SAIR

Spatial AI & Robotics Lab

CSE 473/573 - A

COMPUTER VISION & IMAGE PROCESSING

Chen Wang

Spatial AI & Robotics Lab

Department of Computer Science and Engineering

University at Buffalo The State University of New York

Introduction

University at Buffalo
Department of Computer Science and Engineering

CSE 473/573 - Computer Vision and Image Processing

Fall 2024

Section A: TuTh 9:30AM - 10:50AM
Location: NSC 201
Aug 26, 2024 - Dec 9, 2024

Instructor Information

Instructor:	**Chen Wang, PhD. (https://sairlab.org)**
Office:	304 Davis Hall
Email:	Prefers to be contacted through Piazza

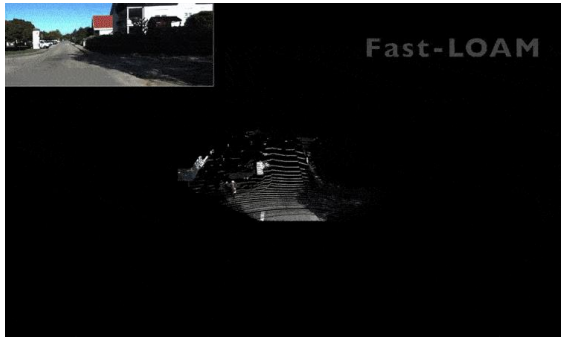
Self-introduction

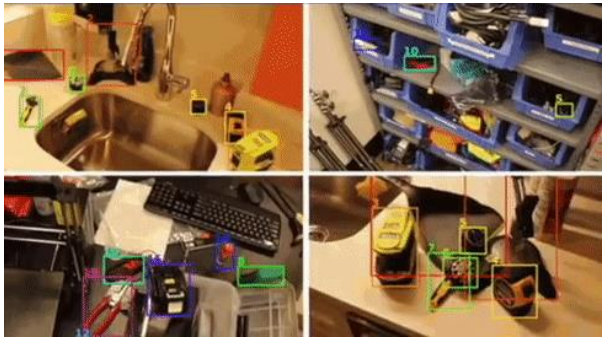
Chen Wang, PhD

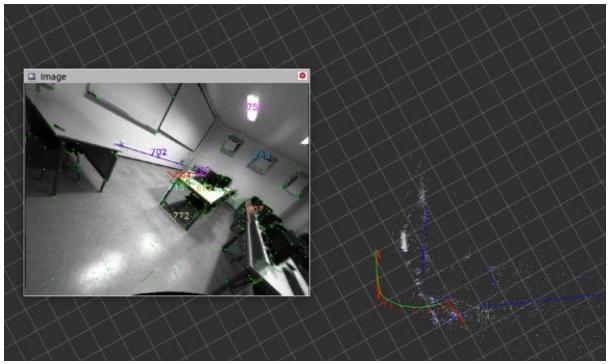
- Assistant Professor, University at Buffalo
- Spatial AI & Robotics Lab (https://sairlab.org)

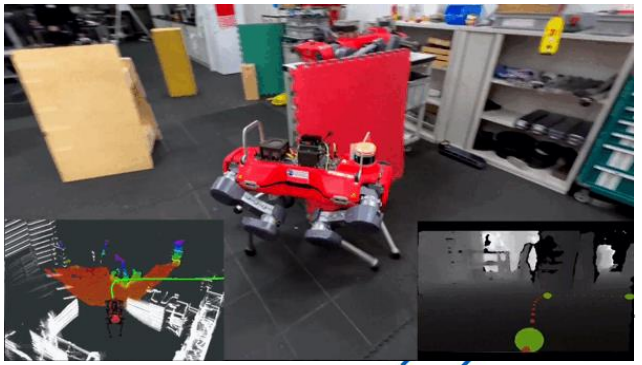
Research Interests

- Robot Perception, Robot Learning, Robot Vision
- Spatial AI, Localization and Mapping
- Application: Robot Autonomy









TA & GTAs:

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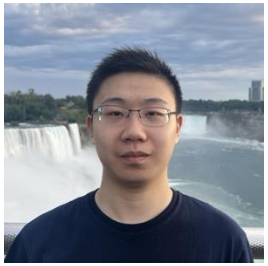
Shijo Varun


Liu Yuxin


Wen Maihan


Chandrashekar Rajath

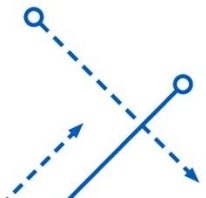

Neogi Debosmit


Devi Varaprasad Reddy Jonnal

Email:	**Prefers to be contacted through Piazza**
Office Hours:	See Piazza – Resources - Staff
Zoom Link:	See Piazza – Resources - Staff
Location:	See Piazza
Piazza	Join through UB Learns.

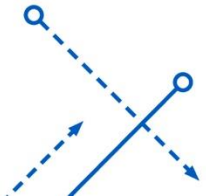
Special Considerations

- Office hours will be a combination of zoom and in person
- Piazza page
  - https://piazza.com/buffalo/fall2024/cse473573a
  - Access code: sairlab
- Slides will be put up one day before class.
- Instructor and TAs will monitor Piazza questions



Course Information

- Lectures, Homework's, Quizzes, Projects and Final Exam over 16-week semester.
- This course is an introduction to those areas of Artificial Intelligence that deal with fundamental issues and techniques of **computer vision** and **image processing**.
- The emphasis is on **physical, mathematical, and information-processing aspects** of the vision.
- Topics to be covered include **image formation, edge detection and segmentation, convolution, image enhancement techniques, extraction of features such as color, texture, and shape, object detection, 3-D vision, and their applications.**
- The material is based on graduate-level texts augmented with research papers, as appropriate.



Overview

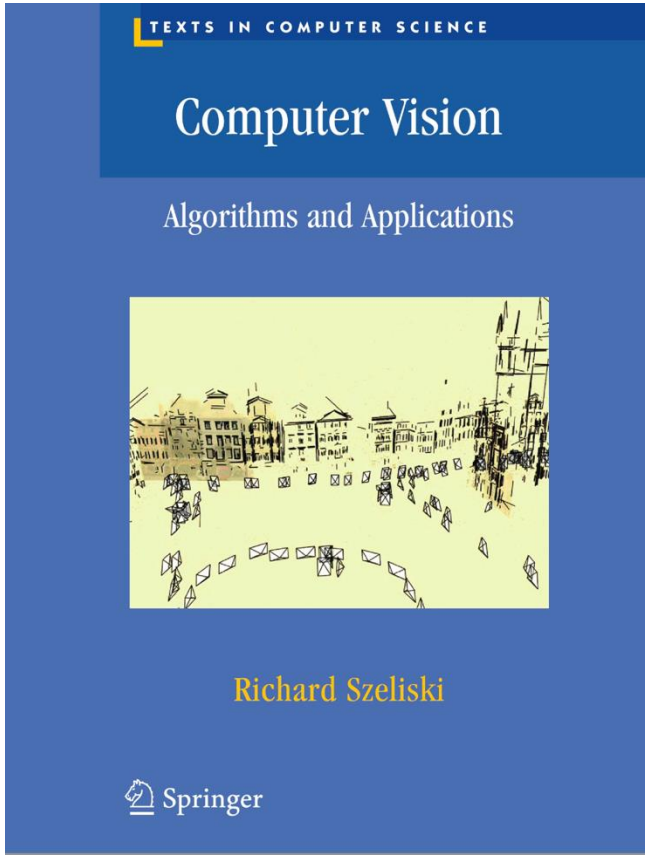
- The course will move fast.
- Self-discipline is important.
- The emphasis of the course is to develop practical skills for solving **Computer Vision** and **Image Processing** problems
- **Fair evaluations: undergraduate and graduate students will be scored separately**
- Academic Integrity (AI) will be taken seriously and zero tolerance to any cheating (work on homework and projects independently)
- ChatGPT and Copilot are not allowed.

Prerequisites:

- CSE 203
  - Data Structure
- Strong Knowledge of Linear Algebra
- Strong Programming Experience in Python
- Git & GitHub:
  - https://www.coursera.org/learn/introduction-git-github

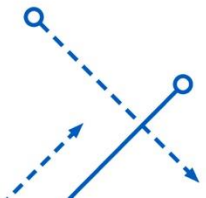
Textbook

- Computer Vision: Algorithms and Applications, by Richard Szeliski



Course Requirements

- Class attendance and participation is expected.
- You are responsible for ALL materials presented in class and assigned to read.
- Quizzes will be given during class time only.
- There will be **three** projects
- Regular deliverables on the projects will be graded during the course.



Grading

Weighting	Assessment	Number
20%	Homeworks	4
20%	Quizzes	5
30%	Projects	3
30%	**Final:** 12/17/2024, 8:00AM - 10:00AM, NSC 201	1

Today: Quiz 0

Grading Table

1. Undergraduate Version

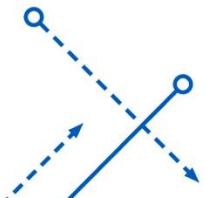
Score	Letter Grade	Score	Letter Grade
[85,100]	A	[52,58)	C+
[80,85)	A-	[46,52)	C
[73,80)	B+	[41,46)	C-
[65,73)	B	[40,41)	D
[58,65)	B-	[0,40)	F

2. Graduate Version

Score	Letter Grade	Score	Letter Grade
[87,100]	A	[55,60)	C+
[82,87)	A-	[50,55)	C
[75,82)	B+	[46,50)	C-
[67,75)	B	[45,46)	D
[60,67)	B-	[0,45)	F

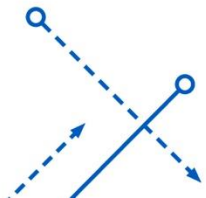
Grading and Submissions

- All assignments will be graded out of 100 points
- **Failure Tolerance**: We will drop **ONE homework or Quiz** Grade, whichever results in a **higher** overall grade.
- All assignments/projects will be turned in via UB Learns.
- GitHub Class will be used to record your coding history.
  - Used to detect AI issues.
- Quizzes will be given online through the UB Learns system.



Late Submission Policy

- Completed homework and project deliverables are to be submitted by their deadline (11:59pm).
- Grace days: You will be allowed a total of 3 grace days throughout the semester
  - Can be used for either homework or project.
- Submissions beyond the 3 grace days will reduce your grade by 50%;
- No individual project/homework will be accepted after 3 days late. No additional late days allowed.



Exam Policy

- No makeup exams will be given except in **provably extreme circumstances** and when consistent with University Policy. Use your “failure tolerance” first.
- Notify your instructor **1 month prior to the exam** via **e-mail** if you are going to miss it. If it is medically impossible for you to give prior notice, please obtain **a note from a physician detailing the period** (with reasons) you were medically incapable of communicating with the instructor.
- If you miss an exam/quiz because of sickness or similar reasons, visit a physician and obtain a note detailing the period and the reason you were medically incapable of taking the exam/quiz.
- You are responsible for knowing about the exam date. Please plan your travel and other activities accordingly.

Regrading for Errors

- Assignments, quizzes and exams may be submitted for regrading to correct grading errors.
- Regrade requests are due **no later than one (1) week** after the scores are posted.
- Regrade requests must be **clearly written and attached** to the assignment.
- When work is submitted for regrade, the entire work may be regraded, **which may result in a lower grade.**
- Work done in pencil may not be considered for regrading.

Questions?

Disabilities

- If you have a diagnosed disability (physical, learning, or psychological) that will make it difficult for you to carry out the course work as outlined, or that requires accommodations such as recruiting note-takers, readers, or extended time on exams or assignments, please **advise the instructor during the first two weeks of the course** so that we may review possible arrangements for reasonable accommodations.
- In addition, if you have not yet done so, contact the **Office of Disability Services**.

Academic Integrity

- All work must be your own
  - Do not take the answers, words, ideas or research findings of other people as yours; cite and acknowledge properly, and develop your own ideas.
  - No cheating
  - According to departmental policy, any violation of academic integrity will result in an “F” for the course, and termination of departmental financial scholarship.
  - Tools will be used to check similarity. **Similar submissions will result in “F” for all involved parties.**
- Use of a code from an online repository, e.g., GitHub, must include a proper and clearly visible attribution in your report.

How to Fail the Course

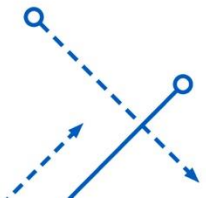
- Don't meet the prerequisites
- Don't pay attention to information on Piazza
- Start your project at the last minute
- Wait until the deadline to submit for the first time
- Don't read the syllabus carefully (Academic Integrity violation and late submission policy etc.)
- **Cheat (please check AI policy of the university and department if you are new)**
- https://catalog.buffalo.edu/policies/integrity.html

Questions?

- **Instructors/TA/Graders will stay for a few minutes after each lecture. Simply ask!**
- Syllabus and Slides are on Piazza.

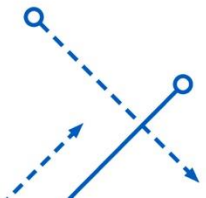
Content

- Definition
- History
- Research Topics
- Applications
- Quiz 0
  - UB Learn, Academic Integrity Letter

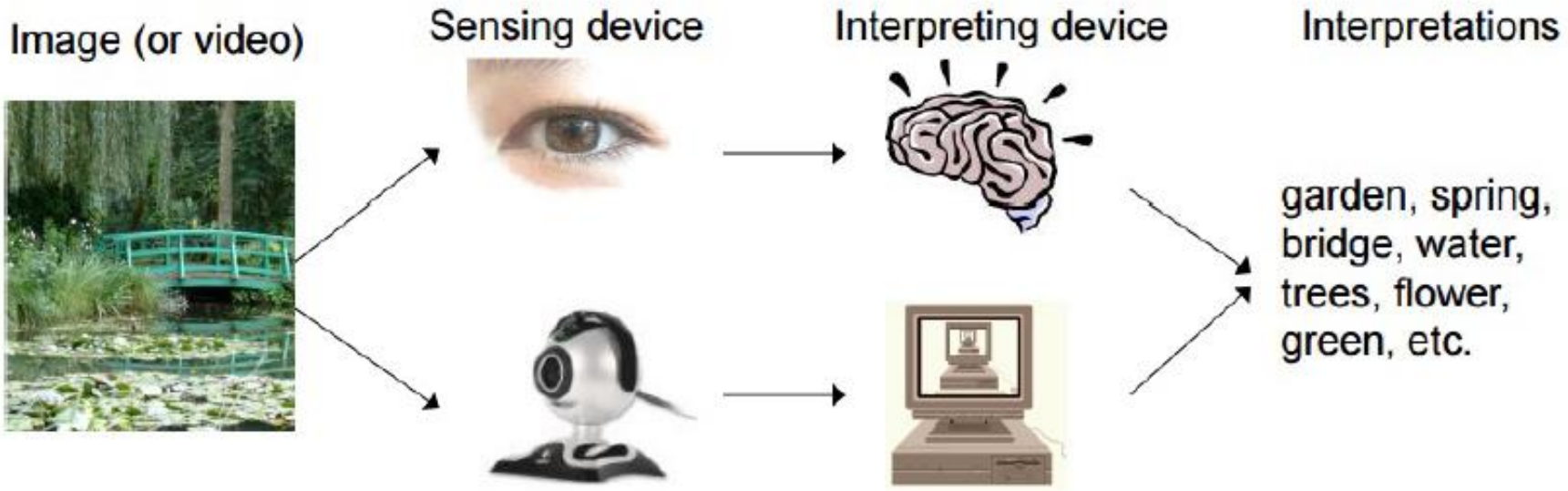


What is Computer Vision

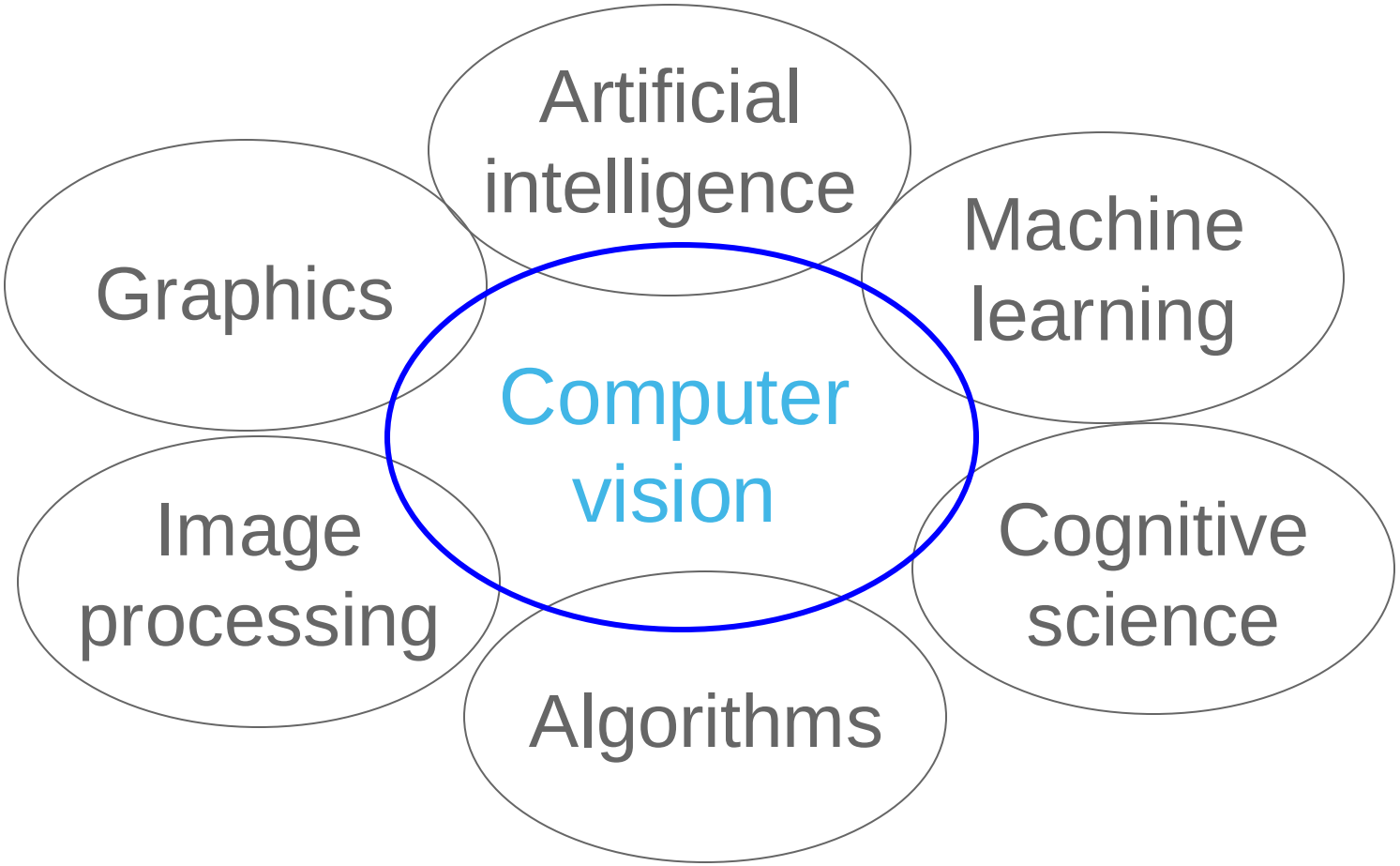
- **Computer vision** is a field of **computer science**
  - works on enabling **computers** to see,
  - identify and process images in the same way that human **vision** does, and
  - then provide proper output.
- It is like imparting human intelligence and instincts about vision to a **computer**.



Computer Vision vs Human Vision



Related disciplines



(Brief) History of Computer Vision

- In 1966, Marvin Minsky at MIT asked his undergraduate student Gerald Jay Sussman to "spend the summer linking a camera to a computer and getting the computer to describe what[illegible]w know that the problem is sli[illegible]cult than that. (Szeliski 2009[illegible]ion)

Marvin Minsky

From Wikipedia, the free encyclopedia

Marvin Lee Minsky (August 9, 1927 – January 24, 2016) was an American cognitive scientist concerned largely with research of artificial intelligence (AI), co-founder of the Massachusetts Institute of Technology's AI laboratory, and author of several texts concerning AI and

Marvin Minsky

Minsky in 2008

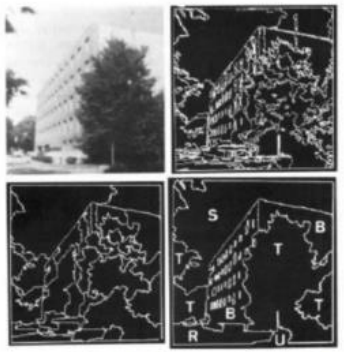
Born	Marvin Lee Minsky August 9, 1927 New York City, New York, U.S.
Died	January 24, 2016 (aged 88) Boston, Massachusetts, U.S.

…identify and process images in the same way that human **vision** does…

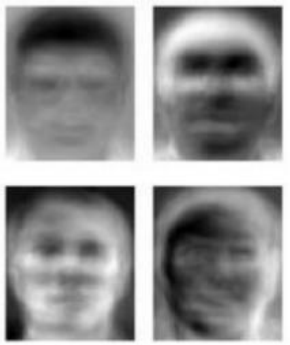
A Brief History of Computer Vision

- 1966: Minsky assigns computer vision as an undergrad summer project
- 1960's: interpretation of synthetic worlds
- 1970's: some progress on interpreting selected images
- 1980's: ANNs come and go; shift toward geometry and increased mathematical rigor
- 1990's: face recognition; statistical analysis in vogue
- 2000's: broader recognition; large annotated datasets available; video processing starts
- 2010's: Deep learning with ConvNets

Guzman '68

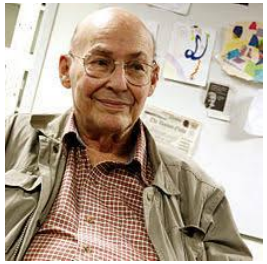


Ohta Kanade '78



Turk and Pentland '91

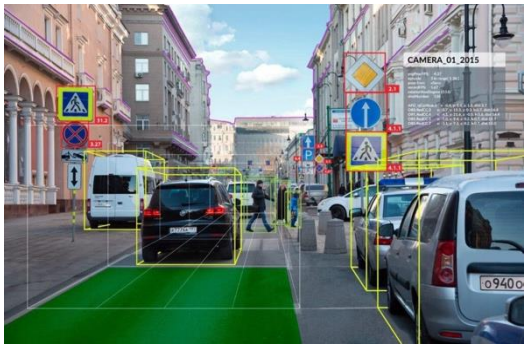
Timeline



1970 1980 1990 2000

Digital image processing
Blocks world, line labeling
Generalized cylinders
Pictorial structures
Stereo correspondence
Intrinsic images
Optical flow
Structure from motion
Image pyramids
Scale-space processing
Shape from shading, texture, and focus
Physically-based modeling
Regularization
Markov Random Fields
Kalman filters
3D range data processing
Projective invariants
Factorization
Physics-based vision
Graph cuts
Particle filtering
Energy-based segmentation
Face recognition and detection
Subspace methods
Image-based modeling and rendering
Texture synthesis and inpainting
Computational photography
Feature-based recognition
MRF inference algorithms
Category recognition
Learning

Computer Vision vs Computer Graphics



Digital Image Processing
Computational Photography

Computer Vision

Images (2D)

Geometry (3D)
Shape

\+

Photometry
Appearance

Computer Graphics

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Example: Visual Effects need CV + CG

Image Processing vs. Computer Vision

- Image Processing
  - Research area within electrical engineering/signal processing
  - Focus on syntax, low level features

image

image
(Denoising/inpainting)

- Computer Vision
  - Research area within computer science/artificial intelligence
  - Focus on semantics, symbolic or geometric descriptions

image

Faces, People
Chairs, etc.

(Recognition/Detection)

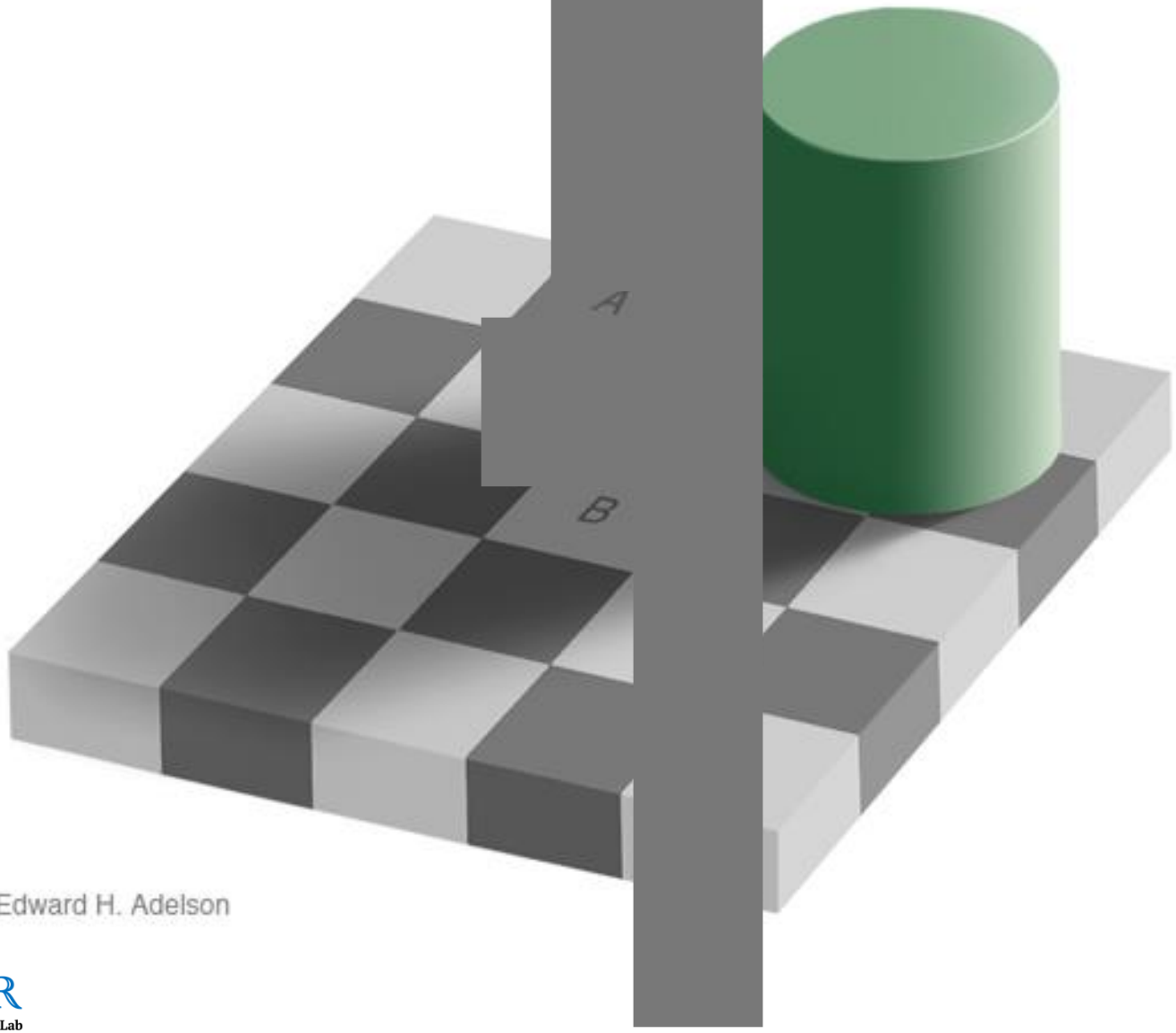
Image & Goal

An image is an array of numbers (pixels).

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

- To Bridge the Gap between Pixels and Meaning

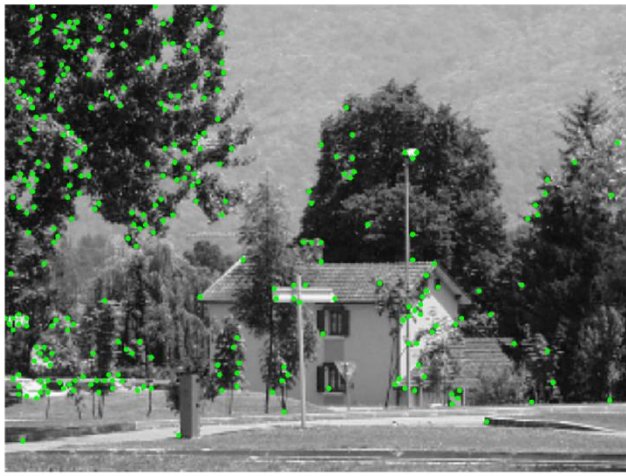
Which one is brig r? A or B?



Edward H. Adelson

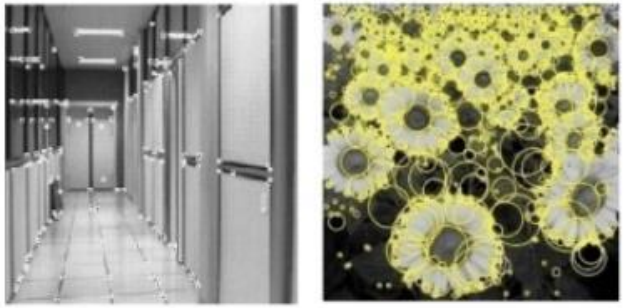
Feature Extraction





- Basic image processing and image formation

Filtering, edge detection



Feature extraction

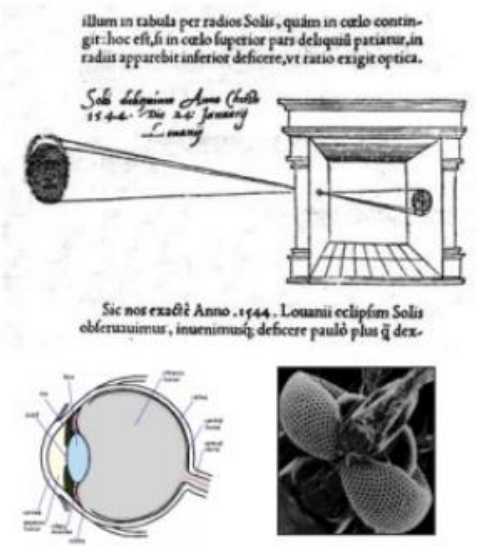
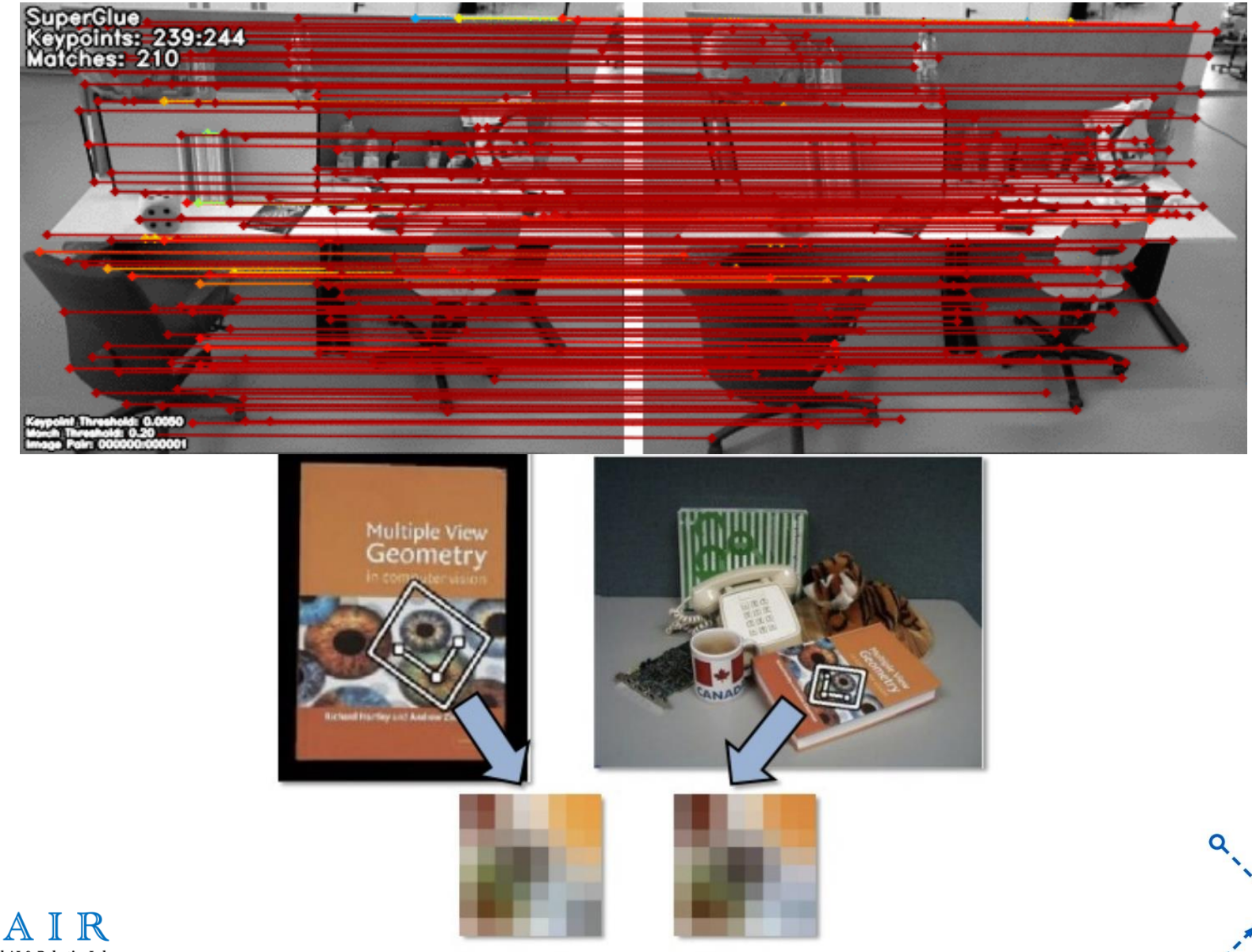
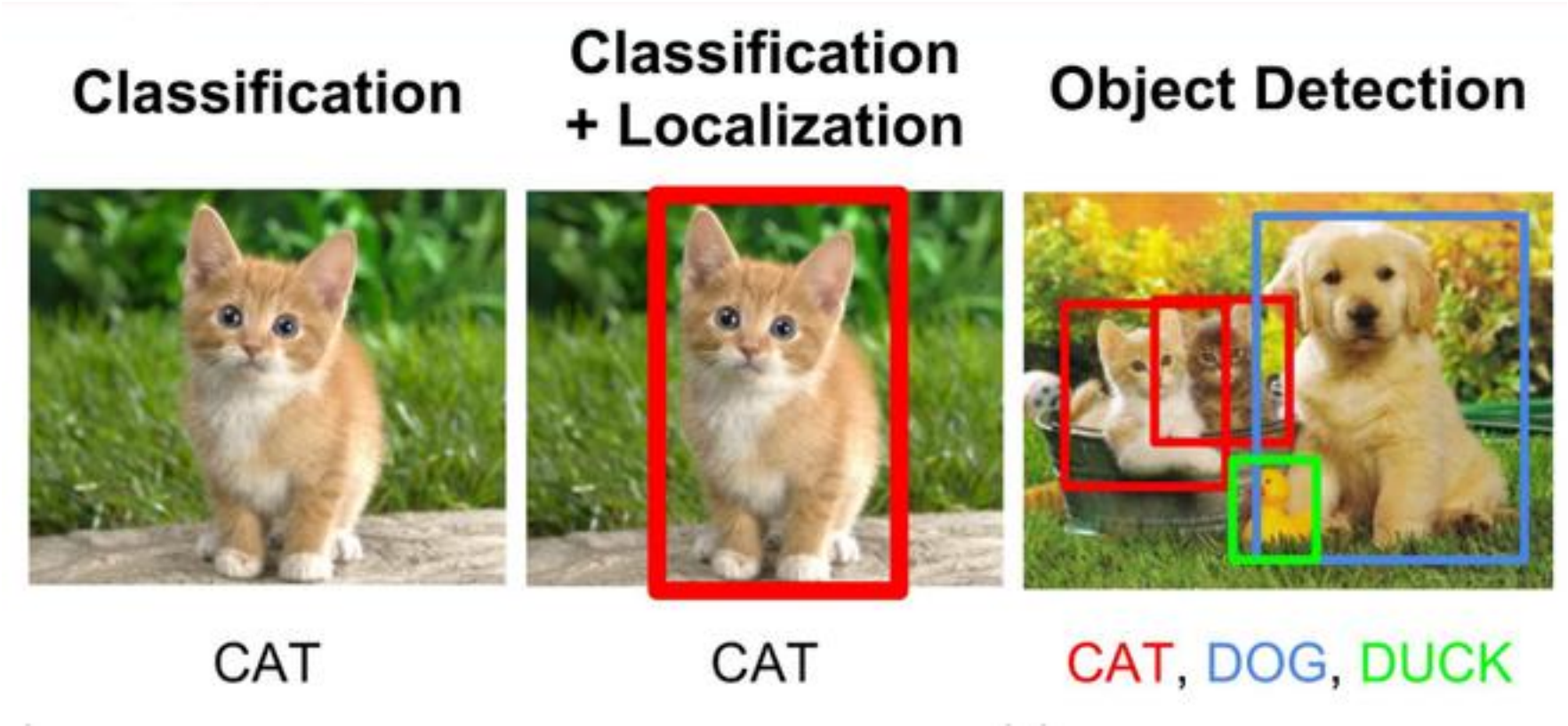


Image formation

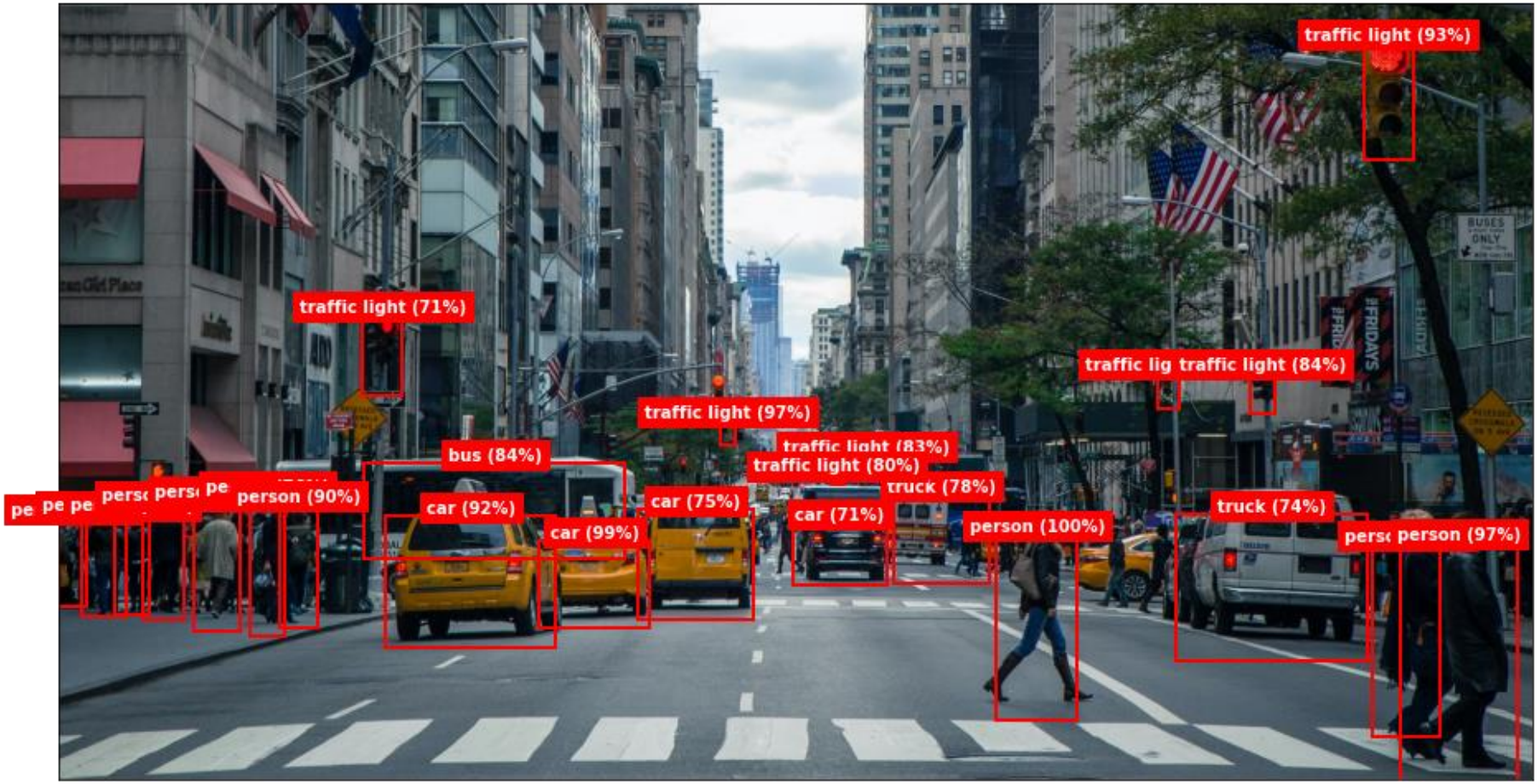
Feature Matching



Recognition and Detection

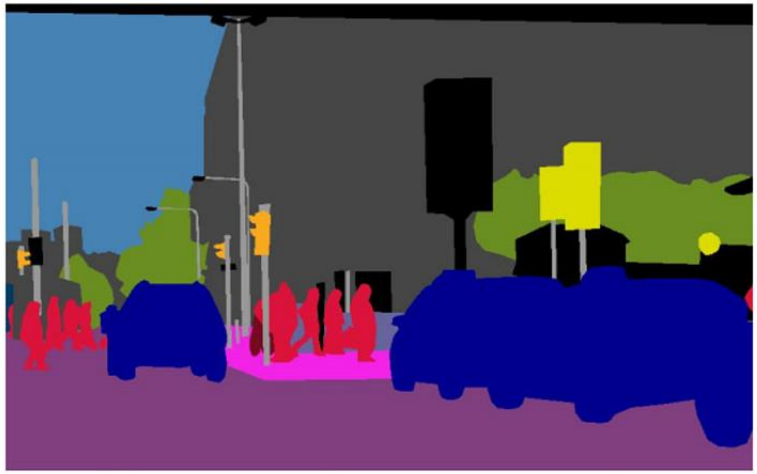


Detection

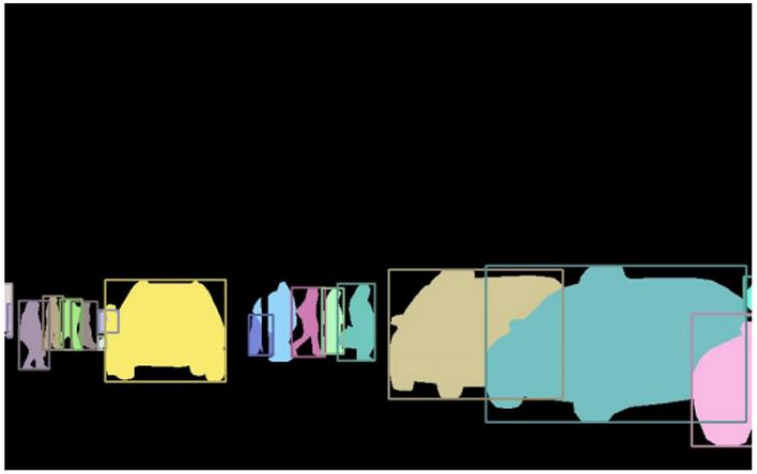

traffic light (93%)
traffic light (71%)
traffic lig traffic light (84%)
traffic light (97%)
traffic light (83%)
traffic light (80%)
bus (84%)
truck (78%)
car (92%)
car (75%)
car (71%)
car (99%)
person (100%)
truck (74%)
person (90%)
person (97%)

Segmentation

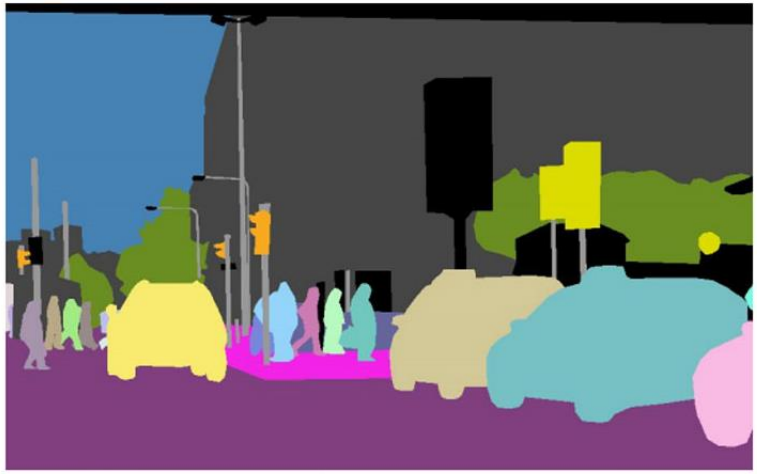
(a) image



(b) semantic segmentation

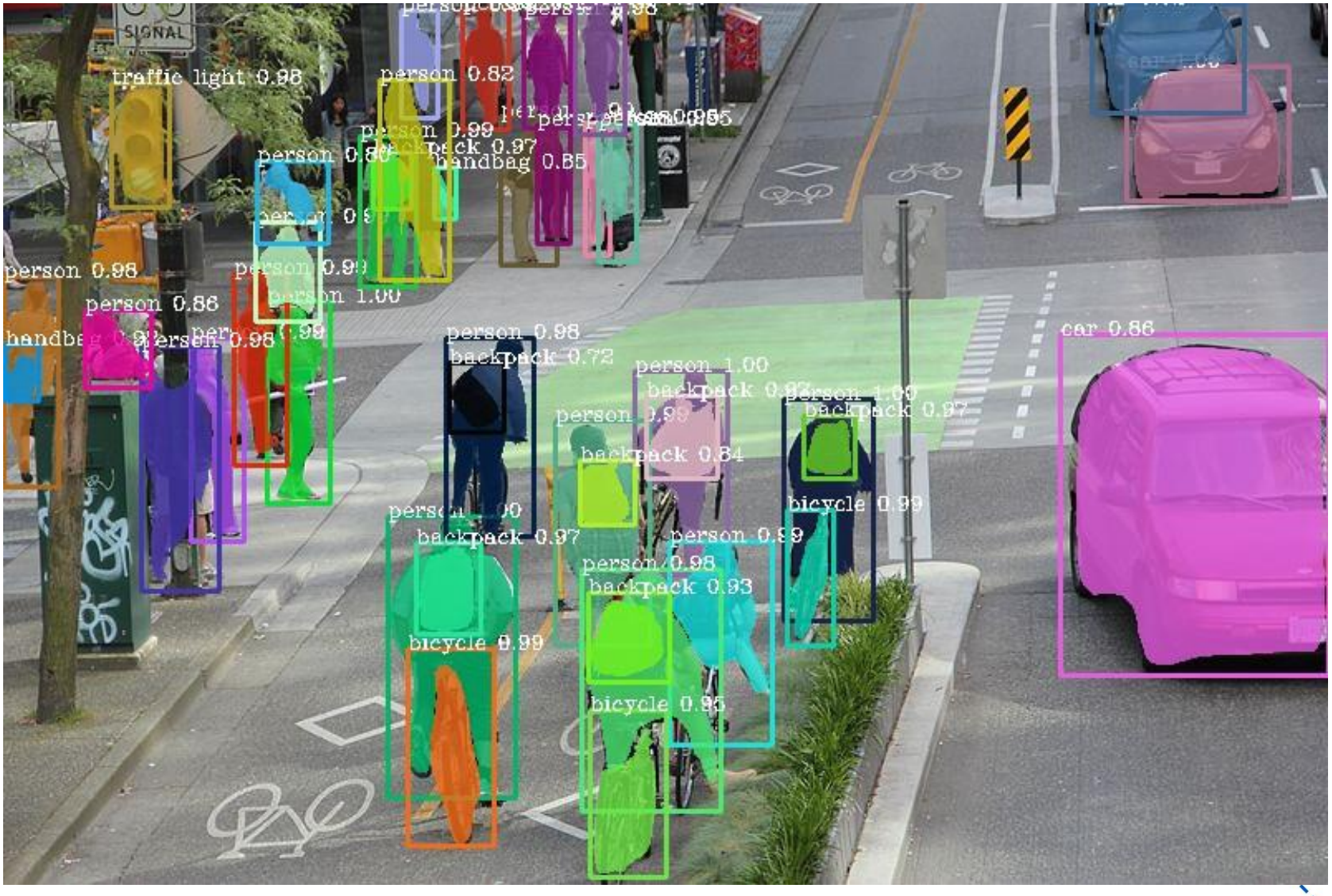


(c) instance segmentation



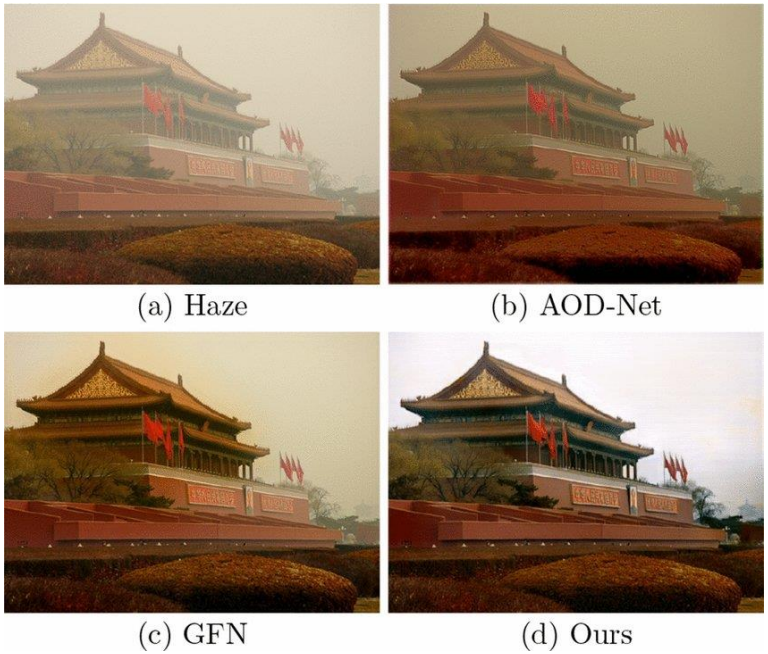
(d) panoptic segmentation

Detection + Segmentation



Inpainting

Denoising (Dehazing, Deblurring)



(a) Haze (b) AOD-Net

(c) GFN (d) Ours

Super Resolution

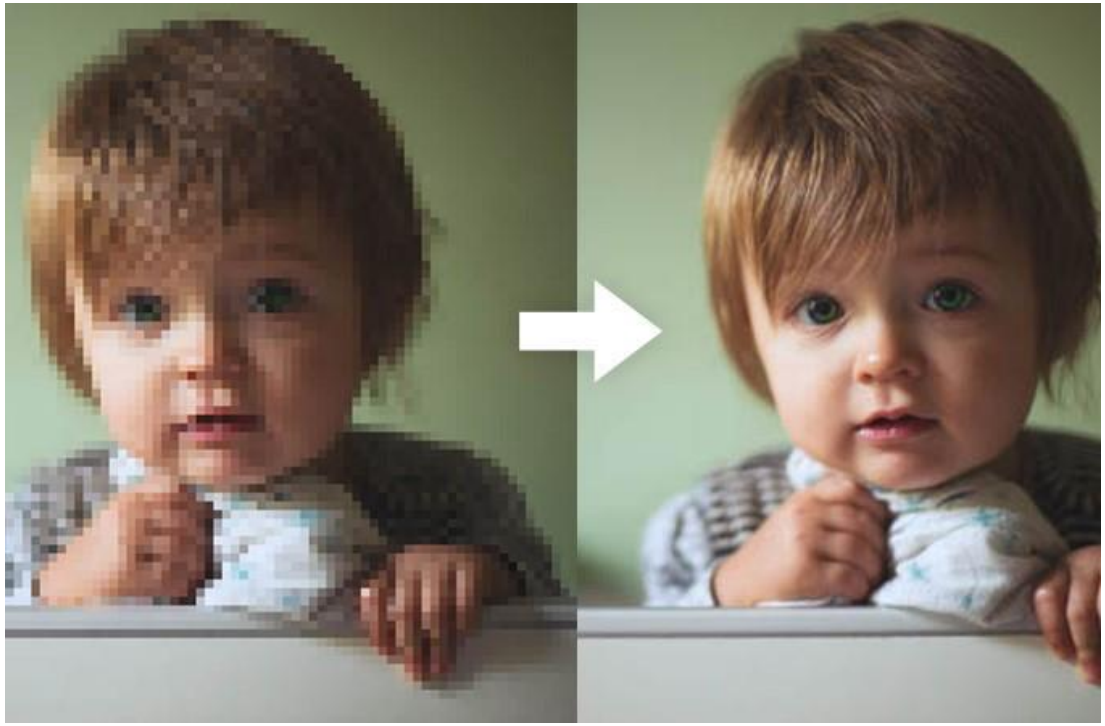
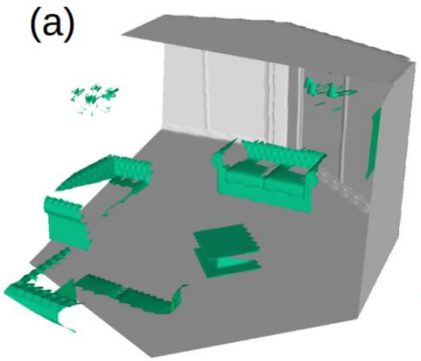


Image Stitching: Panorama

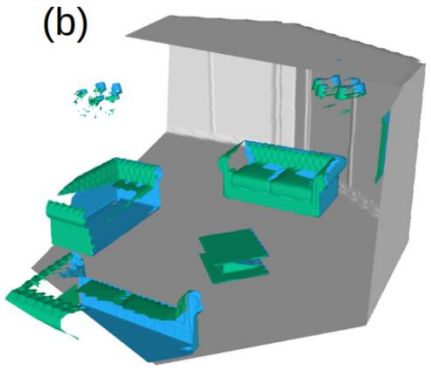
Example: Google Street View

3D Reconstruction (RGB/RGBD)

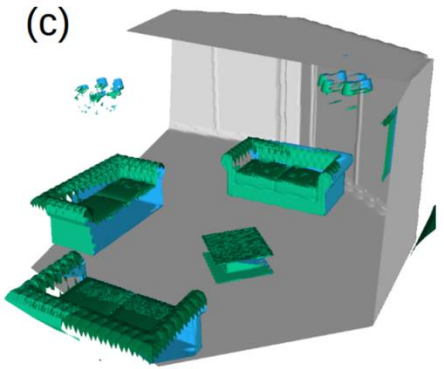
RGB Image



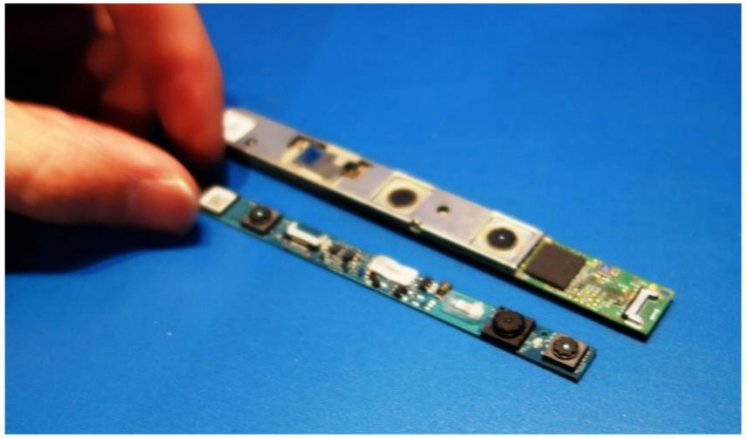
2.5D Object Surfaces



Multi-layer Surfaces



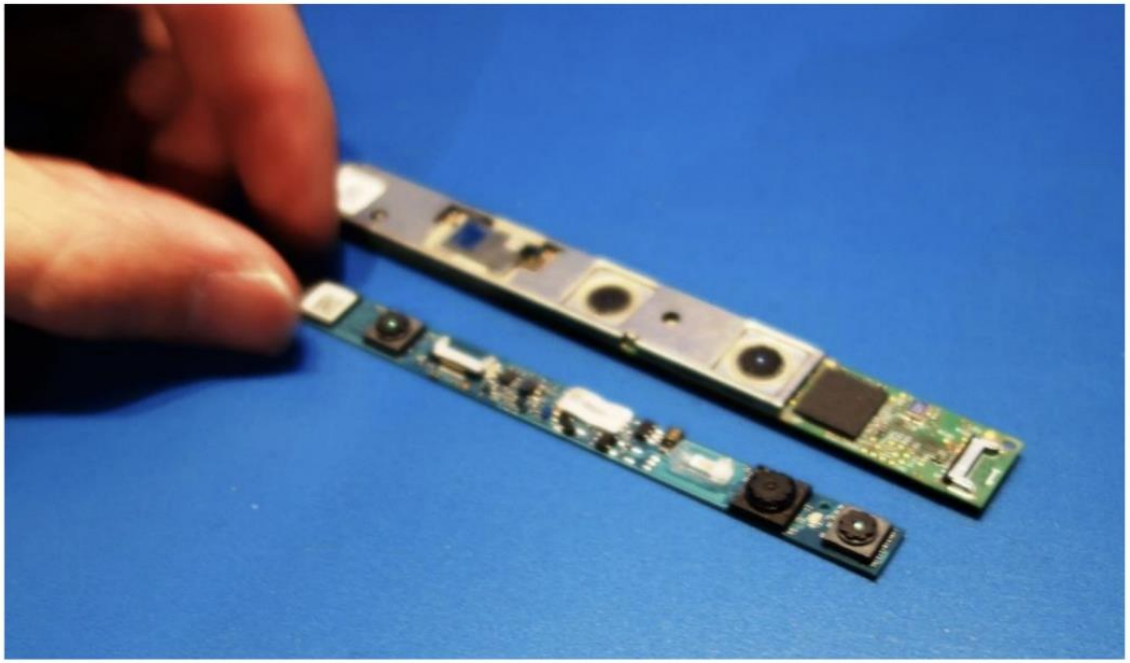
Multi-layer and
Virtual-view Surfaces

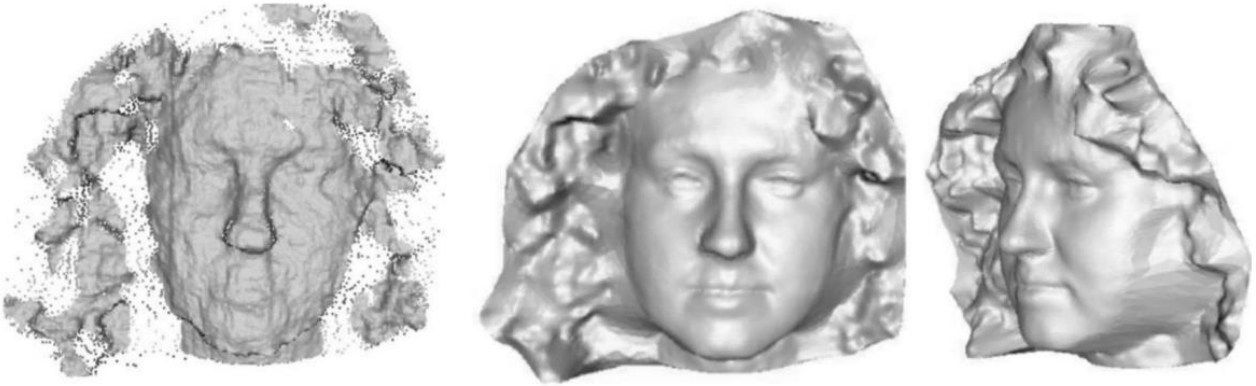


Single depth frame

Reconstructed 3D mesh

Shape Reconstruction using depth sensors





Single depth frame

Reconstructed 3D mesh

Single View Modeling

Can you do single view modeling?

Can you do single view modeling?

Visual Question and Answering (VQA)

What color are her eyes?
What is the mustache made of?

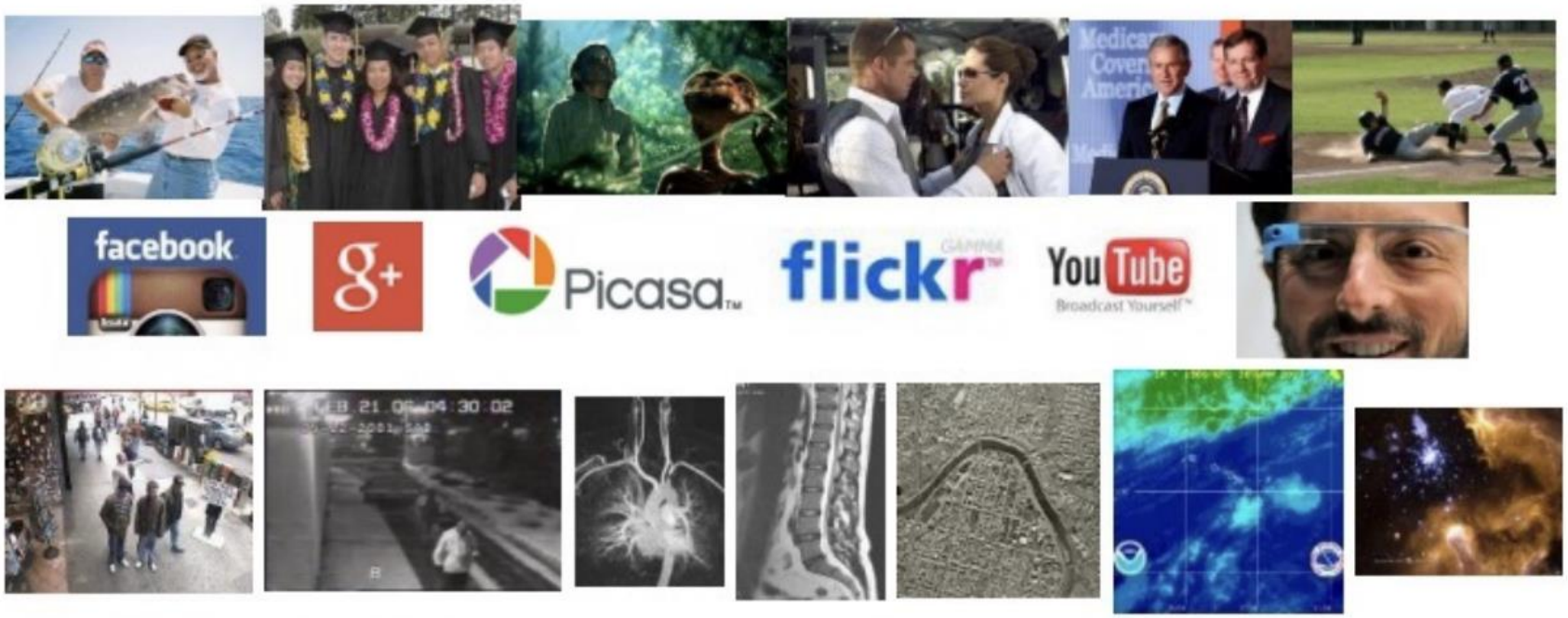
How many slices of pizza are there?
Is this a vegetarian pizza?

Is this person expecting company?
What is just under the tree?

Does it appear to be rainy?
Does this person have 20/20 vision?

Why learn Computer Vision?

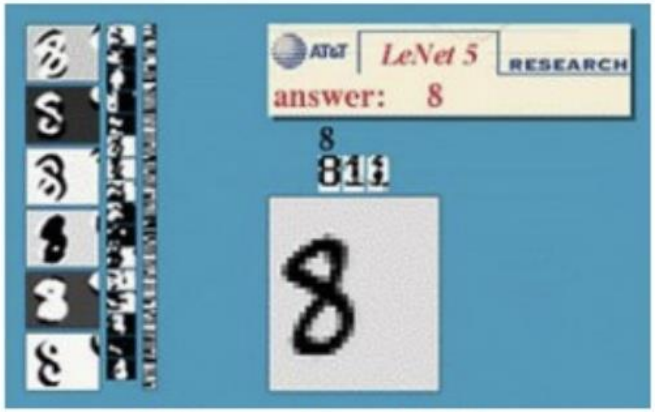
- One third of human brain devoted to vision.
- Millions of images being captured all the time.



What are some other Applications?

Everyday Applications - OCR

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



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

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

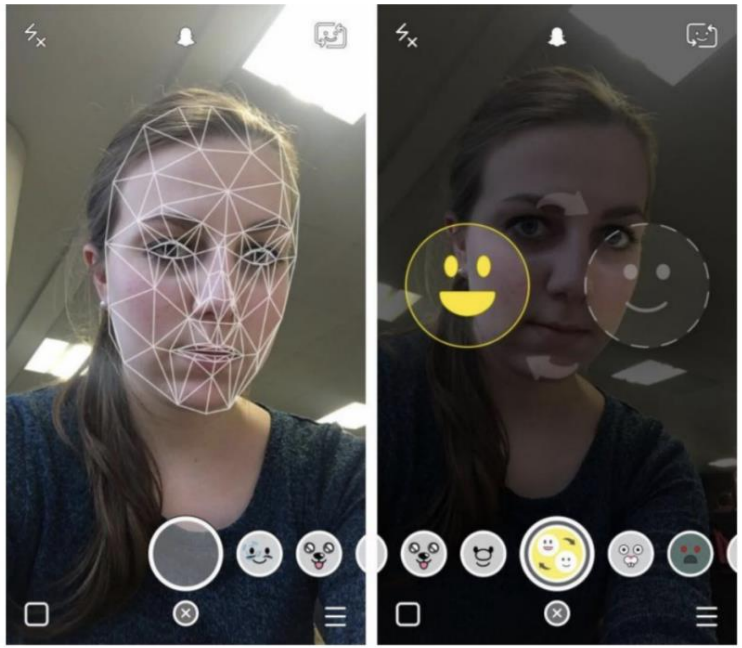
Automatic check processing

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

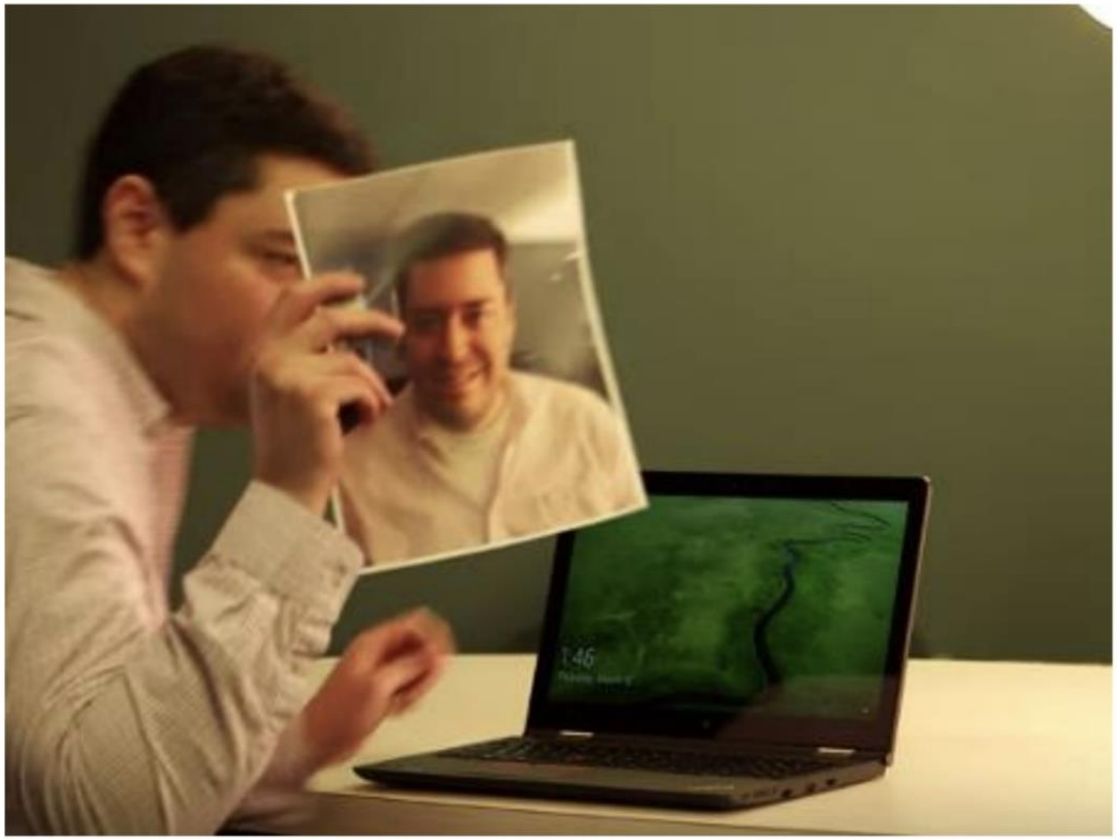
Source: S. Seitz

Object Recognition

Face Detection



Face Recognition

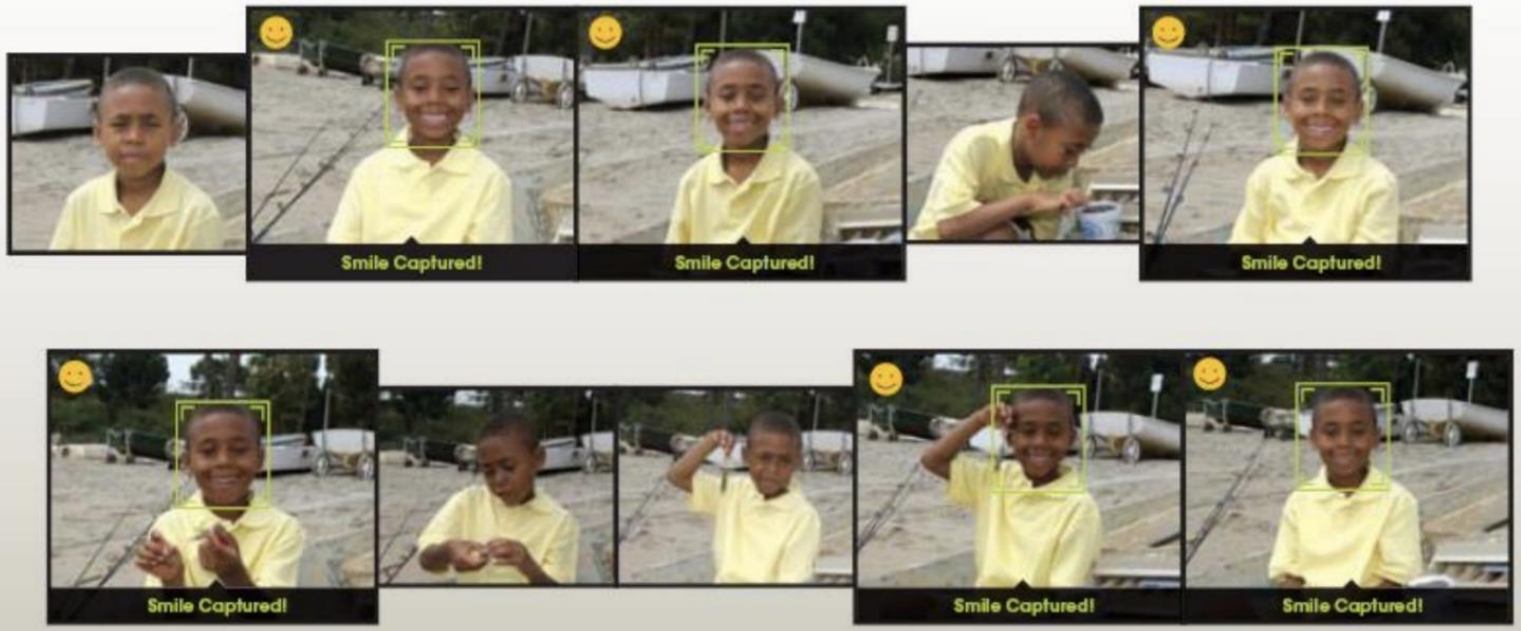


How to solve this problem?

Smile Detection

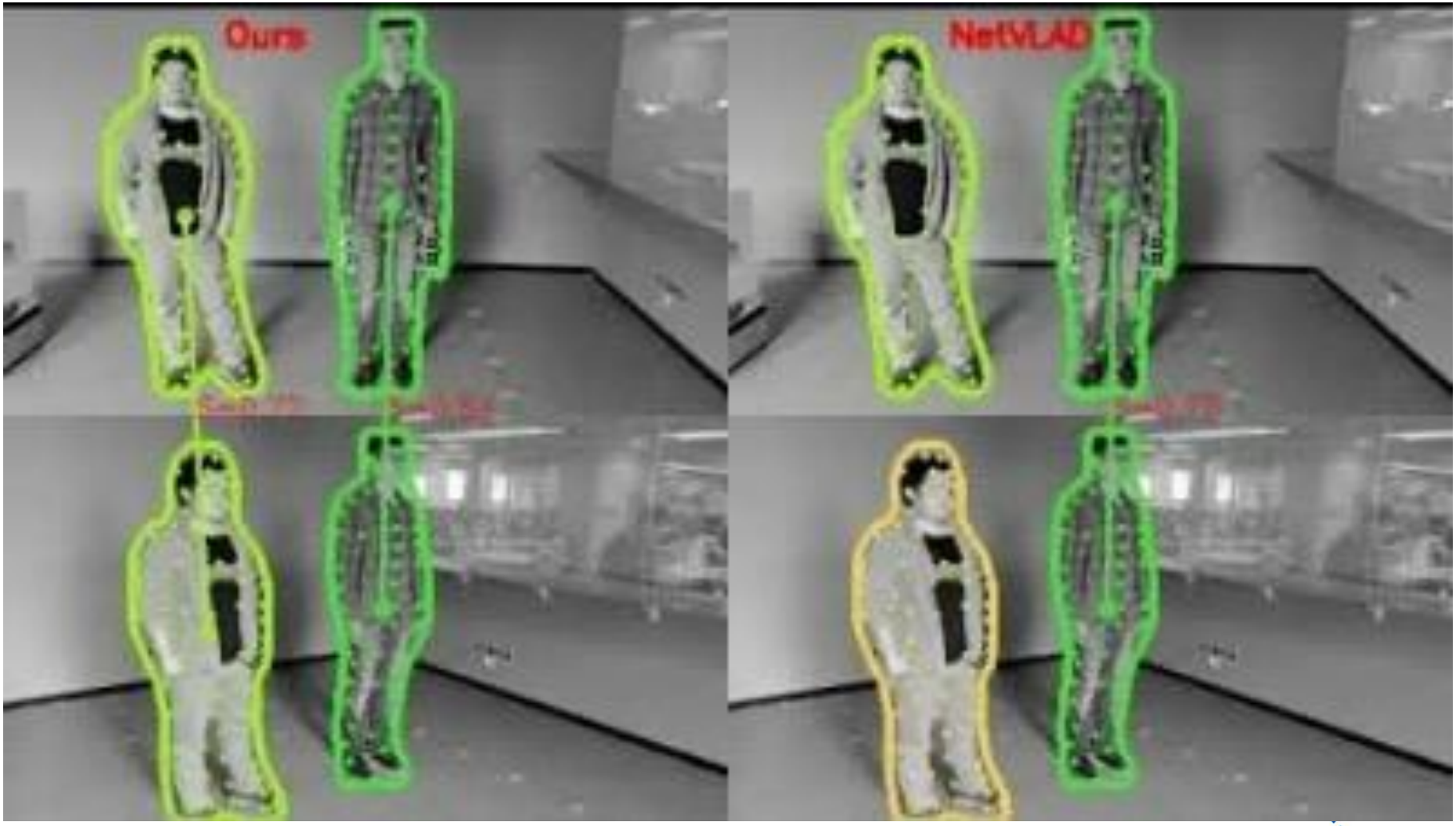
The Smile Shutter flow

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.



Entertainment

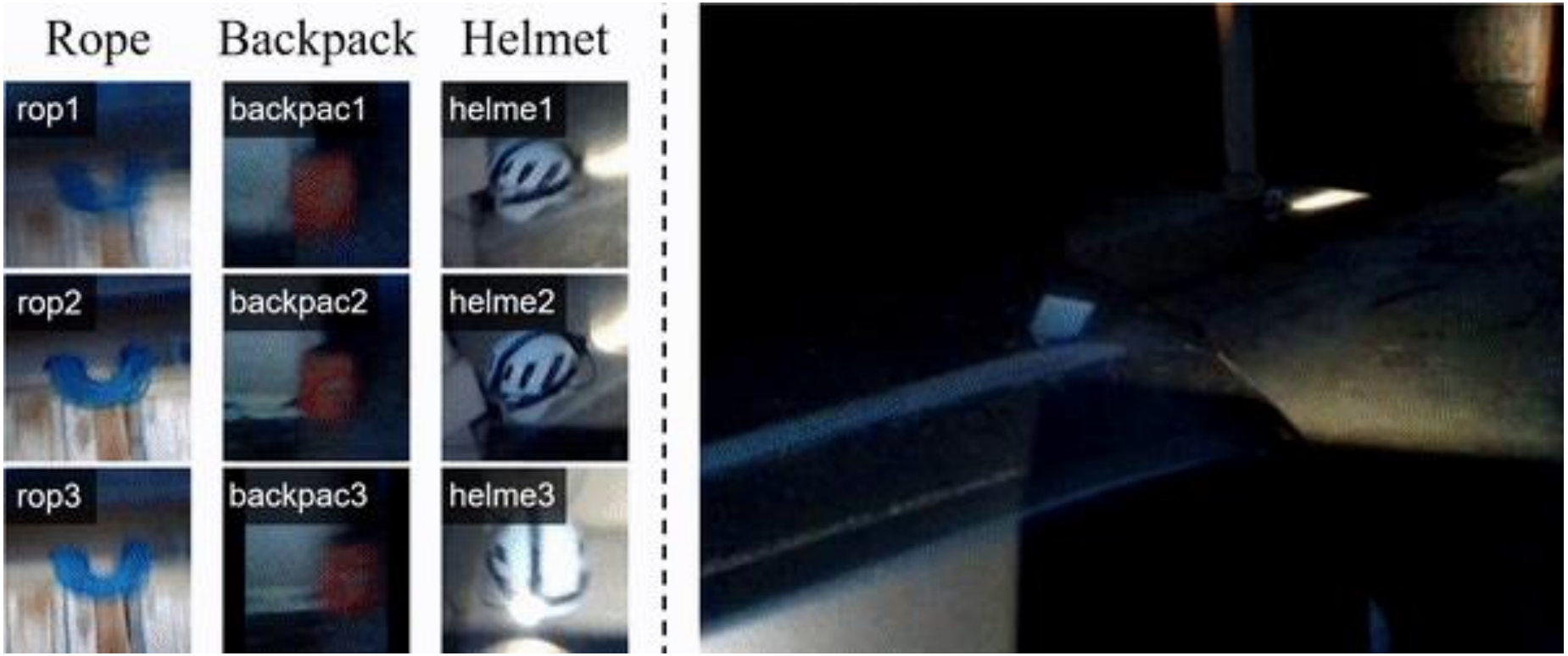
Person Re-identification



SAIR
Spatial AI & Robotics Lab

Credit: Kuan Xu

Search and Rescue (Few-shot Detection)



Credit: Bowen Li

Autonomous Vehicle Navigation

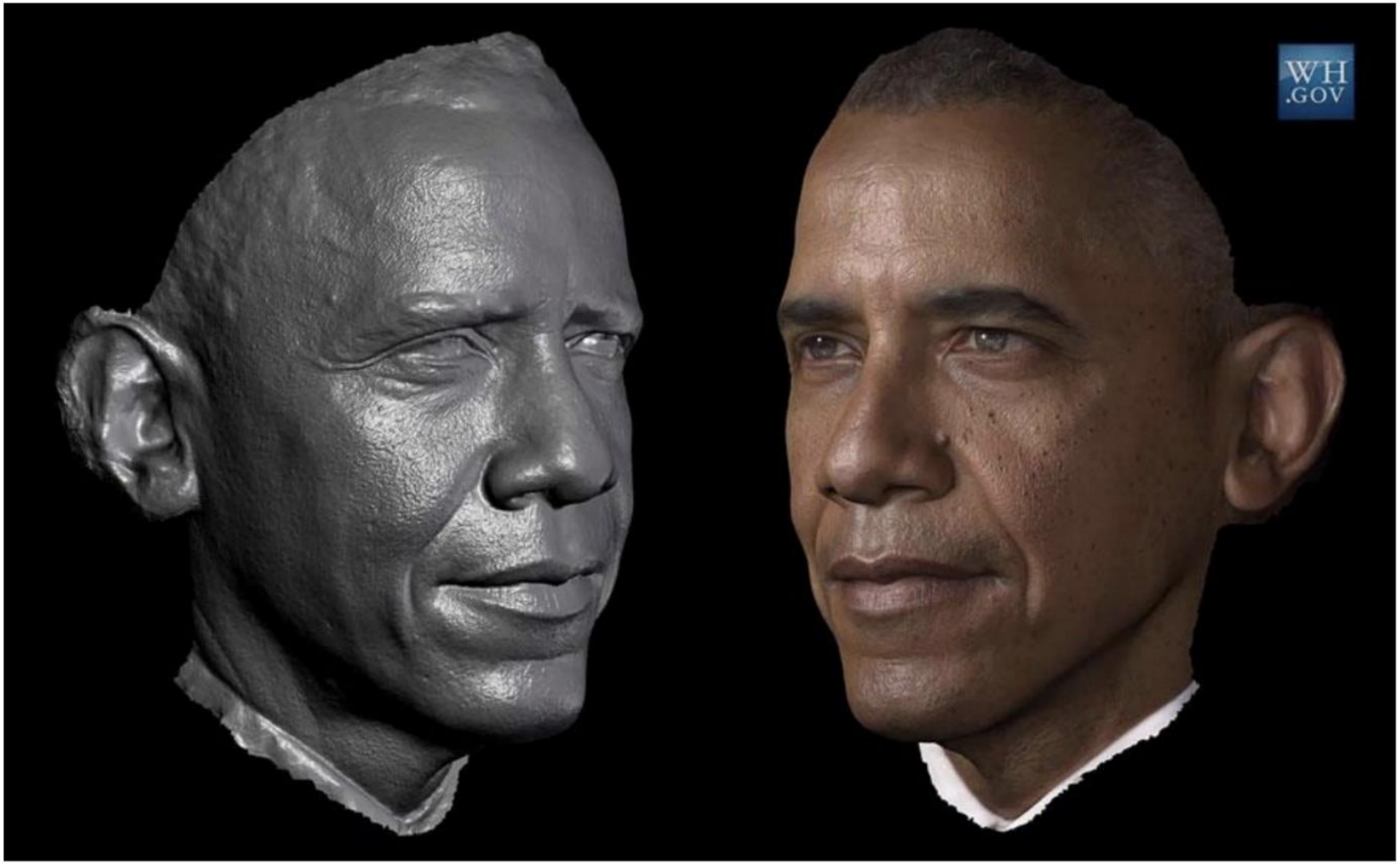
Smart cars

Tesla?

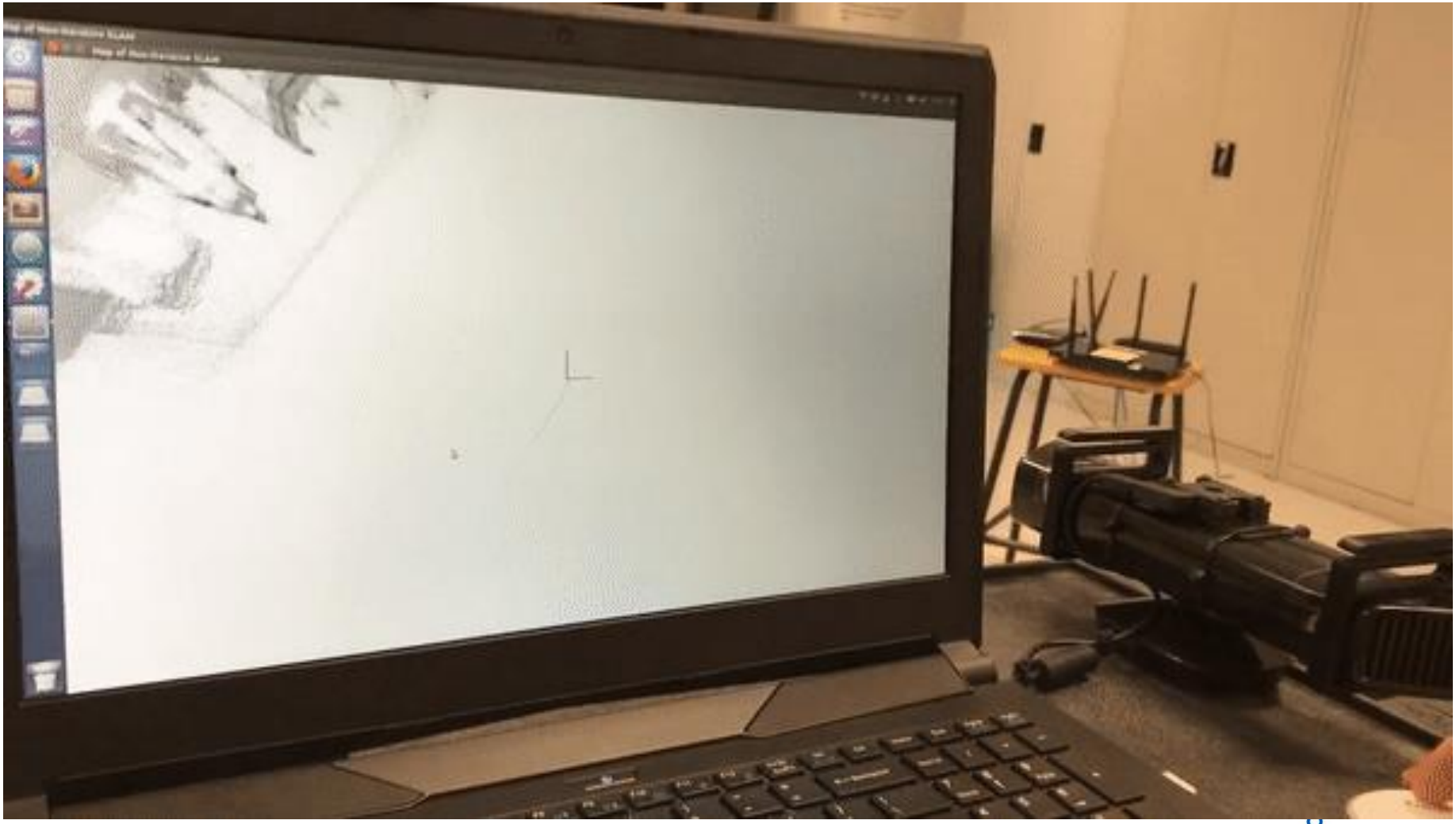
Shashua

Multi-Camera

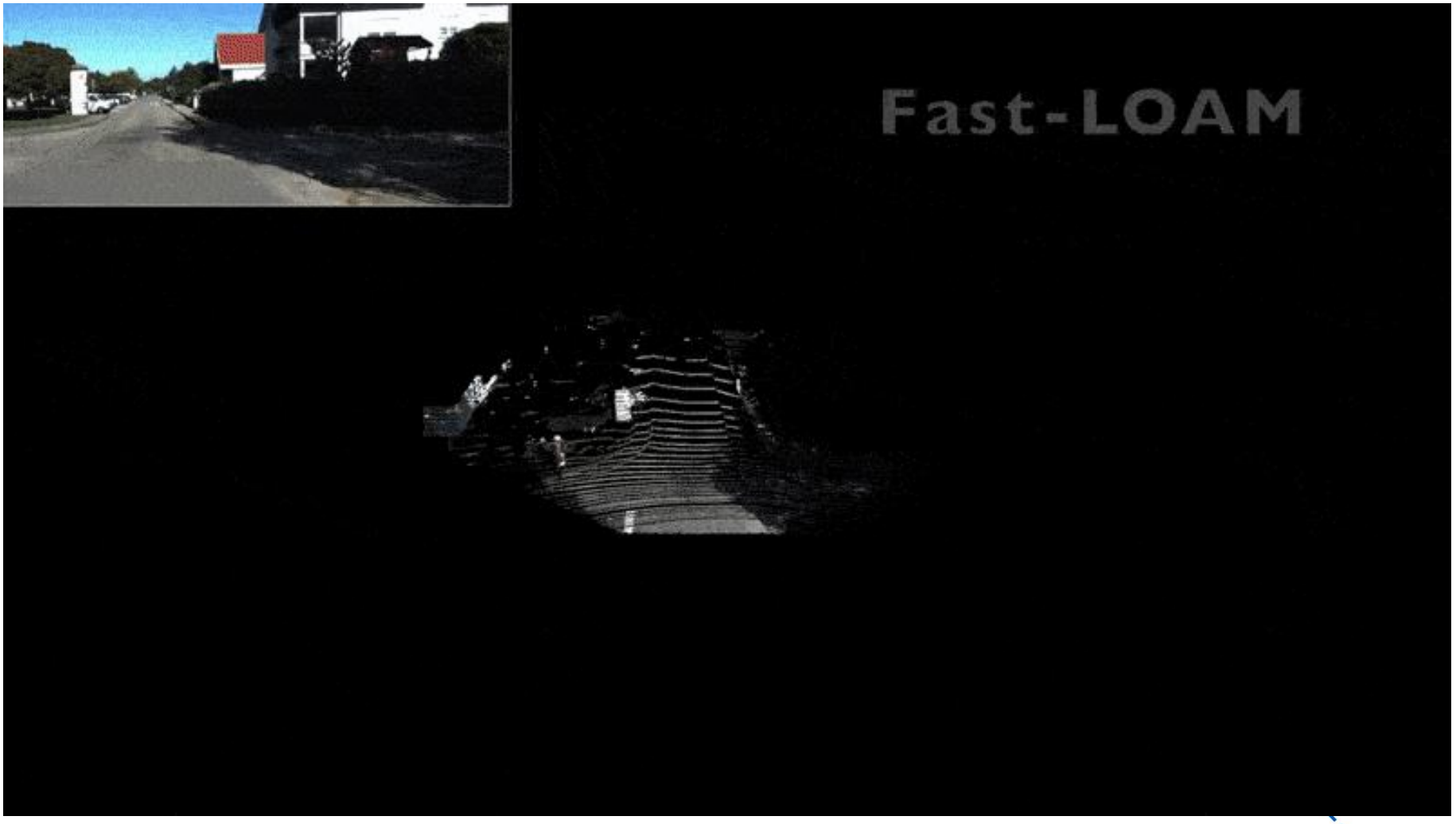
3D Scanning



Room Reconstruction

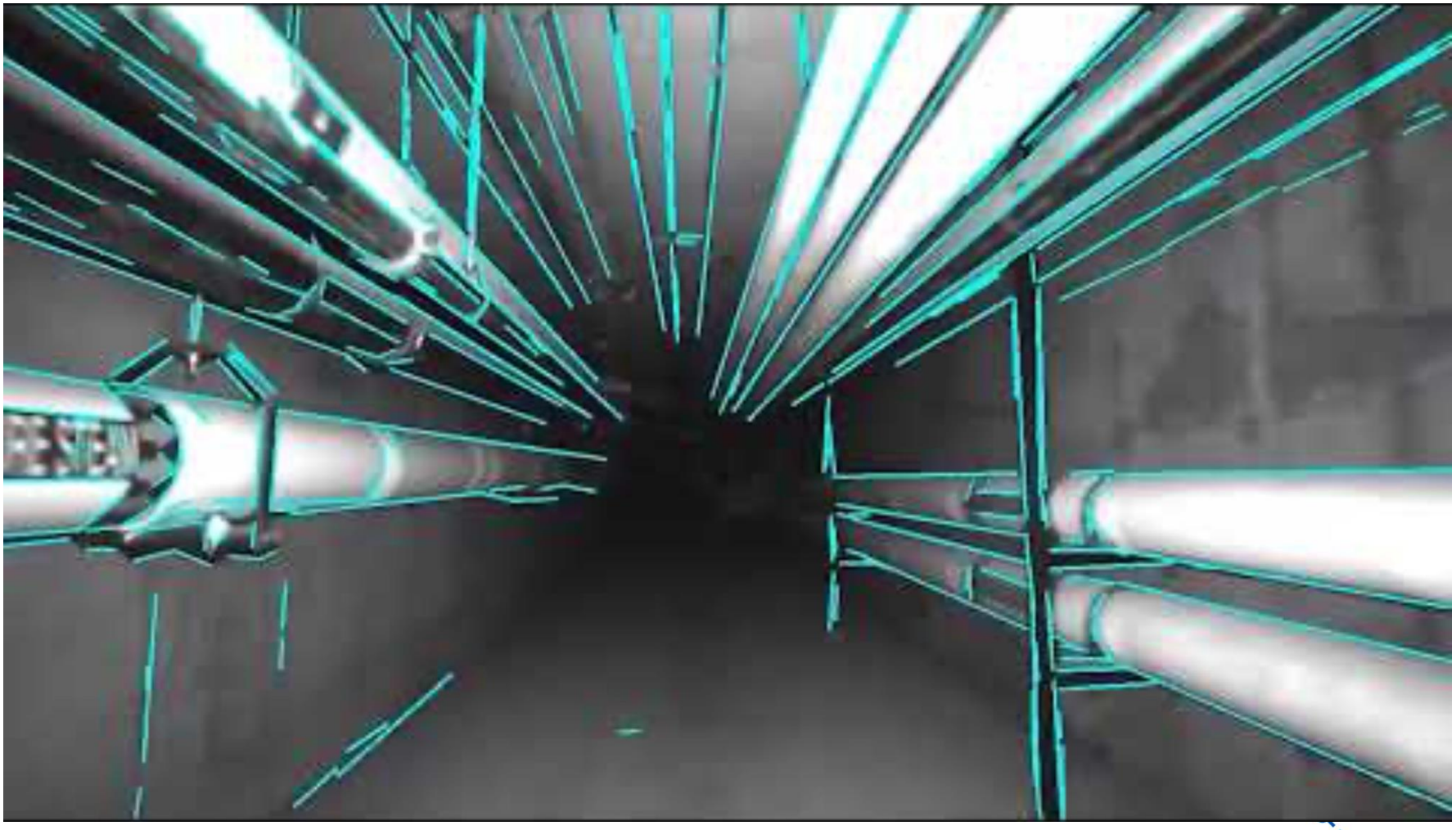


Simultaneously Localization and Mapping (SLAM)



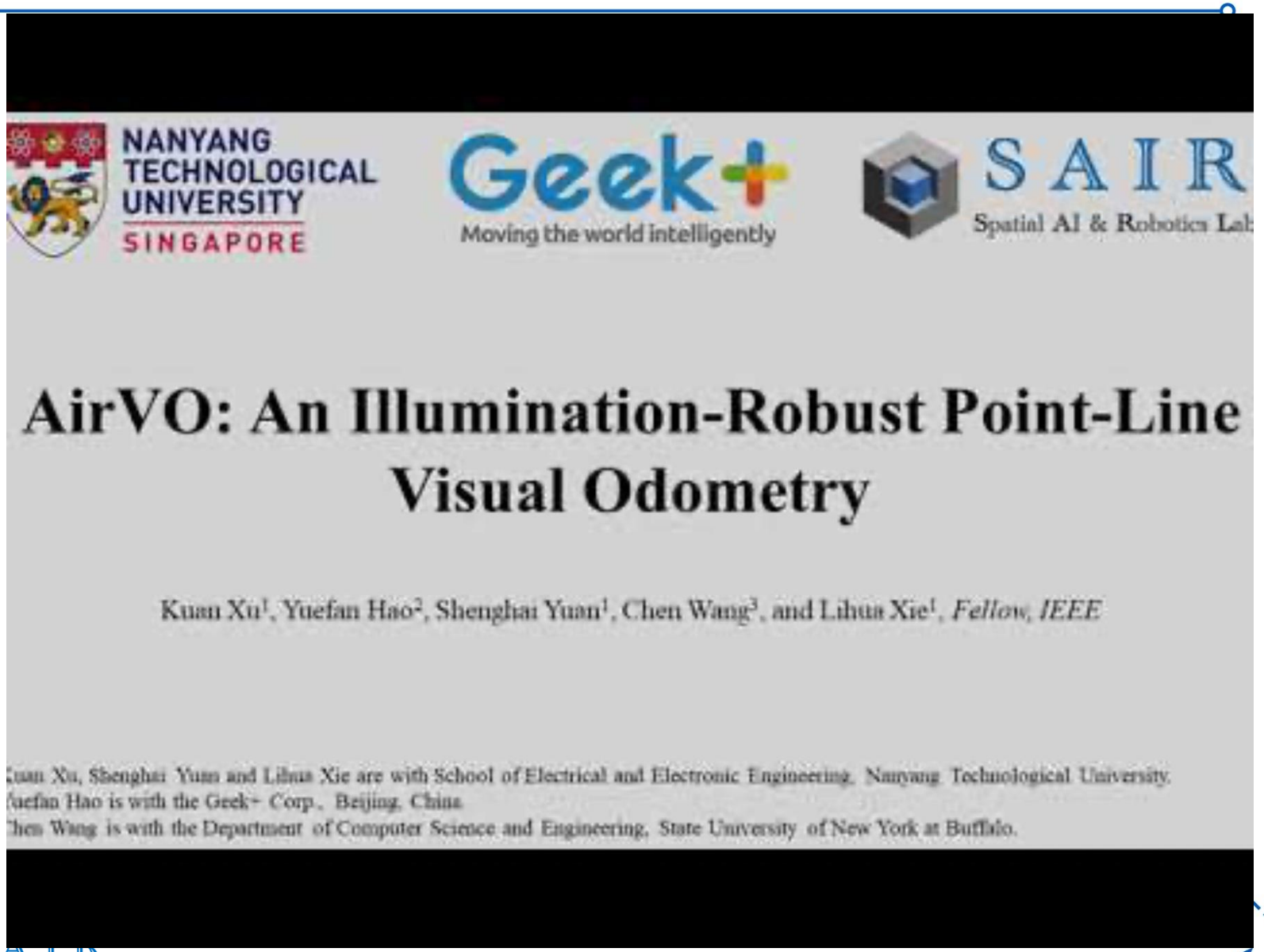
Credit: Han Wang

Line Detection



Credit: Xiao Lin

Visual Odometry



Credit: Kuan Xu

Indoor Localization

AirLoc: Object-based Indoor Relocalization

Aryan[1], Bowen Li[2], Sebastian Scherer[2], and Chen Wang[2,3]

[1]The Department of Electronics and Communication, Delhi Technological University, Delhi, India
[2]The Robotics Institute, Carnegie Mellon University, Pittsburgh, PA 15213, USA
[3]The Department of Computer Science and Engineering, State University of New York at Buffalo, NY 14260, USA

Warehouse Robot

Credit: Kuan Xu

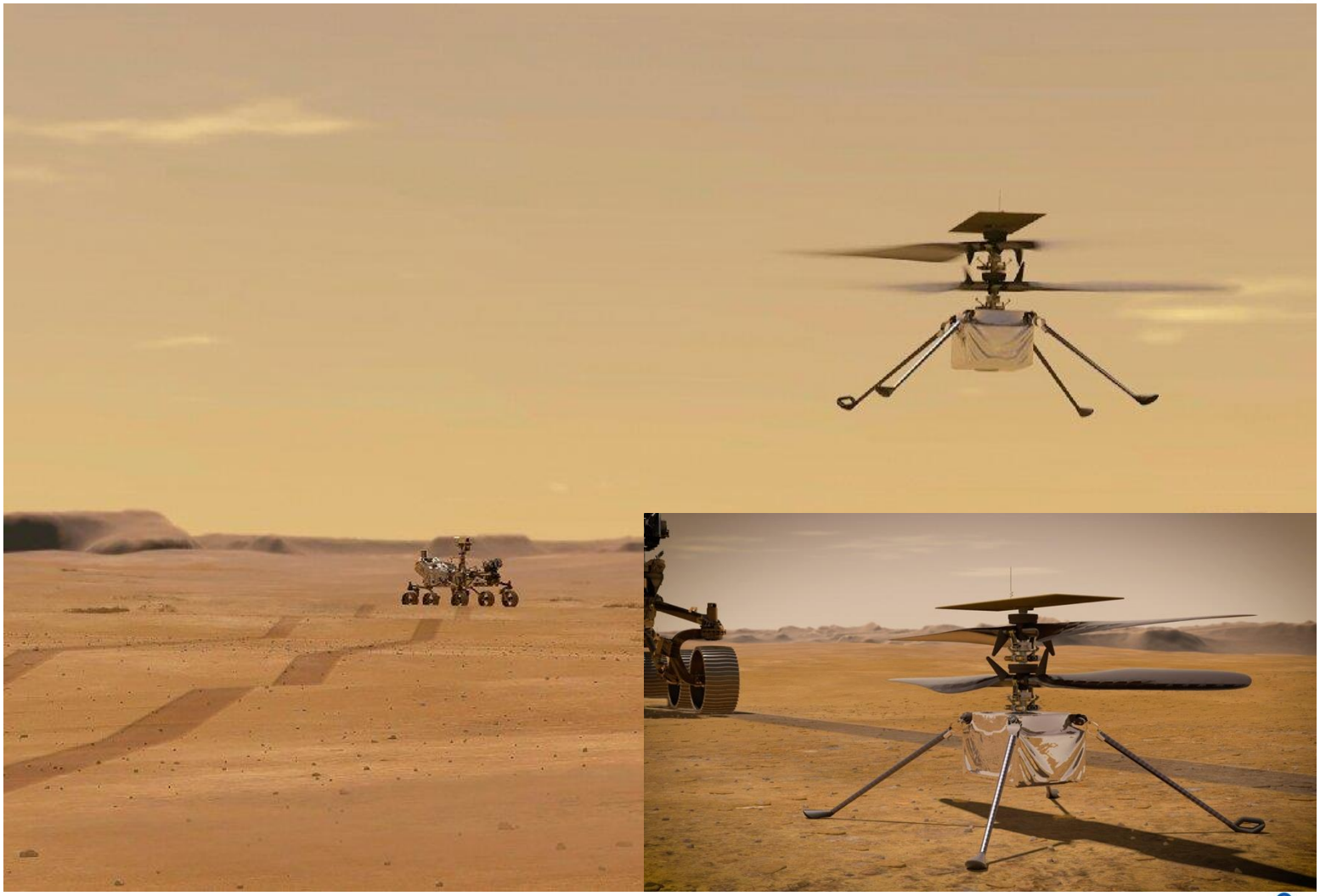
Vision in Space

NASA'S Mars Exploration Rover Spirit captured this westward view from atop a low plateau where Spirit spent the closing months of 2007.

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.

Mars Exploration



Feb. 18, 2021, Jezero Crater, Mars

Perseverance rover and Ingenuity Helicopter on Mars

Techniques behind Mars Helicopter

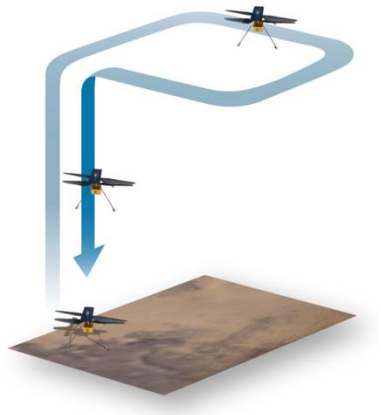
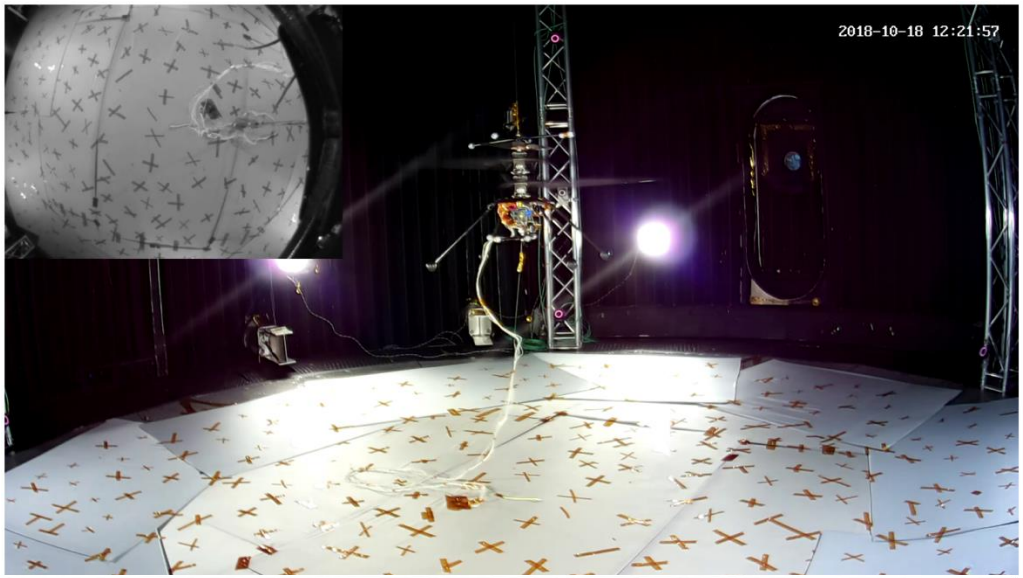
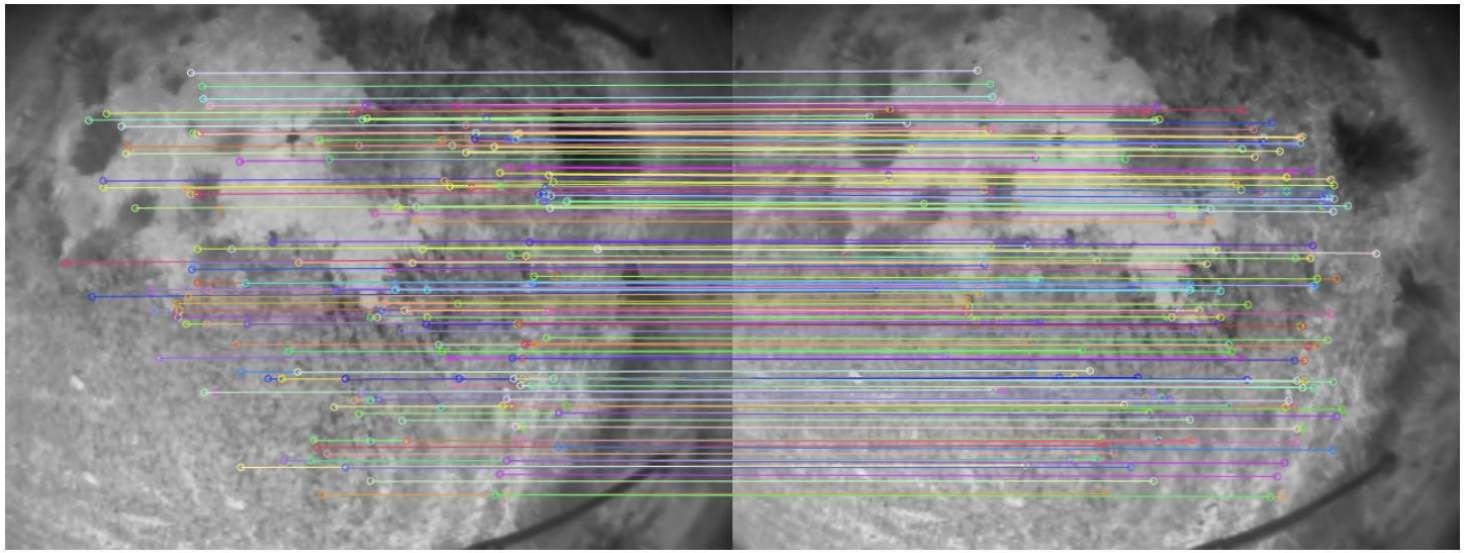
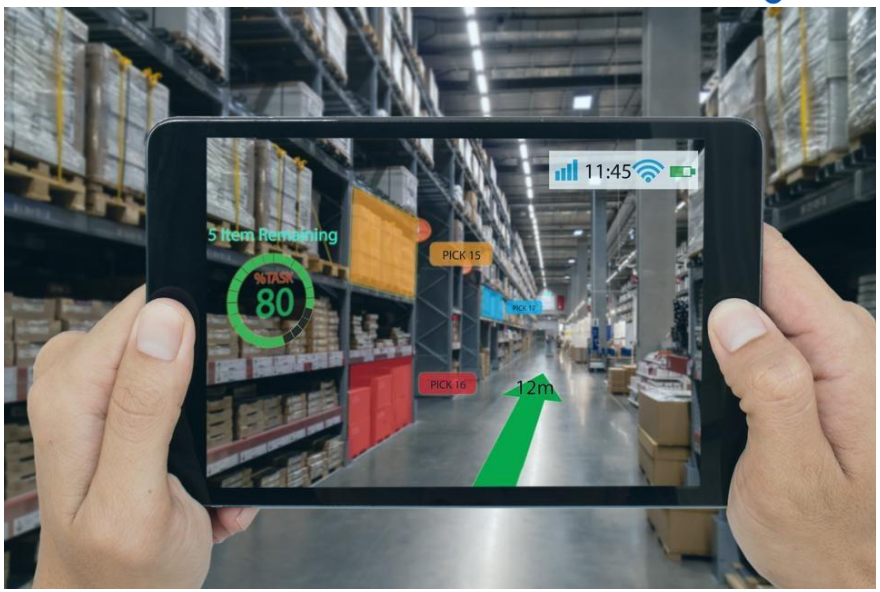


Fig. 2 Illustration of a Mars Helicopter flight, beginning and ending in the same pre-inspected safe area



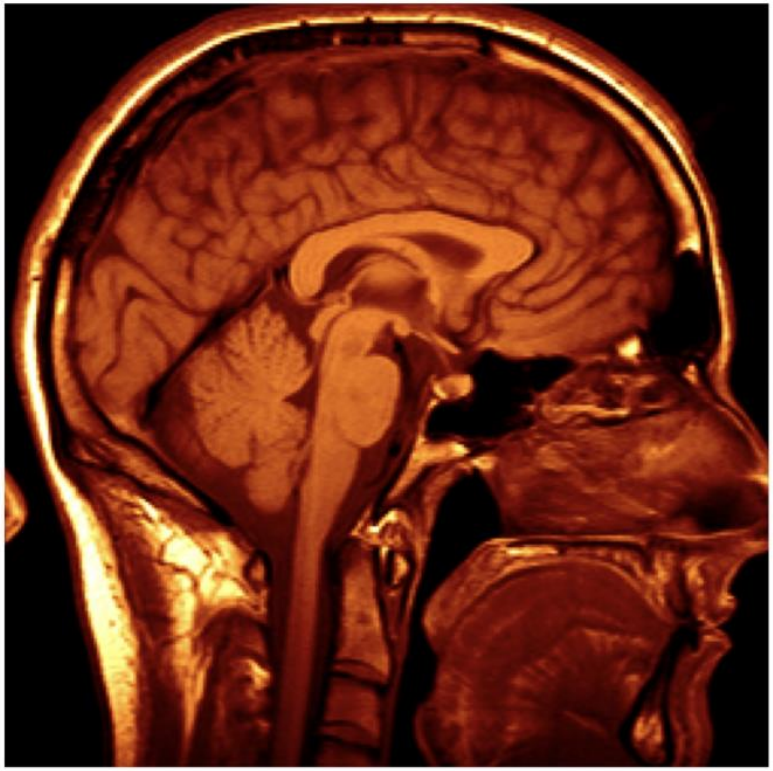


Virtual/Augmented/Mixed Reality



Video Surveillance

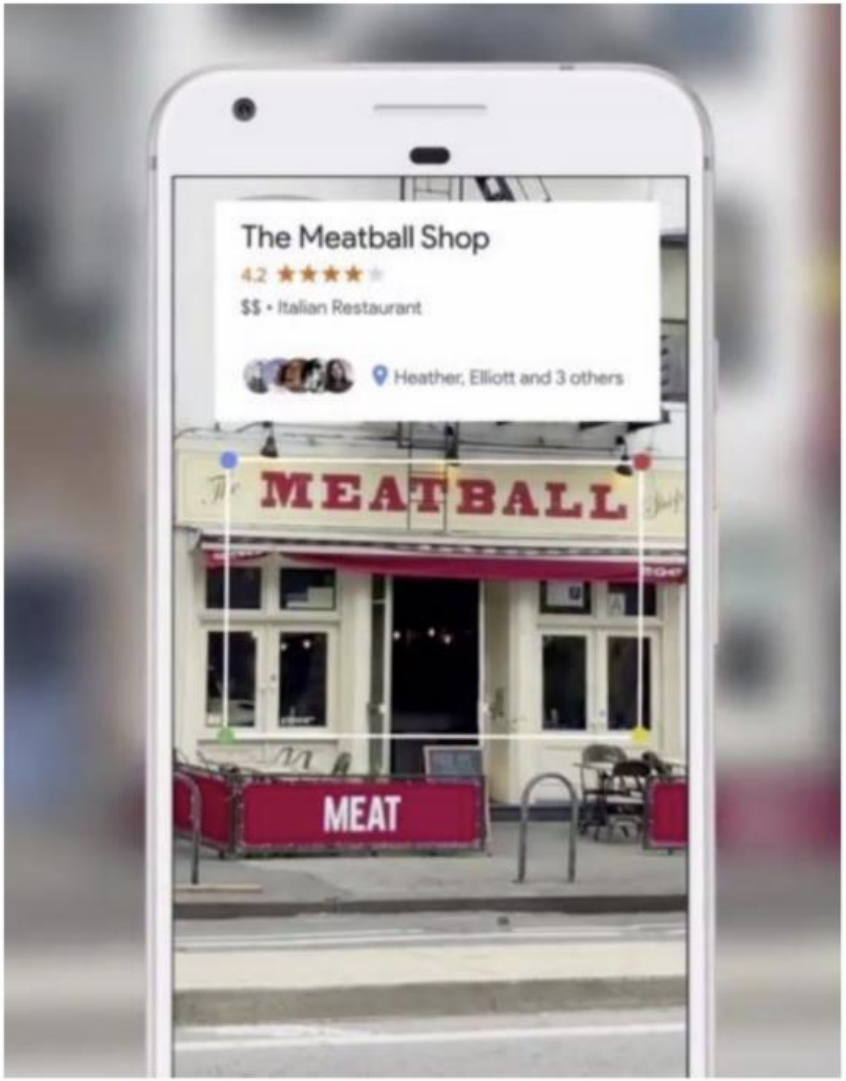
Medical Imaging

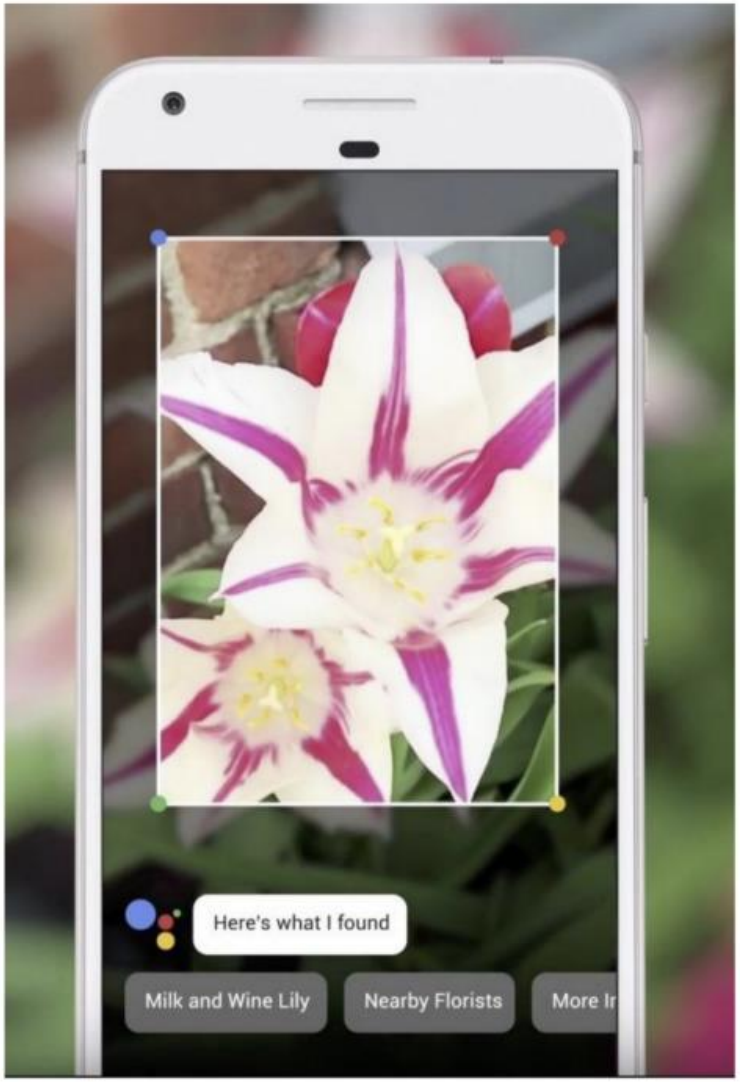


3D imaging
MRI, CT

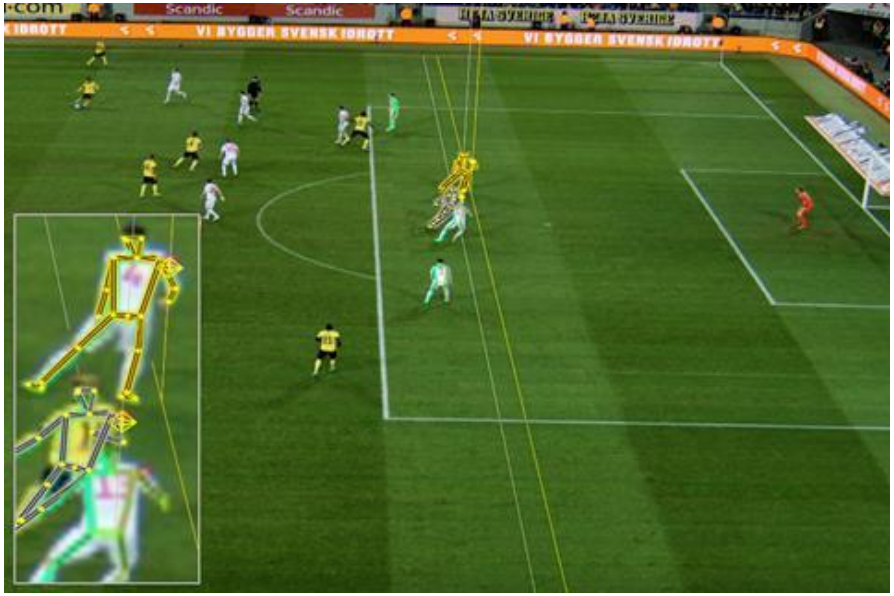
Image guided surgery
Grimson et al., MIT

Visual Search: Google Lens





Sports and Advertising



Last but not least

- Let’s take a picture for memories!