# ENGN6528 Computer Vision Semester 2, 2020

**Thalaiyasingam Ajanthan**

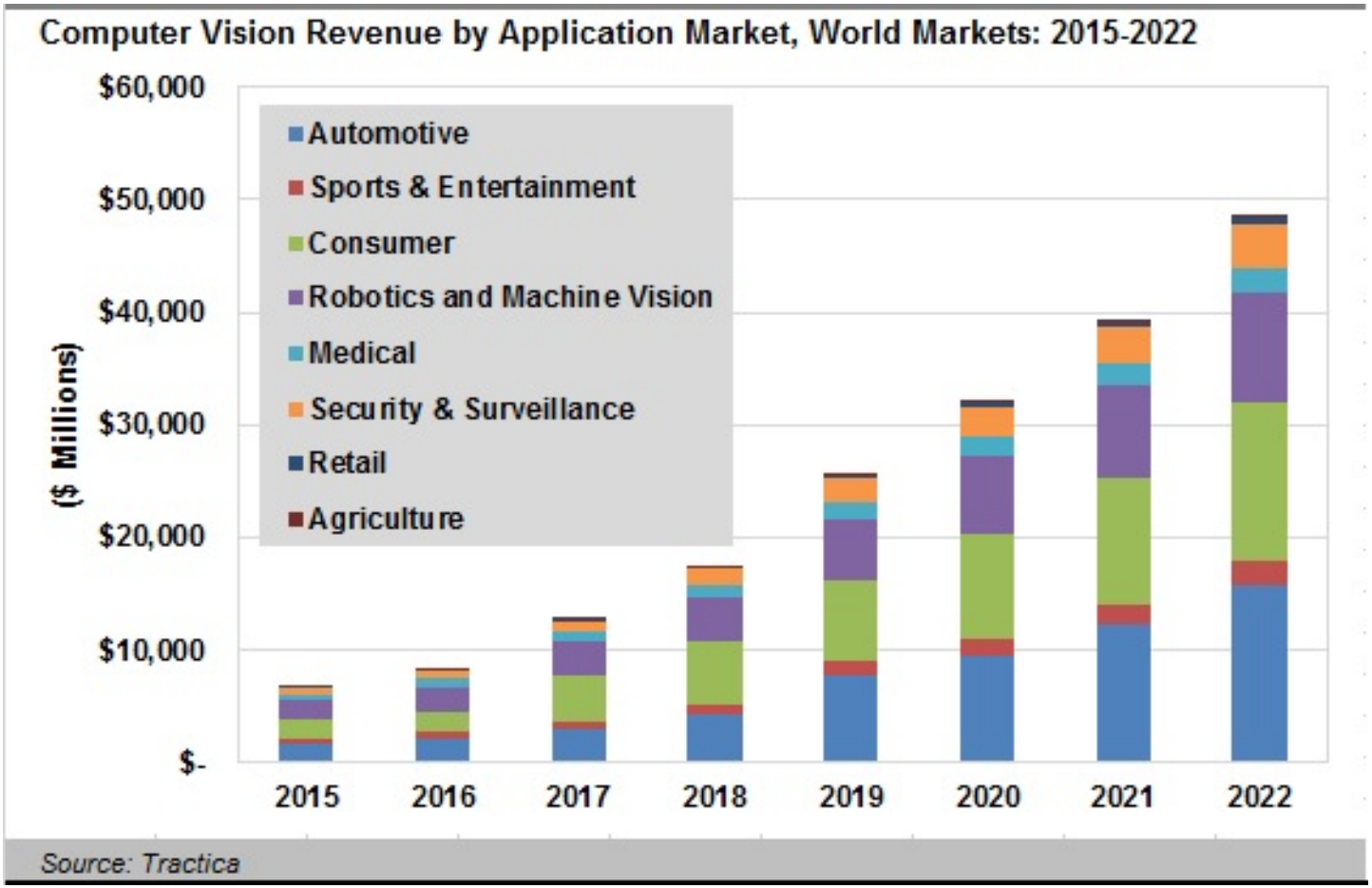
Majority of the slides from Miaomiao Liu

# Overview

- An introductory-level course on computer vision, designed for final-year undergraduates and first-year postgraduate students with electronic engineering, mechatronics, computer science, mathematics, or physics backgrounds.
- We do not assume background knowledge in image and vision processing.
- However, you are required to have some familiarity with calculus, linear algebra, matrix computation, some probability theory, linear system (signal processing or system and control) theory, and
- Desirable: basic programming skills (in Matlab, Python, or C/C++)

# Best time for CV and ML

- Over 50,000 new jobs tagged “computer vision” listed on LinkedIn at moment.
- Investment has grown 20-fold since 2012



# Sponsors for Major CV Conferences

- Global tech firms sponsor major computer vision conferences

# Today's Lecture

- What is Computer Vision

- Administrative information about the course

What is Computer Vision?

Why to study Computer Vision?

What can Computer Vision do?

What do you expect to learn from this course?

# Synonym

Computer Vision

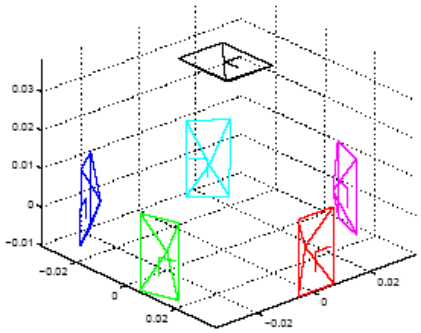
- Image Understanding
- Machine Vision
- Robotic Vision

# Previous Computer Vision Projects @ ANU

# Autonomous vehicles / self-driving cars

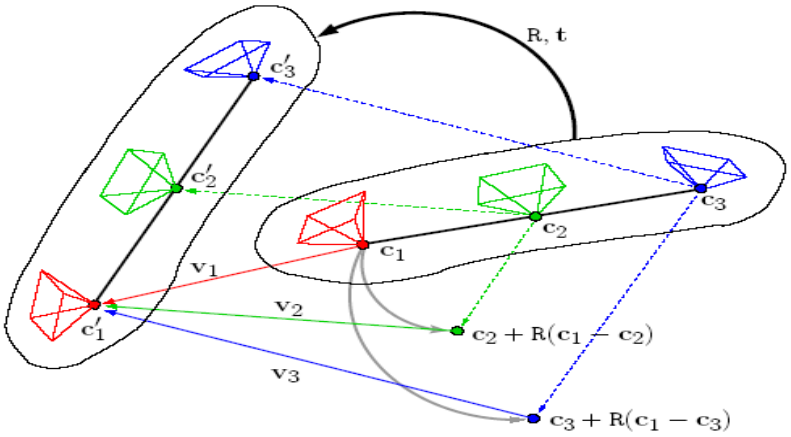


# Multiple Camera City Modelling

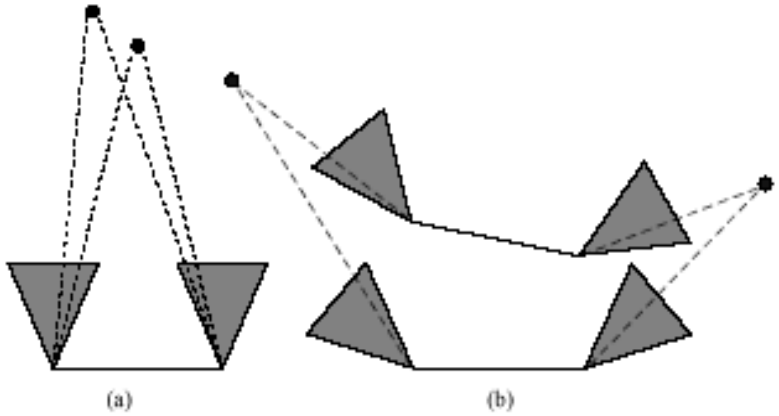


(a)

(b)




Multi-camera system




(a) Overlapping vs. (b) non-overlapping Multi-camera systems

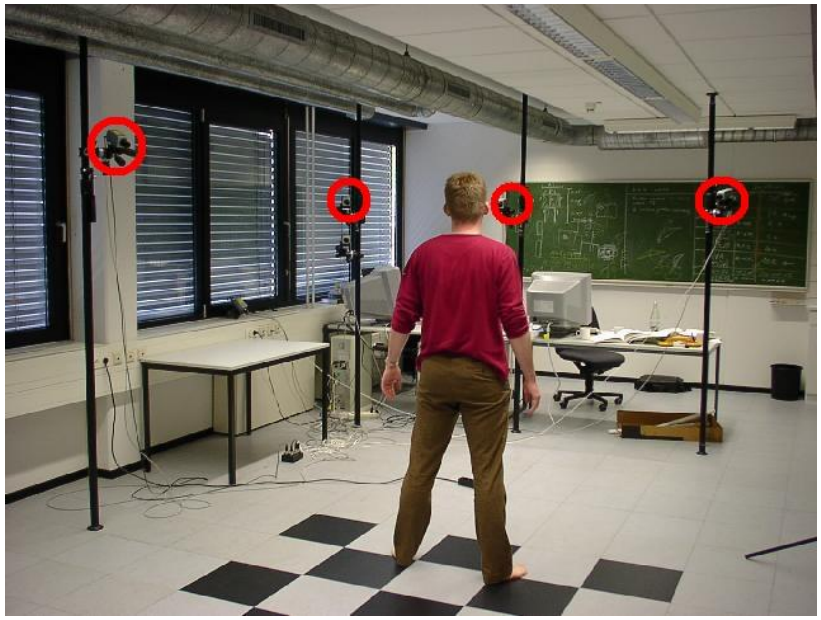
Images from one camera cluster

Kim and Li, Hartley, CVPR 08

# Human Body Shape and Motion 3D Capture

- Marker-free
- No need to wear a special suit or gloves
- No dedicated hardware
- Standard video cameras
- Cost-effective


KINECT
for XBOX 360

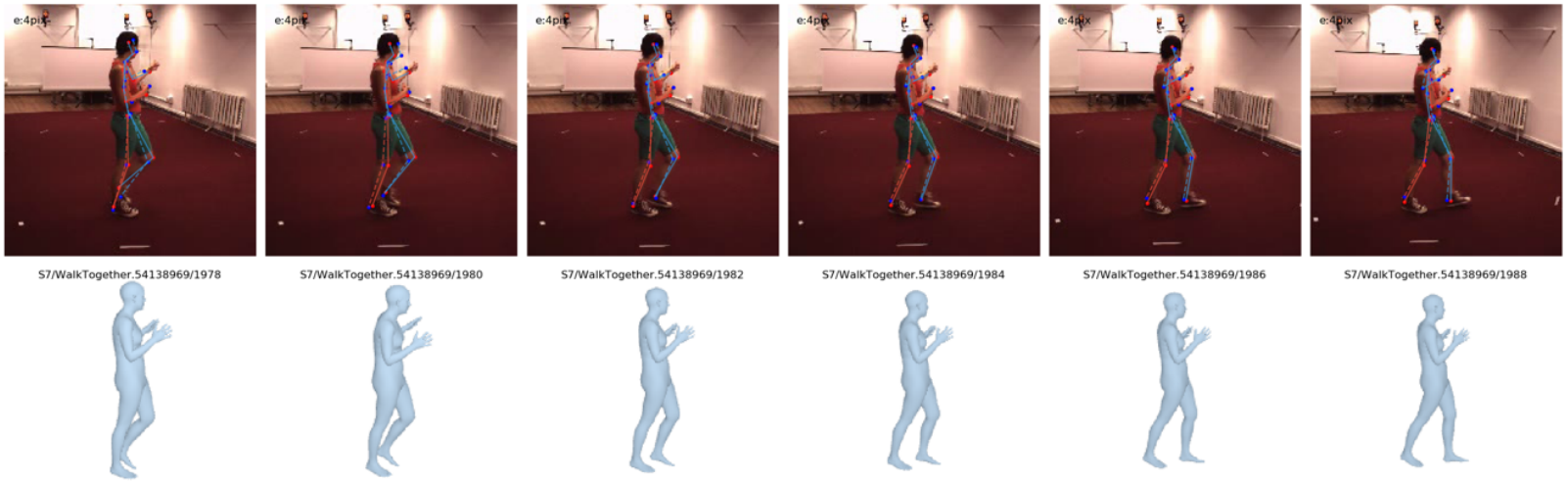


Motion Capture Environment (Image courtesy of Christian Theobalt)

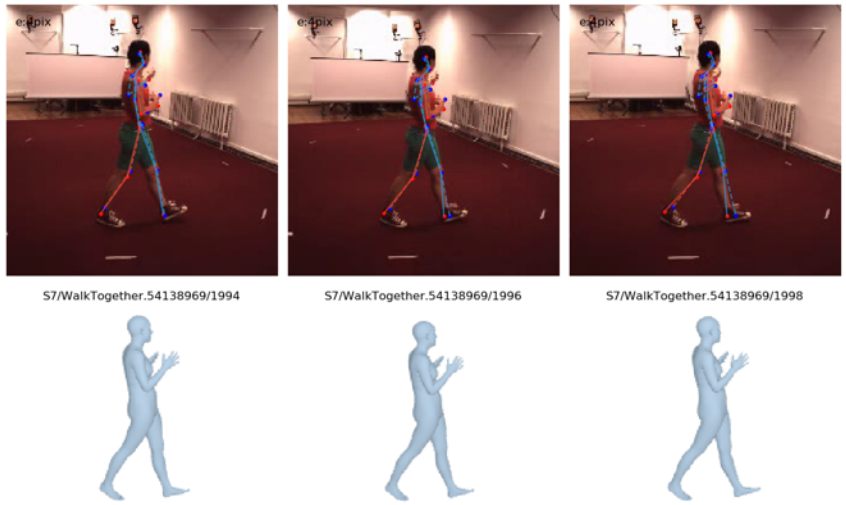
# Human Body Shape and Motion Prediction

- Predict Human Motion Dynamics from a Video sequence

Historical Data:

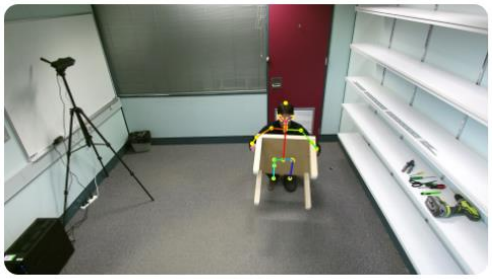



Predict Future Human Motion:

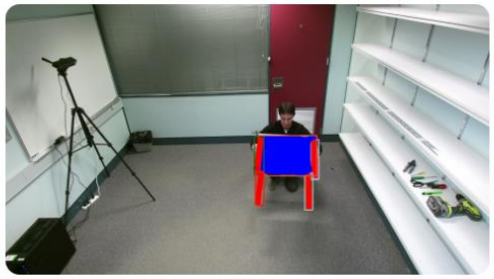



Mao, Liu, Salzmann, Li, ICCV19

# IKEA Assembly Dataset



Human pose



Object segmentation and tracking

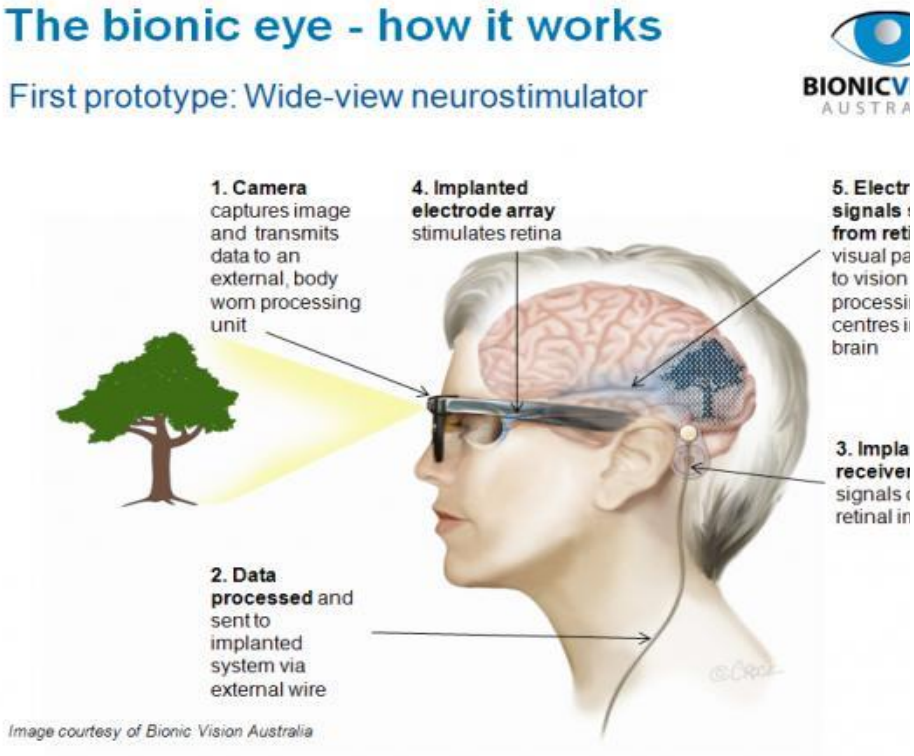

Atomic actions

A multi-modal and multi-view video dataset of assembly tasks to enable rich analysis and understanding of human activities

Ben-Shabat, Yu, Saleh, Campbell, Rodriguez, Li, and Gould, 2020.

# Australian Bionic Eye

- 2020 Summit Project
- Budget $50M for first 4 years
- 5 BVA Members and 2 contributing universities
- Officially started July 2010




THE UNIVERSITY OF MELBOURNE · UNSW · The Bionic Ear Institute · Centre for Eye Research Australia · NICTA

# Patient trial in Canberra 2014

Ms Ashworth had her first 'unplugged' trial in *Canberra*, 2014.

https://www.abc.net.au/news/2014-04-30/bionic-eye-patients-star first-navigation-tests/5422174

# Australian Centre for Robotic Vision

- $25M government funding for 2014- 2020
- 4 Centre Nodes (QUT, ANU, Adelaide, Monash)
- 13 Chief Scientists national-wide


**Oxford University**, Oxford, UK
**Imperial College**, London, UK
**ETH**, Zurich, Switzerland
**INRIA**, Rennes, France
**Georgia Tech**, Atlanta, Georgia, USA
**QUT**, Brisbane
**NICTA**, Sydney, Brisbane, Canberra, Melbourne
**UoA**, Adelaide
**Monash**, Melbourne
**ANU**, Canberra

# What is Computer Vision?

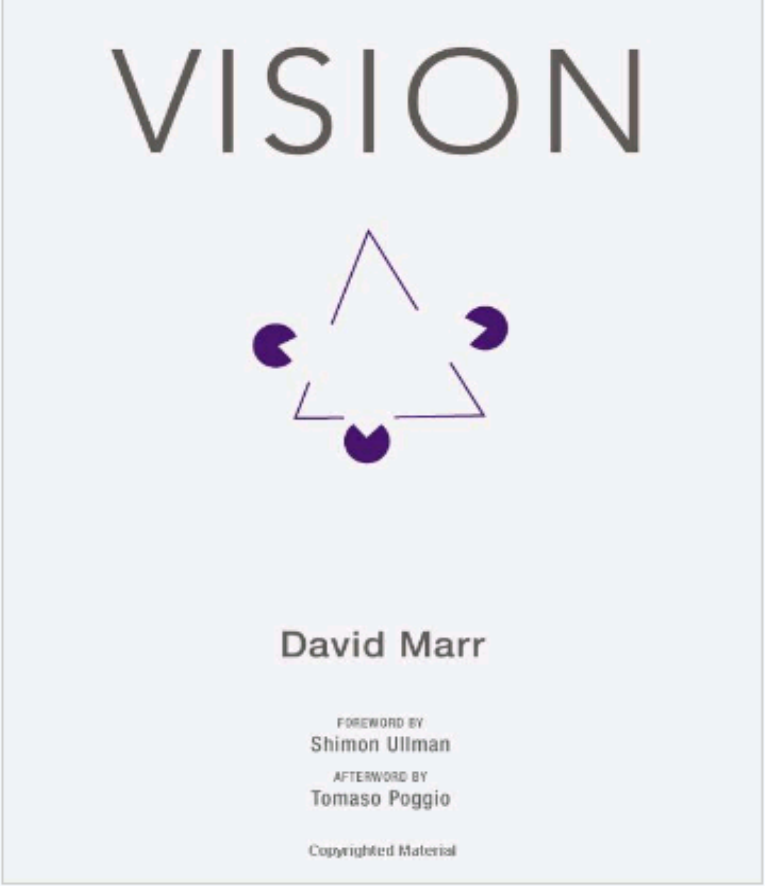
- (aka machine vision, robot vision, image understanding, scene recognition)
- and **applications of Computer Vision**

# What is Computer Vision?

- Humans see things very easily.
- Can a computer do the same task?
- **How to teach a computer (or robot) to see (and understand what it sees)?**

# What is Vision?

Is [the art] ``*to know what is where, by looking*.''

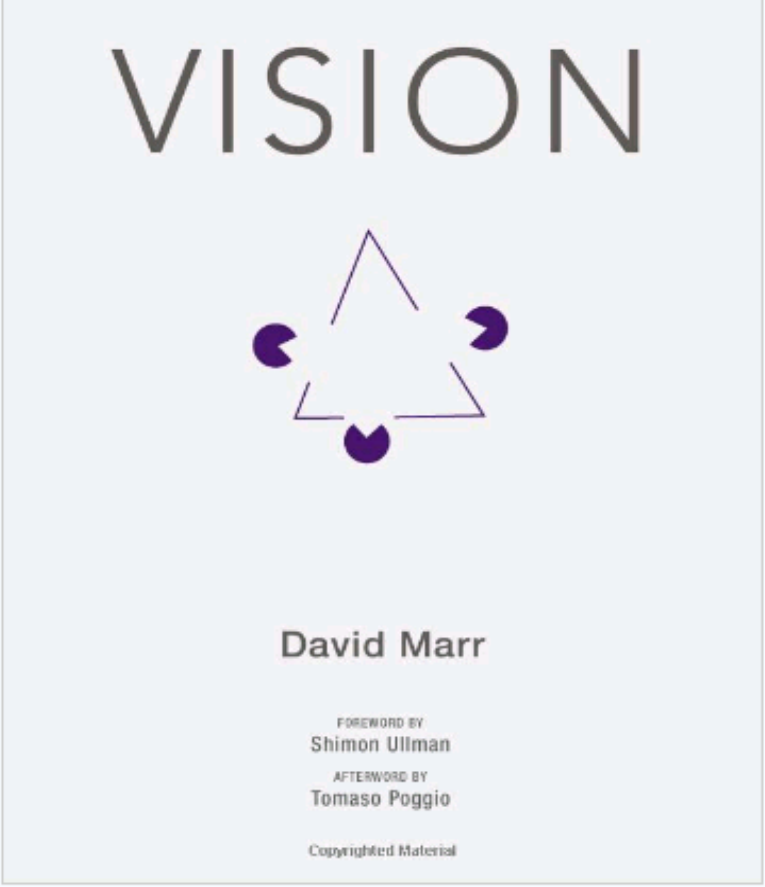



**Published in 1982**

**David Marr (1945 --1980)**

# What is Vision?

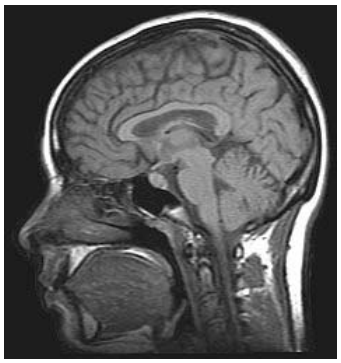
The process of discovering from images what is present in the world and where it is.




**David Marr (1945 --1980)**

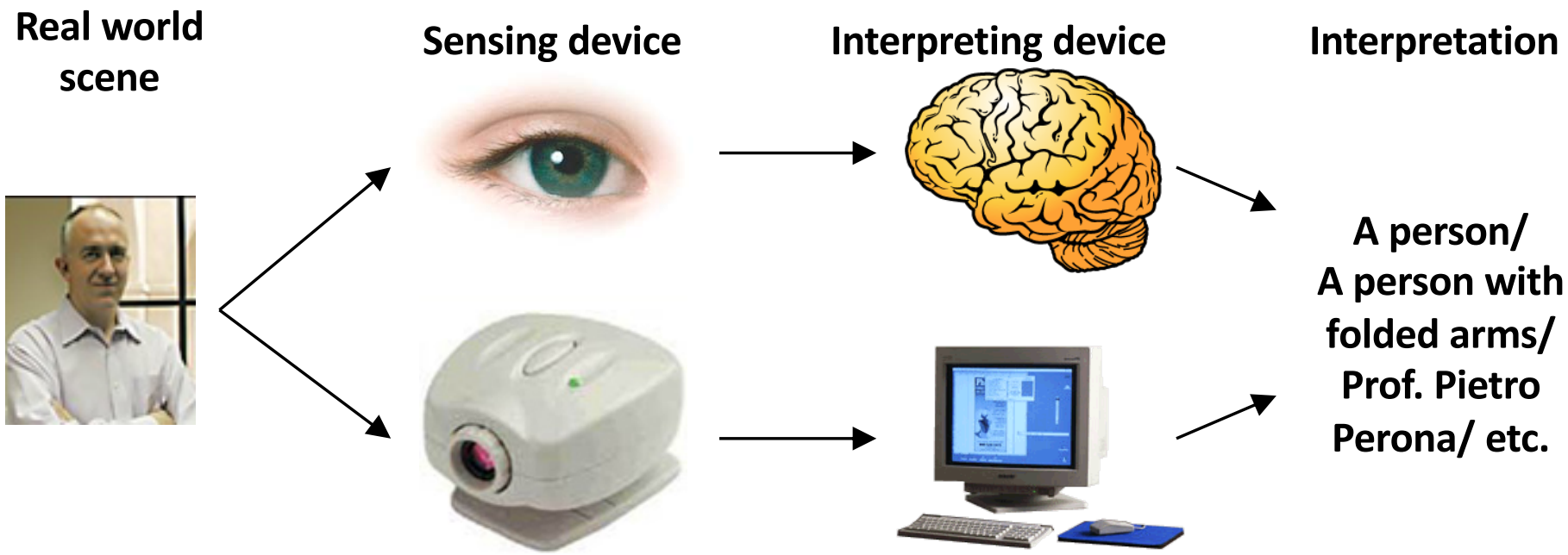
# What is Computer Vision?

- Computer Vision is concerned with the theory of building artificial vision systems that obtain useful information from images.
- Image data taken by many forms, e.g. *video sequence, depth images, multi-dimensional data from a medical scanner etc.*



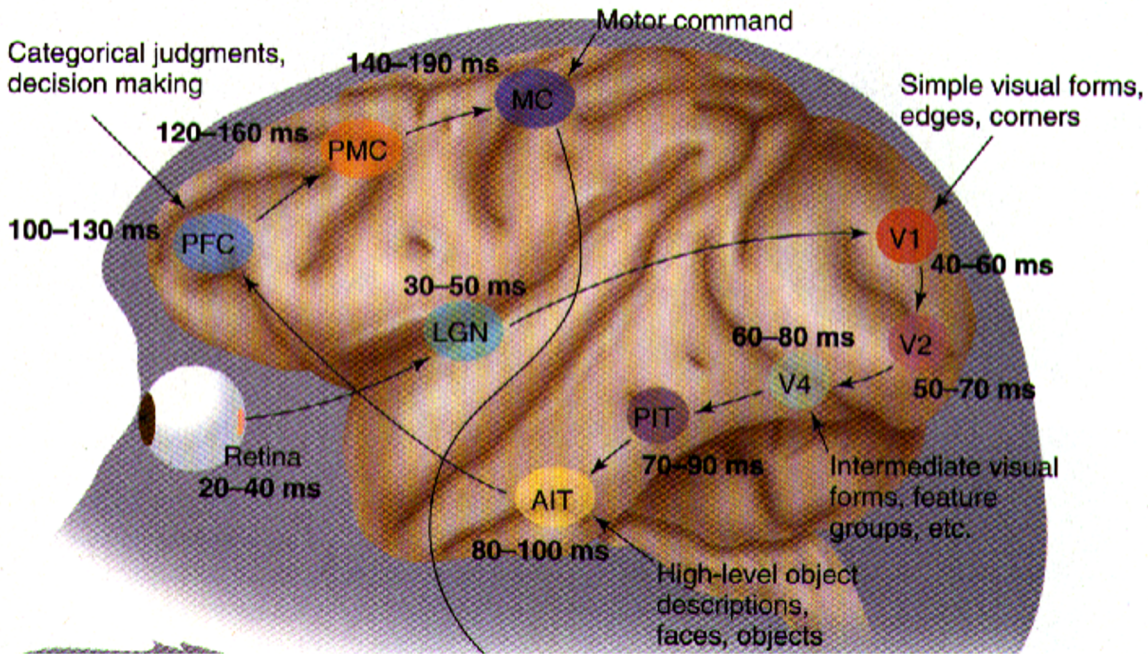
# Computer Vision Problems

- Make a computer see and understand images.
- We know it is physically possible – we do it every day and effortlessly!



# Human Visual System

- Vision is the most powerful sense.

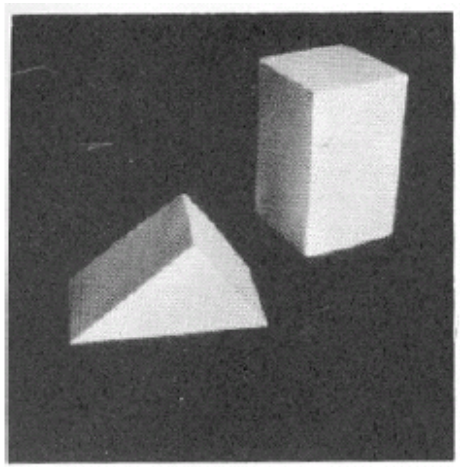



**[Thorpe et. al.]**

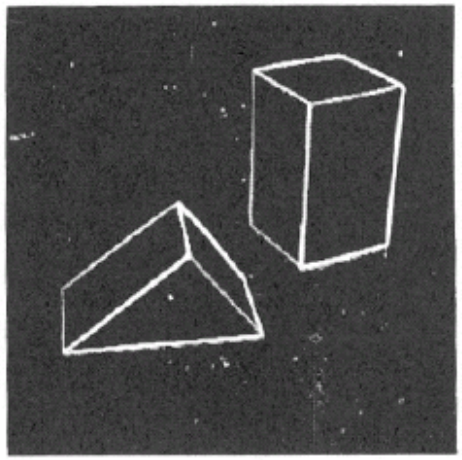
- Over 70% information are from eyes.
- Around 2/3 of our brain cortex area are devoted to processing the signals captured by our eyes.
- The visual cortex alone has around $O(10^{11})$ neurons!

# Brief history of computer vision research

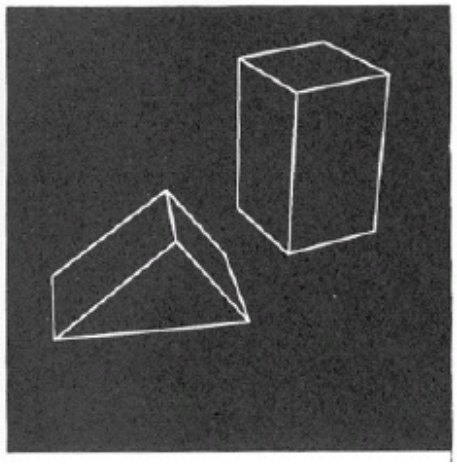
# Origins of Computer Vision

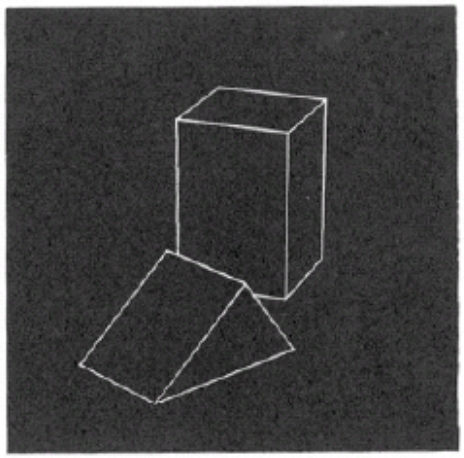


(a) Original picture.



(b) Differentiated picture.





L. G. Roberts, *Machine Perception of Three Dimensional Solids,* Ph.D. thesis, MIT Department of Electrical Engineering, 1963.

# An (overly) optimistic start

In 1966, Marvin Minsky at MIT asked his undergraduate student Gerald Jay Sussman to "***spend 3 months in this summer linking a camera to a computer and getting the computer to describe what it saw***".

Now, nearly fifty years one, we know the problem is significantly more difficult than a 3-month student project.

# Brief history of computer vision

1963: Robert's thesis

1966: Minsky assigns computer vision as an undergrad summer project

1960's: interpretation of synthetic worlds

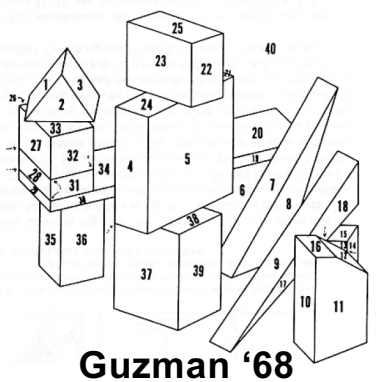
1970's: some progress on interpreting selected images

1980's: ANNs come and go; shift toward geometry and increased mathematical rigor, Marr's book published (after he died).

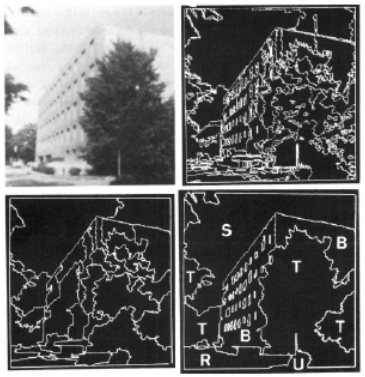
1990's: face recognition; statistical analysis in vogue

2000's: broader recognition; large annotated datasets available; video processing starts; vision & graphics; vision for HCI; internet vision, etc.

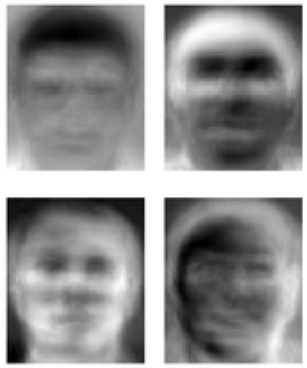
2012: Kinect, big-data, Google Car, …



**Guzman '68**



**Ohta Kanade '78**



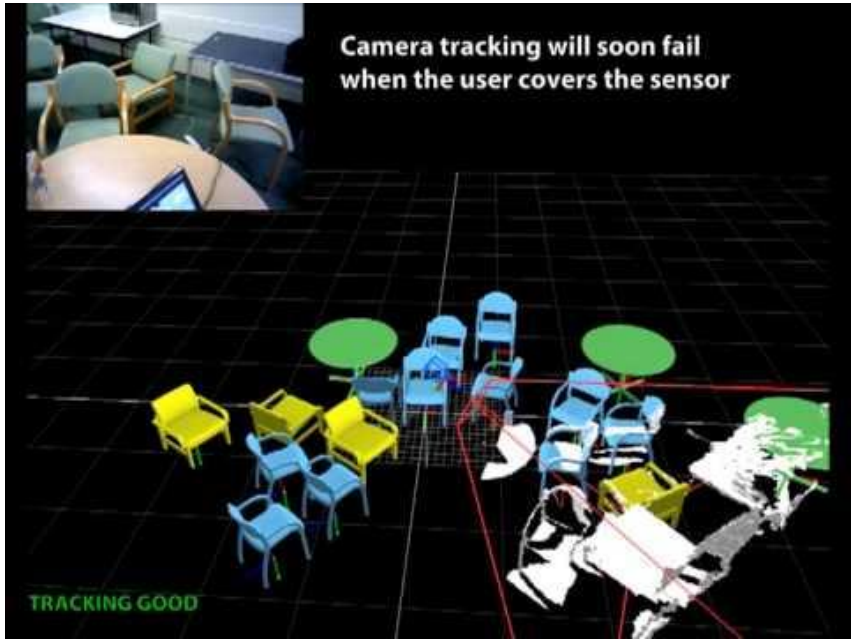
**Turk and Pentland '91**

# Current State of the art of CV

Video Demo

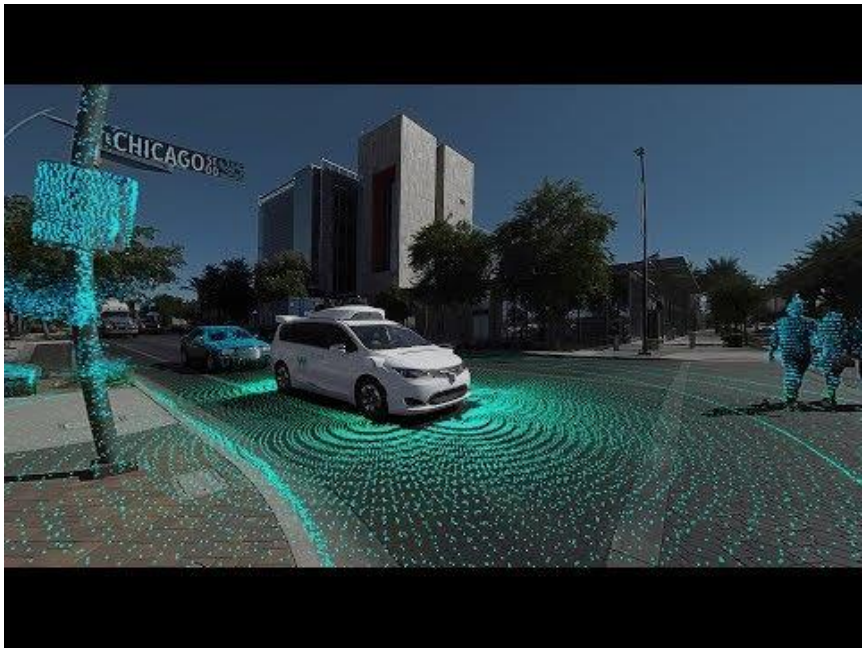
- SLAM
- Google Car
- Amazon Go
- HoloLens

# Classical Visual SLAM (SLAM++)




https://www.youtube.com/watch?v=tmrAh1CqCRo

# Google Self-driving Car




https://www.youtube.com/watch?v=B8R148hFxPw

# Amazon Go


https://www.youtube.com/watch?v=NrmMk1Myrxc

# Microsoft HoloLens

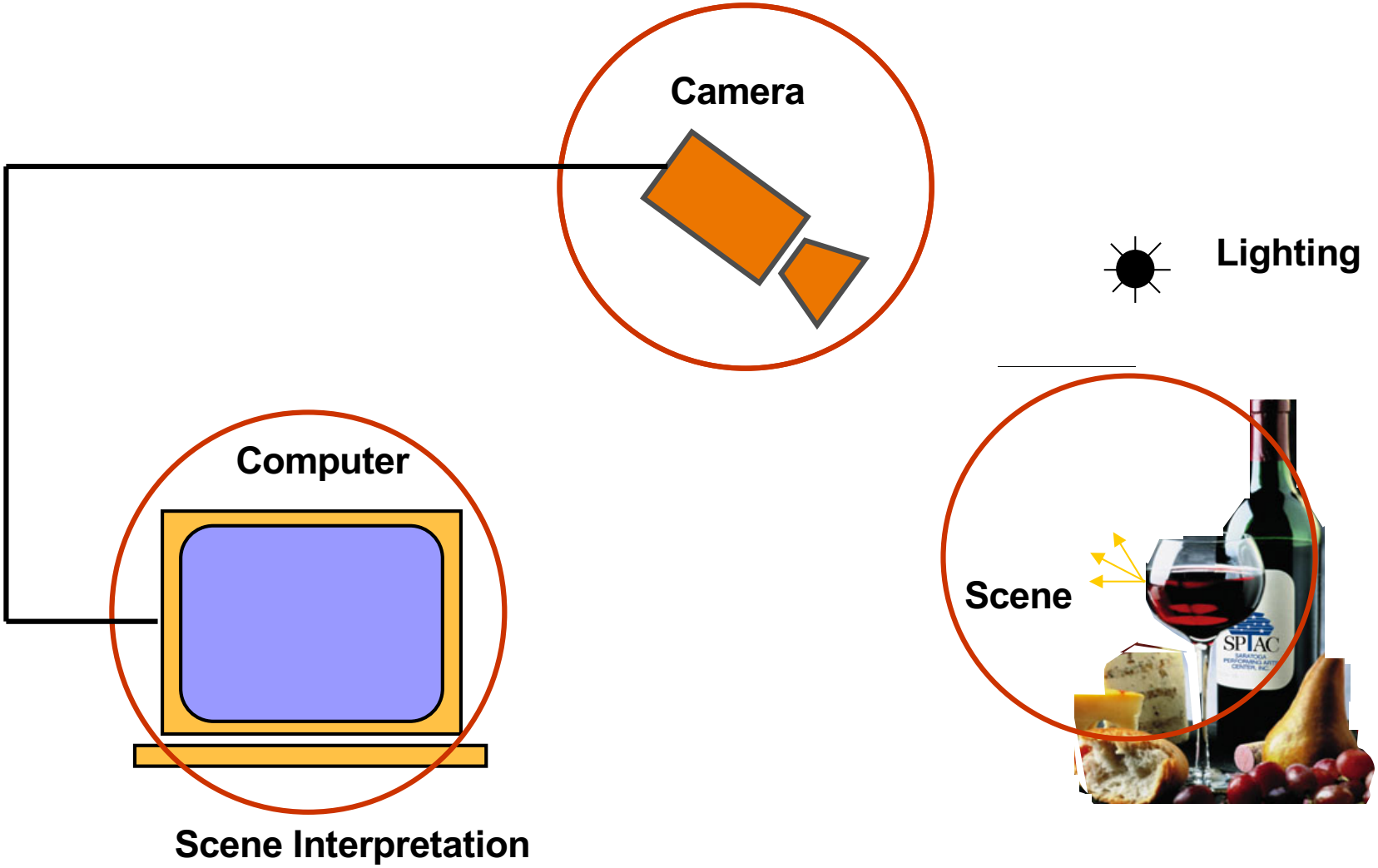
https://www.youtube.com/watch?v=waNNsTI-56k

# What makes a **Computer Vision system** ?

- In a **Computer Vision System**, a camera (or several cameras) is linked to a computer.

- The computer interprets images of a real scene to obtain information useful for tasks such as navigation, manipulation and recognition.

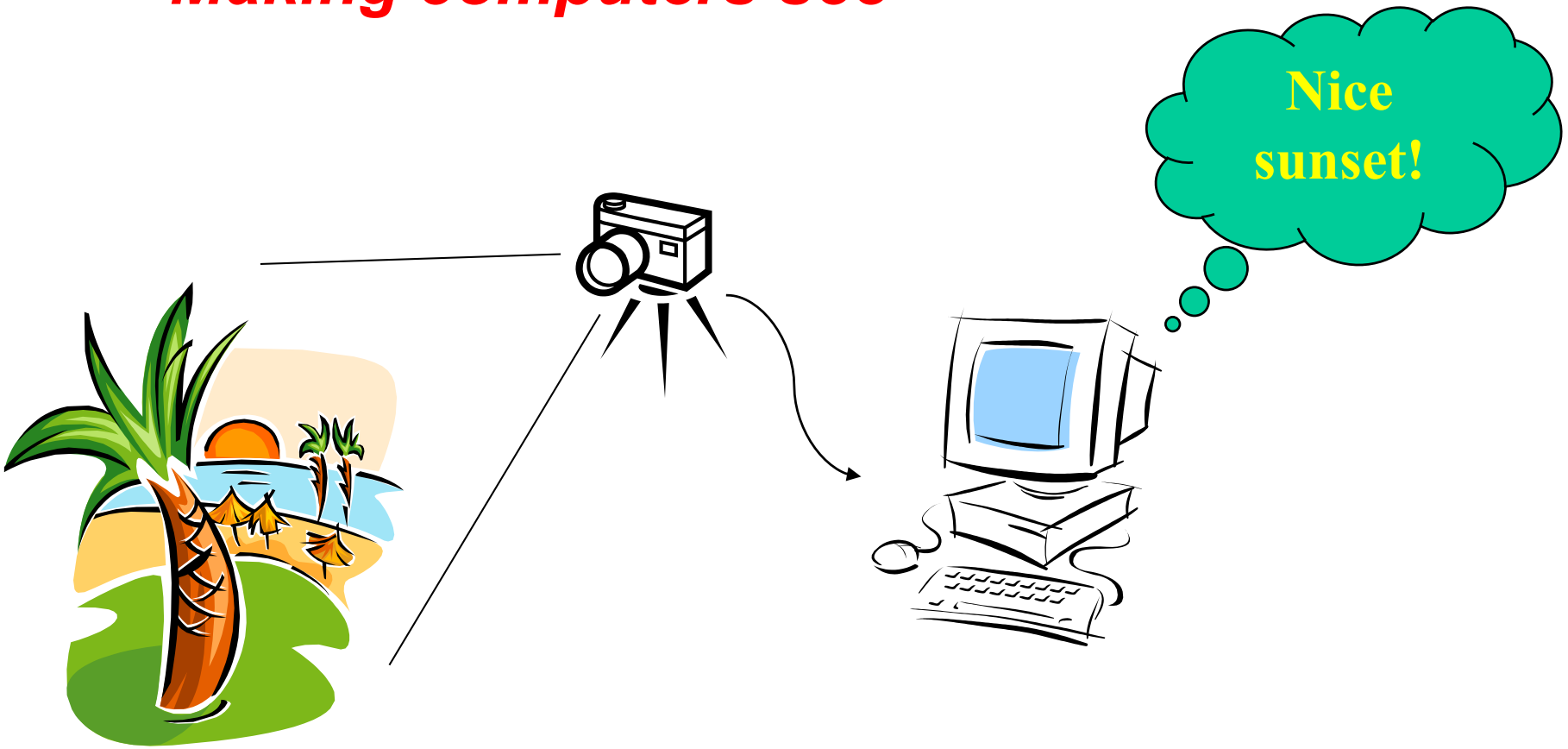
# Computer Vision System Example




Srinivasa Narasimhan's slide

- Computer Vision is also known as *machine vision* or *robot vision*

  – ***"Making computers see"***




  – ***'see' is not only to take image, but also 'to understand' it.***

# Understand the contents of images and videos.


**What kind of scene?**

**Where are the cars?**

**How far is the building?**

**…**

# What we could see

# What computer sees

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01 00 05 00 03 00 02 00 00 03 01 01 01 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 02 00 01
03 30 3A 38 39 2D 1D 15 10 0E 0C 0A 0A 0A 09 06 08 07 06 06 05 05 07 07 04 05 04 04 06 02 01 02 02 02 02 07 01 02 02 03
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02 0C 0B 0A 05 08 09 0A 0C 0A 0A 08 0A 0A 06 08 06 06 04 06 02 06 07 04 04 04 06 09 05 05 08 06 04 05 04 06
01 0A 03 02
02 0B 14 0F 0F 0D 0A 0E 0A 0C 0C 0E 0A 0C 0B 09 0A 09 0A 0A 09 0B 0B 05 0C 0C 0A 04 07 06 03 05 07 04 05 03
02 01 06 03
02 10 12 0B 10 0A 0D 0D 0B 0D 0C 0B 0B 0C 0D 0B 0B 0A 0A 0A 0B 0C 17 15 1C 15 0D 08 09 08 05 05 05 04 02 05
04 04 00 04
01 15 0E 10 12 0C 0D 0C 0C 0A 0B 0B 09 0C 0F 09 09 0D 07 0B 08 15 60 5D 61 59 33 0D 0A 07 08 08 05 03 06 07
01 03 05 02
02 12 10 0F 0F 10 10 0B 0C 0F 0F 0E 0C 10 0D 15 10 09 12 11 12 50 68 66 89 71 5E 3F 08 09 0A 09 0A 03 03 02
05 05 04 02
01 11 12 0C 11 13 10 10 0B 10 0E 0C 11 11 13 0D 0F 0D 0D 0B 25 7A 7F 79 6D 80 6E 54 0C 0D 09 0A 06 04 02 05
00 05 04 03
01 10 0F 0D 12 0E 10 0E 0F 13 13 11 13 17 11 0F 14 11 11 14 39 84 88 7E 8C 73 7A 5C 1E 05 0A 0F 0E 0C 05 02
04 03 06 05
02 0F 15 0D 18 11 0D 11 14 10 12 12 14 19 13 17 13 16 16 20 73 68 87 89 93 8B 83 69 43 07 0A 12 0A 0B 06 06
03 04 05 03
02 13 14 14 16 11 13 13 17 12 17 17 28 1E 1A 17 19 14 12 4F 7D 74 85 91 93 8C 7F 6F 5F 0B 09 12 0D 0C 02 04
07 04 05 04
00 0F 16 0F 13 12 10 1D 12 21 15 1E 21 1F 1C 1D 2D 1A 2D 7C 7A 95 6B 30 48 62 87 71 5C 0A 08 11 0C 09 04 04
02 06 04 03
00 10 1C 10 11 1A 0D 1A 1A 25 28 33 30 26 2B 3E 29 35 6C 83 5E 7B 94 8A 5A 3D 42 76 5C 13 08 13 0F 0C 04 04
01 05 05 03
01 12 17 1A 19 18 15 20 29 20 3F 1F 37 29 39 49 24 33 8F 93 B4 AE 79 42 39 73 7D 89 46 12 06 12 12 0F 08 03
03 03 04 03
01 13 20 0F 14 26 1B 18 20 2F 3D 3E 42 3B 45 2E 48 70 96 9F 96 6B 24 0F 22 4B C3 A4 3F 4F 0C 18 16 0F 05 05
08 05 05 04

…and the output is

*A harbor…*

*… with many dozens of boats;*

*… water is calm and glassy;*

*… vertical masts;*

*… mountains in background,*

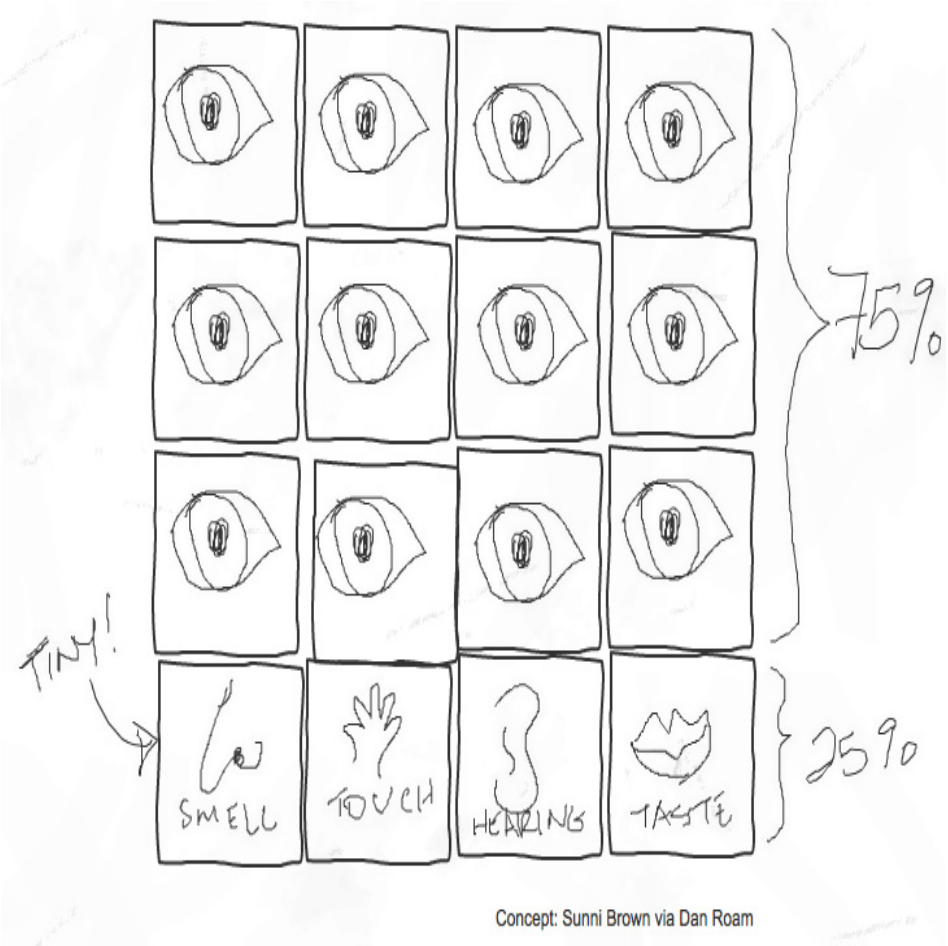
*… blue sky with a touch of clouds…*

**Interpret images.**

**Image → Symbols, Semantics, Meanings,..**

# Why Vision ?

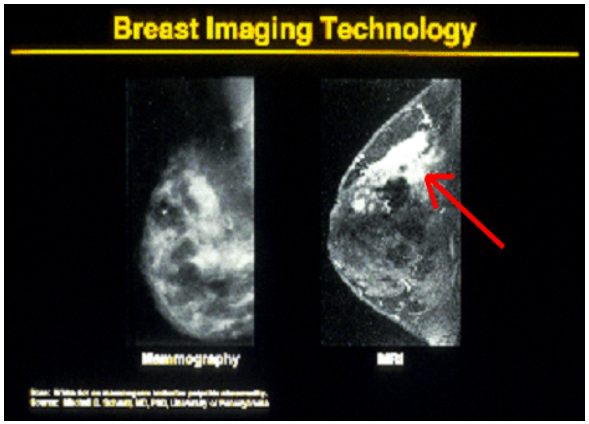
- Vision is the single most important sensing and perception for animals, for human beings,  and for robots.
  - About 80% of daily information is captured by our eyes.
  - On the brain,  two third (2/3) of the cortical areas are devoted to vision related processing.
- An image is worth of thousands of words.
- Camera is cheap, passive and energy-efficient, but very powerful.



# A picture is worth a 1,000 words

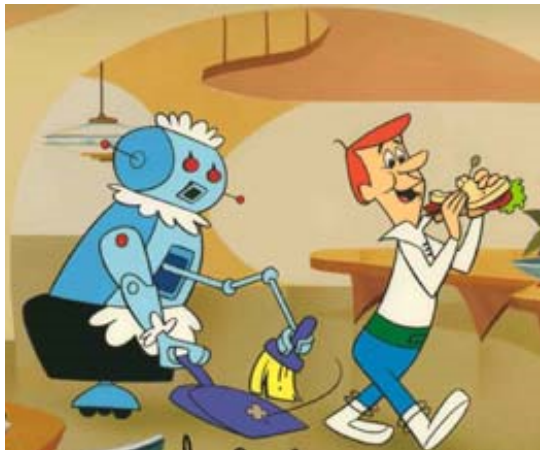
# Why computer vision matters?

Safety



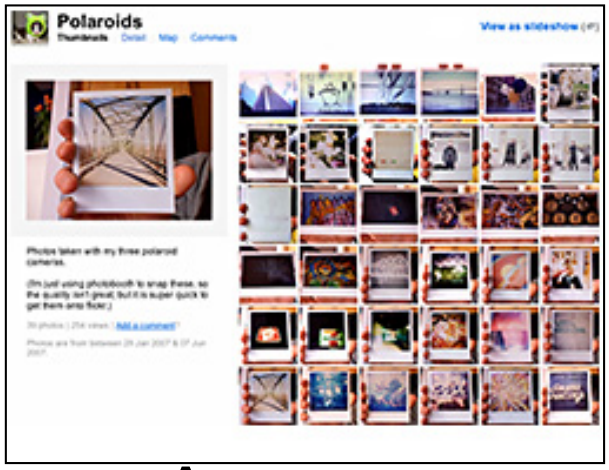

Health

Security



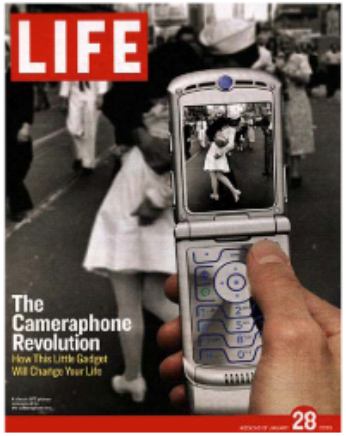
Comfort

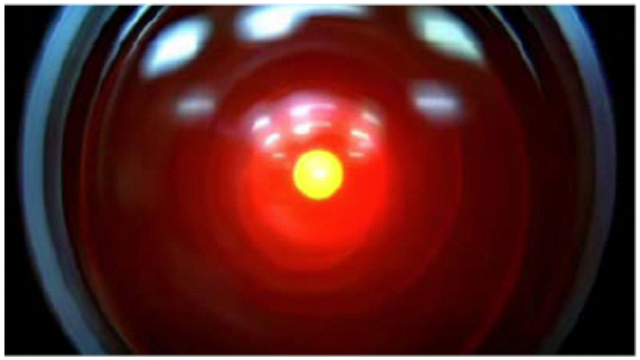
Entertainment



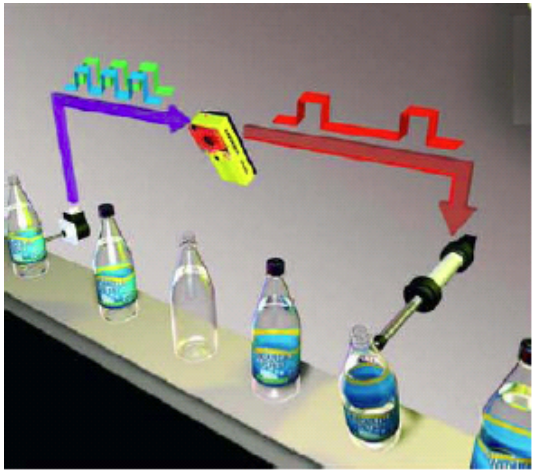

Access

# Cameras are everywhere!



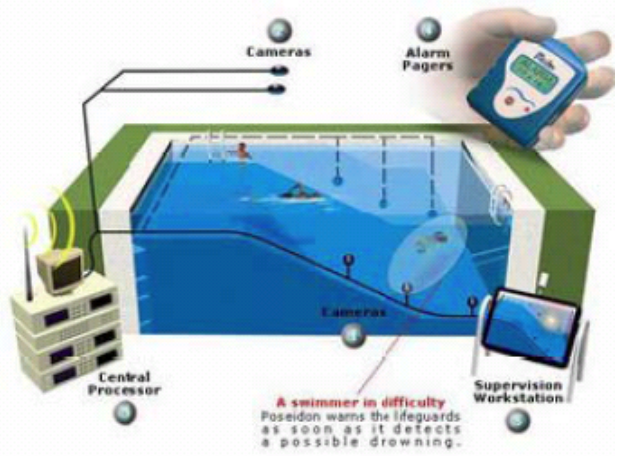



# Sample Applications

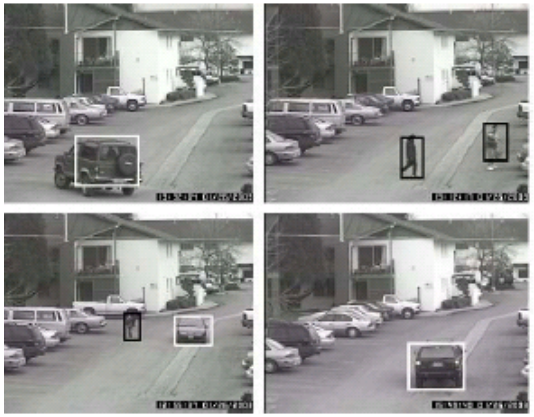


Factory inspection


Reading license plates, checks, ZIP codes




Monitoring for safety (Poseidon)



Surveillance

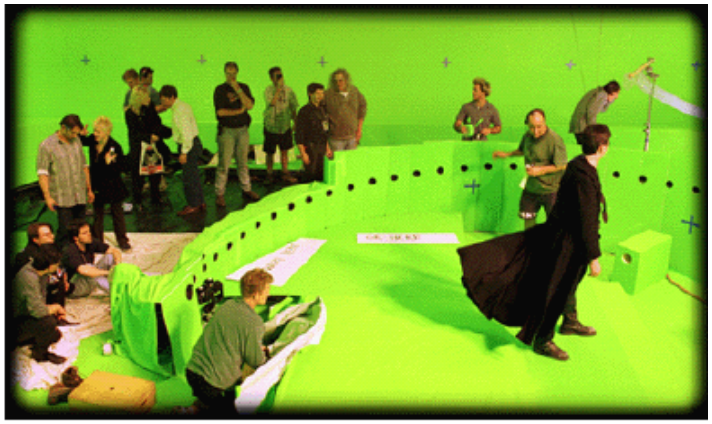
Autonomous driving, robot navigation


Driver assistance (collision warning, lane departure warning, rear object detection)

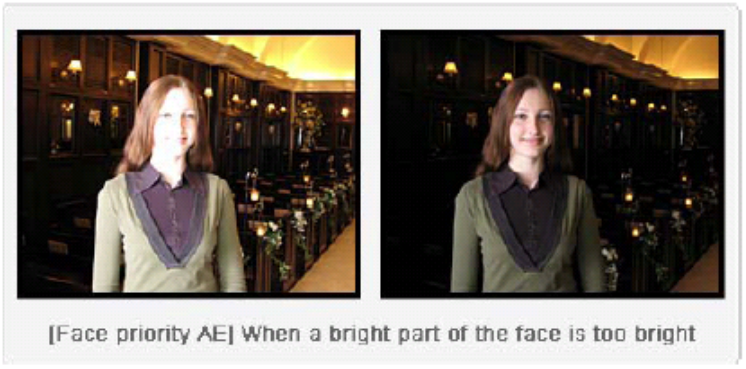
# Sample Applications

Assistive technologies

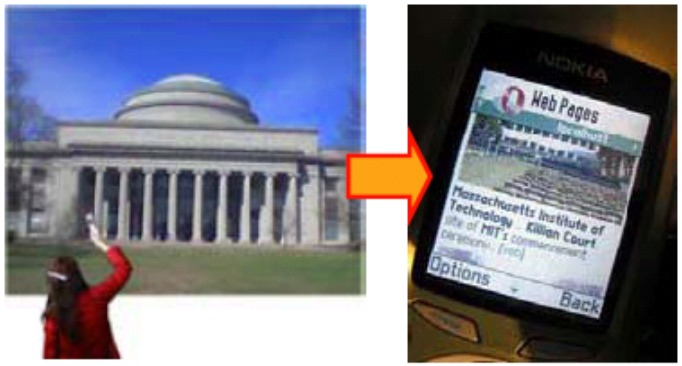

Entertainment (Sony EyeToy)



Movie special effects

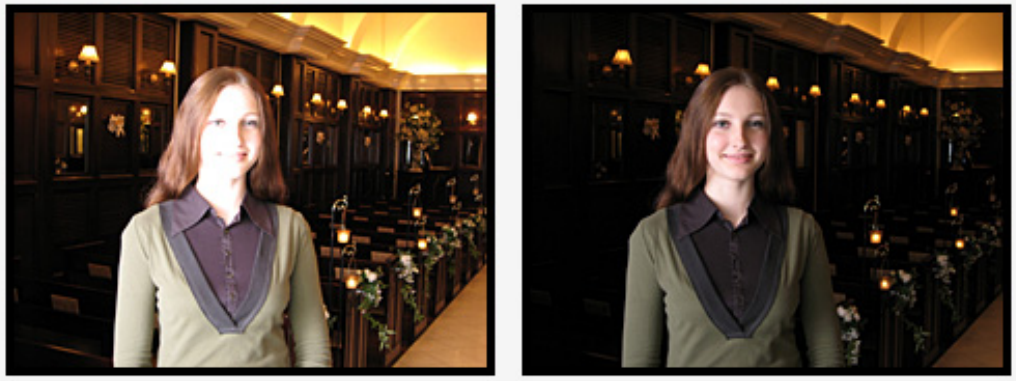




Digital cameras (face detection for setting focus, exposure)



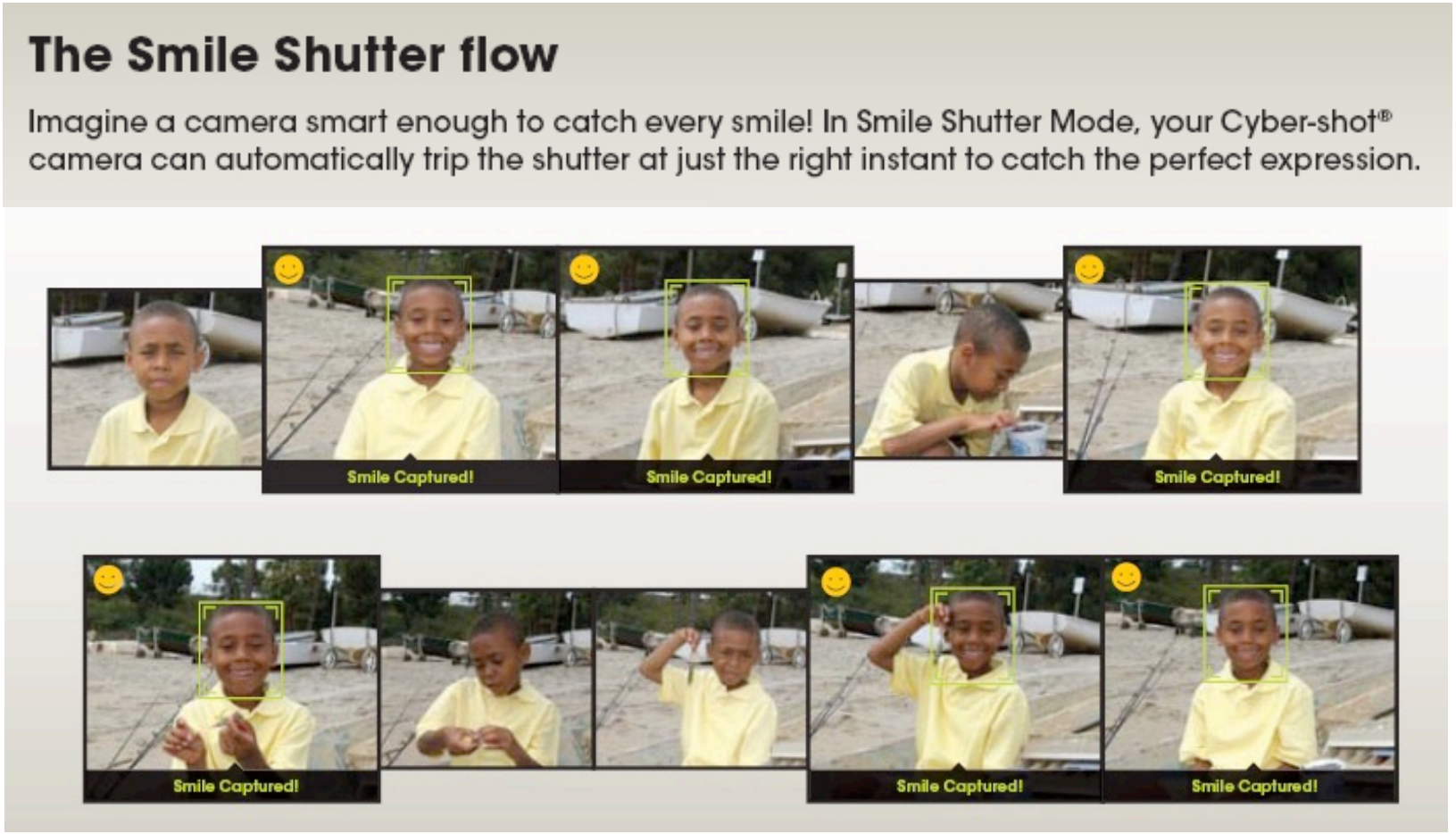

Visual search http://www.kooaba.com/

# Face Detection in Cameras

[Face priority AE] When a bright part of the face is too bright

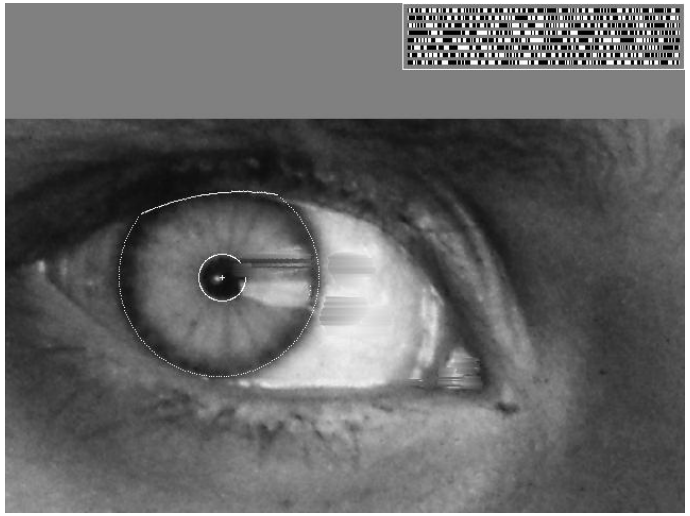
# Smiling face detection?

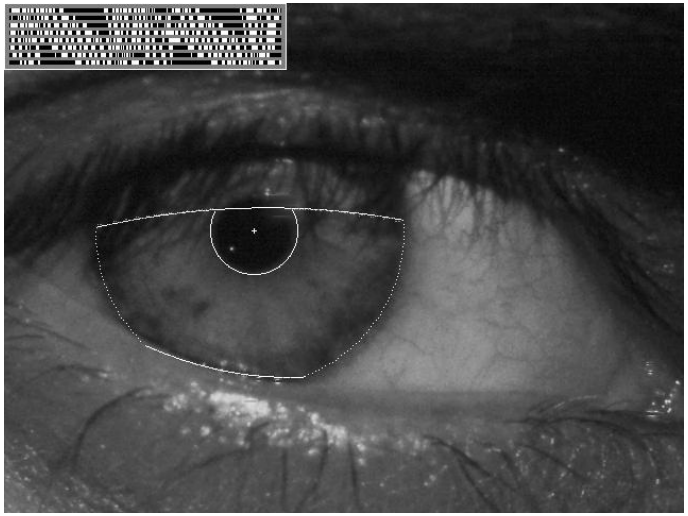



Sony Cyber-shot® T70 Digital Still Camera

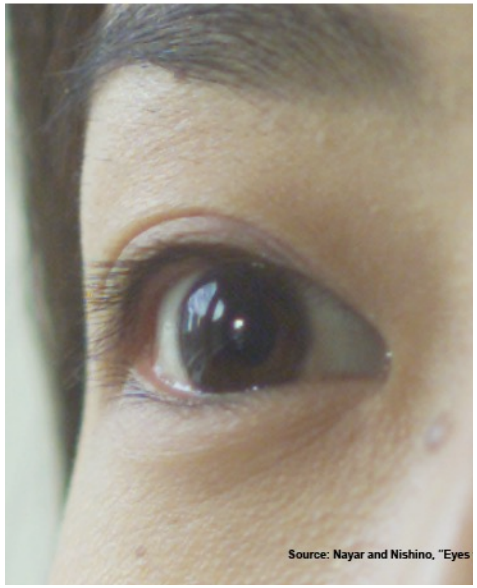
# Vision-based biometrics

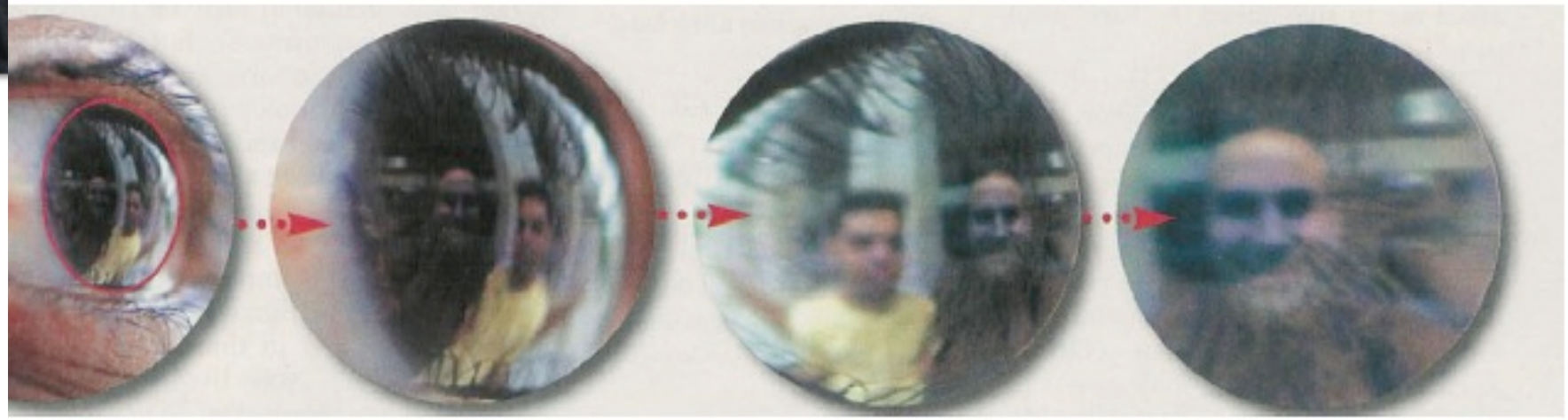
**"*How the Afghan Girl was Identified by Her Iris Patterns*" Read the [story]**



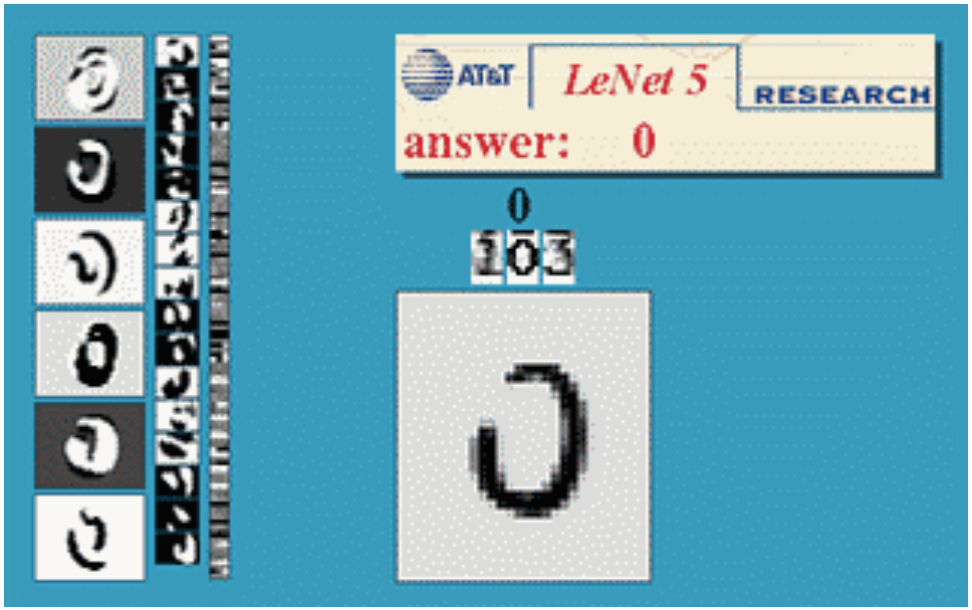


# Forensic



# Handwritten Digit Recognition





**Digit recognition, AT&T labs**
**Prof. Yann LeCun (NYU)**

**License plate readers**
**http://en.wikipedia.org/wiki/Automatic_number_plate_r**

**1/3 of all checks written in US use this system**

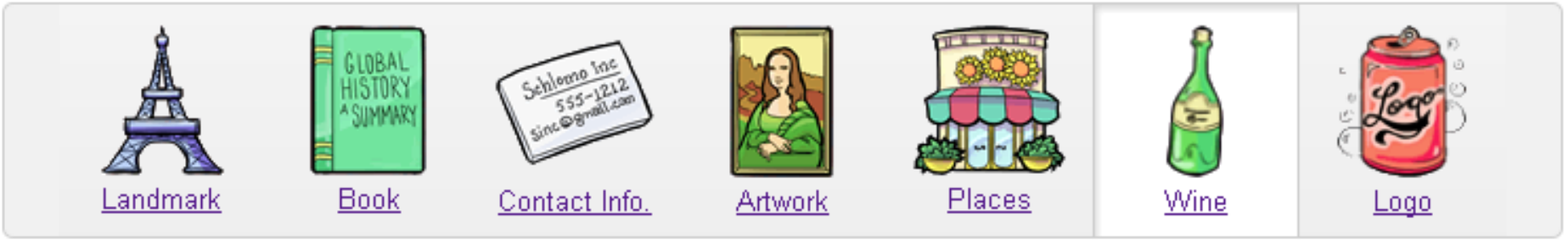
**Source: S. Seitz**

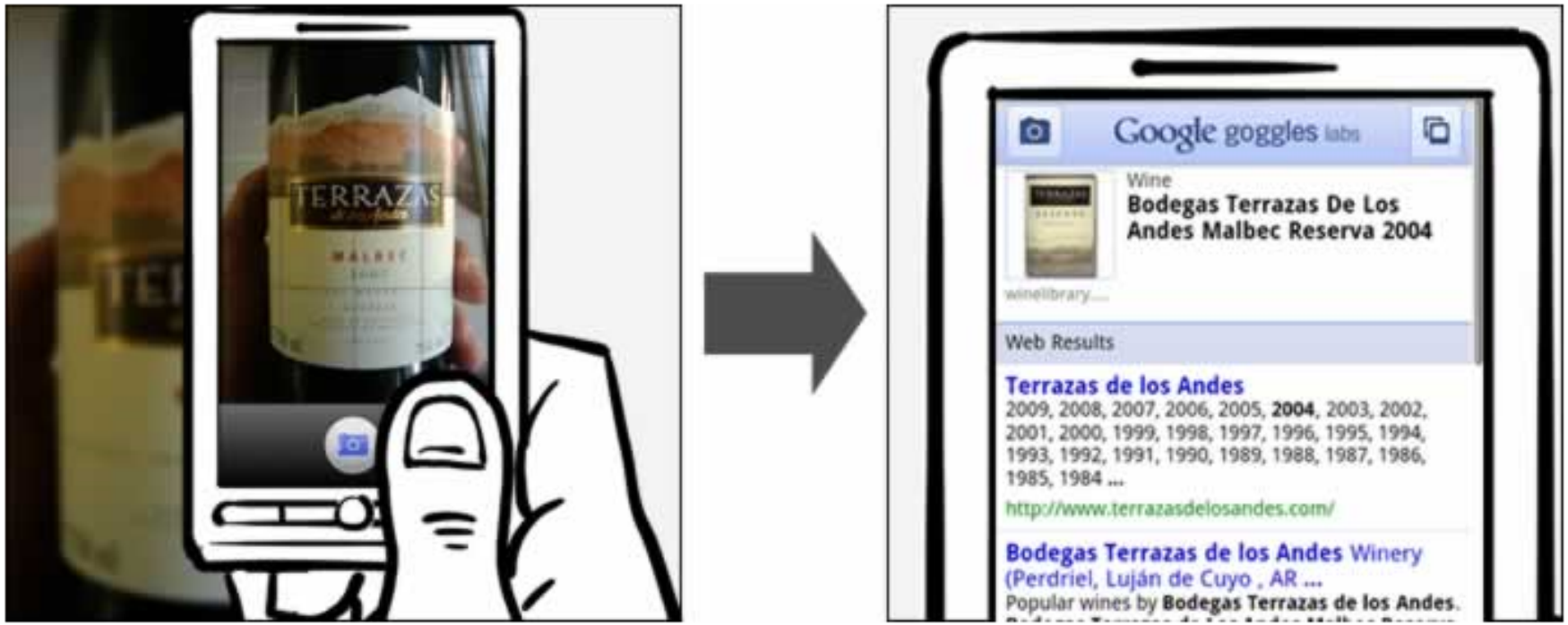
# Mobile visual search: Google Goggles

**Google Goggles in Action**

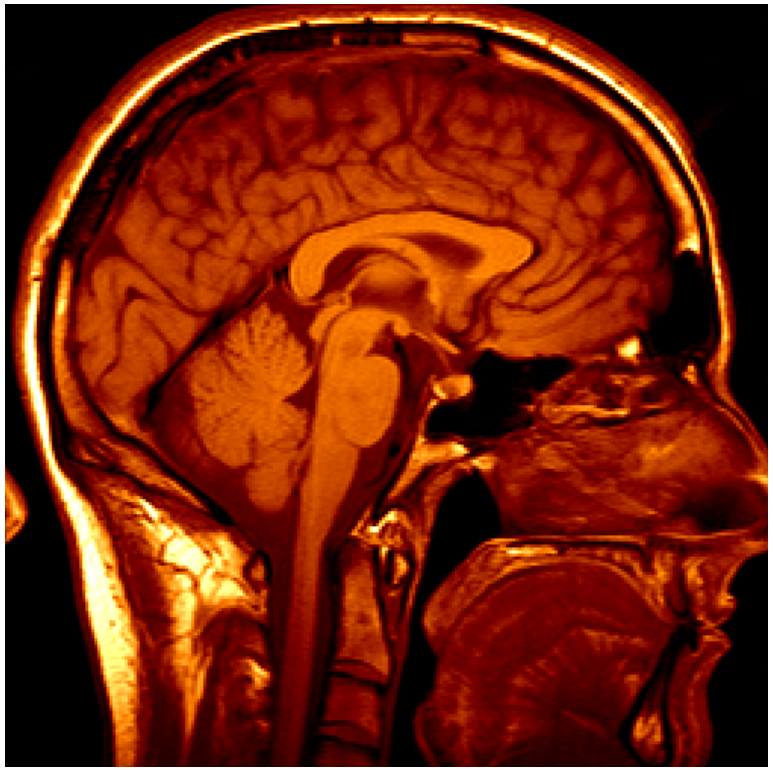
Click the icons below to see the different ways Google Goggles can be used.

Google goggles labs



# Medical Imaging



**3D imaging**
**MRI, CT**

**Image guided surgery**
**Grimson et al., MIT**

# Automotive Safety and Self-driving Cars


Mobileye: Vision systems in high-end BMW, GM, Volvo models

- "In mid 2010 Mobileye will launch a world's first application of full emergency braking for collision mitigation for pedestrians where vision is the key technology for detecting pedestrians."

**Source: A. Shashua, S. Seitz**

# Vision in supermarkets


**LaneHawk by EvolutionRobotics**

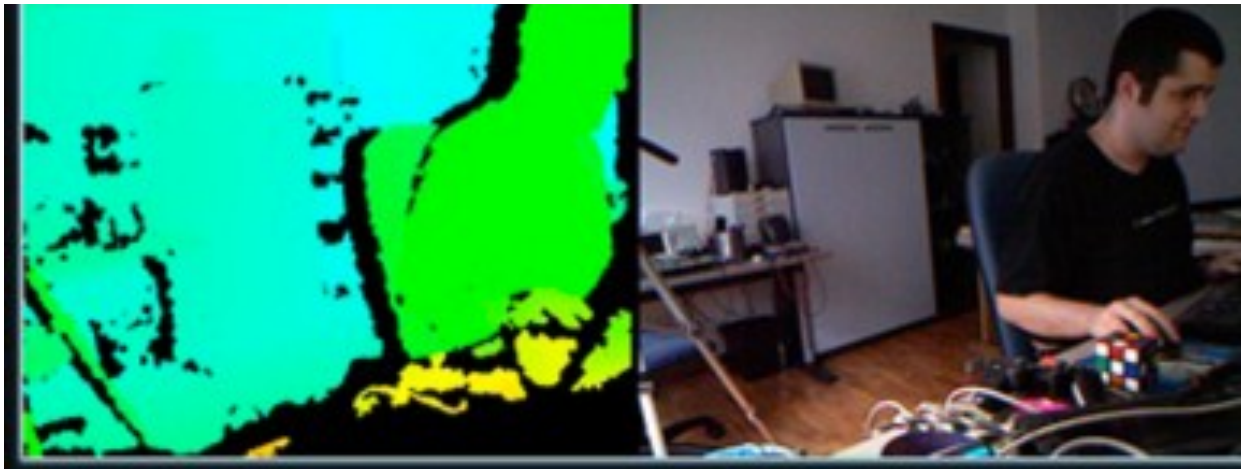
**"A smart camera is flush-mounted in the checkout lane, continuously watching for items. When an item is detected and recognized, the cashier verifies the quantity of items that were found under the basket, and continues to close the transaction. The item can remain under the basket, and with LaneHawk,you are assured to get paid for it… "**

**Source: S. Seitz**

# Vision-based human computer interface

## Microsoft Kinect


KINECT
for XBOX 360.



# Vision for robotics, space exploration

**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**

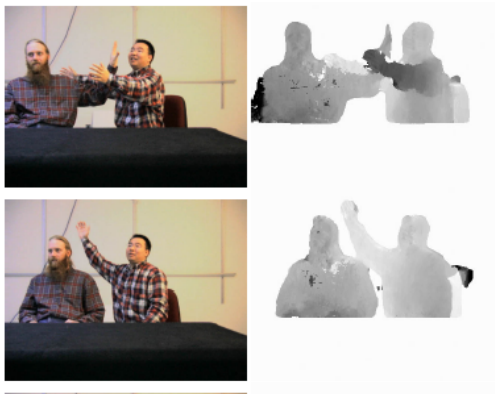
**3D terrain modeling**

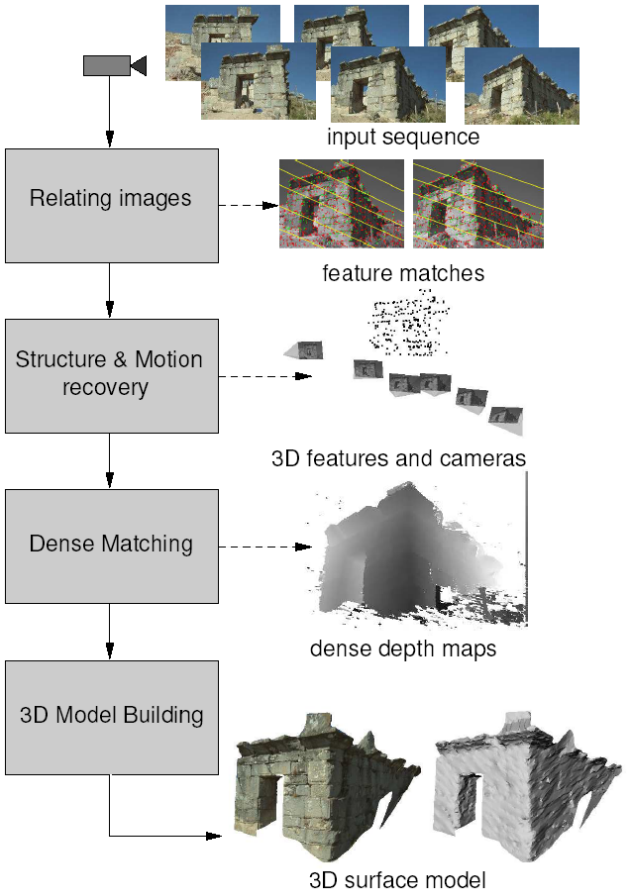
**Obstacle detection, position tracking**

**For more, read "Computer Vision on Mars" by Matthies et al.**

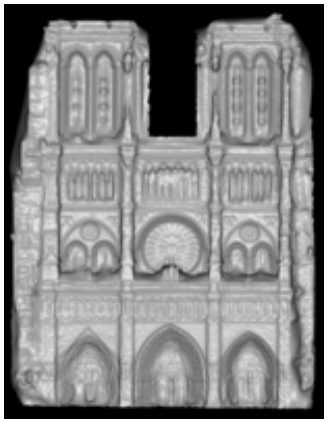
**Source: S. Seitz**

# 3D Reconstruction







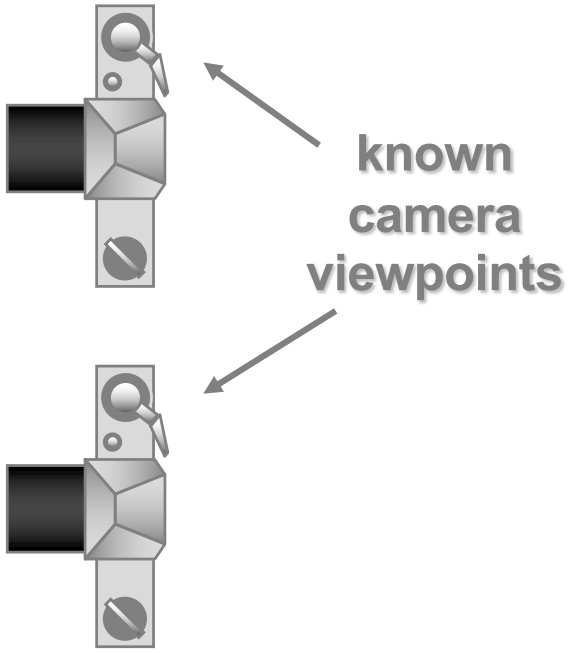


**Pollefeys et al.**

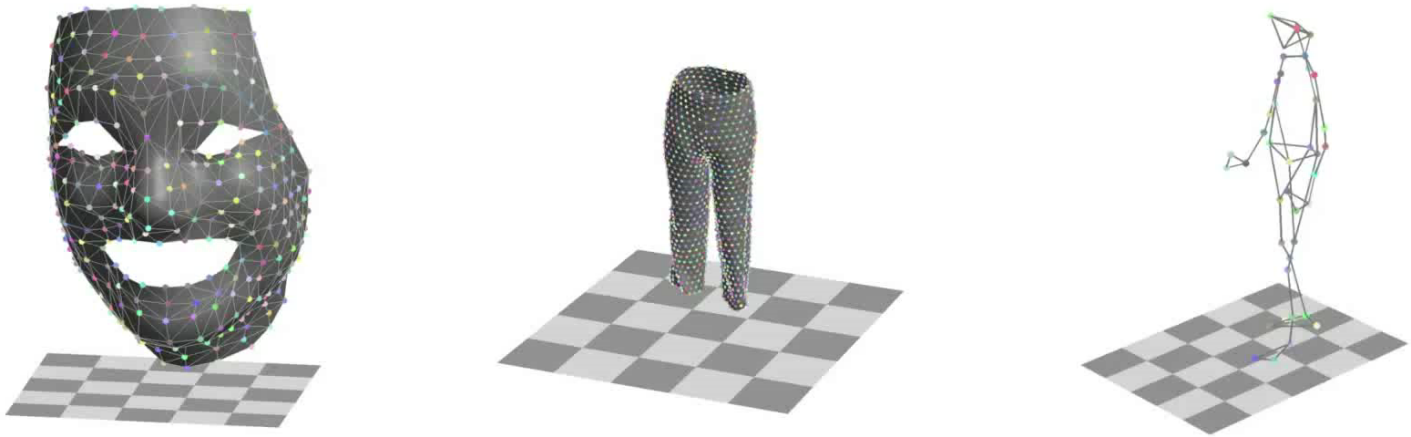
**Goesele et al.**

# Structure from motion

*Given two or more images of the same scene, compute the 3D structure*



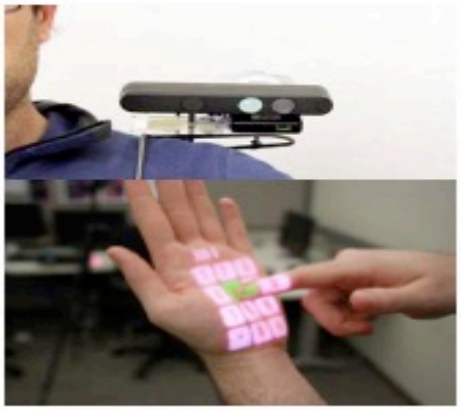
# Non-rigid Structure form motion



# Applications are everywhere

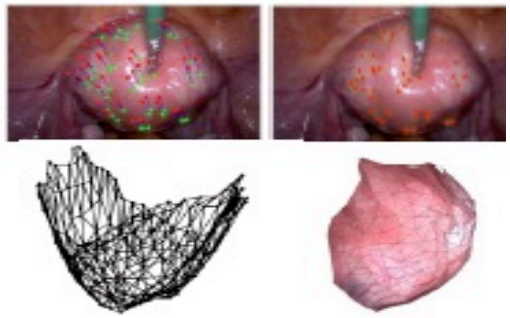
**Motion capture/animation**

Andy Serkins - Rise of the Planet of the Apes



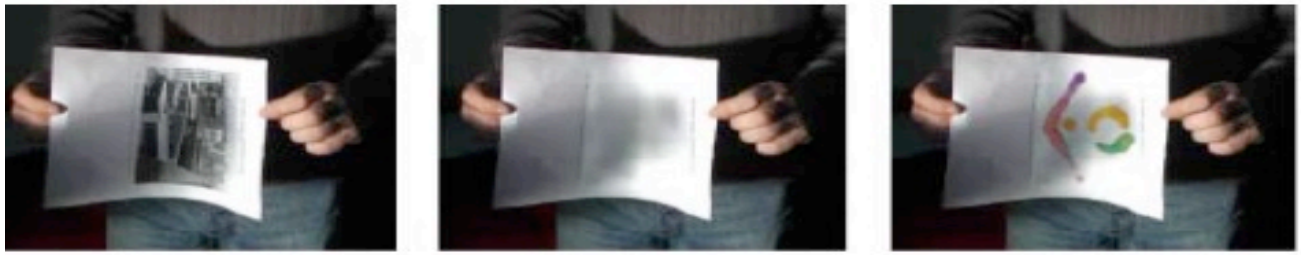
**HCI**

OmniTouch – C. Harrison et al. 2011



**Medical Imaging**

A. Malti et al., MIUA 2011

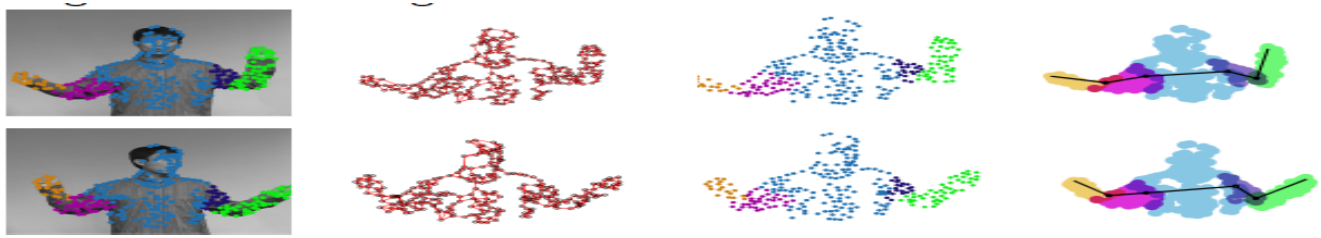


**Augmented reality**

Pilet et al. 2008

**Cloth animation**

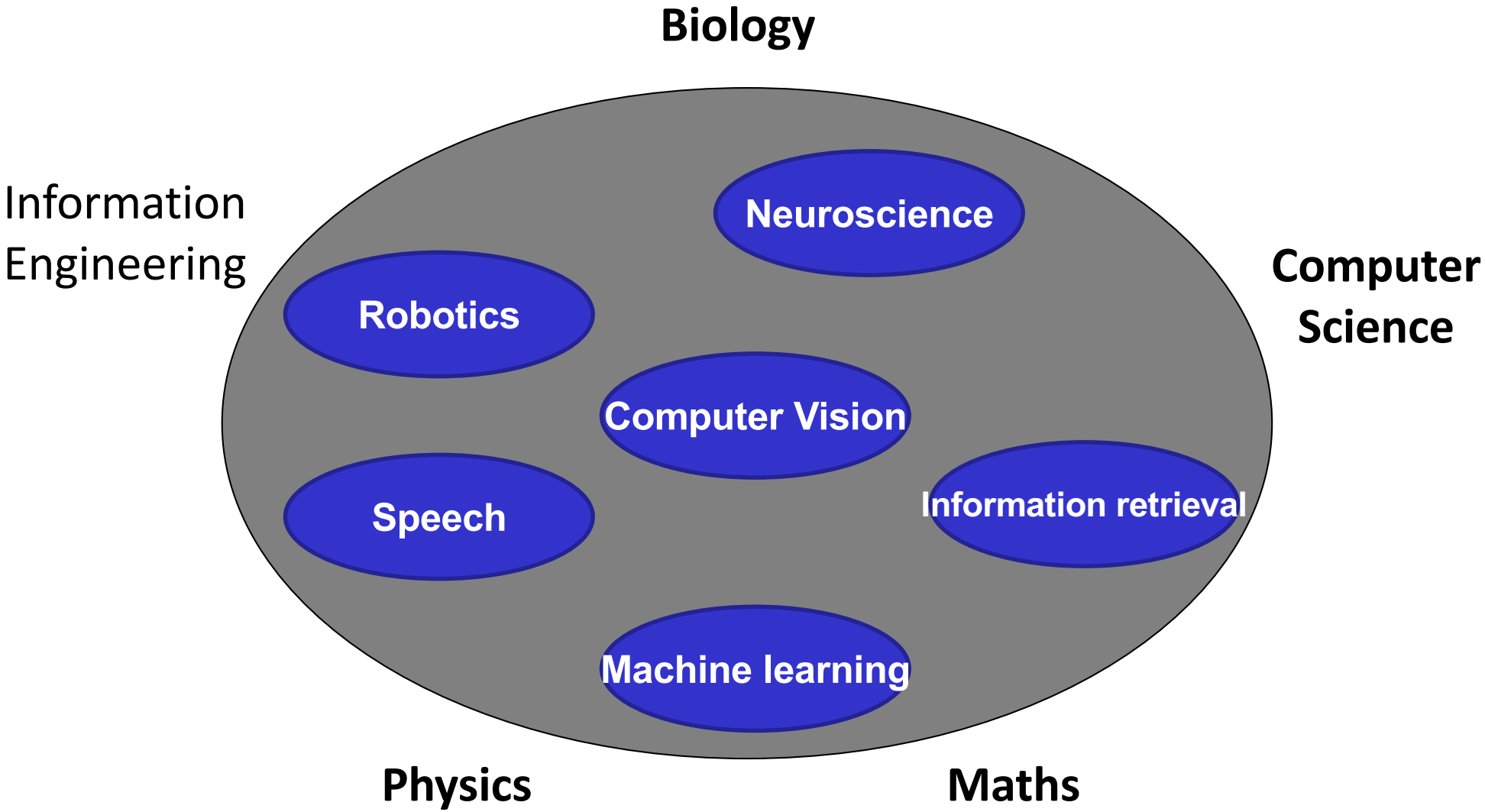
R. White et al., SIGGRAPH 2007



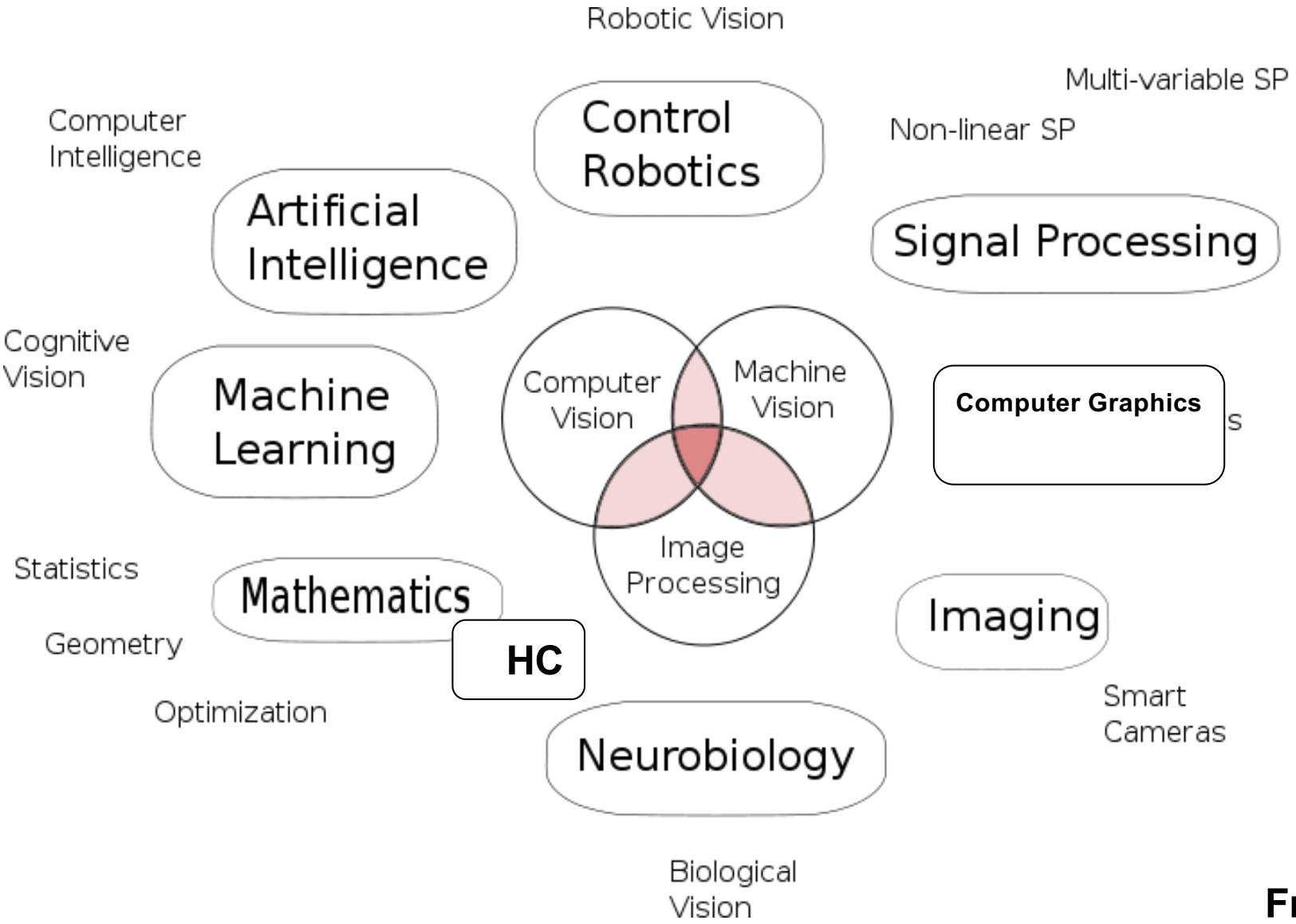
**This slide is taken from Agapito et al's Tutorial at**

# Non-rigid application: movie special effects

# Computer vision- multidisciplinary research field



# See also Wikipedia: computer vision




**From wiki**

# Administrative Information ENGN6528

# General Course Information

- An introductory level (but research-oriented) course for computer vision.
- **Postgraduate students (Masters/PhD)**.
- 12 weeks of 2 ~ 3-hour lectures, 3 computer lab assignments (matlab/python based) 1 assignment, 1 mid-term exam (possibly) and a final exam.
- Lectures will be delivered via Zoom.

# Assessment Components

| **Lectures** | **Tutorials (on demand)** | **Computer lab and Assignments** | **Quiz** | **Final exam** |
|---|---|---|---|---|
| 12 x 2 + 6 x 1 hours | 5 x 1 hours | 3 c-labs and 1 assignment | 1 (TBA) | 1 |
| - | - | 10% x 3 + 20% | 20% | 30% |

# Tutors

- Ryan Pike
- Lin Li
- Sameera Ramasinghe

# Workload and study plan

- 2 ~ 3-hour lectures per week
- 1-hour tutorial (not every week)
- 3-hour computer lab (2-hour in-class + 1-hour after-hours)

# Lectures (12 weeks x (2-3) hours)

1. Introduction & Image processing basics
2. Spatial transformation
3. Image filtering and denoising

4. Feature extraction, Image segmentation
5. PCA and eigen-face,

6. 3D vision: Multi-view geometry-1
7. 3D Vision: Multi-view geometry-2
8. Stereo and optical flow, Shape from X and other 3D vision

9. High level visual recognition
10. Deep Learning-1
11. Deep Learning-2

12. Review

# Lecture Attendance

- You are strongly encouraged to attend as many lectures as you can, as you will benefit significantly from participating lectures, for this open and research-oriented course.

# Classroom rule

- Late arrival: please make all effort to come to the lecture on time
- No small talks
- Asking class-related questions are encouraged (use "raise-hand" feature or chat in zoom)
- Use your courtesy
- Please mute your microphones expect the speaker
- **Academic integrity!!**

# Computer lab group sign in

- Sign in to groups on Wattle from mid this week.
- Each group is capped at 25 students at most.
- C-Lab sessions: Thursdays (10:00 – 12:00), Fridays (12:00 – 14:00).
- Matlab with image processing toolbox or python with opencv, numpy and related packages will be required.

# Tutorials (TBA)

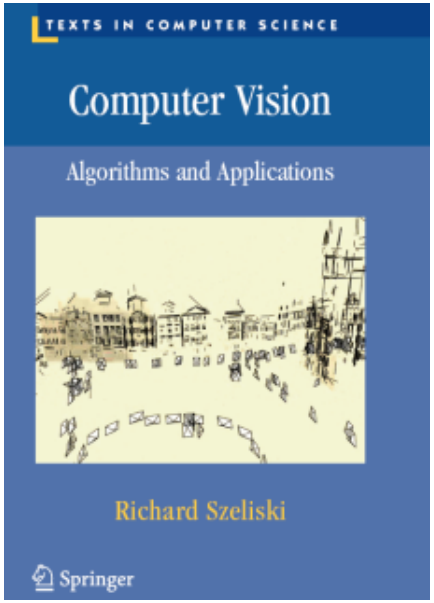
- Typically we will use Wednesday lecture time (13:00 – 14:00)
- Possible topics include introduction to Matlab/python, explain the assignments
- You are strongly encouraged to contact tutors or me, for any questions/inquiry or seeking feedback.

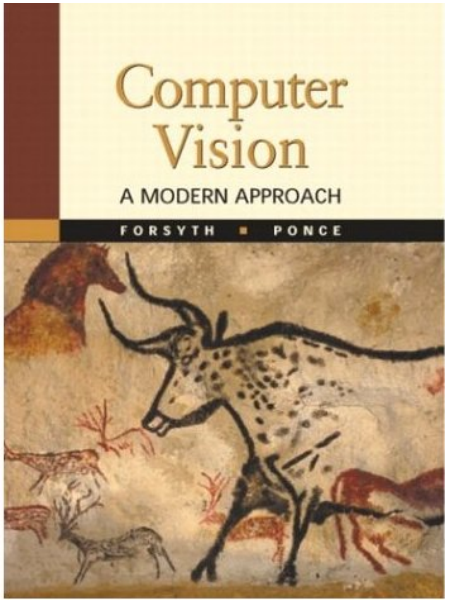
# Recommended textbooks

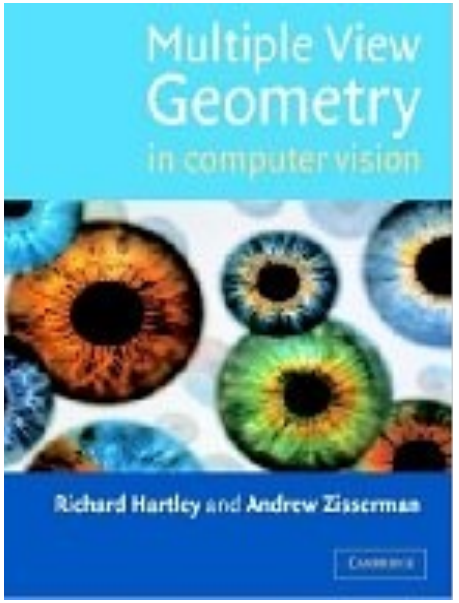
1. Computer Vision: Algorithms and Applications by Rick Szeliski 2010 (online, or can be purchased in hardcopy)

2. Computer Vision: A Modern Approach, Forsyth and Ponce 2002

3. Multiple View Geometry in Computer Vision 2rd Edition, by Hartley and Zisserman 2004.



# Disclaimer

- Many of the slides used here are adapted from online resources (including many open lecture materials) without proper acknowledgement.
- They are used here for the sole purpose of classroom teaching. All credit and all their copy-rights belong to the original authors.
- You should not copy it, redistribute it, put it online, or use it for any other purposes than for this course of ENGN4528/6528.

# Final Exam (30%)

- Basic concepts, basic knowledge points.
- Basic problem-solving-skills, calculations.
- Design problems: algorithm/application system design.

Australian National University

# CECS Course Representatives

## Why become a course representative?

- **Develop skills sought by employers**, including interpersonal, dispute resolution, leadership and communication skills.
- **Become empowered**. Play an active role in determining the direction of your education.
- **Become more aware of issues influencing your University** and current issues in higher education.
- **Ensure students have a voice** to their course convener, lecturer, tutors, and college.

# CECS Course Representatives

## Roles and responsibilities:

- Act as the official liaison between your peers and convener.
- Be creative, available and proactive in gathering feedback from your classmates.
- Attend regular meetings, and provide reports on course feedback to your course convener and the Associate Director (Education).
- Close the feedback loop by reporting back to the class the outcomes of your meetings.

More information about roles and responsibilities can contact
ANUSA CECS representative Sophie Burgess via sa.cecs@anu.edu.au, or
ANUSA President, Lachy Day via sa.president@anu.edu.au

# CECS Course Representatives

**Want to be a course representative? Nominate today!**

Please nominate yourself on **CECS S2 2020 Course Rep EOI** **by 3rd August 2020** to nominate yourself as a course representative. You are free to nominate yourself either you are on campus or off-shore.

You will be contacted by CECS Student Services by 7th August with the outcome of your self-nomination.

**All the course representative meetings will be held in zoom in S2 2020. There are three meetings this semester. The meeting details will be updated to all the course representatives shortly.**

*Subjects of Computer Vision*

*-A quick preview of this semester's lectures*

# Three levels of vision processing

- **Low-level vision**:

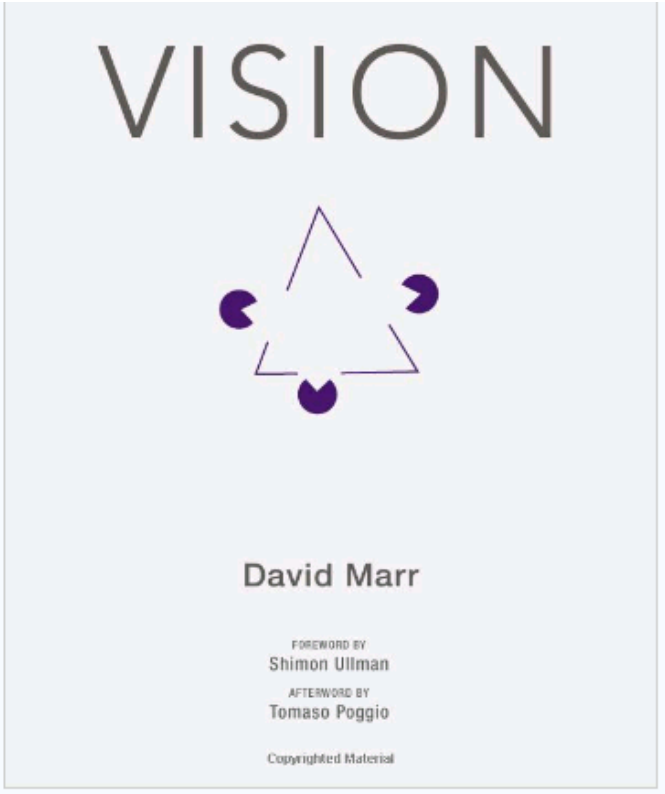
– image processing, denoise,
filtering, image restoration,
low level feature extraction.

- **Mid-level vision**:

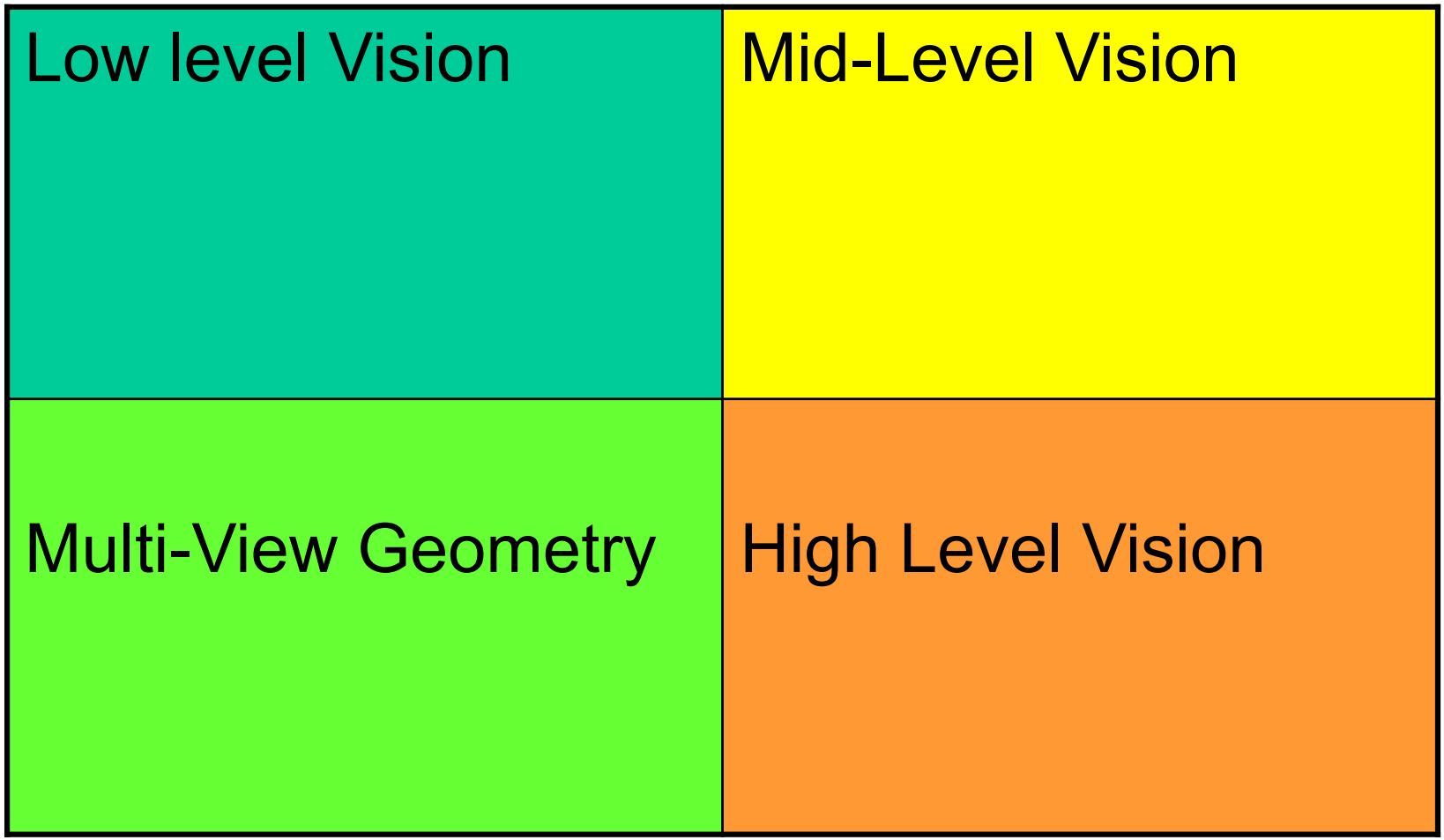
– image analysis, image segmentation,
contour extraction, perceptual organization,
– Multiview Geometry: 2-1/2D representation,
3D information recovery.

- **High level vision**:

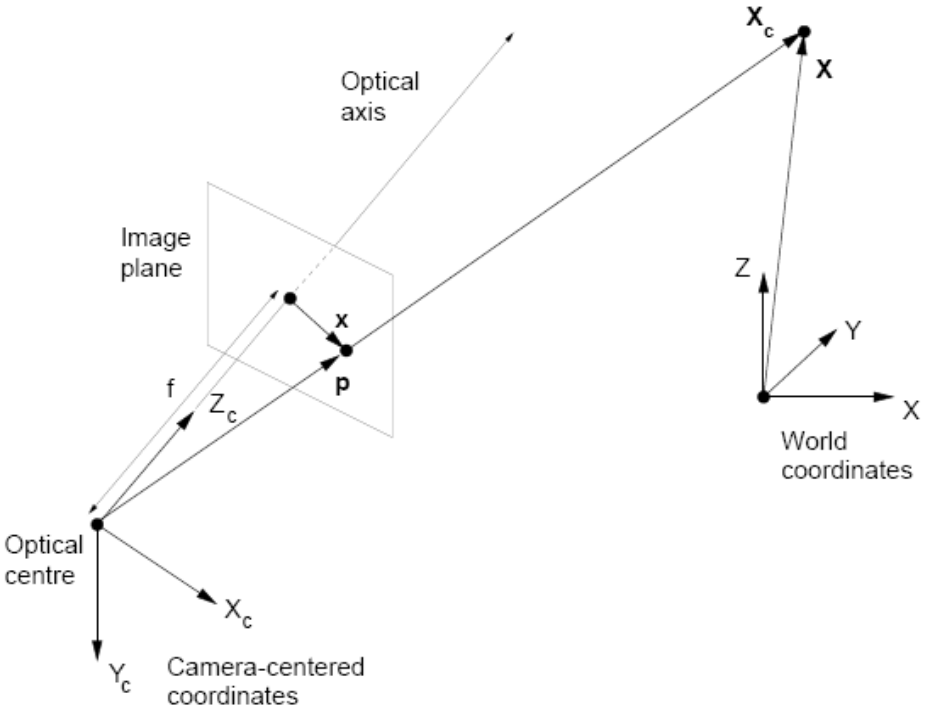
– visual detection, recognition, understanding,
semantic labelling, activity, event detection.

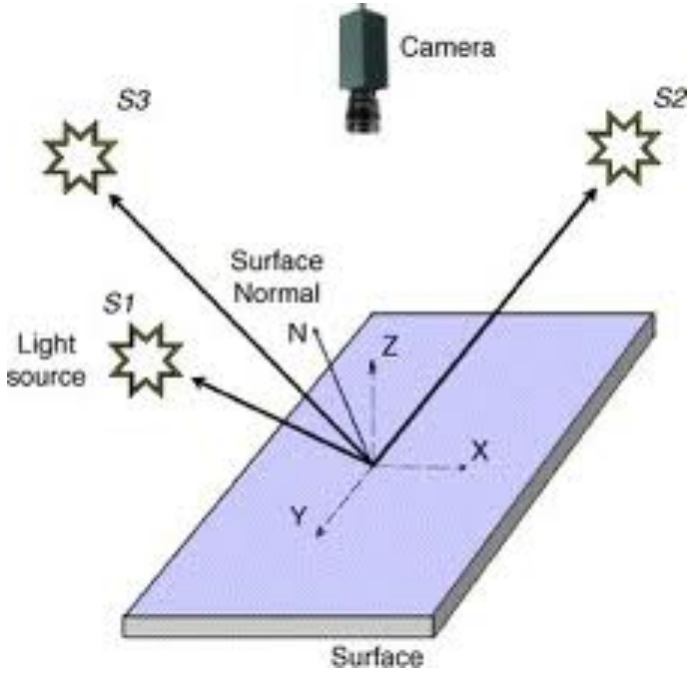


# Four Modules



# Image Formation




**Geometry**

**Photometry (Radiometry**

# Image representation

Binary image,

Grey scale,

Colour space, …

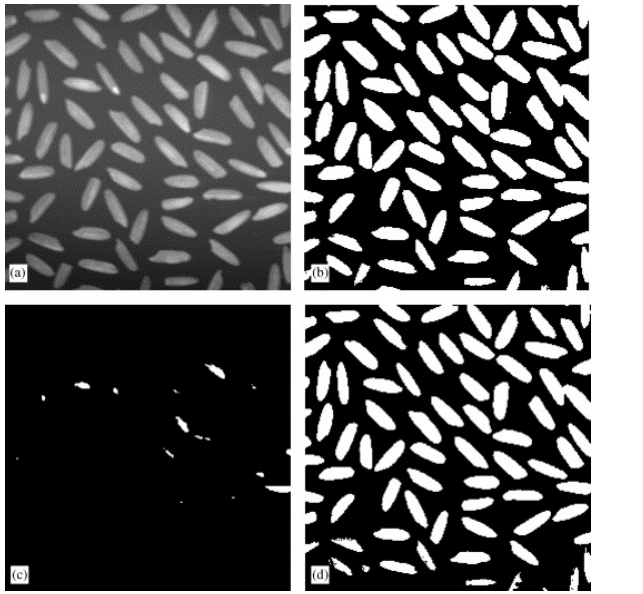
# Image processing (deblur, denoise)

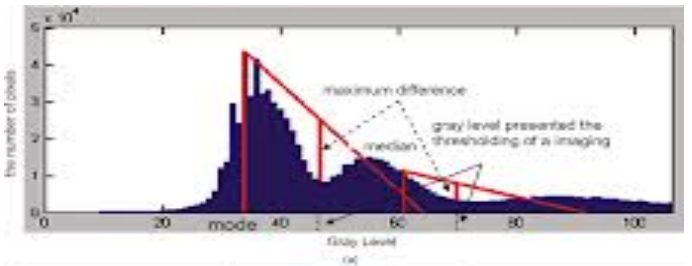

Input blurred image

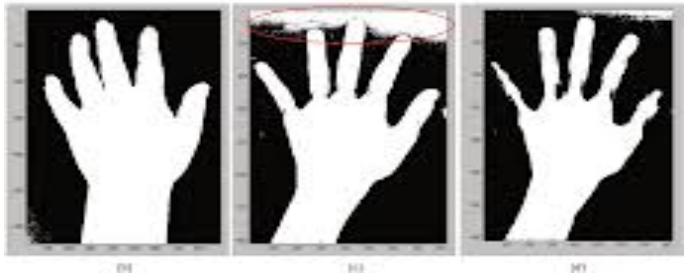
Deblurring result

Magnified views

# Binary image analysis

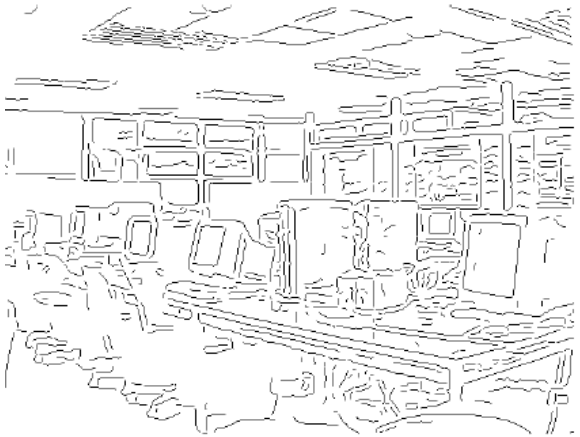


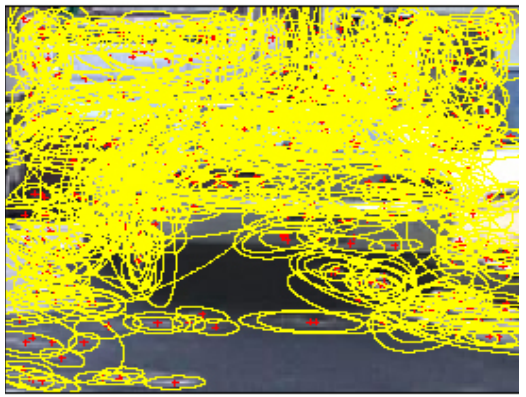



# Feature extraction

## Edges, Corners



## Local regions

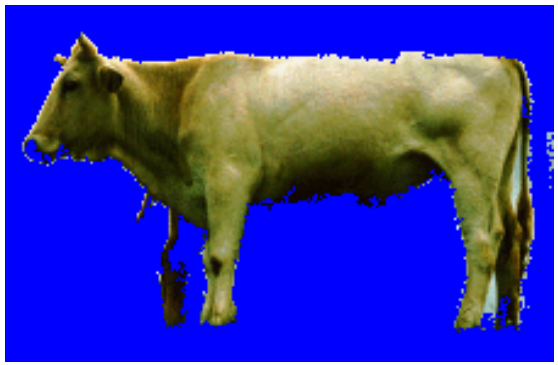


# Image segmentation

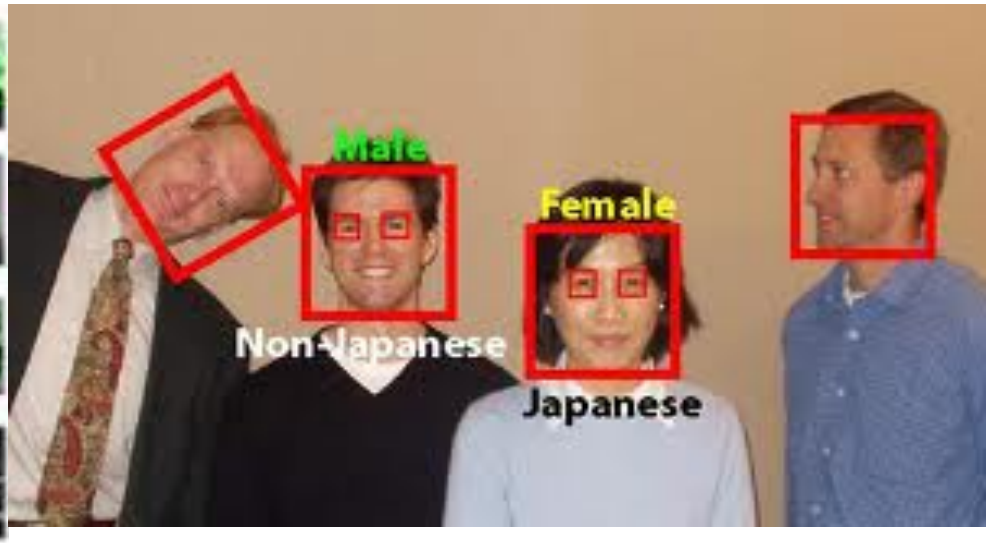

# Image Segmentation

**Image**

**Segmentation**

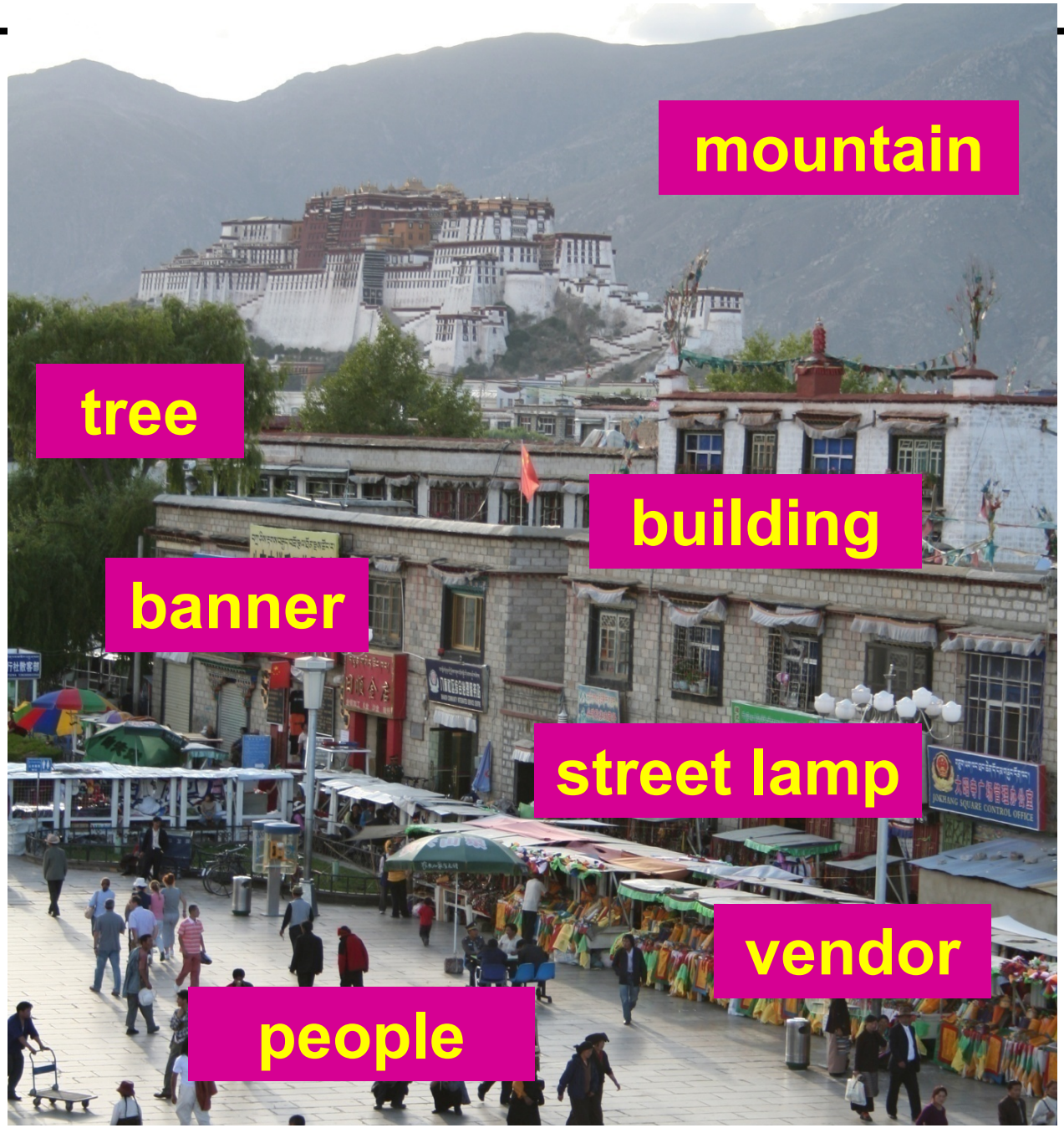


# Face detection and Face recognition




# Object Detection: localize the street-lights

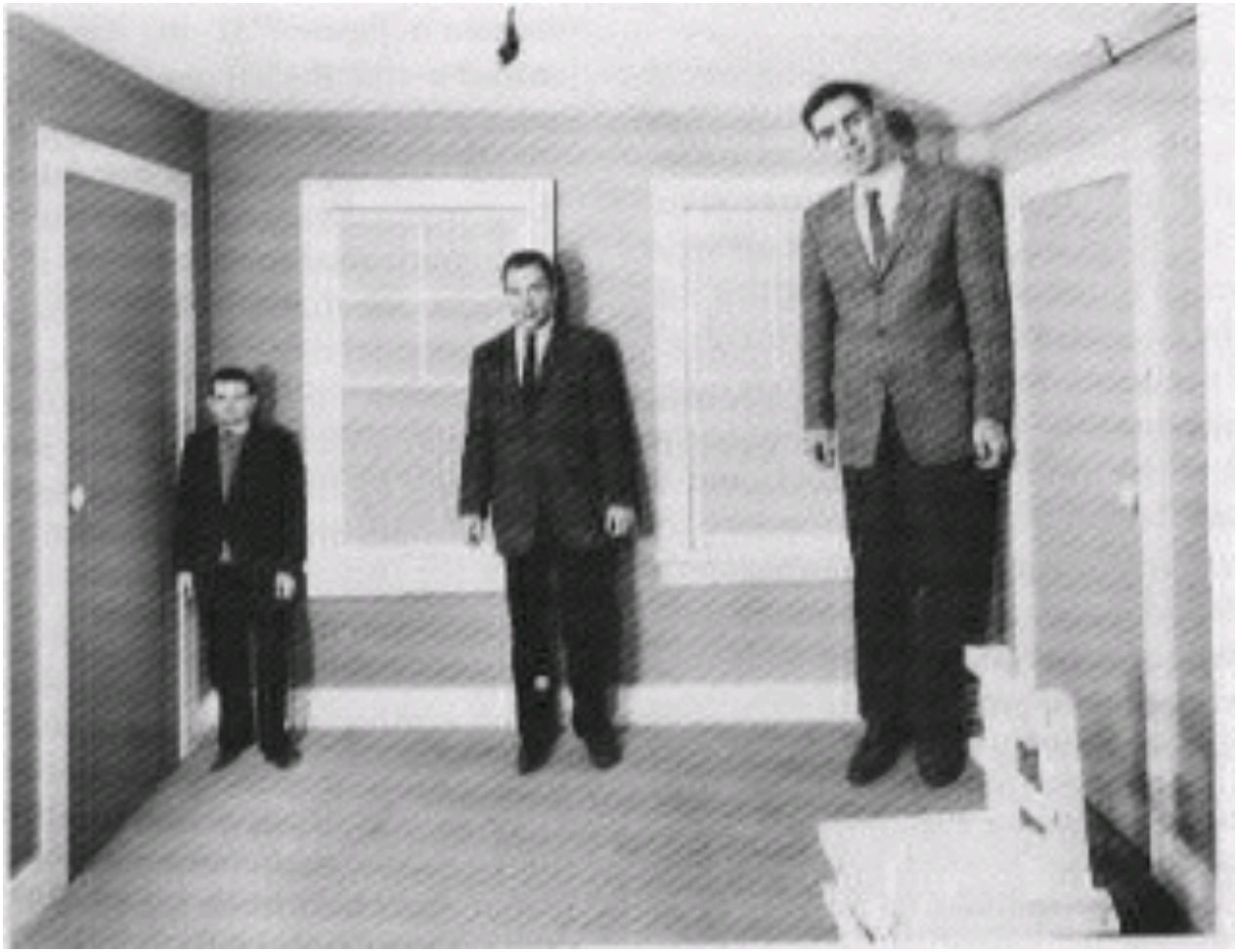
# Object category recognition



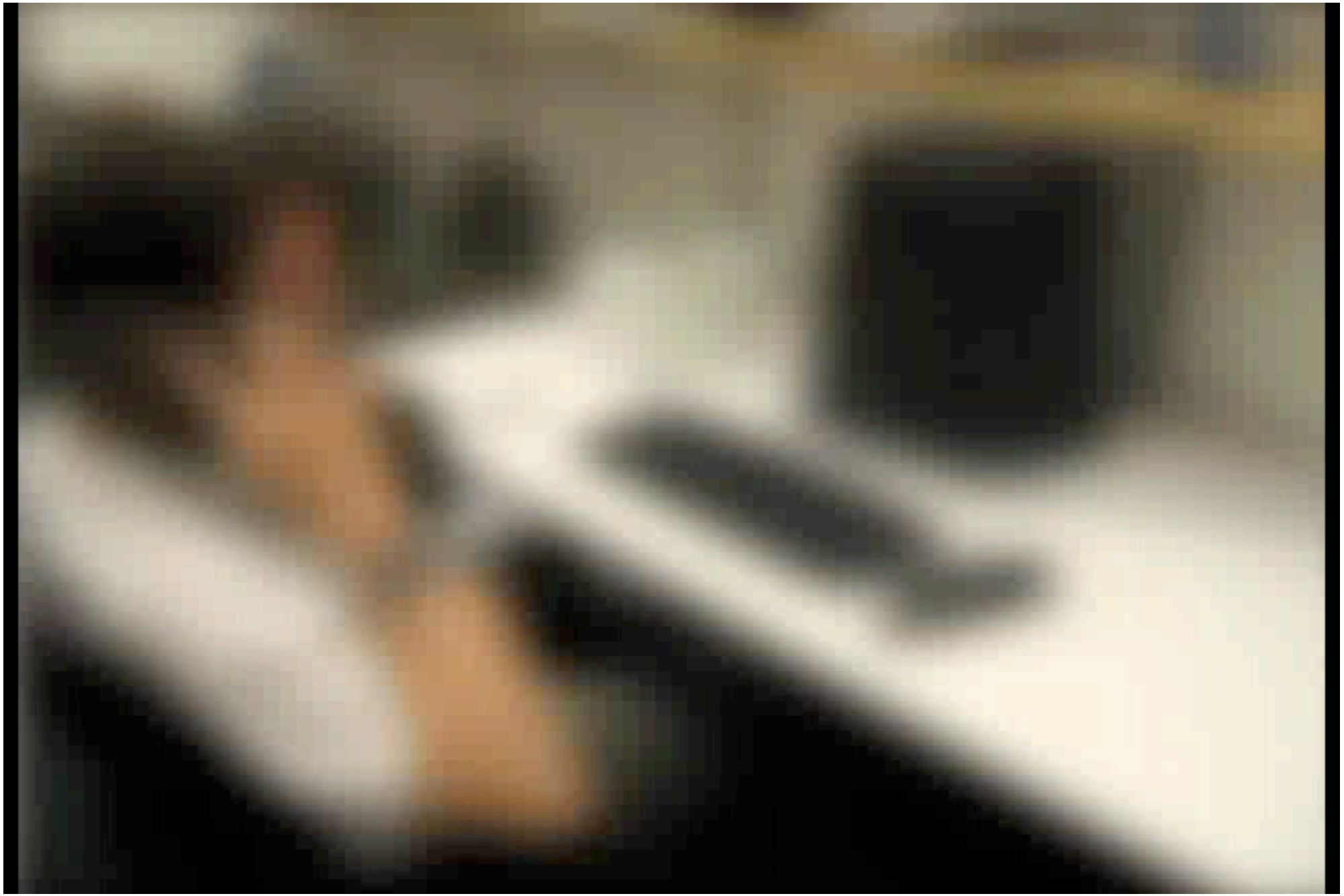
# Human motion detection

*Vision is not an easy task;  even humans sometimes may be confused*

# Prior assumption sometimes can be wrong or misleading



**Ames room**

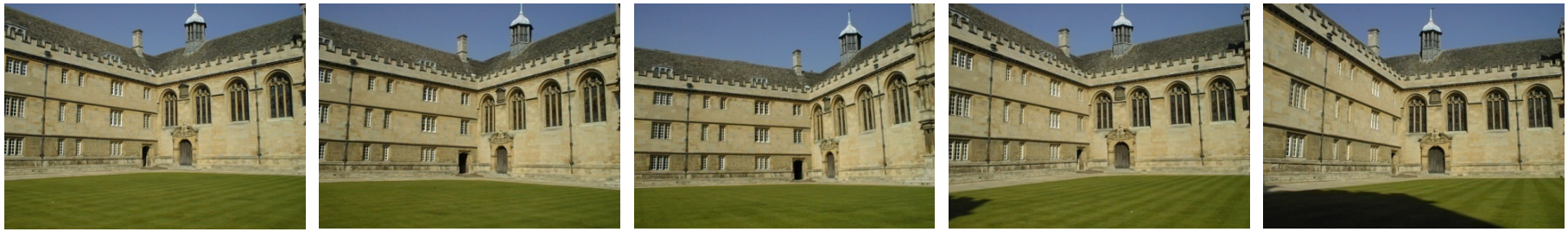


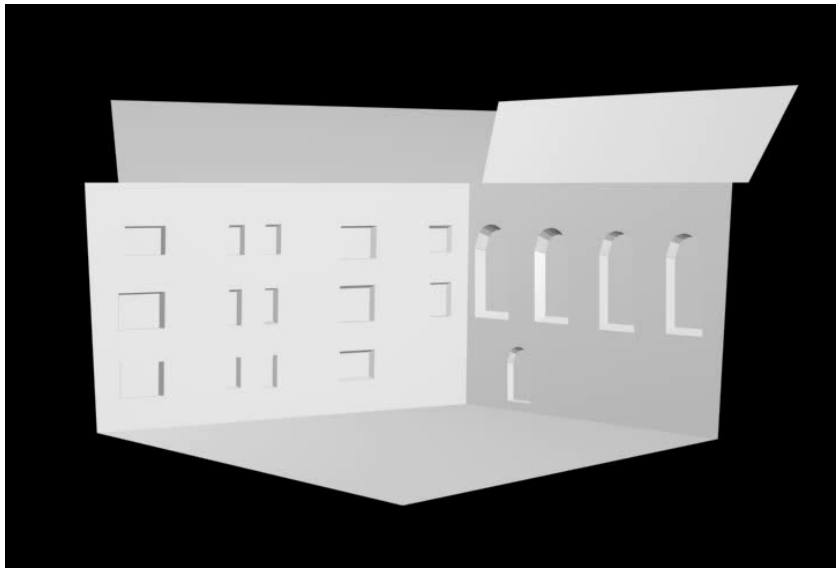
**Credit: Antonio T. (MIT)**

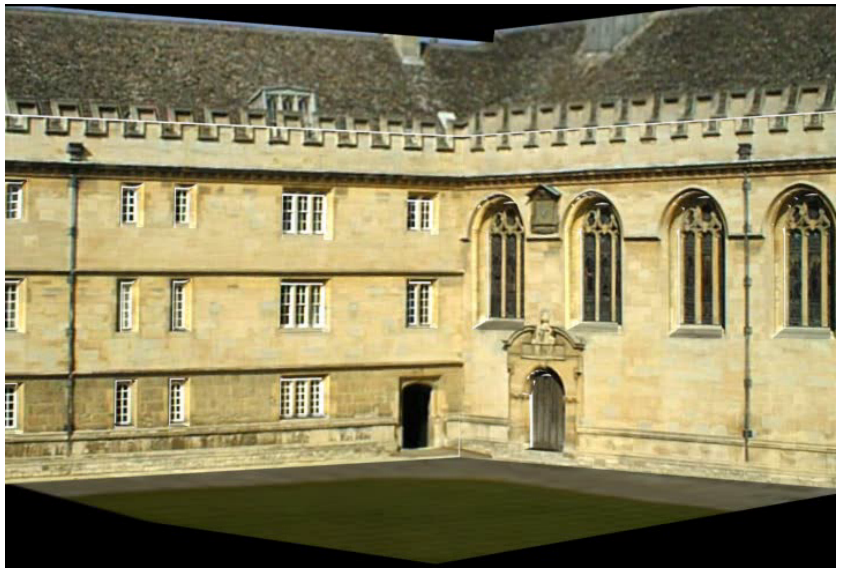
How to develop a vision-based chair recognizer ?

# Design a chair recognizer ?

# Multiview Geometry

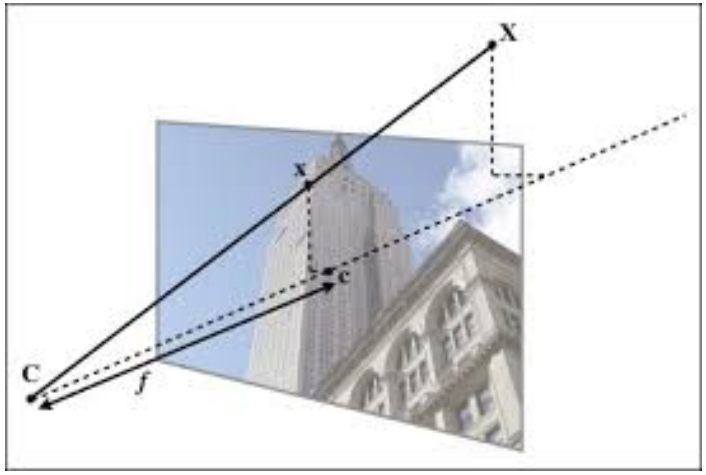


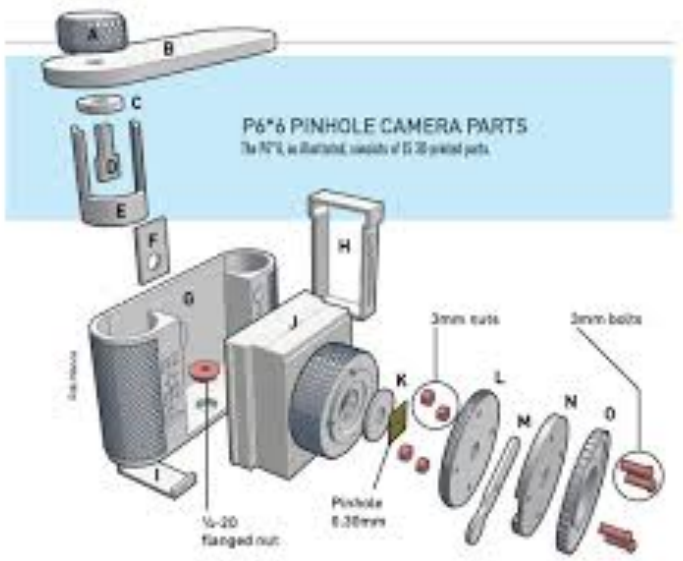


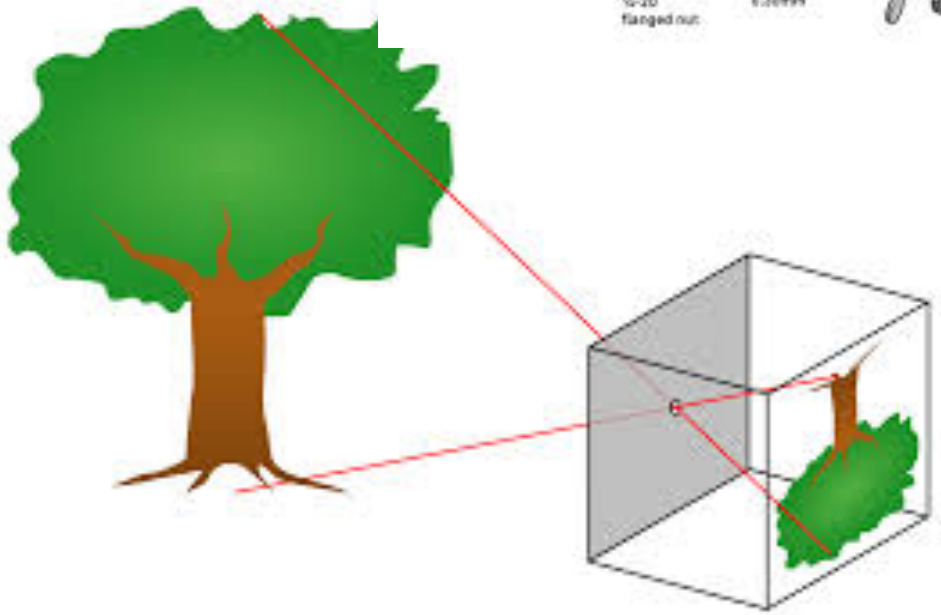


**[Fitzgibbon et. al]**
**[Zisserman et. al. ]**

# Camera model and camera calibration



# 3D Reconstruction: Structure from Motion

## Objective: given a set of images …

- aim to compute where the camera is for each image and the 3D scene structure:

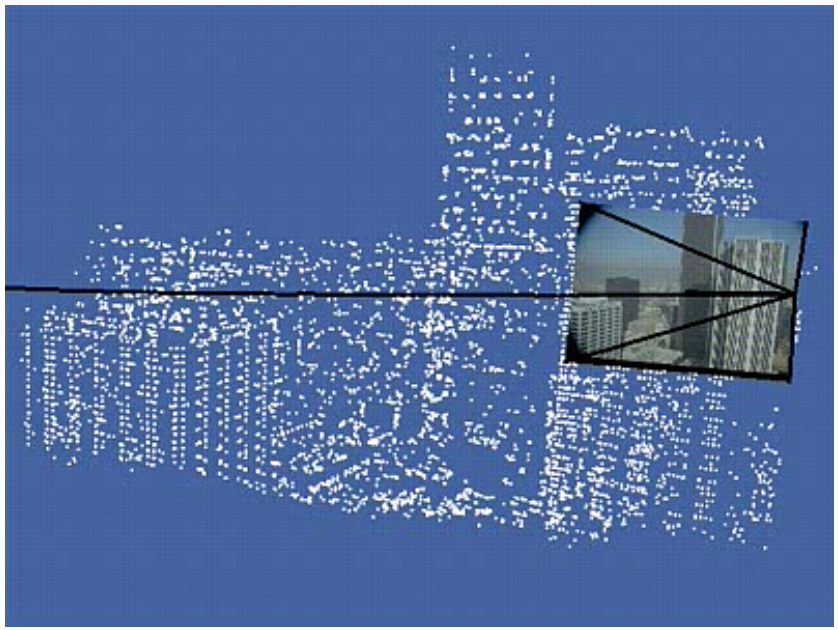
  - Uncalibrated cameras

  - Automatic estimation from images (no manual clicking)

# Example

Image sequence

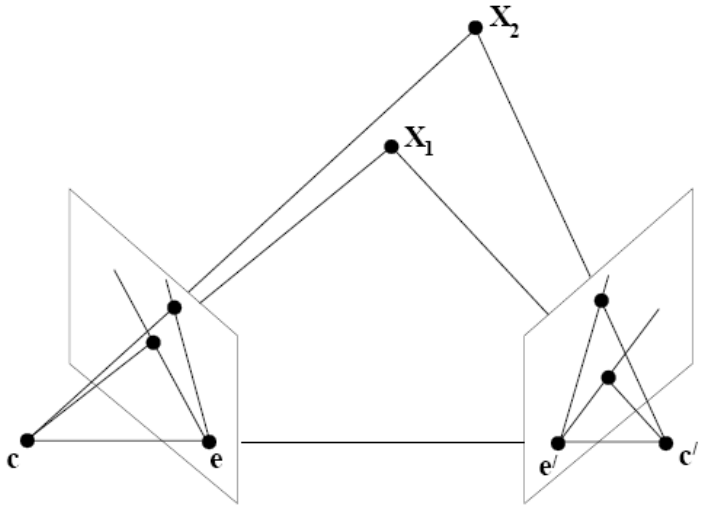

Camera path and points



**[Fitzgibbon et. al]**
**[et. al. Zisserman]**

# Stereo Vision

- By having two cameras, we can triangulate features in the left and right images to obtain depth.
- Need to match features between the two images:
  - Correspondence Problem



# Application: Augmented reality

# Homework

Download and read Ric's book, from page 1 to page 42.

Computer Lab group sign-up will open from Week-2.

Any Questions ?

# Tomorrow  (one hour only)

Image Formation

Image Representation