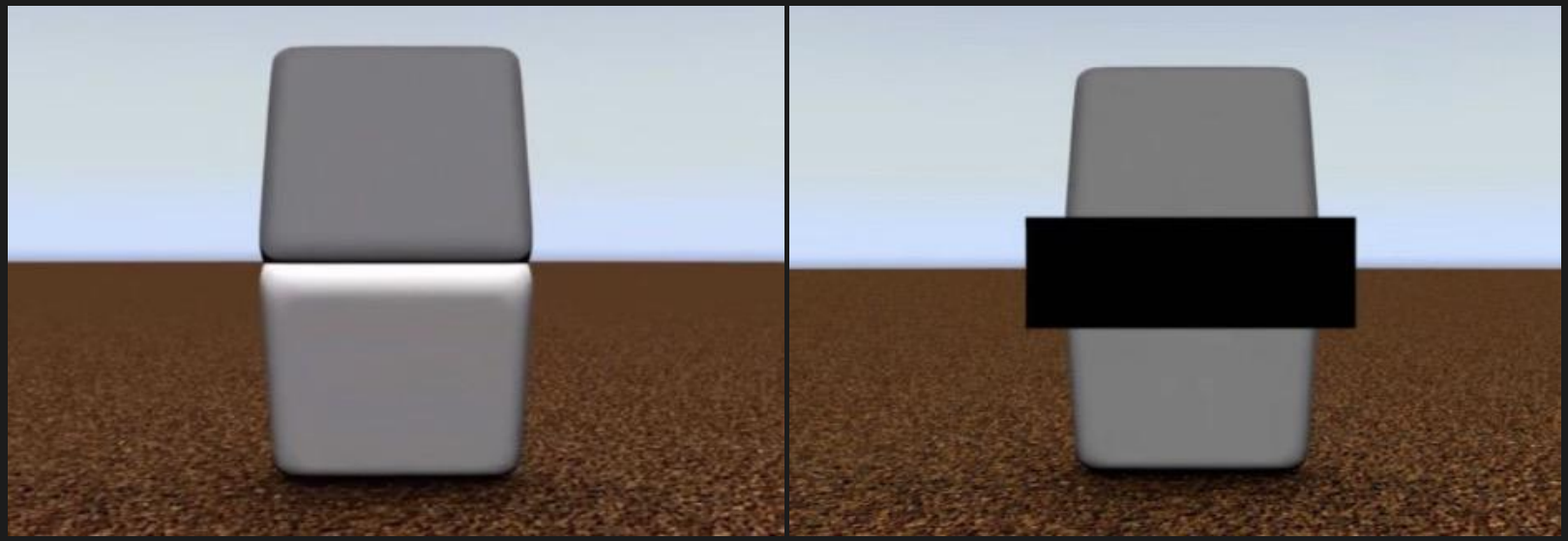
- Basically we are solving an "Inverse Problem"
  - Recover some unknowns given insufficient information to fully specify the solution
- So what do we do?
  - Use physics-based and probabilistic models to disambiguate between potential solutions
  - Let's be honest – we also use a bunch of "tricks"!

Can computers match (or beat) human vision?

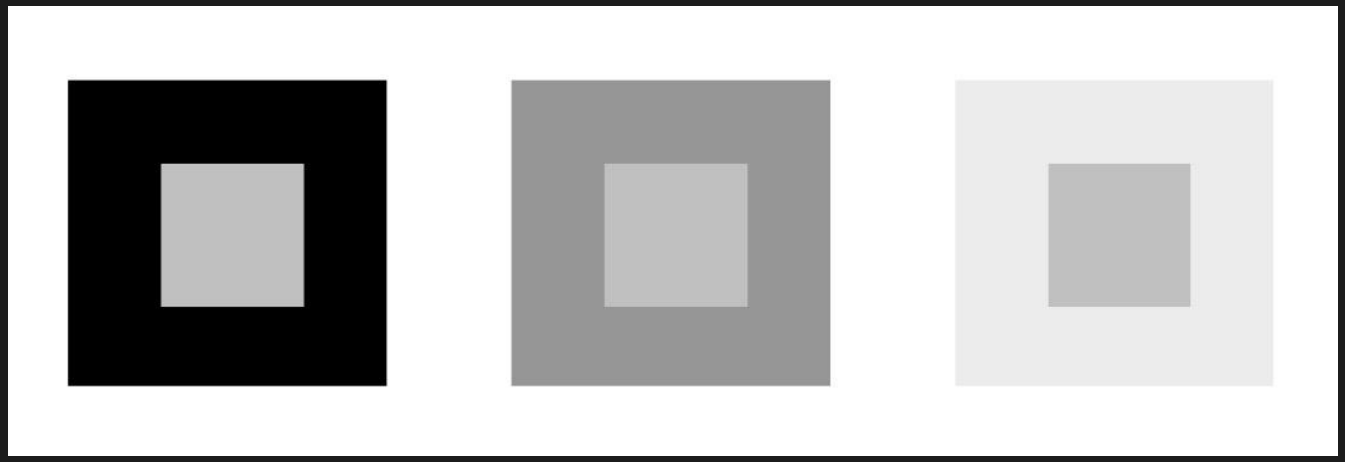


- Yes and no (but mostly no!)
  - humans are much better at “hard” things
  - computers can be better at “easy” things

Optical Illusions



Optical Illusions



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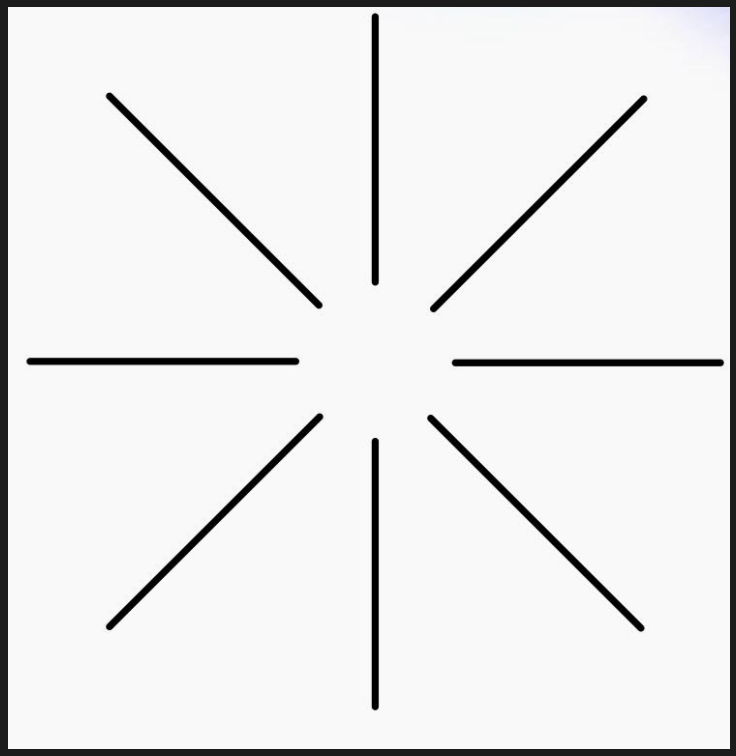

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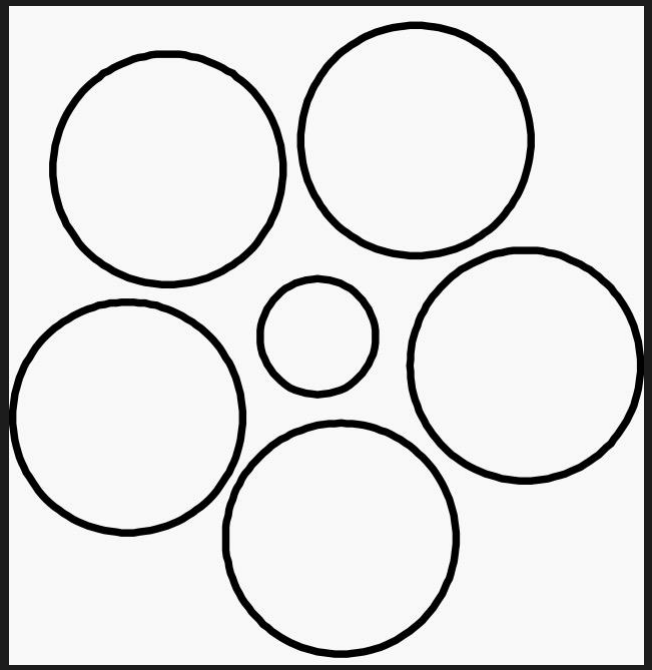
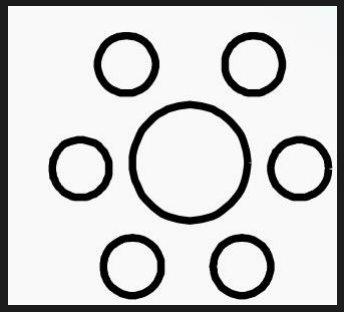
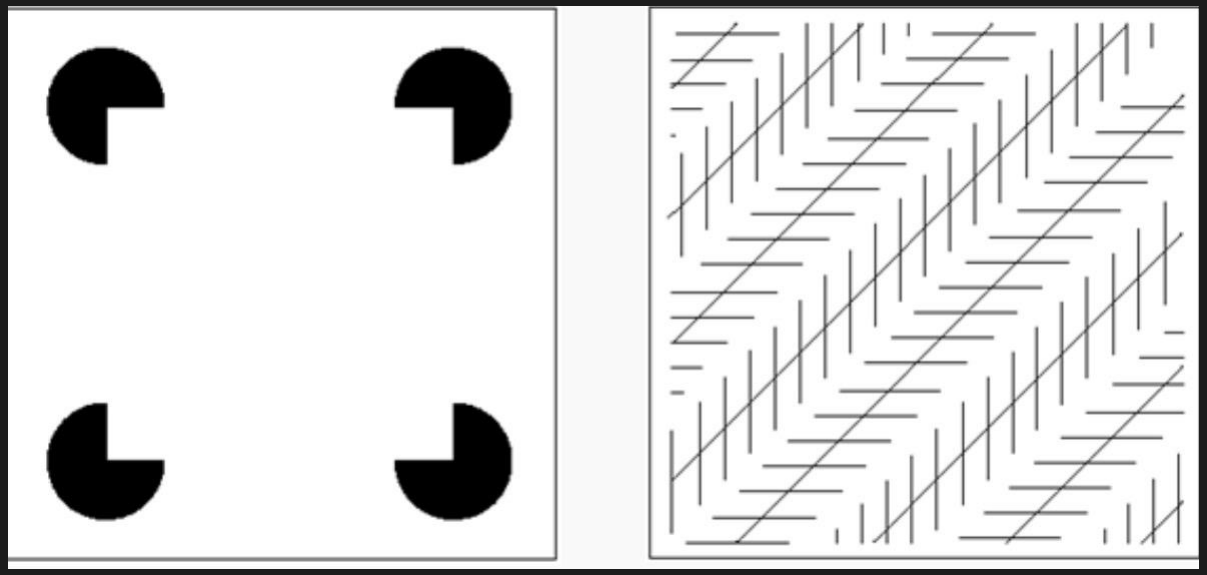
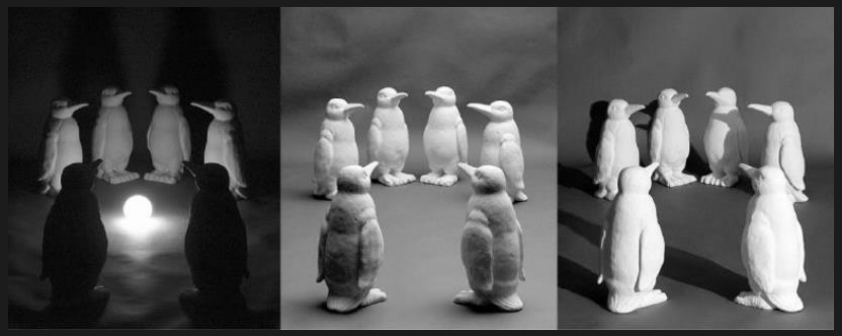




Optical Illusions



Why is vision challenging…?



Illumination and viewpoint

Intra-class variation

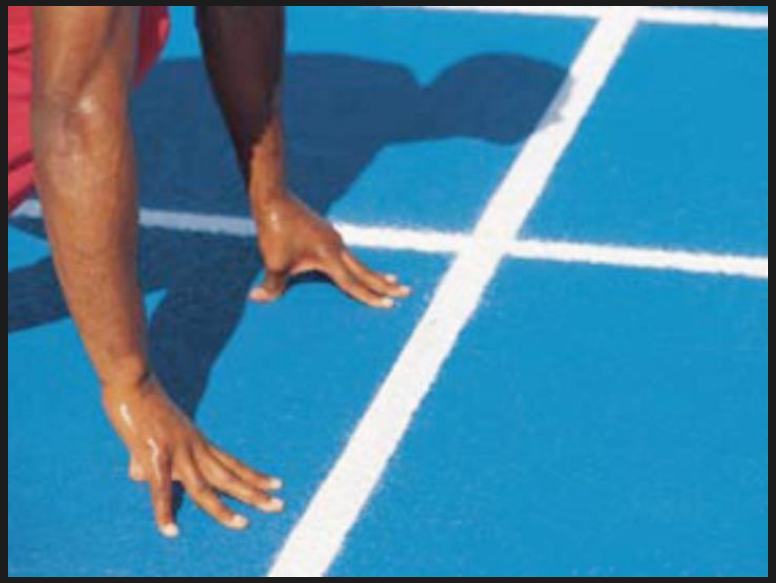
Scale and depth

Why is vision challenging…?

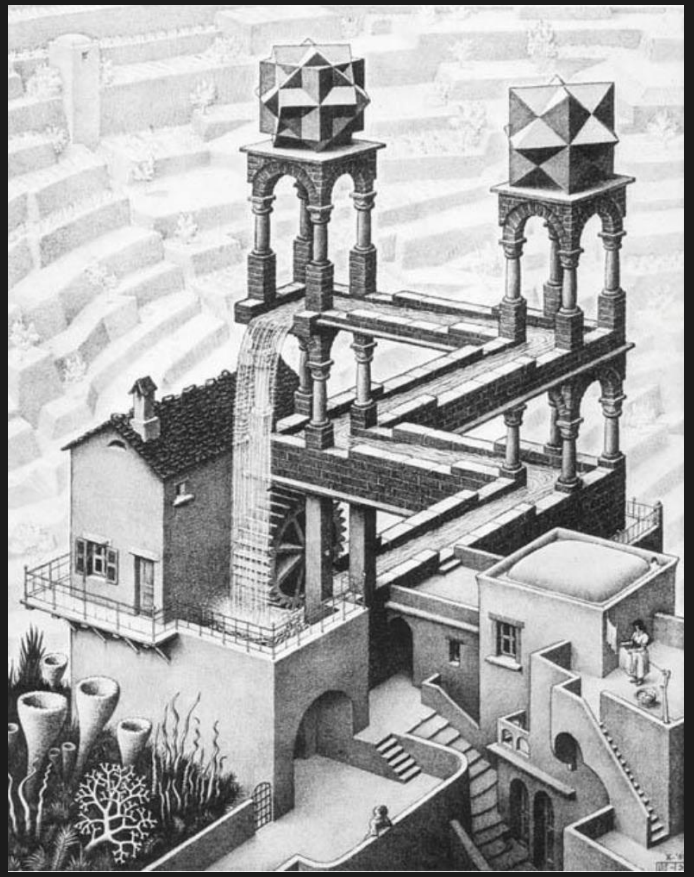
Shadows

Clutter

Why is vision challenging…?



Occlusions



Illusions

Why is vision challenging…?

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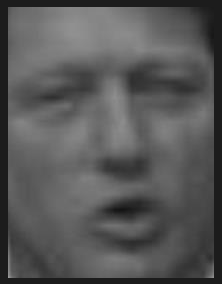
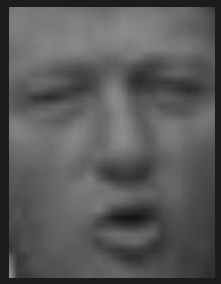


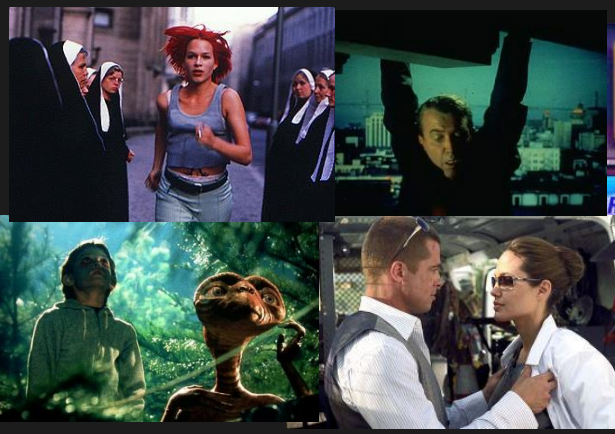


Why Vision?

Every picture tells a story

Why Vision?

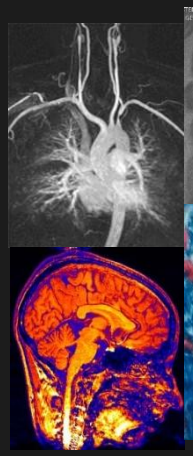
- Images and video are everywhere!







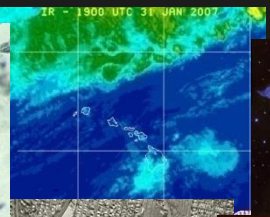
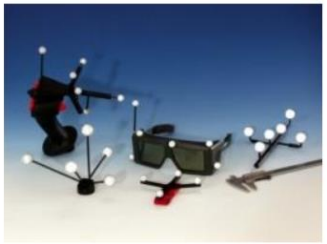






Image modalities (1)



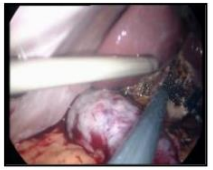
Digital cameras

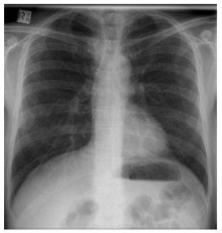
Infrared cameras

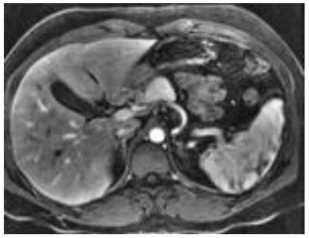
Time-of-flight cameras

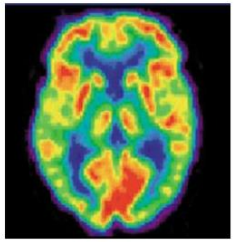
Kinect

Image modalities (2)









Ultrasound | Endoscopy | X-rays | Computed tomography | Magnetic resonance | Positron emission tomography

Application examples

Optical character recognition (OCR)

Digit recognition, AT&T labs
http://www.research.att.com/~yann/

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

Application examples

Face Detection

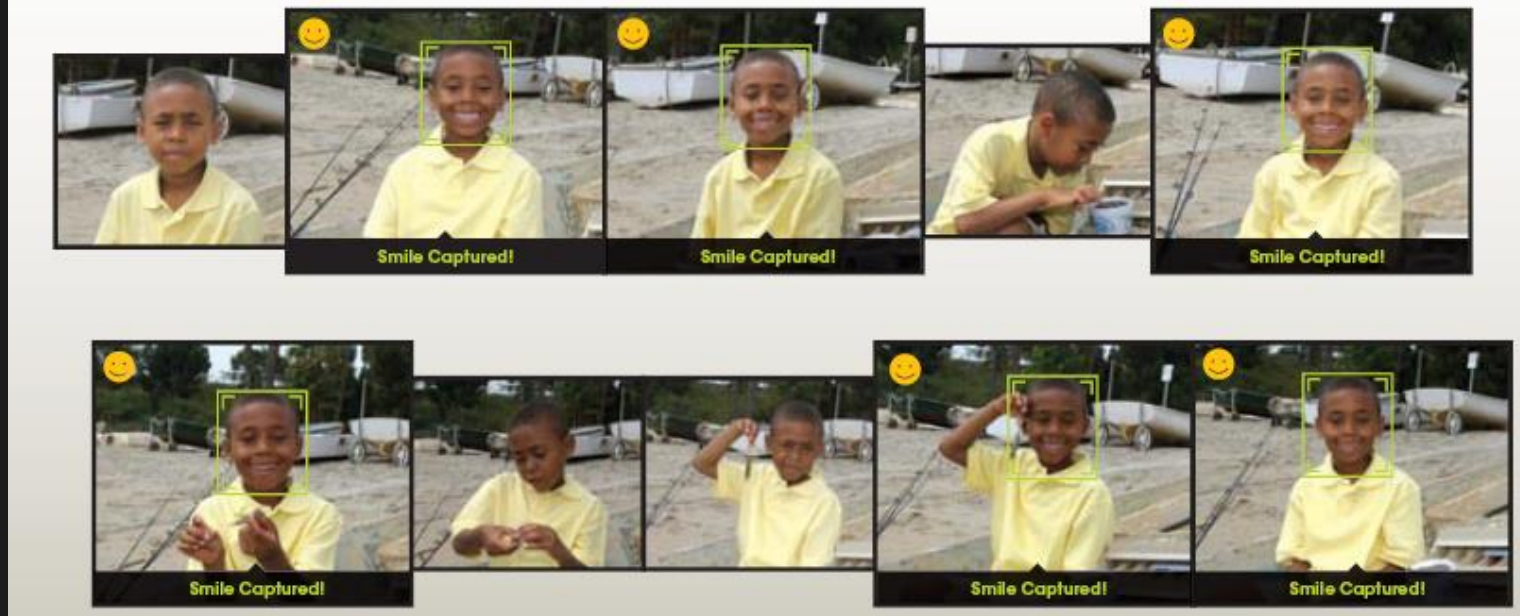
- Many new digital cameras now detect faces
  - Canon, Sony, Fuji, …

Application examples

Smile Detection

The Smile Shutter flow

Imagine a camera smart enough to catch every smile! In Smile Shutter Mode, your Cyber-shot® camera can automatically trip the shutter at just the right instant to catch the perfect expression.



Sony Cyber-shot® T70 Digital Still Camera

Application examples

Login without a password…

Fingerprint scanners on many new laptops, other devices

Face recognition systems now beginning to appear more widely
http://www.sensiblevision.com/

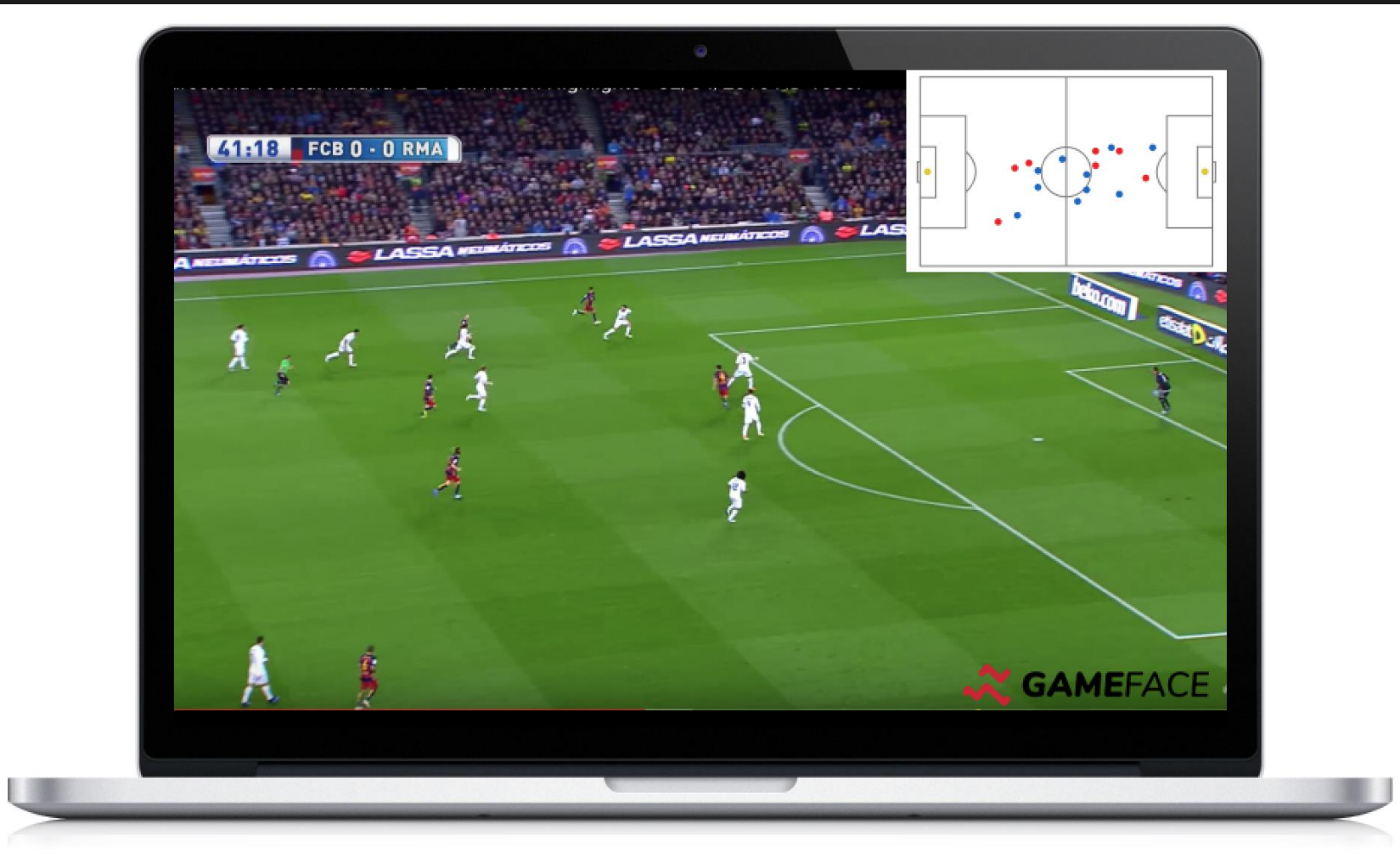
Application examples

Special effects: shape capture

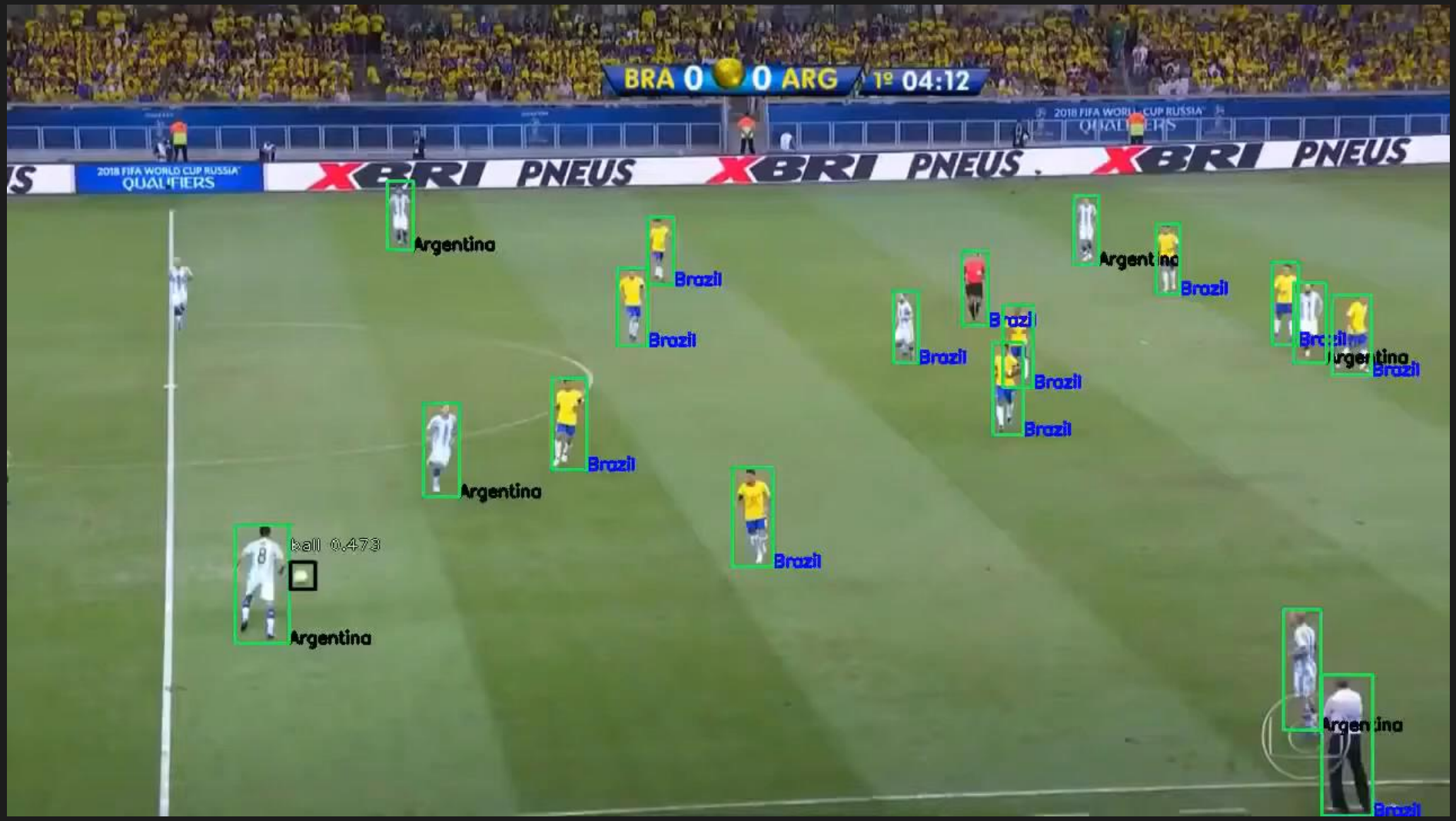
The Matrix movies, ESC Entertainment, XYZRGB, NRC

Application examples

Sports



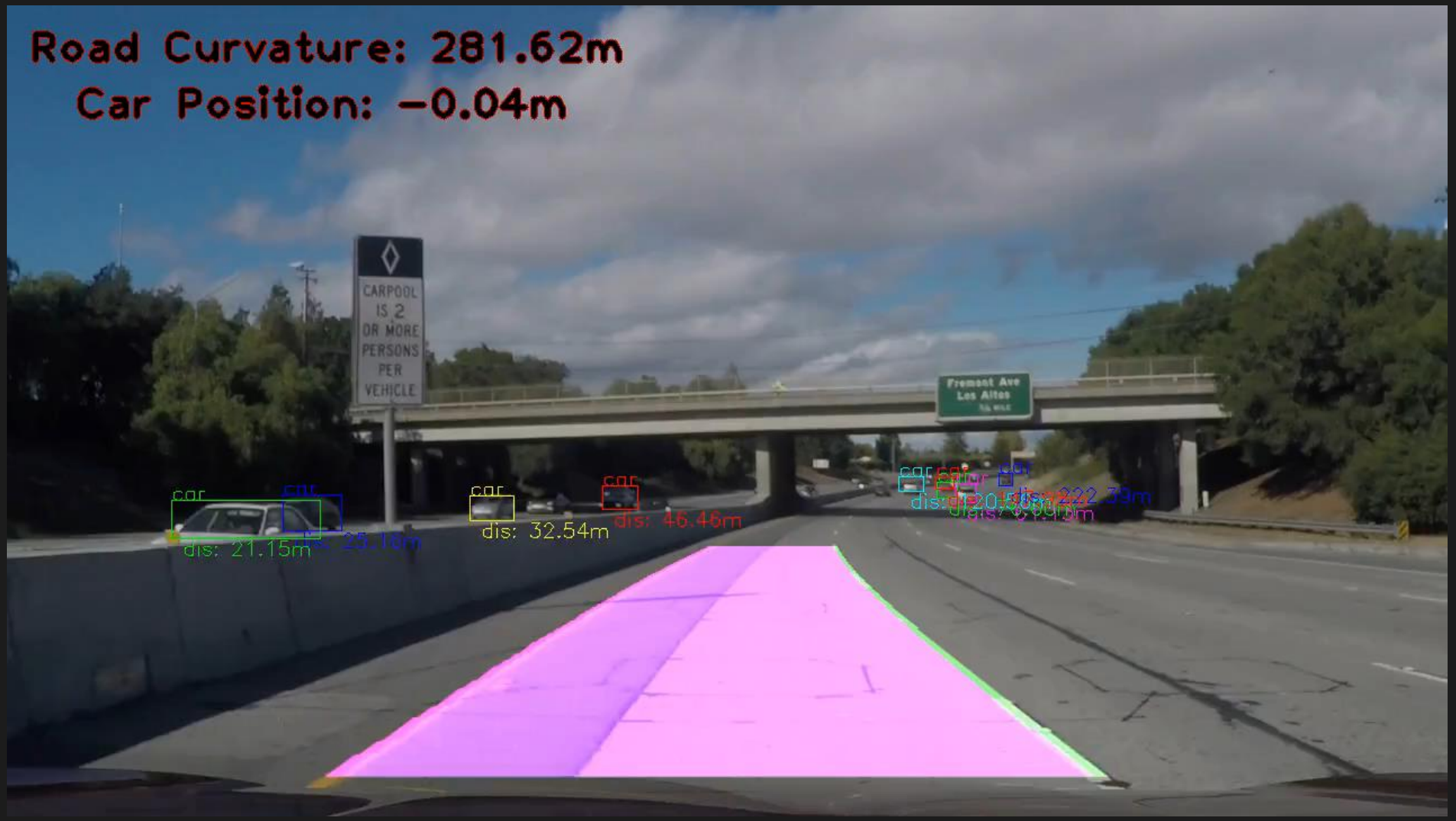
Application examples



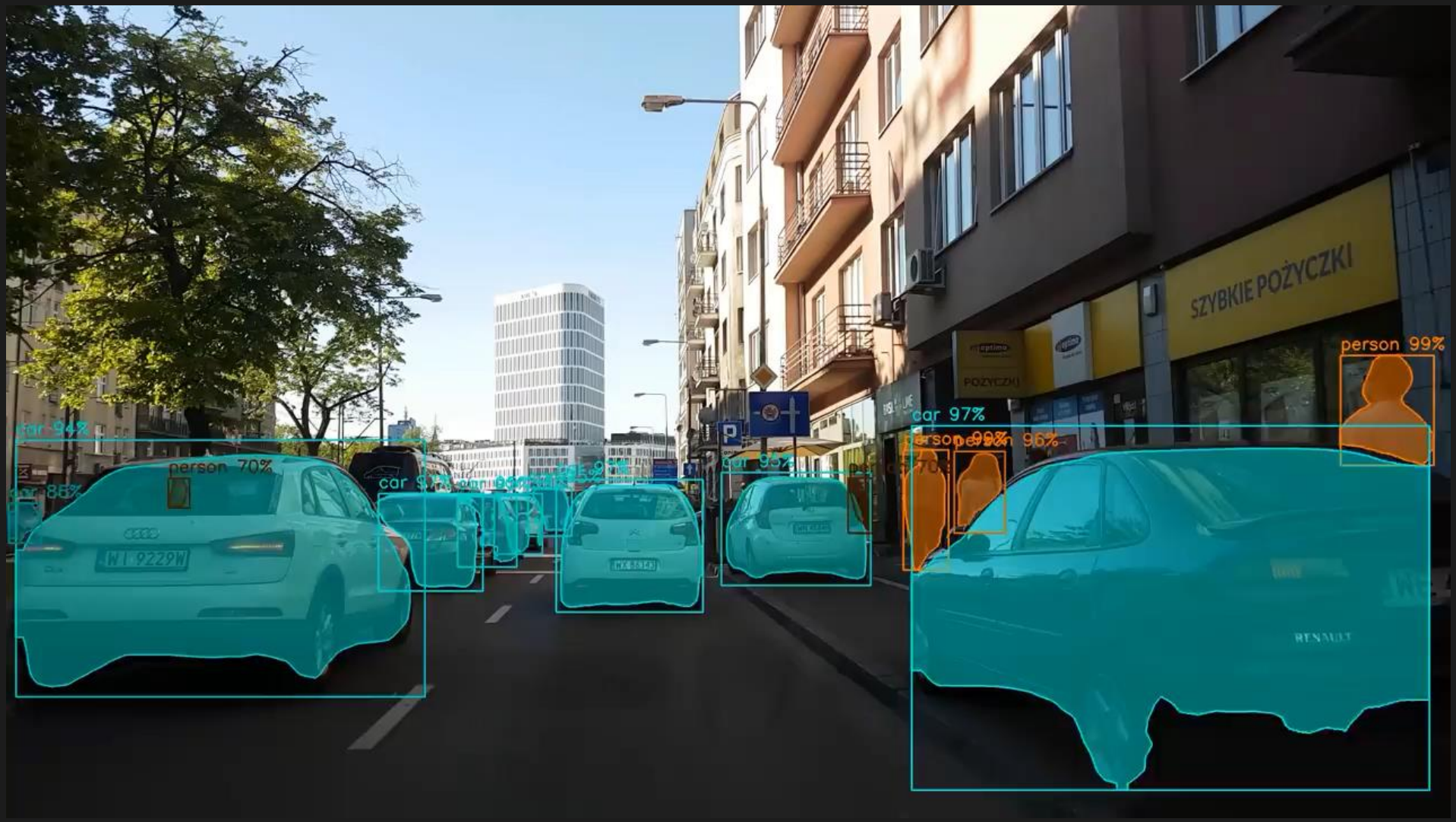
Application examples

- Mobileye
  - Vision systems currently in high-end B
  - By 2010: 70% of car manufacturers.

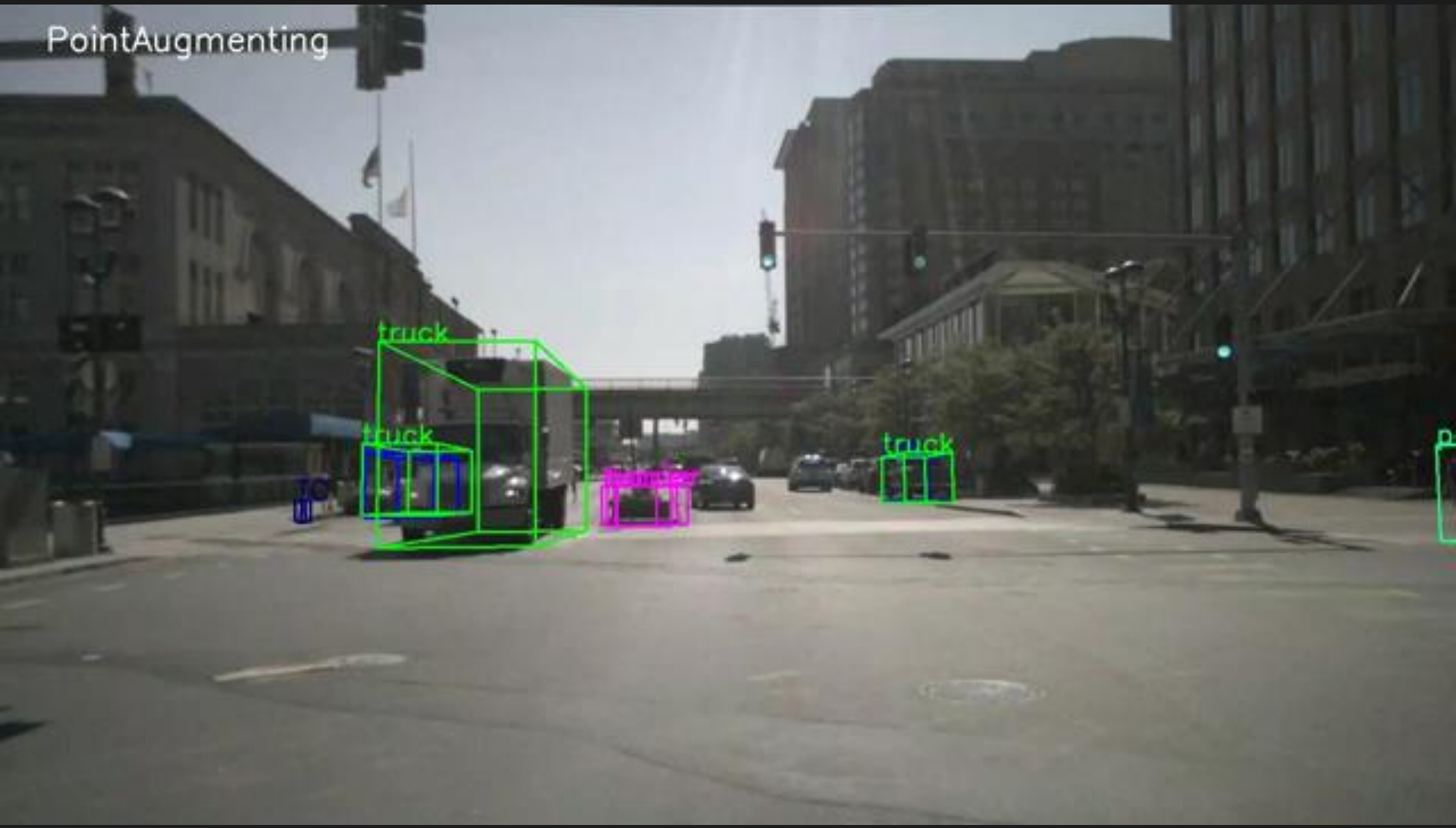
Application examples



Application examples



Application examples



Application examples

Vision in space

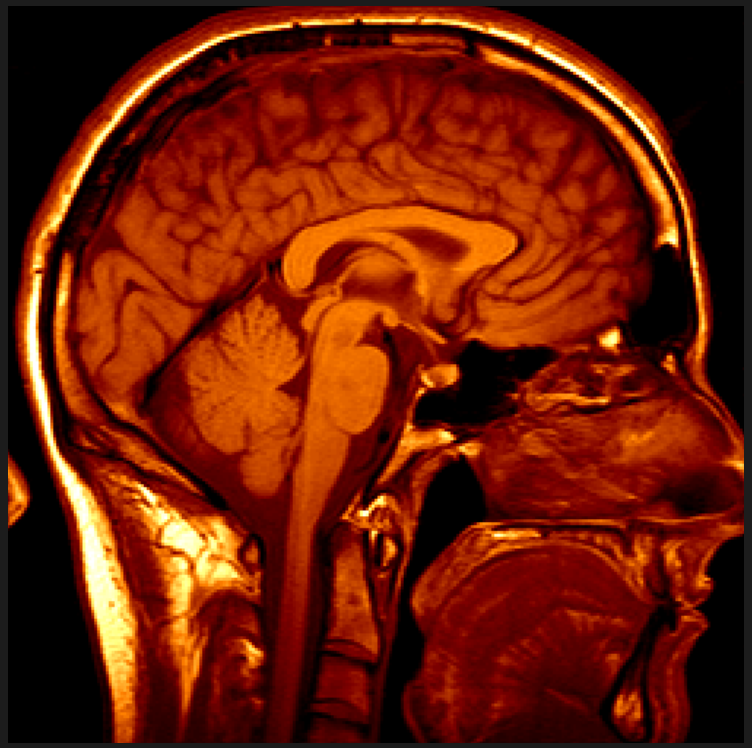
Vision systems (JPL) used for several tasks

- Panorama stitching
- 3D terrain modeling
- Obstacle detection, position tracking
- For more, read “Computer Vision on Mars” by Matthies et al.

Application examples

Application examples

Medical imaging



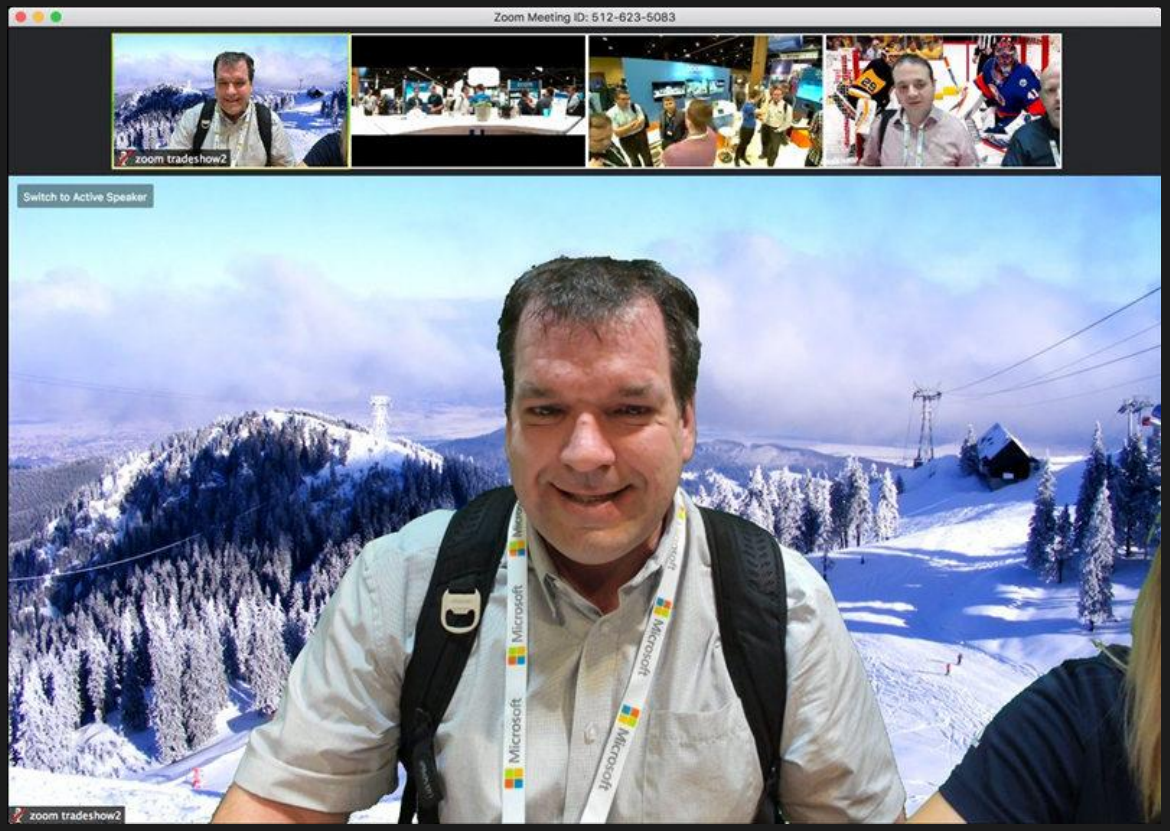
3D imaging
MRI, CT

Image guided surgery
Grimson et al., MIT

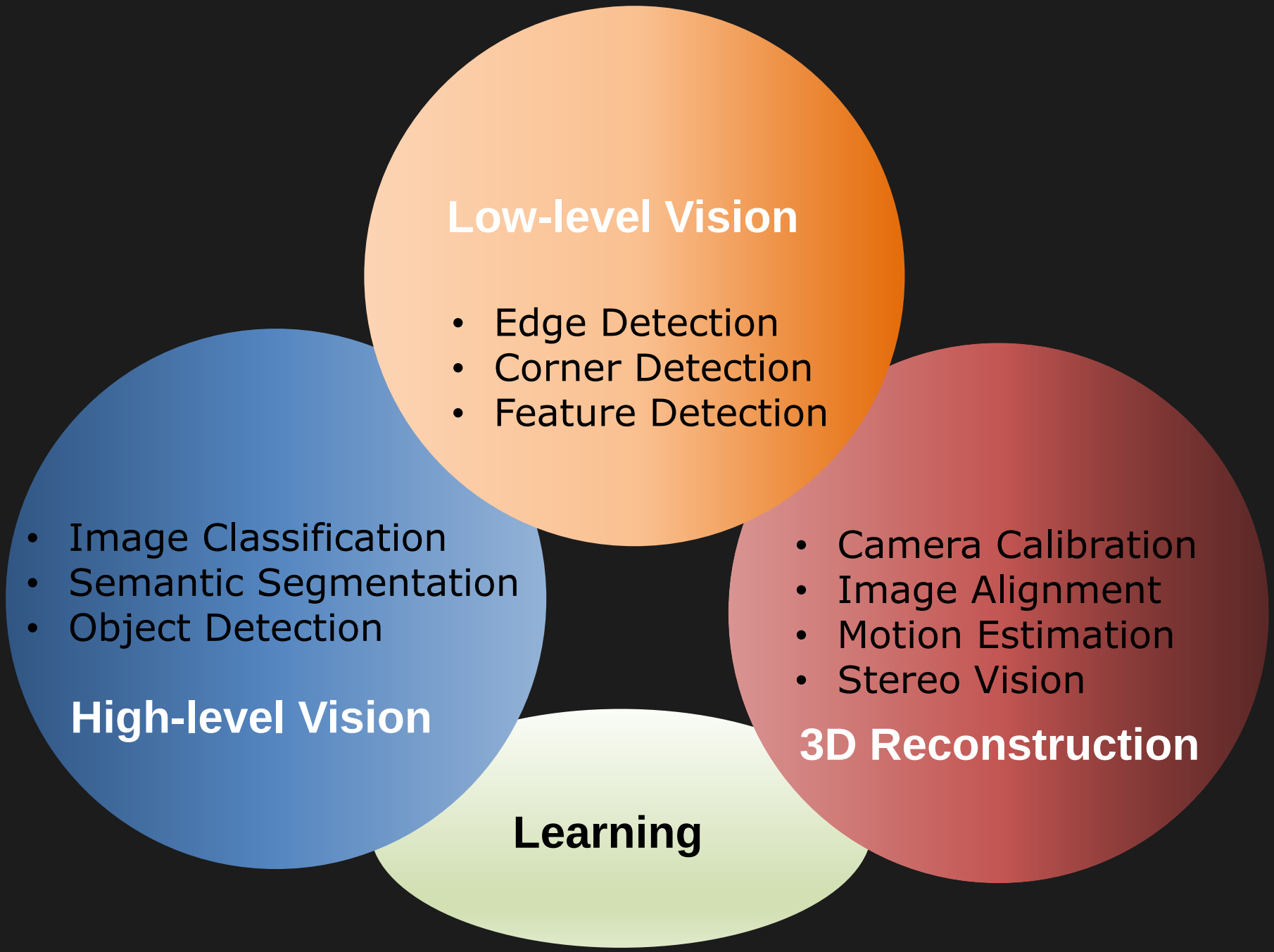
Application examples

Application examples

Virtual Meeting
– Foreground Segmentation



Class Overview


Low-level Vision
• Edge Detection
• Corner Detection
• Feature Detection
• Image Classification
• Semantic Segmentation
• Object Detection
High-level Vision
• Camera Calibration
• Image Alignment
• Motion Estimation
• Stereo Vision
3D Reconstruction
Learning

Topic Relation in This Course

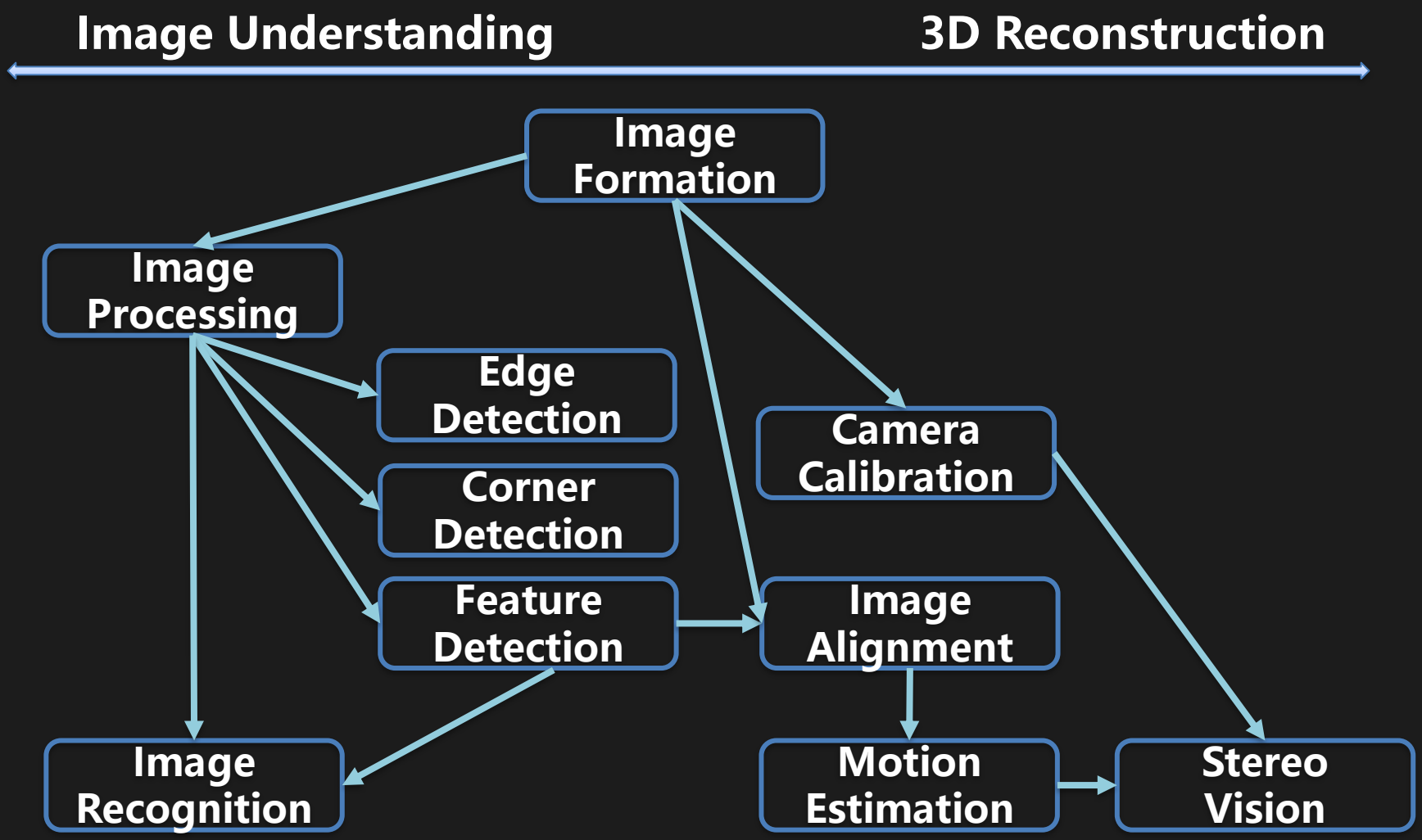
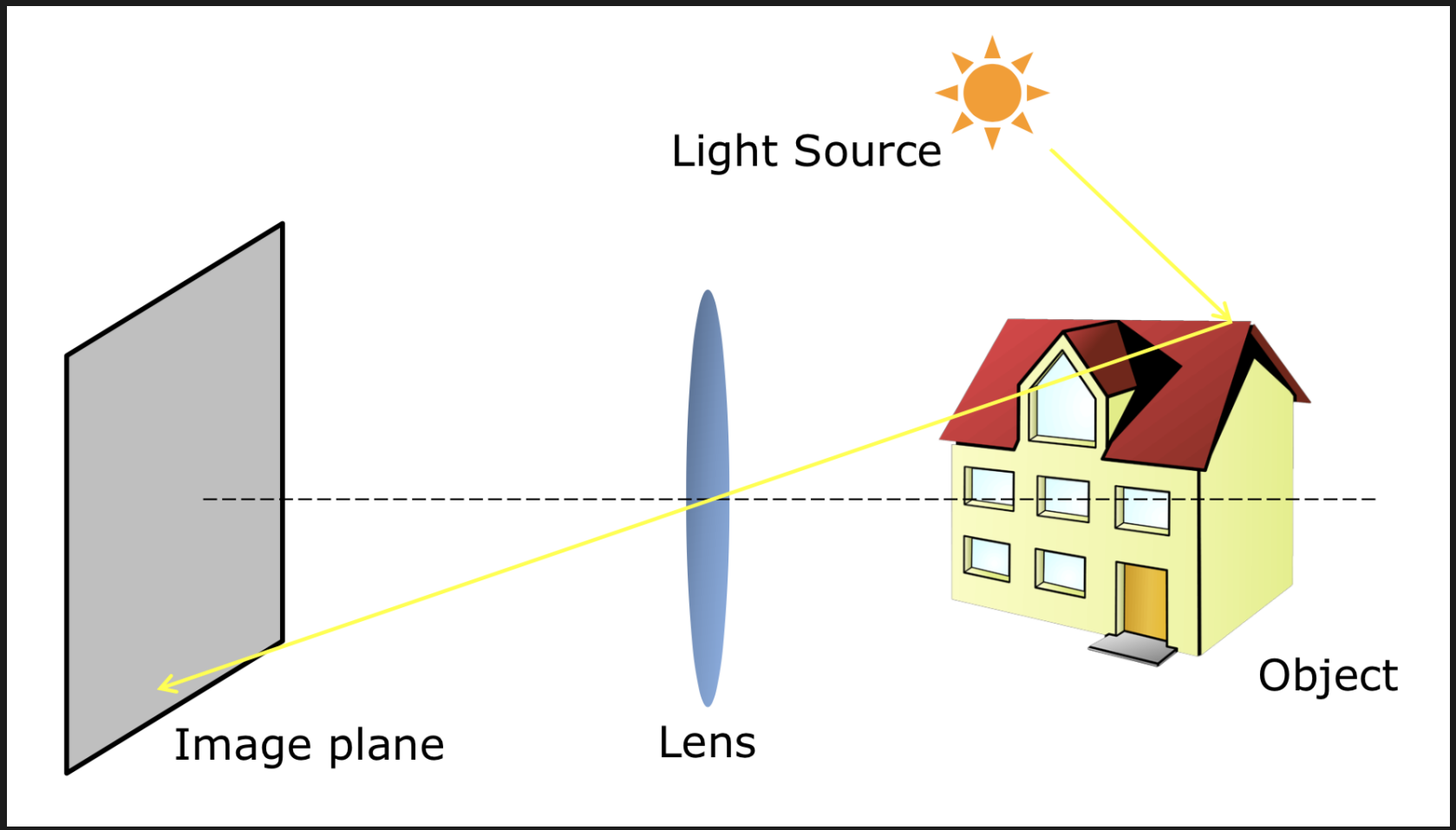


Image Formation and Optics

- Where do Images come from?



Projection of 3D world on a 2D Plane

Image Processing

- Basic operations, linear filters, non-linear filters, binary image processing

Edge Detection

- 1st Derivative, 2nd Derivative, Canny, Hough Transform

Image (I)

$\partial I/\partial x$

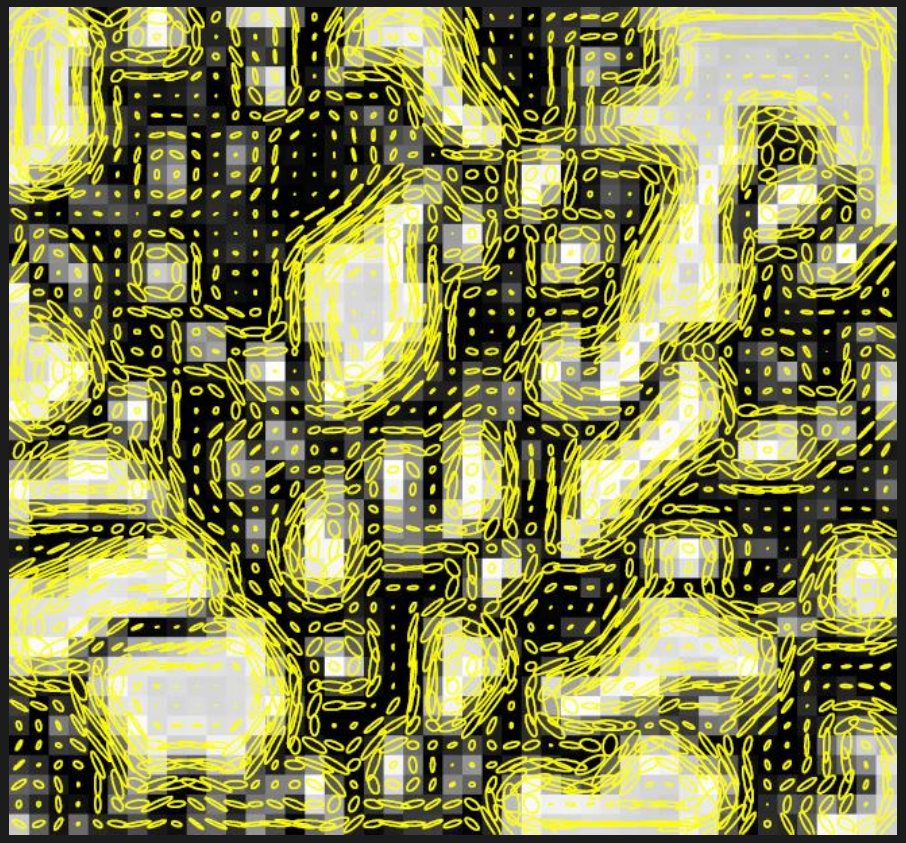
$\partial I/\partial y$

Gradient Magnitude

Thresholded Edge

Corner Detection

- Harris corner detector, cross-corelation



Feature Descriptors

- Feature detection and matching, SIFT

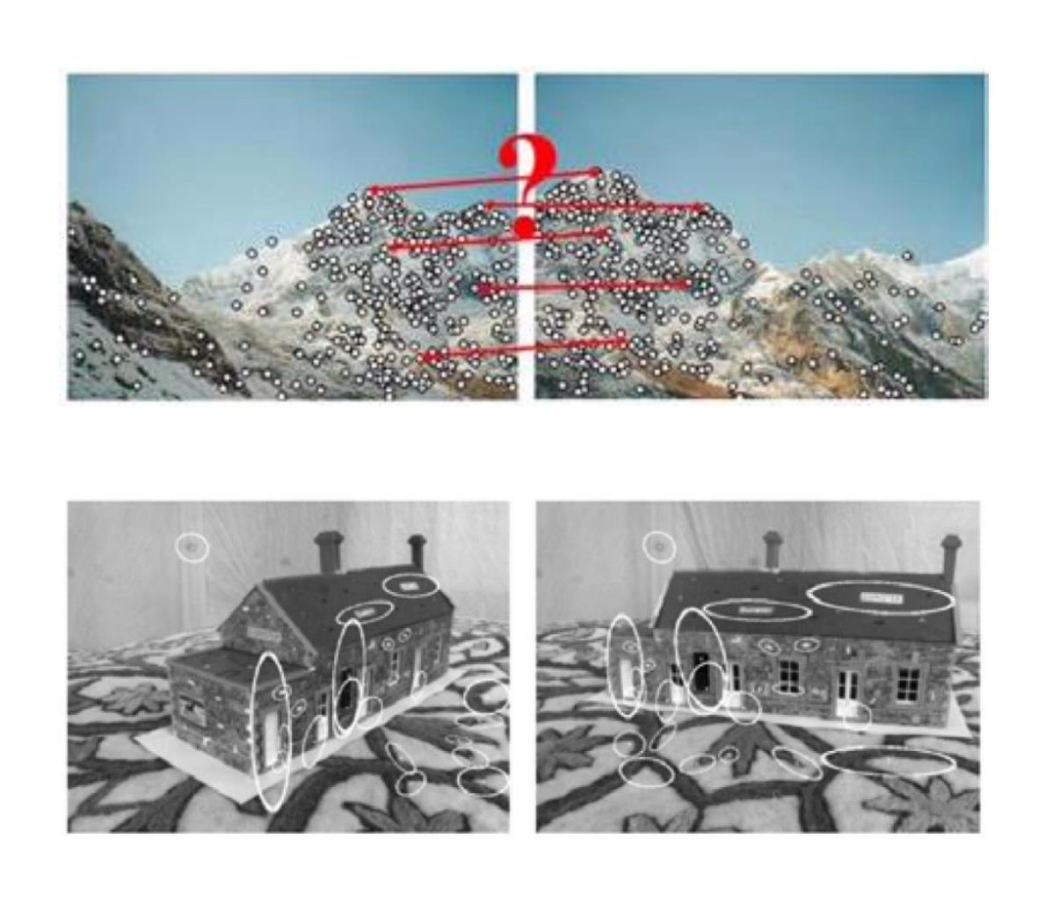
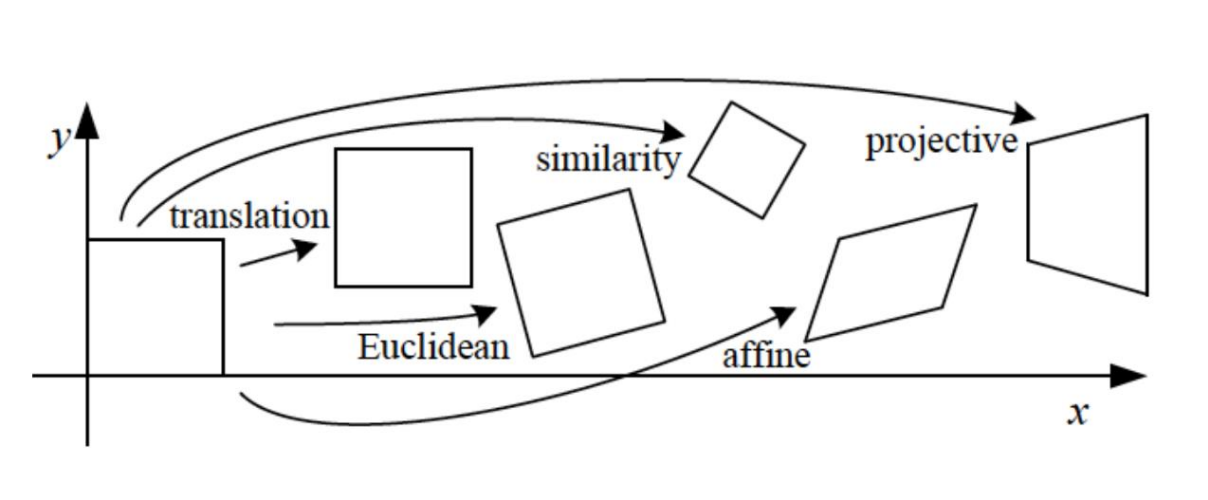


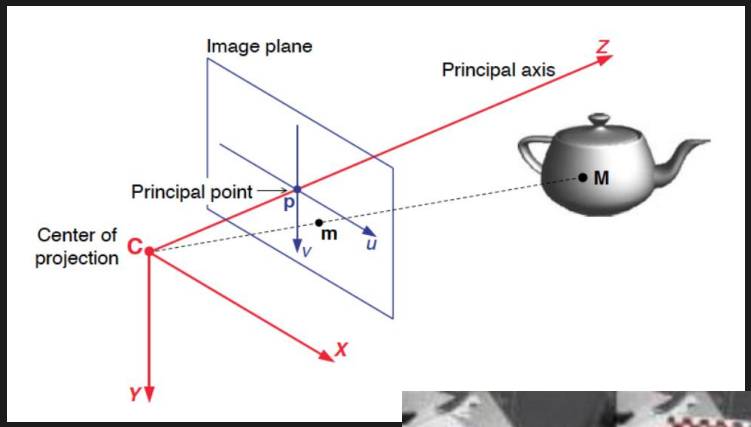
Image Alignment

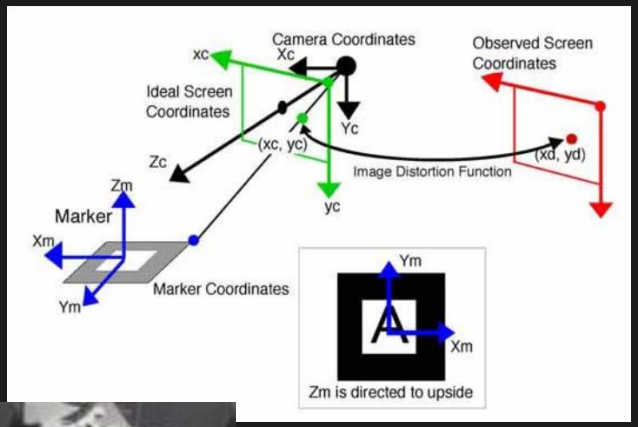
- 2D transformations, homographies

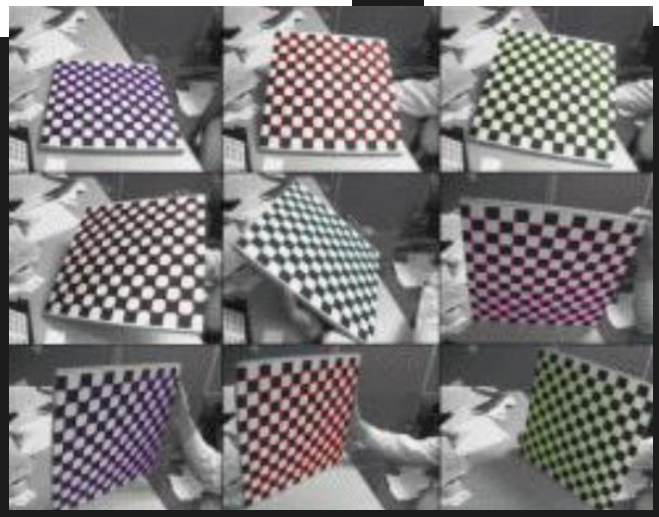


Camera Calibration

- Camera model, calibration method

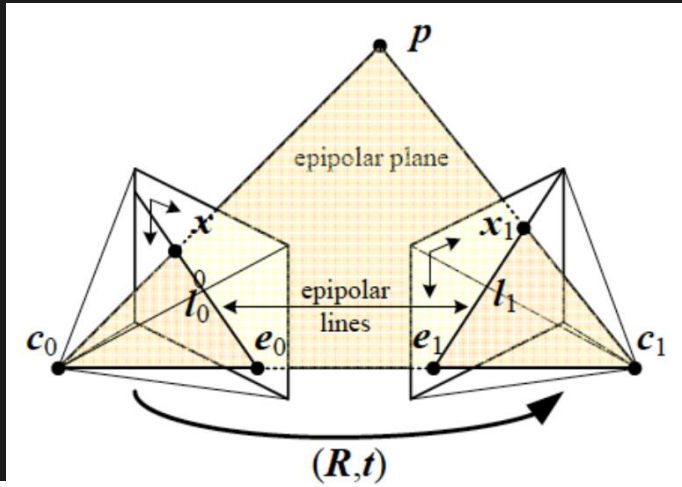


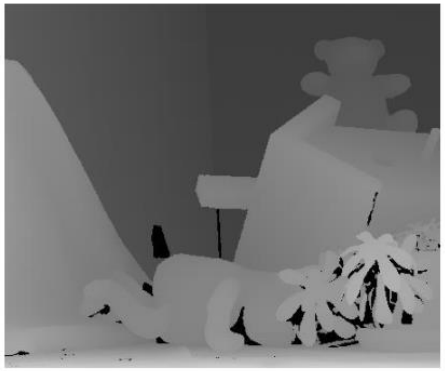


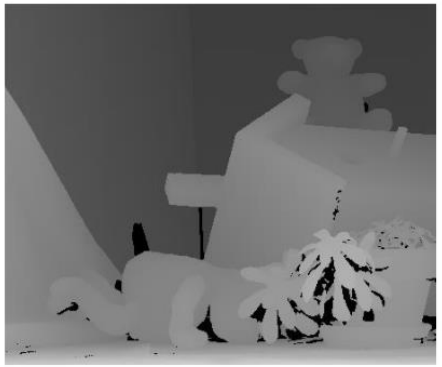


Stereo Vision

- Epipolar geometry, depth estimation

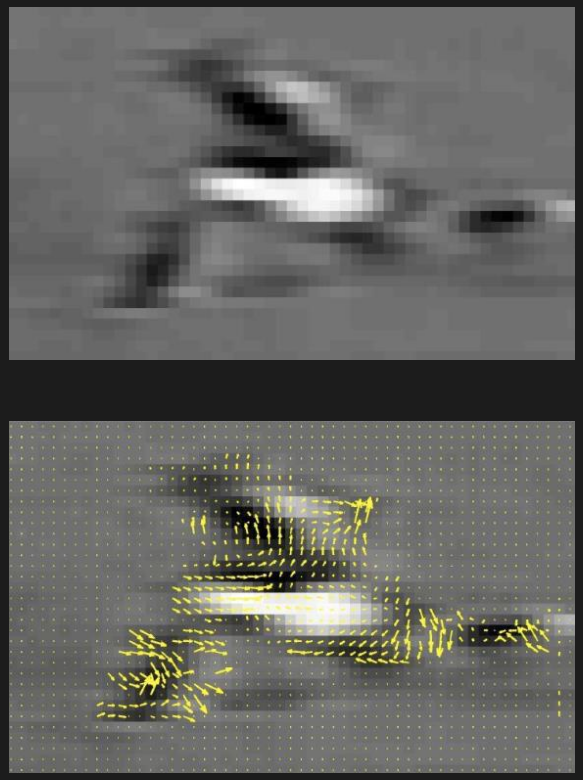




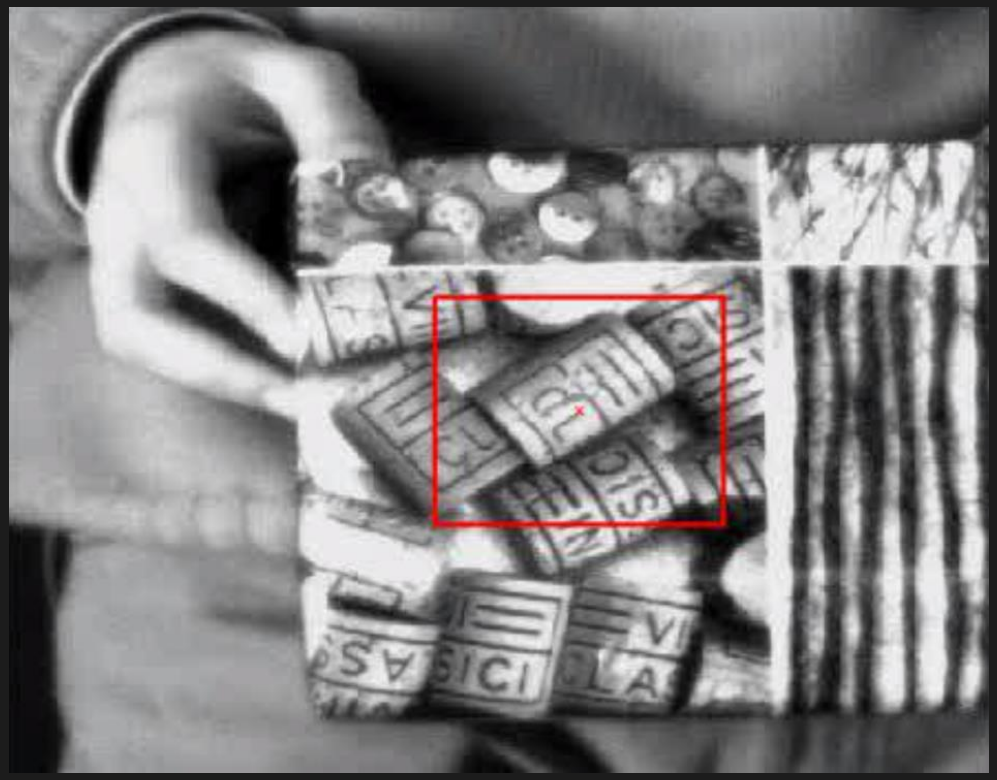


Motion & Tracking

- Optical flow, feature tracking, applications, SSD template tracking



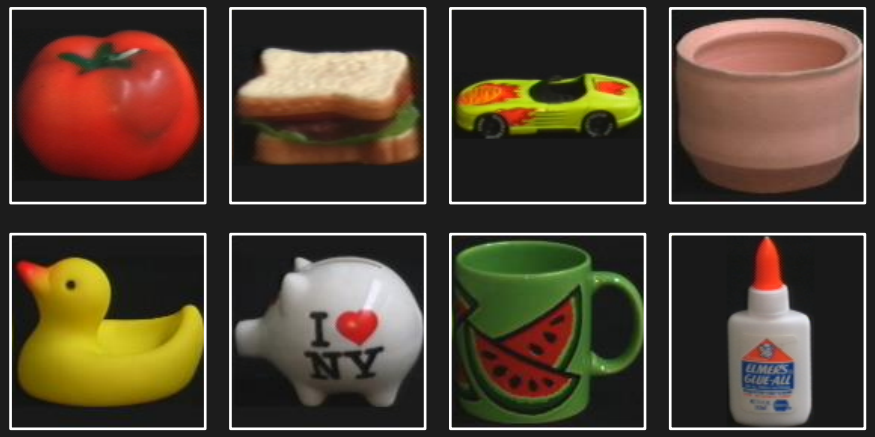
Efros et al.



INRIA

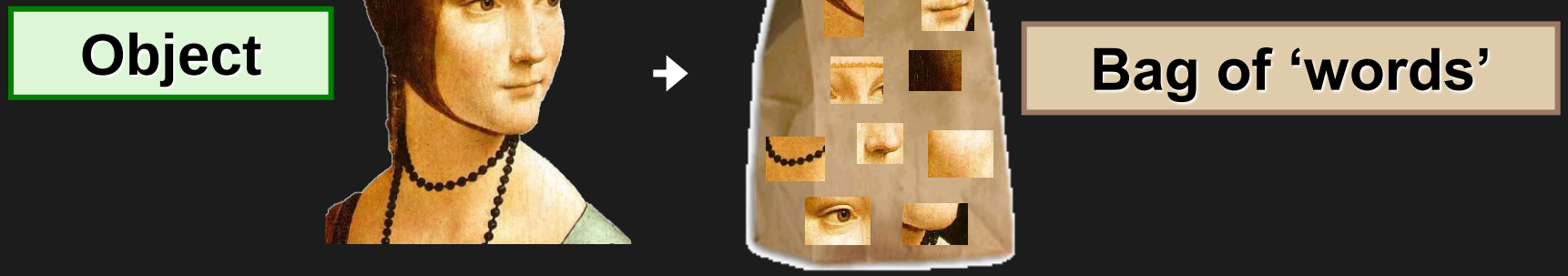
Visual Recognition

- Object recognition by appearance matching, Bag-of-features model



100 Objects Database

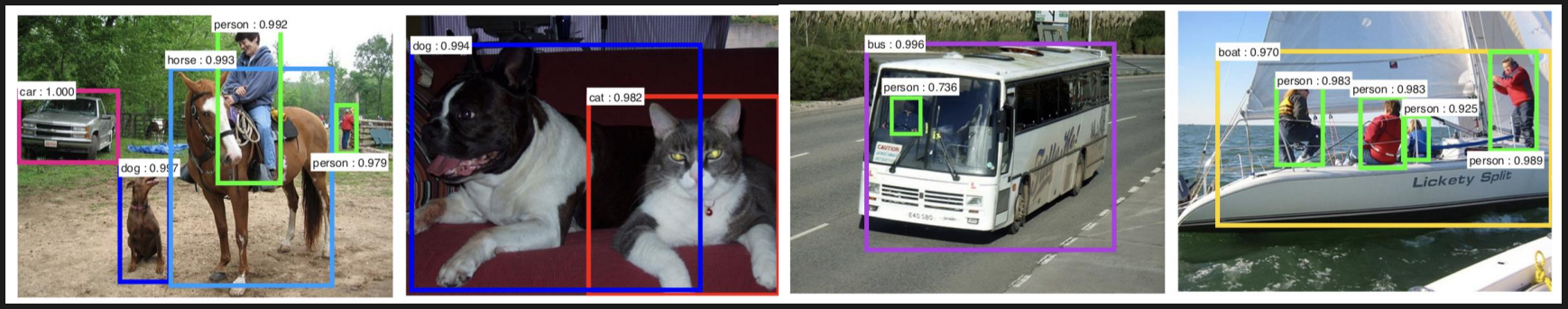
Recognition



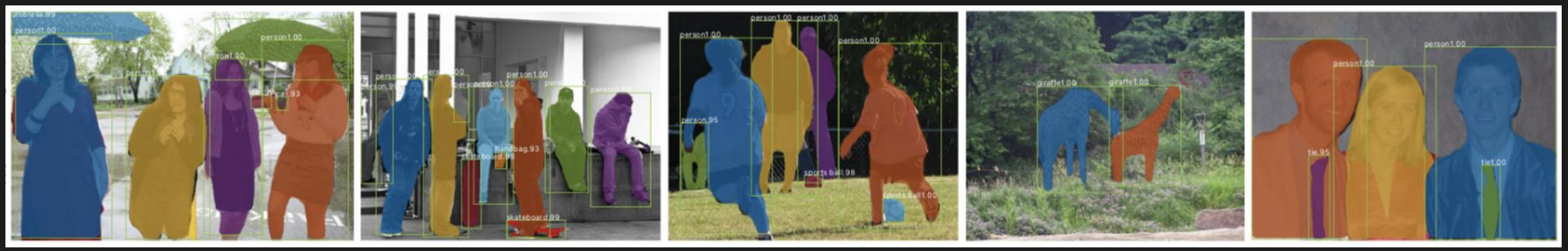
Semantic Segmentation

Chen et al.

Object Detection



Ren et al.



He et al.

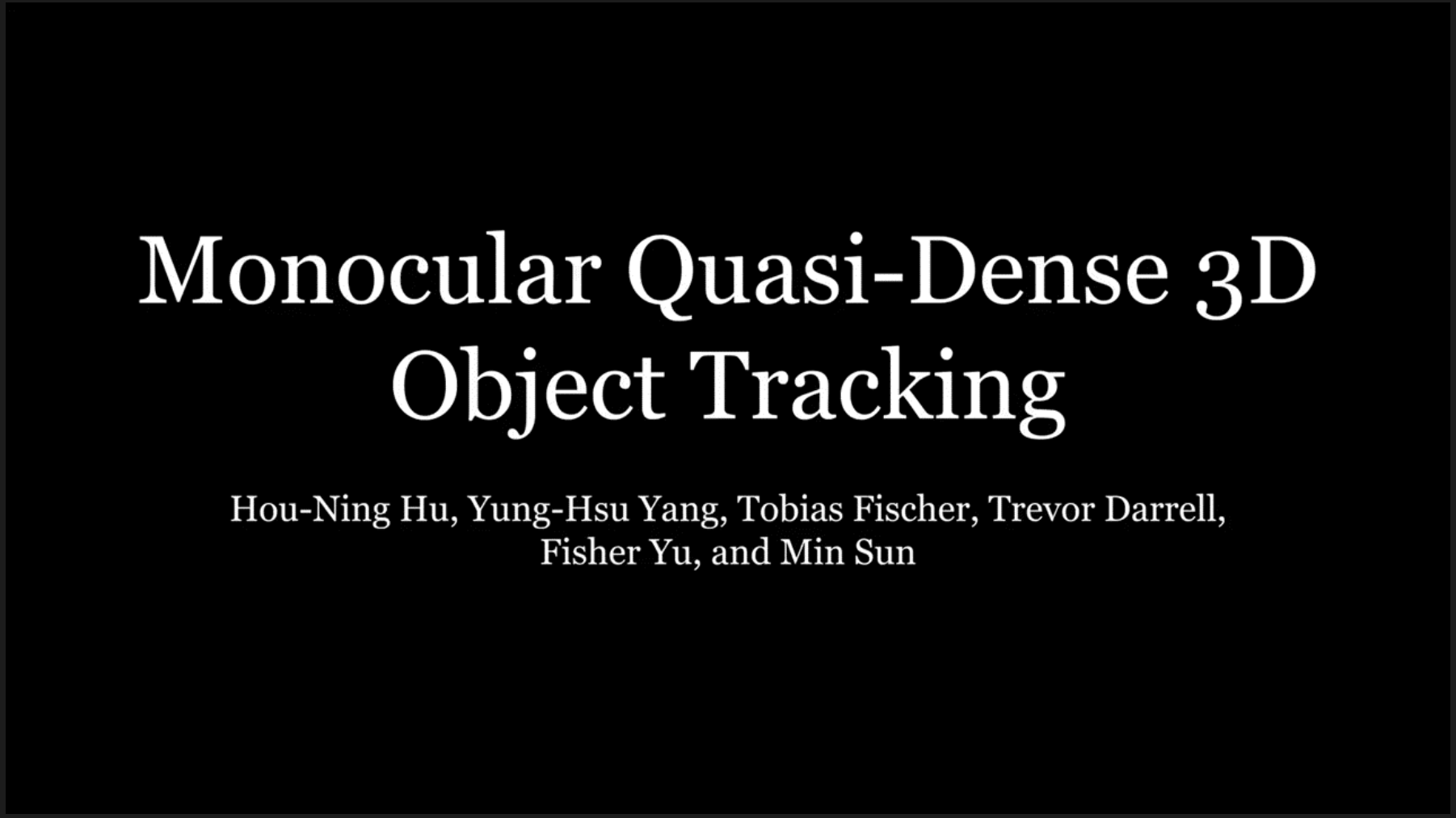
A few videos…

Videos

- Mobile fusion

Videos

- Real-time 3D Object Detection



Videos

- Real-time human pose estimation

Real-time Multi-Person 2D Pose Estimation Using Part Affinity Fields

Zhe Cao, Tomas Simon, Shih-En Wei, Yaser Sheikh

Carnegie Mellon University

Videos

- Robotics

Videos

- AI Agriculture

Videos

- AI Agriculture

What is next?

- Images and image formation
- Basic image operations
- Linear and non-linear filtering

- Please check:
  - Access to CANVAS
  - Access to Python