CS231A

Computer Vision:
From 3D Reconstruction to Recognition

Professor Silvio Savarese

Computational Vision and Geometry Lab

CS231A

- Instructor
  - Silvio Savarese
  - ssilvio@stanford.edu
  - Office: Gates Building, room: 154
  - Office hour: Thursday 2-3pm or under appoint.

- CAs:
  - **Kenji Hata** (head CA)
  - **Sumant Sharma**
  - **Matthew Cong**
  - **Bryan Anenberg**
  - **Kratarth Goel**
  - **Kevin Chen**
  - **Lyne Petse**

- Class Time & Location
  - M-W; 3—4:20PM – **Skilling Auditorium**

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.
- The exam will be open-book and open-notes.
- 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:
  - 1-4 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: 42%
  - 2% for HW0
  - 10% for HW1, HW2, HW3, HW4 (each)
- Mid term exam: 15%
- Course project: 38%
  - mid term progress report 5%
  - final report 25%
  - presentation 8%
- 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

- Late policy for home works:
  - If 1 day late, 50% off the grade for that homework
  - Zero credits if more than one day.
  - 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

- Late 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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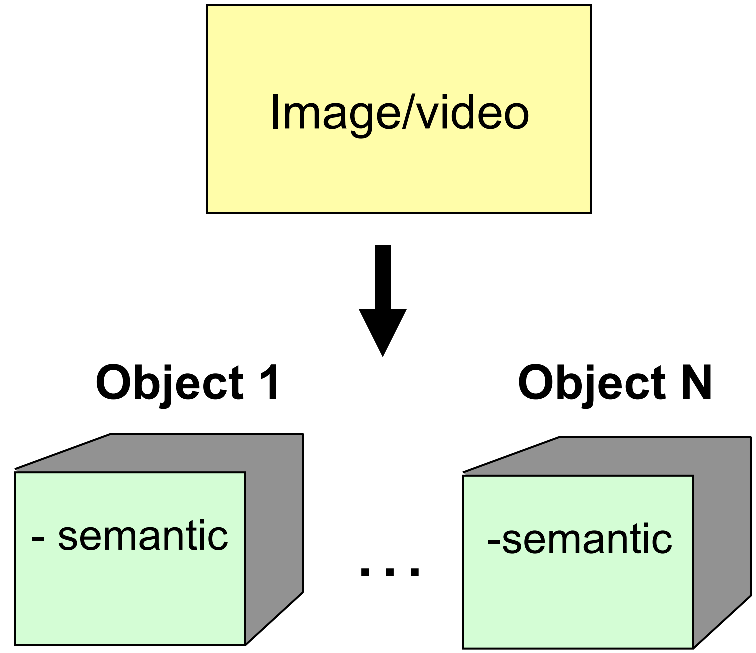
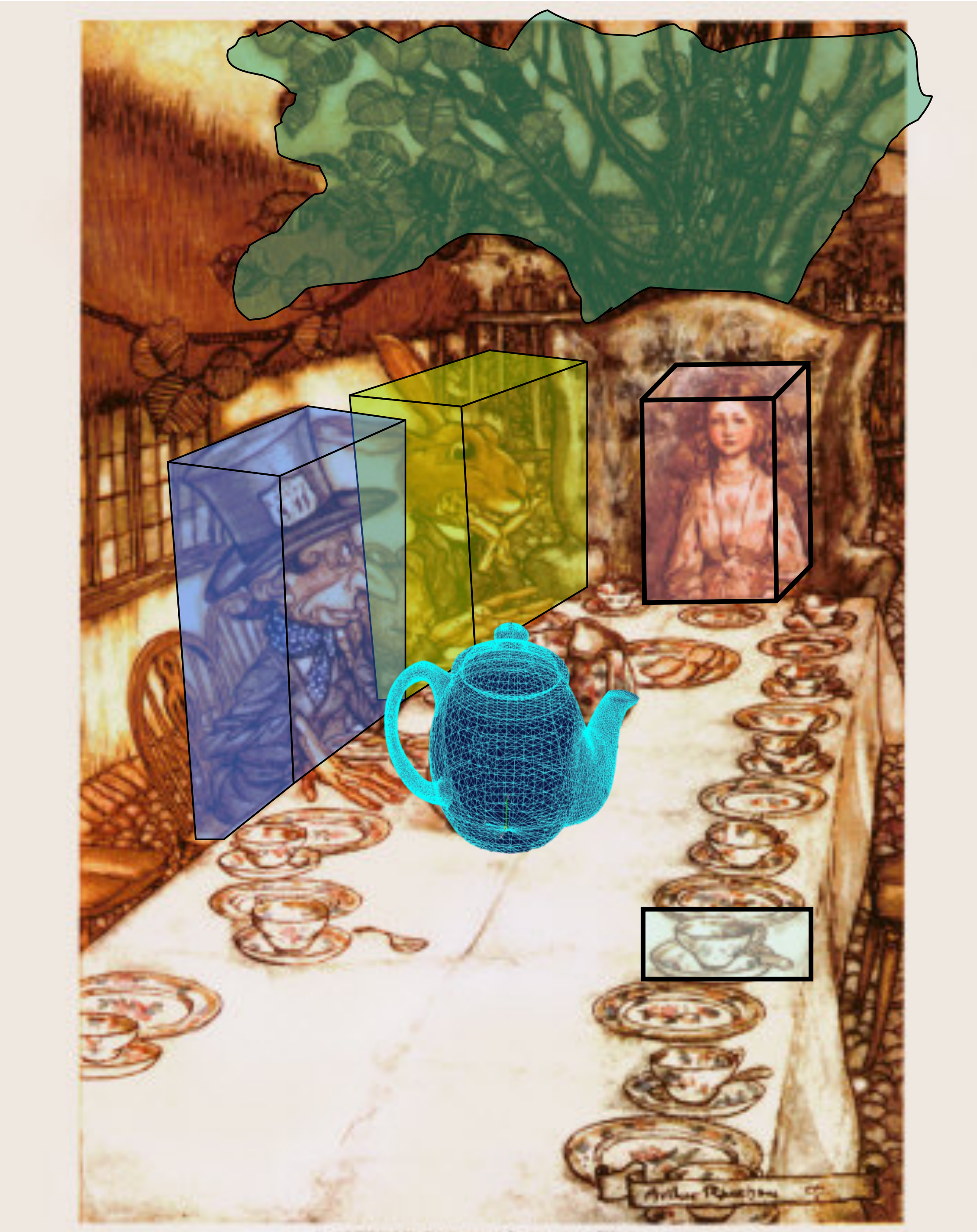
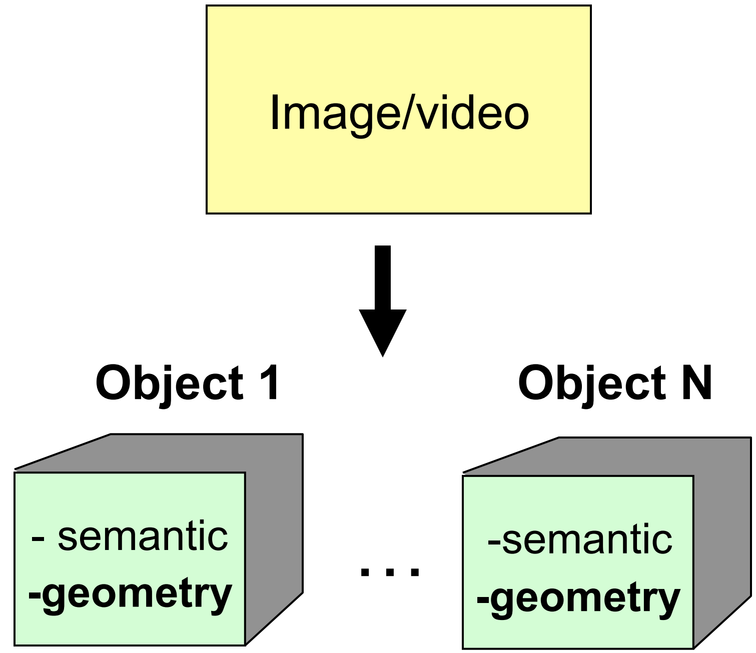
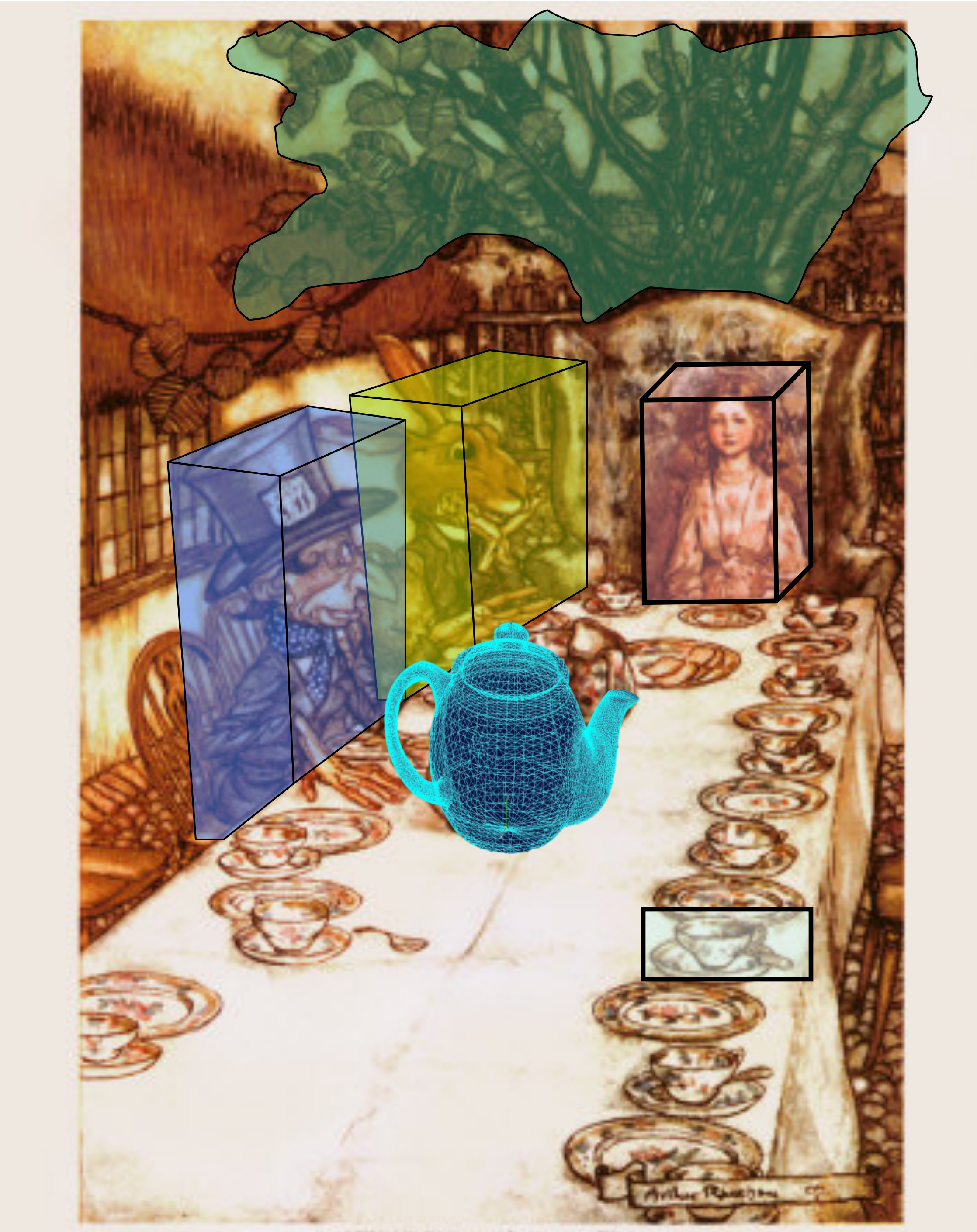
Computer vision



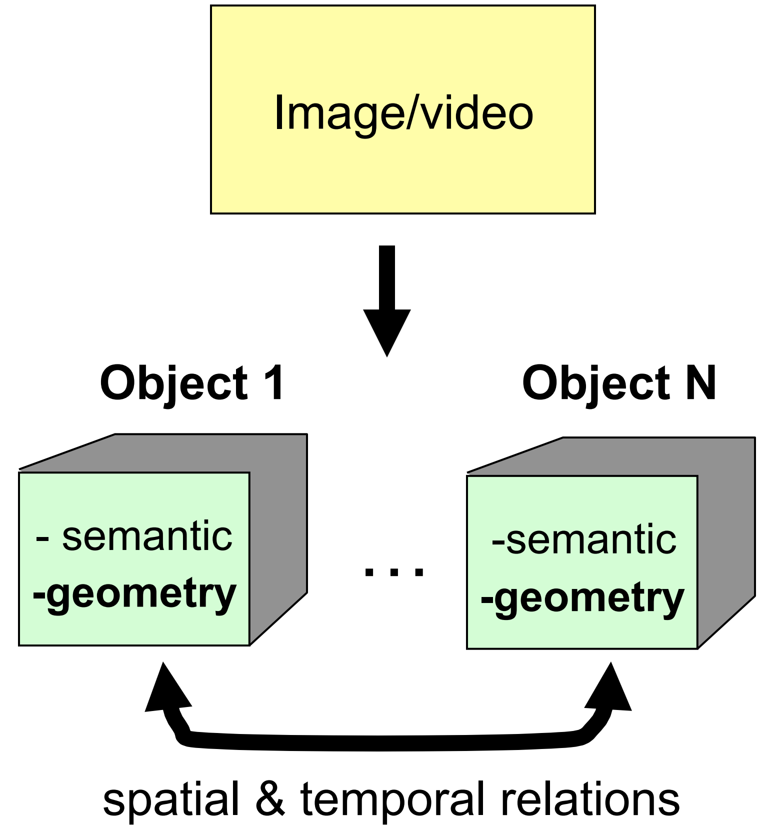
Computer vision



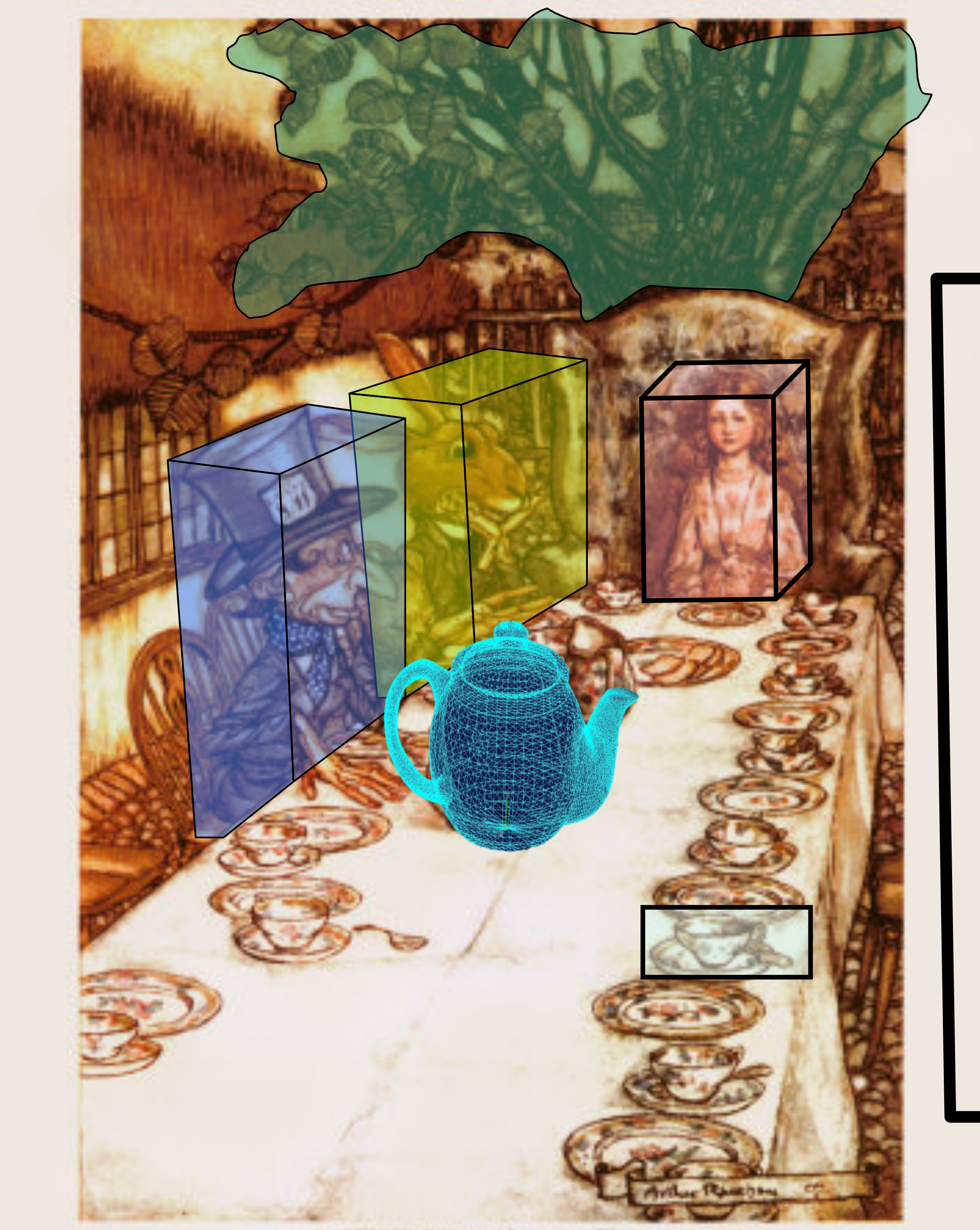


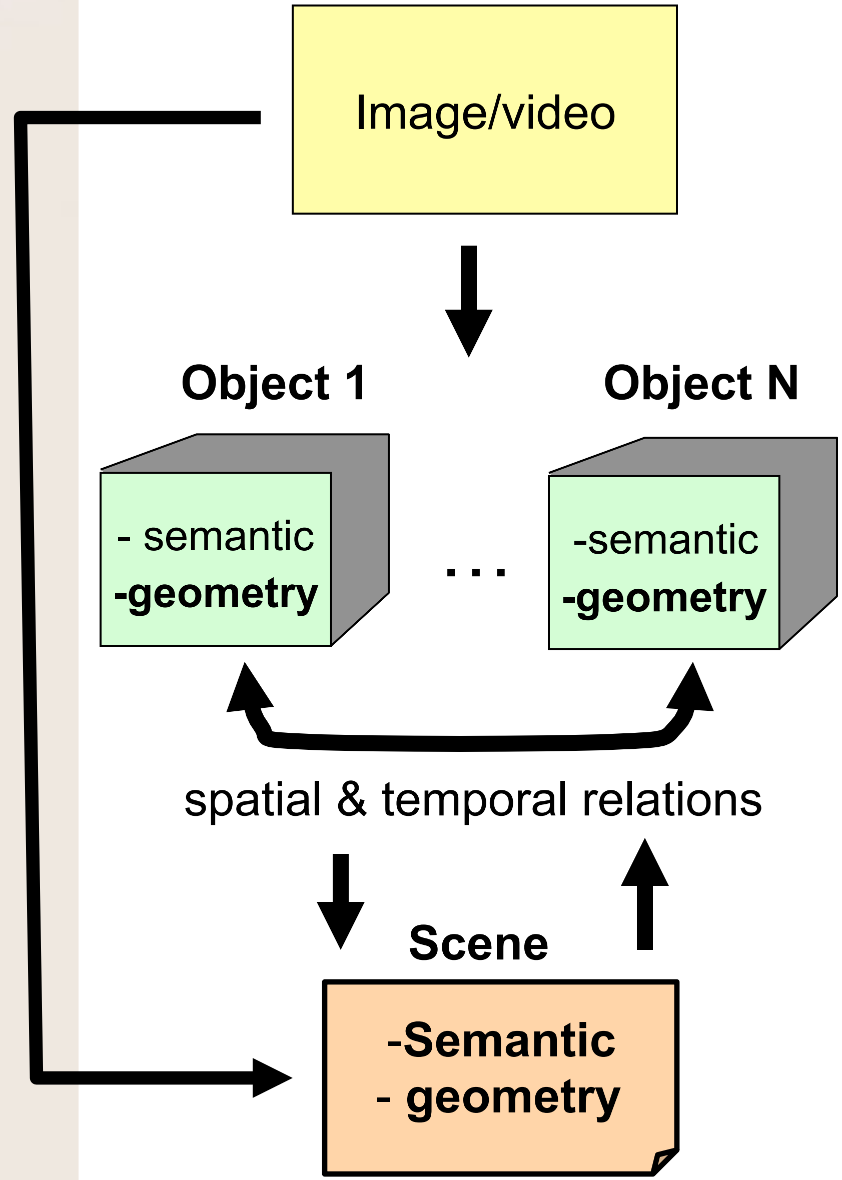


Computer vision



Computer vision





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

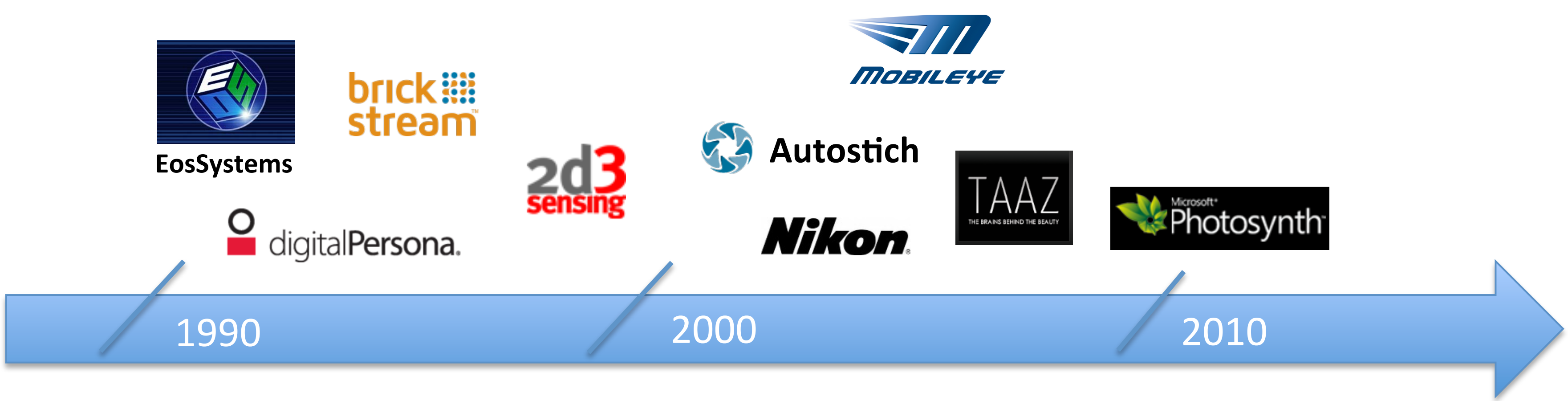
3D object prototyping

EosSystems

Photomodeler

Computer vision and Applications

- New features detector/descriptors
- CV leverages machine learning



Face detection

BBC NEWS

UK version | International version | About the versions | L

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

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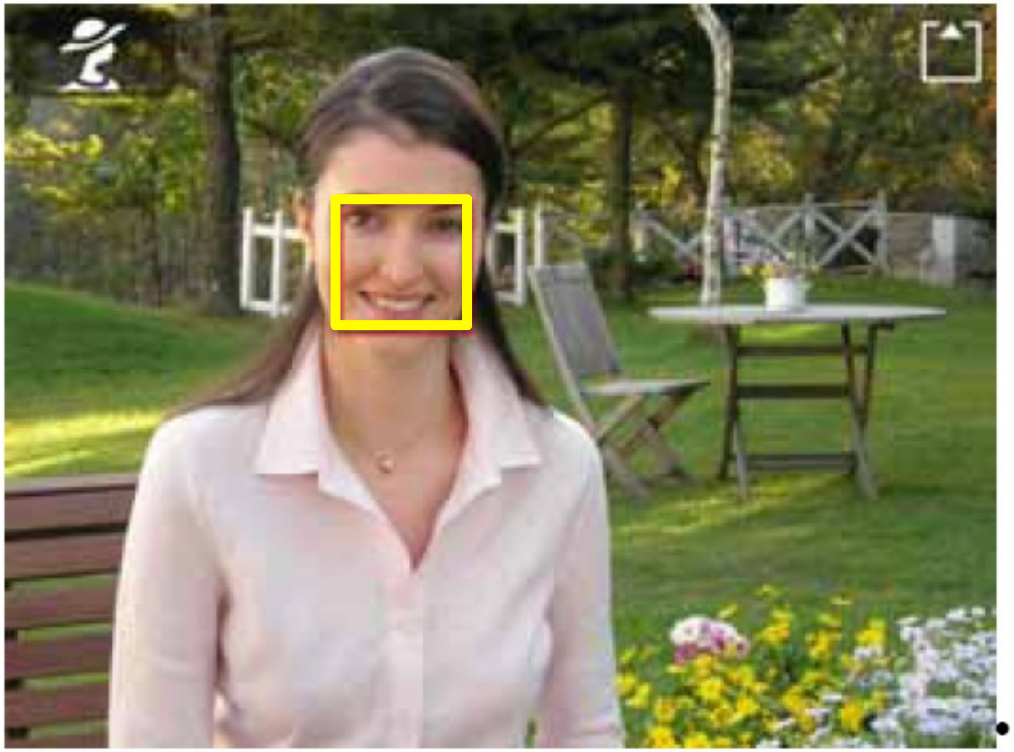
Face-hunting cameras boost Nikon

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

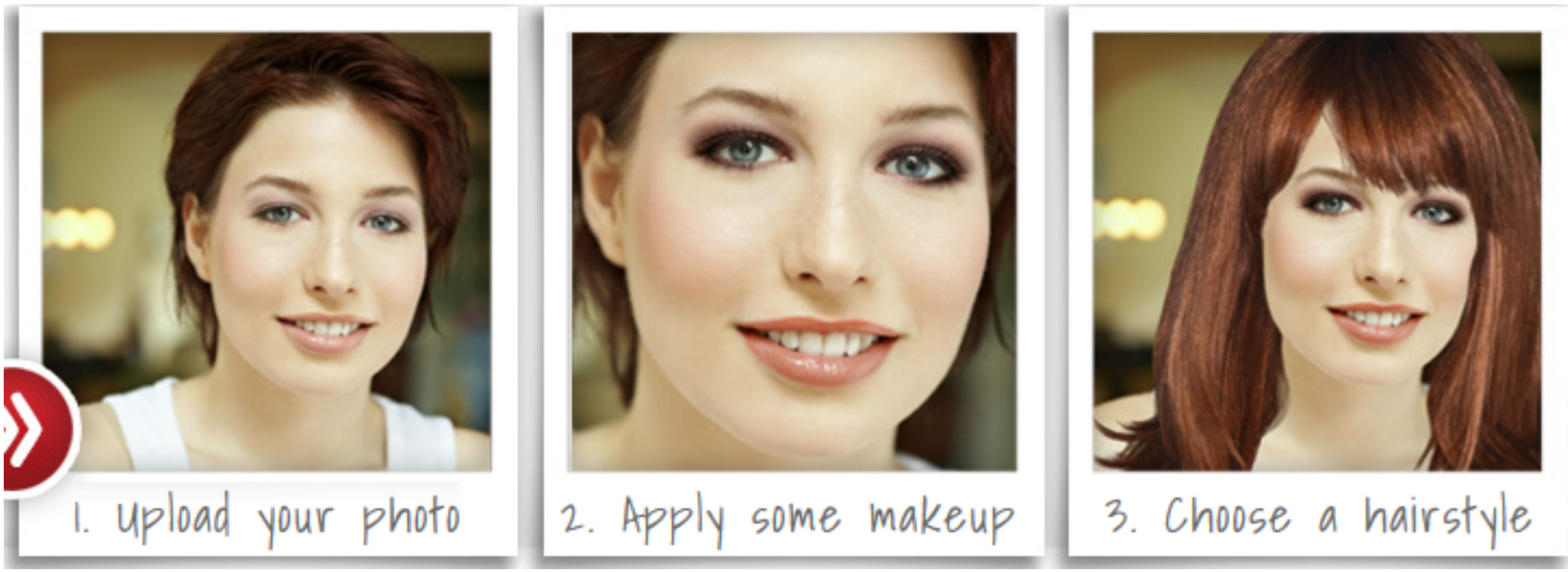
Face recognition cameras like the Coolpix L1 are popular

Face detection



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

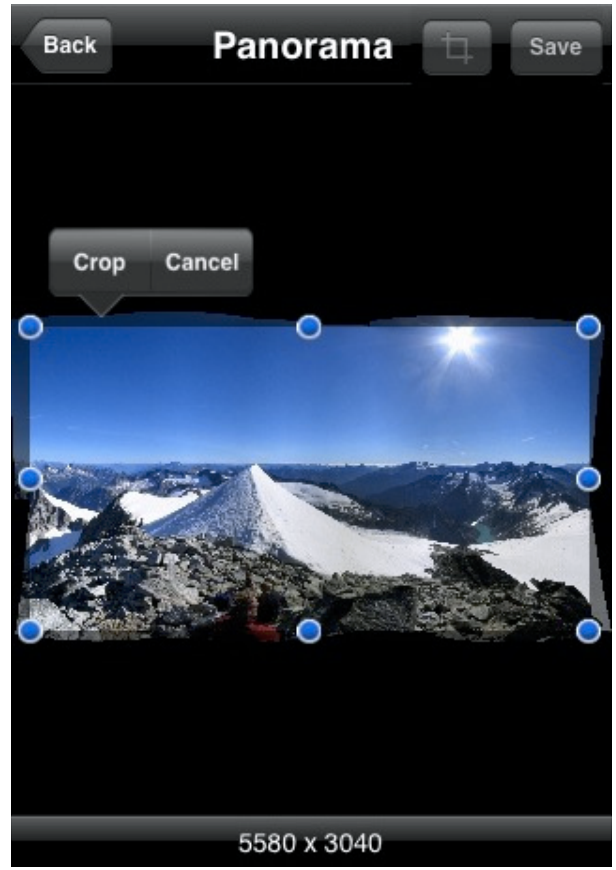
Web applications



TAAZ
THE BRAINS BEHIND THE BEAUTY

Photometria

Panoramic Photography

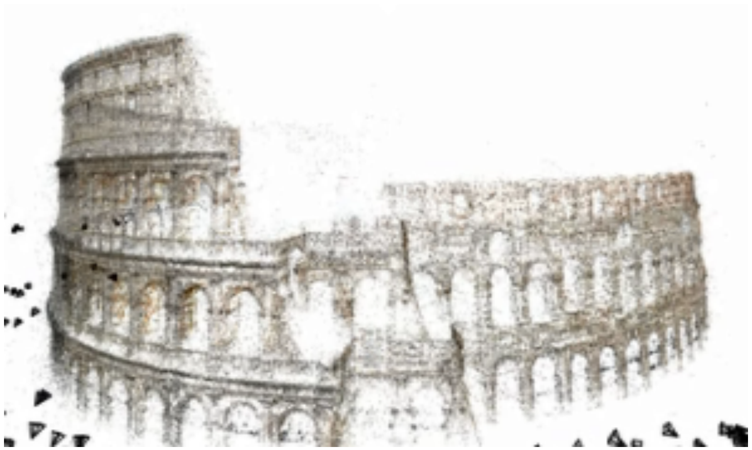


Cloudburst RESEARCH

HumanEyes Print Out of the Box

kolor

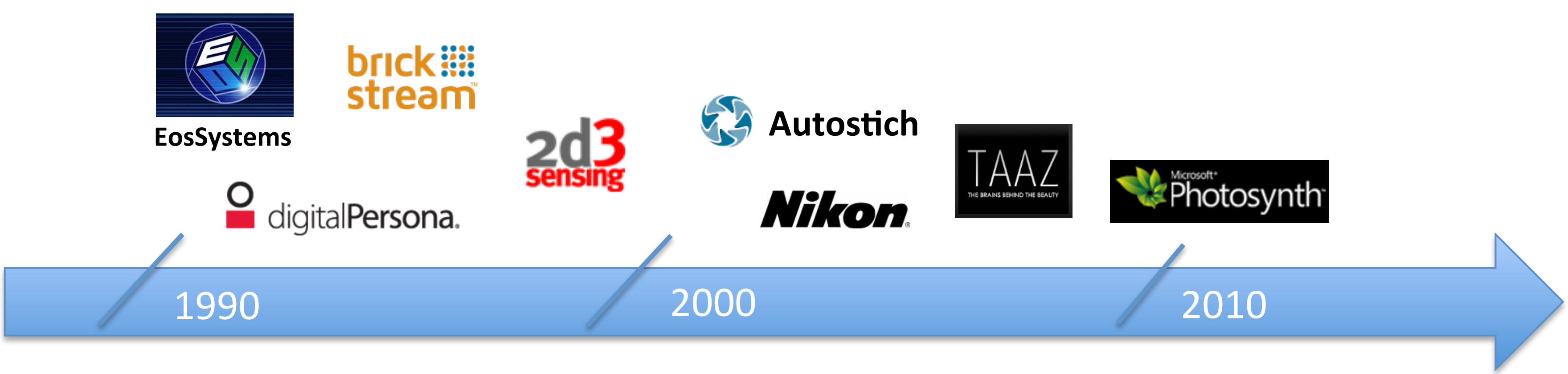
3D modeling of landmarks



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

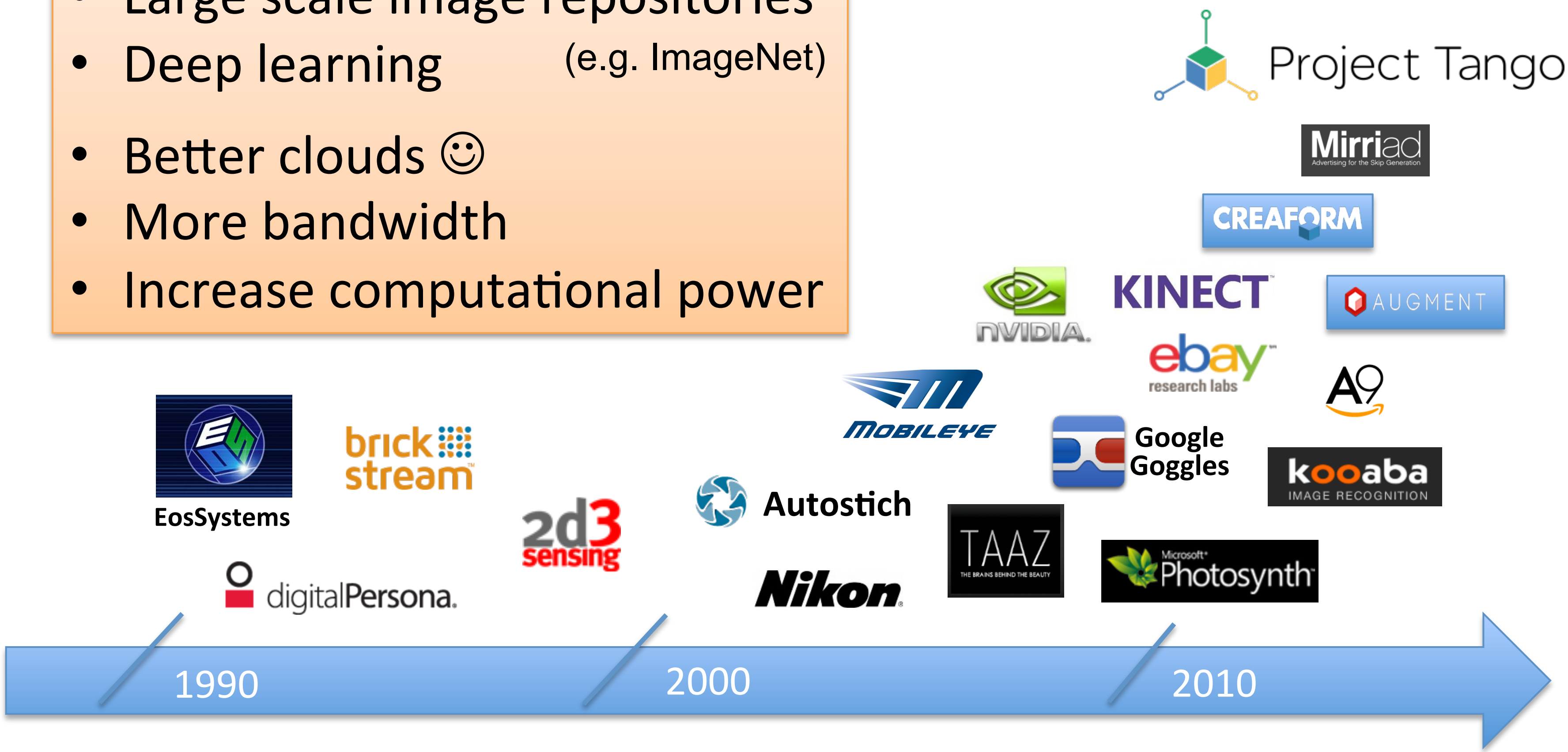
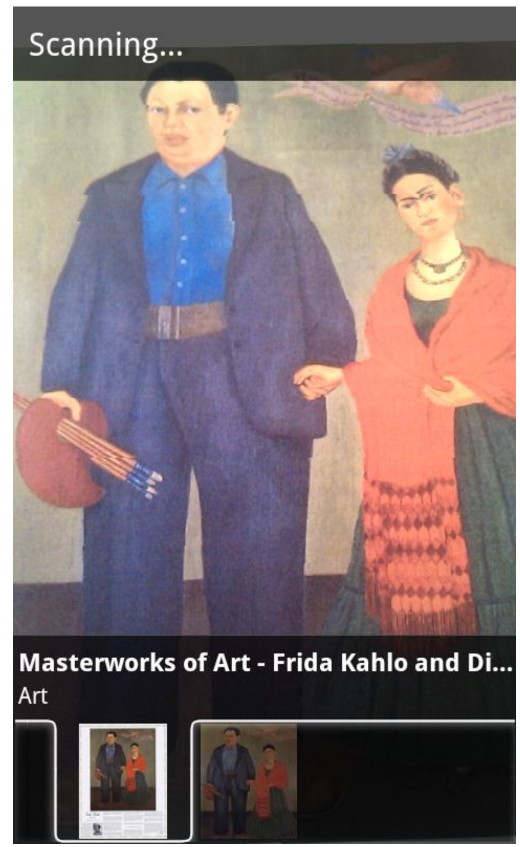


Image search engines

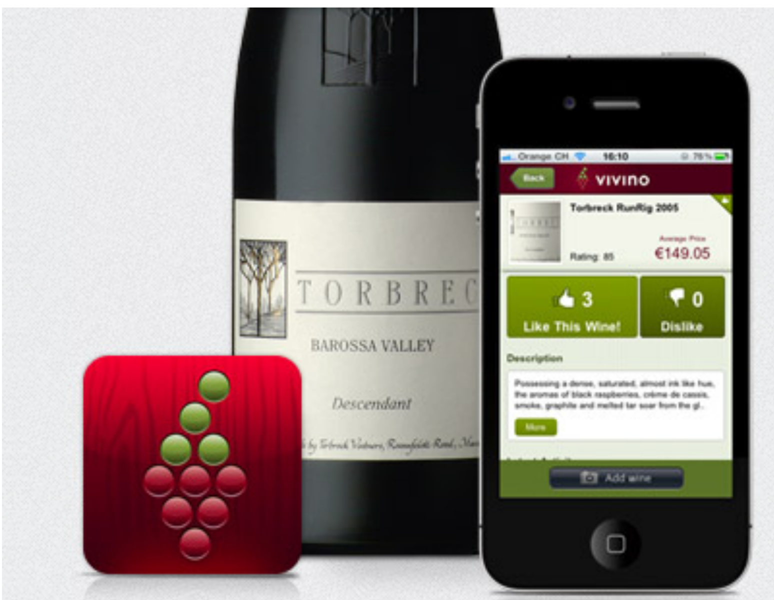
Google Image Search
Picasa
flickr
webshots
bing
YouTube Broadcast Yourself
Incogna
LTU technologies
picsearch
YAHOO!

Visual search and landmarks recognition



Google Goggles

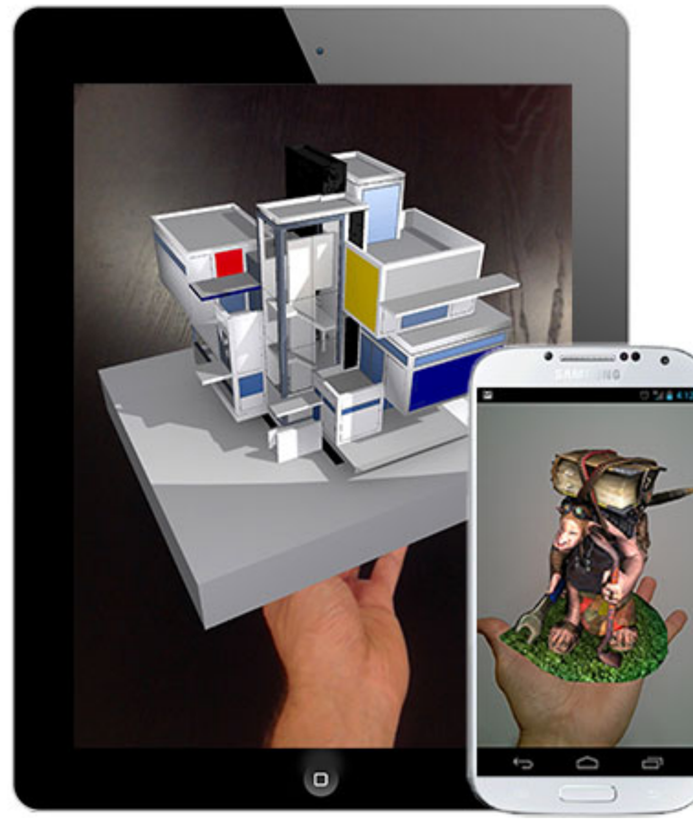
Visual search and landmarks recognition



kooaba IMAGE RECOGNITION

A9

Augmented reality



Mirriad
Advertising for the Skip Generation

AUGMENT

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

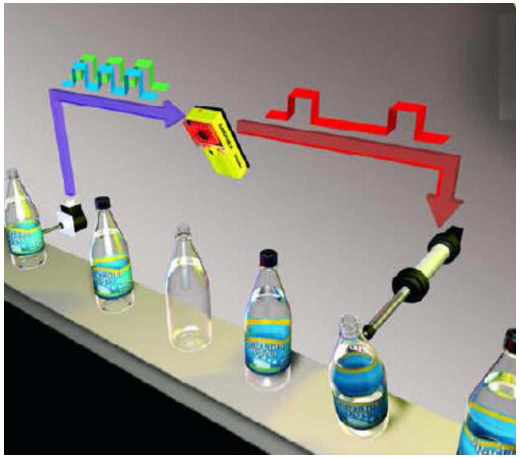
FIVE ELEMENTS ROBOTICS

a

ECOVACS

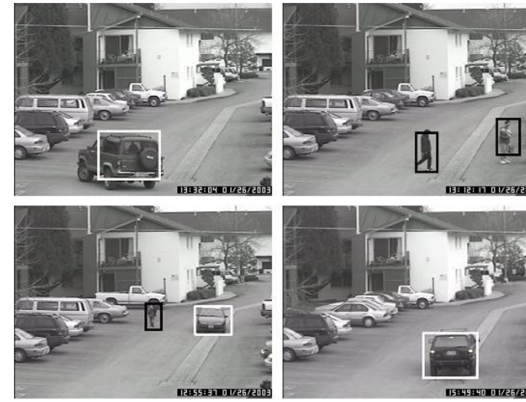
BLUE FROG robotics

Computer vision and Applications



Factory inspection

Assistive technologies



Surveillance

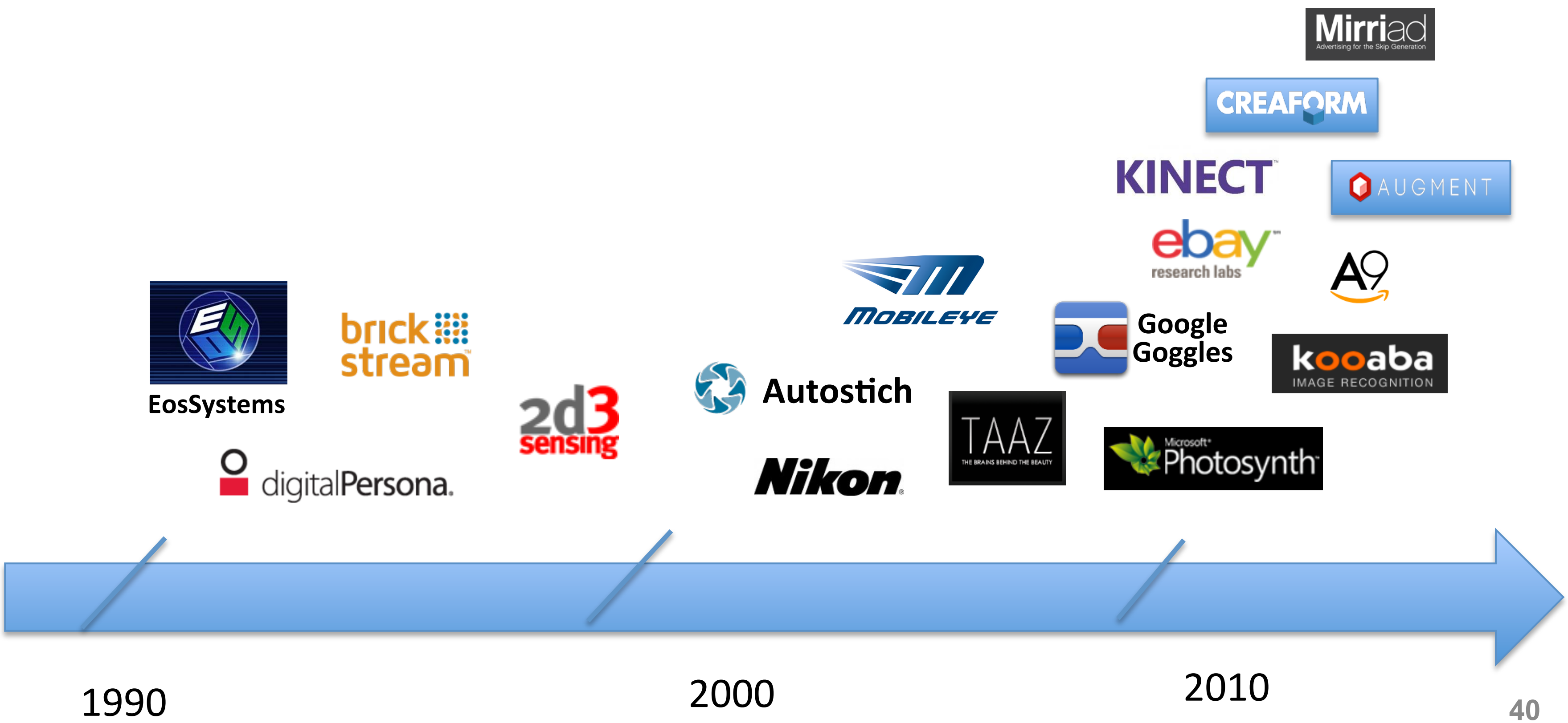
Autonomous driving,
robot navigation

Vision for robotics,
space exploration

Security

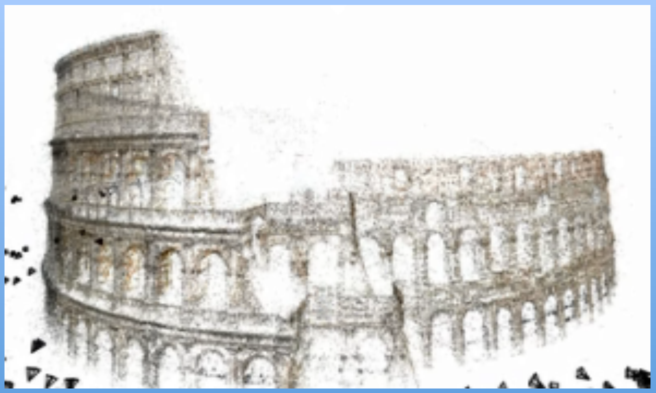
Sources: K. Grauman, L. Fei-Fei, S. Laznebick

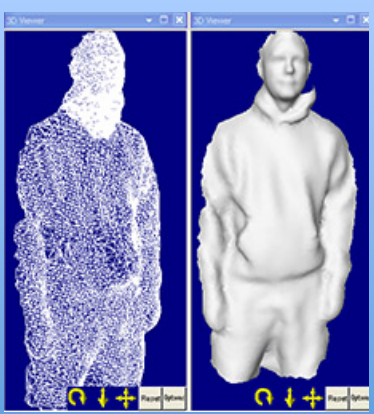
Computer vision and Applications



Computer vision and Applications

Computer vision and Applications





3D

EosSystems

2d3 sensing

Microsoft Photosynth

CREAFORM

AUGMENT

2D

digitalPersona

brickstream

Nikon

TAAZ

Google Goggles

A9

kooaba IMAGE RECOGNITION

1990

2000

2010

Current state of computer vision

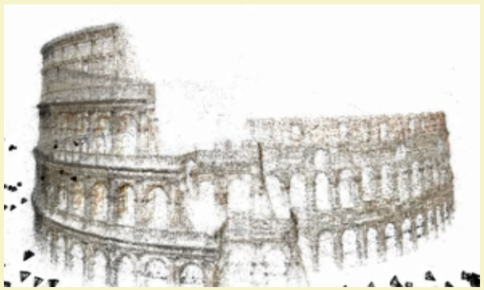
3D Reconstruction

- 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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Microsoft® Photosynth™

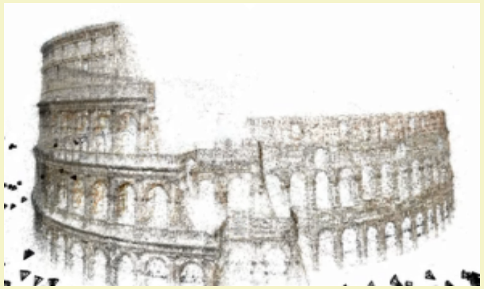
Snavely et al., 06-08

Lucas & Kanade, 81
Chen & Medioni, 92
Debevec et al., 96
Levoy & Hanrahan, 96
Fitzgibbon & Zisserman, 98
Triggs et al., 99
Pollefeys et al., 99
Kutulakos & Seitz, 99

Levoy et al., 00
Hartley & Zisserman, 00
Dellaert et al., 00
Rusinkiewic et al., 02
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
Savarese et al. IJCV 05
Savarese et al. IJCV 06
Microsoft's PhotoSynth
Snavely et al., 06-08
Schindler et al., 08
Agarwal et al., 09
Frahm et al., 10

Current state of computer vision



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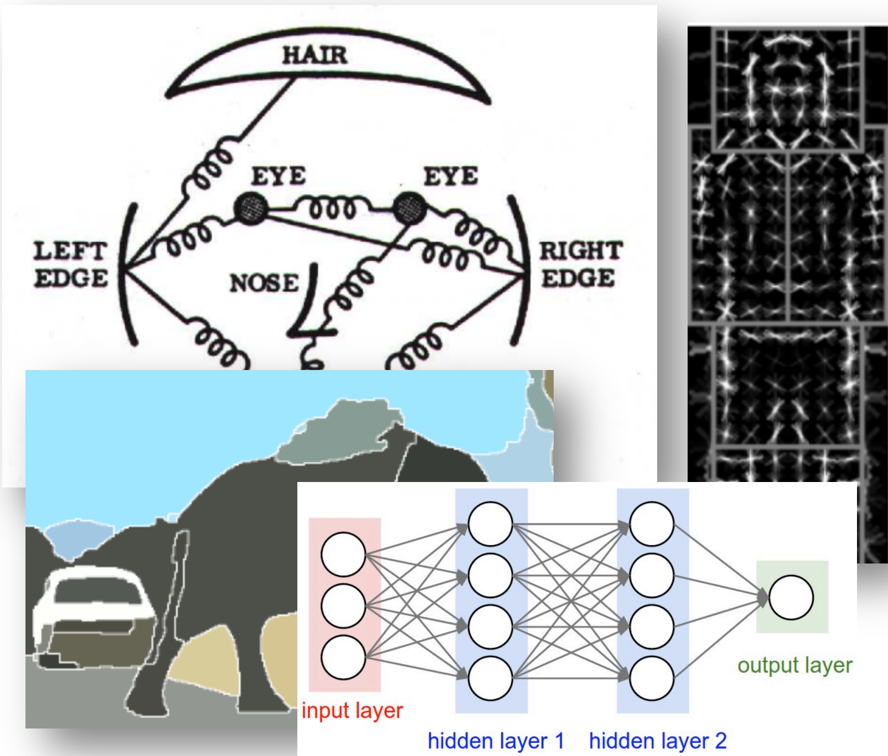


2D Recognition

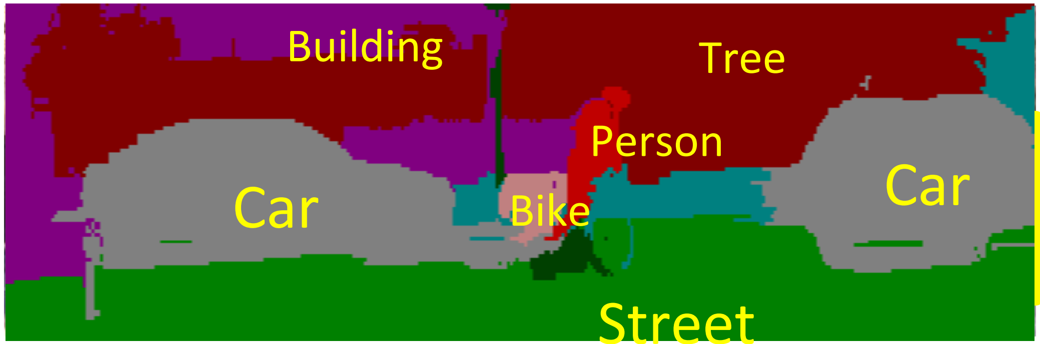
- Object detection
- Texture classification
- Target tracking
- Activity recognition

Turk & Pentland, 91
Poggio et al., 93
Belhumeur et al., 97
LeCun et al. 98
Amit and Geman, 99
Shi & Malik, 00
Viola & Jones, 00
Felzenszwalb & Huttenlocher 00
Belongie & Malik, 02
Ullman et al. 02

Argawal & Roth, 02
Ramanan & Forsyth, 03
Weber et al., 00
Vidal-Naquet & Ullman 02
Fergus et al., 03
Torralba et al., 03
Vogel & Schiele, 03
Barnard et al., 03
Fei-Fei et al., 04
Kumar & Hebert '04

He et al. 06
Gould et al. 08
Maire et al. 08
Felzenszwalb et al., 08
Kohli et al. 09
L.-J. Li et al. 09
Ladicky et al. 10,11
Gonfaus et al. 10
Farhadi et al., 09
Lampert et al., 09

Current state of computer vision



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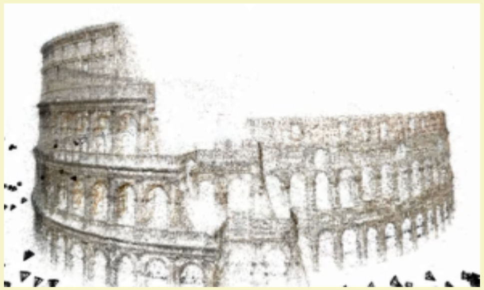

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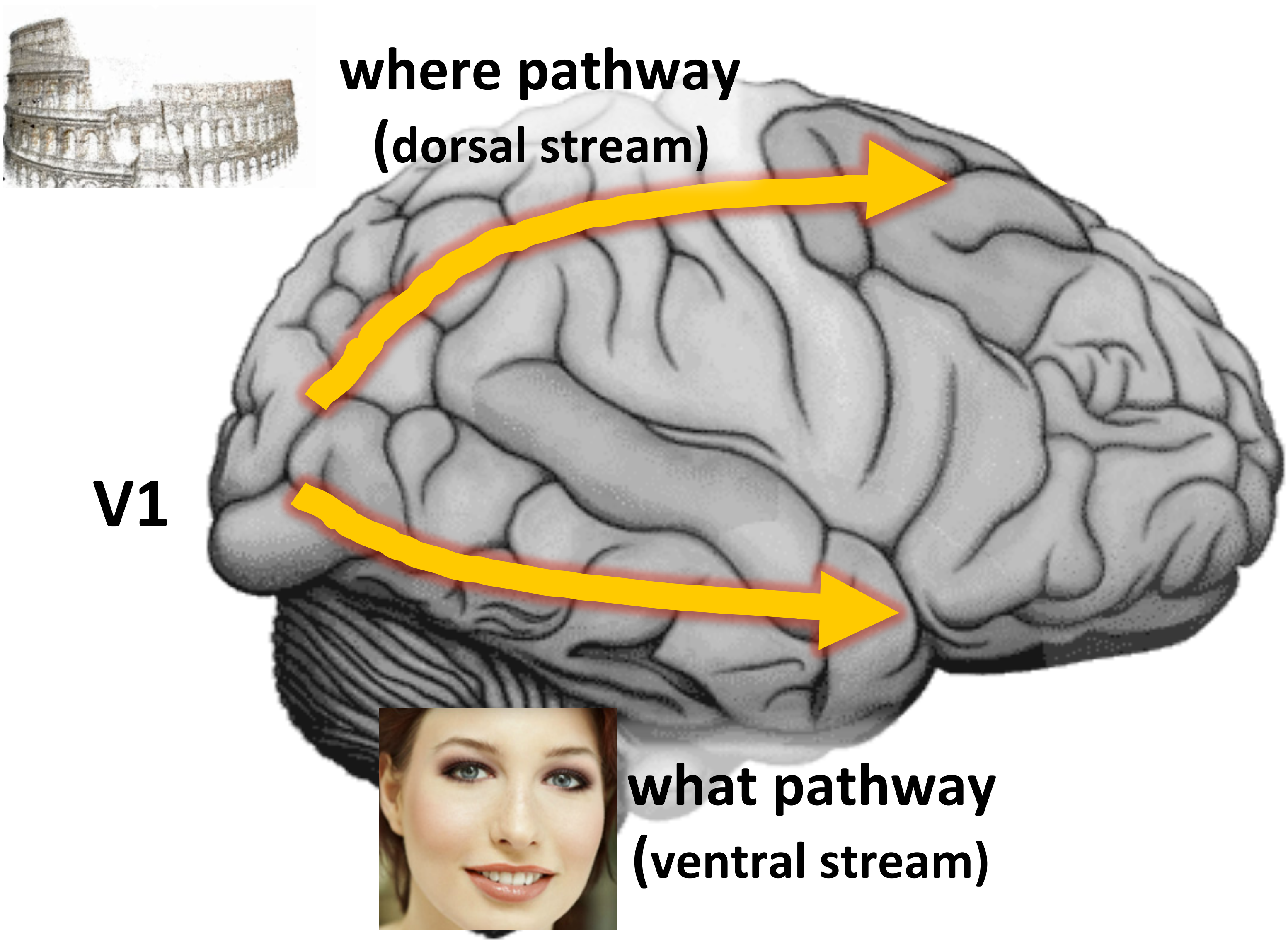
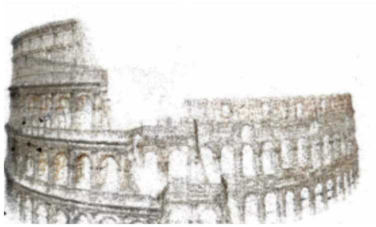
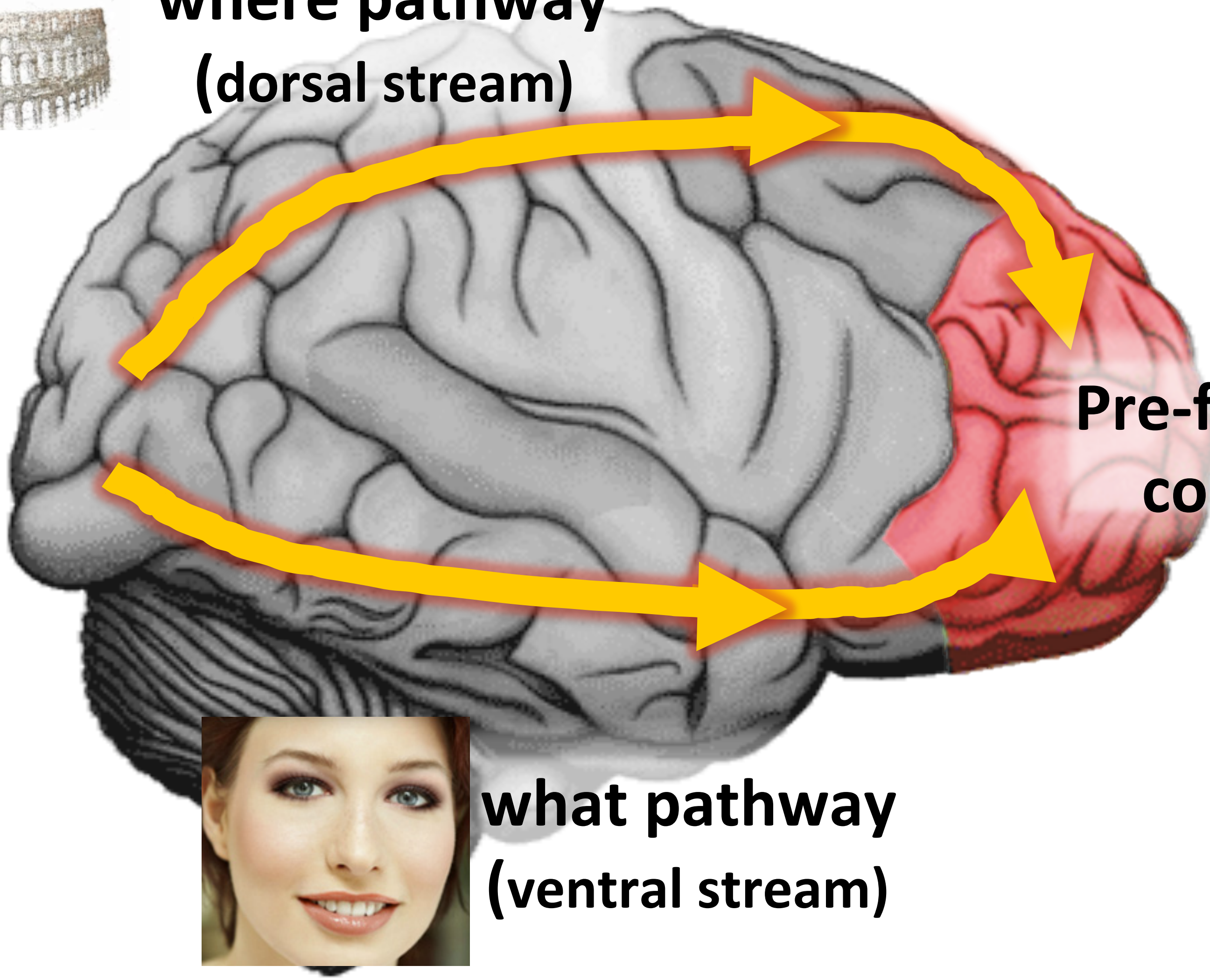
Perceiving the World in 3D!

Visual processing in the brain



Visual processing in the brain





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

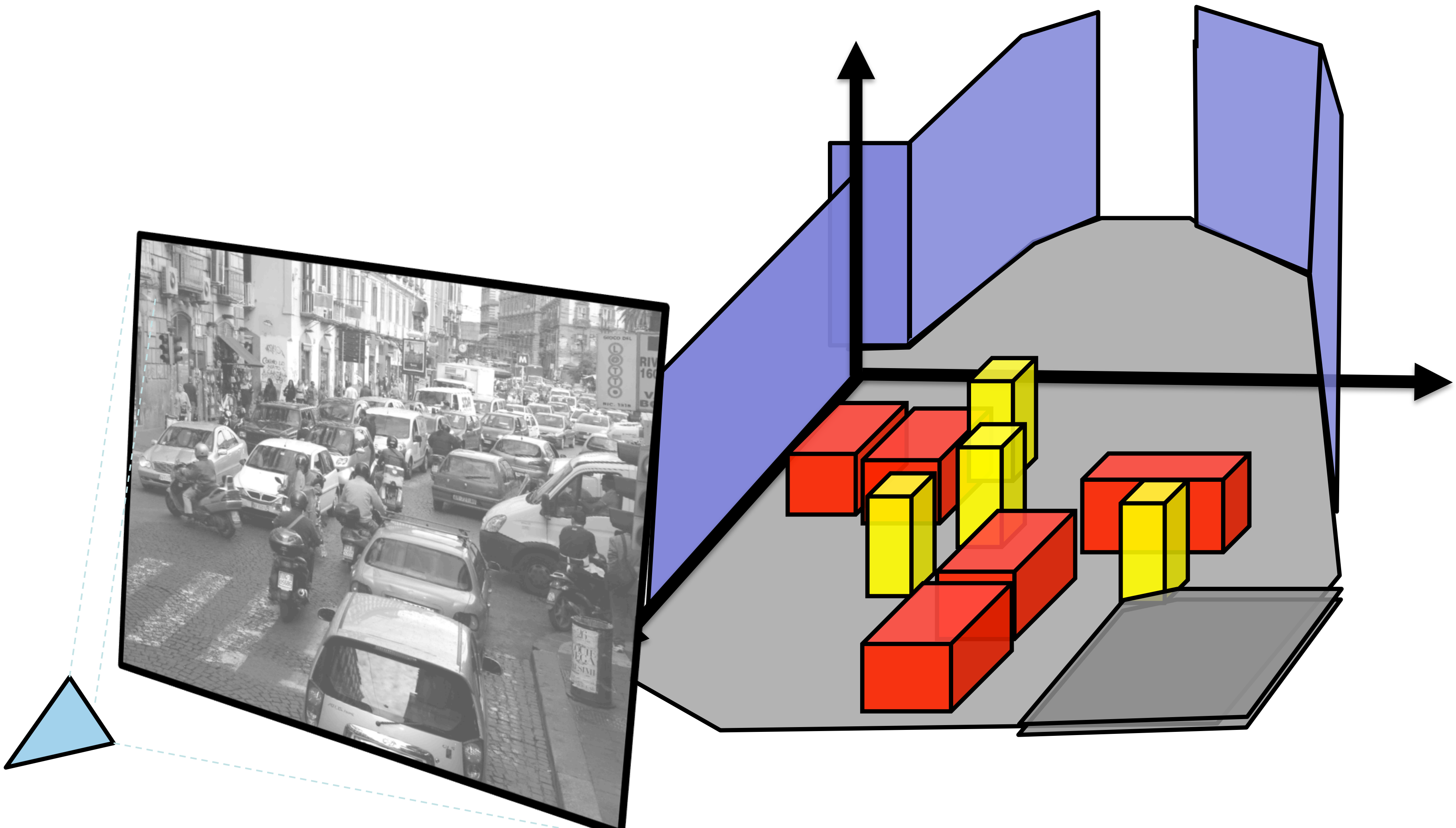
Estimate camera parameters such pose or focal length

Single view metrology

Estimate 3D properties of the world from a single image

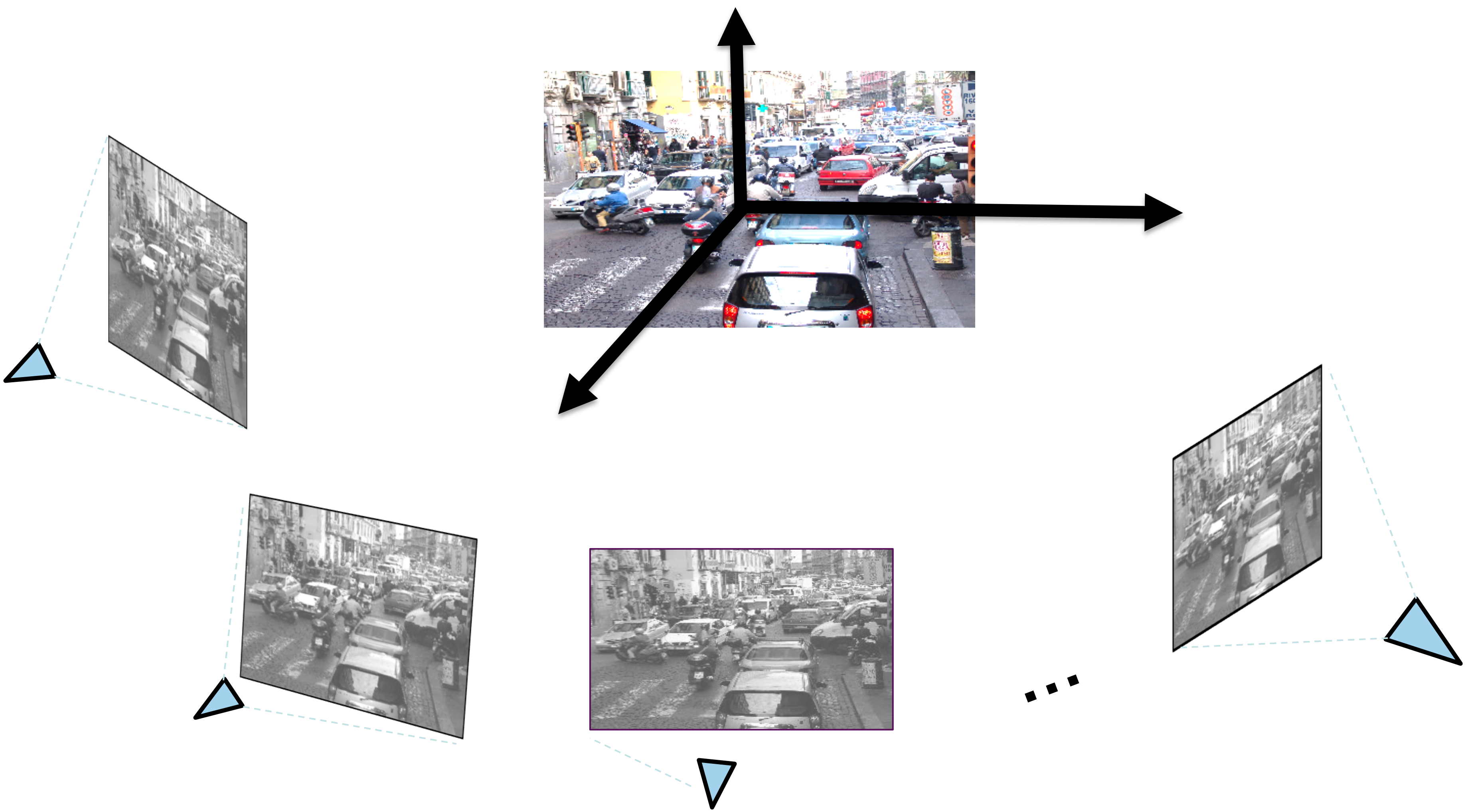
Single view metrology

Estimate 3D properties of the world from a single image

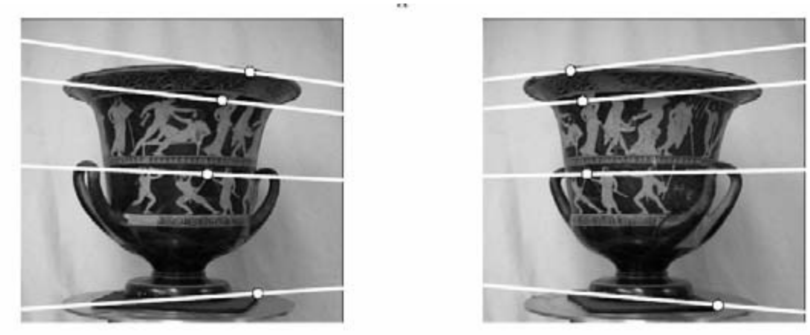


Multiple view geometry

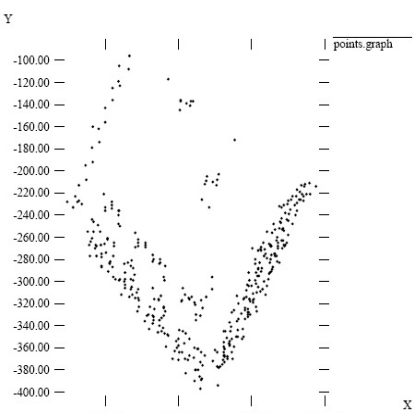
Estimate 3D properties of the world from multiple views

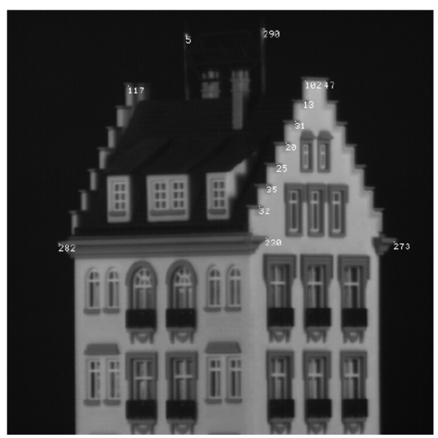


Mathematical tools



Epipolar geometry



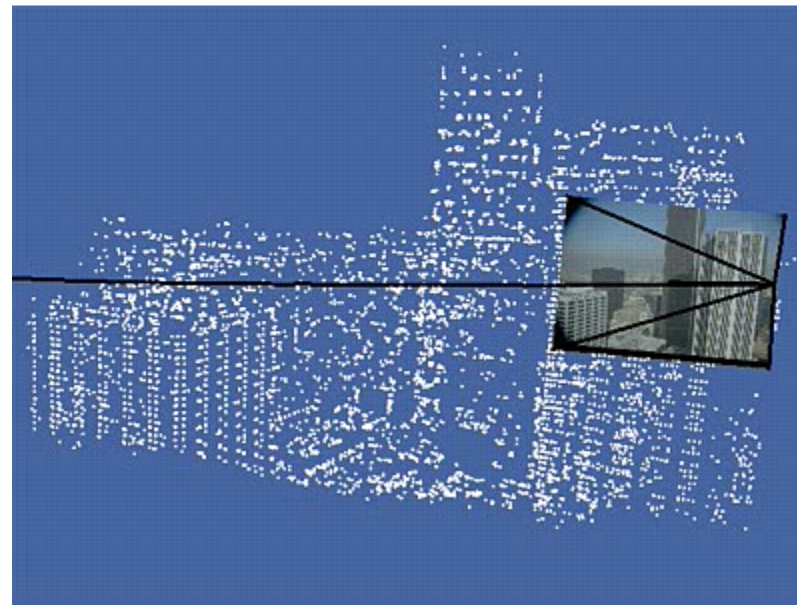


Tomasi & Kanade (1993)

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

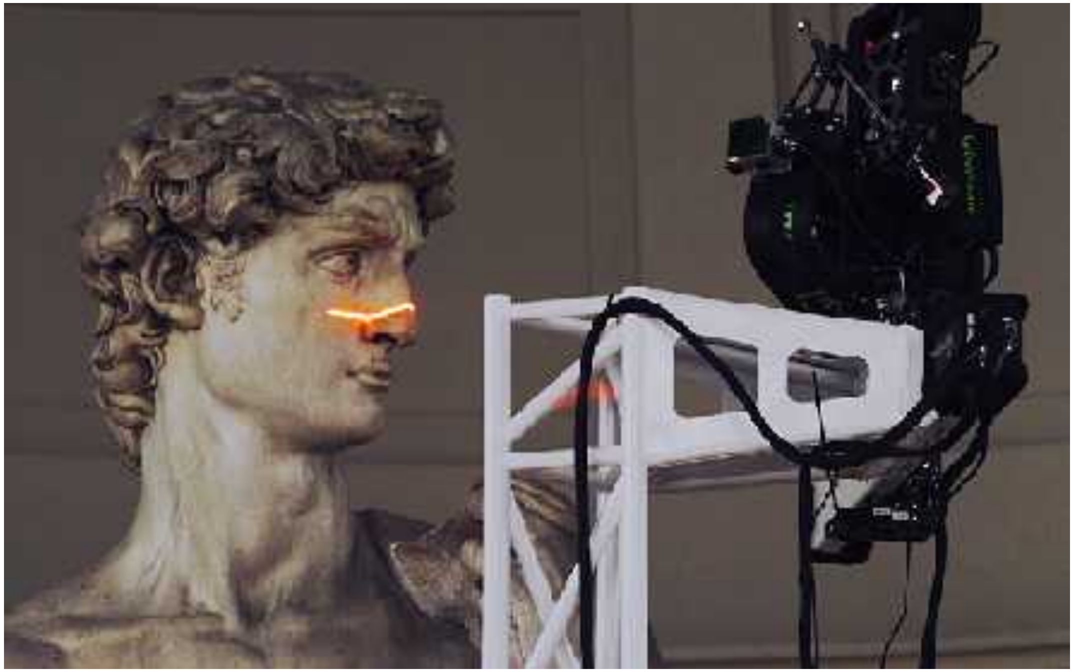
Photoconsistency

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

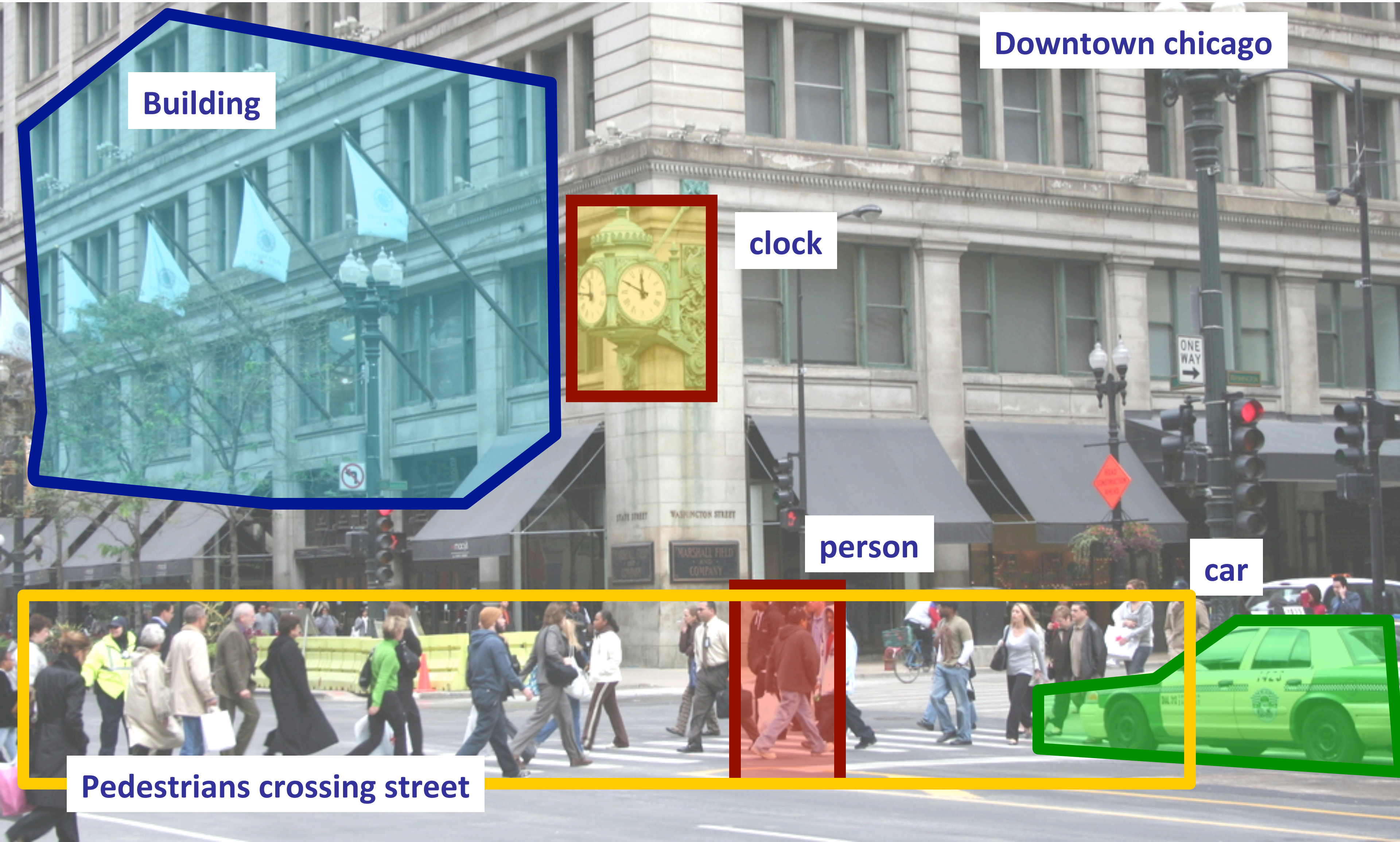
CS 231A course overview

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?

No!

Classification:

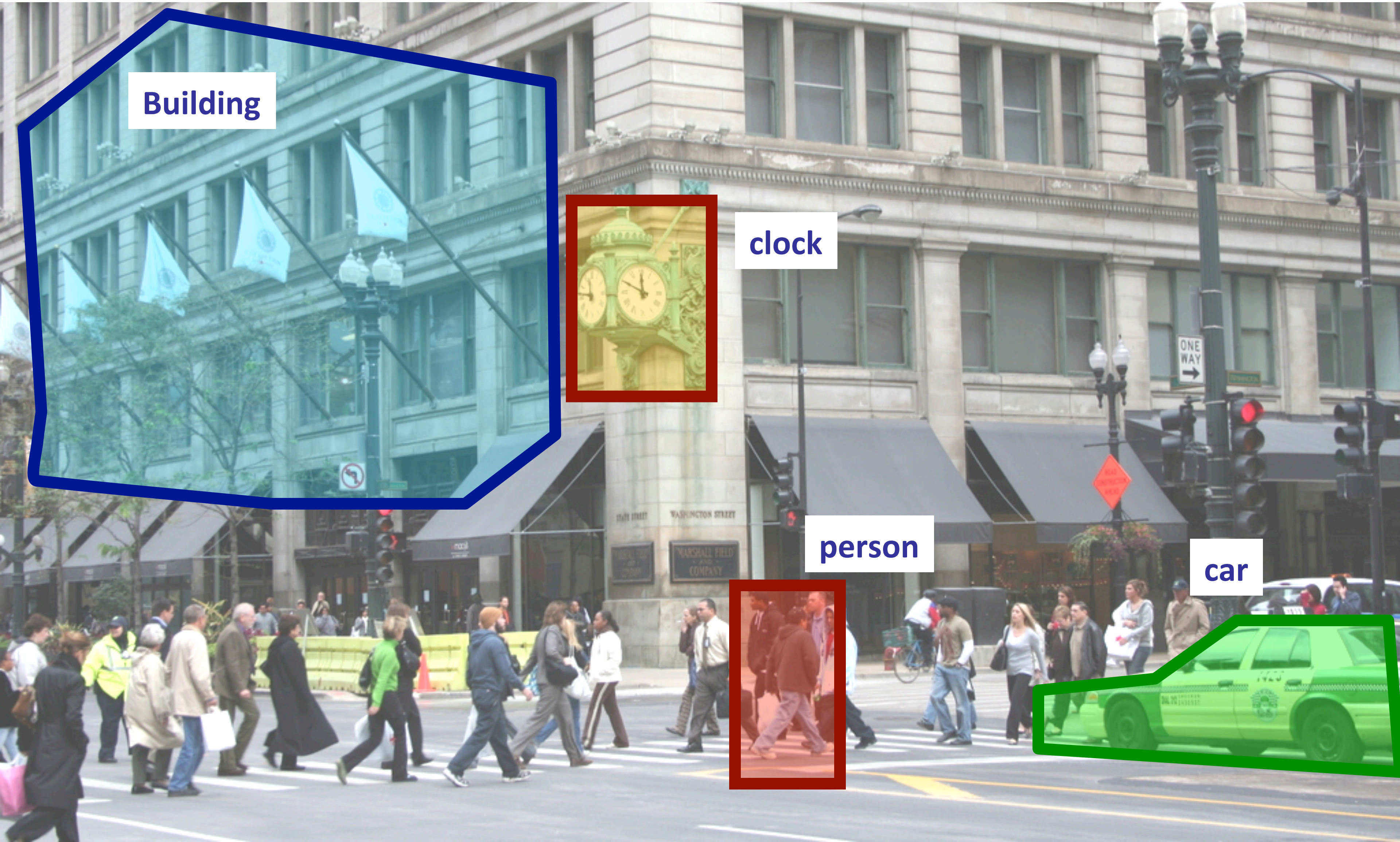
Does this image contain a building? [yes/no]

Detection:

Does this image contain a car? [where?]

Detection:

Which objects do this image contain? [where?]

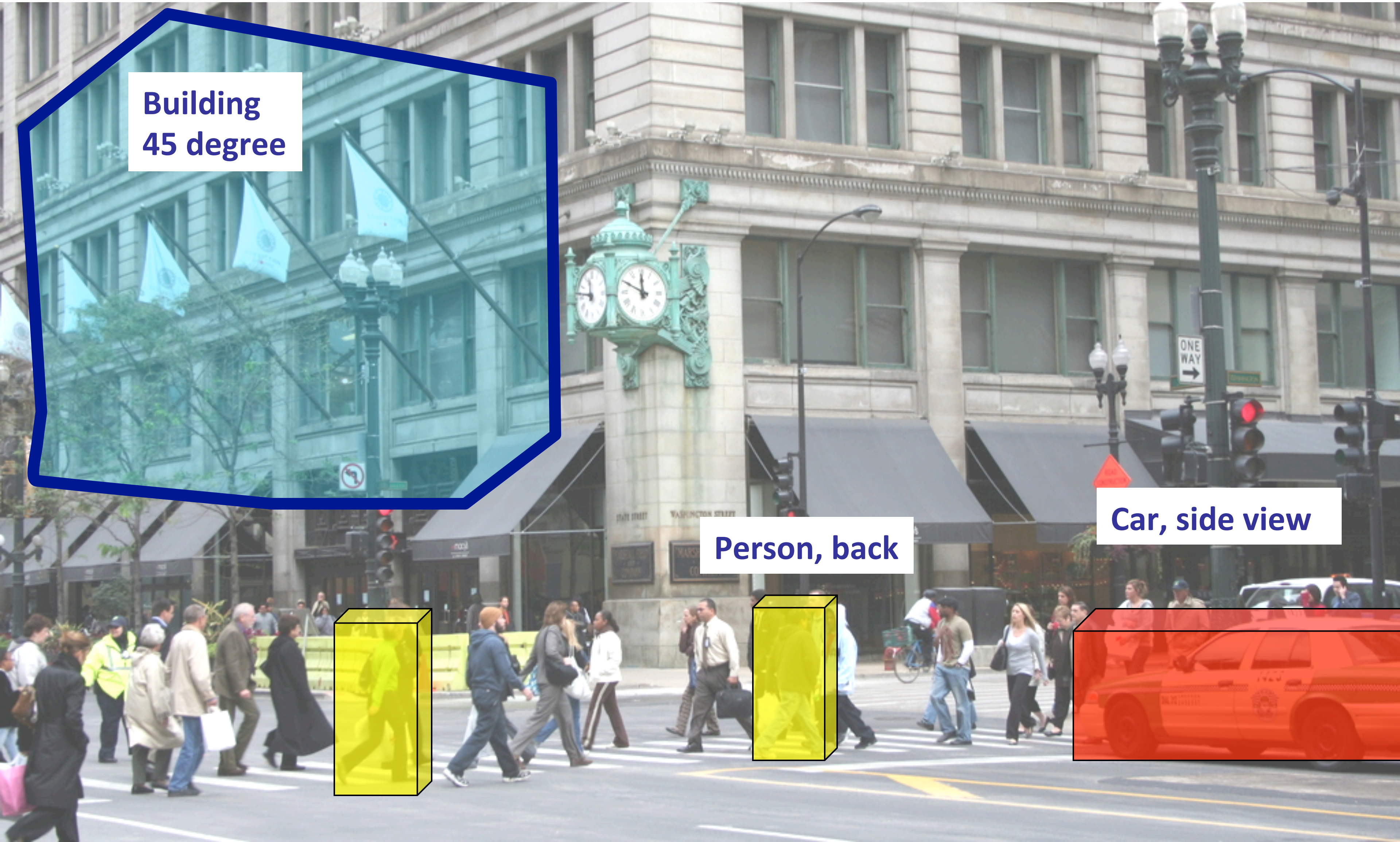


Detection:

Accurate localization (segmentation)

Detection:

Estimating 3D geometrical properties



Challenges: viewpoint variation

slide credit: Fei-Fei, Fergus & Torralba

Challenges: illumination

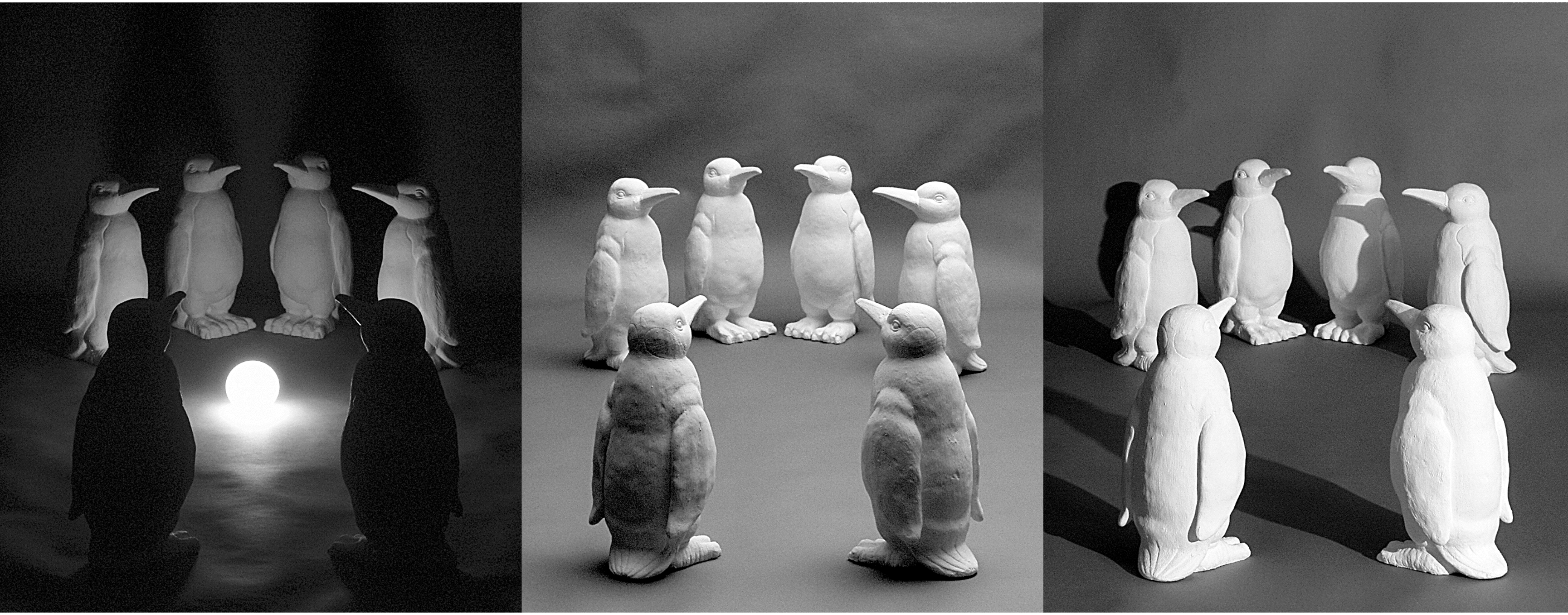


image credit: J. Koenderink

Challenges: scale

slide credit: Fei-Fei, Fergus & Torralba

Challenges: deformation

Challenges: occlusion

Magritte, 1957

Challenges: background clutter

Kilmeny Niland. 1995

Challenges: object intra-class variation






slide credit: Fei-Fei, Fergus & Torralba

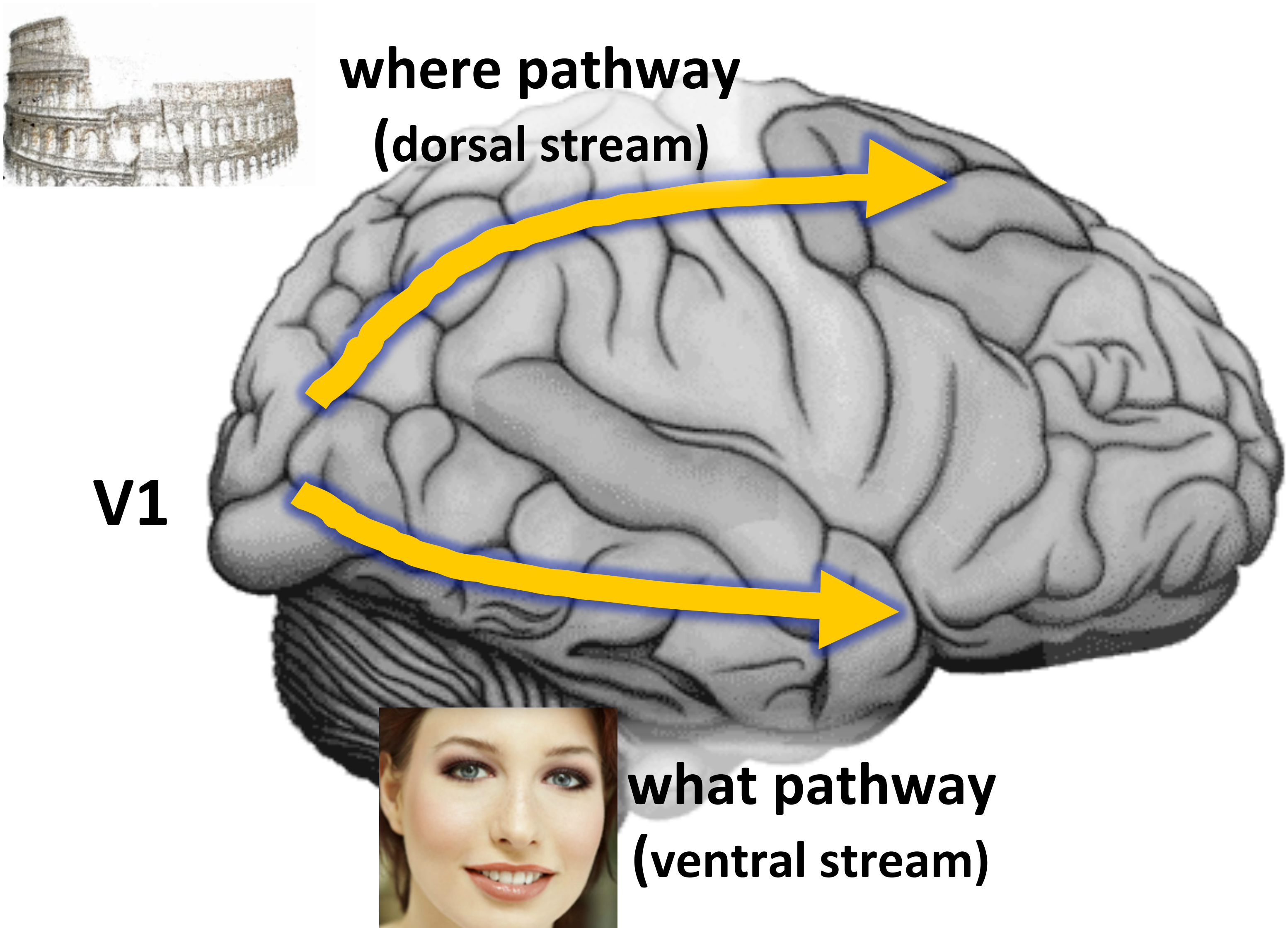

~10,000 to 30,000

CS 231A course overview

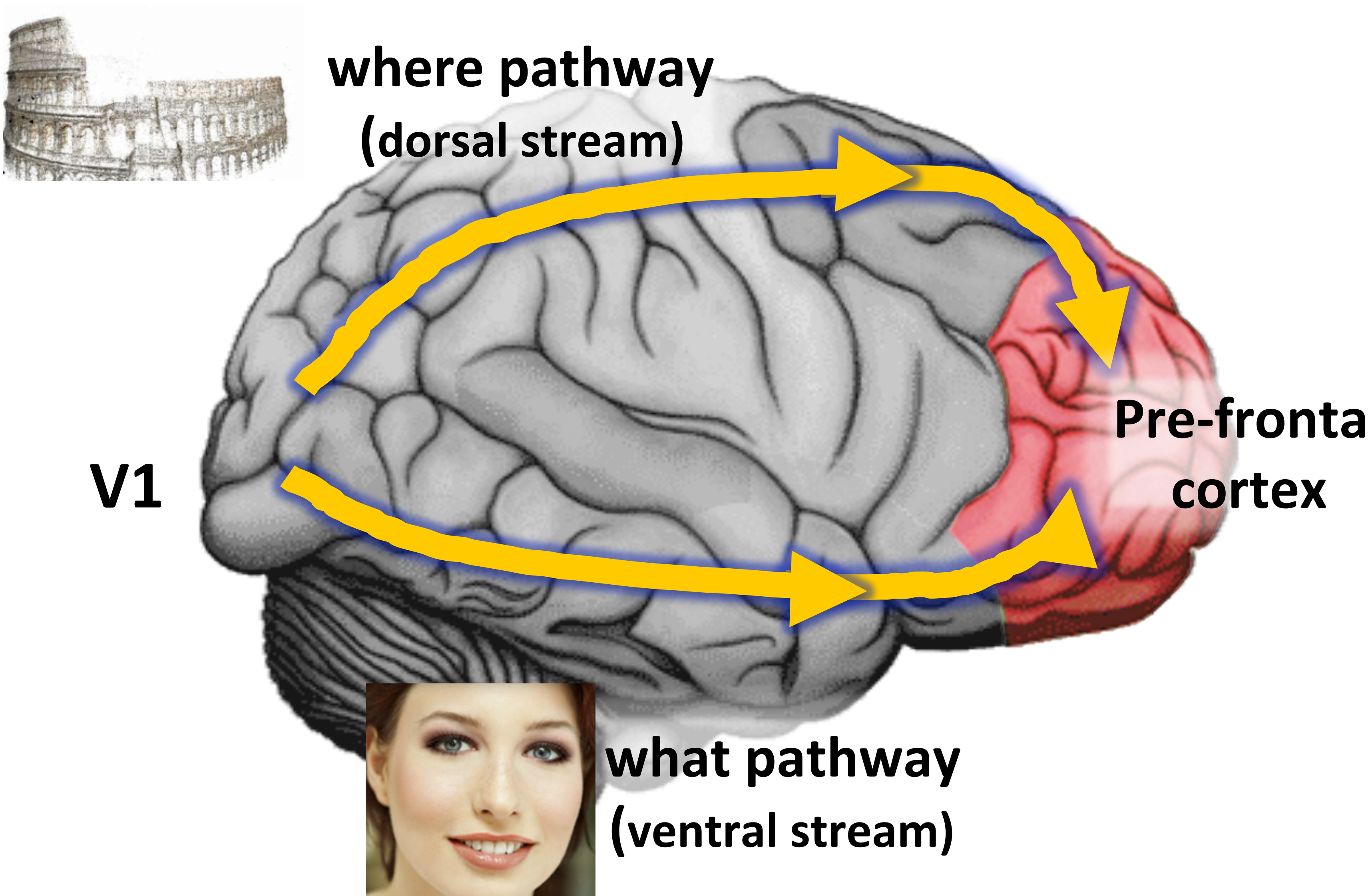
1. Geometry
2. Semantics

Joint recovery of geometry and semantics!

Visual processing in the brain

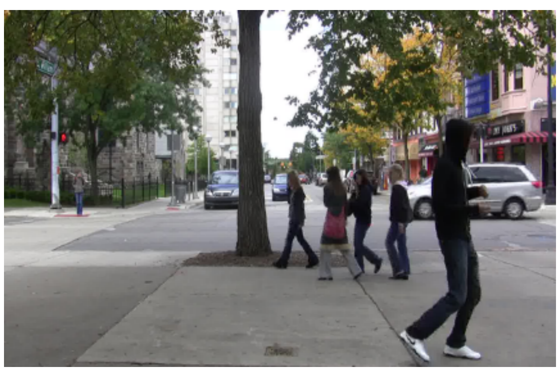


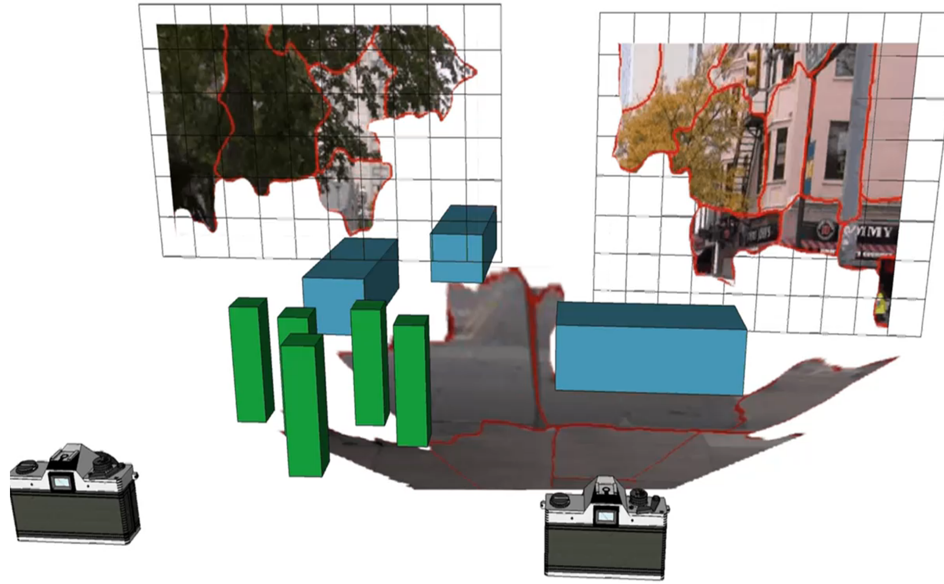
Visual processing in the brain

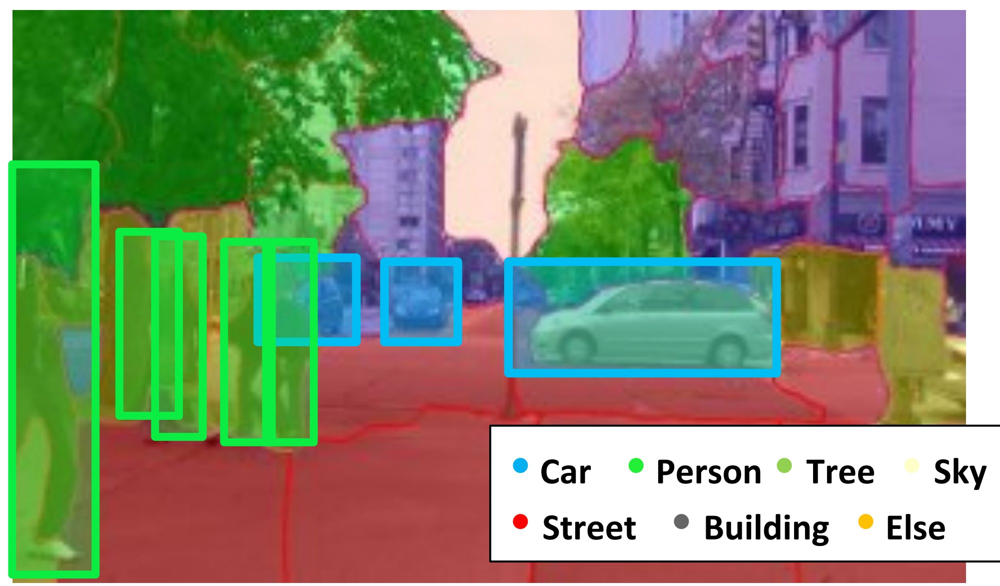


Joint reconstruction and recognition

Input images

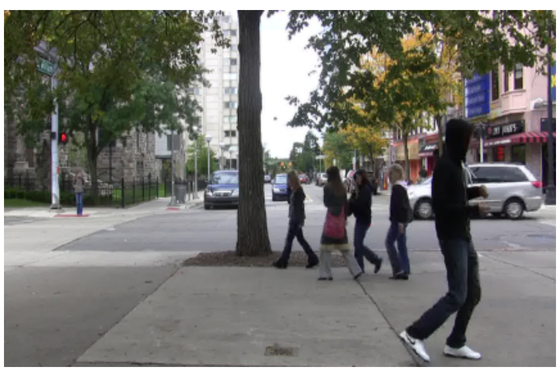


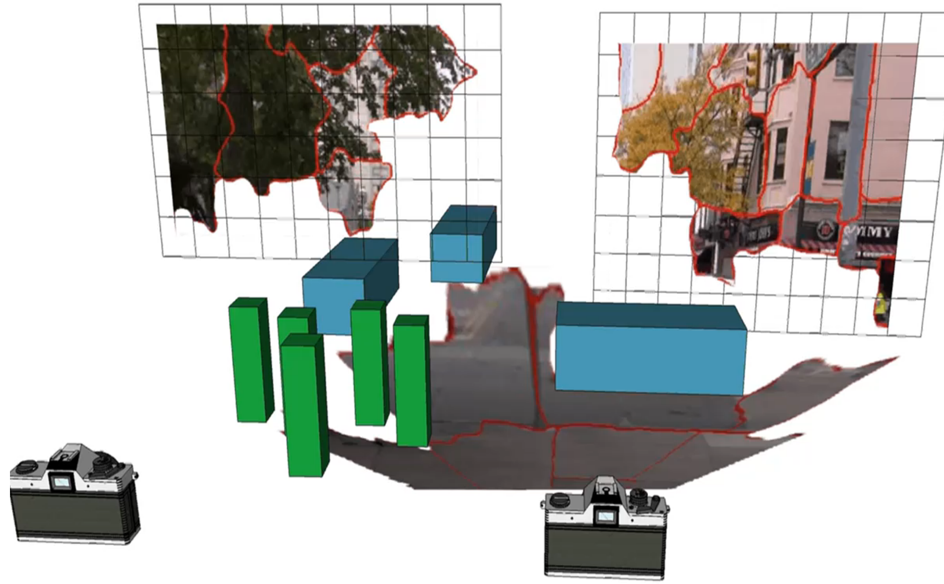




Joint reconstruction and recognition

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	2D Object detection
14	3D Object recognition
15	Scene understanding & segmentation
16	3D Scene understanding

March

April

May

June

3D geometry

Recognition

Proposal due

Project presentations

CS231

Introduction to Computer Vision

Next lecture: Camera systems