CS231A

Computer Vision:

From 3D Reconstruction to Recognition

Class Time & Location:

M-W; 3—4:20PM – **Skilling Auditorium**

CS231A

Instructor

Silvio Savarese

- ssilvio@stanford.edu
- Office: Gates Building, room: 154
- Office hour: Friday 1-2pm or under appoint.

Teaching Assistants

Kenji Hata (Head CA)

JunYoung Gwak

Boris Ivanovic

Jingwei Ji

Helen Jiang

Amir Sadeghian

Trevor Standley

Prerequisites

- This course requires knowledge of linear algebra, probability, statistics, machine learning and computer vision, as well as decent programming skills.
- Though not an absolute requirement, it is encouraged and preferred that you have at least taken either CS221 or CS229 or CS131A or have equivalent knowledge.
- We will leverage concepts from low-level image processing (CS131A) (e.g., linear filters, edge detectors, corner detectors, etc…) and machine learning (CS229) (e.g., **SVM, basic Bayesian inference, clustering**, neural networks, etc…) which we won't cover in this class.
- We will provide links to background material related to CS131A and CS229 (or discuss during TA sessions) so students can refresh or study those topics if needed.

Text books

Required:

- [FP] D. A. Forsyth and J. Ponce. *Computer Vision: A Modern Approach* (2nd Edition). Prentice Hall, 2011.
- [HZ] R. Hartley and A. Zisserman. *Multiple View Geometry in Computer Vision*. Academic Press, 2002.

Recommended:

- R. Szeliski. *Computer Vision: Algorithms and Applications*. Springer, 2011.
- D. Hoiem and S. Savarese. *Representations and Techniques for 3D Object Recognition and Scene Interpretation*, Synthesis lecture on Artificial Intelligence and Machine Learning. Morgan Claypool Publishers, 2011
- Learning OpenCV, by Gary Bradski & Adrian Kaehler, O'Reilly Media, 2008.

Course assignments

- 1 warm up problem set (HW-0)
- 4 problem sets (first problem released next week!)
- 1 mid-term exam
- 1 project

- Look up class schedule for release and due dates.
- Problems will be released through the schedule page and must be submitted through Gradescope (Use code MB5ZB9).

Midterm Exam

- The exam will be held in class and you will have 80 minutes to complete it.
- You will be updated with more details, e.g., material to be covered, review sessions etc., as we approach the midterm.

Course Projects

- Replicate an interesting paper
- Comparing different methods to a test bed
- A new approach to an existing problem
- Original research

- Write a 10-page paper summarizing your results
- Release the final code
- Give a final in-class presentation
- SCPD students can send videos instead.

- We will introduce projects in 1-2 weeks
- Important dates: look up class schedule

Course Projects

- Form your team:
  - 1-3 people
  - The larger is the team, the more work we expect from the team
  - Be nice to your partner: do you plan to drop the course?
- Evaluation
  - Quality of the project (including writing)
  - Final project in-class presentation (~ TBA minutes spotlight presentations)

Grading policy

- Homeworks: 37%
  - 1% for HW0
  - 9% for HW1, HW2, HW3, HW4 (each)
- Mid term exam: 20%
- Course project: 38%
  - Project proposal 1%
  - mid term progress report 5%
  - final report 25%
  - presentation 7%
- Attendance and class participation: 5%
  - Questions, answers, remarks, piazza posts,…
  - Class participation are waived for SCPD students. For the project presentation, SCPD students can send videos instead.

Grading policy (HWs)

- 25% will be deducted per day late.
- Two 48-hours one-time late submission "bonuses" are available; that is, you can use this bonus to submit your HW late after at most 48 hours. This is one time deal: After you use all your bonuses, you must adhere to the standard late submission policy.
- No exceptions will be made.

Grading policy (project)

- If 1 day late, 25% off the grade for the project
- If 2 days late, 50% off the grade for the project
- Zero credits if more than 2 days
- No "late submission bonus" is allowed when submitting your progress report or project report

Collaboration policy

- Read the student code book, understand what is ‘collaboration’ and what is ‘academic infraction’.
- Discussing project assignment with each other is allowed, but coding must be done individually
- Home works or class project coding policy: using on line code or other students/researchers’ code is not allowed in general. Exceptions can be made and individual cases will be discussed with the instructor.

Lecture 1
Introduction

- An introduction to computer vision
- Course overview

“There was a table set out under a tree in front of the house, and the March Hare and the Hatter were having tea at it.”

“The table was a large one, but the three were all crowded together at one corner of it …”

From “A Mad Tea-Party”
Alice's Adventures in Wonderland
by
Lewis Carroll

Illustration by Arthur Rackham

"There was a table set out under a tree in front of the house, and the March Hare and the Hatter were having tea at it."

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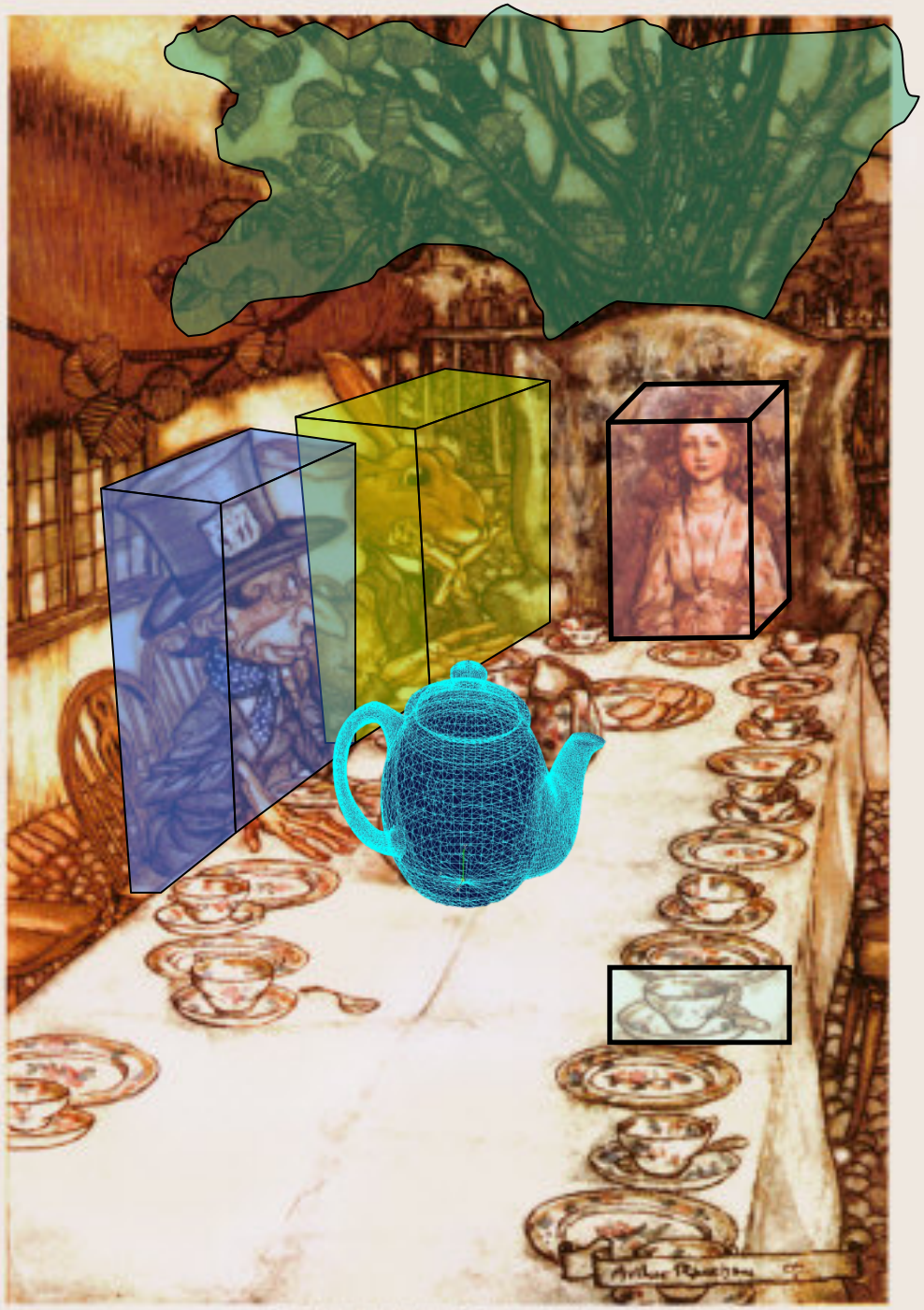
Computer vision

Image/video

Object 1 **Object N**

- semantic … -semantic



Computer vision

Image/video

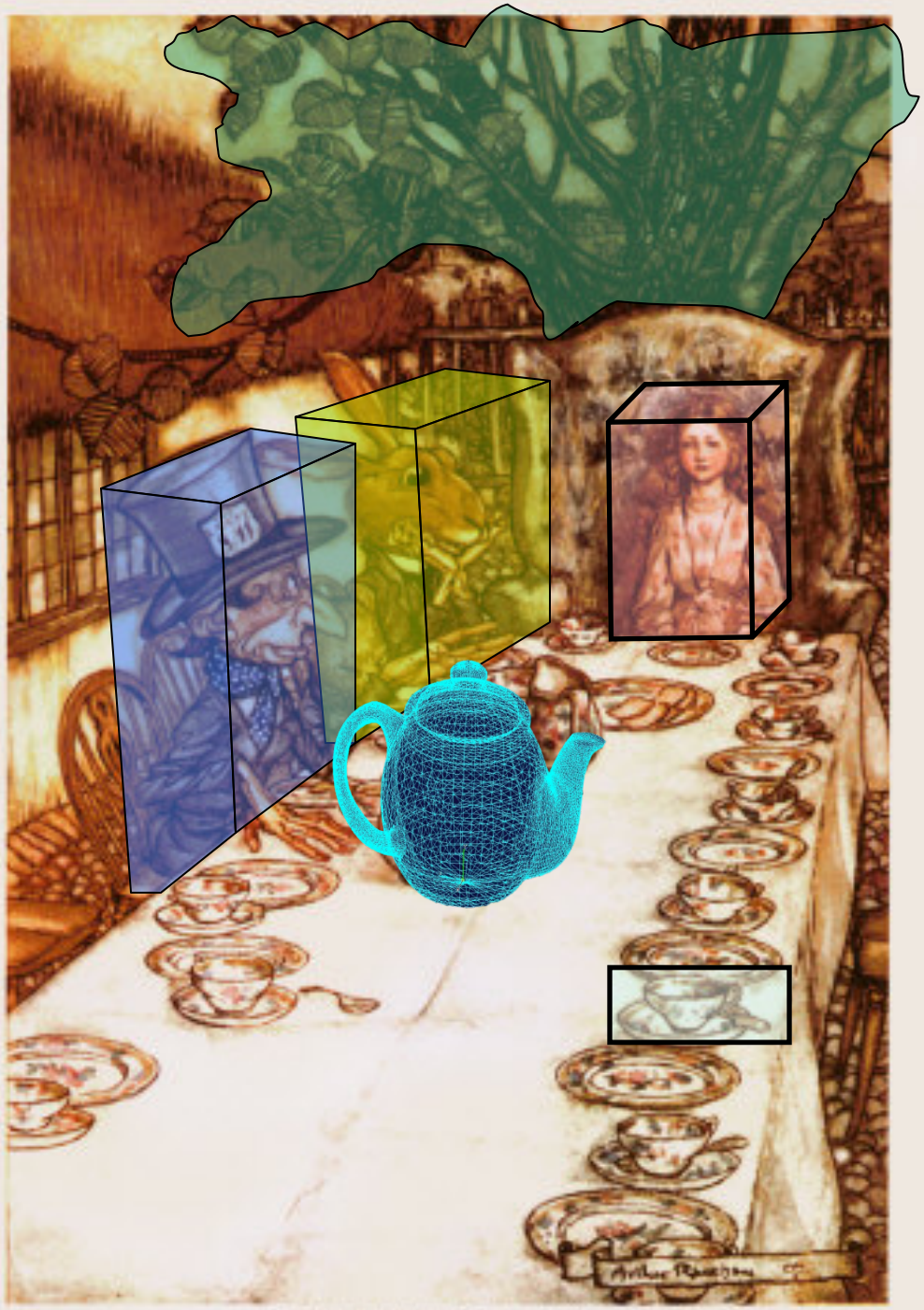
Object 1

- semantic
-geometry

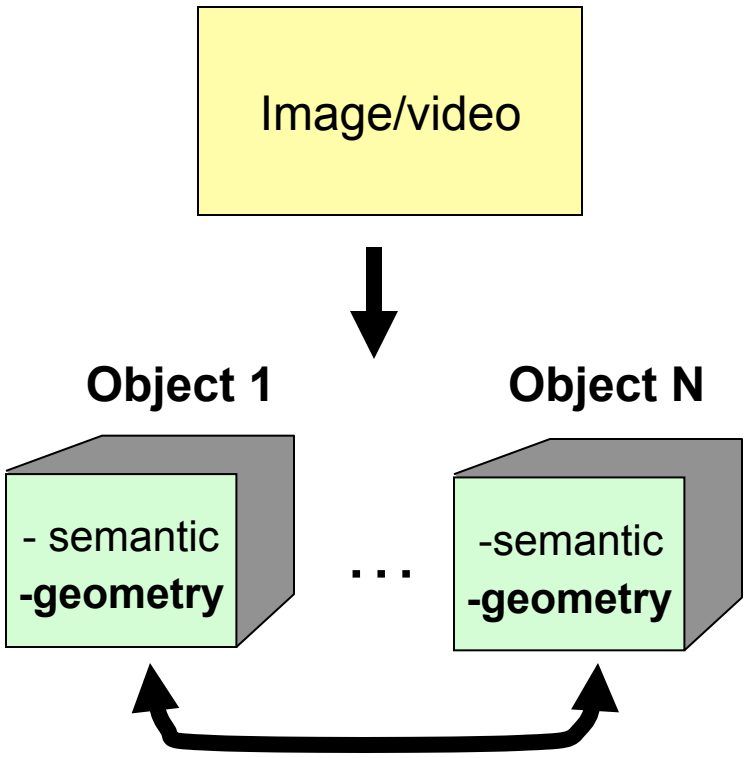
. . .

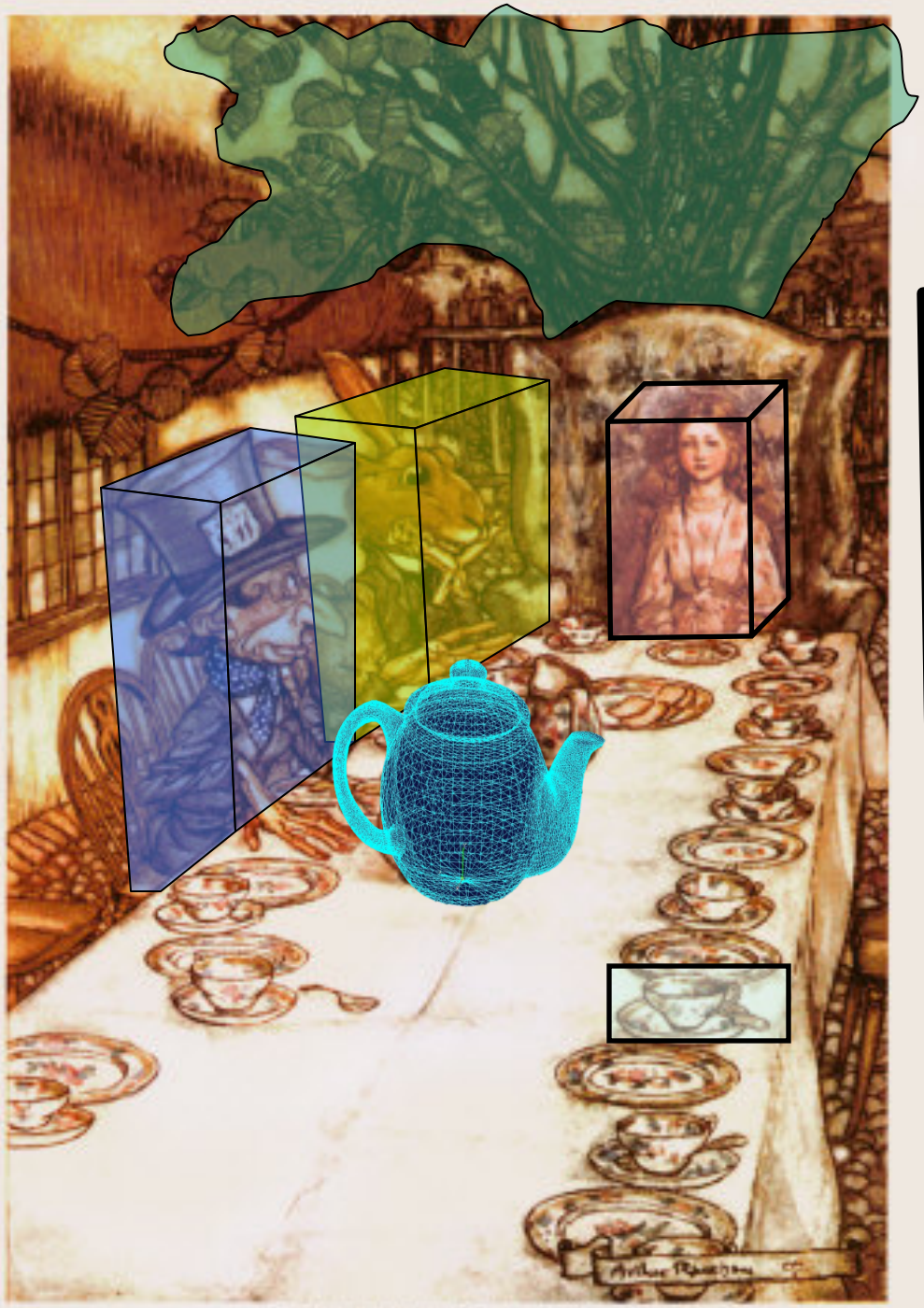
Object N

-semantic
-geometry



Computer vision





Computer vision

Image/video

Object 1 **Object N**

- semantic
-geometry

...

-semantic
-geometry

spatial & temporal relations

Scene

-Semantic
- geometry

Computer vision

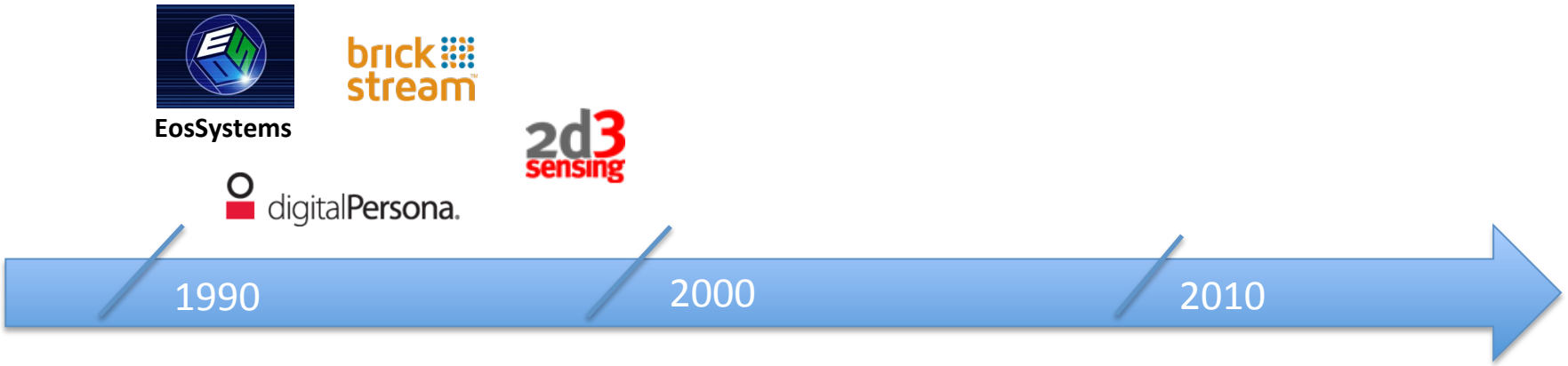
Sensing device

Computational device

- **Information extraction**
- **Interpretation**

1. **Information extraction:** features, 3D structure, motion flows, etc…
2. **Interpretation:** recognize objects, scenes, actions, events

Computer vision and Applications



Fingerprint biometrics

digitalPersona.

Augmentation with 3D computer graphics

2d3 sensing

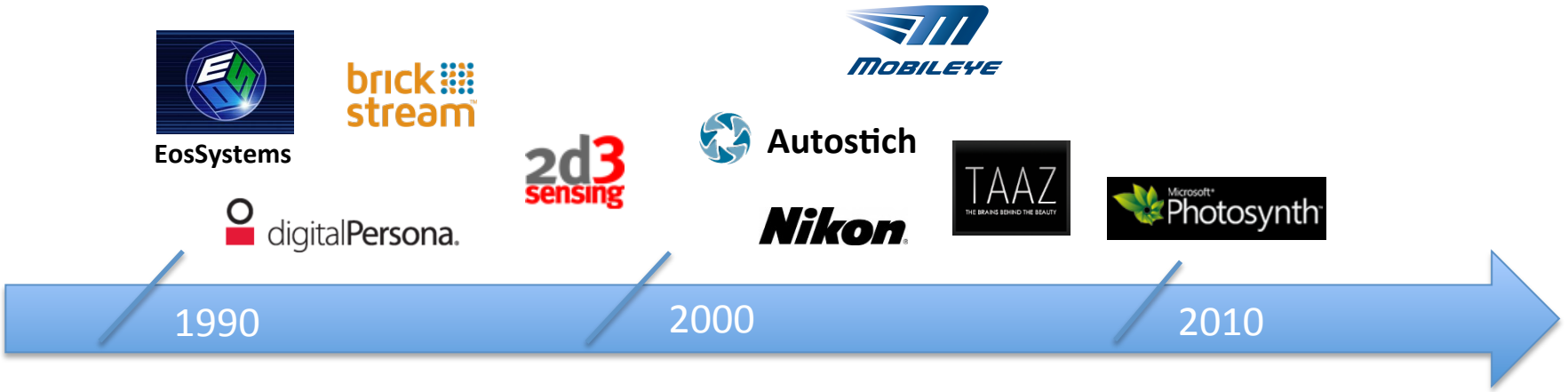
3D object prototyping

EosSystems

Photomodeler

Computer vision and Applications

- New features detector/descriptors
- CV leverages machine learning



Face detection

BBC NEWS

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Last Updated: Monday, 6 February 2006, 14:29 GMT

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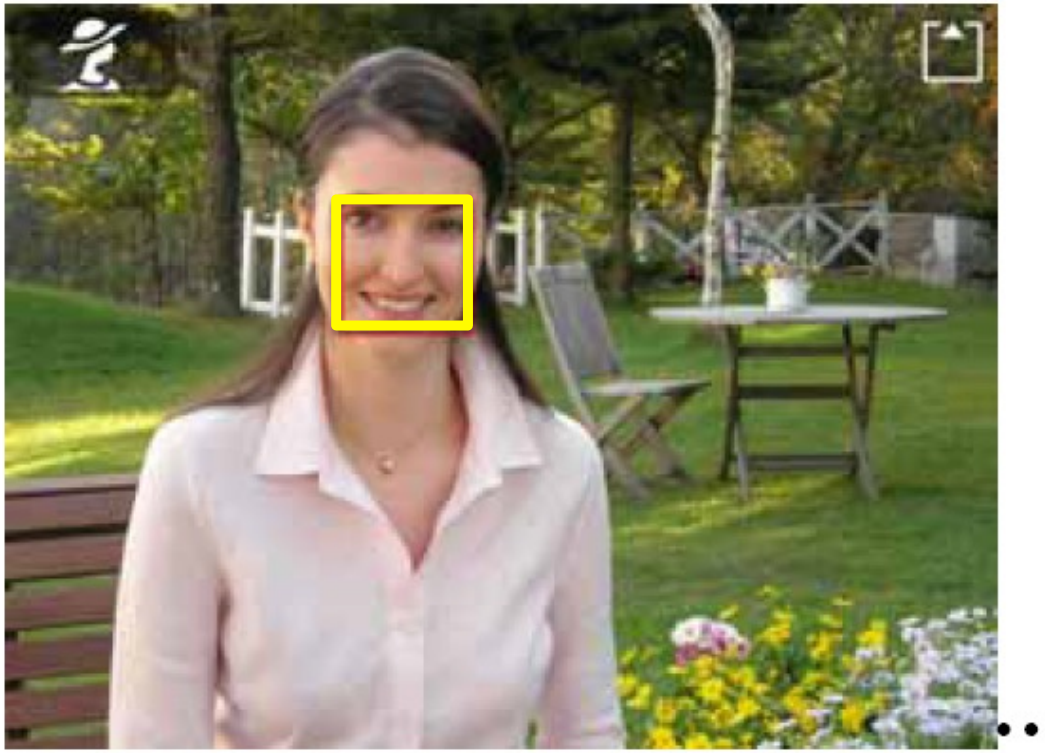
Face-hunting cameras boost Nikon

Japanese camera maker Nikon has tripled its profits on the back of strong sales of digital cameras that automatically focus on human faces.

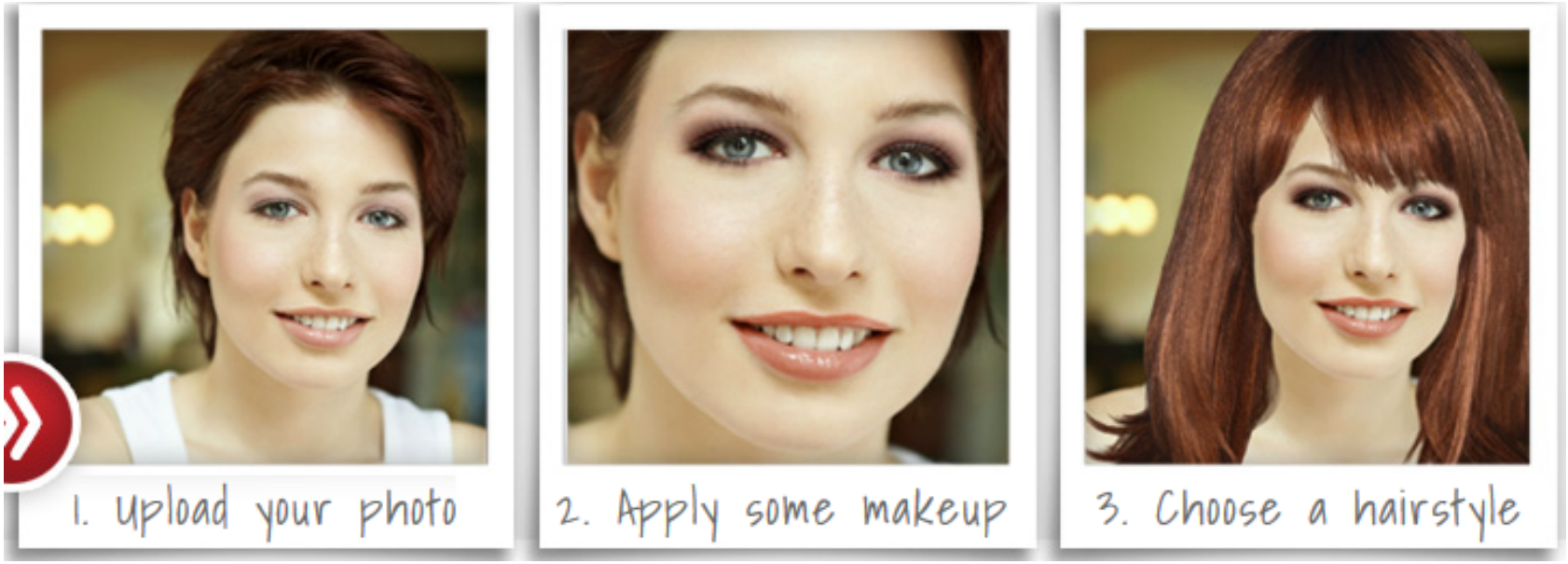
Face recognition cameras like the Coolpix L1 are popular

Face detection



Sample image: Subject as seen on the COOLPIX 5900 camera's color LCD and when using Nikon's Face-priority AF function.

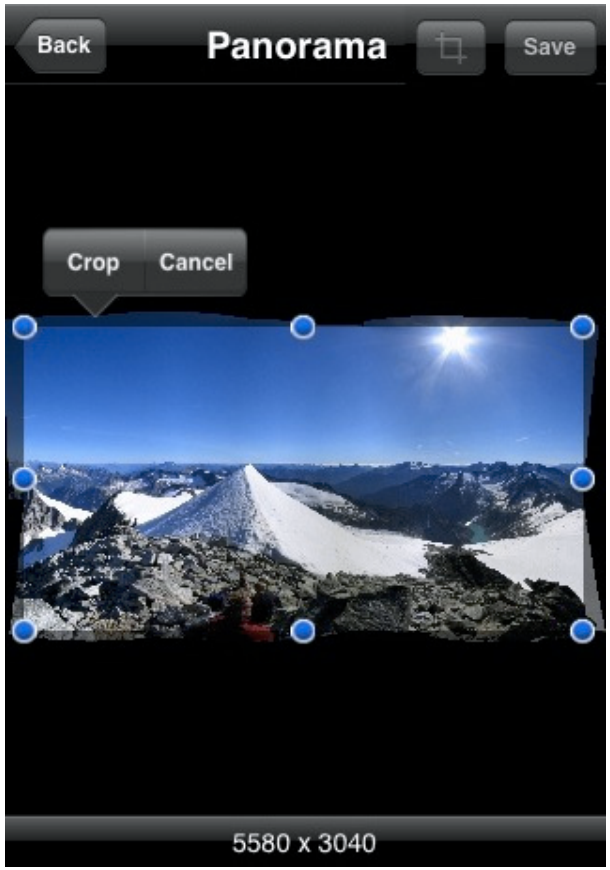
Web applications



TAAZ
THE BRAINS BEHIND THE BEAUTY

Photometria

Panoramic Photography

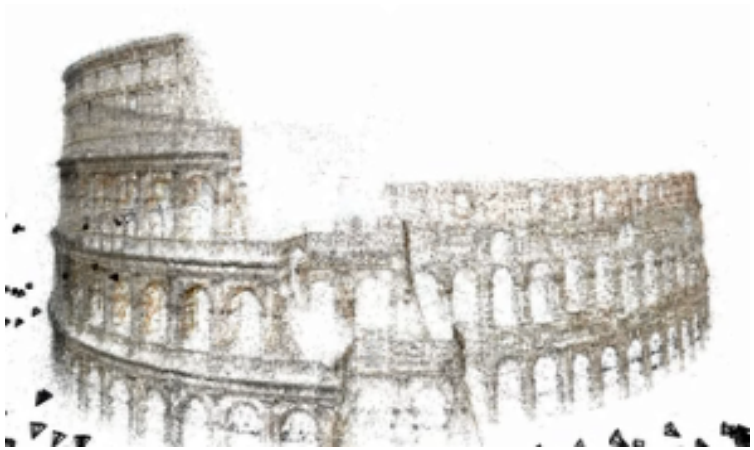


Cloudburst RESEARCH

HumanEyes Print Out of the Box

kolor

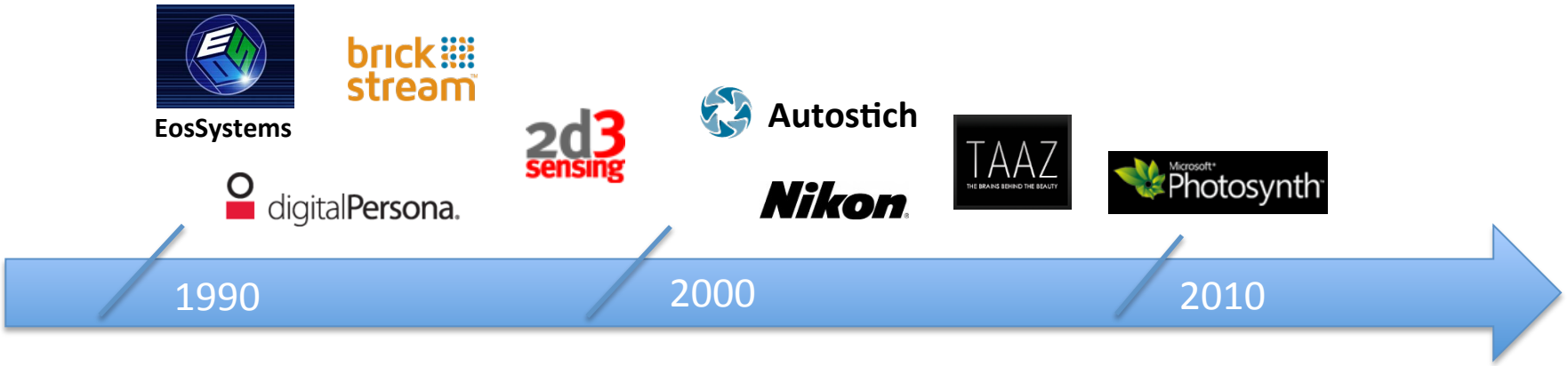
3D modeling of landmarks



Microsoft Photosynth

Computer vision and Applications

- Efficient SLAM/SFM
- Large scale image repositories
- Deep learning (e.g. ImageNet)



Computer vision and Applications

- Efficient SLAM/SFM
- Large scale image repositories
- Deep learning (e.g. ImageNet)
- Better clouds ☺
- More bandwidth
- Increase computational power

Project Tango

Mirriad

CREAFORM

NVIDIA

KINECT

AUGMENT

ebay research labs

A9

MOBILEYE

Google Goggles

kooaba IMAGE RECOGNITION

EosSystems

brick stream

2d3 sensing

Autostich

TAAZ

Microsoft Photosynth

digitalPersona

Nikon

1990 2000 2010

Image search engines

Google Image Search™

Picasa™

flickr™ GAMMA

webshots beta

bing

YouTube Broadcast Yourself™

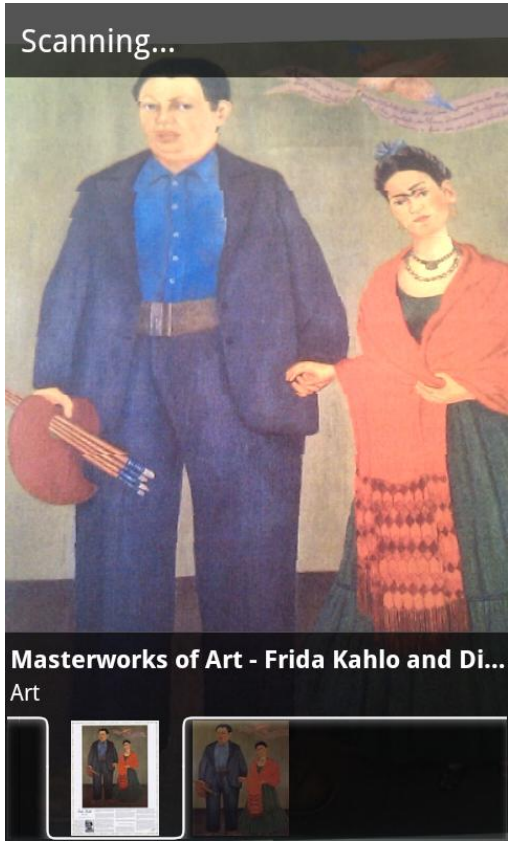
Incogna

LTU technologies LTU

picsearch™

YAHOO!®

Visual search and landmarks recognition



Google Goggles

Visual search and landmarks recognition

kooaba
IMAGE RECOGNITION

A9

Augmented reality

Mirriad
Advertising for the Skip Generation

AUGMENT

- Magic leap
- Daqri
- Meta
- Etc…

Motion sensing and gesture recognition

Autonomous navigation and safety

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

But also, Toyota, Google, Apple, Tesla, Nissan, Ford, etc….

Source: A. Shashua, S. Seitz

Personal robotics

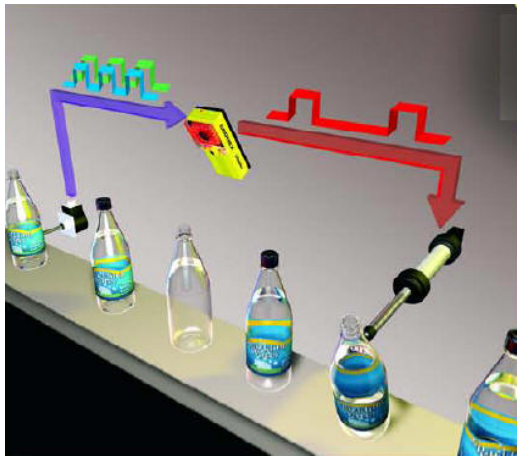
jibo

FIVE ELEMENTS ROBOTICS

BLUE FROG robotics

ECOVACS

Computer vision and Applications



Factory inspection

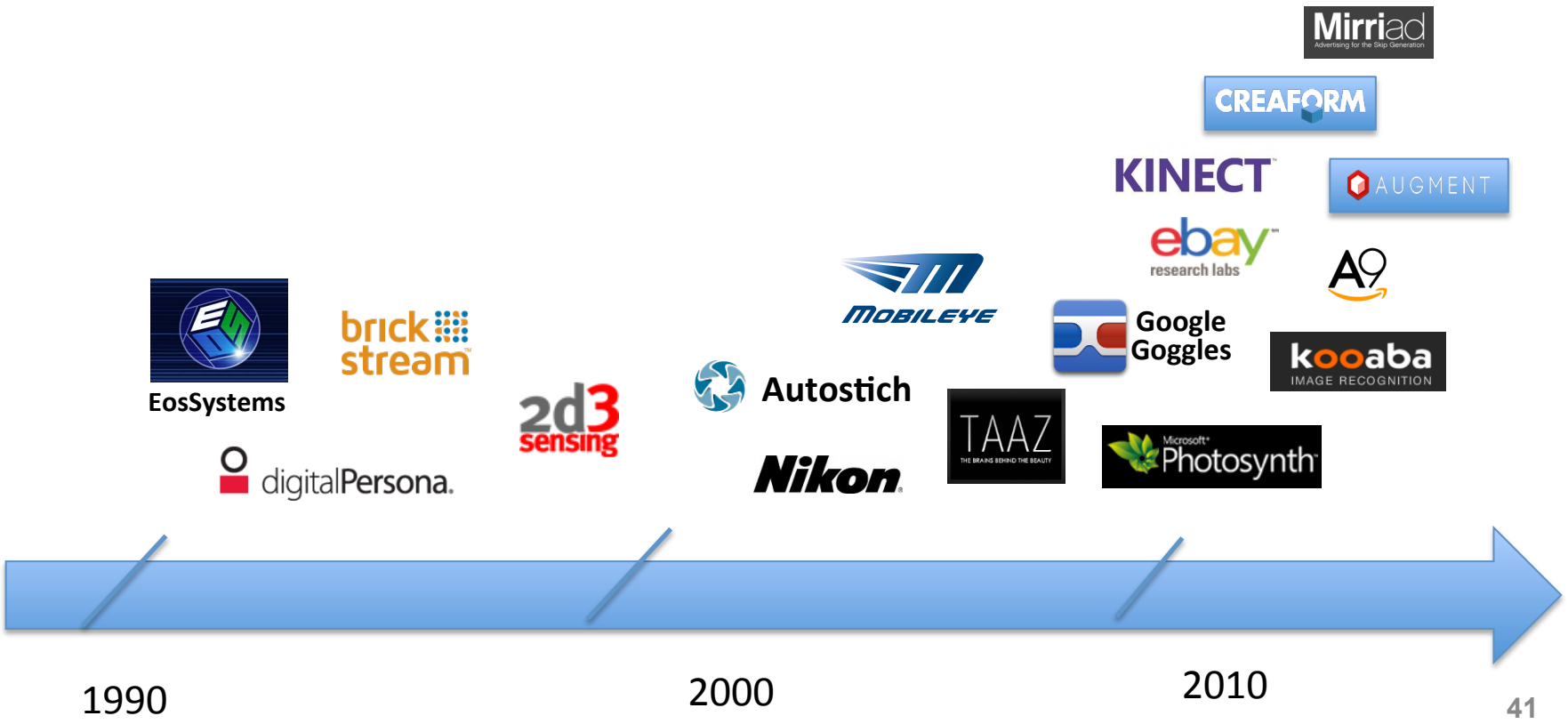
Assistive technologies

Surveillance

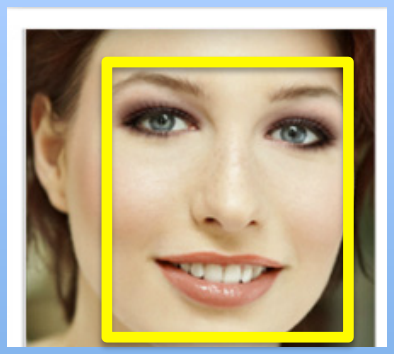
Vision for robotics, space exploration

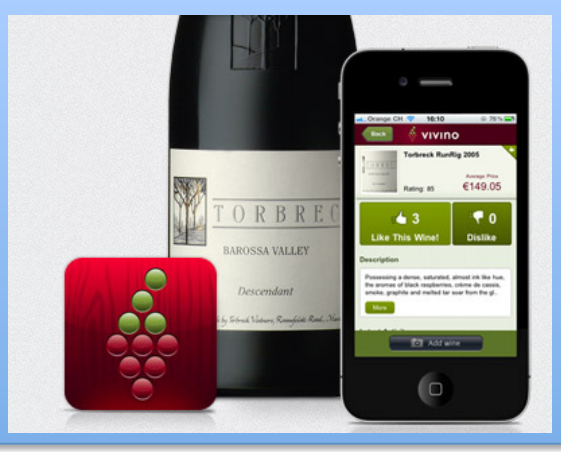
Security

Computer vision and Applications



Computer vision and Applications





3D

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2d3 sensing

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AUGMENT

2D

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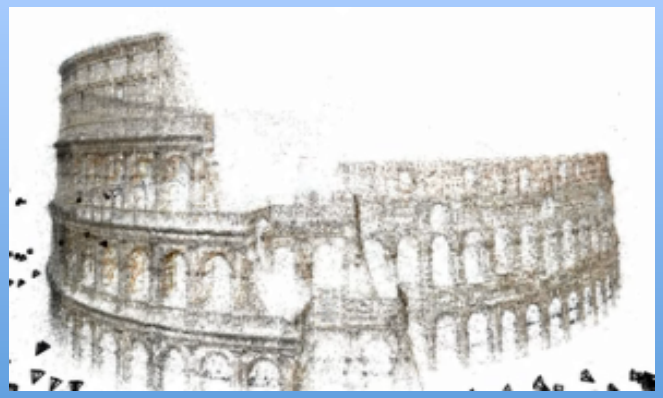
IMAGE RECOGNITION

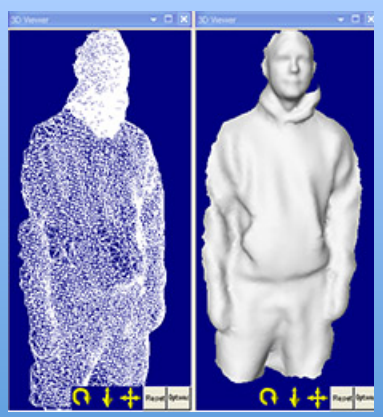
1990

2000

2010

Computer vision and Applications





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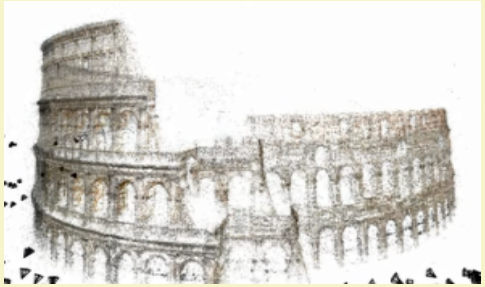
Current state of computer vision



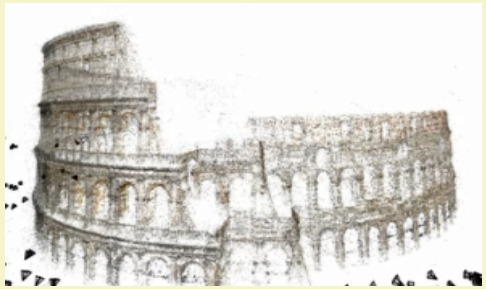
3D Reconstruction

- 3D shape recovery
- 3D scene reconstruction
- Camera localization
- Pose estimation

2D Recognition

- Object detection
- Texture classification
- Target tracking
- Activity recognition

Current state of computer vision



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Snavely et al., 06-08

Lucas & Kanade, 81
Chen & Medioni, 92
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Fitzgibbon & Zisserman, 98
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Nistér, 04
Brown & Lowe, 04
Schindler et al, 04
Lourakis & Argyros, 04
Colombo et al. 05

Golparvar-Fard, et al. JAEI 10
Pandey et al. IFAC , 2010
Pandey et al. ICRA 2011
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Savarese et al. IJCV 06
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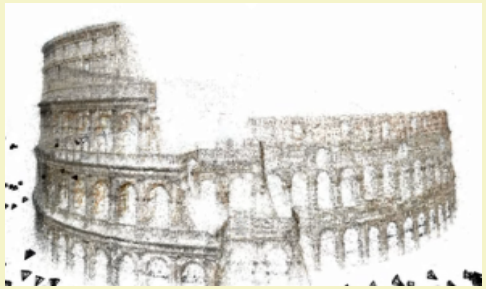
Agarwal et al., 09
Frahm et al., 10

Current state of computer vision



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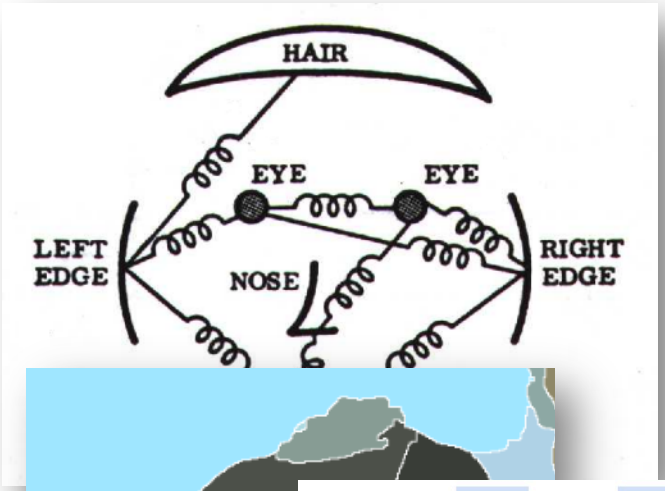

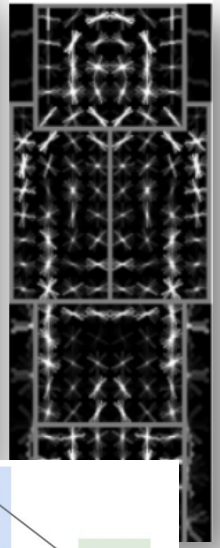

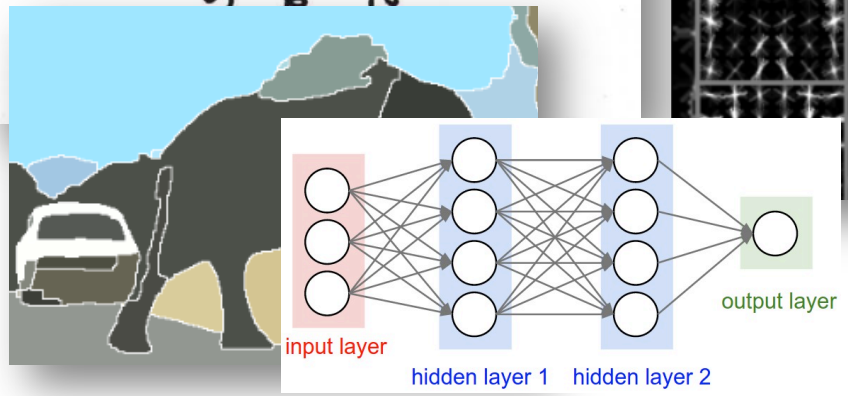

2D Recognition

- Object detection
- Texture classification
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Ullman et al. 02

Argawal & Roth, 02
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Torralba et al., 03
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Kumar & Hebert '04

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Current state of computer vision

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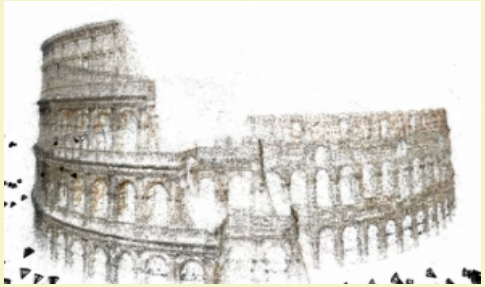
Current state of computer vision



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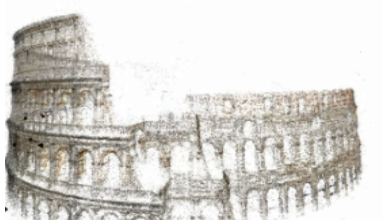
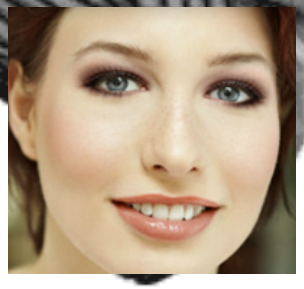
Perceiving the World in 3D!

Visual processing in the brain



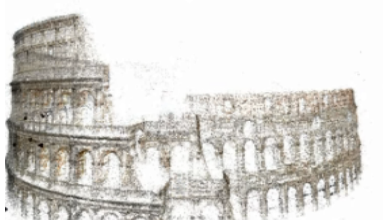
where pathway
(dorsal stream)

V1



what pathway
(ventral stream)

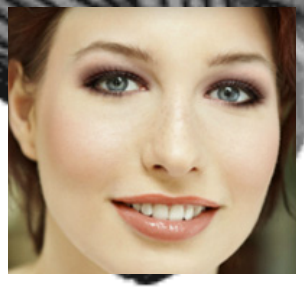
Visual processing in the brain



where pathway
(dorsal stream)

V1

Pre-frontal
cortex



what pathway
(ventral stream)

CS 231A course overview

1. Geometry
2. Semantics

Geometry:

- How to extract 3d information?
- Which cues are useful?
- What are the mathematical tools?

Camera systems

Establish a mapping from 3D to 2D

How to calibrate a camera

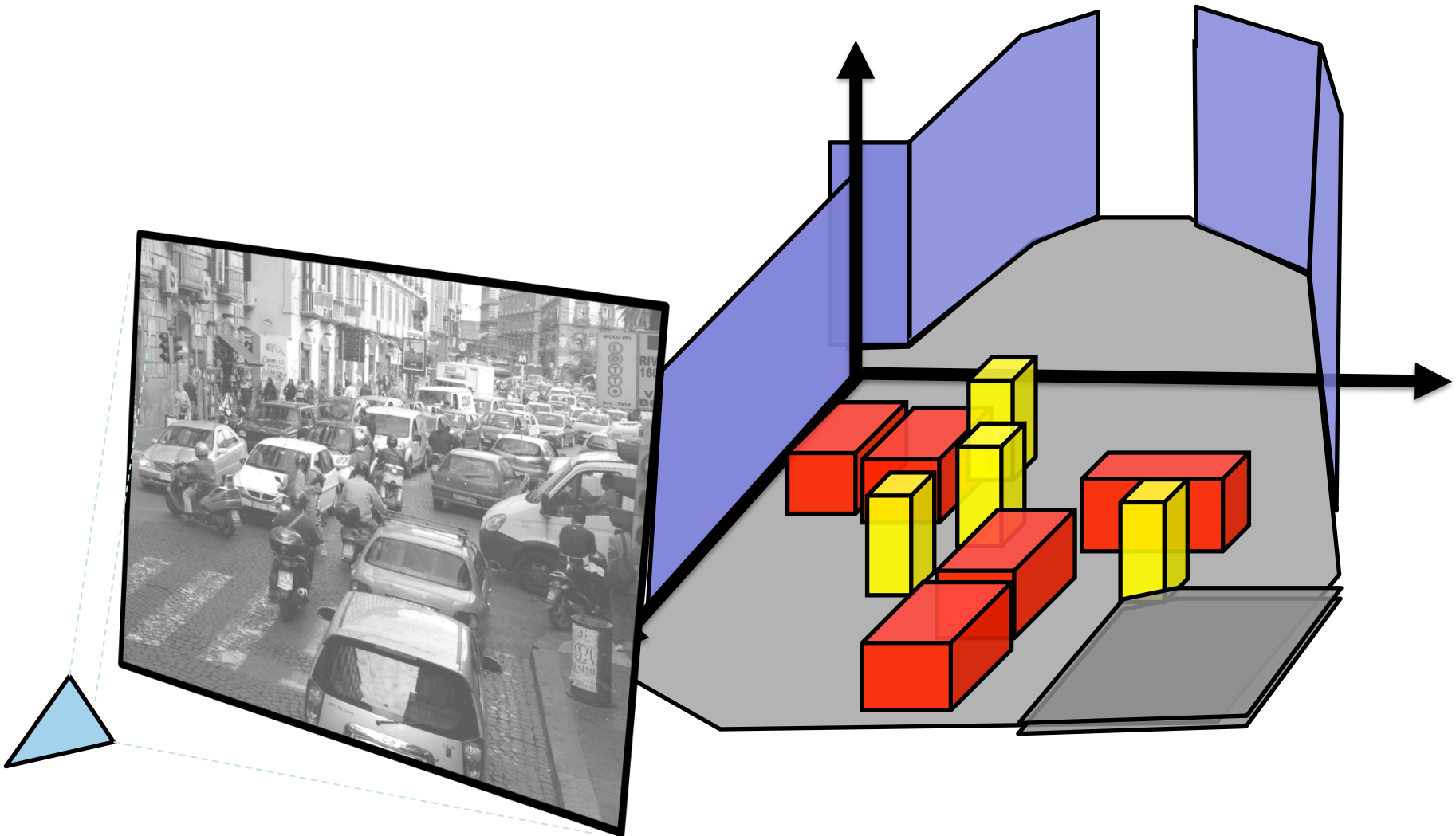
Estimate camera parameters such pose or focal length

Single view metrology

Estimate 3D properties of the world from a single image

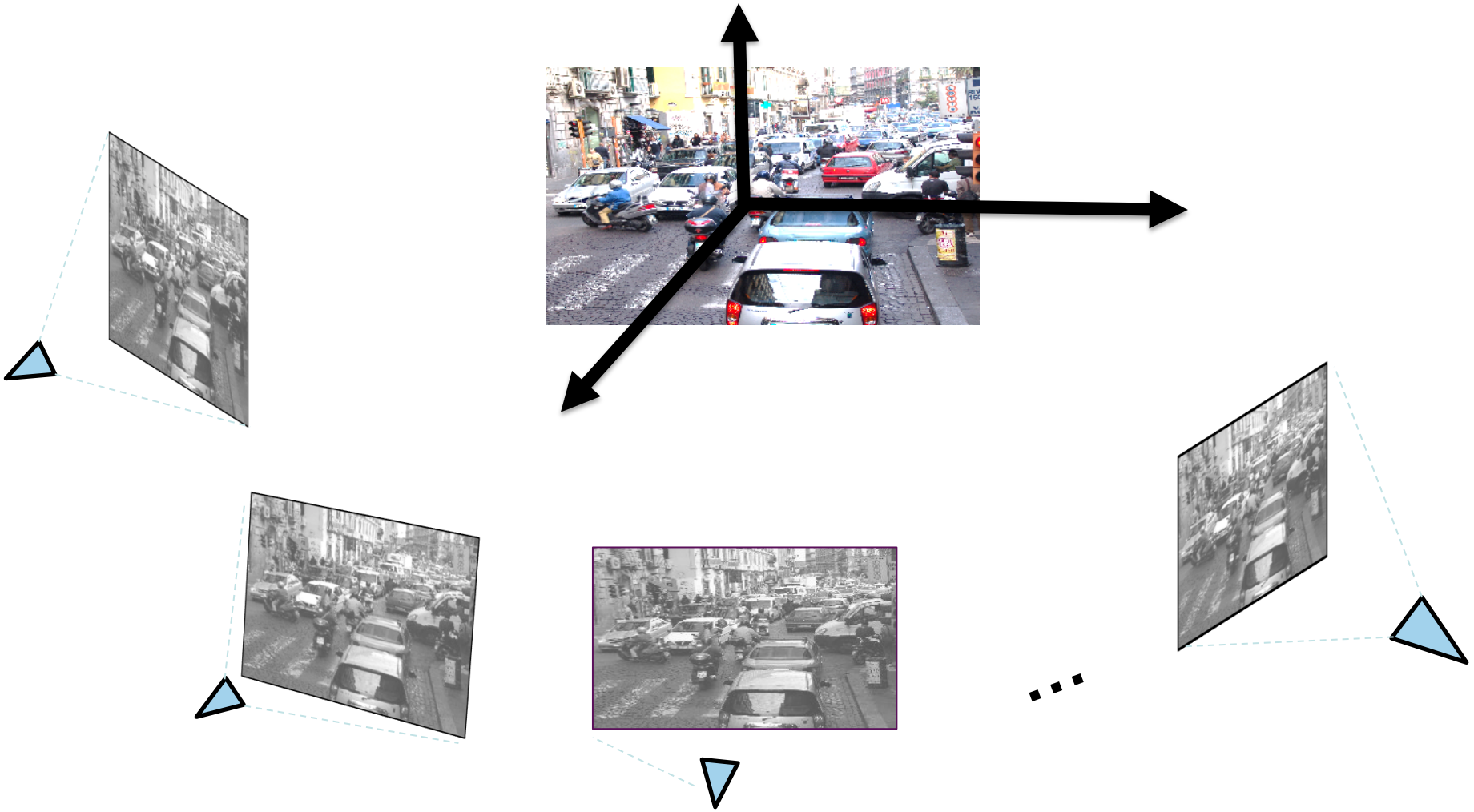
Single view metrology

Estimate 3D properties of the world from a single image

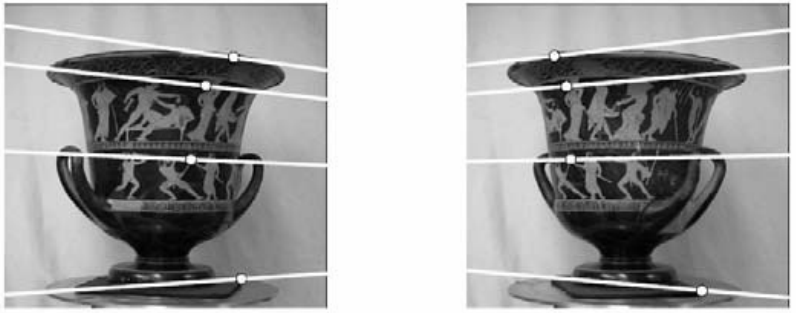


Multiple view geometry

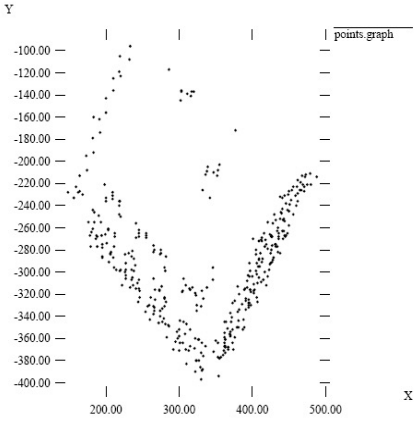
Estimate 3D properties of the world from multiple views

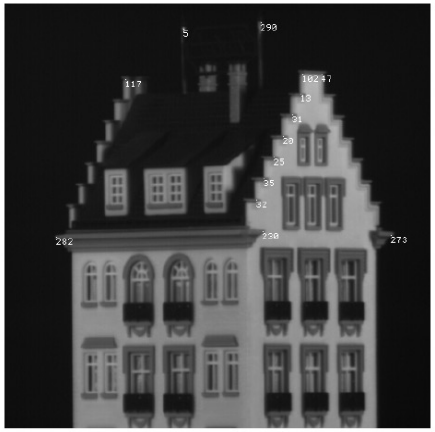


Mathematical tools

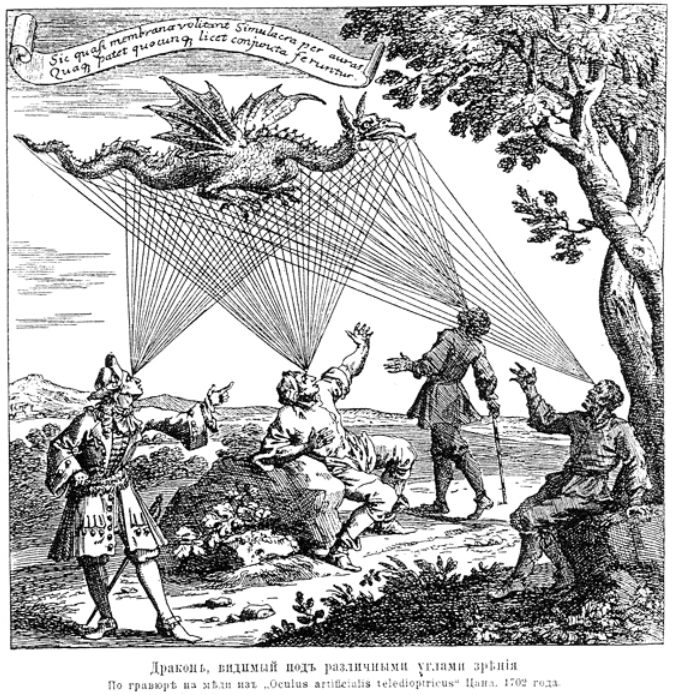


Epipolar geometry





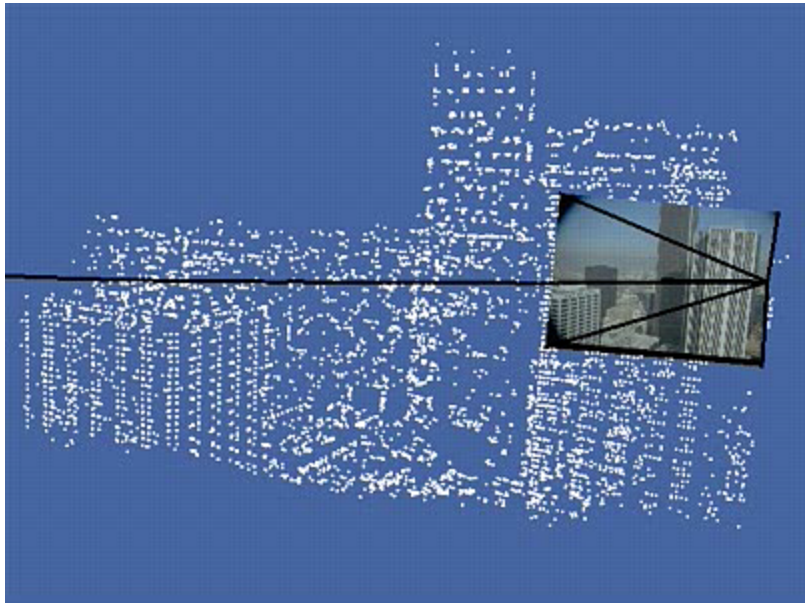
Tomasi & Kanade (1993)



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

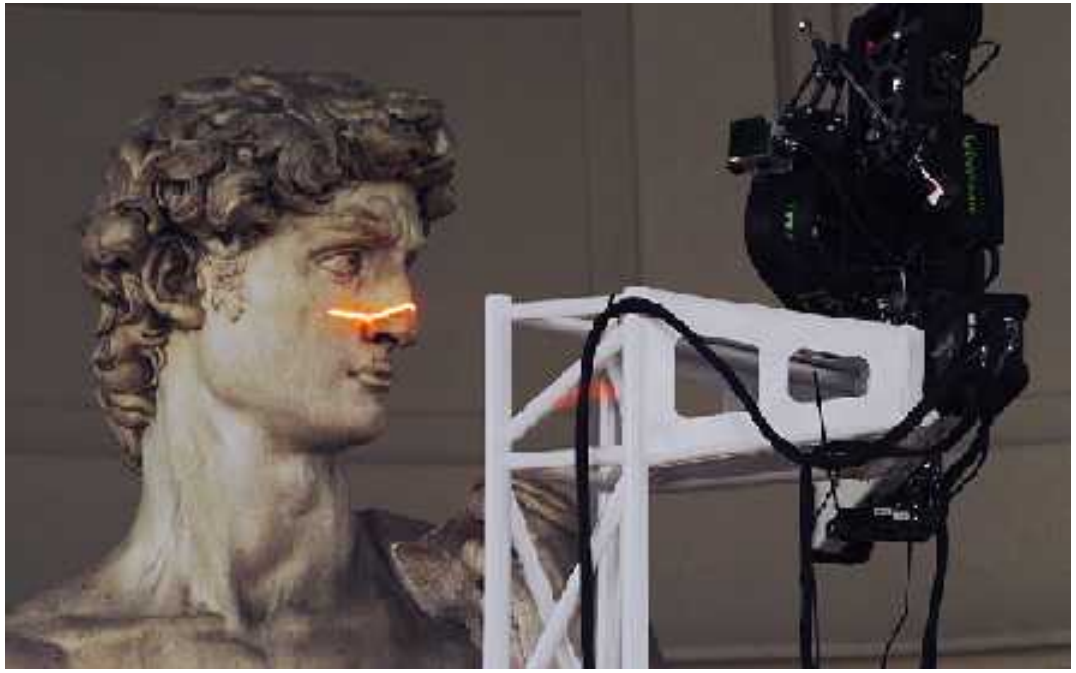
Photoconsistency

Structure from motion



Courtesy of Oxford **Visual Geometry Group**

Structure lighting and volumetric stereo



Scanning Michelangelo's *"The David"*

- The Digital Michelangelo Project
  - http://graphics.stanford.edu/projects/mich/
- 2 BILLION polygons, accuracy to .29mm

CS 231A course overview

1. Geometry
2. Semantics

Semantics:

- How to recognize objects?
- How to classify images or understand a scene?
- How to segment out critical semantics
- How to estimate 3D properties (pose, size, shape…)

Object recognition and categorization

Classification:

Is this an forest?

Classification:

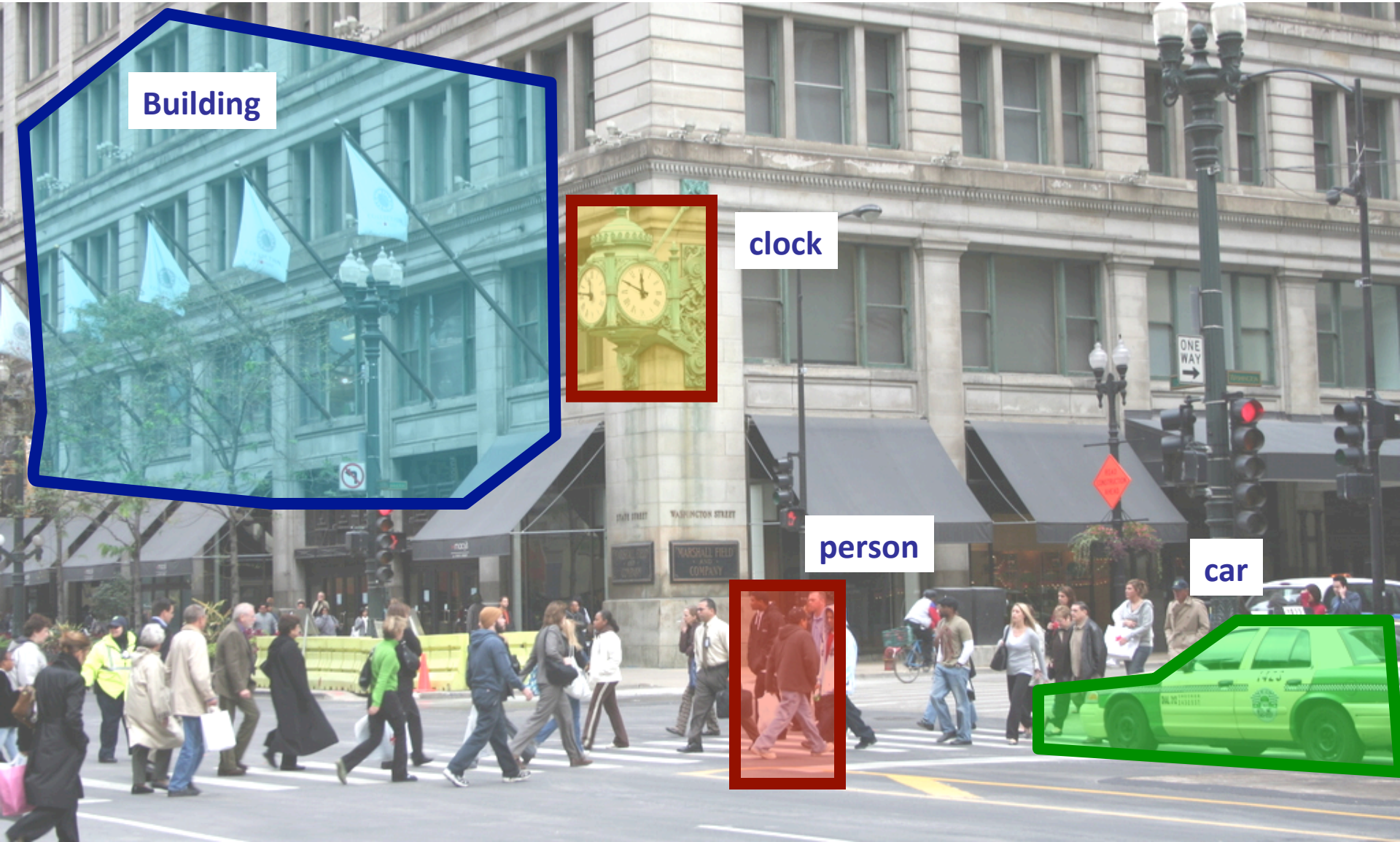
Does this image contain a building? [yes/no]

Detection:

Does this image contain a car? [where?]

Detection:

Which objects do this image contain? [where?]

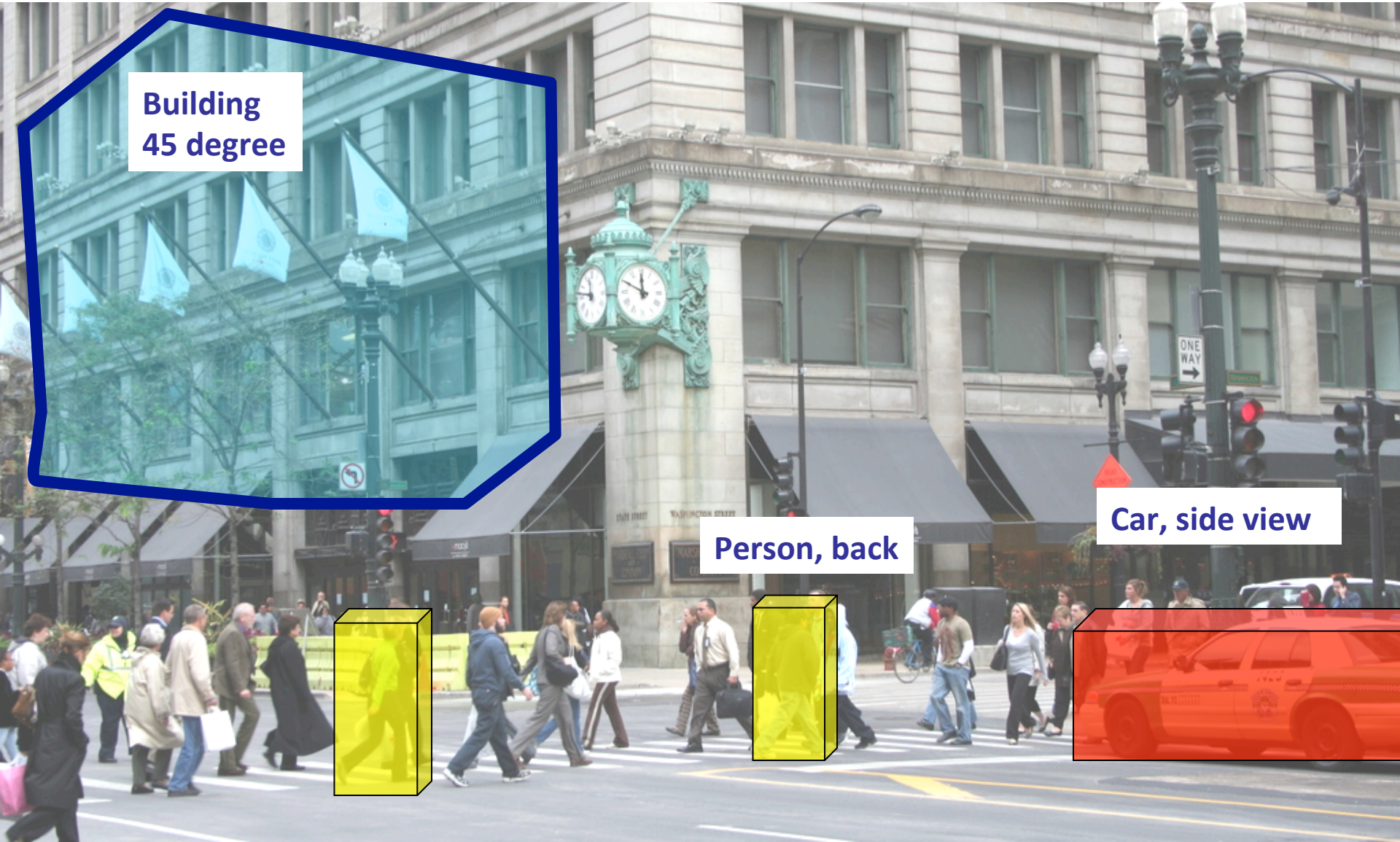


Detection:

Accurate localization (segmentation)

Detection:

Estimating 3D geometrical properties



Challenges: viewpoint variation

slide credit: Fei-Fei, Fergus & Torralba

Challenges: illumination

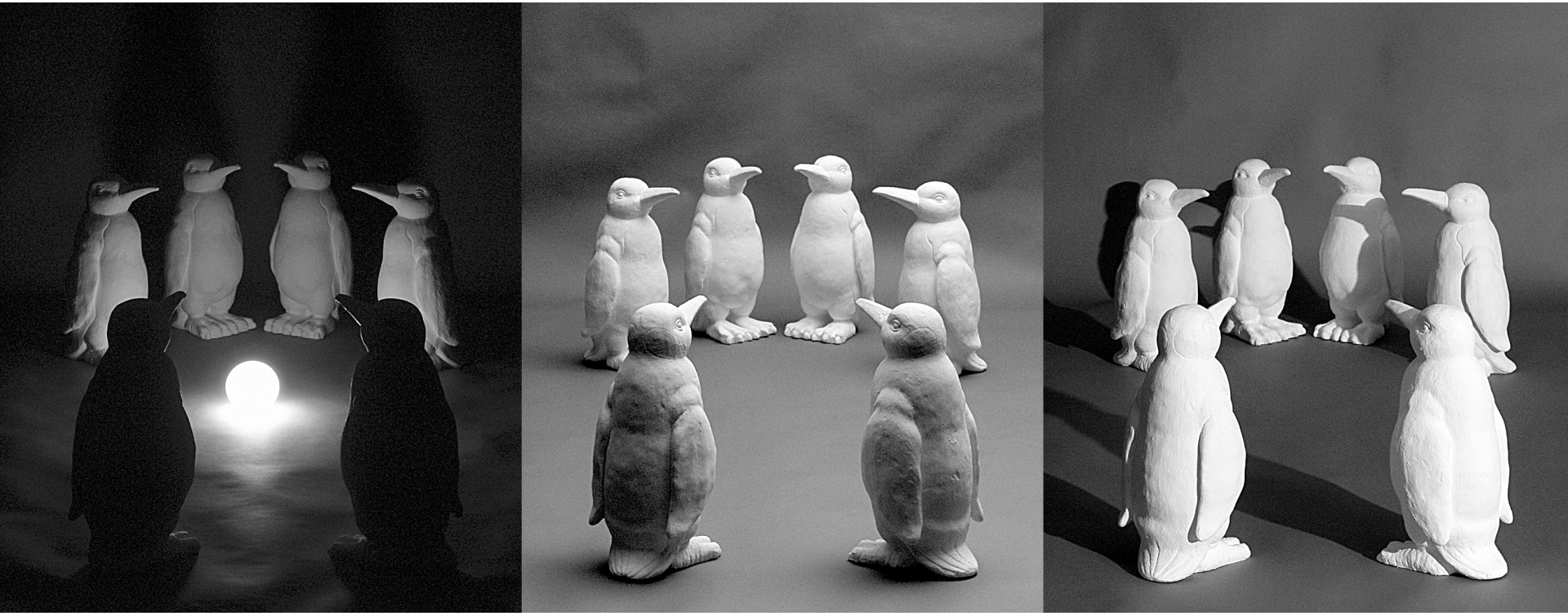


image credit: J. Koenderink

Challenges: scale

slide credit: Fei-Fei, Fergus & Torralba

Challenges: deformation

Challenges: occlusion

Magritte, 1957

slide credit: Fei-Fei, Fergus & Torralba

Challenges: background clutter

Kilmeny Niland. 1995

Challenges: object intra-class variation

slide credit: Fei-Fei, Fergus & Torralba

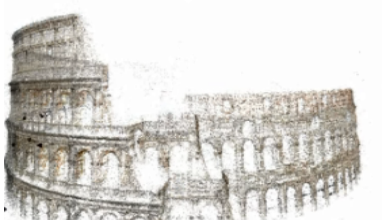

~10,000 to 30,000

CS 231A course overview

1. Geometry
2. Semantics

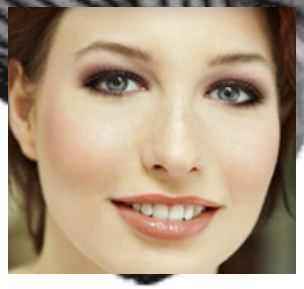
Joint recovery of geometry and semantics!

Visual processing in the brain



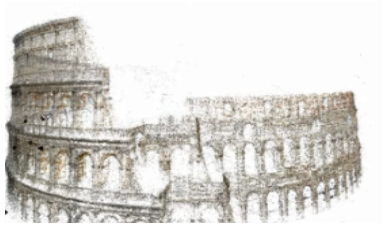
where pathway
(dorsal stream)

V1



what pathway
(ventral stream)

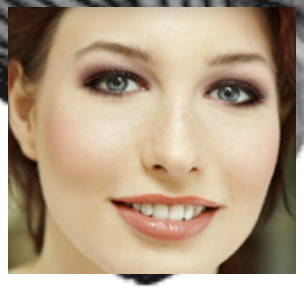
Visual processing in the brain



where pathway
(dorsal stream)

V1

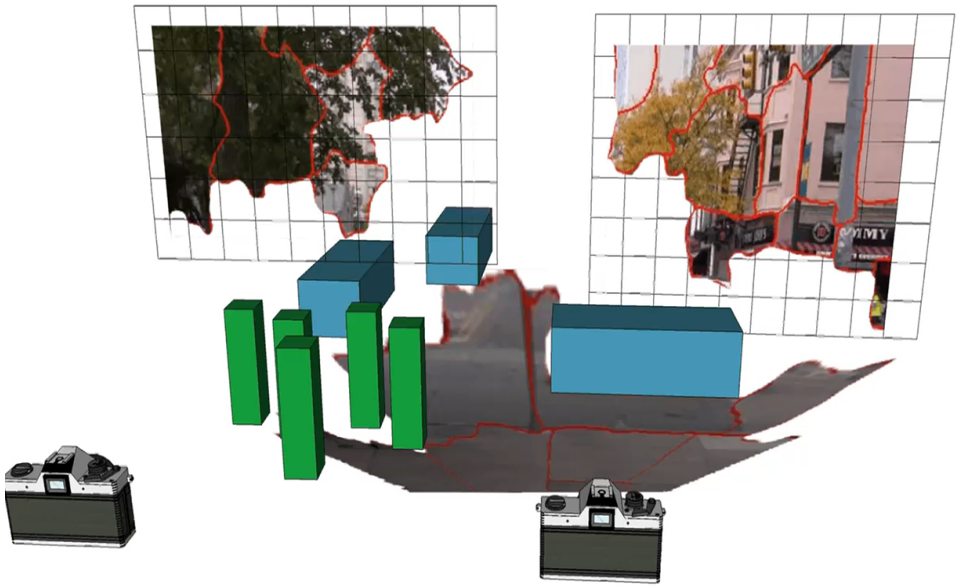
Pre-frontal
cortex

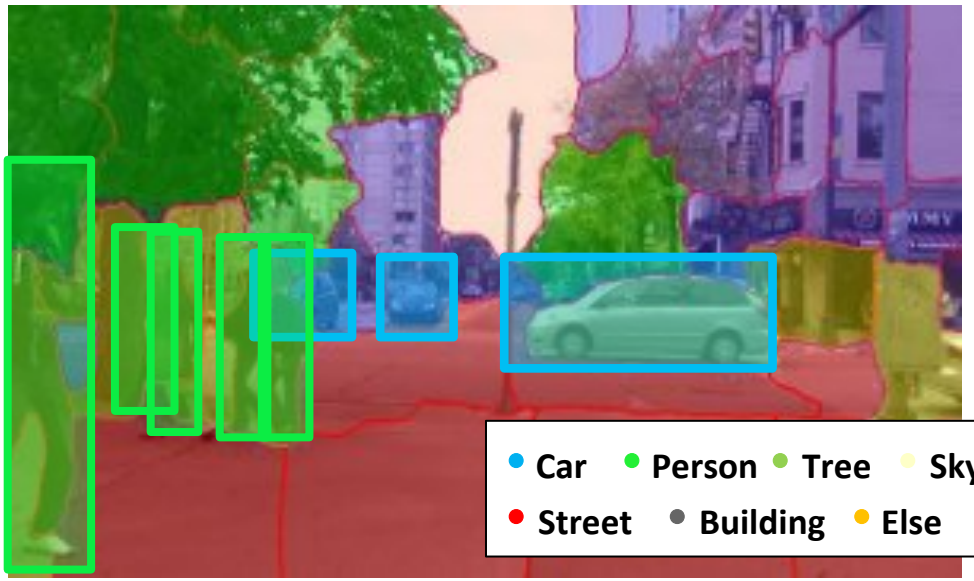


what pathway
(ventral stream)

Joint reconstruction and recognition

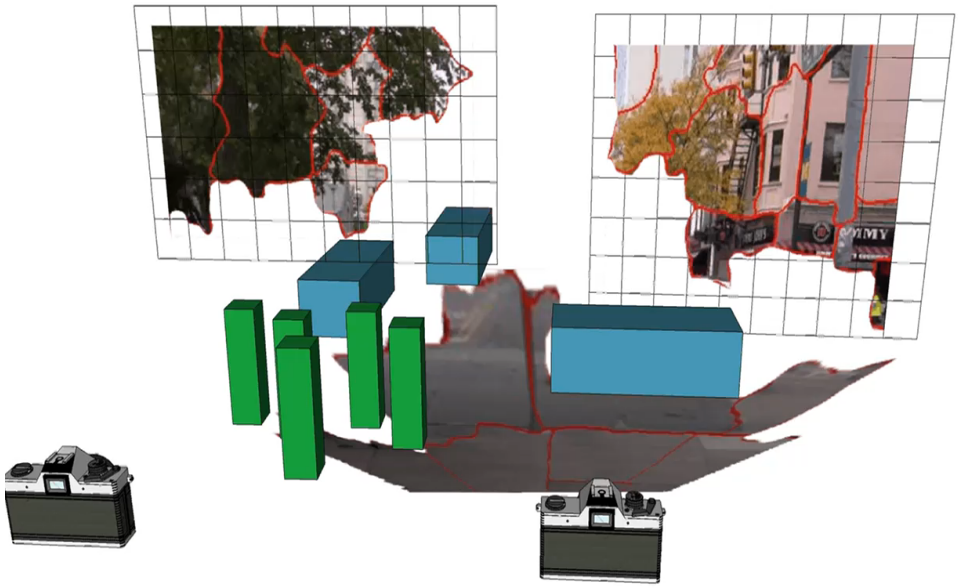
Input images

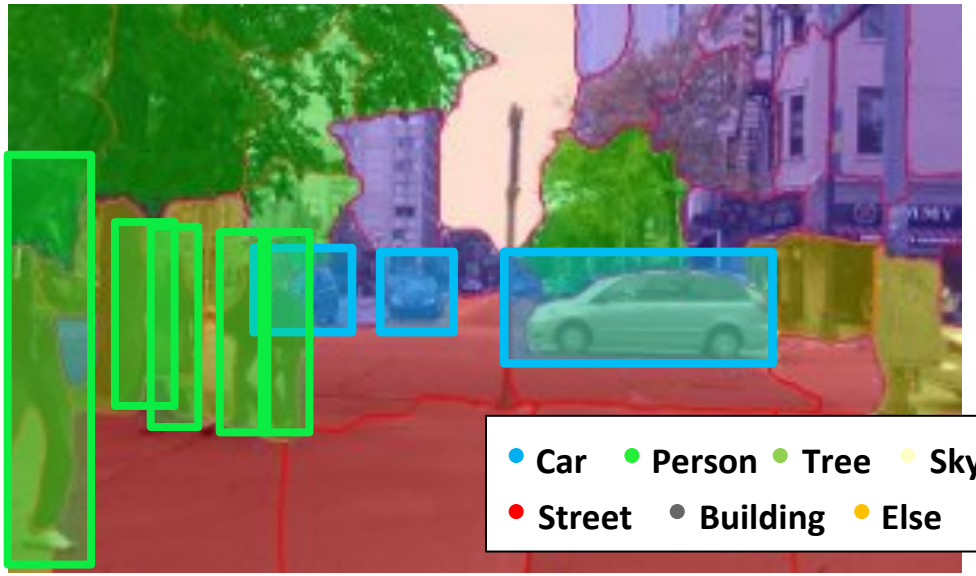


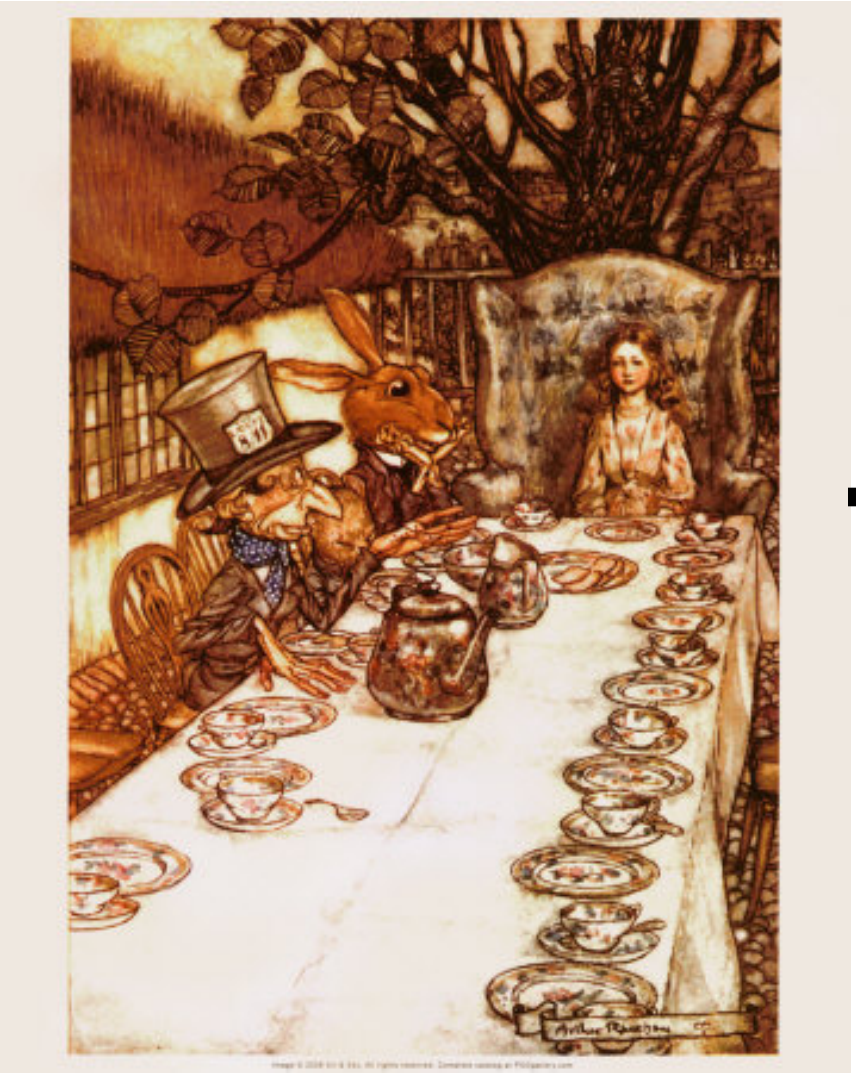


Joint reconstruction and recognition

Input images







“There was a table set out under a tree in front of the house, and the March Hare and the Hatter were having tea at it.”

“The table was a large one, but the three were all crowded together at one corner of it …”

From “A Mad Tea-Party”
Alice's Adventures in Wonderland
by
Lewis Carroll

Syllabus

Lecture	Topic
1	Introduction
2	Camera models
3	Camera calibration
4	Single view metrology
5	Epipolar geometry
6	Multi-view geometry
7	Structure from motion/ SLAM
8	Volumetric stereo
9	Fitting and Matching
10	Detector and Descriptors
11	Intro to Recognition; Object classification I
12	Object classification II
13	Scene understanding & segmentation
14	Visual Representation Learning by NNs
15	3D Object recognition
16	3D Scene understanding

March

April

May

June

Project presentations

3D geometry

Proposal due

Recognition

Mid term

Final projects

CS231

Introduction to Computer Vision

Next lecture: Camera systems